U.S.-Iran Symposium on Climate Change: Impacts and Mitigation

March 30 - April 1, 2015

Irvine, California

NATIONAL ACADEMY OF SCIENCES

فرهنگستان علوم
جمهوری اسلامی ایران
The Academy of Scienses
Islamic Republic of Iran

THE UNIVERSITY OF ARIZONA

The U.S.-Iran Symposium on Climate Change was held in Irvine, CA on March 30-April 1, 2015. Experts in water security impacts, food safety, environmental impacts, and climate change mitigation and adaption from Iran and the United States gathered to share their knowledge and concerns about adverse effects of climate change. The Symposium's goal was to contribute to discussions of climate change and its impact and as a result reduce adverse trends linked to climate change. The opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the sponsors.

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Preface

1. The U.S.-Iran Symposium on Climate Change: Impacts and Mitigation

To promote and enhance understanding of this important issue, the 'Symposium on Climate Change: Impacts and Mitigation' was held from March 30 through April 1, 2015 at the Beckman Center in Irvine, California (USA). The Symposium was organized by the University of Arizona, The United States National Academy of Sciences, and the Academy of Scienses of the Islamic Republic of Iran. Delegations of US and Iranian scientists participated in sharing current research and knowledge on the topic. The goal of the joint U.S.-Iran Symposium was to gather experts in various fields related to climate change to discuss and inform on the important aspects of its impacts and mitigation based on the two countries' experiences.

2. Symposium Motivation

Due to the breadth and extent of its causes and impacts, climate change is one of the most significant challenges facing human-kind. In 2013, the Intergovernmental Panel on Climate Change (IPCC) published their Fifth Assessment Report in which three working groups reported on (https://www.ipcc.ch/report/ar5/index.shtml): (i) the physical science basis, (ii) impacts, adaptation, and vulnerability, and (iii) mitigation of climate change. The first of these reports detailed observational data of the earth climate system including temperature and sea level rise, increasing heat content of the ocean, and melting of glaciers and ice sheets (http://climate.nasa.gov/evidence/). Since the mid-20th century, observed changes are unprecedented over time scales of decades to millennia and are largely accepted by the scientific community as evidence of climate change. The report also states that recent greenhouse gas emissions are the highest in history and the anthropogenic influence on the climate system is clear.

Climate change impacts human and natural systems. However, as seen from the recent UN Framework Convention on Climate Change negotiations, a significant difficulty in addressing climate change drivers and effects is the need for global cooperation to shift human reliance on combustion technologies and overcome political challenges. Given the depth and scope of this problem, it provides a clear opportunity for science diplomacy.

To that end, the Symposium served as a forum to discuss climate issues, learn about the latest research on the topic and understand how each country is moving forward to address this challenge. Assessing the impacts on a local scale is imperative to develop plans to react and minimize potential negative effects. As forecasts are tending to converge over time, mitigation is emerging as the next critical step and was given equal standing with understanding climate change impacts. The spirit of the Symposium was to bring a diverse group of scholars together to initiate dialogue about climate change and the next steps to take as a collective group.

3. Research Fields of Climate Change: Impacts and Mitigation

The scientific committee of the U.S.-Iran Symposium on Climate Change met several times to plan the meeting and converged on a set of focus topics that were of mutual interest:

3.1. Water Security

The focus of this portion of the Symposium was on perhaps the most important natural resource for living beings, water, and how its availability is being altered by climate change. Of particular emphasis was the comparable water challenges of semi-arid regions such as Iran and the southwestern U.S. Presentation topics included climate model projections as they related to water resources, impact of exploitation of groundwater on land subsidence, and impact of climate change on Caspian Sea level, and river flow/discharge changes in Iran.

3.2. Food Safety

In a natural progression after water, impacts of climate on food production as it is threatened by climate change were covered in the next set of talks. Presentations discussed impacts of climate change on the following: food-borne parasites, veterinary infectious diseases, food security in Iran, and farming and agriculture.

3.3. Environmental Impacts

Changes in temperature and water availability also impact the environment that tends to be less robust than human systems and is altered in ways that humans cannot control or find desirable. This broad topic included talks ranging from impacts of climate change on forest decline, soil organic carbon, wetlands, and air pollution.

3.4. Climate Change Mitigation/Adaptation

The first three topic areas provided the groundwork for a broad understanding of climate impacts on various sectors. The emphasis then shifted to mitigation of those impacts and adaptation to climate change. Examples of specific issues included mitigation potential of greenhouse gases emissions in Iran via methods such as use of alternative energy. Talks discussed frameworks to approach adaptation to climate change such as with 'resilient thinking.' As the meeting was held in California, a presentation also provided a unique assessment of whether that state will lose its hydroelectric power production due to climate change.

4. What We Learned from the Symposium on Climate Change

Overall, the content of the Symposium was well-received by all participants and promoted dialogue and interaction. The significance of climate change impacts and mitigation was made clear and similar views were shared by the group about both the urgency of the climate change issue and priority areas for future work. Scientists from both countries interacted at a high level and discussed how to extend collaborations beyond the meeting. Breakout sessions allowed for an organized collection of thoughts about how the scientists could engage in future dialogue and what key priorities should be for future work. A result of these discussions was a list of primary areas of concern for Iran in terms of research and implementation. Discussions motivated the development of a special journal issue to present the findings of papers presented at this meeting and the publication of these proceedings. A reciprocal meeting to be held in Iran was also discussed that garnered interest and that would continue the spirit of science diplomacy and communication between the two countries.

5. Acknowledgements

We are grateful to the persons and institutions that have made this symposium and the publication of these proceedings possible. In particular, we would like to thank: the International Visitor Program; the United States National Academy of Sciences, the United States National Academy of Engineering and the National Academy of Sciences of the Islamic Republic of Iran.

Further, we express our thanks to Mr. Larry Moody of the International Leadership program for his dedication and devotion to the promotion of science. We also would like to thank Mr. Glenn Schweitzer of the United States Academy of Sciences for his tireless efforts to enhance and support

Science Diplomacy and Dr. Hassan Zohoor of the National Academy of Sciences of the Islamic Republic of Iran for his efforts and support of this endeavor.

The organizers would like to thank the University of California at Irvine for their support of this scientific event. In particular, we express our gratitude to Dr. Soroosh Sorooshian for his devotion and efforts to make the symposium a success.The contributions of Ms. Jacqueline Martin of the National Academy of Sciences and the staff at the Arnold and Mabel Beckman Center towards the success of the symposium are greatly acknowledged

In addition, we acknowledge the participants for joining us in Irvine to present their research results, participate in a wide ranging discussion and provide the papers making up this document; their scientific contributions were the basis for the meeting and their enthusiasm enhanced the quality of the meeting.

Also, we are indebted to Dr. David Quanrud of the University of Arizona for his excellent job as Executive Editor and for leading the on-site symposium coordination.

Finally, our special thanks to the staff of the University of Arizona Department of Civil Engineering and Engineering Mechanics, in particular Ms. Therese Lane, Senior Business Manager, and Ms. Sierra Lindsay for their assistance in the organization of the Symposium and preparation of the proceedings.

Kevin Lansey, Co-Chairman
Hassan Vafai, Co-Chairman
Armin Sorooshian, Co-Chairman
February, 2016

Attendees of the U.S.-Iran Symposium on Climate Change, March 31, 2015

Event Program

Monday, March 30

8:00 – 9:30 a.m.	*Registration*
9:30 – 9:40 a.m.	**Welcoming and Opening Remarks –** Dr. Kevin Lansey, University of Arizona
9:40 – 10:00 a.m.	**Ancient Persian Approaches to Climate Adaptability: U.S.-Iran Bilateral Scientific Collaborations –** Dr. Hassan Vafai, University of Arizona
10:00 a.m. – 11:00 a.m.	**Keynote Address: The U.S. National Climate Assessment: Process and Outcomes –** Dr. Katherine Jacobs, University of Arizona
11:00 – 11:30 a.m.	*Break*
11:30 a.m. – 12:30 p.m.	**Keynote Address: Windblown Desert Dust: A Climate Wildcard –** Dr. Charles Zender, University of California at Irvine
12:30 – 2:00 p.m.	*Lunch*

General Session I — Water Security Impacts
Moderator — Dr. Kevin Lansey

2:00 – 2:20 p.m.	**Review of Recent Climate Model projections over Iran and the Potential Value of Remote-Sensing Information for Water Resources Assessment –** Dr. Soroosh Sorooshian, University of California at Irvine
2:20 – 2:40 p.m.	**Comparison General Circulation Models, Green Gas Emission Scenarios and Downscaling Models to Investigate the Impacts of Climate Change on Runoff –** Dr. Alizera Massah Bavani, University of Tehran
2:40 – 3:00 p.m.	**Monitoring of Land Subsidence Caused by Over-Exploitation of Groundwater Using Radar Interferometry –** Dr. Maryam Dehgani, Shiraz University
3:00 – 3:30 p.m.	*Break*

General Session II — Water Security Impacts
Moderator — Dr. Soroosh Sorooshian

3:30 – 3:50 p.m.	**Frequency Domain Analysis of Caspian Sea Level Changes Observed from Altimetry Satellites and their Relation with the Volga River Discharge** – Dr. Madjid Abbasi, University of Zanjan
3:50 – 4:10 p.m.	**Investigation of Trends: Annual and Seasonal Climatology Parameters in Different Regions of Iran –** Dr. Maryam Azarakhshi, University of Torbat Heidaryeh
4:10 p.m. – 4:30 p.m.	**Impacts of Climate Change on River Discharge in the Aji Chay Basin, Northwest of Iran –** Dr. Fariba Karami, Tabriz University
4:30 – 5:00 p.m.	***Breakout Session I***

Tuesday, March 31

8:30 – 9:30 a.m.	**Keynote Address: The U.S. National Climate Assessment: setting the Stage for Risk Management –** Dr. Donald J. Wuebbles, University of Illinois

General Session III — Water Security Impacts
Moderator — Dr. Jennifer Burney

9:30 – 9:50 a.m.	**Epidemiology and Ecology of Food-Borne Parasites –** Dr. Fatemeh Jalousian, University of Tehran
9:50 – 10:10 a.m.	**The Effect of Climate Change on Veterinary Infectious Diseases** – Dr. Mohammad Rahim Haji Hajikolaei, Shahid Chamran University
10:10 – 10:40 a.m.	**Climate Change and Drought: Adverse Effects on Iranian Food Security –** Dr. Mohammad Shahedi, Isfahan University of Technology
10:40 – 11:10 a.m.	***Break***

General Session IV — Environmental Impacts
Moderator — Dr. Maryam Dehghani

11:10 – 11:30 a.m.	**The Effects of Droughts on Food Safety –** Dr. Seyed Shahram Shekarforoush, Shiraz University

11:30 – 11:50 a.m.	**Sustainable Intensification: How to Satisfy the Rising Demand for Animal Protein without Depleting Natural Resources –** Dr. Frank Mitloehner, University of California at Davis
11:50 a.m. – 12:10 p.m.	**Climate and Air Pollution Impacts on Agriculture –** Dr. Jennifer Burney, University of California at San Diego

General Session V — Environmental Impacts

Moderator — Dr. George Ban-Weiss

1:30 – 1:50 p.m.	**Climate Change Forecasting and Impact on Water Resources –** Dr. Dennis Lettenmaier, University of California at Los Angeles
1:50 – 2:10 p.m.	**Trending of Evapotranspiration and Investigating the Meteorological Parameters Influenced on Climate Change in the Zagros Forests and their Effects on Forest Decline –** Dr. Pedram Attarod, University of Tehran
2:10 – 2:30 p.m.	**The Impact of Climate Change on Soil Organic Carbon in Iran Using LARS-WG and RothC Models –** Dr. Raheleh Farzanmanesh, Project Manager, Artnos Company
2:30 – 2:50 p.m.	**Investigating the Effects of Climate Change on Wetlands Using Risk Assessment and Remote Sensing (Case Study: Chogakhor Wetland, Iran) –** Dr. Bahram Malekmohammadi, University of Tehran
2:50 – 3:20 p.m.	*Break*
3:20 – 3:50 p.m.	*Breakout Session II*

General Session VI — Environmental Impacts

Moderator — Dr. Pedram Attarod

3:50 – 4:10 p.m.	**Water Scarcity and Environment in Iran: Challenges and Opportunities –** Dr. Amir Aghakouchak, University of California at Irvine
4:10 – 4:30 p.m.	**Climate Change Impacts on Air Quality in Iran: A Case Study Analysis for Tehran –** Dr. Armin Sorooshian, University of Arizona
4:30 – 4:50 p.m.	**Urban Heat Island and Air Pollution Mitigation as Climate Change Adaptation –** Dr. George Ban-Weiss, University of Southern California
4:50 – 5:15 p.m.	**Tutorial on CHRS – UCI's Satellite Data Products –** Dr. Phu Nguyen, University of California at Irvine

Wednesday, April 1

	General Session VII — Climate Change Mitigation/Adaptation Moderator — Dr. Mohammad Shahedi
8:30 – 8:50 a.m.	**Policy Implementation and Environmental Policy in Sustainable Communities that are Adapting to Climate Change** – Dr. Daniel Mazmanian, University of Southern California
8:50 – 9:10 a.m.	**Overview of Greenhouse Gas Emissions Trends and Mitigation Potential in Iran: Case Study Cement Sector –** Dr. Mohammad Sadegh Ahadi, National Climate Change Office of Iran
9:10 – 9:30 a.m.	**Use of Solar and Alternative Energy to Reduce Greenhouse Gas Emissions –** Dr. Mohsen Lashgari, Institute for Advanced Studies in Basic Sciences
9:30 – 9:50 a.m.	**Resilience Thinking for Adaptation of Cities to Climate Change –** Dr. David Quanrud, University of Arizona
9:50 – 10:20 a.m.	*Break*
	General Session VIII — Climate Change Mitigation/Adaptation Moderator — Dr. David Quanrud
10:20 – 10:40 a.m.	**Wildlife Corridor as Conservation Management Tool to Mitigate the Impacts of Climate Change (Case Study: Maintaining Habitat Connectivity in Isfahan Province, Iran) –** Dr. Sima Fakheran, Isfahan University of Technology
10:40 – 11:00 a.m.	**An Adaptive Approach to Climate Change –** Dr. Kevin Lansey, University of Arizona
11:00 – 11:20 a.m.	**Will California Lose its Hydroelectricity Under Climate Change? –** Dr. Kaveh Madani, Imperial College of London
11:20 – 11:45 a.m.	*Closing Remarks/Rapporteur Comments*
11:45 – 1:00 p.m.	*Lunch*
1:00 – 2:30 p.m.	*Iranian Delegation Program Evaluation*

U.S.-Iran Symposium on Climate Change: Impacts and Mitigation

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Contributions of the Third U.S. National Climate Assessment

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Abstract

The third US National Climate Assessment (NCA) report was completed in May of 2014. The Global Change Research Act of 1990 requires that the 13 federal agencies within the US Global Change Research Program prepare a report not less than every four years, that integrates, evaluates and interprets the findings of the Program and discusses scientific uncertainties; analyzes the effects of global change on a range of sectors; and analyzes current trends in global change, both human-induced and natural, and projects major trends for the subsequent 25 to 100 years. Although two previous assessment reports had been prepared in the intervening 20 years, the process for preparing National Climate Assessments had never been firmly established within the US government. This third NCA process was intended to establish a sustained assessment effort across as well as meeting the requirements of the law. It represented a major step forward for climate assessments internationally on many fronts, including the inclusiveness and transparency of the process, the decision-relevance of the findings, and the highly accessible electronic format of the report itself (see nca2014@globalchange.gov)

Keywords: Climate Change, Adaptation, Decision Support, National Climate Assessment

1. INTRODUCTION

Because the impacts of climate change are already impacting communities across the globe, the Third US National Climate Assessment (NCA) was designed from its inception to be as relevant as possible to decision-makers. The authors of the NCA were asked to prepare their chapters and associated key findings in a risk management framework. This approach was selected because of the need for clear communication of current and future conditions to people who need to make decisions to protect communities, ecosystems and sectors. It also recognizes the challenges of discussing climate change issues in the US, where in some locations climate change is viewed as a political issue rather than a scientific reality. In such circumstances it is clearly acceptable to talk about managing the risks of droughts, floods, sea level rise, etc., while it is more challenging for political reasons in some states to directly discuss climate change [1].

The US Global Change Research Program (USGCRP) makes the largest investment in climate science across the globe, investing roughly $2.6 Billion annually in observing systems, data collection and management, modeling and decision support. Only a small fraction of this investment is in understanding underlying vulnerabilities, assessment processes, climate services, climate adaptation and communications – the vast majority is spent on satellites, buoys and other observing systems and on large scale modelling efforts. The 1990 Global Change Research Act (GCRA) established the USGCRP to provide for development and coordination of a comprehensive and integrated United States research program (to)… assist the Nation and the world to **understand, assess, predict, and respond** to human-induced and natural processes of global change. It is therefore critical to do periodic assessments of what is being learned over time as identifying scientific uncertainties, in order to meet this legal mandate and to translate all of this scientific investment into information that can be used to predict and respond to changes in climate. Scientific assessments, if properly designed, can help develop a coherent, credible foundation for managing risk.

Managing risk requires understanding both likelihood and consequence of future events understanding intensity and duration of future climate drivers AND understanding underlying sources of vulnerability, including social, institutional and physical vulnerabilities. This means that it is not advisable for managers to consider the risks of climate change in the absence of understanding demographic, economic and environmental stresses, especially given that there are uncertainties in both the climate system and in human responses. For this reason, the authors were encouraged to think about climate stresses within sectors and regions in the context of other conditions that contribute to vulnerability, and to think about "key" stresses that were most likely to cause serious problems for society, infrastructure or ecosystems.

It is very challenging to prepare scientific assessment information that is accessible and useful for decision-makers at multiple scales, including individuals, non-governmental organizations, businesses, corporations, universities, cities and towns, watersheds, regional planners, states, as well as tribes, the US federal government, and other countries and continents across the globe. The desire for this third NCA to be relevant to decision-makers at all of these scales led to a decision to deliver the report itself as an interactive website that was linked to background data and reports at multiple scales and levels of detail that supported the key messages and the graphics. For a detailed description of this effort and the associated data management system see [2].

2. THE THIRD NATIONAL CLIMATE ASSESSMENT VISION

The goal that was adopted for the NCA3 was "to enhance the ability of the United States to **anticipate, mitigate, and adapt** to changes in the global environment." This goal directly focuses on the concept of connecting science and decision-making. The vision for the process was "to advance an **inclusive, broad-based, and sustained process** for assessing and communicating scientific knowledge of the impacts, risks, and vulnerabilities associated with a changing global climate in support of decision-making across the United States". The vision emphasizes the importance of a process that welcomes participation from all sectors of society, rather than being conducted entirely within the federal government [3]. The "sustained" part of this vision reflects the desire of the participants to build a long-term process that continues over time, rather than having to rebuild the assessment infrastructure every four (or more) years in order to meet the mandate of the GCRA [4].

The Assessment process was led by the Office of Science and Technology Policy in the White House, with a central coordination staff within USGCRP that worked with agencies to support the central activities of the NCA3 (Fig. 1). The actual report was produced by a 60-member federal advisory committee, the NCA Development and Advisory Committee (NCADAC). In addition, a network of 150 external organizations called the NCAnet provided a variety of services and helped with the engagement and outreach efforts [5].

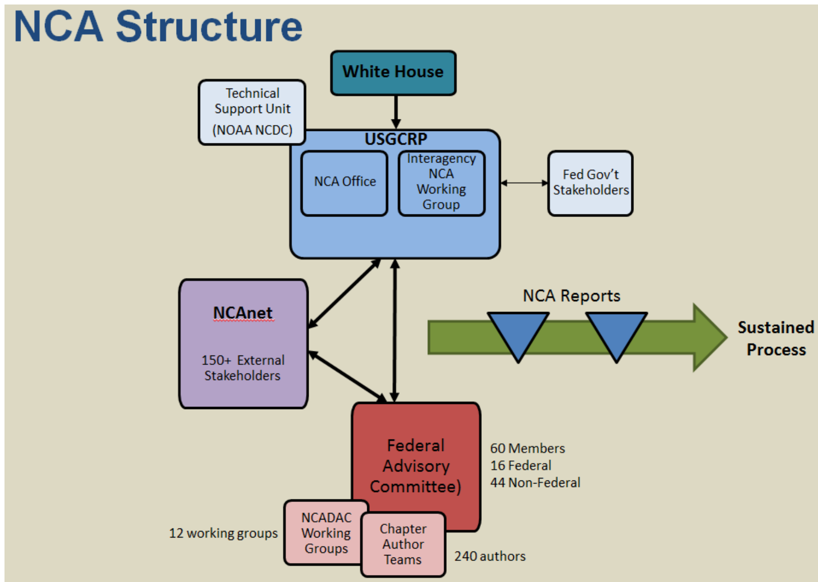

Figure 1: Structure of the National Climate Assessment

3. The NCA Approach

Because of the broad outreach strategy and the desire to be decision-relevant in multiple sectors and regions, the NCA3 involved a large number of authors (300) and one of the largest ever federal advisory committees members (60 members). Although this did increase the complexity of the effort, it allowed for a wide diversity of perspectives and the potential for reaching into multiple existing 'knowledge networks.' In retrospect, this broad-based approach clearly led to the success of the "roll-out" of the assessment products, which were widely hailed as very accessible and resulted in hundreds of thousands of downloads of portions of the report [5]. In addition to the very broad-based approach, from the beginning the leaders of the NCA worked to build the concept of a sustained assessment process and participants as a flexible "learning organization" that could adapt to changing circumstances and different administrations within the federal government.

The authors of the assessment came from a wide range of vocations, including professors, government scientists, non-governmental organizations, private sector companies. There was a deliberate attempt to build author teams that were comprised of scientists as well as managers and decision-makers, and to develop "knowledge networks" that could support adaptation efforts across the country [3]. Fourteen workshops were held before the author teams were selected to provide guidance to the participants on a wide range of topics. Technical input documents were solicited from the public and through federal agencies to provide a foundation for the 30 chapters of the NCA3 report [6]. Unlike previous NCA reports, there were six "cross-cutting" chapter topics in addition to the standard discussion of climate science and impacts on 8 geographic regions and 7 economic sectors. These experimental, interdisciplinary chapters included: *Water, Energy, and Land Use; Urban Systems, Infrastructure, and Vulnerability; Impacts of Climate Change on Tribal, Indigenous, and Native*

Lands and Resources; Land Use and Land Cover Change; Rural Communities; and *Biogeochemical Cycles.* Each of these chapters examined the impact of climate change on the intersections between systems rather than looking at individual, highly segregated topics like agriculture, energy, or transportation.

4. Products

In addition to the full 840 page report, which was delivered to the government electronically as an interactive, web-based, searchable product, there were a number of printed products including a 148 page Highlights document (available from USGCRP at globalchange.gov), a series of regional and sectoral summaries, and some much shorter documents focused on the key messages from all of the chapters. Within the electronic website are the "traceable accounts," an innovation of this report that provides insight into the authors' rationale for selecting key messages and important literature. The traceable accounts also characterize the author's degree of certainty about the findings [7]. The website provides multiple ways to search for topics using keywords, but also provides links to data and sources for those who want to delve into topics more deeply. The graphics are also available as high-resolution files, and some of them are interactive.

Despite the importance of all of these products, many felt that the process itself was a more important outcome than the report. This was partly because of all of the new knowledge that was generated through the interactions of so many people from different walks of life, but also because the idea of building a sustained partnership between the government and its citizens to allow for joint learning across the science/society interface was inspiring to many. The contributions of the NCA3 to adaptation and resilience efforts included:

- Joint learning between scientists and stakeholders
- A decision support focus
- Explicit support for "tacit" (real-world) as opposed to only "expert" (academic) knowledge
- Focus on relationship building, networks and science translation
- New modes of inter-agency support: the Interagency NCA Task Force, and a Technical Support Unit provided by the National Oceanic and Atmospheric Administration.

The high level messages that were included in the report, as well as many of the fundamental components of the climate science chapter, can be found in the Wuebbles article in this journal.

5. Conclusions

There were many ways in which the NCA3 paved a new path in both the products and the processes of national climate assessments, but none of its contributions were more important than the foundation that it laid for subsequent Executive Actions from the White House related to climate change. A long list of executive orders were issued by the Obama administration related to climate adaptation, resilience and preparedness between 2009 and 2015. The President's Climate Action Plan (June, 2013), which mentioned the NCA, had three major components: managing emissions, preparedness for the impacts of climate change, and providing international leadership. There is a long list of accomplishments associated with each one of these categories, all of which are underpinned by the investments in climate science and the knowledge of on-the-ground practitioners that are reported in the NCA3. The recently announced conclusion of the Paris climate negotiations are directly related to these efforts.

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Comparision General Circulation Models, Green Gas Emission Scenarios and Downscaling Models to Investigate the Impacts of Climate Change on Runoff

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Abstract

Three sources of uncertainty, namely 15 General Circulation Models (GCMs), Three Green Gas Emission Scenarios (GGES) including A1B, A2, and B1 as well as two downscaling techniques (LARS-WG and SDSM) has been used in order to evaluate the impacts of climate change on runoff for the future period (2015-2030). In this research, firstly LARS-WG, SDSM and HEC-HMS models have been calibrated and validated for the 1971-2000 period. Then, Lumped HEC-HMS model utilized the outputs of statistical downscaling models so as to simulate the continuous runoff in future period (2015-2030). According to the results, increase in mean monthly temperature, and both increase and decrease in future mean monthly precipitation, compared to the base period, have been predicted for the future period (2015-2030). Also, the deviation range among 15 GCMs and emission scenarios for temperature are less, so the uncertainty is insignificant. However, this amount among 15 GCMs is high for precipitation, thus there is remarkable uncertainty. Furthermore, some months, namely February, June, and September demonstrate the major uncertainty among emission scenarios for precipitation. Finally, quite a few months such as November, December, to name but a few shows the significant uncertainty for both emission scenarios and GCMs for future runoff. What is more, the difference of change percentage between two downscaling models is between 4% and 117% which indicate high uncertainty in some months.

Keywords: Uncertainty, General Circulation Models, Green Gas Emission Scenarios, SDSM, LARS-WG

1. INTRODUCTION

Assessment of climate change effects on water resources is one of the critical issues in recent years. Wilby and Harris (2006) have categorized numerous sources of uncertainty, including greenhouse gas emission scenarios; Global climate models (GCMs), downscaling methods, impact model and natural climate variability [1]. Several researches have been assessed various sources of uncertainty in climate change that some of them have been indicated hereunder. Sajjad Khan et al. (2005) analyzed uncertainty of three statistical downscaling models, namely SDSM, LARS-WG, and ANN on Chute-du-diable sub-basin situated in the Saguenay-Lac-Saint-Jean watershed in northern Quebec in Canada [2]. According to this research, LARS-WG and SDSM models have had same performances; however, ANN model has shown weak functions in assessing of variability and uncertainty of downscaled precipitation and temperature. Teng et al. (2011) assessed the uncertainty of 15 GCMs and five lumped hydrological models to investigate the effects of climate change on runoff across southeast Australia [3]. The consequences show that the uncertainty of GCM model (28%-35% difference between the minimum and maximum results) is greater than five rainfall-runoff models (less than 7%between the minimum and maximum results). Khoi and Hang (2015) investigated the uncertainty of climate change on hydrology in the Srepok watershed in the Central highlands of Vietnam. Seven GCMs structures, four emission scenarios and SWAT hydrological Model were utilized in this research [4]. According to this study, GCM structure was chosen as an important source of uncertainty in comparison with emission scenarios and climate sensitivity.

The main aim of this research is to investigate the uncertainty of GCMs, emission scenarios as well as downscaling techniques with respect to the impact of climate change on the runoff of the Gharesuo basin for the future period (2015-2030) in Iran. The paper first presents the features of basins as well as climate data. Then, the basic methodology, containing a brief explanation of the hydrological model, GCMs structures, emission scenarios, and downscaling techniques has been described. Subsequently, this research explains the calibration and validation of models, the sources of uncertainty regarded, and gives more detail of results. Finally, Conclusions are given in final section.

2. SECTIONS

2.1. Case Study Introduction

This research has been accomplished on Northwest Kharkheh Basin in Iran which is named Gharesuo basin (Fig.1). The area of this basin, include mountains and plains, is 5,793 km^2. The mean annual precipitation and discharge are between 300 and 800 mm and more than 700 MCM, respectively. The available daily meteorological data is in 1970-2000 period. To start with, Kermanshah synoptic station was chosen as daily temperature data because there is no missing data in the period of 1970-2000 and its elevation is equal to the mean elevations of other stations. Moreover, average of daily data of eleven rainfall stations were used as rainfall inputs for lumped hydrological models. Finally, daily data of GhareBaghestan hydro station were conducted for lumped model.

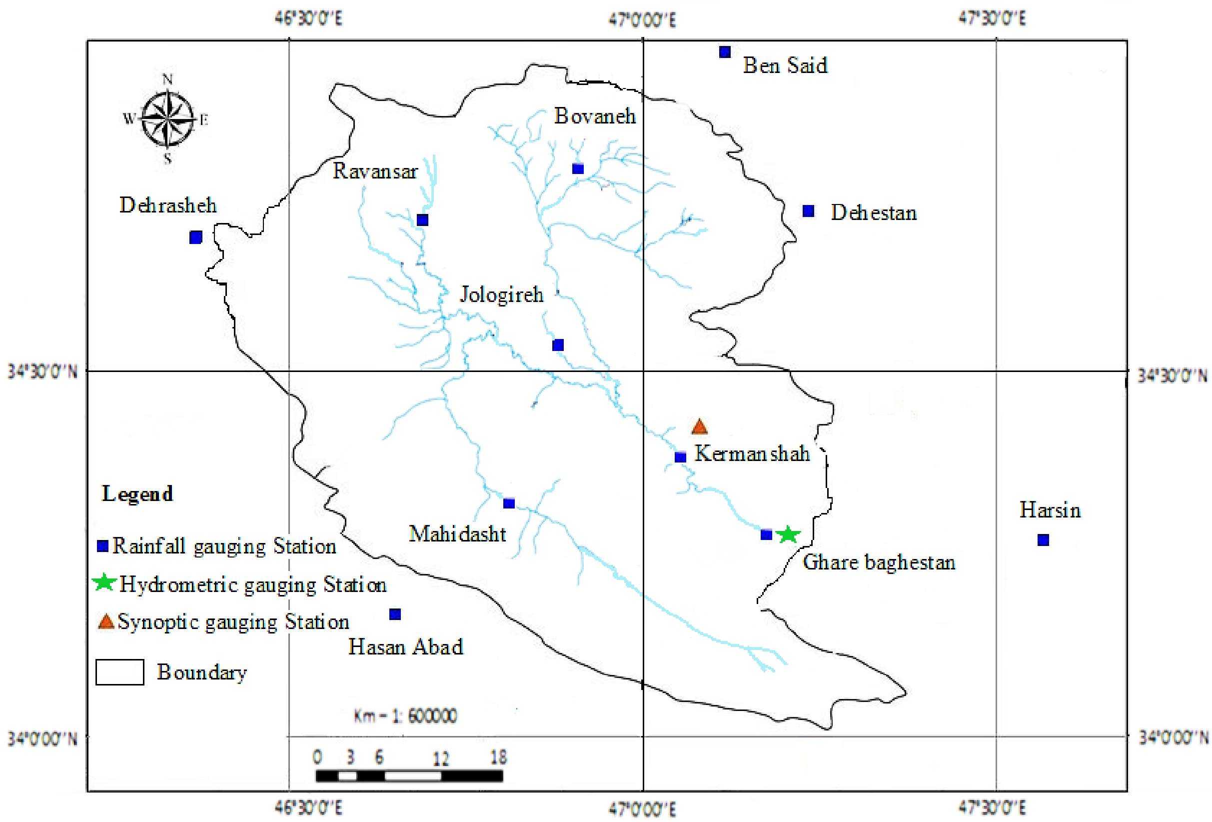

Figure 1: Location of meteorological and hydrometric stations in Gharesuo basin

2.2. Methodology

This study evaluates the contributions of GGES, GCMs, and downscaling techniques uncertainties to the overall uncertainty in the impacts of climate change on runoff.

2.2.1. Emission scenarios and GCM structures

Grid resolution, available emission scenarios and so forth which are momentous features of these GCMs have been demonstrated in Table 1. [5]. As shown, A2, B1, A1B emission scenarios are accessible for most GCMs from the IPCC AR4 multi-model ensemble. In this research, multi-models ensemble of climate predictions from 15 global climate models used in the IPCC AR4, which has been combined with emission scenarios [6], have been utilized in order to assess the uncertainty in impacts of climate change for future period (2015-2030).

TABLE 1: GLOBAL CLIMATE MODELS FROM THE IPCC AR4 (ASSESSMENT REPORT 4) THAT ARE INCORPORATED IN THE LARS-WG WEATHER GENERATOR (NAKICENOVIC &SWART 2000)

Model	Research Center	Country	Grid Resolution	Emission Scenarios	Source
CSMK3	Commonwealth Scientific and Industrial Research Organisation	Australia	1.9° × 1.9°	A1B, B1	[7] [8]
CGMR	Canadian Centre for Climate Modelling and Analysis	Canada	2.8° × 2.8°	A1B	[9]
FGOALS	Institute of Atmospheric Physics	China	2.8° × 2.8°	A1B, B1	[10]
CNCM3	Centre National de Recherches Meteorologiques	France	1.9° × 1.9°	A1B, A2	[11]
IPCM4	Institute Pierre Simon Laplace	France	2.5° × 3.75°	A1B, A2, B1	[12]
MPEH5	Max-Planck Institute for Meteorology	Germany	1.9° × 1.9°	A1B, A2, B1	[13]
MIHR	National Institute for Environmental Studies	Japan	2.8° × 2.8°	A1B, B1	[14]
BCM2	Bjerknes Centre for Climate Research	Norway	1.9° × 1.9°	A1B, B1	[11]
INCM3	Institute for Numerical Mathematics	Russia	4° × 5°	A1B, A2, B1	[15]
HADCM3	UK Meteorological Office	UK	2.5° × 3.75°	A1B, A2, B1	[16], [17]
HADGEM	Met offices Hadly center for climate prediction	UK	1.3° × 1.9°	A1B, A2	[18] [19]
GFCM21	Geophysical Fluid Dynamics Lab	USA	2.0° × 2.5°	A1B, A2, B1	[20]
GIAOM	Goddard Institute for Space Studies	USA	3° × 4°	A1B, B1	[21]
NCPCM	National Centre for Atmospheric Research	USA	2.8° × 2.8°	A1B, B1	[22] [23]
NCCCSM	National Centre for Atmospheric Research	USA	1.4° × 1.4°	A1B, A2, B1	[24]

2.2.2. Statistical downscaling techniques

Two downscaling methods, Statistical Downscaling Model (SDSM) [25] and Long Ashton Research Station-Weather Generator (LARS-WG) [26,27], have been considered in this research.

The LARS-WG technique utilizes semi-empirical distribution in order to estimate daily climate variables, namely minimum and maximum temperature, precipitation, and solar radiation. Also, the statistical Downscaling Model (SDSM) is a decision support tool which is a hybrid between regression based and stochastic weather generation techniques [25].

2.2.3. Lumped HEC-HMS model structure

Hydrological Engineering Center-Hydrological Modeling Center (HEC-HMS) has been developed by US Army-hydrologic Engineering Center [28].

In this research, soil moisture accounting (SMA), Fig. 2, was utilized to compute loss parameter. Soil-moisture storage is divided into two zones, including an upper zone and a tension zone.

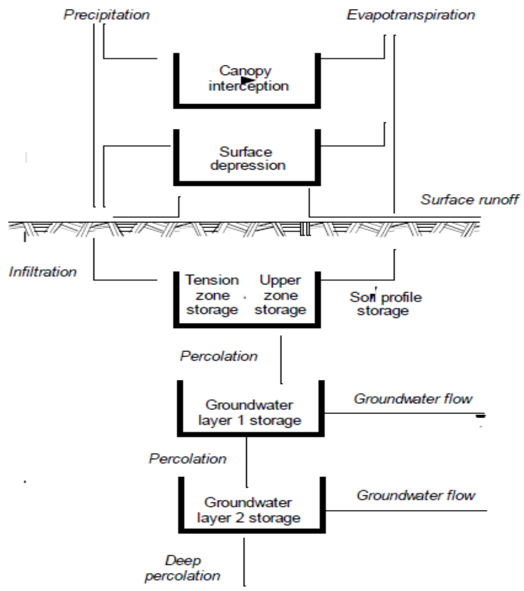

Figure 2: Schematic diagram of HEC-HMS soil-moisture accounting module

In this model, the actual evapotranspiration (AET) is calculated by (Eq. 1).In which PET is actual evapotranspiration in tension zone, also CTs and Ts are current and maximum tension zone storage, respectively.

$$AET = PET \times f\,(CTS_s\,,\,T_s) \tag{1}$$

Since long-term stream flows have been successfully simulated by Clark unit hydrograph [29], [30], this method was applied in this study. Moreover, Recession method was selected in order to calculate subsurface Runoff (Eq. 2). In which RTIOR parameter in HEC-1 is the ratio of current recession flow to the recession flow one hour later.

$$Recession\ Constant = \frac{1}{(\mathrm{RTIOR})^{24}} \tag{2}$$

The criteria in Equation (3, 4, 5 and 6) are considered in order to assess hydrological model performance. According to these Equations, simulated and observed stream flow at time step i are shown by $Q_{sim,i}$ and $Q_{obs,i}$, respectively. In addition, $\bar{Q}_{obs}$ and $\bar{Q}_{sim}$ are the mean observed and simulated discharge, respectively. Moreover, standard deviations of observed and simulated hydrographs are demonstrated by σ_{obs} and σ_{sim} , respectively.

$$Bias = \frac{\left(\frac{1}{N}\sum_{i=1}^{N}\left(Q_{sim,i} - Q_{obs,i}\right)^2\right)^{0.5}}{\bar{Q}_{obs}} \times 100 \tag{3}$$

$$RMSE = \left(\frac{\frac{1}{n}\sum_{i=1}^{n}\left(Q_{obs_t} - \bar{Q}_{obs}\right)\left(Q_{sim_t} - \bar{Q}_{sim}\right)}{\sigma_{obs} \times \sigma_{sim}}\right)^2 \times 100 \tag{4}$$

$$R^2 = \frac{\sum_{i=1}^{N}\left(Q_{obs,i} - Q_{sim,i}\right)^2}{\sum_{i=1}^{N}\left(Q_{obs,i} - \bar{Q}_{obs}\right)^2} \tag{5}$$

$$E = 1 - \frac{\sum_{i=1}^{N}\left(Q_{obs,i} - Q_{sim,i}\right)^2}{\sum_{i=1}^{N}\left(Q_{obs,i} - \bar{Q}_{obs}\right)^2} \tag{6}$$

2.3. RESULT AND DISCUSSION

2.3.1. Downscaling method evaluation

The test results of LARS-WG model for rainfall, maximum and minimum temperature data are given in Table 2. According to this table, LARS-WG model with the confidence level of 10% has enough capability to simulate meteorological variables of this sub-basin for future period.

TABLE 2: RESULTS OF K-S AND P-VALUE OF RAINFALL, MAXIMUM AND MINIMUM OF TEMPERATURE GENERATED BY LARS-WG MODEL IN LUMPED METHOD

	Precipitation		**Min T**		**Max T**	
Month	***K-S***	***P-value***	***K-S***	***P-value***	***K-S***	***P-value***
Jan	0.037	1	0.053	1	0.106	0.9989
Feb	0.05	1	0.053	1	0.105	0.9991
Mar	0.042	1	0.053	1	0.053	1
Apr	0.041	1	0.053	1	0.053	1
May	0.076	1	0.053	1	0.053	1
Jun	0.457	0.0105	0.053	1	0.053	1
Jul	0.391	0.043	0.085	1	0.106	0.9989
Aug	0.435	0.0173	0.158	0.9125	0.158	0.9125
Sep	0.218	0.5895	0.053	1	0.053	1
Oct	0.115	0.9963	0.105	0.9991	0.053	1
Nov	0.06	1	0.106	0.9989	0.053	1
Dec	0.052	1	0.106	0.9989	0.106	0.9989

Also, the calibration period of SDSM model is from 1971 to 1994, and validation period of it is from 1995 to 2000. According to the evaluation criteria in Table 3, SDSM has suitable performance to simulate future climate variable.

TABLE 3: EVALUATION CRITERIA OF SDSM IN CALIBRATION (1971-1994) AND VALIDATION (1995-2000) PERIOD FOR LUMPED MODEL

		Precipitation				Tmax				Tmin			
Indicator	***seasons***	***Calibration***		***Validation***		***Calibration***		***Validation***		***Calibration***		***Validation***	
		Obs.	***SDSM***	***Obs.***	***SDSM***	***Obs.***	***SDSM***	***Obs.***	***SDSM***	***Obs.***	***SDSM***	***Obs.***	***SDSM***
Mean	DJF	2.55	2.48	2.17	2.39	8.08	9.35	11.07	8.78	-2.76	-2.01	-1.72	-2.39
	MAM	2.1	2.23	2.1	1.87	19.94	20.81	21.62	21.48	5.13	5.15	5.19	5.55
	JJA	0.01	0.06	0.04	0.05	35.95	35.04	37.95	35.62	14.77	13.9	16.37	14.27
	SON	1.15	1.05	0.55	1.08	24.62	23.63	25.97	24.3	6.61	6.83	7.12	7.24
	Annual	1.45	1.45	1.21	1.34	22.24	22.27	24.21	22.6	6	6	6.77	6.2
Variance	DJF	29.14	30.55	20.61	28.95	24.77	36.36	20.35	35.7	26.34	23.81	19.8	23.68
	MAM	23.72	27.13	23.71	23.46	39.74	61.49	46.3	70.42	23.35	33.59	25.65	36.89
	JJA	0.04	0.8	0.15	0.5	10.14	27.39	8.36	26.48	11.66	20.43	12.51	20.11
	SON	20.51	13.8	5.61	12.86	54.24	67.52	50.79	70.8	26.86	35.93	26.87	37.36
	Annual	19.24	18.9	13.38	17.19	131.72	131.53	124.14	141.87	60.61	60.44	62.91	64.61
Max dry spell	DJF	90	56	90	7	10	3	0	5	33	15	0	19
	MAM	21	10	48	14	12	4	4	1	59	29	22	9
	JJA	90	84	14	84	1	2	5	0	12	9	22	1
	SON	90	90	56	56	2	0	0	0	9	3	2	5
	Annual	158	153	95	124	12	4	5	3	65	29	22	19
Max wet spell	DJF	12	7	9	6	90	90	90	43	90	85	90	8
	MAM	22	10	9	8	90	90	90	90	50	38	42	27
	JJA	12	11	14	4	90	90	90	90	90	90	21	90
	SON	10	3	10	3	90	90	90	90	90	90	90	59
	Annual	22	11	14	6	360	325	360	331	233	189	141	165
Mean dry spell	DJF	13.21	5.8	50.52	2.11	1.18	0.6	0	0.98	4.27	2.09	0	3.7
	MAM	3.63	2.12	8.81	2.55	1.22	1.07	0.66	0.5	4.42	3.01	4.09	1.97
	JJA	15.68	8.9	3.7	23.12	0.83	0.16	1.16	0	1.38	1.16	4.28	0.16
	SON	50.23	35.99	10.25	7.46	0.1	0	0	0	0.86	0.42	0.66	1.23
	Annual	7.73	4.63	9.45	4.69	1.77	1.19	1.83	1.2	4.38	2.56	4.3	2.75

2.3.2. Hydrological model evaluation

The calibration period for hydrological modeling is from 1979 to 1983, and the validation is from 1985 to 1987 for the lumped HEC-HMS model. The evaluation criteria of hydrological models in calibration and evaluation periods are demonstrated in Table 4, which shows high performance. Moreover, observed and simulated discharge hydrographs are displayed in Figs. 3 and 4.

TABLE 4: VALUES OF EVALUATION CRITERIA OF HYDROLOGICAL MODELS IN CALIBRATION (1979–1983) AND VALIDATION (1985-1987) PERIODS

Hydrological model	Calibration				Validation			
	R^2	***E***	***%RMSE***	***%Bias***	***R^2***	***E***	***%RMSE***	***%Bias***
Lumped	0.7	0.68	58.84	-4.9	0.61	0.6	72.25	-7.55

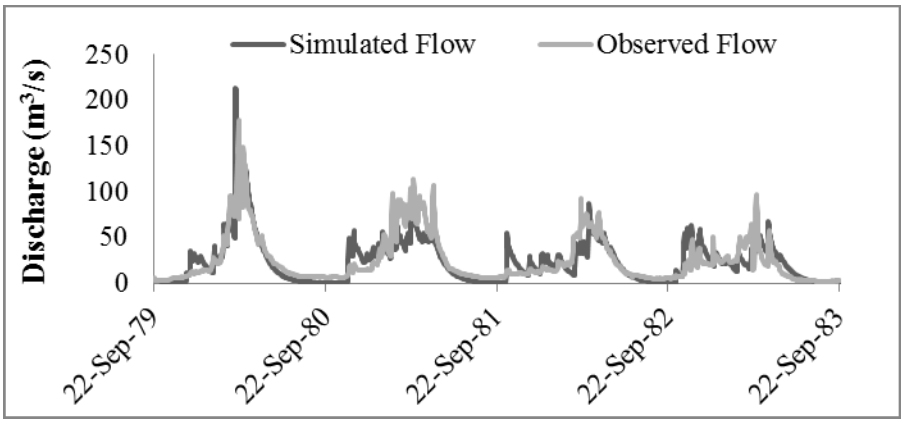

Figure 3: Observed and simulated daily discharge hydrograph in calibration period lumped model

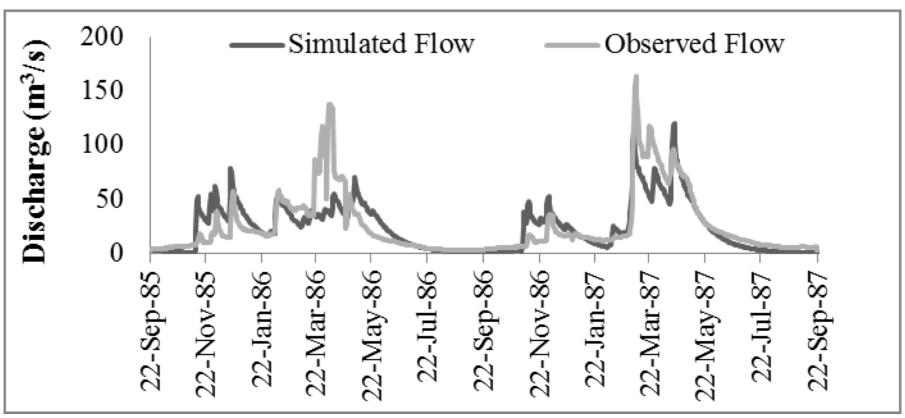

Figure 4: Observed and simulated daily discharge hydrograph in validation period lumped model

2.3.3. Uncertainty analysis of GCM models and emission scenarios

The mean monthly temperature under three emission scenarios has increased for all months (Fig. 5). Also, the deviation range among 15 GCMs under three emission scenarios is between 0.71°C and 1.61°C. In addition, the difference of deviation range among three emission scenarios is between 0°C and 0.75°C. The aforementioned values indicate that there is not any superiority among 15 AOGCMs models as well as three emission scenarios.

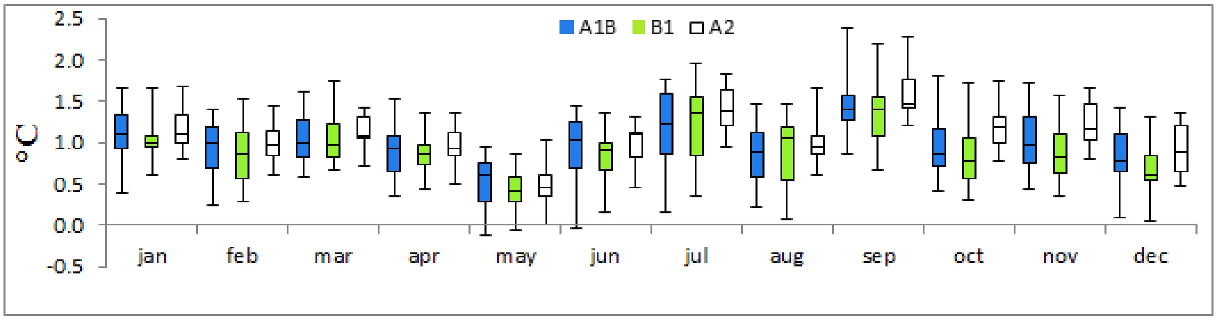

Figure 5: Difference of monthly temperature in the future period (2015-2030) relative to base period (1971-2000) using 15 GCMs models of LARS-WG

According to the Fig. 6, which shows the percentage change of monthly precipitation, there is a significant uncertainty among GCMs models that the maximum of it is in September. Also, totally the positive and negative percent change means increase and decrease in runoff, respectively.

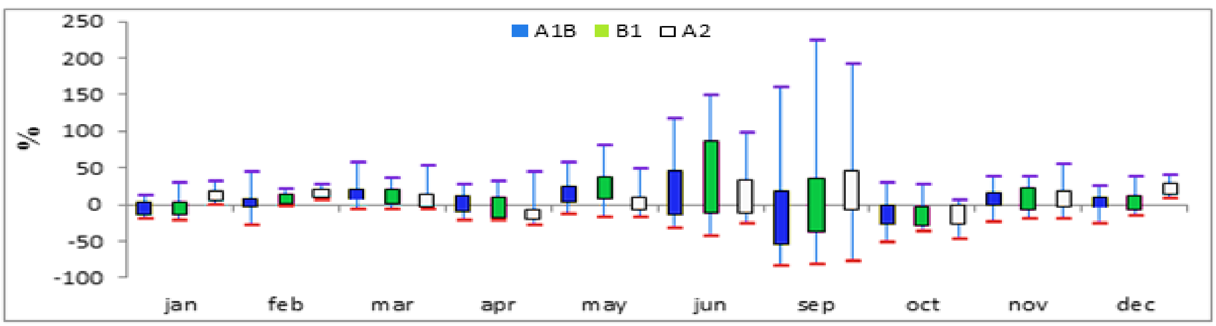

Figure 6: Change percentage of monthly precipitation in the future period (2015-2030) relative to base period (1971-2000) using 15 GCMs models of LARS-WG

Regarding Fig. 7, some months, namely October, November and December have high percent variation range, so there is major uncertainty in these months. However, the uncertainty among GCMs is insignificant in some months.

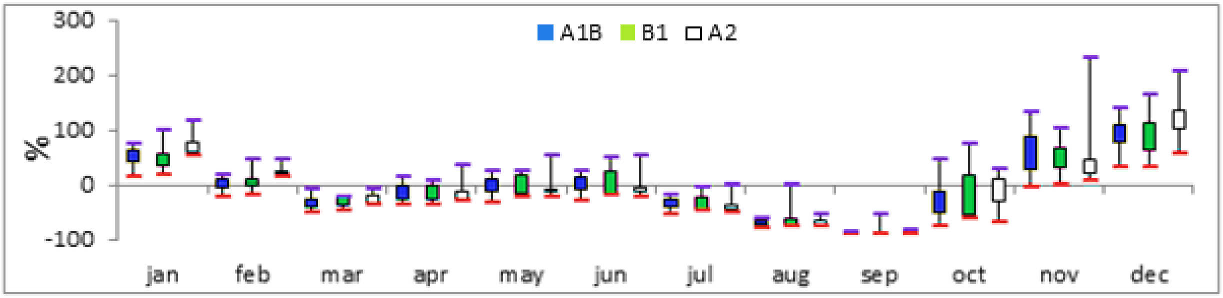

Figure 7: Change percentage of monthly runoff in the future period (2015-2030) relative to base period (1971-2000) by using 15 GCMs models of LARS-WG

The point is that upper and lower Whiskers represent values which are upper than 75% and lower than 25%, respectively. As shown in Fig. 8, percent variation ranges among three emission scenarios except of November under A2 scenario and August under B1 scenario have equal percent variation ranges. To conclude, it should be mention that the uncertainty among them is trivial.

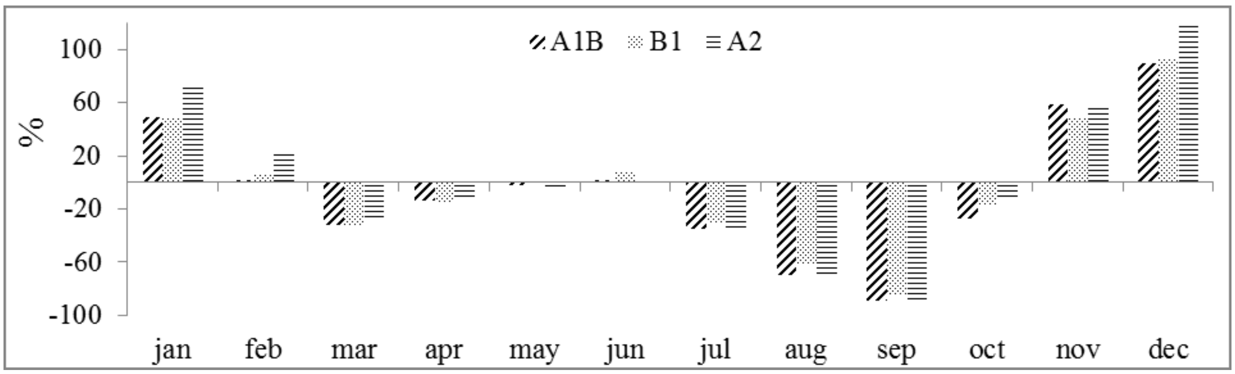

Figure 8: Percentage change of monthly mean runoff between base (1971-2000) and future period (2015-2030) using 15 GCM models

2.3.4. Uncertainty evaluation of downscaling models

SRES scenario A2 from HadCM3 model is chosen as a GCM in both LASR-WG and SDSM downscaling models; and prediction has been accomplished in 2015-2030 period. According to Fig. 9, the maximum and minimum difference of percentage change between two downscaling methods is 117% in December and 4% in May, respectively. The aforementioned results show that the major uncertainty between two downscaling models belongs to December, and the minor of it is related to May. Furthermore, the decrease in runoff is predicted for most of months in future period.

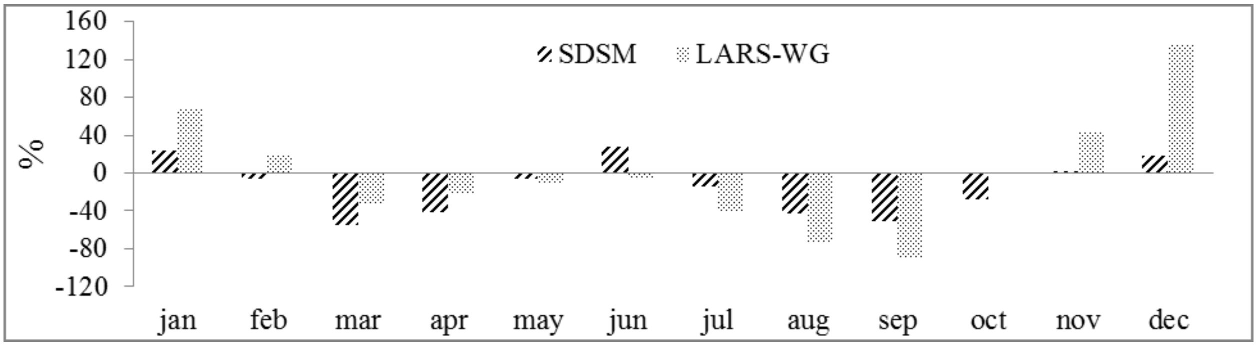

Figure 9: Percentage change of monthly mean runoff under two downscaling models between base (1971-2000) and future period (2015-2030) under two downscaling models

3. CONCLUSION

This research assesses three sources of uncertainty, including GCMs, GGES and Downscaling techniques. According to the consequences, increase in mean monthly temperature for the future period (2015-2030) has been predicted. Also, the deviation range among 15 GCMs under three emission scenarios and among three emission scenarios is below 2°C and 1°C, respectively. These results demonstrate that there is minor uncertainty among 15 GCMs models as well as three emission scenarios for temperature. The deviation range among 15 GCMs under three emission scenarios for precipitation is between 22% and 305% which indicate significant uncertainty. The uncertainty of emission scenarios for precipitation is remarkable in some months such as February, June, and September, while for some months is minor. The significant uncertainty for runoff in some months, especially for October, November and December is driven. In addition, some months, namely August, November, and December have significant uncertainty for emission scenarios. Also, according to the results, major uncertainty between two downscaling models belongs to December, and the minor of it is related to May. Finally, the impacts of climate change on the Gharesuo Basin will cause increase in mean monthly temperature of all months and decrease in monthly runoff of the most months for the future period (2015-2030). So, this basin will be threatened by drought in the future.

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Monitoring of Land Subsidence Caused by Over-Exploitation of Groundwater using Radar Interferometry

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Abstract

Over-exploitation of groundwater has caused land subsidence in large rural areas located in the Mashhad sub-basin, in northeast Iran. Time series analysis using Interferometric SAR (InSAR) data has shown ability to monitor the temporal evolution of land subsidence. In this paper, time series analysis based on Small Baseline Subset (SBAS) algorithm is applied to study the Mashhad sub-basin subsidence. Eighteen interferograms were generated using twelve ENVISAT ASAR images spanning between 2003 and 2005. In order to decrease the temporal decorrelation effect caused by the agricultural fields, only interferograms with small temporal baselines were used in the time series analysis. However, to prevent the solution from the rank deficiency, generation of as many interferograms as possible was performed. Because the interferograms with large spatial baselines are influenced by topographic artifacts, they were refined before use in the time series analysis. Moreover, the atmospheric-error free deformation corresponding to every acquisition time was retrieved by applying a smoothing constraint in the least squares solution. The maximum deformation rate in the study area is estimated as ~23 cm/yr. Finally, the compressibility of the aquifer system wasinvestigated by quantitative integration of the InSAR displacement measurements with observations of the hydraulic head fluctuations at a few piezometric wells.

Keywords: Subsidence, Radar interferometry, ENVISAT ASAR, Mashhad

1. INTRODUCTION

Climate change is likely to cause global temperatures to increase with more erratic rainfall, resulting in more droughts. It causes the over-exploitation of groundwater. The majority of groundwater is used for agricultural activities. Moreover, increased population will increase the demands on groundwater. Excessive groundwater pumping results in an increasing effective stress within the sediments of the aquifer system [1]. An aquifer system is typically composed of a series of poorly permeable and highly compressible fine-grained interbeds. The theoretical basis of interbeds compaction is based on the Terzaghi's principle of effective stress. When water is removed from fine-grained, highly compressible sediments, such as clay and silt interbeds in an aquifer, these sediments are compacted [2]. Hence, the aquifer system has undergone some degree of deformation in response to the changes in stress.

Land subsidence due to the extraction of excessive groundwater is a major problem with considerable environmental consequences in many areas (e.g., [3-7]). Environmental consequences of land subsidence mainly include damage to engineered structures (such as buildings, roadways, pipelines and well casings), earth fissures and surface runoff [2].

One of the areas in Iran subject to land subsidence caused by over-exploitation of groundwater is the Mashhad sub-basin. Mashhad, located in northeast Iran, is the second largest city with a population of 3,500,000 people. The main part of the subsidence area is covered by cultivated fields. Therefore, excessive groundwater extraction from pumping wells to provide water for the agricultural activities has lowered aquifer hydraulic heads. The average decrease in groundwater table in Mashhad sub-basin reaches to 12.3 m during 16 years [8].

The subsidence rate in Mashhad sub-basin was first measured by geodetic observations of precise leveling surveys between 1995 and 2005 across the area. In order to monitor the temporal subsidence behavior in Mashhad sub-basin, one permanent GPS station was installed by National Cartographic Center (NCC) in the subsidence area in 2005. However, it was only possible to measure the deformation at GPS station location. GPS and leveling surveys generally give precise measurements at a few sparse points of the deformed area. Therefore, they are not able to map the extent and pattern of the ground surface deformation. Among the various ground- and space-based techniques available, interferometric Synthetic Aperture Radar (InSAR) provides precise measurements of land surface deformation over large areas and at high spatial resolution [6,9-14]. Time series analysis of a significant number of interferograms allows us to study the temporal behavior of the subsidence [15]. In this study, InSAR time series analysis using 12 ENVISAT ASAR images spanning between 2003 and 2005 is applied to study the subsidence behavior of Mashhad sub-basin. Simple time series analysis without taking into account the error sources was already applied on the radar images of Mashhad sub-basin. However, some of the interferograms were mainly affected by the topographic artifacts due to large spatial baselines. Moreover, other sources of error including the atmospheric effect may reduce the accuracy of the results.

The main purpose of this paper is to measure the deformation caused by subsidence along with mitigating the nuisance terms. The lack of precipitation due to the climate change will result in the increase in pumping more groundwater and subsidence occurrence in Mashhad plain. The mechanics of the Mashhad aquifer system, as well as the spatial heterogeneity of the aquifer system structure are studied. The stress–strain relationships are derived using InSAR measurements and groundwater information from the piezometric wells to understand the mechanics of the compaction of the aquifer system as a function of water level decline. The quantitative integration of the InSAR results and groundwater observations yields information about the storage properties of the aquifer system.

This paper is organized as follows: Section 2 gives a brief background of the study area. In Section 3 the complete time series procedure is introduced. Results are presented in Section 4, including the comparison of InSAR-derived displacements and groundwater information. Finally, concluding remarks are presented in Section 5.

2. STUDY AREA

Mashhad is located in the northeast region of Iran between the Binalood and Hezarmasjed mountains with northwest and southeast trailing. The Mashhad sub-basin is a part of the Ghareghom basin with an area of 44,165 (km^2). The main part of the subsidence area is covered by cultivated fields as shown in the Landsat ETM+ color composite image depicted in Fig. 1. The average temperature of the Mashhad sub-basin is 12.5°C. According to the data acquired during a 30-year period, the average amount of annual rainfall is 315 and 258 mm in mountainous and plain areas, respectively. The main rainfall occurs in spring and winter seasons; however, the aquifer does not receive sufficient recharge, resulting in a continuous decrease of groundwater level. As a result, land subsidence due to excessive groundwater extraction has occurred.

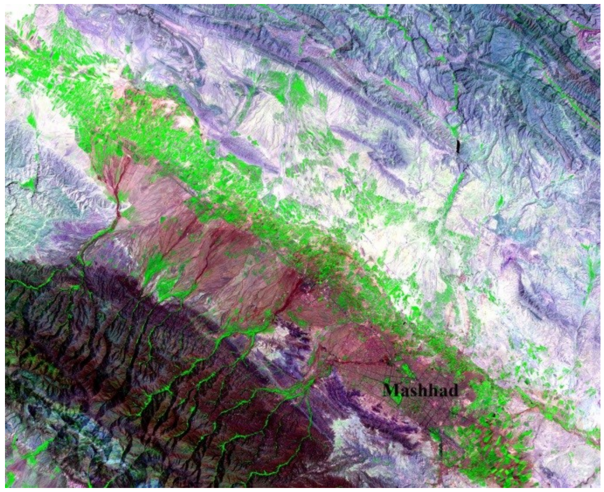

Figure 1: Landsat ETM+ color composite image (R:7, G:4, B:2) of the Mashhad sub-basin

3. INSAR TIME SERIES ANALYSIS

Radar interferometry is used to generate the deformation time series. Least squares inversion is employed to obtain the time-series deformation provided that there are at least as many linearly independent interferograms as acquisition dates and that chain of interferograms is not broken at any point. In time series analysis the deformation due to each acquisition date is estimated assuming the deformation corresponding to the starting date is known. Assume that the interferometric phase, $\delta\phi_k$, computed from two SAR images at times t_i and t_j is given by:

$$\delta\phi_k = \phi(t_i) - \phi(t_j), \qquad k = 1,\dots,M \quad i,j = 1,\dots,N \tag{1}$$

where M and N are the total number of processed interferograms and SAR images, respectively.

It should be noted that $\phi(t_i)$ and $\phi(t_j)$ are the unknown phase values associated with the deformation. Therefore, there is a system of M equations including N unknowns as follows:

$$A\phi = \delta\phi, \tag{2}$$

where ϕ is the vector of N unknown phase values, $\delta\phi$ is the vector of M known interferometric phase and A is the design matrix in the least squares solutions.

The interferometric phase is composed of various phase components. It can be decomposed into more components as shown below:

$$\delta\phi_k = \phi(t_i) - \phi(t_j) \\ \approx \Delta\phi_{def.k} + \Delta\phi_{topo.art.k} + \Delta\phi_{atm.k} + \Delta\phi_{n.k} \quad (3)$$

The first component, i.e., $\Delta\phi_{def.k}$ is surface deformation. This component is computed as,

$$\Delta\phi_{def.k} = \frac{4\pi}{\lambda}[d(t_i) - d(t_j)], \quad (4)$$

where $d(t_i)$ and $d(t_j)$ are the cumulative deformation at times t_i and t_j with respect to the starting time ,t_0, as a reference time and λ is the radar signal wavelength. The second term of Eq. (3), i.e., $\Delta\phi_{topo.art.k}$ is the phase artifacts caused by an error Δz in the knowledge of the topography. The effect of Δz on the interferometric phase depends on slant range r, incidence angle θ, and perpendicular baseline of the interferogram k, $B_{\perp k}$:

$$\Delta\phi_{topo.art.k} = \frac{4\pi}{\lambda}\frac{B_{\perp k}\Delta z}{r\sin\theta} \quad (5)$$

The third component of Eq. (3) is referred to the atmospheric inhomogeneities between two SAR acquisitions at times t_i and t_j . Eventually, the last term $\Delta\phi_{n.k}$ is considered as a noise caused by various types of phenomena including baseline and temporal decorrelation.

In this study we follow a processing algorithm illustrated in the block diagram of Fig. 2 to generate the subsidence time series. This algorithm was originally presented by [15]. The major contribution of their proposed method is use of a large number of SAR acquisitions distributed in small baseline subsets via the singular value decomposition (SVD) method [15]. However, in our study the chain of interferograms is not broken at any point and only one dataset exists.

In the conventional Small Baseline Subset (SBAS) method, only the interferograms with small spatial baselines are processed. However, in some cases we have to use the interferograms that are only characterized by the small temporal baseline. In these cases the spatial decorrelation caused by the large spatial baselines is insignificant in comparison with temporal decorrelation. As we employ the interferograms with spatial baselines larger than in the conventional method (as explained in the next section), the topographic artifacts caused by the large spatial baselines are remarkable. Therefore, the interferograms should be refined before applying in the time series analysis using the method introduced by [15]. After phase-unwrapping step, orbital errors due to the tilts and offsets remaining in the interferograms are removed by subtracting a plane fitted to the data in the far-field, away from the deformation signal. In the next step a method is used to remove the topographic artifacts ([15]) caused by the large spatial baselines.

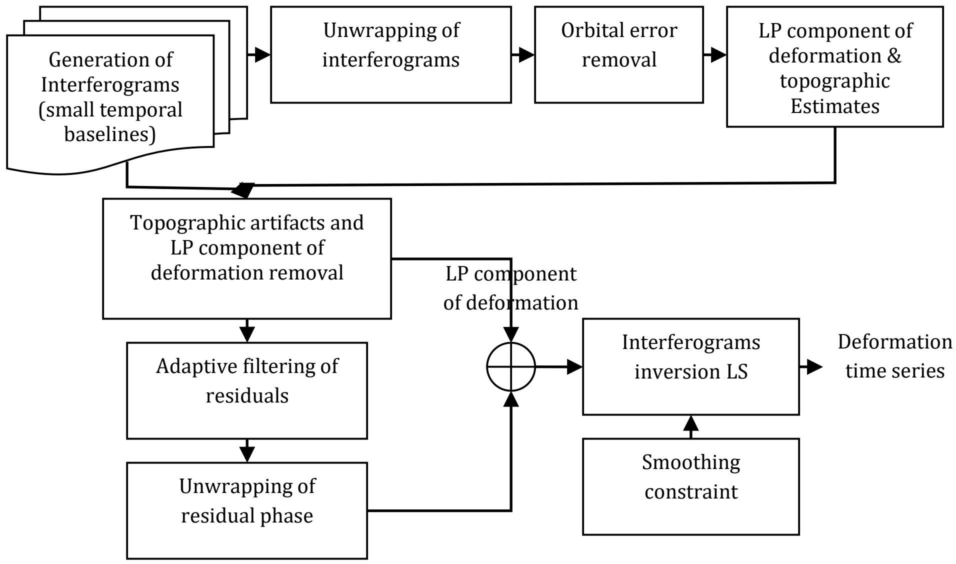

Figure 2: Block diagram of the time series analysis algorithm used in this study

It is assumed that the phase is a linear function of temporal low-pass (LP) components of the deformation, i.e., mean velocity, $\bar{v}$, mean acceleration, $\bar{a}$, and mean acceleration variation, $\Delta\bar{a}$:

$$\phi(t_i) = \bar{v}.(t_i - t_0) + \frac{1}{2}\bar{a}.(t_i - t_0)^2 + \frac{1}{6}\Delta\bar{a}.(t_i - t_0)^3 \qquad (6)$$

The temporal low-pass (LP) components of the subsidence are then jointly estimated with the topographic artifacts (Eq. 5) using the least squares solution. For further details, see [15]. The estimated LP phase patterns and topographic artifacts are then subtracted modulo-2π from each input interferograms as shown in block diagram of Fig. 2. This results in the fringe rate reduction. Accordingly, an adaptive filter is easily applied to reduce the phase noise leading to a high-performance unwrapping of the residuals. A refined unwrapped phase pattern is finally obtained by adding back the subtracted LP component of the deformation. At this stage, the interferograms are inverted via a least squares solution of the equation system of Eq. (2) to obtain the cumulative phase. To mitigate the atmospheric artifacts, noise and unwrapping errors, a smoothing constraint is incorporated into the inversion problem. The smoothing constraint used here is based on the finite difference approximation for the second order differential of the time series applying the minimum curvature concept, i.e. constant velocity. By using the finite difference approximation for the second order differential of the time series as the smoothing constraint, Eq. (2) is written as:

$$\begin{pmatrix} A \\ \gamma^2 * \partial^2 / \partial t^2 \end{pmatrix} \phi = \begin{pmatrix} \delta\phi \\ 0 \end{pmatrix}. \qquad [7]$$

γ is the smoothing factor to be determined optimally. If a small smoothing factor is selected, the obtained deformation time series is rough, while a large one will damp any nonlinear deformation.

Hence, a trade-off methodology should be applied to select the most appropriate smoothing factor regarding reduction of the errors as well as preservation of the nonlinear seasonal deformation signal. The phase values corresponding to each acquisition time are finally obtained using the least squares solution of the equation system of (7). In the last step, the estimated phase values are converted into the displacement signal via a multiplication by the correction factor $\frac{\lambda}{4\pi}$.

4. INSAR TIME SERIES ANALYSIS RESULTS

In conventional interferometry we should be able to process the interferograms as coherently as possible. Small baseline interferograms can be easily formed and individually phase-unwrapped for areas with high coherence. In this study, 18 coherent interferograms are calculated from 12 Level0 ENVISAT ASAR images acquired from track 392 by applying GAMMA software. The acquisition geometry is illustrated in Fig. 3. The processed interferograms are characterized by small temporal baselines and relatively large small baselines. After processing the coherent interferograms, in order to remove the topographic phase component a Digital Elevation Model (DEM) from Shuttle Radar Topography Mission (SRTM) with the spatial resolution of 90 m is used.

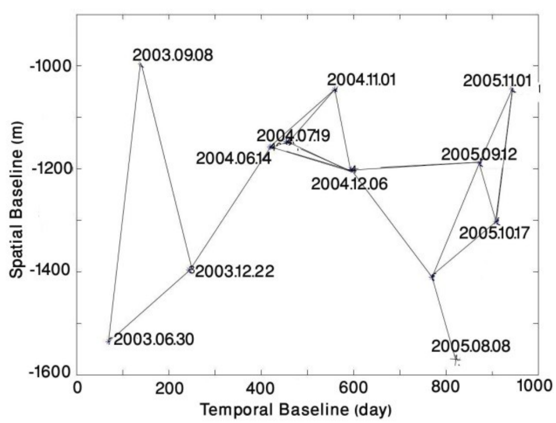

Figure 3: Acquisition geometry of the available radar data in the study area: temporal baselines against spatial baselines. The connections represent the processed interferograms

The time series analysis approach presented in the previous section is then implemented to the interferometric data of Mashhad sub-basin subsidence. In order to highlight the major features of the subsidence and investigate its long term behavior, a Line-Of-Sight (LOS) mean displacement velocity map is computed using the time series results (Fig. 4). The maximum deformation rate estimated from the mean displacement velocity map is 23 cm/yr in the subsidence area. The subsidence trend is northwest towards southeast, following the topographic trend in the study area. Therefore, the subsidence pattern is probably controlled by the linear structures such as faults (see Fig. 4). The faults and structural lineaments shown in Fig. 4 are extracted from a geology map with the scale of 1:250,000 and satellite images. These faults and structures can act as barriers in the aquifer system that controls the groundwater flow. Furthermore, they may be considered as the boundaries of material zones with different controlling hydrogeological parameters that affect the subsidence, such as specific storage and hydraulic conductivity.

Water level information of the piezometric wells is analyzed in order to study the effective stress changes in Mashhad sub-basin. Water level measurements have been made monthly by the Water Management Organization since 1995.

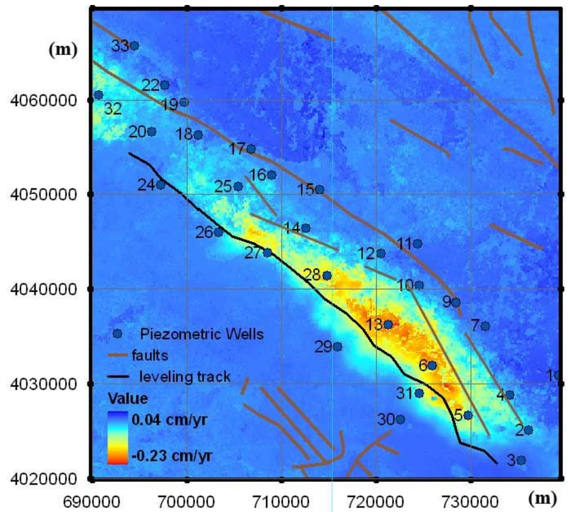

Figure 4: Mean displacement velocity map. Piezometric wells along the subsidence area are illustrated by the filled circles. Numbers along the axes represent the coordinates in the Universal Transverse Mecator projection system

The compaction mechanism and the stress-strain relationship of the aquifer system can be derived from InSAR displacement time-series and contemporaneous measurements of water level. One of the appropriate methods in order to investigate the relationship between groundwater level fluctuations and surface displacements is to map both parameters in a unique plot. The water level variations representing the stress are plotted on the y-axis, whereas the InSAR deformation time-series showing the aquifer compaction are plotted on the x-axis. A rough estimate of the skeletal storage coefficient of the aquifer system can be obtained by the inverse slope of the best fitting line to the plotted points [3]. The Storage coefficient is the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer. The storage coefficient of an aquifer system that contains the responses of the aquifer and fine-grained interbeds to variations in hydraulic head can be also determined by pumping tests. However, the extracted storage coefficients are representative of only the most permeable fraction of the aquifer system. The values extracted by the relationship between the InSAR-derived displacements and groundwater levels yield spatially varying estimates of storage coefficients at the well locations. Furthermore, the estimated values of the slope of the best fitting line enables us to predict the amount of subsidence caused by water level decline.

The water level variations plotted against the ground displacements for some of the piezometric wells are illustrated in Fig. 5. Ground displacements are linearly interpolated to the water level observation dates since the water level observations are made monthly. The red lines in these plots represent the best fitting line to the plotted points. The estimated slope of the best fitting line for each piezometric well is indicated as “S” in its corresponding plot in Fig. 5. Higher storage coefficient corresponds to higher response of the ground surface to water level variations.

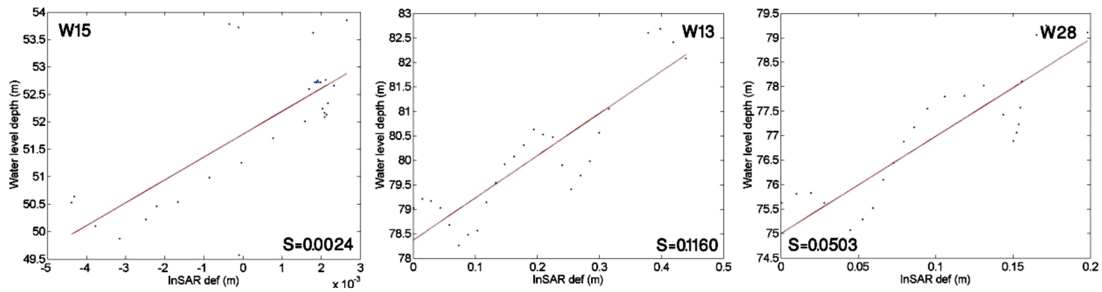

Figure 5: Storage coefficient calculated from stress displacement analysis. Data are plotted in a stress–strain diagram. 'S' in the plots corresponds to the estimated storage coefficient

It should be noted that there is a time delay between the water table decline and compaction of the aquifer system due to the low vertical hydraulic conductivity of the compressible sediments of the aquifer system. Therefore, the estimated values of the storage coefficients do not exactly reflect the compressibility of the aquifer system due to the time delay involved in the equilibration of the fine-grained interbeds. However, the estimated storage coefficients can be used to predict the surface subsidence as a function of water level decline in the near future, though a more reliable prediction can be performed by fitting a sinusoidal function to the plotted points. In order to estimate more reliable values of the storage coefficients, other information including interbeds thicknesses and their distributions in the aquifer system is required. Furthermore, the InSAR-derived displacements can be applied to produce a map of storage coefficients using the hydraulic heads calculated from a groundwater flow model [2].

5. Conclusion

The lack of precipitation due to the climate change will result in an increase in groundwater pumping and occurrence of subsidence. Subsidence caused by drought is the costliest natural hazard in some parts of world. The first step in monitoring land subsidence is to measure its deformation rate. In this paper, the temporal behavior of Mashhad sub-basin is studied using a multi-step time series analysis approach based on InSAR measurements. The processed interferograms used in the time series analysis are only characterized by the small temporal baselines in order to decrease the temporal decorrelation. The spatial baselines of the interferograms are not as small as in the conventional SBAS method. As the interferograms with large spatial baselines are influenced by the topographic artifacts, they are refined before using in the time series analysis. Moreover, the atmospheric-error free deformation corresponding to every acquisition time is retrieved by applying the smoothing constraint into the least squares solution. The maximum deformation rate is estimated as 23 cm/yr. Most parts of the Mashhad plain are highly vulnerable to the effects of regional pumping-induced land subsidence due to climate change. The InSAR-derived deformation time series and water level information are finally used to determine the stress-strain relationship at the piezometric wells. Quantitative integration of deformation time series and water level measurements yields compressibility properties of the aquifer system. The results achieved here can be used to model the compaction of the aquifer system under the climate change scenario. This is considered as future work.

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Frequency domain analysis of the Caspian Sea level changes observed from altimetry satellites and their relation with the Volga River discharge

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Abstract

We analysed the Corrected Sea Surface Height (CorSSH) data, obtained from Topex/Poseidon (T/P), Jason1 and Jason2 satellites between 1993 and 2014 over Caspian Sea (CS). SSH time series were created for points along 9 passes of the satellites as well as for their crossover points which are regarded as virtual tide gauges. The corresponding time series reflect local sea level variations in the area surrounding each point. Each pass contains 760 cycles, long enough to perform detailed analysis in both temporal and spectral domains. During this period, CS level drops about 2.6 cm per year. Spectral analysis shows 11.2 years quasi-decadal periodic variation. The amplitude of a given harmonic component varies spatially over the CS surface. We plotted a one year periodicity (dominant component) amplitude map which shows a maximum of 16 cm.

Volga River (VR) is the main water input source of CS. Volga discharge shows a decreasing rate of 7.3 m^3/s (0.23 km^3/year) per year for the period of 1993-2014. We distinguish a 12.5 years quasi-decadal periodicity as well as its harmonics. By observing the similarity between the spectrum of the VR discharge and that of the CS level variations, we conclude that this periodicity and the above mentioned 11.2 years periodicity originates from the same phenomenon. This means that not only the short-term annual but also the quasi-decadal variations of CS level are tightly controlled by the variations of the VR discharge. For long-term, like multi-decadal periodicities, more observations are needed for an eventually similar conclusion.

Keywords: Caspian Sea, Volga River, Spectral Analysis, Satellite Altimetry, Discharge, Sea Level Variations

1. INTRODUCTION

Based on combined geological evidences and tide gauge observations, CS level has experienced considerable variations in the last millennium: from a high-stand of up to −19 m during the Little Ice Age (1350-1850 AD) [1], to -29 m from mean sea level in 1977 [2].

Many experiments have been conducted to observe water level changes over continental lakes and great rivers using satellite altimetry [3]. Based on this method and in situ gauges measurements, several studies on the CS level changes have been published (see for example [4], [5], [6], [7] and [8]). In a near real time data base developed by [9], the water level and storage variations of important lakes and rivers mainly from remotely sensed satellite altimetry and satellite gravimetry data are monitored. The corresponding reports and time series are given in HYDROWEB database (available at http://www.legos.obs-mip.fr/soa/hydrologie/hydroweb/). Using water level time series given by this data base, [10] reports a decrease of water storage of Caspian and Aral seas, East African lakes, and North American lakes for the period 1993–2008, contributing approximately +0.1 mm/year to the global sea level rise. We computed a mean drop of CS level of about 2.6 cm/year for the period 1993-2014, using the data furnished by [9].

Periodicity analysis of CS is a subject of particular interest. A point-wise Least Squares Spectral Analysis (LSSA) was performed [11] on the SSH data observed by T/P and Jason1 from 1993 to 2009 in order to calculate a local tidal correction model. They report a list of statistically significant periodicities, notably a low frequency quasi-decadal component of 12.5 years period from altimetry and tide gauge observations. The origin of some of these periodicities remains unknown.

CS level is constrained only by river discharge and precipitation and evaporation over the sea and, thus, is very sensitive to changes in the climate system over the region [12]. On average, 130 rivers flow into CS. Volga River (VR) is the greatest river of the CS discharging from the north and providing about 80% of all river influx of the sea [1]. According to [13], the average runoff of VR for the period of 1880–1990 was 241 km^3/year. This amount of inflow has a direct influence on the sea level fluctuations. According to [14], the annual changes of the CS level and the annual changes of the VR mean discharge show the same pattern. Other (probably long-term) periodicities, however, have not been the subject of similar study.

The main objective of this paper is to compare the CS level and the VR discharge time series in the spectral domain, with particular interest in quasi-decadal variations. The main question here is: “does the VR discharge control the CS quasi-decadal variations, or do other climatic factors like precipitation or evaporation play the main role?” Amplitude of annual fluctuations of sea level is the other objective of this study: how much the CS level varies annually from one point to another.

2. DATA

Two different data sets we used in this work: first, Corrected Sea Surface Height (CorSSH), with ±4.2 cm root mean square error, published by AVISO website (http://www.aviso.oceanobs.com), and second, the discharge time series of VR, provided by Global Runoff Data Centre (GRDC) and available at http://www.bafg.de/GRDC/EN/Home/homepage_node.html.

The data from three satellites were used: T/P data from 1993 to 2002 (cycles number 1 to 343), Jason1 data from 2002 to 2008 (cycles number 1 to 239) and Jason2 data from 2008 to 2014 (cycles number 1 to 178). Fig. 1 shows the ground tracks of these satellites. During these periods, their orbits were nearly the same (AVISO website). Also, BRAT (Basic Radar Altimetry Toolbox) software was used to prepare the data series. The T/P, Jason1 and Jason2 satellites orbit the earth in a ground track repeat orbit mode. Consequently, we can consider each altimetry footprint as a virtual tide gauge, where the SSH is observed every 9.915625 days [11].

The VR discharge time series are measured at a station situated in (44.58E, 48.80N) and consists of monthly discharge measurements from 1993 to 2014.

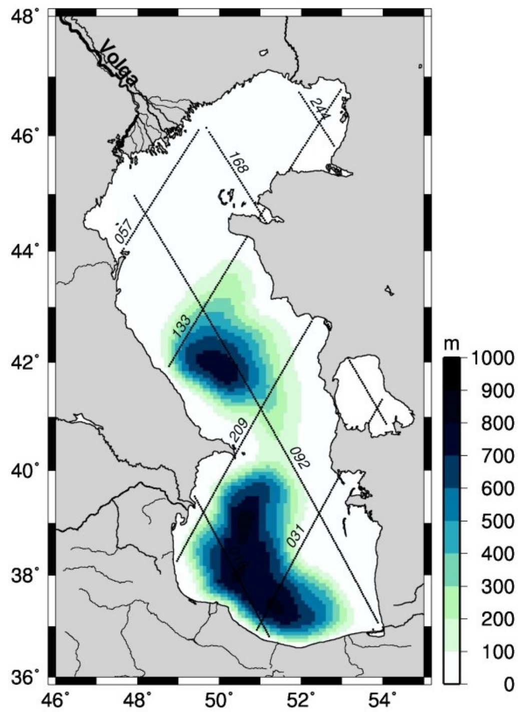

Figure 1: T/P, Jason1 and Jason2 ground tracks over the CS. Each line is enumerated with its pass number

3. DATA PROCESSING

3.1. Spectral Analysis of SSH Time Series

Spectral analysis was performed for all the 860 time series of SSH time series. Due to the existing gaps in the data, they were not always equally spaced in the time domain. Therefore, the Least Squares Spectral Analysis (LSSA) method was employed instead of the classical Fourier method. LSSA was first developed by [15] and its properties were further studied by [16] and [17]. In the next two paragraphs we explain briefly the method and the corresponding test in order to distinguish statistically significant harmonic components in the spectrum as introduced by [17].

The least squares spectral value is defined by

1. $$\mathrm{s}(\omega_i) = \frac{\mathbf{f}^{\mathrm{T}}\mathbf{C}_{\mathbf{f}}^{-1}\hat{\mathbf{g}}(\omega_i)}{\mathbf{f}^{\mathrm{T}}\mathbf{C}_{\mathbf{f}}^{-1}\mathbf{f}}, \quad i = 1, 2, \ldots \tag{1}$$

In this equation, the vector $\mathbf{f} = [f(t_1), f(t_2), \ldots]^{\mathrm{T}}$ represents the observed time series $\{f(t_j), j = 1, 2, \ldots\}$. The observation times $\{t_1, t_2, \ldots\}$ are not necessarily equally spaced. The vector $\hat{\mathbf{g}}(\omega_i)$ is the best approximation of $\mathbf{f}$ in the least squares sense in the subspace spanned by the base vectors $\{\sin\omega_i t, \cos\omega_i t\}$ where ω_i, $i = 1, 2, \ldots$ is a positive real number from the set $\Omega = \{\omega_1, \omega_2, \ldots\}$ of frequencies chosen from zero to Nyquist frequency. $\mathbf{C}_{\mathbf{f}}$ is the (fully populated) covariance matrix of $\mathbf{f}$. The least squares spectral value $\mathrm{s}(\omega_i)$ is always between zero and one (normalized) and reflects the contribution of each harmonic in the total energy of the signal. When $s(\omega_i)$ is multiplied by 100, we call it percentage variance [17].

The critical value c_α at the significance level α, above which least squares spectral peaks are significant, is determined by

$$c_\alpha = \left[1 + \frac{\nu}{2} H_{\nu,\alpha}\right]^{-1} \tag{2}$$

In these equations, ν is the number of freedom in the least squares approximation process, and H is the probability integral of a random variable derived from the ratio of two random variables with Fisher distribution. The computation procedure of H is rather complicated and we used the values given by [17]. If $s(\omega_i) > c_\alpha$ for at least one $\omega_i \in \Omega$, then $\mathbf{f}$ contains statistically significant component(s) at the significance level α, within Ω.

Fig. 2a shows the SSH time series at the crossover point of passes number 92 and 209 and Fig. 3a shows its spectrum. Harmonic components with significant spectral values are 11.2 years, 4.9 years, 3.8 years, 3.1 years, 1 year and 6 months. Except for the north Caspian which experiences a glaciation period each year, all the time series contain the same important harmonic components.

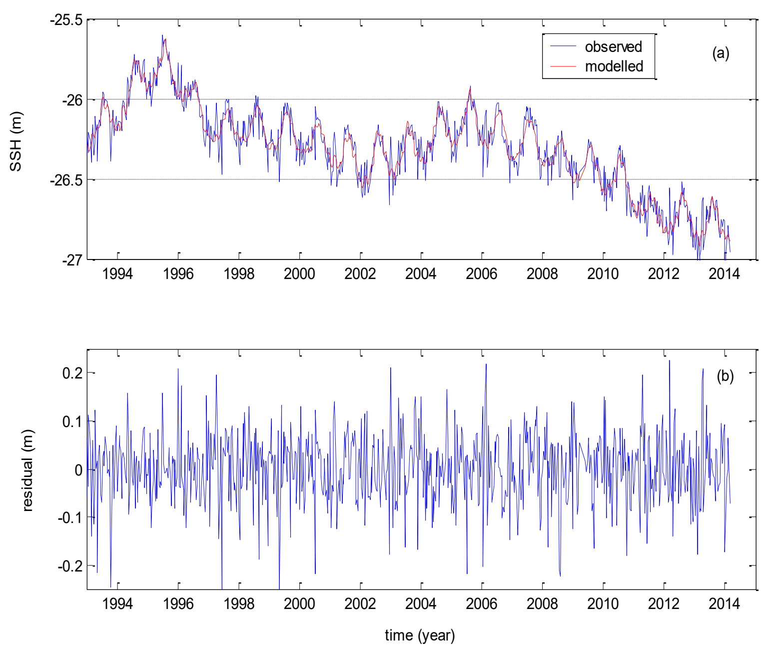

Figure 2: (a) SSH of the crossover point of passes number 92 and 209. A deterministic model comprised of a linear trend and harmonic sine and cosine functions was fitted to the time series and (b) residual time series after removing the deterministic model

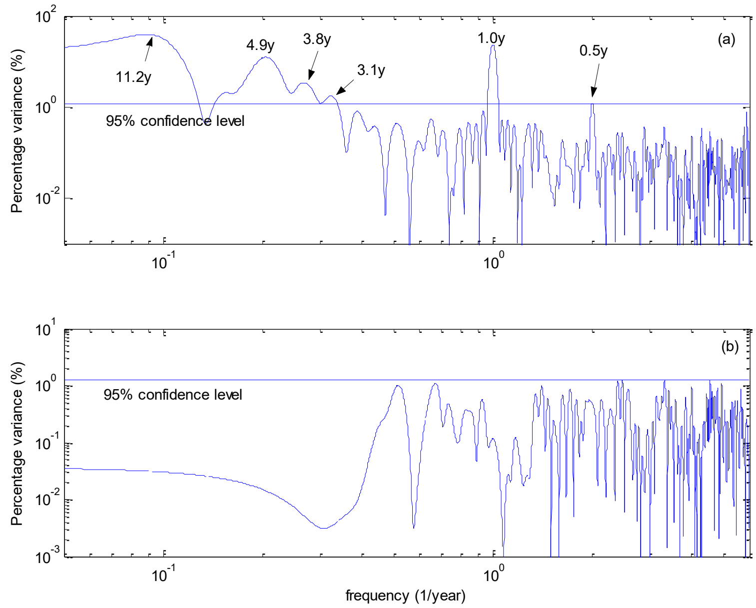

Figure 3: (a) Least squares spectral value of SSH time series for the crossover of passes number 92 and 209, and (b) the same, after removing the deterministic model

The long-term variations of SSH (Fig. 2a), with 11.2 years quasi-decadal periodicity detected from our analysis is related to the 12.5 years period reported by [11]. Our reasoning is as follows: their observation time window [4-8] is shorter than ours (1993-2014, 21 years), however the number of repetitions of sine and cosine functions within 16 or 21 years of observation is not enough for a stable estimation of such long-period variability in the data and a longer time series is needed for a sure conclusion. The near zero, very low frequency variations (with periods more than 50 years) of the CS level observed in the spectrum (Fig. 3a), are considered to be originated from long term (probably non-periodic) variations mainly started since the middle of the last century. These variations were the subject of numerous research studies (e.g.,[5,18]). According to these studies, the main reasons for the long-term variations are changes in the climatic factors in the region.

In the spectrum (Fig. 3a), we observe three peaks in 0.2045 year^{-1}, 0.2670 year^{-1} and 0.3235 year^{-1} corresponding to the periods of 4.9, 3.8 and 3.1 years, respectively. For the quasi-decadal 11.2 years periodicity, we expect to see a train of peaks in the frequency domain with spacing of 1/11.2, namely at 1/11.2=0.089 year^{-1}, 2/11.2=0.18 year^{-1}, 3/11.2=0.27 year^{-1} and 4/11.2=0.36 year^{-1} (i.e., periods of 11.2, 5.6, 3.7 and 2.8 years respectively). The difference between expected periods (5.6, 3.7 and 2.8 years) and observed periods (4.9, 3.8 and 3.1 years) might be explained by the existence of stochastic noise in the data, as well as by the spectral leakage phenomenon. This means that these periodicities can be considered as the harmonics of the main quasi-decadal 11.2 years fluctuation.

Two peaks with decreasing amplitudes are observed in the spectrum corresponding to 12 months and 6 months periods (Fig. 3a). This behaviour of a time series recalls the Fourier series expansion of a periodic function with a one year fundamental period. Because of spectral leakage and presence of random signals on the time series, we cannot distinguish the peaks with periods shorter than 4 months, but theoretically they are present in the spectrum. When we remove the meaningful harmonic components from the time series, we obtain a random signal (Fig. 2b) for which its spectrum is shown in Fig. 3b.

3.2. Amplitude of Annual Variations in Different Parts of CS

Different parts of the CS are situated in different regions from a climatic point of view and each region contributes differently in the water input and evaporation process. CS is generally divided into three distinct parts, namely 1) the northern Caspian which contains only about one percent of its water volume, 2) the middle part with about one third of the total volume, and 3) the southern Caspian which contains the largest volume of its water with depths more than 1000 m [8]. The Apsheron-Balkhan Sill (depths of 160-180 m) separates the middle and southern parts (acts as a boundary) and thus influences currents and water salinity as well as the input/output process of water.

Fig. 4 shows the amplitudes of annual variations over CS. As it can be seen, the spectral values vary along the pass, particularly for the dominant frequency 1 year^{-1}. In this frequency, from the South-East we observe a decrease of amplitudes toward the Apsheron-Balkhan sill (point A on Fig. 4) where the minimum value of 6 cm is computed. Hereafter, amplitudes increase considerably to the North-West and reach a maximum value of 16 cm (point B on Fig. 4). Amplitudes decrease again toward the shallow Northern Caspian with the mean depth of 5-6 m (point C on Fig.4).

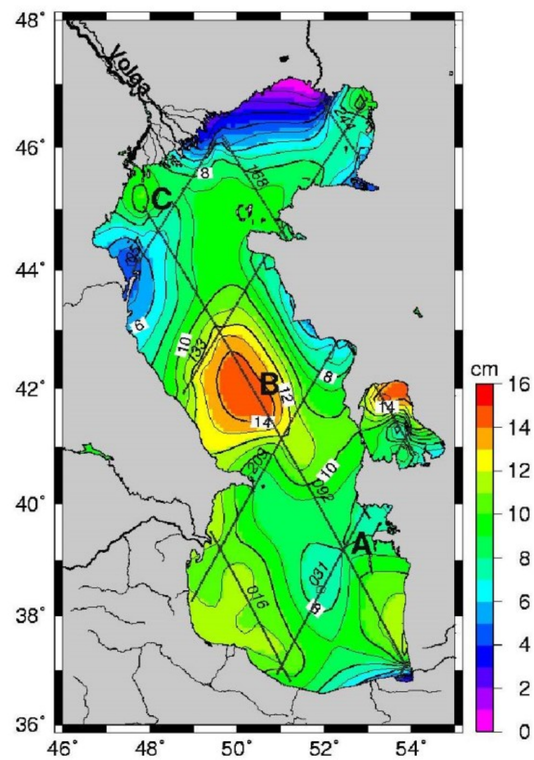

Figure 4: Amplitude of the annual variations of the CS level. Contours are in cm

3.3. Spectral Analysis of the Volga River Discharge

CS level is directly influenced by VR [12]. Fig. 5a shows the monthly discharge time series of VR between 1993 and 2014 for which we computed the mean discharge equivalent as 7,890 m^3/s, or 248.8 km^3/year with a decreasing rate of 7.2 m^3/s (0.23 km^3/year) per year. Therefore we expect (and we observe) a CS level drop. Based on the altimetry measurements, the CS level dropped 2.6 cm per year for the period of 1993 to 2014.

In order to investigate the similarity between the variations of the VR discharge and that of the CS level, we compare the sea level time series with the VR discharge time series in the spectral domain. Fig. 6 shows the spectrum of the VR discharge time series and that of the crossover of passes number 92 and 209. A sequence of peaks is observed at frequencies 1 year^{-1}, 2 year^{-1}, 3 year^{-1}. This observation implies once more the existence of an annual periodic function as it has been seen already in the spectrum of the altimetry data (Fig. 3a).

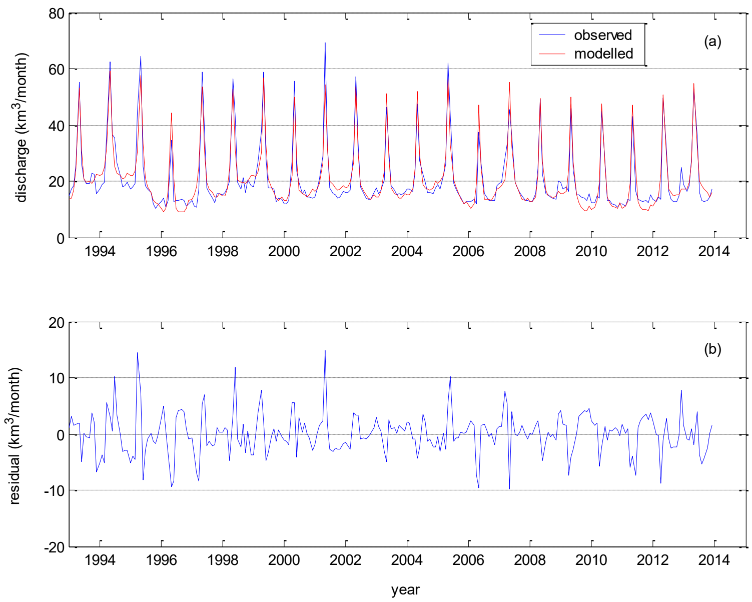

Figure 5: (a) Observed VR discharge (blue curve), and modelled time series (red curve) using the least squares fitting of a linear trend and a linear combination of sine and cosine functions, and (b) the residual time series

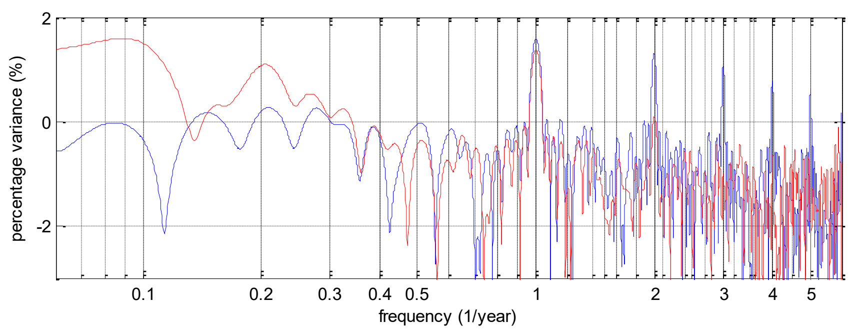

Figure 6: Least squares spectrum of the VR discharge from 1993 to 2014 (blue curve), and that of the CS level (red curve) for the crossover of passes number 92 and 209

The most remarkable similarity of two spectra in Fig 6 is due to the large peak of 1 $year^{-1}$ frequency. For 2 $year^{-1}$ frequency, the two spectra show again a larger peak with respect to their surrounding frequencies, but the (normalized) amplitude of this component in the CS variations is much smaller than that of the VR discharge. For frequencies higher than 2 $year^{-1}$ there is nearly no similarity between the two spectra. This may imply that the yearly periodic variation of the CS level is a smoothed version of that of VR. The smoothing of discharge pattern is related to its spatial spreading over the large area. We suspect that the bathymetry and sea currents control the way the smoothing is done by distance from the point VR enters into the CS.

We observe another sequence of peaks with smaller amplitudes in the spectrum of VR in frequencies 0.0797 $year^{-1}$, 0.1509 $year^{-1}$, 0.2120 $year^{-1}$, 0.2997 $year^{-1}$ (or 12.5, 6.6, 4.7 and 3.3 years respectively). Regarding Fig. 6, it can be concluded that this 12.5 year periodicity and its harmonics correspond to quasi-decadal periodicity of CS level and its harmonics. Based on statistically meaningful periodicities detected in the time series of the VR discharge, we computed a model comprised of a linear trend and a linear combination of harmonic functions with the least squares method. This model is shown on Fig. 5a, and the corresponding residual time series on Fig. 5b.

4. Summary and Conclusions

Variations of the CS level during 1993-2014 were analyzed based on satellite altimetry observations. Spectral analysis of SSH data series shows clear annual and semi-annual periodicities as well as an 11.2 years quasi-decadal oscillation and its harmonics. Our observation time window is not long enough for a sure conclusion about the stability of this periodicity.

We observed in this study that the variations of the CS level are correlated, even in the quasi-decadal time scale, to the variations of the VR discharge. For this reaffirmation, we analyzed the spectrum of the VR discharge time series for the period of 1993-2014. Volga discharge time series shows a decreasing rate of 7.3 m^3/s (0.23 $km^3/year$) per year for the period of 1993-2014. The spectrum of discharge time series shows a 12.5 years quasi-decadal periodicity and its harmonics as well as a sequence of peaks with periods 1 year/p (p=1, 2, 3, …). These are due to the Fourier series decomposition of the mean annual variations of river discharge.

The amplitude of different harmonics in the spectrum varies spatially. We computed a map showing the amplitude of annual sea level changes in different parts of CS. These amplitudes vary from less than 6 cm to 16 cm. This phenomenon can be considered to be due to a simultaneous action of sea bottom topography, sea currents, and climatic parameters.

Acknowledgment

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Investigation of Trends Annual and Seasonal Climatology Parameters in Different Regions of Iran

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Abstract

Climate change is defined as the change in climatic behavior of a region compared to long term behavior based on recorded data. Many studies about climate change have been conducted in different regions of the world. Present trends of annual and seasonal climatology parameters of Iran were studied in 24 synoptic stations over a 50 year data period (1956-2005). The Mann-Kendall test was used to analyze the trends of climatic factors. The results show a combination of increasing and decreasing trends in annual rainfall for various regions of Iran. Temperature trends in most of the stations were positive. The trend of number of cloudy days is accurate in winter and is negative in spring. In the northern, southern, and southwestern parts of Iran, the trend of rainy days is positive but in the central and eastern region there is no trend. The trends of days with thunder storms in most regions of Iran are positive. The trend of number of dusty days is positive in the south, west, southwest, and southeast regions of Iran but is negative in the northeast and central regions of Iran. The trend of the number of freezing days in the north half of Iran is positive. The trend of relative humidity is positive in the north section of Iran but is negative in the east and northwest. Wind velocity trend is decreasing in the eastern area while in the western section no trend is visible. Results show that climate change is apparent in Iran especially with regard to temperature, so consideration of the role of rising temperature on evapotranspiration is needed; we should seek better ways to manage water resources and water use.

Keywords: Climate change, Trend, Mann–Kendall Test, Climatology Parameters, Iran

1. INTRODUCTION

One of the most important problems in the world is global warming and climate change that affect human life and development. The American National Academy of Sciences attributes the main factors causing this phenomenon as human activity and production of greenhouse gases. Global warming and climate change affect the environment and human life. Global warming raises sea level and increases climate phenomena that will happen in the future and will pose dangerous effects on natural ecosystems. Global climate change has special effects on environmental parameters such as precipitation and temperature in many parts of world, that variation of precipitation and temperature characteristics effect directly on hydrology and natural ecosystems. Because of high spatial and temporal variation of precipitation in different climatology zones of Iran, determining direction oftrends could be important in future water management decisions. The analysis of temperature data has shown important variation in extreme values. The global average of surface temperature has increased about 0.6 °C over the twentieth century and significant warming have been observed in many regions of world during that last 50 years [1]. This warming may not be uniform in spatial and temporal variation but it is projected to continue and will likely be accompanied by more extreme climate events. Many studies have been conducted in countries in southwest Asia such as Bahrain [2], Syria [3] and the Arab region [4] about climate change Results clearly showed that in these regions climate has changed as a result of human interference on the ecosystems. In Iran the most significant increasing trend of relative humidity and dew point exists in summer and the least trend of relative humidity was observed in winter [5]. In a study about climate change effects on trends of time series of some climatology parameters in Iran, results showed the minimum temperatures of 75% of stations in summer and autumn and more than 65% of stations in spring and winter were increased; downward trends of dew point were observed in 85% of stations in spring, autumn and winter and 60% of stations in summer. The trend of wind velocity was positive in 60% of stations in summer, autumn and winter [6]. In four big cities of India the relations between urbanization and temperature trend were studied. Most trends showed positive change in temperature with varied rates in different seasons. The relation between temperature variation and population growth was negative [7]. The negative trend of annual precipitation was observed in north and northwest of Iran while positive trend of maximum 24 hours of precipitations are mostly located in arid and semi-arid regions of Iran [8]. In a 40 year period, annual precipitation decreased in west and south eastern Iran, and increased in other stations. Increasing and decreasing monthly rainfall trends were found over large continuous areas of Iran. These trends were statistically significant during the winter and spring seasons [9]. Trend of the indices of daily temperature extremes in South America indicate no consistent change in the indices based on daily maximum temperature while significant trends were found in the indices based on minimum temperature [10]. Warming was defined in various parts of Brazil and it was sometimes related to change in land use, including the development of large cities such as Sao Paulo and Rio de Janeiro [11]. Analysis of the daily rainfall from 1910 to 1995 on a regional and seasonal basis in Australia identified significant change in percentiles and frequency of extreme events but the magnitude and the significant of the changes varying with season and region [12].

Iran is one of the countries that lies on the dry belt of earth and has low water resources. Population growth, rising demands of agriculture and domestic production and limitation of soil and water resources causes decreasing water availability. With respect to previous studies, it appears that in some parts of Iran the time series of rainfall and temperature have trend. The aims of this research were determination of the existence and direction of trends for climatology parameters in Iran and also the similarity of trend changes for climatology parameter in different parts of country. Finally, regions with higher risk caused by climate change were identified.

2. METHODOLOGY

2.1. Study Area

The Islamic Republic of Iran is located in west of Asia between 25° to 40° in north latitude and between 24° to 64° in eastern longitude. Nearly 35% of Iran has a very dry climate, 29.9% is dry, 20.1% is semidry, 5% is Mediterranean and 10% is wet. The average annual precipitation of Iran is about 250 mm and the coefficient of variation (CV) varies from 18% in the north to 75% in the southeast of the country. The average daily temperature varies from -20 to 50°C.

2.2. *Data*

In this study the monthly data of 24 synoptic stations from 1956 to 2005 were used (Table 1). Climatology parameters that were analyzed included precipitation (P), mean temperature (TM), mean minimum temperature (TMIN), maximum temperature (TMAX), absolute minimum temperature (ATMIN), absolute maximum temperature (ATMAX), mean relative humidity (RH), velocity of wind (VW), number of cloudy days (No. Cl), rain (No. R), snow (No. S), thunder storm (No. TS), freezing (No. F), and dust (No. D). Data quality and homogeneity assessments were performed before computation of climatology parameter trends.

TABLE 1: CHARACTERISTICS OF STUDIED STATIONS

Station	**Longitude**	**Latitude**	**Elevation(M)**	**Climate (Emberger Classified)**	**Station**	**Longitude**	**Latitude**	**Elevation(M)**	**Climate (Emberger Classified)**
Ahvaz	48° 40'	31° 20'	22.5	Midrate warm desert	**Gorgan**	54° 16'	36° 51'	13.3	Midrate wet
Arak	49° 46'	34° 06'	1708	Cold semi-arid	**Kerman**	56° 58'	30° 15'	1753.8	Dry cold
Bandarabbas	56° 22'	27° 13'	9.8	Wet warm	**Kermanshah**	47° 09'	34° 21'	1318.6	Cold semi humid
Tehran	51° 19'	35° 41'	1190.8	Dry cold	**Khorramabad**	48° 17'	33° 26'	1147.8	Cold semi humid
Bam	58° 21'	29° 06'	1066.9	Low warm desert	**Oromiyeh**	45° 05'	37° 52'	1315.9	Semi dry cold
Bandaranzali	49° 28'	37° 28'	-26.2	Very wet	**Rasht**	49° 3'6'	37° 15'	-6.9	Very wet
Boushehr	50° 50'	28° 59'	19.6	Wet warm	**ZAhedan**	60° 53'	29° 28'	1370	Dry cold
Esfahan	51° 40'	32° 37'	1550.4	Dry cold	**Yazd**	54° 17'	31° 54'	1237.2	Dry cold
Mashhad	59° 38'	36° 16'	999.2	Dry cold	**Tabriz**	46° 17'	38° 05'	1361	Semi dry cold
Sharekord	50° 51'	32° 17'	2048.9	Semi dry cold	**Shiraz**	52° 36'	29° 32'	1484	Semi dry cold
Shahroud	54° 57'	36° 25'	1345.3	Dry cold	**Ramsar**	50° 40'	36° 54'	-20	Very wet
Bi Rjand	59° 12'	32° 52'	1491	Dry cold	**Sabzevar**	57° 43'	36° 12'	977.6	Dry cold

2.3. *Non Parametric Test for Change Detection*

Hydrological phenomena are usually considered as stationary, but new research has shown that many time series of hydrological data have a trend. They may be caused by human activities or natural characteristics of earth's climate. Trends may be observed in hydrological and meteorological parameters that are divided into step change and monotonic trends [13]. Parametric and non-parametric methods are usually used to determine the trend in time series data. The Mann-Kendall method is one statistical method that recently has been used to defined the trends [14-18].

2.3.1. Mann- Kendall test

In the Mann Kendall test, each value of a time series is compared with other values of the time series continuously. First, S values are calculated that are a summation of all counting as equation1.

$$S = \sum_{i=1}^{n-1} \sum_{k=i+1}^{n} \operatorname{sgn}(X_k - X_i) \tag{1}$$

Where X_k and X_i are sequential data values, n is the length of the data set and sgn(θ) is equal 1,0 or -1 if θ is greater than, equal to, or less than zero, respectively. Test results (Z) are assessed based on equation (2). Positive values of Z indicate an increasing trend while negative values indicate a decreasing trend.

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var(S)}} \rightarrow S > 0 \\ 0 \rightarrow S = 0 \\ \dfrac{S+1}{\sqrt{Var(S)}} \rightarrow S < 0 \end{cases} \tag{2}$$

Where var(S) is calculated from equation (3).

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5) \right] \tag{3}$$

Where tp is the number of ties for the pth value and q is the number of tied values. In the present research, significance levels of P=0.01 and 0.05 were applied. Positive, negative and non-trends of each climatology parameter were defined in each station. Maps of positive, negative and non-trend zones for each climate parameter were prepared using GIS.

3. Results and Discussion

Figs. 1 and 2 show the zonation map of annual precipitation and the mean annual temperature trends of Iran, respectively. Results of Mann- Kendall tests for the studied climatology parameters are shown in Ttable 2 in annual scale.

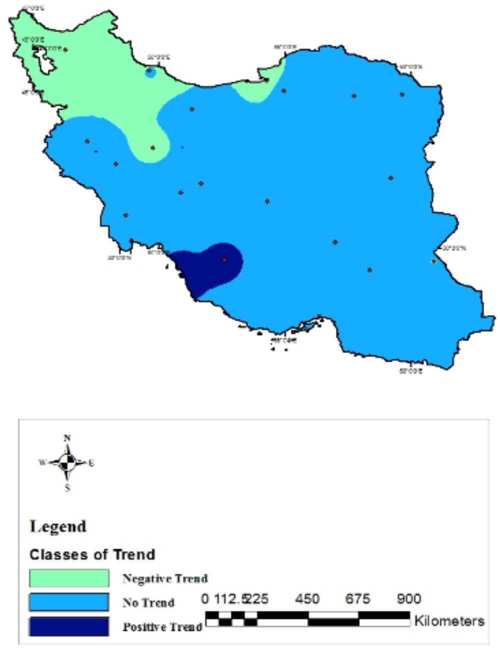

Figure 1: Zonation map of annual precipitation trend of Iran

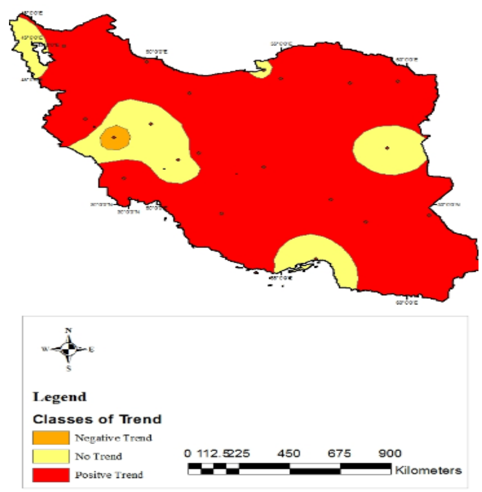

Figure 2: Zonation map of annual mean temperature trend of Iran

Precipitation trendsare visible in different stations but are not statistically significant in many stations. In different regions of Iran, composition of positive and negative trends are seen. Because of the concentration of precipitation in winter and spring in many parts of Iran, most variations of seasonal precipitation were observed in winter and spring. The largest decrease of precipitation happened in Bandar-Anzali, equal 8 mm/year. The annual rainfall trends were negative in northern slope of Alborz and western slope of Zagross, while in central parts of Iran trends were positive and in eastern and southeastern parts of Iran trends were negative. Similar results have been presented by other researchers [9,20]. The seasonal precipitation trends were varied in different regions of country; similar results were obtained in Australia [12]. Rising temperature is observed in different regions of Iran but the trend values were varied spatially, as observed in nother parts of the world [1]. The trends of temperature in most of the stations were positive. Maximum temperature rise occurred in big cities such as Tehran, Shiraz and Mashhad, where population and industrial growth were high. Direct correlations between temperature rise and population growth in big cities of India have also been reported [7].

TABLE 2: TRENDS OF ANNUAL PARAMETERS

Station	P	TM	TMIN	T MAX	AT MIN	AT MAX	No. Cl	No. R	No.S	No. TS	No.D	No. F	RH	VW
Ahvaz	0.925	0.04**	-0.06**	0.015*	0.067**	0	0.23*	0.589**		0.53**	0.8*		-0.04	0.005
Arak	-1.97*	-0	0.004	-0.01	0.022	0	-0.21	0.25	0.077	0.13**	-0.16	-0.05	-0.03	0.007
Bandarabbas	0.191	-0.01	-0.02	0	-0.06**	0.034*	0.08	0.241**		0.18**	1.731**		0.046	-0.02
Tehran	1.36*	0.044**	0.073**	0.016*	0.124**	-0.01	0.14	0.227	0.032	0.073	-0.24		0.1**	-0.01
Bam	-0.2	0.042**	0.058**	0.026**	0.043*	0.032**	-0.03	-0.13*		-0.06**	0.53**		-0.3**	-0.04+
Bandaranzali	-8*	0.012*	0.048**	-0.02*	0.05*	-0.03*	0	0.467**	0	0.467**			0.022	0.011
Boushehr	1.776	0.029**	0.045**	0.015	0.029*	0	-0.3**	0.36**		0.4**	1.33*		-0.01	-0.02
Esfahan	0.738	0.022**	0.019*	0.019*	0	0.007	0.11	-0.18*	-0.06*	0	-0.41**		-0.08*	-0.05**
Mashhad	0.58	0.053	0.072	0.027	0.183	0.043	-0.15	0.179	0.077	0.185	-0.06	-0.1	-0.08	0.013
Sharekord	1.085	-0.02*	-0.02	-0.01	0.04	-0.04*	-0.88**	0.619**	0.25**	0.296**	0.136**	-0.11*	0.017	0.022**
Shahroud	0.26	0.03**	0.064**	-0	0.07**	0.014*	-0.14	-0.24*	0.108	0.278**	-0.16**	0	-0.15**	-0.09**
Birjand	-0.1	-0.01	-0.01	-0.02	-0.09	-0.02	0.06	0.032	0	0.03	-0.52		-0.08	-0.02
Gorgan	-2.71*	0.006	0.004	0.004	-0.02	0	-0.38**	0.593**	0	0.464**	0		0.318**	-0.02
Kerman	-0.75	0.031**	0.035**	0.024**	0.05	0.019*	-0.33**	-0.04	0	0.059*	-0.59**		0.032	-0.06**
Kermanshah	-0.71	0.04**	0.043**	0.035**	0.063	0.003	-0.08	0.238	0	0	-0.1	0	-0.16**	-0.02*
Khorramabad	-1.08	-0.04**	-0.05**	-0.03**	-0.01	-0.04*	-0.15	0.029	0	0.33**	0.176		0.002	0.002
Oromiyeh	-1.71+	-0.01	-0.01	-0.01	0.006	-0.03*	-0.35*	0.053	0	0.3**	-0.05	-0.22	-0.03	0.021*
Rasht	1.274	0.026**	0.043**	0.002	0.044	0	-0.3**	0.368*	0.056	0.57**	0		0.126**	-0.02**
ZAhedan	-1.21**	0.028**	0.037**	0.019*	0.03	0	0.09	0	0	0.094*	0.188		-0.14**	-0.04**
Yazd	0.007	0.037**	0.055**	0.022**	0.07**	0	-0.52**	0.286**	0	0.07**	-0.33		-0.08*	-0.02*
Tabriz	-1.88**	0.04**	0.046**	0.033**	0.083*	-0.01	0.1	0.241	0	0.24*	0.125	-0.36*	-0.12**	-0.04**
Shiraz	1.66	0.05**	0.078**	0.024**	0.067**	0.018*	-0.4+	0.316*	0	0.24**	0.857*		-0.08*	-0.05**
Ramsar	-2.56	0.015*	0.03**	0.002	0.025	0.021	-0.44**	-0.07	0	0.29**	-0.08**		-0.01	-0.03*
Sabzevar	0.883	0.056**	0.088**	0.025**	0.125**	0	0.23	0.286*	0	0.21**	-0.95**		0.019	-0.08**

* . Significant at 95% confidence level
**. Significant at 99% confidence level

In big cities, the average of minimum and maximum temperature and absolute minimum temperature were additive, which could be caused by their industrial growth and development; similar results were obtained in Brazil [21]. The maximum temperature rise trend was 0.056 °C/ year in Sabzevar. The seasonal trend of temperature showed maximum and minimum variations in summer and winter, respectively. In most cities of Iran it seems that the temperature trends are toward warming, while in Birjand ,Khoramabad and Bandar Abbas, trends are toward cooling. Trends at Ahwas and Khorramabad stations were toward cooling in all seasons. Sharekord and Bandarabbas stations were toward cooling in summer and in winter. The most trends for number of cloudiness days were in winter and spring, which were negative. In annual scale, some parts of northeast and northwest toward central regions of Iran had negative trends while in most parts of Iran the trend of the number of cloudiness day were not observed. The number of rainy days increased in northcoastal Iran but the amount of rain declined. Similar results have been reported previously for Iran [9]. The most trend of number of rainy days happened in winter and autumn. In the north, south and southwest parts of Iran, trends were positive but in central and eastern parts there was not any trend. The number of thunderstorm days had a positive trend in most parts of Iran and the highest values happened in spring and in autumn. In the eastern region of Iran, the trends of storm days were positive but not significant statistically. The number of dusty days had positive trends in south, west, southeast and southwest of Iran, but in northeast and central parts of Iran trends were negative. From northeast to center, no trend was observed. The lowest trend of dusty days was observed in autumn and the highest trends observed in summer and spring. The number of freezing days was positive in northeast, northwest and some parts of center of the country and in other parts there was no trend. The trends of annual and seasonal averages of relative humidity were visible in the studied stations. In northern region of Iran this trend was positive and in east and northwest it was negative, consistent with previous research in Iran [5,22]. Wind velocity declined in eastern half of Iran while no trend was observed in the western region.

4. CONCLUSIONS

This study presents an examination of trends in climatologic parameters for Iran during 1956-2005. Data quality and homogeneity assessments were performed. The trends of studied parameters were calculated. Comparison of absolute minimum and maximum temperatures, showedthat in the central parts of Iran, the absolute minimum temperature increased, while absolute maximum temperature did not vary, so the range of temperature variation was smaller and these regions trended towards warming. Also, in south coastal Iran, absolute minimum temperature did not vary but maximum absolute temperature increased, showing that these regions trended toward warming. From the Zagross slopes to central Iran, absolute maximum temperature declined but absolute minimum temperature did not vary, so the weather trended toward cooling in these regions. Comparison of the maps of mean minimum and maximum temperature showed that in some parts of Iran, except southwestern and western regions, the variation between mean minimum and maximum temperature declined , thus it indicating that the weather of Iran is trending toward warming in most areas. By comparing the trend maps of the number of days with snowfall and temperature, it appeared that in Shahrekord station with decreasing temperature, the number of days with snowfall was increasing. But in these areas, the minimum temperature is rising, while the number of freezing days is declining. Zonation maps show the mean wind speed and the number of dusty days in the eastern half of the country was reduced, but in western and southern parts of the country, the situation was reversed. In different seasons the numbers of cloudy days have negative trends and were decreasing in many stations. According to the results, we can say that the signs of climate change, especially in terms of temperature are visible. Therefore, with consideration to the role of rising temperature on increasing evapotranspiration, we should seek better ways to manage water resources and water use. In this regard, one of the sectors that must adapt to future requirements is agriculture. Also, in the water allocation plane we must have more flexibility in for the future situation.

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Impact of climatic change on river discharge in the AjiChay Basin, Northwest of Iran

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Abstract

One of the most significant potential consequences of climate change may be alteration of regional hydrological cycles and riverflow regimes. In the present study, the trends in discharge and rainfall at 3 hydrometrics and 3 rain gauge stations located in the AjiChay basin in Northwest Iran were analyzed using the non-parametric Mann–Kendall method during 1975-2009. The MK1 test was used for time series which have non significance autocorrelation and MK3 was used for series which have significance autocorrelation. The magnitudes of trends were computed using the Sen's estimator method. Trend analysis through the MK1 and MK3 test and Sen's slope estimator indicates drastic decline in the discharge, with the strongest decline ($0.07m^3$/year) in June at Zinjanab station. Rainfall trend was decreasing in 13 cases. In June and December rainfall in all selected 3 stations was decreasing, while in months such as February, April, July, August, September and November is increasing.Decreasing trend in discharge can affect agriculture and Uremia lake level fluctuations.

Keywords: Mann-Kendall, Rainfall, Discharge, Trend. AjiChay Basin.

1. INTRODUCTION

In recent years, there has been intense discussion about the global water balance, particularly concerning its response to changing climate and social use [1]. The runoff of rivers is the effect of many factors, among which the most crucial are the climatic ones. River flow in a specific geographical region is affected by rainfall, evaporation, topography, lithology, subsurface flow systems, vegetation heterogeneity and other factors, including regional and global climatic fluctuations [2].

There are a large number of analyses referring to discharge in various river basins, regions, countries and continents worldwide. For example Senand Niedzielski [3] examined the daily discharge time series in 15 gauge stations along the Upper Oderbasin from November 1971 to October 2006, and found a statistically significant decreasing trend in the daily discharge data for all sites. Michal czykand Paszczyk [4] concluded that global climaticchanges exerted no significant influence on water discharge in the river, based on the water balance of Oder River catchment area for the 1901–2000 period. Ilnicki et al. [5] analyzed discharge in the Warta River in Poland. The annual mean discharge of the Warta River for the period 1981–2010 was equal to the average value for the last 163 years(209 m3 s^{-1}), and there was no significant change in comparison with the ratio of runoff in the summer and winterhalf-years. There is a positive and very significant correlation (r = 0.705) between the annual discharge andannual precipitation totals. The aim of this study is evaluate the Impact of climatic change AjiChay river discharge in the Northwest of Iran for the period 1975-2009.

2. Material and Methods

2.1. Study Area

AjiChay is the most important river of Uremia Lake watershed (Fig. 1). Main stream flows from southern slope of Sabalan Mountain.Other streams of Sahand and Bozghoush Mountains join it. Total area of this basin is 10,730 km^2 and it is the largest watershed in East Azerbaijan Province. Three rain stations and 3 hydrometry stations was selected in order to detection trend in rainfall and discharge in these stations. Each hydrometry station has rain station. The selected stations are Sahzab, Saeid Abad and Zinjanab. Fig. 1 shows the location of these stations at AjiChay basin east of Uremia lake.

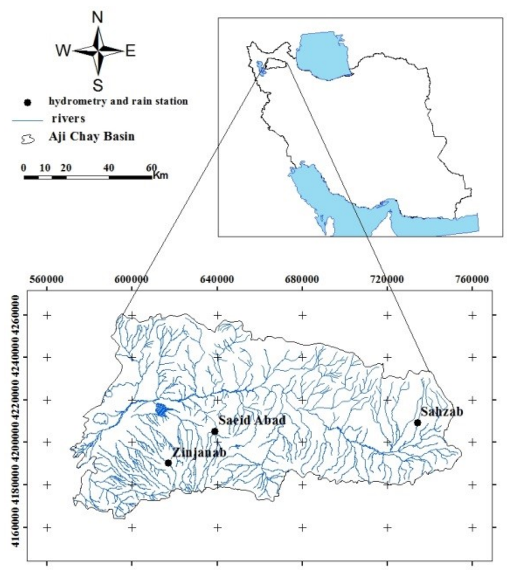

Figure 1: Map of AjiChay Basin showing rivers, hydrometery and Rain stations

2.2. Methods

In this study, the lag-k autocorrelation coefficient (r_i) was computed using:

$$r_k = \frac{\frac{1}{n-k}\sum_{i-1}^{n-k}(X_i - X)(X_{i+k} - \overline{X})}{\frac{1}{n}\sum_{i=2}^{n}(X_i - \overline{X})^2} \quad (1)$$

If $\frac{-1-1.96\sqrt{n-2}}{n-2} \le r_i \le \frac{-1+1.96\sqrt{n-2}}{n-2}$ then the data are assumed to be serially independent at 10% significance level (CL = 90%) and no pre- whitening is required. Else data are considered to be serially correlated. MK1 was used when autocorrelation coefficients weren't significant and MK3 test was used autocorrelation coefficients were significant.

2.3. Mann-Kendall Test (MK1)

The conventional MK test given by Mann (1945) and Kendall (1975) has been extensively used to assess the significance of monotonic trends in hydro-meteorological time series such as precipitation, temperature and discharge [6]. This is a classical form of Mann-Kendall test used in many of trend studies. If x_1, x_2, x_3, ….., x_n is the time series of length n, then the Mann-Kendall test statistic S is given by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(X_j - X_i) \tag{2}$$

Where $$\mathrm{sgn}(x) \begin{Bmatrix} 1 & \text{for } x>0 \\ 0 & \text{for } x=0 \\ -1 & \text{for } x<0 \end{Bmatrix} \tag{3}$$

The null hypothesis HO for the test is 'there is no trend in the time series'. If H_o is true then S is normally distributed with:

$$E(s) = 0 \tag{4}$$

$$V(S) = \frac{n(n-1)(2n+5)}{18} \tag{5}$$

Where E(S) is the mean and V(S) is the variance of S. Then the Mann-Kendall z is given by:

$$Z \begin{cases} \frac{S-1}{\sqrt{V(S)}} \; for S > 0 \\ 0 \; for S = 0 \\ \frac{S+1}{\sqrt{V(S)}} \; for S < 0 \end{cases} \tag{6}$$

2.4. Modified Mann-Kendall Test (MK3)

The Modified Mann-Kendall test (MK3), proposed by Hamed and Rao (1998), considers all the significant autocorrelation structure in a time series. In this method, modified variance $V(S)^*$ is used for calculating the Mann- Kendall Z:

$$V(S)^* = V(S)\frac{n}{n^*} \tag{7}$$

$$\frac{n}{n^*} = 1 + \frac{2}{n(n-1)(n-2)} \sum_{i=1}^{n-1} (n-i)(n-i-1)(n-i-2) r_i \qquad (8)$$

V (S) is calculated as per the eq. (4), r_i is lag-I significant autocorrelation coefficient (Eq. (5)) of rank i of time series (at 90% CL in this study). To compute the Mann-Kendall Z in Eq. (1), V(S) is replaced by $V(S)^*$. Hamed and Rao [7] have shown this approach is able to detect the significance of the trend more correctly than the classical Mann- Kendall test, without affecting the power of the test.

Magnitude of trends has been determined using Theil-Sen approach (TSA). The TSA slope β is given by:

$$\beta = median\left[\frac{X_j - X_i}{j-i}\right] (\forall j > 1) \qquad (9)$$

Mk1 test was used for time series which have non-significance autocorrelation and MK3 test was used for time series with significance autocorrelation [8].

3. RESULTS

The application of MK1 and MK3 tests resulted in the identification of trend direction in the rainfall and discharge in the AjiChay basin. A negative trend indicates the decrease of rainfall and discharge and a positive trend indicates the increase of rainfall and discharge during the years. The values of Z statistics which was obtained using MK1 and MK3 tests for rainfall and discharge was shown in Table 1 and Table 3, respectively.

3.1. Trends in Rainfall

Both declining and increasing trend, at 10% significance level were witnessed in the under study area. Trend analysis through MK1 and MK3 andSen's slope estimator indicates was shown in Table 1 and Table 2, respectively.

Results showed that about 13 cases witnessed decreasing trend, which 4 cases are significant. While about 23 cases witnessed increasing trend, which 10 cases are significant. The more increasing trend is observed in February at Zinjanab station.

TABLE 1: MANN-KENDALL Z STATISTICS FOR RAINFALL IN AJICHAY BASIN

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Saeid Abad	*-1*	*1.13*	*-0.61*	*1.45*	***-2.89***	*-0.24*	***2.22***	***2.19***	*1.45*	*-1.36*	*0.67*	*-1.27*
Sahzab	***-1.92***	*0.04*	*0.95*	***2.33***	*0.4*	*-1.14*	***2.68***	***2.74***	***2.63***	*0.03*	***1.85***	*-0.74*
Zinjnab	*0.41*	***3.07***	*0.06*	***1.85***	***-1.9***	*-0.97*	*1.62*	*0.65*	*1.56*	***-1.79***	***2.29***	*-0.55*

The bold numbers indicate significant at $\alpha = 0.1$

Decreasing trend is observed in June and December in all stations and in February, April, July, August, September and November. Table 2 presents the trend line slopes of rainfall in the study area. One can observe from the table that the median of slopes vary from 0 to -2.51 m/year. The most negative slope occurred in Saeid Abad station at the rate of about -2.51 m/year. The most positive slope (0.95 m/year) occurred at Zinjanab in November.

TABLE 2.SEN'S SLOPE VALUES FOR RAINFALL IN AJICHAY BASIN

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Saeid Abad	-0.47	0.32	-0.15	0.75	-2.51	-0.1	0.25	0.15	0	-0.37	0.42	-0.4
Sahzab	-0.5	0	0.23	0.8	0.54	-0.45	0.2	0.13	0	0	0.56	-0.28
Zinjnab	0.05	0.5	0	0.83	-1.01	-0.96	0.24	0	0.13	-0.46	0.95	-0.12

To better understand the variation of Sen's slope in the rainfall, box-whisker plots (Fig. 2) were drawn. Sen's slope values were found to be positive in all months.

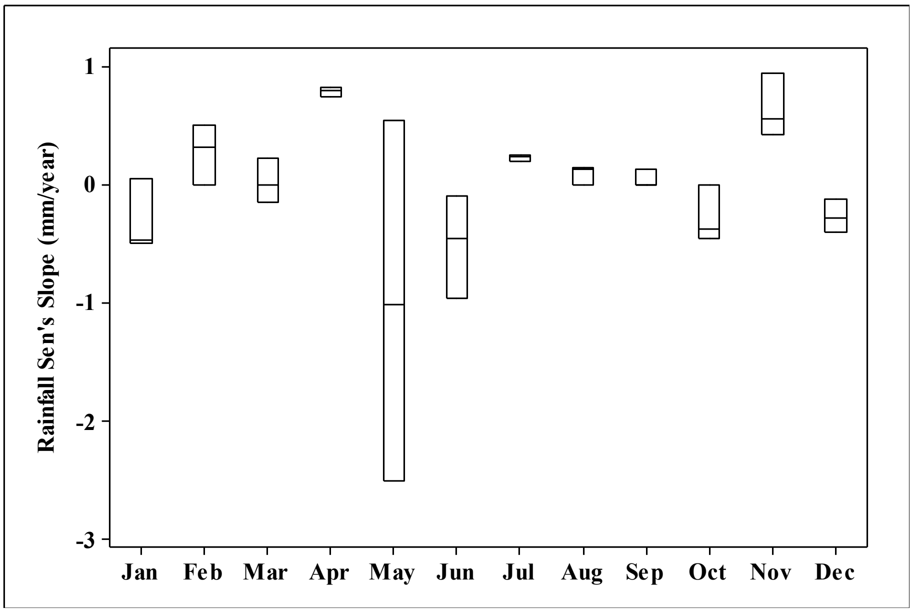

Figure 2: Box-whisker plots of trend magnitudes of rainfall in AjiChay basin

3.2. Trends in Discharge

Table 3 shows the results of MK test for discharge in AjiChay basin. At Sahzab station Z statistics in some months such as December and February was obtained using MK3.Most of the time series showed negative trends indicating the decline in the discharge in the selected stations, while only 5 cases witnessed significant positive trends.Estimated Sen's slopes vary from 0.0007 to -0.07 (m^3/s)/year.

TABLE 3: MANN-KENDALL Z STATISTICS FOR DISCHARGE IN AJICHAY BASIN

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Saeid Abad	**-1.96**	**-1.98**	-1.57	-1.45	**-2.08**	**-3.55**	**-1.98**	**-1.78**	**-1.64**	**-3.95**	**-2.73**	**-2.06**
Sahzab	-0.2	-1.38	-1.28	**-1.97**	-0.27	-1.48	**-2.5**	-1.07	**-1.96**	-0.81	-0.72	**-1.64**
Zinjnab	**1.75**	1.2	0.18	-0.79	-0.53	**-1.84**	-0.44	-0.71	1.05	-0.71	-0.21	0.49

The bold numbers indicate significant at $\alpha = 0.1$

As it can be seen from Table 3, discharge trend shows decreasing direction at all months in selected stations. Table 4 shows the Sen's slope values of discharge. The estimated Sen's slopes vary within a range of 0.0007 and -0.07 (m^3/s) /year.

TABLE 4: SEN'S SLOPE VALUES FOR DISCHARGE IN AJICHAY BASIN

Station	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Saeid Abad	-0.016	-0.014	-0.011	-0.01	-0.02	-0.005	-0.001	0	-0.0003	-0.002	-0.007	-0.014
Sahzab	0	-0.004	-0.003	-0.01	-0.006	-0.02	-0.01	-0.003	-0.003	-0.001	-0.001	-0.008
Zinjnab	0.003	0.001	0.0007	-0.002	-0.004	-0.07	0	0	0.0006	-0.0005	-0.0003	0.001

As it can be seen from Fig. 3 all of stations show negative median of slopes in all months.

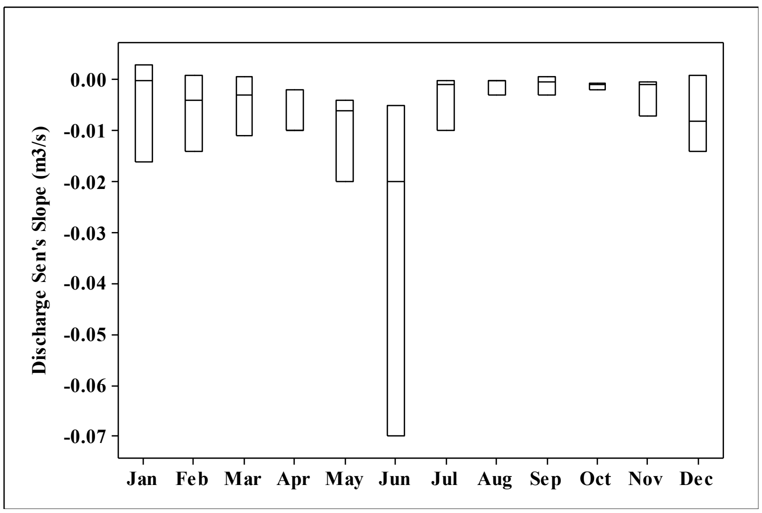

Figure 3: Box-whisker plots of trend magnitudes of discharge in AjiChay basin

4. CONCLUSION

In this paper an attempt has been made in order to estimate the trend direction in the rainfall and discharge in selected stations at AjiChay Basin. The findings of this study indicated that in contrast with the river discharge trends, the rainfall trend showed both decreasing and increasing directions which are significant in some months. The majority of the monthly rainfall trends were positive which some of them are significant. Because the rainfall data in the summer month in the arid and semi-arid regions has many zero values, the significant positive trends detected in summer rainfall are not reliable. The results of this research indicated that the trend of discharge is negative in all months, especially in Saeid Abad and Sahzab stations. Because precipitation is one of the key drivers of river flow, the decreasing flows may be largely due to decreased rainfall totals. In some months such as January and June when rainfall is decreasing, discharge is decreasing too. There is increasing trend in rainfall in months such as, February, April and November whereas in these months the trend in discharge is negative. The increasing trend in air temperature might be the reason for the decrease in discharge. Therefore, it is concluded that decreasing trend of monthly discharge is most likely related to some anthropogenic factors such as population growth, intensified irrigation and agriculture activities, land use change and natural factors, i.e. increase in air temperature and as a result in evapotranspiration. So, further studies investigating the effects of temperature on the trend of discharge could be valuable.

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U.S.-Iran Symposium on Climate Change: Impacts and Mitigation

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The U.S. National Climate Assessment: Setting the Stage for Risk Management

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Abstract

The 2014 U.S. National Climate Assessment (NCA) draws upon the latest scientific understanding of climate and climate change, synthesizing recent advances in the understanding of the science of climate change, and providing a succinct overview of the past and projected effects, and resulting impacts, of climate change on the United States. As such, this assessment provides a useful approach for assessing climate change in other countries. The NCA was conducted under the auspices of the Global Change Research Act of 1990 that requires reporting to the President and the U.S. Congress that integrates, evaluates, and interprets the state of the science and the potential effects of global change on the natural environment, agriculture, energy production and use, land and water resources, transportation, human health and welfare, human social systems, and biological diversity. Regional and sector analyses of potential impacts of the changing climate are central to the assessment. The assessment shows that climate change is clearly happening now, happening rapidly, and that the changes are primarily because of human activities. The new assessment analyzes of the observed trends and projected future climate changes. Along with increasing temperatures over all regions of the U.S., the pattern of precipitation change in general is one of increases generally at higher northern latitudes and drying in the tropics and subtropics over land. Scientific analyses indicate a strong link between changing trends in severe weather events and the changing climate. In addition, there are many concerns about potential impacts of the changing climate, e.g., the effects of sea level rise on coastal areas. This paper describes major findings from the U.S. National Climate Assessment with a focus on the methodology and how such assessments can help address risk management issues.

1. INTRODUCTION

The science is clear that the Earth's climate, including that of the United States (U.S.), is changing, changing much more rapidly than generally occurs naturally, and it is happening primarily because of human activities [1-3]. Many analyses have concluded that climate change, often referred to as global warming in the media, is one of the most important issues facing humanity. There is essentially no debate in the peer-reviewed scientific literature about the large changes occurring in the Earth's climate and the fact that these changes are occurring as a response to human activities, especially the burning of fossil fuels. Natural factors have always affected our climate in the past and continue to do so today; but now human activities are the dominant influence in many of the observed changes occurring in our current climate.

The 2014 U.S. National Climate Assessment (NCA) [2] is the most comprehensive analysis to date of how climate change is affecting the U.S. now and how it could affect it in the future – it is a model for the approach that can be useful for assessing climate change impacts and potential risks in other countries. A team of more than 300 experts (listed in the full report online), guided by a 60-member National Climate Assessment and Development Advisory Committee, produced the assessment. Stakeholders involved in the development of the assessment included decision-makers from the public and private sectors, resource and environmental managers, researchers, representatives from businesses and non-governmental organizations, and the general public. The resulting report went through extensive peer and public review before publication. The NCA collects, integrates, and assesses observations and research from around the country, helping us to see what is actually happening and understand what it means for our lives, our livelihoods, and our future. The report includes analyses of impacts on seven sectors – human health, water, energy, transportation, agriculture, forests, and ecosystems – and the interactions among sectors at the national level. The report also assesses key impacts on all U.S. regions: Northeast, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska, Hawai`i and Pacific Islands, as well as the country's coastal areas, oceans, and marine resources. By being so comprehensive, the NCA helps inform Americans' choices and decisions about investments, where to build and where to live, how to create safer communities and secure our own and our children's future.

Along with the overall changes in climate, there is strong evidence of an increasing trend over recent decades in some types of extreme weather events, including their frequency, intensity, and duration, with resulting impacts on our society. It is becoming clearer that the changing trends in severe weather are already affecting us greatly. The U.S. has sustained 144 weather/climate disasters since 1980 where damages/costs reached or exceeded $1 billion per event (including CPI adjustment to 2013), with an overall increasing trend (http://www.ncdc.noaa.gov/billions/) [4]. The total cost of these 144 events over the 34 years exceeds $1 trillion. In the years 2011 and 2012, there were more such weather events than previously experienced in any given year, with 14 events in 2011 and 11 in 2012, with costs greater than $60 billion in 2011 and greater than $110 Billion during 2012. The events in these analyses include major heat waves, severe storms, tornadoes, droughts, floods, hurricanes, and wildfires. A portion of these increased costs could be attributed to the increase in population and infrastructure near coastal regions. However, even if hurricanes and their large, mostly coastal, impacts were excluded, there still would be an overall increase in the number of billion dollar events over the last 30 plus years. Similar analyses by Munich Re and other organizations show that there are similar increases in the impacts from severe weather events worldwide. In summary, there is a clear trend in the impacts of severe weather events on human society.

The harsh reality is that the present amount of climate change is already dangerous and will become far more dangerous in the coming decades. The more intense extreme events associated with a changing climate pose a serious risk to global agricultural production, energy use, human health and property, as well as the transportation, retail, service, and insurance industries that support and sustain economic growth. The purpose of this study is to summarize the findings from the new assessments, to examine the changes occurring in the climate, to discuss the current understanding of severe weather in relation to the science of climate change, and to look at the projected changes in climate, with a special emphasis on the issues and remaining uncertainties affecting our future.

2. OUR CHANGING CLIMATE

Climate is defined as long-term averages and variations in weather measured over multiple decades. The Earth's climate system includes the land surface, atmosphere, oceans, and ice. Scientists from around the world have compiled the evidence that the climate is changing, changing much more rapidly than tends to occur naturally (by a factor of ten or more according to some studies), and that it is changing because of human activities; these conclusions are based on observations from satellites, weather balloons, thermometers at surface stations, ice cores, and many other types of observing systems that monitor the Earth's weather and climate. A wide variety of independent observations give a consistent picture of a warming world. There are many indicators of this change, not just atmospheric surface temperature. For example, ocean temperatures are also rising, sea level is rising, Arctic sea ice is decreasing, most glaciers are decreasing, Greenland and Antarctic land ice is decreasing, and atmospheric humidity is increasing.

Temperatures at the surface, in the troposphere (the active weather layer extending up to about 5 to 10 miles above the ground), and in the oceans have all increased over recent decades. Consistent with our scientific understanding, the largest increases in temperature are occurring closer to the poles, especially in the Arctic (this is primarily related to ice-albedo feedback, that as snow and ice decreases, the exposed surface will absorb more solar radiation rather than reflect it back to space). Snow and ice cover have decreased in most areas of the world. Atmospheric water vapor (H_2O) is increasing in the lower atmosphere, because a warmer atmosphere can hold more water. Sea levels are also increasing. All of these findings are based on observations.

As seen in Fig. 1, global annual average temperature (as measured over both land and oceans) has increased by more than 0.8°C (1.5°F) since 1880 (through 2012). While there is a clear long-term global warming trend, some years do not show a temperature increase relative to the previous year, and some years show greater changes than others. These year-to-year fluctuations in temperature are related to natural processes, such as the effects of El Niños, La Niñas, and the effects of volcanic eruptions. Globally, natural variations can be as large as human-induced climate change over timescales of up to a few decades. However, changes in climate at the global scale observed over the past 50 years are far larger than can be accounted for by natural variability [1]. At the local to regional scale, changes in climate can be influenced by natural variability for multiple decades [5].

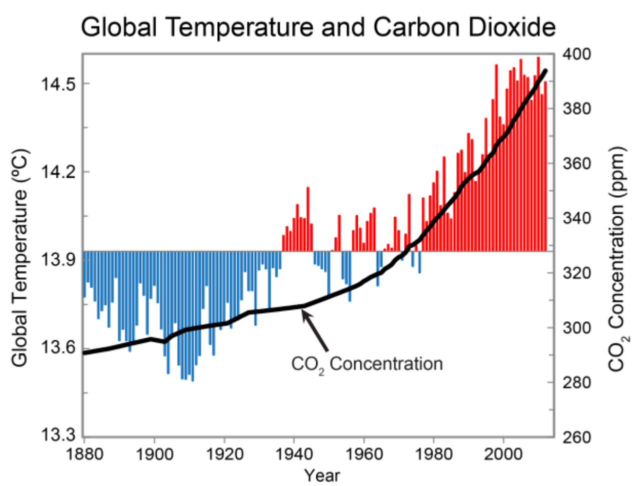

Figure 1: Changes in observed globally-averaged temperature since 1880. Red bars show temperatures above the long-term average, and blue bars indicate temperatures below the long-term average. The black line shows the changes in atmospheric carbon dioxide (CO_2) concentration in parts per million (ppm) over the same time period (Temperature data from NOAA National Climate Data Center) [2]

While there has been widespread warming over the past century, not every region has warmed at the same pace (Fig. 2). A few regions, such as the North Atlantic Ocean and some parts of the U.S. Southeast, have even experienced cooling over the last century as a whole, though they have warmed over recent decades. This is due to the stronger influence of internal variability over smaller geographic regions and shorter time scales. Warming during the first half of the last century occurred mostly in the Northern Hemisphere. The last three decades have seen greater warming in response to accelerating increases in heat-trapping gas concentrations, particularly at high northern latitudes, and over land as compared to the oceans. These findings are not surprising given the larger heat capacity of the oceans leading to land-ocean differences in warming and the ice-albedo feedback (melting of ice leading to a higher surface albedo and more solar absorption) leading to larger warming at higher latitudes. As a result, land areas can respond to the changes in climate much more rapidly than the ocean areas even though the forcing driving a change in climate occurs equally over land and the oceans.

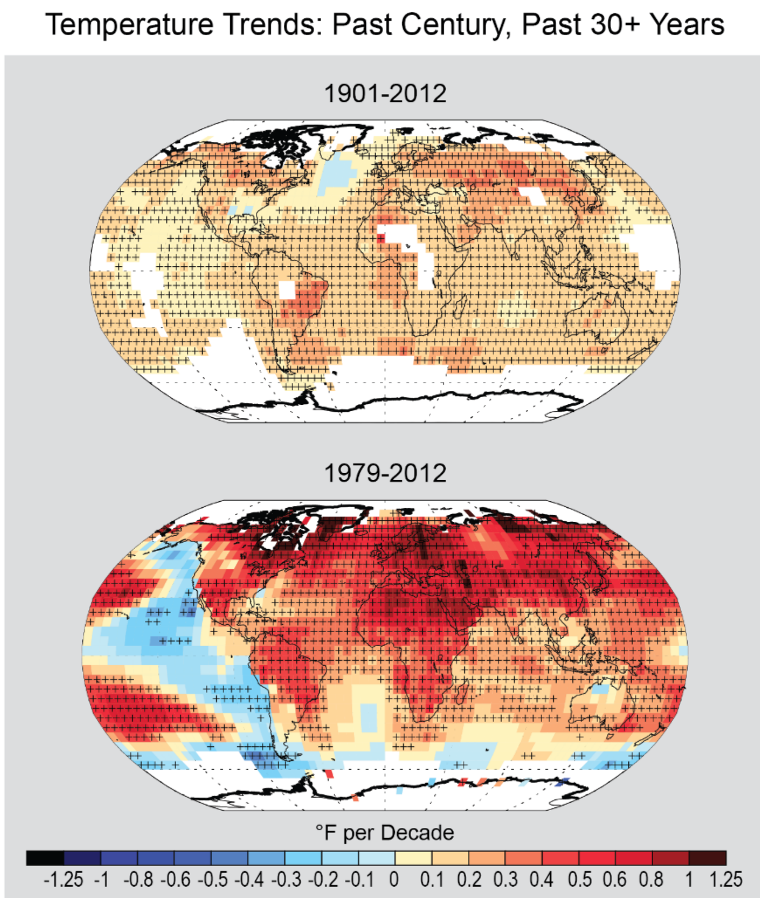

Figure 2: Surface temperature trends for the period 1901-2012 (top) and 1979-2012 (bottom) from NOAA National Climate Data Center's surface temperature product. Updated from [6]. From [2]

Even if the surface temperature had never been measured, scientists could still conclude with high confidence that the global temperature has been increasing because multiple lines of evidence all support this conclusion. Fig. 3 shows a number of examples of the indicators that show the climate on Earth is changing very rapidly over the last century. Temperatures in the lower atmosphere and oceans have increased, as have sea level and near-surface humidity. Basic physics tells us that a warmer atmosphere can hold more water vapor; this is exactly what is measured from the satellite data showing that humidity is increasing. Arctic sea ice, mountain glaciers, and Northern Hemisphere spring snow cover have all decreased. Over 90% of the glaciers in the world are decreasing at very significant rates. The amount of ice on the largest masses of ice on our planet, on Greenland and Antarctica, are decreasing. As with temperature, many scientists and associated research groups have analyzed each of these indicators and come to the same conclusion: all of these changes paint a consistent and compelling picture of a warming world.

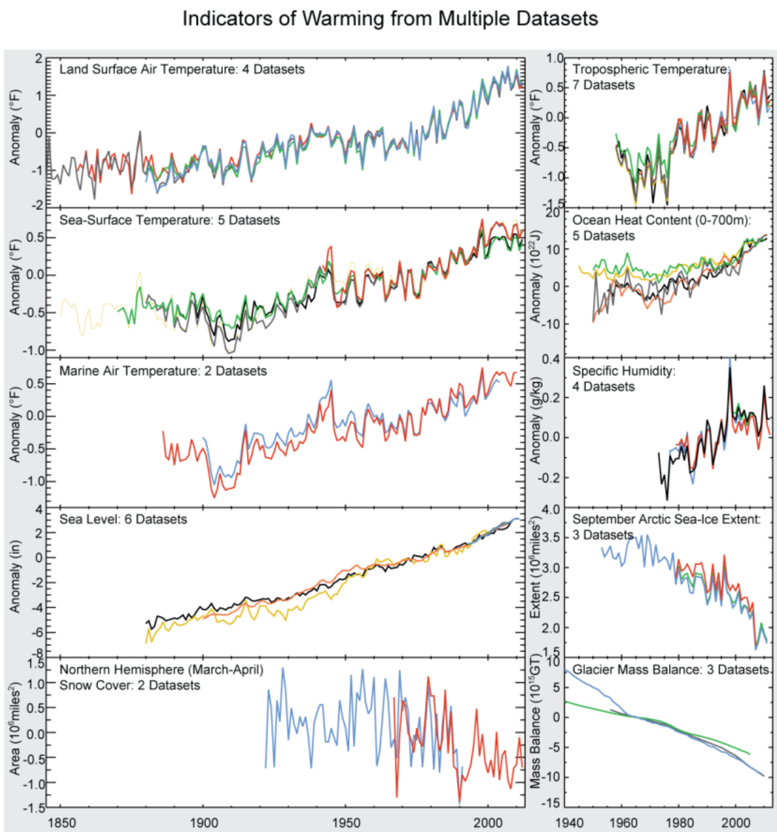

Figure 3: Observed changes, as analyzed by many independent groups in different ways, of a range of climate indicators. All of these are in fact changing as expected in a warming world. Further details underpinning this diagram can be found at http://www.ncdc.noaa.gov/bams-state-of-the-climate/ [2]

Precipitation is perhaps the most societally relevant aspect of the hydrological cycle and has been observed over global land areas for over a century. However, spatial scales of precipitation are small (e.g., it can rain several inches in Washington, DC, but not a drop in nearby Baltimore) and this makes interpretation of the point-measurements difficult. Based upon a range of efforts to create global averages, there does not appear to have been significant changes in globally averaged precipitation since 1900 (although as we will discuss later there has been a significant trend for an increase in precipitation coming as larger events). However, in looking at total precipitation there are strong geographic trends including a likely increase in precipitation in Northern Hemisphere mid-latitude regions taken as a whole (see Fig. 4). Stronger trends are generally found over the last four decades. In general, the findings are that wet areas are getting wetter and dry areas are getting drier, consistent with an overall intensification of the hydrological cycle in response to global warming [1].

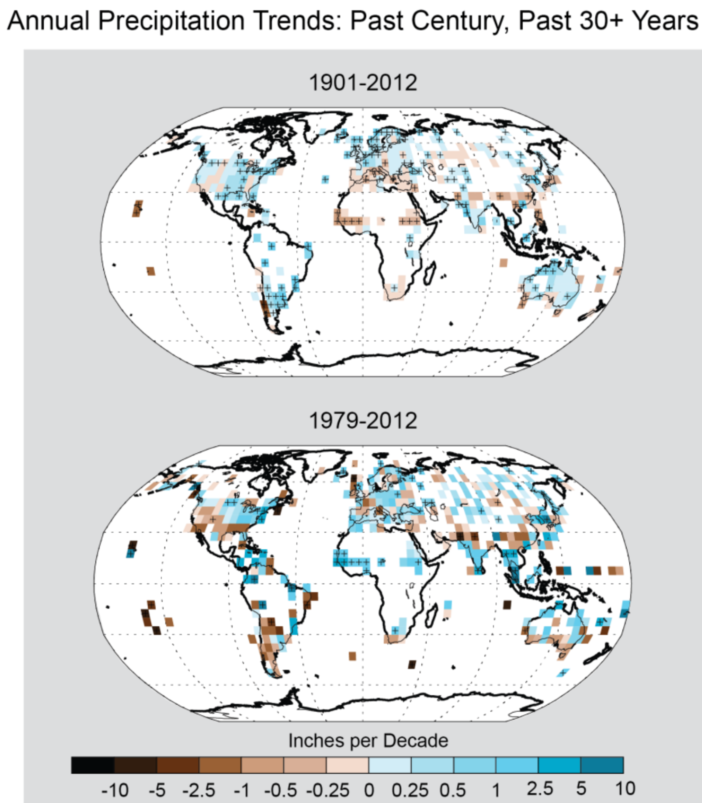

Figure 4: Global precipitation trends for the period 1901-2012 (top) and 1979-2012 (bottom). Based on date from NOAA NCDC. From [2]

It is well known that warmer air can contain more water vapor than cooler air. Global analyses show that the amount of water vapor in the atmosphere has in fact increased over both land and oceans. Climate change also alters dynamical characteristics of the atmosphere that in turn affect weather patterns and storms. At mid-latitudes, there is an upward trend in extreme precipitation in the vicinity of fronts associated with mid-latitude storms. Locally, natural variations can also be important. In contrast, the subtropics are generally tending to have less overall rainfall and more droughts. Nonetheless, many areas show an increasing tendency for larger rainfall events when it does rain [1,2,7].

3. Attribution: Why is the Climate Changing?

Over the last five decades, natural drivers of climate such as solar forcing and volcanoes would actually have led to a slight cooling. Natural drivers cannot explain the observed warming over this period. The majority of the warming can only be explained by the effects of human influences [1,8-10], especially the emissions from burning fossil fuels (coal, oil, and natural gas), and from changes in land use, such as deforestation. As a result of human activities, atmospheric concentrations of various gases and particles are changing, including those for carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), and particles such as black carbon (soot), which has a warming influence, and sulfates, which have an overall cooling influence. The most important changes are occurring in the concentration of CO_2; its atmospheric concentration recently reached 400 ppm (400 molecules per 1 million molecules of air; this small amount is important because of the heat-trapping ability of CO_2). 400 ppm of CO_2 has not been seen on Earth for over 1 million years, well before the appearance of humans. The increase in CO_2 over the last several hundred years is almost entirely due to burning of fossil fuels and land use change [1].

The conclusion that human influences are the primary driver of recent climate change is based on multiple lines of independent evidence. The first line of evidence is our fundamental understanding of how certain gases trap heat (these so-called greenhouse gases include H_2O, CO_2, CH_4, N_2O, and some other gases and particles that can all absorb the infrared radiation emitted from the Earth that otherwise would go to space), how the climate system responds to increases in these gases, and how other human and natural factors influence climate.

The second line of evidence is from reconstructions of past climates using evidence such as tree rings, ice cores, and corals. These show that the change in global surface temperatures over the last five decades are clearly unusual, and outside the range of natural variability. These analyses show that the last decade (2000-2009) was warmer than any time in at least the last 1300 years and perhaps much longer [1,11,12].

Globally averaged surface air temperature has slowed its rate of increase since the late 1990s. This is not in conflict with our basic understanding of global warming and its primary cause. The decade of 2000 to 2009 was still the warmest decade on record. In addition, global surface air temperature does not always increase steadily and can be influenced by natural variability on the scale of a few decades (for further discussion, see 1, 2; the explanation for the slowdown in global surface temperature is further discussed in a special issue of Nature from March 2014). Other climate change indicators, like the decrease in Arctic sea ice and sea level rise, have not seen the same slowdown.

The third line of evidence comes from using climate models to simulate the climate of the past century, separating the human and natural factors that influence climate. As shown in Fig. 5, when the human factors are removed, these models show that solar and volcanic activity would have tended to slightly cool the earth, and other natural variations are too small to explain the amount of warming. The range of values account for the range of results from the 20+ different models from around the world used in these analyses for the international climate assessment [1]. Only when the human influences are included do the models reproduce the warming observed over the past 50 years.

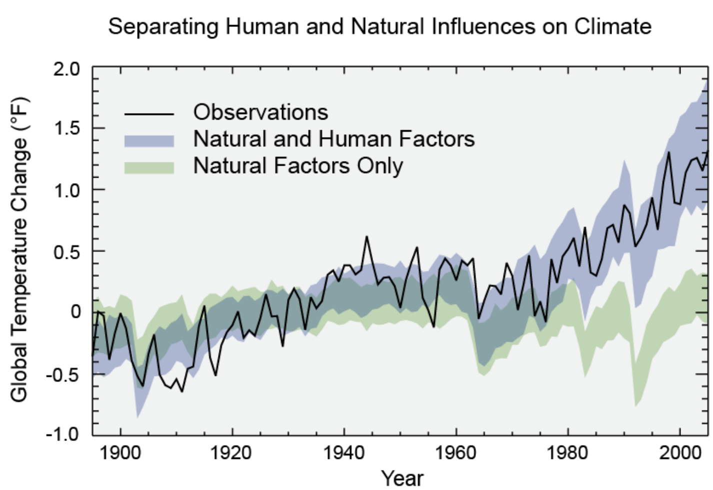

Figure 5: Observed global average changes (black line), and model simulations using only changes in natural factors (solar and volcanic) in green, and with the addition of human-induced emissions (blue). Climate changes since 1950 cannot be explained by natural factors or variability, and can only be explained by human factors. Figure source: adapted from [13]. From [2]

4. TRENDS IN EXTREME WEATHER EVENTS

A series of studies by Kunkel et al. [14], Peterson et al. [15], Vose et al. [6], and Wuebbles et al. [17], along with many other journal papers, has led to a collective assessment regarding changes in various weather extremes relative to the changing climate. The adequacy of the existing data to detect trends in severe weather events was examined relative to the current scientific ability to understand what drives those trends, i.e., how well the physical processes are understood, and thus how the extremes are expected to change in the future. This assessment shows that there are some events, such as those relating to temperature and precipitation extremes, where there is strong understanding of the trends and the underlying causes of the changes. The adequacy of data for floods, droughts, and extratropical cyclones to detect trends is also high, but there is only medium understanding of the underlying cause of their long-term changes. There is also medium understanding of the observed trends and cause of changes in hurricanes and in snow events. For some events, such as strong winds, hail, ice storms, and tornadoes, there is currently insufficient understanding of the trends or of the causes for the trends to make strong conclusions about these events in a changing climate. These findings also correlate well with global analyses of climate extremes [1,18].

Changing trends in some types of extreme weather events have been observed in recent decades. Modeling studies indicate that these trends are consistent with the changing climate. Much of the world is being affected by changing trends in extreme events, including increases in the number of extremely hot days, less extreme cold days, more precipitation events coming as unusually large precipitation, and more floods in some regions and more drought in others [2,17-21]. High impact, large-scale extreme events are complex phenomena involving various factors that come together to create a "perfect storm." Such extreme weather obviously does occur naturally. However, the influence of human activities on global climate is altering the frequency and/or severity of many of these events. Observed trends in extreme weather events, such as more hot days, less cold days, and more precipitation coming as extreme events, are expected to continue and to intensify over this century.

In most of the United States over the last couple of decades, the heaviest rainfall events have become more frequent (e.g., see Fig. 6) and the amount of rain falling in very heavy precipitation events has been significantly above average. This increase has been greatest in the Northeast, Midwest, and upper Great Plains. Similar findings are being found in many other parts of the world. Since basic physics tells us that a warmer atmosphere should generally hold more water vapor, this finding is not so surprising. Analyses indicate that these trends will continue [2,7,17,21]. The meteorological situations that cause heat waves are a natural part of the climate system. Thus the timing and location of individual events may be largely a natural phenomenon, although even these may be affected by human-induced climate change [22]. However, there is emerging evidence that most of the increasing heat wave severity over our planet is likely related to the changes in climate, with a detectable human influence for major recent heat waves in the U.S. [23,24,25], Europe [10, 22], and Russia [26]. As an example, the summer 2011 heat wave and drought in Oklahoma and Texas, which cost Texas an estimated $8 billion in agricultural losses, was primarily driven by precipitation deficits, but the human contribution to climate change approximately doubled the probability that the heat was record-breaking [27]. So while an event such as this Texas heat wave and drought could be triggered by a naturally occurring event such as a deficit in precipitation, the chances for record-breaking temperature extremes have increased and will continue to increase as the global climate warms. Generally, the changes in climate are increasing the likelihood for these types of severe events.

In the tropics, the most important types of storms are tropical cyclones, referred to as hurricanes when they occur in the Atlantic Ocean. Over the 40 years of satellite monitoring, there has been a shift toward stronger hurricanes in the Atlantic, with fewer smaller (category 1 and 2) hurricanes and more intense (category 4 and 5) hurricanes. There has been no significant trend in the global number of tropical cyclones [1,18] nor has any trend been identified in the number of U.S. landfalling hurricanes [2].

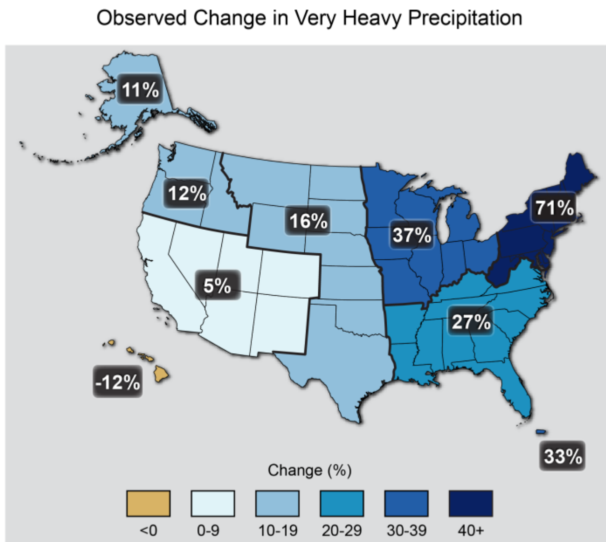

Figure 6: Percent increases in the amount of precipitation falling in very heavy events (defined as the heaviest 1% of all daily events) from 1958 to 2012 for each region of the continental U.S. These trends are larger than natural variations for the Northeast, Midwest, Puerto Rico, Southeast, Great Plains, and Alaska. The trends are not larger than natural variations for the Southwest, Hawaiʻi, and the Northwest. The changes shown in this figure are calculated from the beginning and end points of the trends for 1958 to 2012. From [2]

Trends remain uncertain in some types of severe weather, including the intensity and frequency of tornadoes, hail, and damaging thunderstorm winds, but such events are under scrutiny to determine if there is a climate change influence. Initial studies do suggest that tornadoes could get more intense in the coming decades [28].

5. Climate Projections: Temperature and Precipitation

On the global scale, climate model simulations show consistent projections of future conditions under a range of emissions scenarios (that depend on assumptions of population change, economic development, our continued use of fossil fuels, changes in other human activities, and other factors). For temperature, all models show warming by late this century that is much larger than historical variations nearly everywhere (see Fig. 7). For precipitation, models are in complete agreement in showing decreases in precipitation in the subtropics and increases in precipitation at higher latitudes. As mentioned earlier, extreme weather events associated with extremes in temperature and precipitation are likely to continue and to intensify.

Choices made now and in the next few decades about emissions from fossil fuel use and land use change will determine the amount of additional future warming over this century and beyond. Global emissions of CO_2 and other heat-trapping gases continue to rise. How much climate will change over this century and beyond depends primarily on: 1) human activities and resulting emissions; and 2) how sensitive the climate is to those changes (that is, the response of global temperature to a change in radiative forcing caused by human emissions). Uncertainties in how the economy will evolve, what types of energy will be used, or what our cities, buildings, or cars will look like in the future are all important and limit the ability to project future changes in climate. Scientists can, however, develop scenarios – plausible projections of what might happen, under a given set of assumptions. These scenarios describe possible futures in terms of population, energy sources, technology, heat-trapping gas emissions, atmospheric levels of carbon dioxide, and/or global temperature change.

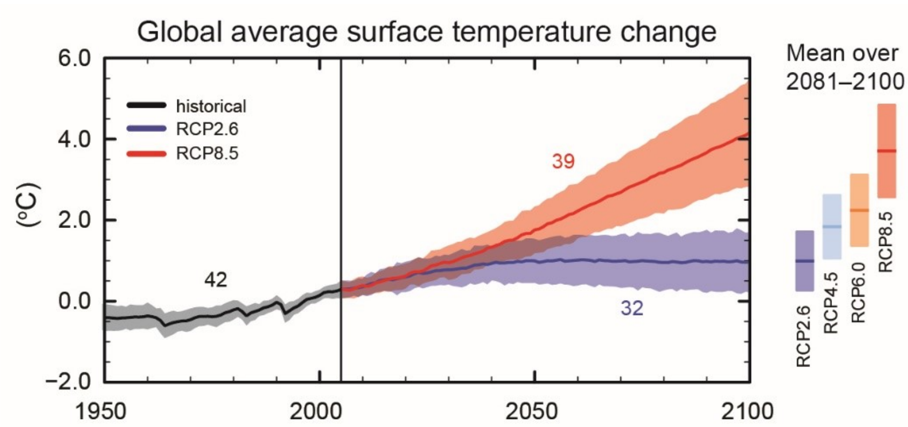

Figure 7: Multi-model simulated time series from 1950 to 2100 for the change in global annual mean surface temperature relative to 1986–2005 for a rang of future emissions scenarios that account for the uncertainty in future emissions from human activities (as analyzed with the 20+ models from around the world used in the most recent international assessment [1]). The mean and associated uncertainties (1.64 standard deviations (5-95%) across the distribution of individual models (shading)) based on the averaged over 2081–2100 are given for all of the RCP scenarios as colored vertical bars. The numbers of models used to calculate the multi-model mean is indicated. (Fig. 7a from [1])

A certain amount of climate change is already inevitable due to the build-up of CO_2 in the atmosphere from human activities (although there is a rapid exchange of CO_2 with the biosphere, the eventual lifetime for atmospheric CO_2 is dependent on removal to the deep ocean). The Earth's climate system, particularly the oceans, tends to lag behind changes in atmospheric composition by decades, and even centuries due to the large heat capacity of the oceans and other factors. Another 0.2-0.3°C (about 0.5°F) increase is expected over the next few decades [29] although natural variability could still play an important role over this time period [30]. The higher the human-related emissions of CO_2 and other heat-trapping gases over the coming decades, the higher the resulting changes expected by mid-century and beyond. By the second half of the century, however, scenario uncertainty (that is, uncertainty about what will be the level of emissions from human activities) becomes increasingly dominant in determining the magnitude and patterns of future change, particularly for temperature-related aspects [30].

As seen in Figs. 7 and 8 for a range of scenarios varying from assuming strong continued dependence on fossil fuels in energy and transportation systems over the 21st century (scenario RCP8.5) to assuming major mitigation actions (RCP2.6), global surface temperature change for the end of the 21st century is *likely* to exceed an increase of 1.5°C (2.7°F) relative to 1850 to 1900 for all projections except for the RCP2.6 scenario [1]. Note that the RCP2.6 scenario is much lower than the other scenarios examined because it not only assumes significant mitigation to reduce emissions, but it also assumes that technologies are developed that can achieve net negative carbon dioxide emissions (removal of CO_2 from the atmosphere) before the end of the century.

A number of research studies have examined the potential criteria for dangerous human interferences in climate where it will be difficult to adapt to the changes in climate without major effects on our society [31]. Most of these studies have concluded that an increase in globally average temperature of roughly 1.5°C (2.7°F) is an approximate threshold for dangerous human interferences with the climate system (see [1] for further discussion), but this threshold is not exact and the changes in climate are geographically diverse and impacts are sector dependent, so there really is no defined threshold by when dangerous interferences is actually reached.

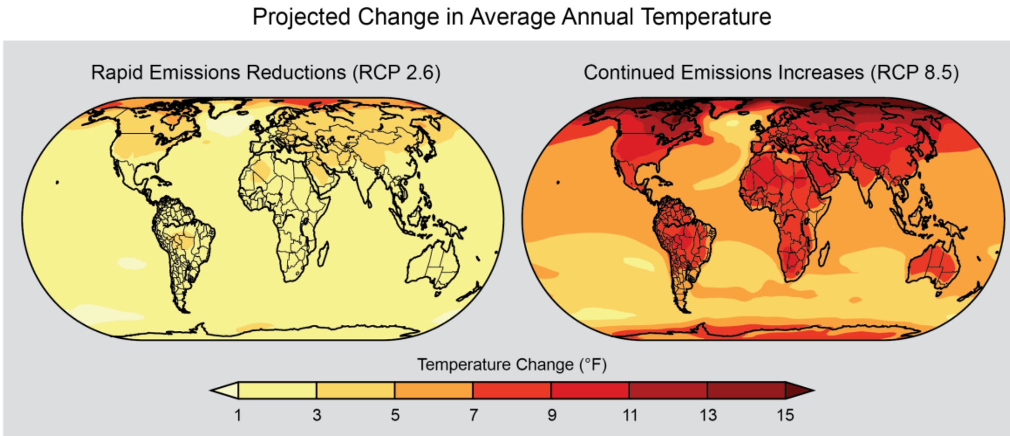

Figure 8: Projected change in average annual temperature over the period 2071-2099 (compared to the period 1971-2000) under a low scenario that assumes rapid reductions in emissions and concentrations of heat-trapping gases (RCP 2.6), and a higher scenario that assumes continued increases in emissions (RCP 8.5). From [2]

The warming and other changes in the climate system will continue beyond 2100 under all RCP scenarios, except for a leveling of temperature under RCP2.6. In addition, it is fully expected that the warming will continue to exhibit interannual-to-decadal variability and will not be regionally uniform.

Projections of future changes in precipitation show small increases in the global average but substantial shifts in where and how precipitation falls (see Fig. 9). Generally, areas closest to the poles are projected to receive more precipitation, while the dry subtropics (the region just outside the tropics, between 23° and 35° on either side of the equator) will generally expand toward the poles and receives less rain. Increases in tropical precipitation are projected during rainy seasons (such as monsoons), especially over the tropical Pacific. Certain regions, including the western U.S. (especially the Southwest [2]) and the Mediterranean [1]), are presently dry and are expected to become drier. The widespread trend of increasing heavy downpours is expected to continue, with precipitation becoming more intense [32-34]. The patterns of the projected changes of precipitation do not contain the spatial details that characterize observed precipitation, especially in mountainous terrain, because of model uncertainties and their current spatial resolution [1].

Projected Change in Average Annual Precipitation

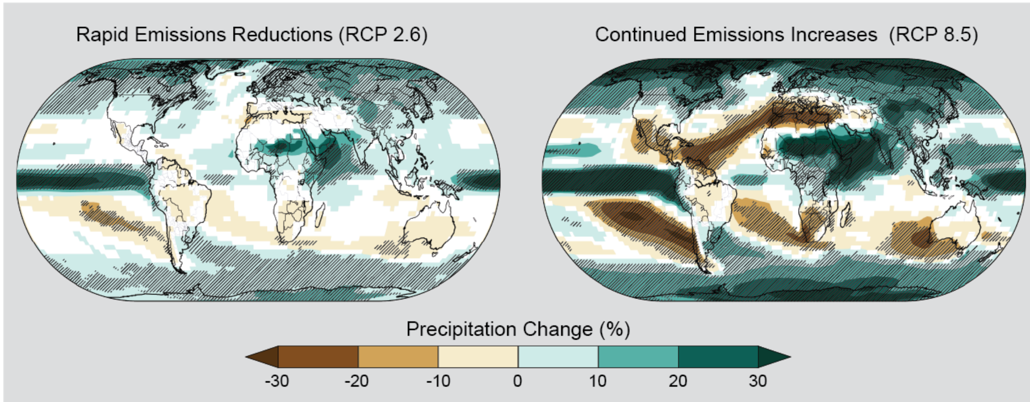

Figure 9: Projected change in average annual precipitation over the period 2071-2099 (compared to the period 1971-2000) under a low scenario that assumes rapid reductions in emissions and concentrations of heat-trapping gasses (RCP 2.6), and a higher scenario that assumes continued increases in emissions (RCP 8.5). Hatched areas indicate confidence that the projected changes are significant and consistent among models. White areas indicate that the changes are not projected to be larger than could be expected from natural variability. In general, northern parts of the U.S. (especially the Northeast and Alaska) are projected to receive more precipitation, while southern parts (especially the Southwest) are projected to receive less. From [2]

6. Climate Projections: Extreme Weather Events

As mentioned earlier, some areas both in the U.S. and throughout the world are already experiencing climate-related disruptions, particularly due to extreme weather events. These trends are likely to continue throughout this century. Existing research indicate the following trends over the coming decades (see [1,2] for more details):

- It is likely that over the coming decades the frequency of warm days and warm nights will increase in most land regions, while the frequency of cold days and cold nights will decrease. As a result, an increasing tendency for heat waves is likely in many regions of the world.
- Some regions are likely to see an increasing tendency for droughts while others are likely to see an increasing tendency for floods. This roughly corresponds to the wet getting wetter and the dry getting drier.
- It is likely that the frequency and intensity of heavy precipitation events will increase over land. These changes are primarily driven by increases in atmospheric water vapor content, but also affected by changes in atmospheric circulation.
- Tropical storm (hurricane)-associated storm intensity and rainfall rates are projected to increase as the climate continues to warm.
- Initial studies also suggest that tornadoes are likely to become more intense.
- For some types of extreme events, like wind storms, and ice and hail storms, there is too little understanding currently of how they will be affected by the changes in climate.

7. Sea Level Rise and Ocean Acidification

After at least two thousand years of little change, the world's sea level rose by roughly 0.2 meters (8 inches) over the last century, and satellite data provide evidence that the rate of rise over the past 20 years has roughly doubled. Around the world, many millions of people and many assets related to energy, transportation, commerce, and ecosystems are located in areas at risk of coastal flooding because of sea level rise and storm surge. Sea level is rising because ocean water expands as it heats up and because water is added to the oceans from melting glaciers and ice sheets.

Sea level is projected to rise an additional 0.3 to 1.2 meters (1 to 4 feet) in this century (see Fig. 10 [2]; similar findings in [1]). The best estimates for the range of sea level rise projections for this century remain quite large; this may be due in part to what emissions scenario we follow, but more importantly it depends on just how much melting occurs from the ice on large land masses, especially from Greenland and Antarctica. Recent projections show that for even the lowest emissions scenarios, thermal expansion of ocean waters [35] and the melting of small mountain glaciers [36] will result in 11 inches of sea level rise by 2100, even without any contribution from the ice sheets in Greenland and Antarctica. This suggests that about 0.3 m (1 foot) of global sea level rise by 2100 is probably a realistic low end. Recent analyses suggest that 1.2 m (four feet) may be a reasonable upper limit [1,2,37]. Although scientists cannot yet assign likelihood to any particular scenario, in general, higher emissions scenarios would be expected to lead to higher amounts of sea level rise.

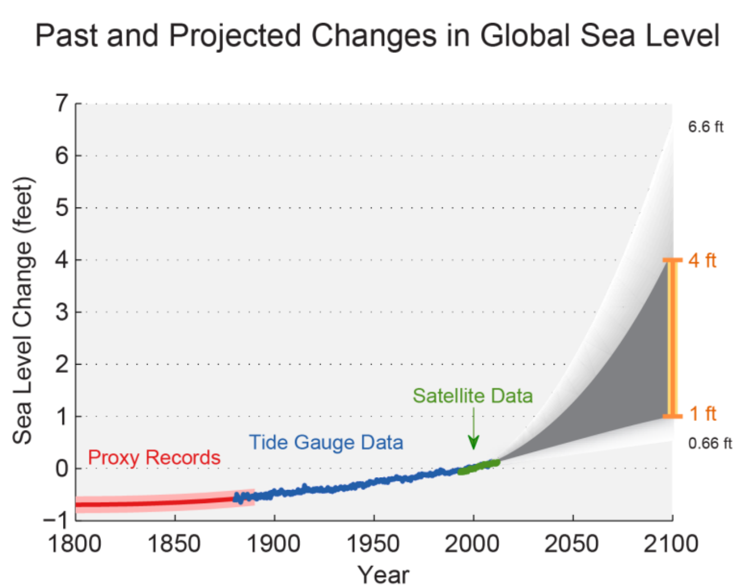

Figure 10: Estimated, observed, and projected amounts of global sea level rise from 1800 to 2100, relative to the year 2000. Estimates from proxy data (for example, based on sediment records) are shown in red (1800-1890, pink band shows uncertainty), tide gauge data in blue for 1880-2009 [49, 50] and satellite observations are shown in green from 1993 to 2012 [51]. The future scenarios range from 0.66 feet to 6.6 feet in 2100 [52]. These scenarios are not based on climate model simulations, but rather reflect the range of possible scenarios based on scientific studies. The orange line at right shows the currently projected range of sea level rise of 1 to 4 feet by 2100, which falls within the larger risk-based scenario range. The large projected range reflects uncertainty about how glaciers and ice sheets will react to the warming ocean, the warming atmosphere, and changing winds and currents. As seen in the observations, there are year-to-year variations in the trend. From [2]

Because of the warmer global temperatures, sea level rise will continue beyond this century. Sea levels will likely continue to rise for many centuries at rates equal to or higher than that of the current century. Many millions of people live within areas than can be affected by the effects of storm surge within a rising sea level. The Low Elevation Coastal Zone (less than 10 m elevation) constitutes 2% of the world's land area but contains 10% of the world's population based on year 2000 estimates [38].

As CO_2 concentrations build up in the atmosphere, some of this CO_2 is dissolving into the oceans where it reacts with seawater to form carbonic acid, lowering ocean pH levels ("acidification") and threatening a number of marine ecosystems [39]. The oceans currently absorb about a quarter of the CO_2 humans produce every year [40]. Over the last 250 years, the oceans have absorbed 560 billion tons of CO_2, increasing the acidity of surface waters by 30% [2]. Although the average oceanic pH can vary on interglacial timescales [41], the current observed rate of change is roughly 50 times faster than known historical change [42,43]. Regional factors such as coastal upwelling [44], changes in discharge rates from rivers and glaciers [45] sea ice loss [46], and urbanization [47] have created "ocean acidification hotspots" where changes are occurring at even faster rates.

The acidification of the oceans has already caused a suppression of carbonate ion concentrations that are critical for marine calcifying animals such as corals, zooplankton, and shellfish. Many of these animals form the foundation of the marine food web. Today, more than a billion people worldwide rely on food from the ocean as their primary source of protein. Ocean acidification puts this important resource at risk.

Projections indicate that in a higher emissions scenario (that assume continuing use of fossil fuels), ocean pH could be reduced from the current level of 8.1 to as low as 7.8 by the end of the century [48]. Such large rapid changes in ocean pH have probably not been experienced on the planet for the past 100 million years, and it is unclear whether and how quickly ocean life could adapt to such rapid acidification [42]. The potential impact on the human source of food from the oceans is also unclear.

8. Conclusions

Observations show that climate change is happening, that it is happening rapidly, and that it is primarily due to human activities, especially the emissions occurring from our dependence on fossil fuels. There is an increasing level of risks to society from severe weather events and from sea level rise.

Large reductions in global emissions of heat-trapping gases would reduce the risks of some of the worst impacts of climate change. Meanwhile, global emissions are still rising and are on a path to be even higher than the high emissions scenario examined in this study.

As the impacts of climate change are becoming more prevalent, humanity faces choices. Especially because of past emissions of long-lived heat-trapping gases, some additional climate change and related impacts are now unavoidable. This is due to the long-lived nature of many of these gases, as well as the amount of heat absorbed and retained by the oceans and other responses within the climate system. The amount of future climate change, however, will still largely be determined by choices society makes about emissions. Lower emissions of heat-trapping gases and particles mean less future warming and less-severe impacts; higher emissions mean more warming and more severe impacts.

There are a number of areas where improved scientific information or understanding would enhance the capacity to estimate future climate change impacts. For example, knowledge of the mechanisms controlling the rate of ice loss in Greenland and Antarctica is limited, making it difficult for scientists to narrow the range of expected future sea level rise. Improved understanding of ecological and social responses to climate change is needed, as is understanding of how ecological and social responses will interact [2].

Adaptation to the changing climate is not an option; our choice is to prepare proactively or to respond to events after they happen. Proactively preparing for climate change can reduce impacts while also facilitating a more rapid and efficient response to changes as they happen. Such efforts are beginning in the U.S. and other parts of the world, to build adaptive capacity and resilience to climate change impacts. Using scientific information to prepare for climate changes in advance can provide economic opportunities, and proactively managing the risks can reduce impacts and costs over time.

The choices we make will not only affect us, they will affect our children, our grandchildren, and future generations.

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Impact of Climate Change (Global Warming) on Food-Borne Parasites

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Abstract

Parasitic food-borne zoonosis could impose heavy toll on human health and cause serious direct and indirect economic losses. A wide variety of helminthes parasites which are quite prevalent in Iran can infect human by the oral route. In the present study food-borne parasites have been discussed according to the main sources of transmission include: meat, vegetables, water and soil and reviews the parasitic infection affected the current available evidence and scenarios of climate changes in Iran. The four major climatic zones of Iran are considered. Meat-borne parasites, *cysticercus bovis* significantly decreased in Iran as a result of improve community health particularly excreta disposal in rural areas. Pork is not consumed in Iran because of the religious prohibition and human infection case with *cysticercus celluluse* and *Trichinella spiralis* is rare. And the prevalence of fish-borne parasites is not considerable because fish consumption in Iran is not high. Fascioliasis is now the most important food-borne parasites in Iran, mainly from Gilan province where placed in the zone1. Hydatidosis is endemic in Iran. Eating raw vegetable is the main cause of infection. *Dracunculus medinensis* was the most important water-borne parasites; the infection has been eradicated in Iran, which is due to consumption the most sanitary water. Although the prevalence of soil-borne parasites is very low compared to the past but it is the most common parasites in the zone1. A comprehensive study contain detailed estimations of food-borne parasites can provide useful solutions for their control and preventions.

Keywords: Food-Borne Parasites, Ecology, Epidemiology, Climate Change, Iran

1. INTRODUCTION

Food borne diseases caused by helminthes are quite prevalent all through the country. Because of the habit of living the risk of food contamination with parasites is normally high. Iran is a vast country with a population of 75 million. Weather of Iran is such countries with a semi–arid climate. Consideration of climatological data and of topography of country led to division of Iran into the four major climatic zones (Fig. 1) where it seemed likely that differences in parasite problems may be found. Iran in terms of geopolitics is located in a region of the world which is called the heart of the earth, although the term has been used for political and military goals [1]. Therefor Iran has strategically very important role in the spread of infections [2]. Climate change refers to any interpretation to be certain about the expected patterns of average weather, which Happen to the Earth or in a specific region in the long term. Climate change has a major impact on the biology of parasites and parasites distribution subsequently effects on human health and food security [3,4]. Since ancient, data have been collected on the impact of climate on human health [5]. Iran has four climate of medical climatology as follows (Fig. 1): 1) The Caspian zone, 2) The Mountain plateaux zone, 3) The Persian Gulf zone, 4) The Desert zone [2,6]. There are eight sub-continents which are not shown here. Studies have been conducted on the epidemiology of parasitic infections in Iran, although not comprehensive but have long been considered to the Prevalence and abundance of parasitic infections [6]. Skerman et al. (1967) studied the incidence and epidemiology, control and economic importance of Gastro-Intestinal parasites in the small ruminants in two climatic zones (Caspian Sea climate and Mountain climate) of Iran [6]. Based on these results, the Prevalence and abundance of Gastro-intestinal nematodiasis were different in small ruminants in the two zones (zones 1 and 2) [6]. After strategic treatment with anti-helminthes and reduce worm burden as a result, the protein content increased 2.5 kg. As well, to feed the future population is affordable [6]. In Iran, food of animal protein is produced from 75,000,000 sheep and goats, 7,000,000 native and industrial cattle and 25,000,000,000 poultry [7]. More than 150 different species of fish found in the Persian Gulf and more than 78 species of fish found in the Caspian Sea. Caspian Sea is the hosts of one of the most valuable fish stocks in the world. The Caspian Sea is the host of sturgeon, one of the valuable foods in the world, provides a source of fish for human food [8]. Lamb meat is the most popular meat in the food supply and beef in the next. Other sources of meat include goat, camel and buffalo. Milk consumption in Iran is 70-80 Kg annually. Milk is pasteurized and helminthes infective larvae have not been reported from milk [7]. The aim of this study was to investigate the epidemiology and ecology of food-borne parasites. In the present study, parasites were studied by means of transmission to humans. Also the impact of climate change on the parasites is investigated. It is noted that most food-borne parasites are zoonotic.

2. TYPES OF PARASITES

2.1. Meat-borne Parasites (Helminthes Parasites)

Taenia saginata Commonly known as the beef tapeworm, is a zoonotic tapeworm belonging to the order Cyclophyllidea and genus *Taenia*. It is an intestinal parasite of humans, causing taeniasis. Cattle are the intermediate hosts, where larval development (metacestod) occurs and named *cysticercus bovis,* it is most prevalent where cattle are raised and beef is consumed. Consuming of infected beef with cysticercus bovis as raw or semi-cooked products causes human taeniasis due to *Taenia saginata*. Beside of meat, infected liver or lungs may also take a role in transmission to the man under condition. Raw meat is not eaten in Iran but the barbecue is very common and desirable and the meat may be raw in the middle of it. The incidence of adult tapeworm in man cannot be figured out accurately, and is estimated about 0.5- 1 per cent in Iran [9] the rate of infection varies from one part to another. The highest was 17% recorded from Mazandaran and next 14% from Gilan province. Now, the prevalence of taeniasis in Mazandaran is 0.5% [9]. And the most prevalence of cysticercosis in cattle is 2-3% reported from north of Iran [9]. The prevalence of Taeniasis decreased in Iran as a result of Improve community health particularly excreta disposal in rural areas. In the slaughterhouse, Carcass inspection was done carefully. And infected meat is maintained in the freezer according to Health guidelines so Meat hygiene is increased [10].

Taenia solium is the pork tapeworm belonging to cyclophyllidea cestodes in the family Taeniidae. The adult worm is found in humans and metacestode (cysticercus cellulosae) in pigs. It is transmitted to pigs through human faeces or contaminated food, and to humans through uncooked or undercooked pork. However, accidental infection in humans by the larval stage causes cysticercosis. The most severe form is neurocysticercosis, which affects the brain. It is most prevalent in countries where pork is eaten [11]. Pork is not consumed in Iran Because of the religious prohibition. Before the Islamic Revolution, domestic pig was reared in Iran. This pig and wild swine were used for research on cysticercus cellulosae, 0.3-3% of pigs and 4% of boars were infected (10) but human infection have not been reported yet.

Trichinella spiralis is a parasitic nematode that has a direct life cycle, meaning it completes all stages of development in one host. The larval forms are encapsulated as a small cystic structure within the infected host. Humans typically become infected when they eat undercooked *Trichinella* infected pork and affected the disease trichinosis. Before the Islamic Revolution, examination of pig meat using trichinoscope was routine in Tehran abattoir, but it has not been reported *Trichinella* infection in domestic pigs in Iran yet. But from 4,950 carcasses of boars examined for *Trichinella spiralis* the larva was found in 2 of them [12]. This parasite has been reported also from more than 60% of Jackals and wild cats and 16% of Brown Bear from north of Iran [13]. After the Islamic Revolution, Domestic pig breeding was stopped although Wild boar meat is consumed for Armenians. *Trichinella* infections from a group of humans have been reported recently, by consuming grilled hunting boar meat infected with *Trichin* [14].

2.2. Fish-borne Parasites

Fish consumption in Iran is not high. Average annual consumption of fish is 7 grams per day in Iran, while it is about 18Kg in the world. In Iran, Coastal residents eat more fish, they have different diets. Coastal residents consume about 13 kg of fish per year [8]. The prevalence of Fish-borne parasites in Iran is not significant.

Anisakis or herring-worm is a natural parasite of marine fish-eating mammals. Human cases occur where fish are eaten raw, larvae are found in abscesses in the wall of the intestinal tract and stomach. Larvae of Anisakis were found in the flesh of Persian Gulf fish [15]. The results of the recent study showed that more than 90% of the *Thannus tonggol* fish were infected [16] but human infection with anisakidae has not been reported, since eating raw fish is rare in Iran [15].

Dioctophyma renale is a natural parasite of the kidney or the body cavity of carnivores and the unembryonated eggs are passed out in urine. Eating infected raw fish likely leads to dioctophymosis. Adult worms in the kidney cause renal colic and later dysfunction. A case is reported of a woman's lived in east Azerbayjan (North West of Iran) [17]. But in Iran the prevalence of Infection in stray dogs and other carnivores are considerable [18].

2.3. Vegetable-borne Parasites

***Fasciola* sp.:** Fasciolosis is a well-known parasitic disease, because of its medical and veterinary importance. It is now also an important human parasitic disease with estimated ranging from 2.4 to 17 million people infected [19]. *Fasciola hepatica* and *F. gigantica* the causative agents of fasciolosis of animals and man are reported from different regions in Iran [20,21], although the distribution of both species overlaps in many parts of the country [19,21].Human fasciolosis is a matter of concern in provinces situated along the shore of the Caspian Sea, especially in Gilan Province. This province has experienced two waves of the fasciolosis epidemics. The first wave was begun in 1987 when an outbreak in Gilan affected more than 10,000 people. The second wave of the epidemic began within 10 years later where several thousand people were infected [22]. Reports of several hundred cases of human fasciolosis between two outbreaks and afterward show that Gilan Province has become an endemic area for human fasciolosis in Iran. At least 17,000 human infections have been reported in Gilan Province since 1989 [22]. Recently worldwide losses in animal productivity due to fasciolosis were conservatively estimated at over US$ 3.2 billion per annum [23]. In Asia the most human cases were reported from Iran, mainly from Gilan Province [24], findings showed that fasciolosis is very prevalent among animals in Rasht and Bandar- Anzali. Considering the prepatent period of fasciolosis [12 weeks], the absence of *Fasciola* egg in calf is a natural phenomenon. But the percentage of infection in other animals and animal manure was higher than 21. 5% previously reported from ruminants of Gilan [25]. Fasciolosis may cause serious economic problem. Climate change is effective in *Fasciola*. When summer rainfall is high, Facilitate the growth of wild plants (*Menta piperita, Menta aquatica, Nasturium officinale*) but damaged farming vegetable, therefore Humans consume the wild plants, which are the sources of infection. In addition, the environment of *Lymnaea truncatula* (the intermediate host of *Fasciola hepatica)* is prepared well. The impact of this climate change on the incidence of Fasciolosis is undeniable [26].

Hydatid cyst: Hydatidosis, caused by Echinococcus spp. (E. granulosus and E.multilocularis in Iran) is one of the most important zoonotic diseases, throughout the most parts of the world [27]. E. granulosus is the causative agent of cystic hydatid disease or hydatidosis, whereas infection with E. multilocularis in man leads to the more aggressive form of alveolar echinococcosis. Ingesting embryonated eggs through hands, food, drinks or material contaminated with parasite eggs infects humans; the larvae reach the blood and lymphatic circulation and transport to the liver, lungs and other organs [28]. Cystic echinococcosis is considered endemic in the entire Mediterranean zone including all countries from the Middle East [29], but alveolar echinococcosis is less prevalent and has been reported only from Iran, Turkey, Iraq and Tunisia [30]. Hydatidosis is endemic in Iran and is responsible for approximately 1% of admission to surgical wards [31]. The annual incidence rate of hydatidosis in human in Iran 0.61/100,000 [31] are among documented reports. E. multilocularis is another agent of human hydatidosis (alveolar echinococcosis) with red fox (Vulpes vulgaris) and jackal (Canis aureas) as final hosts as well as social vole (Microtus socialis) as intermediate host [32] in Iran , where is recognized an endemic country for the disease [33]. Here is tendency to eat raw vegetables with food. Unfortunately, in most vegetable farms, dogs freely prowl and contaminate the vegetables. Another potential source of infection is carrot juice, which almost everywhere is sold in a mixture with ice cream. The washing system of carrots is such that the parasites' eggs are retained in washing water and most of them are not separated from the carrots [31]. A tendency to eat soil by pregnant women especially in rural areas makes the situation in benefit of infecting with hydatidosis.

The importance of environmental factors in influencing the transmission intensity and distribution of Echinococcus spp. is increasingly being recognized [31].

Dicrocoelium dendriticum: Low human cases have been reported. But this is one of the most common infections in ruminants in Iran now; it is one of the main causes of liver destruction in the slaughters house [34]. Despite consumed the wide range of anti-helminthic drugs, Infection with this parasite remains considerable and researchers have been suspected to drug resistance in *D.dendriticum*, but it is obvious that this issue requires further study [35].

Trichostrongylidae: Contamination of vegetables with Trichostrongylid eggs and eating them raw was causing haemonchosis, osthertagiasis, in the past. But now, Strategic treatment of nematodes with anti-helminthes drugs has led to completely eliminate the infection in humans and significantly reduce infection in ruminants [36].

2.4. Water-Borne Parasites

Dracunculus medinensis or Guinea worm is a nematode that causes dracunculiasis. The disease is caused by the large female nematode of *D. medinensis* and it was the most important water borne parasites. Fortunately, the disease has been eradicated in Iran. Indeed, the most sanitary water consumption is due to eradicate the infection [37].

2.5. Soil-Borne Parasites

Important parasite infections in humans are caused by eating soil. Dining on soil may be an accident, like children who Play on the ground and do not wash their hands and sometimes it is a bad habit in humans, most often in rural or pre-industrial societies among children and pregnant women which are may be related to pica. Toxocarasis is one of the most important soil-borne and emerging parasites. Most people are infected by contact with contaminated soil [37]. Forty years ago, Ascariasis infection was 83% in Khozestan province (South West Iran) and infections have also been reported in other areas with suitable climatic conditions. But now, due to improving public health, it is 1%. *Trichuris trichura* although its prevalence is very low compared to the past but it is a one of the most common parasites in Iran especially in zone 1, Fig. 1 [37].

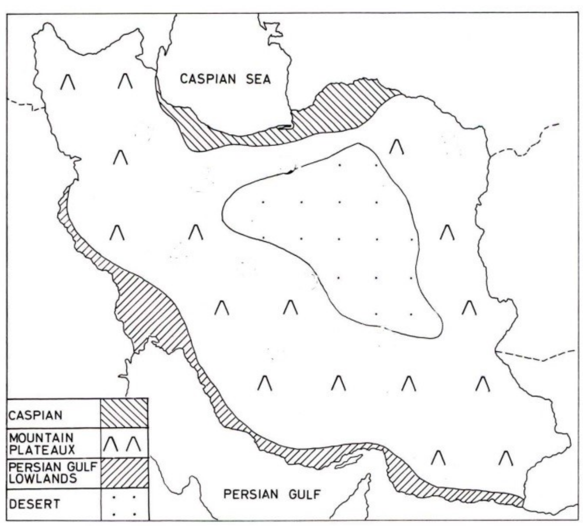
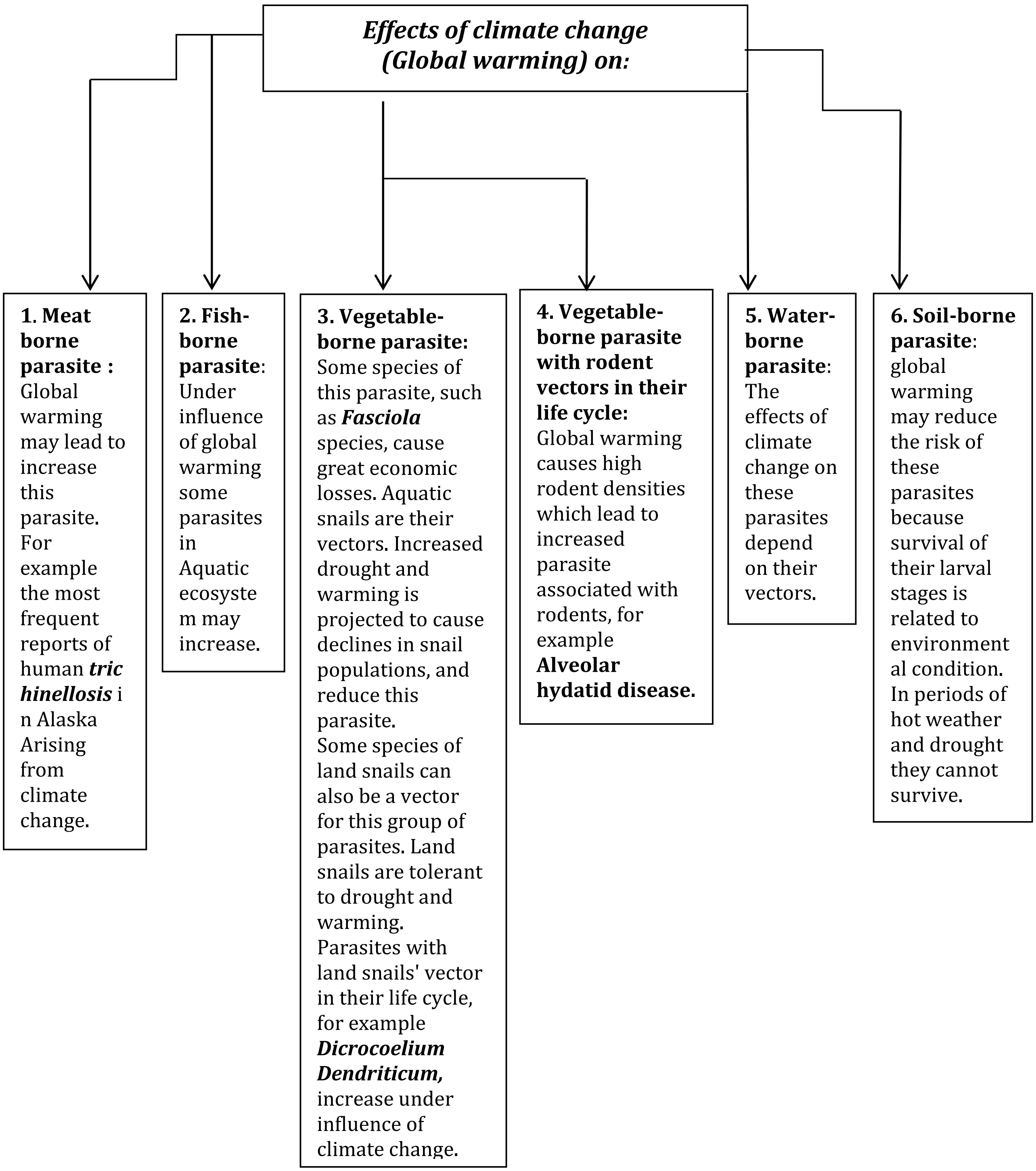


Figure 1: The major climatic zones of Iran (Skerman etal., 1967)

3. RESULTS



4. DISCUSSION

The globalization of food supply, increased international travel, increase of *population* with highly susceptible persons and changing the habits of life are important factors associated with increasing food-borne parasites [4]. In the present study the evaluation of the food-borne helminthes classified in the four groups. Moreover, the important food borne protozoa should not be ignored such as Toxoplasmosis and Sarcocystiasis (meat-borne protozoa), Giardiasis and Cryptosporidiosis and Cyclosporiasis (water-borne protozoa). With the advent of climate change and the influence of global population expansion, food insecurity and land-use changes, questions about the potential impact of changing temperature, rainfall patterns, increasing urbanization, deforestation, grassland degradation and overgrazing on zoonotic disease transmission are being raised [5]. Since it is inadequate systems for diagnosis and monitoring the parasitic infections as well lack of supervision systems to report the detailed of the infections and the mechanisms of transmitted usually the incidence of food-borne parasites infections are underestimated. And the same is true of drug resistance [38]. It must be noted that, personal and Laboratory safety, in other word biosafety, is essential to study food-borne and zoonotic parasites and research on the most cases should be performed in the laboratory with class II and III, so Research has been limited on this parasites. Climate change is one of the main causes gain food-borne parasites [4]. Some of these changes are rooted in global warming can predict the epidemic of parasitic infections in humans and livestock population in the future. In Iran heat and dryness is more likely in the future, so the pattern of tropical diseases expands in temperature zone, and of the low-lying areas to the highlands [3]. According to the forecast, in Iran should be expected to reduce the incidence of *malaria* and increased the prevalence of *Leishmania*. In these times the density of mice rises, and increases the risk of diseases transmitted from mice [2]. Parasitic pathogens in freshwater and marine ecosystems are affected by climate change. As the temperature increases the rate of transfer of fish parasites and pathogenic factors increases and fisheries economy suffers. Emigration Iran via the border of East and South East (especially from Afghanistan country) affect the epidemiology of food-borne parasites. For example, surgical Cases of Hydatidosis are high in Afghans who are living in Iran, but Source of infection and transmission mechanism has not been studied yet. Although Gastro-intestinal helminthes-parasites have decreased in human and ruminants but must be wide-awake about emerging parasites which are resistance to heat temperature and anti- helminthes drugs [38]. With the current available evidence and scenarios for climate change in Iran, it would appear that the public health effects of climate change especially on parasitic infections that need to be intensively studied. A comprehensive study contain detailed estimations of food-borne parasites are still lacking for Iran. Study on forecasting model of spreading of food-borne parasites can provide useful solutions for their control and preventions as well provide food security for the human society.

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The Effect of Climate Change on Veterinary Infectious Diseases

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Abstract

More than 500 arboviruses are known, of which some 40 cause disease in domestic animals and many of the same cause zoonotic disease. Climate change plays an important role in the seasonal pattern or temporal distribution of diseases result from arboviruses that are carried and transmitted through vectors because the vector animals often thrive in particular climate conditions. Because of climate changes and their influence on population of vectors, we conquer with new-emergence or re-emergence diseases in the countries that had no history of these diseases. Lumpy skin disease (LSD) is one of the new-emergence diseases that had no probability of introduce into Iran. It at first occurred in Iran in 2014 in a village of Kordestan province, close to the Iraq border. The affected epidemiological unit was visited by state veterinarians and skin tissue samples were collected and submitted to laboratory. The diagnostic test used was Restriction Fragment Length Polymorphism-PCR (RFLP-PCR). Control measures such as control of arthropods, quarantine, movement control inside the country, screening, zoning, vaccination in response to the outbreak, disinfection of infected and no treatment of affected animals were applied for control of LSD. It is necessary to determine why this exotic virus introduced into, spread and probably persistence in these regions.

***Keywords:* Climate Change, Veterinary, Infectious Diseases, Lumpy Skin Disease, Iran**

1. INTRODUCTION

Recent events, such as the introduction, rapid spread and permanent residence of West Nile Virus (WNV) in the Americas, and or the emergence, spread and continuing transmission of Bluetongue virus in northern Europe, provide a number of examples for unexpected spread of certain mosquito borne viruses to area where they have never been recorded before and where efficient transmission cycles have been considered unlikely in the past. However, a number of factors in the globalized world, such as increasing and rapid transportation of people, animals, plants and goods favor the worldwide spread of pathogen and their vectors. The first effects of global climate changes enable certain vector species to conquer regions previously unsuitable to them [1]. Climate exerts powerful effects on the distribution and abundance of the earth's insect species, and we should expect climate warming to generate changes for many insect populations and the ecosystems they inhabit [2].

Climate variability’s effect on infectious diseases is determined largely by the unique transmission cycle of each pathogen. Transmission cycles that require a vector or non-human host are more susceptible to external environmental influences than those diseases which include only the pathogen and human. Important environmental factors include temperature, precipitation and humidity. Several possible transmission components include pathogen (viral, bacterial, etc.), vector (mosquito, snail, etc.), non-biological physical vehicle (water, soil, etc.), non-human reservoir (mice, deer, etc.) and human host.

Important properties in the transmission of vector-borne diseases include:

1. Survival and reproduction rate of the vector
2. Time of year and level of vector activity, specifically the biting rate
3. Rate of development and reproduction of the pathogen within the vector.

Vectors, pathogens, and hosts each survive and reproduce within certain optimal climatic conditions and changes in these conditions can modify greatl y these properties of disease transmission. The most influential climatic factors for vector-borne diseases include temperature and precipitation but sea level elevation, wind, and daylight duration are additional important considerations [3].

Climate change plays an important role in the seasonal pattern or temporal distribution of diseases result from arboviruses that are carried and transmitted through vectors because the vector animals often thrive in particular climate conditions. Because of climate changes and their influence on population of vectors, we conquer with new-emergence or re-emergence diseases in the countries that had no history of these diseases. Lumpy skin disease (LSD) as a vector-born viral disease is one of the new-emergence disease that had no probability of introduce into Iran. It at first occurred in Iran in 2014 in a village of Kordestan province, close to the Iraq border.

The aim of this paper is to evaluate the outbreak of LSD in Iran. At first the methods of virus transmission especially effect of climate change on virus transmission and then various aspect of LSD will be explained.

2. VIRUS TRANSMISSION

Virus survives in nature only if they can be transmitted from one host to another, whether of the same or another species. Virus transmission may be horizontal or vertical. Vertical transmission describes transmission from dam to offspring. However, most transmission is horizontal – that is between animals within the population at risk, and can occur via direct contact, indirect contact, or a common vehicle, or may be airborne, vector-borne (arthropod-borne), or iatrogenic. Some viruses are transmitted in nature via several modes, others exclusively via a single mode [4].

2.1. Arthropod-Borne Virus Transmission Pattern

More than 500 arboviruses are known, of which some 40 cause disease in domestic animals and many of the same cause zoonotic disease. Sometimes arthropod transmission may be mechanical, in which mosquitoes act as “flying –needle” more commonly, transmission involves replication of the virus in the arthropod vector, which may be a tick, a mosquito, a sandfly (*phlebotomus* spp.), or a midge (*Culicoides* SPP) [4].

2.2. Effect of Climate Change on Virus Transmission

Many human activities disturb the natural ecology and hence the natural arboviruses life cycles, and has been incriminated in the geographic spread or increased prevalence of the diseases caused by these viruses. Climate change, affecting sea level, estuarine wetlands, fresh water swaps, and human habitation pattern may be affecting vector-virus relationship through at the tropics, however, definitive data are lacking and many programs to study the effect of global warming on emergence of infectious disease have failed to adequately address the potential importance of other environmental and anthropogenic factors in the process. In general, vector borne disease is also related to climate change, that mosquito as a vector will significantly increase when the environment temperature increases. Many viral infections show pronounced seasonal variations in incidence. In temperature climates, arboviruses infections transmitted by mosquitoes or sandflies occur mainly during the months of late summer and early fall when vectors are most numerous and active. Infections transmitted by ticks occur most commonly during the spring and early summer months [4]. Warm and wet environments are excellent places for mosquitoes to breed. If those breeding mosquitoes happen to be a species that can transmit disease and if there is an infected population in the region, then the disease is more likely to spread in that area. Because they are sensitive to climate, the distribution and number of vectors is also affected by climate change. There is evidence that the geographic range of ticks and mosquitoes that carry disease has changed in response to climate change. While future climate change is expected to continue to alter the distribution of disease vectors, it is important to recognize that there are several other factors (such as changes in land use, population density, and human behavior) that can also change the distribution of disease vectors as well as the extent of infection.

3. EMERGING VIRAL DISEASES

An emerging viral disease is one that is newly recognized or newly evolved, or that has occurred previously but shows an increase in incidence or expansion in geographical, host or vector range. Constant changes in demographic, ecological, and anthropogenic factors ensure that new and recurring diseases will continue to emerge, but virological and host determinants also contribute to the emergence of some viral diseases, and the emergence of new diseases in particular [4]. To understand the role of environmental changes in disease emergence requires an integration of diverse branches of biology such as ecology, wildlife biology, conservation biology, invasion biology, wildlife veterinary medicine and microbiology into current studies of human and domestic animal disease emergence [5].

4. LUMPY SKIN DISEASE (LSD)

4.1. Etiology

Lumpy skin disease (LSD) is a severe, systemic disease of cattle associated with the Neething poxvirus, a Capripox virus. It has close antigenic relationship to sheep pox and goat pox viruses which are close in the same genus. There appears to be a difference in virulence between strains [6]. 1 New outbreaks of LSD in previously free regions require immediate notification under the Terrestrial Animal Health Code of the World Organization for Animal Health (OIE) [7].

Some field outbreaks are associated with severe and generalized infections and a high mortality, while with others there are few obviously affected animals and no deaths but in generals outbreaks are more sever with the initial introduction of the infection to a region and then abate, probably associated with the development of widespread immunity. Morbidity rates reach 80% during epizootics, but are nearer 20% in enzootic areas. [6, 2].The morbidity rate depend on the: i) distribution and abundance of insect vectors; ii) breed of cattle affected; and iii) general health and nutritional status of the animals in question. Occasional mortality rates from 10 to beyond 40 percent have been reported, but the rate of 1 to 5 percent is considered more usual. The mortality rate is low, but the economic loss is high. In all cattle there is severe loss of milk production and the occurrence of secondary mastitis predisposed by the development of lesions on the teats. Loss also occurs from damage to hides, the loss of bodily condition during the course of disease, and the loss of fertility in affected bulls [6,7,8]

4.2. Epidemiology

LSD was first reported in Africa, where it crippled the production potential of cattle and compromised vulnerable livelihoods on the continent. LSD moved beyond Africa in 1989 when Israel confirmed its first LSD outbreak. In subsequent years Bahrain, Kuwait, Oman, Yemen and the West Bank also reported LSD incursion. Lebanon, Jordan and Turkey joined LSD affected countries in 2012 and 2013 [7]. Iran also joined to LSD affected countries in 2014. The first affected cow was detected during routine FMD vaccination in the village Kokh-Bashovan, city of Baneh, province of Kordestan, close to the Iraq border. The vaccination team reported abnormal skin problems in a native dairy cow. Following this report, the affected epidemiological unit was visited by state veterinarians and skin tissue samples were collected and submitted to RAZI Vaccine & Serum Research Institute (OIE Reference Laboratory for sheep pox and goat pox). The diagnostic test used was Restriction Fragment Length Polymorphism-PCR (RFLP-PCR). Following the laboratory confirmation all affected animals destroyed. After the first occurrence of LSD, although control measures were applied, but unfortunately the disease distributed to another regions such as Kermanshah, Hamadan, West Azerbaijan, Ilam, Khouzestan and etc. [9]. The morbidity rate was 12.30%. For example, from September to October 2014, 191 cattle were referred to the hospital of faculty of veterinary medicine, Shahid Chamran university of Ahvaz, 85 (45%) had clinical signs related to LSD.

Cattle can be infected by drinking water, but ingestion and direct contact transmission are not common routes, even though the virus is present in nasal and lacrimal secretions, semen, and milk of infected animals. Most cases are believed to result from transmission by an arthropod vector. Historically, LSD virus has been isolated from *Stomaxys calcitrans*, and *Musca confiscata* and transmitted experimentally using *Stomaxys calcitrans* but other vectors are also suspect including *Biomyia*, *Culicoides*, *Glossina*, *Aedesaegypti* and *Musca* spp. [6,10]. Mosquitoes that had fed upon lesions of LSDV-infected cattle were able to transmit virus to susceptible cattle over a period of 2-6 days post-infective feeding [1]. All ages and types of cattle are susceptible to the causative virus, except animals recently recovered from and attack, in which case there is a solid immunity lasting for about 3 months. In outbreaks, very young calves, lactating and malnourished cattle develop more severe clinical disease [6].

Extensive epizootics of LSD have been associated with periods of high rainfall and concomitant high levels of insect activity. The disease is reported to occur throughout mild winters into the following summers, with a peak of activity during late summer/autumn. These observations are consistent with the ideal requirements for the rapid increase of the putative insect vector populations [11].

4.3. Pathogenesis

In the generalized disease there is viremia accompanied by a febrile reaction, and localization in the skin occurs with development of inflammatory nodules [6].

4.4.   Clinical Findings

An incubation period of 2-4 weeks is common in field out breaks and 7-14 days following experimental challenge. In an outbreak, all ages and breeds and both sex may be infected. In severe cases there is an initial rise of temperature(40.5C°), which lasts for over a week [7-12 days), sometimes accompanied by lacrimation, nasal discharge, salivation, and lameness. Multiple nodules appear suddenly about a week later, although the first ones usually appearing in the perineum but cover whole animal body. They are round and firm, varying from 1 to 4 cm in diameter, and are flattened and the hair on them stands on end (Fig. 1). They vary in number from a few to hundreds; they are intradermal and, in most cases, are confined to the skin area (Fig. 2).

Figure 1: Multiple Nodules of LSD in cattle

Figure 2: Multiple Nodules of LSD in cattle

Other manifestations that may be observed in severe cases include lesions in the nostrils and on the turbinates, causing mocopurulent nasal discharge, respiratory obstruction and snoring, plaques, later ulcers, in the month causing salivation; nodules on the conjunctivae (Fig. 3), causing severe lacrimation, and on the prepuce or vulva, and spreading to nearby mucosal surfaces.

Figure 3: Nodules of LSD on the conjunctivae in a calf

Keratitis (unilateral or bilateral) may present. The limbs may become grossly distended with edema fluid. Lymph node draining the affected area become enlarged and cause local edema (fig 4) [6,8].

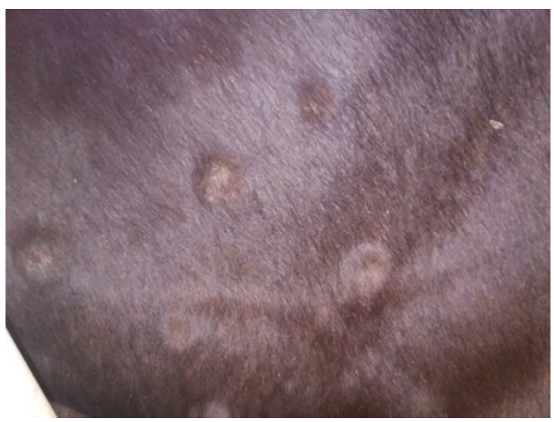

Figure 4: Edema and enlargement of prescapular lymph node in a cattle affected LSD

The skin lesions provide an excellent point of entry for screw worms. Pneumonia is a common sequel in cases where lesions occur in the respiratory tract. A convalescence of 4-12 weeks in usual. Pregnant cows may abort [6,11].

LSD should be differentiated from Allerton (herpes) virus infection, which also causes skin nodules, so-called false, or pseudo lumpy skin disease. Pseudo lumpy skin disease is characterized by a less prominent, flat skin lesion, which resolves rapidly and is accompanied by a mild transient fever [11].

4.5. Treatment

No specific treatment is available, but prevention to secondary infection is essential. The use of antibiotics of sulfonamides is recommended [6].

4.6. Control

Lumpy skin disease moves into new territory principally by means of the movement of infected cattle or possibly by wind-borne vectors. In the new territory further spread is accepted as being via an insect vector. Control of cattle movement from uninfected territory is an important control measure. Further control can only be by vaccination [6].

5. CONCLUSION

The occurrence of LSD in Israel, Lebanon, Jordan, the West Bank, and Turkey and most recently in Iraq and Iran indicates the potential for further spread of this emerging disease to other countries in the region and beyond where the cattle population is susceptible. It is necessary to determine why the agent of this disease as an exotic virus introduced into, spread and probably persistence in these regions.

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Climate Change and Drought Adverse Effects on Iranian Food Security and Food Safety

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Abstract

Iran has experienced its driest years during the past 15 years, compared with several decades before. Iran is located in semiarid and arid region and receives average rainfall of 250 mm per year. The coefficient of variation varies from 75% in the southeast to 18% in the north. Average precipitation of some central and eastern parts of the country has been about 100mm in recent years. Therefore many parts of Iran suffer from water shortage. People who live in these regions are facing a serious economic crisis. Lower food material production and income of small family farmers (which is dominant in dry regions) lead to social problems, migration of people and difficulties such as uncertainty of food security and food safety. The relative importance of climate change for food security differs according to region in Iran. It affects social and environmental determinants of safe drinking water, sufficient and safety of food related to irrigation of some small farms with polluted water, pesticide residue in most products which is due to the excessive use of pesticides against insects and plant diseases which are more serious problem during drought periods and consequently on human health. The main objective of this paper is to provide brief information on drought and climate changes in Iran and its adverse effects on food safety and security and some key points which could help to improve planning and decision making involved in the regions which suffer from water shortage, food safety and food security hazards.

Keywords: Climate Change, Drought, Food Safety, Food Security

1. INTRODUCTION

Iran is among the countries having diverse climatic zones and is located in the arid desert belt of the world [1]. About 64% of the country's area is arid, 20% semi-arid, 4.9% Mediterranean, 3.4% semi-humid, 3.6% humid, 4.1% very humid [2]. The average annual daily temperature in different regions of the country ranges between zero °C at altitudes above 3,000 meters above sea level in Azerbaijan province and 27°C on the southern low plains. In winter in the highlands, the temperature falls down to -30°C and during summer in some parts of Iran, it rises above 50°C. The population of Iran is about 75 million at this time. More than 82% of Iran's territory faces shortages of water and the challenges caused by drought in its different regions [2]. The geographic location of Iran in the Middle East and Annual Precipitation Map of Iran is shown in Fig. 1 [3]. Iran has experienced a warmer air temperature since 1998. This has resulted in severe droughts, floods and strong winds [1]. Continuation of decrease in rainfall is the main reason for drought in 18 of 30 provinces of Iran [4]. Rising temperature and variable precipitation are likely to decrease the production of staple foods in many of the poorest regions [5]. This will increase the prevalence of malnutrition and under nutrition, which currently cause more epidemics and non-epidemic diseases. A lack of safe water can compromise hygiene and increase the risk of diarrheal disease, strongly affect water-borne diseases and diseases transmitted by insects. High air temperatures contribute to deaths from respiratory and cardiovascular disease, particularly among infants and elderly people. People may be forced to migrate, which in turn heightens the risk of health effects, from mental disorders to communicable diseases.

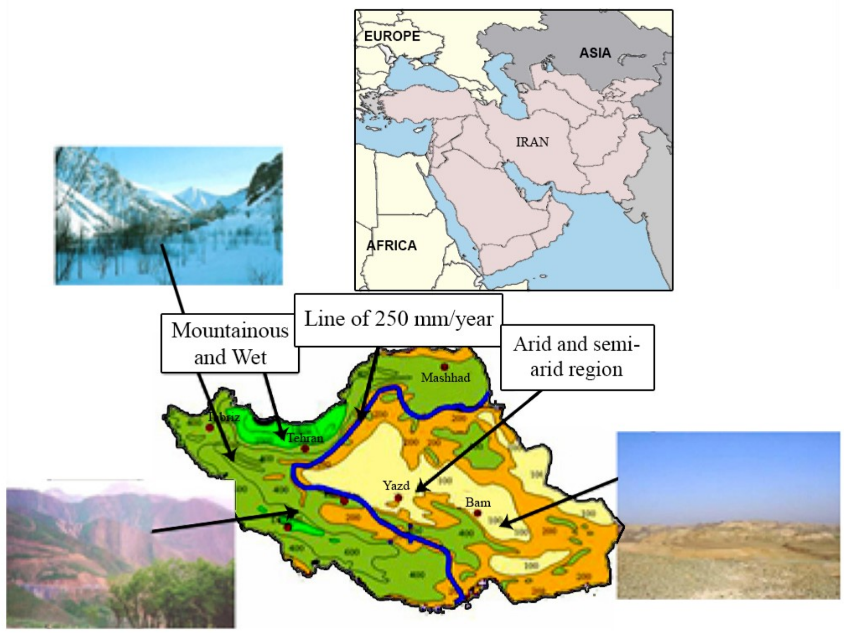

Figure 1: Geographic Location of Iran in the Middle East and Annual Precipitation Map of Iran [3]

Oil income has brought about unbalanced development of the Iranian society with respect to its natural ecological potential. The main problems include: ever-increasing limitation of national water resources such as surface and subsurface waters, waters pollution, frequent floods and the resultant losses of life and property, topsoil erosion and loss of natural resources, gradual migration of people from villages close to central deserts, and south and south eastern parts due to water shortage, and decreasing water availability for crop cultivation. The main problem is drought and ignoring the optimal use of water, especially for agriculture production. Despite the efforts made for creating a feasible situation for natural resources and environment of the country during the last years, there is still a long way to create desirable condition**.** The main objective of this paper is to provide brief information on drought and climate changes in Iran and its adverse effects on food safety and security and some key points which could help to improve planning and decision making involved in the regions which suffer from water shortage, food safety and food security hazards.

1.1. Surface Water Resources

The annual average precipitation is about 427 billion m^3. Of this, however 297 billion m^3 evaporate, 38 billion m^3 permeate into underground water tables, leaving only 92 billion m^3 available as surface running water. About 25 billion m³ are directly used to recharge underground water tables and another 13 billion m³ run into those tables through underground currents out of the 427 billion m³ of precipitation. This renders the total amount of renewable water supplies as much as 130 billion m³ (30.4% of the total precipitation) [6]. Large numbers of lagoons and wetlands have dried or are going to dry in different provinces of country. Gavkhooni and Hamoon are examples of dried wetlands and lagoons [1]. Prediction of rainfall change during the period of 2010 to 2039 is shown in Fig. 2. [7]. Based on average data of drought of recent years, out of 30 river basins of Iran, 5 are in critical, 11 are in water shortage and 8 are in water tension conditions [8].

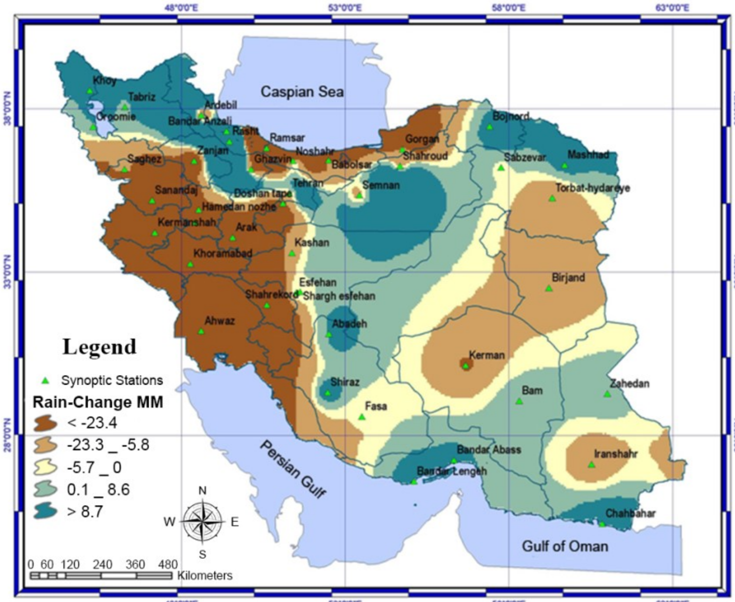

Figure 2: Prediction of rainfall change during the period of 2010 – 2039 (Model LARS-W) [7]

1.2. Groundwater Resources

Well technology was introduced to Iran around 1950 and was very badly adapted. Very soon Qantas were replaced by well pumps. There were more than 70,000 chain-wells of Qantas operational before that time. But now not more than 20,000 effective Qantas are left with a very little discharge. Today, not only most of the Qantas of Iran are dried up but water tables have also been lowering very fast. The results of this inappropriate pumping of water from water tables are visually seen all over the area. Land subsidence has created gullies on the lands, deep sink holes, and cracks on the roads and buildings in central and south-east of Iran. Rising up of the pipes of pumping plants is also a common phenomenon [1]. Considering the groundwater balance in different parts, discharge rate is 63.691 billion m³, and recharge rate is about 58.631 billion m³ so over 5 billion m³ of water is overdrawn per year from aquifers of arid and semi-arid regions. Ground water harvest of Iran (2014) is shown in Table 1 [7]. Excessive withdrawal of groundwater resources cause many environmental problems, including groundwater salinity, drying of springs, water shortage in villages around the center plateau and south, and south eastern regions of Iran. Migration of rural people to cities and other provinces is usual in the dry parts of Iran [9]. Population and water available per capita of Iran during period of 1935 to 2025 is shown in Fig. 3. [3]. The main objective of this paper is to provide brief information on drought and climate changes in Iran and its adverse effects on food security and safety and some key points which could help to improve planning and decision making involved in the regions which suffer from water shortage, food safety and food security hazards.

TABLE 1: GROUND WATER HARVEST OF IRAN (2014)

Maximum allowable harvest	50 billion cubic meters
current harvest	61 billion cubic meters
Negative balance of	11 illion cubic

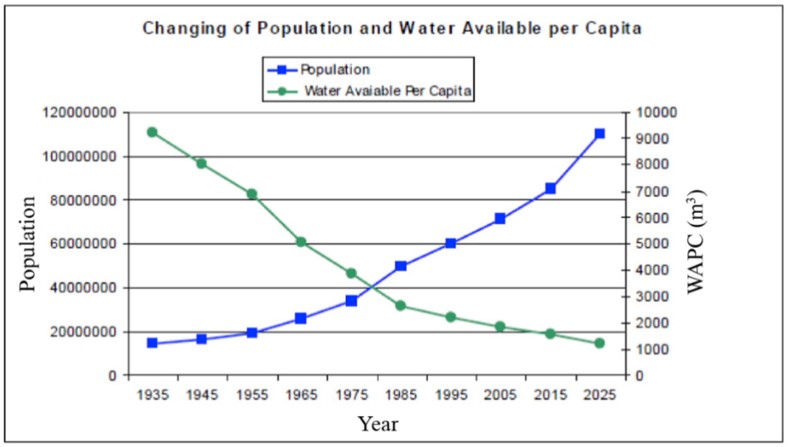

Figure 3: Population and water available per capita of Iran during period of 1935 to 2025 [3]

1.3. Water Resources Quality

Due to lack of attention to household sewage and industrial effluents, an excess amount of chemical fertilizers, herbicides, and pesticides are used in agriculture; the surface waters (most rivers) and some ground waters in some areas are polluted with chemicals [10]. According to studies conducted in 2002, industrial workshops in the Northern provinces produced 15,747 million m^3 of sewage. About 29.9% of the workshops discharged their sewage into rivers. According to research statistics from 2002, industries located on the Caspian Sea coastline discharged 28,200 tons of BOD, 600 tons of nitrates, 210 tons of phosphorus and 12,500 tons of fat oil into the Sea [2]. About 241,000 tons of chemical fertilizers, especially ammonium compounds, are used on the southern coasts of the Caspian Sea [2]. The agricultural run-off is discharged into the rivers, carrying with it some of the fertilizers that pollute the water.

Zayandeh Rood located in Isfahan province is polluted during several months of the year that have water flow and its contamination is more than usual conditions due to water shortage. Its water is used for irrigation of agricultural products located on the two sides of this river [2]. Low water flow of different rivers such as Sefidrud (in north), Zayandehrud in central , Kor (near Shiraz city), Karoon in south, Karaj River near Tehran during the summer will cause more concentrated pollution of river waters and have more adverse effects on the environment and the agricultural products irrigated with the water and consequently on peoples health. Tehran's ground water is polluted with nitrate compounds. This water is used as municipal water. The lack of water causes the use of wells with higher nitrate concentrations as Tehran municipal water. The concentration of nitrate in 10 water samples of municipal water of Tehran was measured by newsletter scientific group on 25 November 2014. The nitrate concentration of four samples was about 50 milligrams per liter (WHO standards for nitrate and nitrite in drinking water are 50 and 3 mg per liter, and the standard for nitrate nitrogen and nitrite nitrogen is 11 and 0.9 mg per liter respectively) and for one of the samples was 51.8 milligram per liter which is higher than the standard level [11]. Recently, both Persian Gulf and Gulf of Oman are experiencing several types of pollution including oil spills and heavy metal pollution as well as Harmful Algal Blooms (HAB) caused by biological and environmental changes [12].

1.4. Heavy Metal Contamination of Some Irrigation Waters

Industrial development is increasingly causing the contamination of soil, rivers and air with heavy metals such as cadmium, lead, and mercury. These chemical contaminants can eventually enter the human food chain, with potential harmful effects on food safety and consumer health. Agriculture products of some lands that have shortage of water are irrigated with river water contaminated with heavy metals or improperly treated sewage [10]. The Zayandeh Rood (the river in Isfahan) is contaminated with heavy metals and toxic substances; water from this river is used for the irrigation of orchards and crops [13]. Similarly, sewage not completely treated from Tehran city which drains to the southern part of the city is used for growing vegetables [10]. This kind of irrigation of crop products with polluted water increases during shortage of water in different parts of the country.

2. AIR POLLUTION

Iran energy consumption increased by 5.1% in 2004 over the previous year and reached 725.1 million barrels of oil. All the different fossil fuels types were increasingly consumed in 2004. This figure is 1,052 million barrels of crude oil equivalent in 2007 [14]. It shows that there is 45 percent increase in energy consumption within 4 years. Increasing energy consumption increases air pollutants in cities. Air quality was obtained from the data of 11 air quality-monitoring stations in 2004 and 2005. There were 200 healthy and 165 unhealthy days, which mean that only 55% of days were healthy in 2004. There were 279 healthy and 87 unhealthy days, meaning that only 76.9% healthy days in 2004 [2]. Despite this fact the number of motor vehicles has increased daily in Tehran over recent years. This kind of pollution in cities and beside roads has adverse effect on safety of farm products around the roads.

Dust risen from factories such as gypsum and cement, land without coverage, lands with destruction soil structure due to the lack of enough rainfall are also an important source of pollution for cities, environment and people health [1]. Nowadays, two important sources of dust air pollutants are the southwestern and western winds from Saudi Arabia, Syria and Iraq countries. This kind of pollution is so severe that it causes the close down of activities in some cities in the southwest and south of the country. The intensity of the dust is to such an extent in the early days as to have canceled domestic air flights [15].

3. FLOOD OCCURRENCE

Studies show that the occurrence of floods in the past 50 years has been regularly increasing every year to create high criminal and financial conditions. It washes top fertile soils and carries sediments to dam lakes and the Sea, and destroys high volumes of forests and farms. Reasons for increasing floods can be due to deforesting, degraded pastures and loss of land vegetation, construction of structures in river paths and inappropriate riverside places, lack of attention to flood prevention knowledge and drought. Among natural disasters, floods and storms have the biggest losses and destructive damages in today's society. In just a decade, the amount of damages from flood and storm was over 1,705 thousand dollars versus 1,462 thousand dollars of damage caused by earthquake [8].

4. EFFECT OF CLIMATE CHANGE AND DROUGHT ON FOOD SECURITY OF IRAN

During the second half of the twentieth century, the great drought phenomenon caused the loss of agricultural production in Iran. Assessment of drought impacts on social – economical situation of wheat-producers of Nehbandan County was investigated by H. Alipour et al. [16]. The statistical population of this research included all wheat-producers households in Nehbandan County (3,817 Households). The results of factor analysis of economical impacts of drought showed that these impacts can classify into 5 categories, namely increasing production costs, reduction of wheat production and economic ability of farmers [16]. Decreasing farm productivity may cause farmers to exit the agriculture sector [17]. Social impacts of drought showed that the drought and climate change impacts can be classified into five categories, namely, increasing social challenges, decreasing the level of Hygiene and tuition, mental impacts of drought, social involvements and creating poverty in society. And the solutions can be classified into five categories, namely, extension of appropriate farming operations, education of farming management options, encouraging farmers to defend with drought, education and empowerments of farmers and establishment of data base of drought. Drought stress is an abiotic factor affecting growth and yields of crop plants and one of the most important limiting factors for productivity in Iran [16].

5. CLIMATE CHANGE AND DROUGHT ADVERSE EFFECTS ON FOOD SAFETY

Although there are not enough studies that specifically show that there is a relationship between waterborne disease incidence and drought or projection of changes in disease incidence with drier conditions in Iran, it is accepted that decreases in water supply could cause more pressures on limited sources of water. More limited water sources that have variety of influences, including increased water use for multiple purposes and the contribution of wastewater (treated or untreated) to the total water volume could potentially increase concentrations of pathogens [18].

Climate change and drought could influence food safety hazards at different stages of the food chain, from farm to table. There are multiple pathways through which the factors related to climate might impact food safety. Climate change might also affect socio-economic aspects that are related to food systems such as plant and animal production, global trade, human behavior and demographics which all influence food safety. The investigators make this conclusion that it is required for intersect oral and international cooperation to understand the situation of the changing food safety and there is also a need in developing and applying adaptation strategies to address emerging risks related to climate change [19]. Quality and quantity of water have important effects on diarrheal diseases, food, and poor sanitation waterborne pathogens. In 2004, 1.8 million deaths (4 million cases) happened due to gastroenteritis. Eighty eight percent of them were due to poor sanitation and unsafe water [20].

Consumption of contaminated water causes gastroenteritis. Insufficient treatment of water for taps, irrigation and agricultural products washing could be the main sources of the problem. Several studies have noted that increased pathogen loads related to heavy precipitation, run-off and floods include enteric viruses (e.g., enteroviruses, noroviruses, adenoviruses) Protozoan parasites (e.g., *Cryptosporidium*, *Giardia*, etc.), Enteric bacteria (e.g., *Salmonella*, *Campylobacter*, *E. coli*, and fecal indicator bacteria) [20]. Climate change and temperature rise influence the insect populations therefore more plant protection is necessary [21].

Currently, approximately 2.5 million tons of pesticides are used globally every year. Almost 89% of the pesticides are applied in developed countries. The scope for pesticide application is, however, gradually increasing in developing nations and the incidence of toxicosis has been reported to be 13 times higher in developing countries, than they are in developed countries [2]. In Iran, chemical control is more widely applied than biological control. Nearly 25,000 tons of pesticides are applied on an annual basis in Iran. Droughts and water shortage have caused insect outbreaks to increase. They result in overuse of pesticides, insecticides and fungicides in farms and vegetable production greenhouses due to lack of farmers' knowledge of safe methods for pests and fungi control in agricultural production applications. Thiomethon, which is not permitted, and Methalaxile (Ridomethyle®) are, respectively, used as cucumber pesticide and fungicide in greenhouses. Mossaffa [22] investigated the dissociation of these pesticides on cucumbers and indicated that more than two weeks are required for these pesticides to reach a permitted level of 0.5 mg of pesticide per kg of fruit. Unfortunately, some producers sell their products prior to this two-week period. It has however been shown that exposure to pesticides can cause genetic mutations and have a carcinogenic impact [22]. Pesticides are indispensable in controlling pest damage and in increasing production yields. However, one of the main concerns is the need to train farmers in the correct and safe handling of pesticides to produce safe products containing pesticide residue below the maximum residue limits (MRL) [10].

6. Strategies and Recommendations for Reducing the Effect of Climate Change and Drought Mitigation on Food Security and Food Safety

There is enough evidence to support that waterborne diseases increase under projected climate change scenarios. It is important to collect basic surveillance data on the diseases that are sensitive to climate. It is also important to improve understanding of the mechanisms by which climate change and drought influence the pathogens that affect human life, especially those which are effective on food safety [23].

Mitigation and adaptation will be enhanced by understanding the ecology of pathogens. Therefore, the underlying factors that provide the link to climate should be clarified and the mechanism through which changing landscapes affects disease incidence under changing climate conditions is needed to be studied. The effects of climate change on water and food borne diseases can be mitigated by focusing on public health response and basic infrastructure as well as paying more attention to treatment options. There are enough tools to address the problems and prevent the diseases by understanding how climate may increase diseases in societies. These measures followed by the same sound practices that the public health community always uses to prevent diseases including awareness of vulnerabilities, investments in the upkeep and development of infrastructure to ensure clean water, and focused attention on best management practices for treatment of water. Since trends suggest, the risk to human health due to water stress and water and food borne disease is correlated with attention and investment in sound sanitation practices and education of the public and it will go a long way in mitigating these risks [18].

Countries should review/develop their own food safety emergency plans as well as review and update other disaster/emergency plans to ensure adequate consideration of food safety management and veterinary public health issues in any emergency situation. Developing and ensuring the capacity to implement such plans may require investment in training human resources and in facilities [19]. Allocation rules under both normal and drought conditions should be understood and accepted by farmers- water users and a more accurate selection of crops is necessary based on the water capacity. Under water-short conditions, allocation decisions should be made at basin and system levels instead of local distribution system levels. To make the systems less sensitive and vulnerable to drought, changes in the catchment area has to be taken into consideration for irrigation planning. Up-to-date data should be used to capture those changes in the watershed and climate changes related to development. Early warning systems that monitor condition changes and trigger contingency plans when the first sign of water shortage detected offer water managers and farmers the best chance of avoiding crop failure. Some techniques for saving water such as, precision irrigation, zero tillage, raised bed planting, and laser leveling of fields can help farmers to improve the water productivity [24]. For drought plain countries like Iran, micro-insurance or crop insurance strategies are recommended for risk management. There are several unpredictable factors out of farmers' control. Accordingly, insurance plays an important role in agricultural production [25].

7. RECOMMENDATIONS

Following are recommended subjects that could reduce the adverse effects of climate change on food security and food safety:

There should be a reduction of the factors affecting environmental global warming and climate change and occurrence of long and continuous drought,. for example, to reduce carbon dioxide emissions. A strong management of natural and environmental resources such as water and energy, using sustainable resource planning, and reduction of energy consumption and environmental pollution and increasing energy consumption efficiency is required. Resolution of economic problems of people who work in connection with pasture, forest and water resources, and contrasting the economic interests of individuals and community groups with environmental values, especially water resources should be considered. It is also important to promote environmental knowledge of society using proper training methods in primary and secondary schools, high schools, universities, and through national mass media especially radio and television, and NGOs. For example, a course of environmental importance and protection should be included in university teaching programs and the main content of this course should be the environmental values and natural resource protection and the methods of social, economical, and constructional activities without environmental damage. Country laws and regulations should be evaluated and their destructive effects on environment and water and energy resources should be assessed to reform them to be helpful to sustainability, and to prepare strong regulations and executive protocols within the framework of the existing environmental laws by emphasizing on water and energy consumption. There should be a serious implementation of international environmental treaties between environmental institutes and organizations. Population control is one of the important subjects, the unbalanced population growth with ecosystems potential has imposed a great pressure on environmental resources. The activity of environmental NGOs and comprehensive sections of the people among them should be encouraged by involving all people from school children to senior citizens with an effective program planning organization. The economic structure, rules and regulations should be changed to an environmentally friendly economy, encouraging the green technologies by decreasing taxes, subsiding environmental friendly energies to decrease fossil fuels consumption and provide conditions that reduce air pollution, and gradual reduction of subsidies of environmental destructive products such as fossil fuel and fertilizers, and harmful chemicals such as pesticides. Farmers should be encouraged to produce healthy and organic food products. A special water resources planning program in countries having dry and semidry climates should be used and the withdrawal of groundwater and surface water resources should be managed to have a balanced charge, and better governmental policies and control on water systems and water consumption and water price for a better control of water resources should be established. The activities against the environment should be condemned and considered as a low level cultural action to improve the environmental culture of society. Soils, rivers, sea and underground waters should be protected by increasing the costs of dumping pollutant materials to air, water resources and soils, gradually and inhibiting it ultimately. A particular attention should be made to environmental impact of various infrastructure development projects like roads, towns, airports, factories, etc. A strong council with expertise in environmental departments should be established to guide the decision makers on the subjects related to soil, water and energy. Academies should take efforts to guide policy makers, authorities, community managers, schools, universities, and mass media for continuous improvement of culture toward serious environmental problems of societies. Optimal water use and water conservation technologies should be used in industries, homes and agriculture, and recycling of water and using of treated water for landscape and parks and preventing of using polluted water for production of food products should be educated. It could be useful to select proper type and varieties of agricultural production based on the water demand in each province and to produce plant varieties with more tolerance to drought. Planning to improve the techniques with higher efficiency water desalination plants is one of the important subjects. Planning to upgrade the national food safety program which harmonize the functions of the research and administrative sectors, extension councils and farmers along with educational programs for the training of farmers in the efficient and safe use of pesticides is essential (governments, organizations and related bodies will play a vital role in achieving this subject).

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The Effects of Droughts on Food Safety

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Abstract

Droughts are projected to be more frequent and intense over the next decades, and may pose a threat to human health. Of potential concern to human health is the increase in food contamination by food safety hazards which can occur at various points in the food chain. This review was therefore conducted to investigate the potential effects of drought on emerging food safety hazards. Water scarcity and atmospheric dust are the most important drought-related factors that present a number of challenges for effective food safety. A lower water quantity and quality along with waste-water reused may exert both direct and indirect impacts on human health through their influence on crops, food animals and marine products and also poor hygienic practices. Malnutrition and more intensive farming are the main factors contribute to increase the incidence and prevalence of the infectious diseases in farm animals which may finally affect human health. Besides, drought stress can increase the susceptibility of plants to contaminate by mycotoxigenic fungi which have also some health consequences. The chemical, biological and radioactive components of drought-related dust storms may contaminate water resources and pastures which in turn threat human health. Reduced photosynthesis due to the settlement of dusts on the leaves, a considerable rise in radiation and global warming will deteriorate the situation. Low availability and increased prices of food and feeds increase the use of decomposed and contaminated ingredients in feed and foodstuffs. The development of algal blooms may be favored by both low water levels and dust storms.

Keywords: Drought, Dust Storm, Feed Safety, Food Safety, Water Scarcity

1. INTRODUCTION

A food safety hazard is defined as "any biological, chemical or physical properties that may make a food unsafe for human consumption". The transmission of such agents to foodstuffs can occur at any point during growing, harvesting, storage, processing, packing, distribution or preparation. Microbiological hazards in food products including bacterial, viral and parasitic organisms originate from different sources such as air, food, water, soil, animals and the human body. Chemical hazards fall into two categories including naturally occurring chemicals such as mycotoxins and plant toxins, as well as poisonous chemicals or deleterious substances such as pesticides, heavy metals, radioactive material, antibiotics, food additives and cleaners which intentionally or unintentionally enter the foods. Physical hazards usually result from accidental contamination and/or poor food handling practices. Examples include slivers of glass, human hair, nails, metal fragments, bone chips and stones [1].

Among the multiple factors that can provoke changes in the nature and occurrence of food safety hazards, climate changes have attracted less attention and debate [2]. Climate events which are predicted to be more frequent and intense over the next decades [3,4] could exert both direct and indirect influences on food safety hazards [2]. Although just about 8% of global natural disasters are attributed to droughts [5], such extreme weather events are expected to increase by more than 100% in many parts of Asia in 2020s [6]. Drought can be categorized into meteorological drought (less precipitation than normal), hydrological drought (limited surface- and groundwater resources), agricultural drought (low soil moisture) and environmental drought (a combination of mentioned conditions) [7-9]. Contrary to the other natural hazards (such as a flash flood or earthquake), droughts are slow-onset, long duration and spatially diffuse emergency phenomena with multiple destructive impacts [7]. Drought outcomes include lack of water, pasture, energy and food; increased livestock and wildlife death rates; damage to wildlife and fish habitat; famine; less income, increased prices for food, hunger, unemployment, and migration [5,10]. While the potential effects of the conditions on food insecurity and poverty have been extensively addressed, much less has been published on the relationship between droughts and several aspects of human health. Deaths, malnutrition, infectious and respiratory diseases as well as chemical poisoning are several health consequences of drought [11]. Insufficient data, however, exist about how drought may affect food safety. Therefore, the aim of this review is to elucidate drought impacts on emerging food safety hazards.

2. Food Safety Implications

Drought-related food safety hazards predominantly arise from water scarcity, farming conditions and dust storm which will then affect plant, animal and human health through biological and chemical agents.

2.1. Water Availability and Quality

The water scarcity arising from drought coupled with an increasing trend in population growth and food demand could be a cause of special concern in the coming decades [7,9,12]. Regions, whose vulnerabilities are likely to be exacerbated by climate change, are highlighted in Fig. 1. Currently, 1.4 to 2.1 billion people are living in the areas suffering from severe water stress where a ratio of withdrawals to long-term average annual runoff is above 0.6 [9]

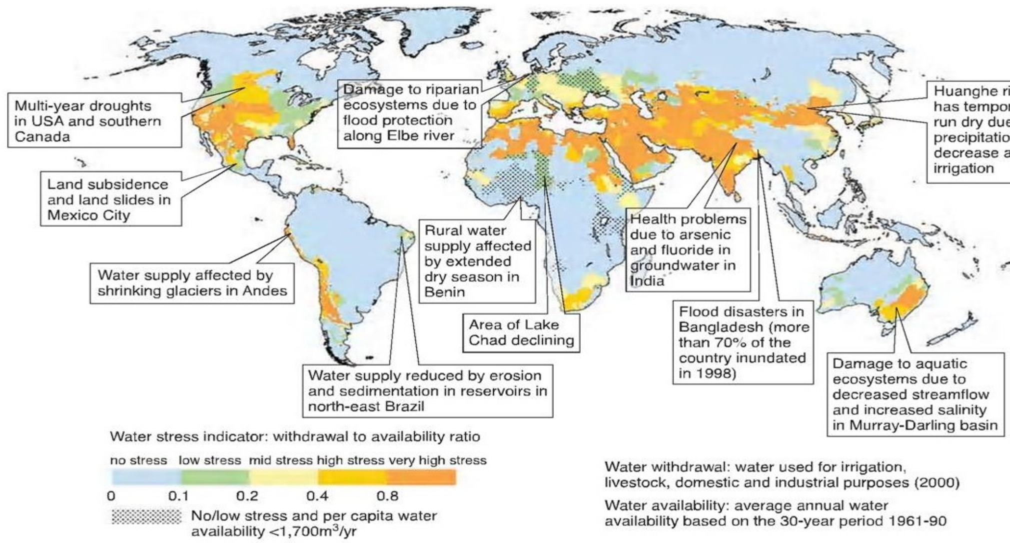

Figure 1: Examples of current vulnerabilities of freshwater resources and their management; in the background, a water stress map [9]

Drought has an effect not only on water quantity, but also on its quality, safety and thus incidence and prevalence of water-borne diseases, either by drinking it or by consuming water-treated foods [2,7,9,13]. On the other word, rain-fed agricultural production as well as water supply for domestic, industrial, livestock and irrigation purposes is affected by droughts which may, in turn, cause adverse health outcomes [9].

2.1.1. Poor hygienic practices

Poor sanitation including poor personal hygiene, due to reduced availability and quality of water, may give rise to the risk of infectious diseases [7,13-15]. Limited access to adequate and safe water may result in poor hygienic practices in food handling and processing operations, as well [13]. Water is essential for almost all stages of food animals slaughtering and processing. For instance, considerable amount of potable water is needed in different stages of poultry slaughtering including scalding, plucking, washing and chilling [16]. Reduced water availability and quality may have several consequences: 1) contaminant transmission from water to carcasses; 2) unacceptable reduction of microbial loads due to improper processing; and 3) increased cross-contamination among carcasses especially with bacteria of concern, such as *Salmonella* and *Campylobacter* [17-21]. Furthermore, plant hygiene and sanitation which are fundamental to control food safety hazards, can be adversely affected by water scarcity. In dairy farms, washing of the udder before milking is important to assure the quality and safety of milk and dairy products and also to prevent mastitis [22]; while the shortage in water supplies will reduce the hygienic situation.

2.1.2. The contamination of agricultural products

In general, decreased stream flow to rivers and lakes and also stagnant water conditions caused by drought will lead to greater concentration of dissolved chemical and biological pollutants including sediments, nutrients, organic carbon, pathogens, pesticides, toxic metals and salts [7,9,23]. On the other hand, under drought stress, plants and animals are physiologically more susceptible to infections [24,25] which in turn increase the use and consequently the residue of fertilizers, insecticides, fungicides and veterinary drugs in water resources [26]. Crop irrigation either by such resources or by untreated wastewater will eventually lead to agricultural products contamination [4,11,14]. In addition, using the contaminated crops to feed farm animals can indirectly contribute to human health problems. Application of nitrate fertilizers along with an inadequate plant growth as a result of drought can potentially lead to toxic concentrations of nitrates in the plant tissues; furthermore, nitrate/nitrite contamination of water can also occur. Nitrate poisoning of animals [27] and high exposure of humans to nitrosamines derived from nitrates are potential consequences of such conditions.

2.1.3. The contamination of marine products

As mentioned, due to the reduction in quality and safety of water resources, the chemical and biological contaminants may transfer to human by consumption of affected farmed and freshwater wild fish [23].

2.2. Farming Conditions

Malnutrition is a common cause of secondary immune deficiency and increased susceptibility to infection in farm animals. Under drought conditions, reduced availability of water and grazing pastures may result in malnutrition due to not enough consumption of feed and safe water or the use of poor quality forages or alternative feed sources. Metabolic diseases are consequences of prolonged nutrient deficiencies [25,27]. Moreover, herds may be forced to crowd near feed and water resources which could increase direct animal-to-animal contacts [28]. Overcrowding together with malnutrition, metabolic diseases and immune deficiency may increase the risk of infectious disease.

More intensive farming, as a measure to combat heat stress and feed/water shortage, may promote the spread of contagious diseases through increased direct contact between animals. The other farming management response to drought, movement of livestock to areas having better grasslands, may result in more contacts between herds and therefore the increased risk of infections. In the urban areas, close contact between the farm animals and humans has emerged the risk of zoonotic disease [29].

Obviously, both the quality and safety of animal-based food products is directly related to the feed safety and quality. Hence, the biological, chemical and the other etiologic agents in feed can pose potential risks to human health [30]. Increasing the price of crop and livestock products during drought periods [10,28] may lead to the use of low quality and decomposed ingredients not only in feed production, but also in foodstuffs. One particular facet of such frauds is the impact of these ingredients on food safety. The role of animal feed in food safety has been highlighted in relation to both *Salmonella*, in poultry, and bovine spongiform encephalopathy in cattle and more recently dioxins in animal feeds in Belgium [31].

2.3. Atmospheric Dust

Atmospheric or wind-borne dust comes from arid and dry regions where high velocity winds are able to remove mostly silt-sized material, deflating susceptible surfaces [32]. One-third of the global land area is covered by dust-producing surfaces, made up of hyper-arid regions like the Sahara which covers 0.9 billion hectares and dry-lands which occupy 5.2 billion hectares [33]. Dust storms are natural resources of high levels of airborne fine particulate matter with diameter smaller than 2.5 micrometers ($PM_{2.5}$). Chronic exposure to these particulates is associated with adverse human health impacts especially in regions where ambient concentrations exceed 10 μg/m^3. Over the 2001 to 2006 period, dust transport in the fine mode has contributed to large-scale $PM_{2.5}$ of approximately 20–50 μg/m^3 in some areas of the world especially in Middle East and North Africa (Fig. 2) [34].

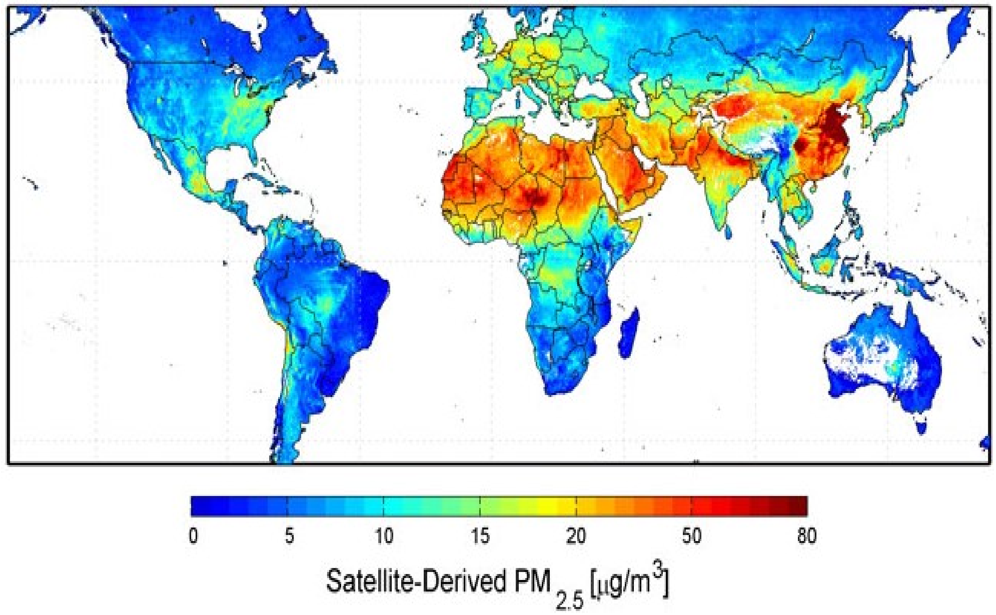

Figure 2: Global satellite-derived map of $PM_{2.5}$ averaged over 2001-2006 [35]

Droughts resulting in overgrazing and changing the land use may increase desertification and dust-producing surfaces [28,36,37]. Airborne dusts can produce strong local radiative forcing [32] which in turn makes the desertification process much worse. Dust particulates will settle on grasslands and subsequently reduce plant photosynthesis efficiency which may in turn lead to poor pastures.

The chemical, biological and radioactive contaminants of drought-related dust are more dependent on the region from which the dust originates [38,39]. Dust storm can transport these contaminants far from the vicinity of source [40,41] which will then contaminate soils, water and food sources [39,42].

To date, different species of fungi and bacteria including fecal-oral pathogens, that infect plant and animals, have been isolated from the desert dusts which seem to adversely affect food products shelf-life and safety [42-44].

Dust settlement in water resources may increase the concentration of dissolved chemical and biological pollutants which will contribute to agricultural products contamination. In addition, the content of dust storms can stimulate the production of marine toxins via harmful algal blooms such as red tides [40,42].

2.4. Food Habit Changes

In resource poor settings, when a staple food crop fails and becomes less available following drought, people can be forced to make major changes to their usual diet. This can include eating less familiar foods or cutting corners in processing foods. In Afghanistan in 1970-2, 22% of a drought-affected population developed veno-occlusive liver disease associated with eating wheat that had not been properly winnowed from a plant contaminant containing pyrrolizidine alkaloids. In India and Ethiopia, consumption of drought-resistant meadow pea (*Lathyrus sativus*) led to irreversible neurodegenerative disease due to neurolathyrism. In Tanzania and Mozambique, outbreaks of Konzo, another serious neurological disease which causes irreversible paralysis, were due to inadequately processed cassava (*Manihot esculenta*) [7,45,46]. On the other hand, due to inadequate feed/forage supplies, farmed animals may consume toxic plants that they would not commonly eat which in turn make them more susceptible to infectious disease [25,27,28].

2.5. Fungal Contamination

Mycotoxins are toxic secondary metabolites of some fungal species especially *Aspergillus*, *Fusarium* and *Penicillium* genera that contaminate staple food and feeds [47]. Climate change appears to be the most important factor involved in crop contamination by mycotoxins [48]. Crops suffer from drought stress may be less resistant to nematodes and insects as well as viral infections; while they will be a hostile environment for bacteria. Poor conditions coupled with the lack of bacterial competition can increase plant susceptibility to molds [24,49]. On the other hand, disease agents and insect invasion favored by drought will lead to more mycotoxin contamination in several crops [2]. In fact, insects can spread mycotoxigenic fungi [48] and also their multiplication produces more metabolic water (higher a_w) which can in turn initiate spoilage mold activity with the possibility for increased contamination by mycotoxins. Considering the potential ability of Xerophilic fungi such as *Wallemia sebi*, *Xeromyces bisporus* and *Chrysosporium* spp., as well as some strains of *Aspergillus flavus* to grow under very dry conditions, they could be the most important colonizers of food commodities during drought periods [47].

As consequence of increased food/feed prices, the use of decomposed crops with high level of such toxic contaminants by humans and animals may be more frequent during periods of drought [7]. On the other hand, feeding of aflatoxin contaminated crops to livestock resulting in high levels of aflatoxin in the milk, meat, fish, poultry and eggs may impose a threat to human health.

2.6. Algal Blooms

Although a large increase in nutrients such as phosphorous and nitrates in water resources and a large numbers of algal blooms in them have been previously reported during drought period [8], a detailed understanding of relationship between drought and harmful algal blooms (HAB) is lacking. The falling water velocities and levels may be accompanied by high level of cyanobacteria (blue-green algae) and their microcystin toxins in drinking water reservoirs which can be toxic to animals and humans [7,27].

3. Conclusion

Drought conditions may pose food safety challenges through many different and complex pathways. The water scarcity arising from such conditions is accompanied by high level of chemical and biological pollutants in water resources, as well as poor personal and industrial hygienic practices which in turn will adversely affect the safety of drinking water, irrigation water, crops/pastures, marine products, feeds, food animals and consequently foods. Drought-related dust containing chemical, biological and rarely radioactive contaminants will exert similar influences. Increased nutrient concentration of rivers, lakes and seas under mentioned conditions will also contribute to the development of algal blooms which could adversely affect human health. Moreover, animal farming conditions (more intensive ones and low quality feeds) causing animals to be more susceptible to infectious diseases, poor plant resistance to mycotoxigenic fungi, increasing the price of feeds and foods and also food habit changes under drought stress conditions are associated with adverse human health consequences. To face drought-related food safety hazards, therefore, the consideration of all above mentioned aspects seems to be crucial.

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Trending Evapotranspiration and Investigating the Meteorological Paramaters Influenced on Climate Change in the Zagros Forests and Their Effects on Forest Decline

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Abstract

Decline of the Zagros forests of western Iran dominated by oak trees is assumed to be highly connected with changes in meteorological parameters. To examine this hypothesis, the present research aimed at observing the long-term trends of meteorological parameters and reference evapotranspiration (ET_0) in the Zagros region. Long-term (1961-2010) data of air temperature, relative humidity, precipitation, and wind speed were obtained from six synoptic meteorological stations located all over the region. The Penman-Monteith equation was applied to calculate the ET_0. The results indicated within 2000 to 2010, coincided with the emerging oak decline, meteorological parameters and ET_0 have been changed dramatically, i.e., air temperature: +0.6 °C; precipitation: -60 mm; relative humidity: -3 %, wind speed: +0.4 m s^{-1}, and ET0: +0.25 mm d^{-1}. The precipitation events lower than 2.5 mm increased in two stations. If this trend continues to the future, regarding the amounts of oak canopy water storage capacities which measured approximately 1.6 and 0.6 mm within the growing and non-growing seasons, respectively, the Zagros forests will unquestionably experience reduction in the available water because of increased evaporative loss. Although this preliminary research confirmed a significant linking between oak decline and altering the meteorological parameters, full datasets recorded in different parts of the Zagros regions is essential for a comprehensive and reasonable research to fully explain this hypothesis. Managers should necessarily think of the expected changes in meteorological parameters and evapotranspiration owing to global warming while proposing the preventative actions to mitigate oak decline in the Zagros region.

Keywords: Evapotranspiration, Meteorological parameters, Oak decline, The Zagros forests.

1. INTRODUCTION

The effect of anthropogenic changes to the land and atmosphere on climate change is being pursued as a dynamic multi-disciplinary problem. Atmospheric temperature is probably the most widely used indicator of climate change at both global and regional scales. According to the fourth assessment report of [1], global temperature has increased by 0.3 to 0.6 °C since the late 19th century and by 0.2 to 0.3 °C over the past forty years. Previous research suggests that climatic change may have a significant impact on hydrological parameters, namely runoff, evapotranspiration (ET), soil moisture, rainfall interception, and ground water (e.g., [2-4]). Some researchers have also investigated the trends in different types of hydrological, ecohydrological, and hydro-meteorological parameters such as soil moisture, drought characteristics, ground water, pan evaporation (Epan) and reference evapotranspiration (ET_0) [2,3,5]. ET_0, a major component of the hydrological cycle, is one of the most important elements for quantifying available water since it generally constitutes the largest component of the terrestrial water cycle [6]. ET_0 is considered to be critical to many applications including water resource management, irrigation scheduling, and environmental studies [7], is one of the main factors in the hydrological cycle and can be affected by the changes in air temperature, sunshine duration, wind speed, and so on. It is well-known that ET_0 is a nonlinear complex function of many parameters and changes in any one parameter can change the other parameter(s) [5]. Therefore, any change in climatic parameters due to climate change will likely affect ET and ET_0 [8]. Eventually, climate change will increase the dry conditions in the arid regions by increasing potential evapotranspiration, aggravating the process of desertification in conjunction with the ever-growing impact of humans and domestic animals on fragile and unstable ecosystems [5]. In drier regions, evapotranspiration may produce more frequent drought periods.

Small changes in ET may have important consequences in arid regions. For example, [8] reported that a one percent increase in air temperature could increase ET_0 by 12.7% in arid regions of Rajasthan, India, where the annual rainfall varies from 100 to 400 mm and mean yearly air temperature is 25 °C. According to [9], a 3 °C rise in the air temperature in California resulted in approximately 19% increase in ET_0 where annual average precipitation is 640 mm and mean yearly air temperature is 15 °C. Furthermore, [10] and [11] reported that a 3 °C increase in air temperature resulted in around 17% increase in ET_0 over a grassland in Northeastern Kansas, USA, during the summer with an air temperature range between 24 and 35 °C. The effect of climate change may be exacerbated by the ever-growing impact of humans and domestic animals on the fragile and unstable ecosystems [12].

Increasing decline of oak trees and in particular Quercus petraea has been observed in European countries (e.g. [13-15]). Decline of the Zagros forest in the west of Iran with an area of 5 million hectare dominated by oak trees (Quercus brantii var. persica) has been occurring since 2000. Forest managers in Iran believe that no single cause is responsible for the decline of oak forests. In other words, diseases and pests are not the sole reason for the death of this seriously vulnerable ecosystem located in a semiarid climate. The impacts of changes in meteorological parameters on Zagros forests are likely to be unevenly distributed not only across different bioclimatic zones but also among different climate types of each zone.

Research shows that several biotic and abiotic factors have been considered in oak decline studies, such as extreme weather conditions, drought, storms, heat, and insect fluctuations, or human induced influences such as climate change, air pollution, and fires. These factors may modify the functioning of the whole forest ecosystem and may lead to tree decline events [16].

Not surprisingly, forest degradation, frequent droughts, suspended particles and dusts originated from neighboring countries coupling with changes in meteorological parameters in recent years assumes to deteriorate the ability of the ecosystem to combat environmental stresses. Oak trees react to the stress of prolonged drought and defoliation by converting starch stored in the roots to sugar to support continued metabolism [17]. Once these stored reserves are depleted, trees are not able to maintain the status quo and begin to decline [17]. To our knowledge, no studies have used meteorological variables to detect and monitor the oak decline of Iran.

One of the prevalent hypotheses in decline of the Zagros forest is variations in meteorological parameters and consequently ET_0. Therefore, to examine this assumption, our objectives were (i) to observe the long-term trends of the meteorological parameters and ET_0, and (ii) to reveal the relationships between changes in meteorological parameters and oak decline in the Zagros forests.

2. MATERIALS AND METHODS

2.1. Study Area

The research was conducted in the Zagros region, west of Iran (Fig. 1). The average annual precipitation varies with approximately 250 mm to 800 mm and the mean annual air temperature differs from 9 ºC to 25 ºC [18].

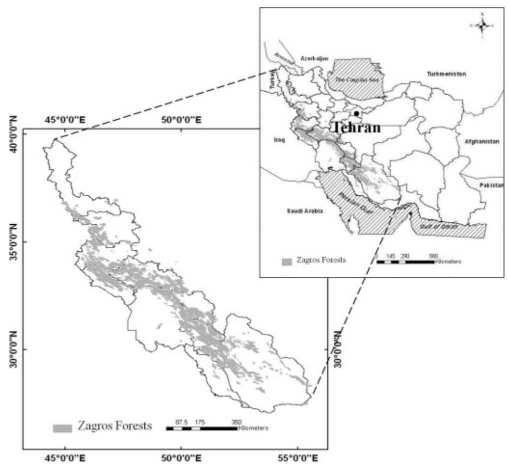

Figure 1: Location of the Zagros region, west of Iran

2.2. Meteorological Data

Detection of climatic changes requires the use of a large number of long, high quality series of observed meteorological variables. To achieve this, long-term meteorological data (1961-2010) from six synoptic meteorological stations (Fig. 2) were used to parameterize the De Martonne Aridity Index (Equation 1) [19].

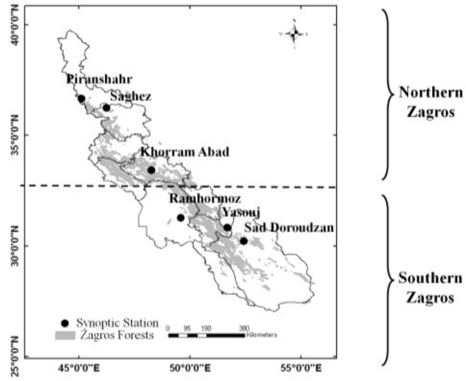

Figure 2: Positions of the selective synoptic weather stations in the Zagros region, west of Iran

The De Martonne Aridity Index was used to classify the climate for the region surrounding each station (Table 1).

TABLE 1: CHARACTERISTICS OF THE SYNOPTIC METEOROLOGICAL STATIONS LOCATED IN THE ZAGROS REAGION, WEST OF IRAN (1961 – 2010). CLIMATE CLASSIFICATION ACCORDING TO THE DE MARTONNE ARIDITY INDEX (I_{DM}) AFTER [5].

Station	Lat. (North)	Long. (East)	Elevation	I_{DM}	Climate classification	Range of meteorological data
Piranshahr	36° 42′	45° 09′	1455	29	Humid	1986-2009
Saghez	36° 15′	46° 16′	1523	23	Mediterranean	1961-2009
Khorram Abad	33° 26′	48° 17′	1148	18	Semiarid	1961-2010
Ramhormoz	31° 16′	49° 36′	150	8	Arid	1987-2010
Yasuj	30° 50′	51° 41′	1831	33	Humid	1987-2009
Sad Doroudzan	30° 13′	52° 26′	1620	17	Semiarid	1988-2010

2.3. Evapotranspiration Model

We used the Penman-Monteith combination equation to calculate daily ET_0. The Penman-Monteith combination equation is a reliable method for determining reference ET worldwide.

2.4. Effective Pprecipitation

Precipitation is not necessarily useful or desirable at the time, rate, or amount in which it is received. Some of it may be unavoidably wasted while some may even be destructive. The useful portion of precipitation is stored and supplied to the user; the unwanted part needs to be conveyed or removed speedily [6]. Effective or utilizable precipitation was satisfied by Equations (1 & 2):

$$PE = 0.6\,(PT) - 10 \quad \text{where} \quad PT < 70\ mm \tag{1}$$

$$PE = 0.8\,(PT) - 2.4 \quad \text{where} \quad PT > 70\ mm \tag{2}$$

in which PE is the monthly effective precipitation (mm) and PT is the total monthly precipitation (mm) [20].

3. Results

3.1. Trends of Meteorological Parameters and ET_0

The mean values of meteorological parameters within the growing and non-growing seasons are shown in Table 2. Our data suggested that mean annual air temperature and precipitation in the selected stations at Zagros region are 16.7 ºC and 545.8 mm, respectively. Mean annual relative humidity, wind speed, and ET_0 were 45%, 2.0 m s^{-1}, and 4.2 mm d^{-1}, respectively. The maximum daily ET_0 was calculated in Ramhormoz (6.1 mm) and highest yearly precipitation was recorded in Yasuj.

Table 2: Long-Term (1961 – 2010) Average Annual and Standard Deviation (±SD) of Meteorological Parameters as well as Reference Evapostranspiration in the Zagros Region of Western Iran

Station	Season	Air temperature (ºC)	Precipitation (mm)	Relative humidity (%)	Wind speed (m. s^{-1})	Reference evapotranspiration (mm. d^{-1})
Piranshahr (1986-2009)	G	19.7 ± 1.2	146 ±68.2	40 ± 5.4	2.4 ± 0.5	5.1 ± 0.5
	N - G	4.7 ± 1.5	512 ± 154.4	63 ± 4.6	3.0 ± 0.5	2.0 ± 0.2
	A	12.4 ± 1.1	658 ± 178.4	51 ± 4.3	2.7 ± 0.5	3.9 ± 0.4
Saghez (1961-2009)	G	18.8 ± 1.2	141 ± 66.8	40 ± 5.6	2.5 ± 0.6	5.0 ± 0. 5
	N - G	3.7 ± 1.8	339 ± 108.7	64 ± 4.2	2.3 ± 0.4	1.9 ± 0.2
	A	11.3 ± 1.2	480 ± 135.8	52 ± 3.8	2.4 ± 0.5	3.7 ± 0. 3
Khorram Abad (1961-2010)	G	24.7 ± 1.1	99 ± 69.1	33 ± 4.7	2.0 ± 0.6	5.8 ± 0.8
	N - G	10.3 ± 1.2	396 ± 120.9	59 ± 4.8	1.8 ± 0.5	2.2 ± 0.2
	A	17.2 ± 1.1	504 ± 122.9	46 ± 4.2	1.9 ± 0.5	4.1 ± 0.4
Ramhormoz (1987-2010)	G	34.2± 1.0	22 ± 20.6	22 ± 2.3	2.4 ± 0.5	9.5 ± 1.2
	N - G	18.7 ± 1.0	296 ± 95.4	52 ± 4.4	1.6 ± 0.3	2.8 ± 0.3
	A	26.5 ± 1.1	307 ± 1008	37 ± 2.2	2.0 ± 0.4	6.1 ± 0.8
Yasuj (1987-2009)	G	22.0 ± 0.6	88 ± 59.9	31 ± 8.4	1.6 ± 0.5	4.4 ± 0. 8
	N - G	8.4 ± 07	752 ± 195.4	87 ± 6.2	1.3 ± 0.4	2.9 ± 0.1
	A	15..2 ± 0.6	841 ± 211.5	44 ± 7.0	1.4 ± 0.5	3.6 ± 0. 2
Sad Doroudzan (1988-2010)	G	24.7 ± 0.6	48 ± 38.5	31 ± 3.8	2.3 ± 0.6	6.2 ± 0.6
	N - G	10.8 ± 0.7	437 ± 124.1	50 ± 4.2	1.9 ± 0.5	2.4 ± 0.2
	A	17.7 ± 0.6	485 ± 135.1	40 ± 3.7	2.1 ± 0.5	4.3 ± 0.4

[a] G: growing season (April-September); N - G: non-growing season (October - March); A: annual.

Table 3 shows the ET_0, relative humidity, and wind speed trends in terms of Kendall's Tau static within the long-term period (1961-2010). Two and one out of six stations exhibited statistically significant positive and negative trends ($p < 0.05$) for the annual air temperature time series, respectively. Positive and negative trends were similarly pronounced for air temperature during this period.

TABLE 3: TREND TESTS, KENDALL'S TAU, OBTAINED THROUGH THE MANN-KENDALL METHOD FOR THE METEOROLOGICAL PARAMETERS AS WELL AS REFERENCE EVAPOTRANSPIRATION IN THE ZAGROS REGION OF WESTERN IRAN WITHIN THE PERIOD OF 1961 - 2010

Station	Air temperature	Precipitation	Relative humidity	Wind speed	Reference evapotranspiration
Piranshahr	0.6**	-0.1	-0.2	0.0	0.1
Saghez	-0.2	-0.1	0.2	0.1	-0.2*
Khorram Abad	-0.3**	-0.1	0.1	0.0	0.8
Ramhormoz	0.4**	-0.2	-0.4**	0.1	0.2
Yasuj	0.0	0.4	0.0	0.0	0.1
Sad Doroudzan	0.2	-0.4*	-0.4*	0.2	0.3
+ Trend number	4 (2)	1 (0)	3 (0)	6 (0)	5 (0)
-Trend number	2 (1)	5 (1)	3 (2)	0 (0)	1 (1)

* Statistically significant trends at the 95% confidence level. ** Statistically significant trends at the 99% confidence level.
In the last two rows, two numbers, in each cell, denote the number of trends with positive or negative sign, and the number of statistically significant trends at 5% level.

Fig. 3 shows the yearly ET_0, relative humidity, and wind speed time series of selected stations in the period of 1961-2010. The magnitude of trend in annual ET0 in Ramhormoz station located in the central Zagros region revealed the highest positive trend line slope with a value of 0.4 mm per decade. Similarly, for wind speed, the highest positive trend line slope was observed in Sad Doroudzan station with a value of 0.3 m s^{-1} per decade.

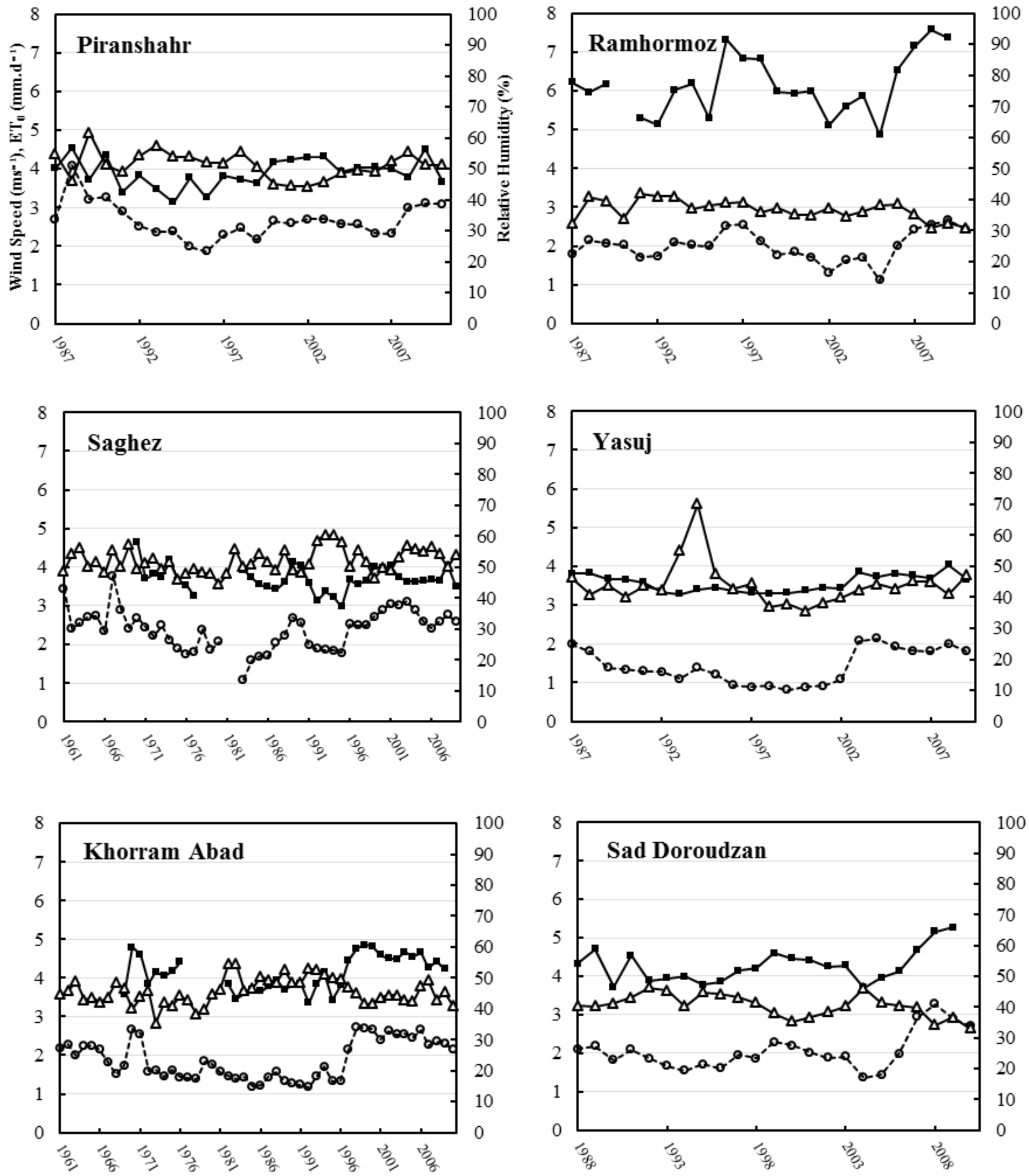

Figure 3: Long-term (1961–2010) trends of mean annual wind speed, relative humidity, and reference evapotranspiration in the Zagros region of western Iran. Triangles, squares, and open circles denote relative humidity, reference evapotranspiration (ET_0) and wind speed, respectively.

Table 4 shows the quantitative value of meteorological parameters and ET0 changed in recent years (2000-2010) in comparison with the previous period (1961-1999). Exclusive of Saghez, air temperature increased by approximately 4% in whole stations as an average. The highest change in wind speed was observed in Yasuj, approximately 0.4 m s^{-1} from 2000 to 2010. Except Yasuj station, showing very slight change in annual precipitation, in other stations a notable decrease was observed. Our data proposed that reference evapotranspiration increased by around 5% in selected stations. The Results demonstrated that De Martonne Aridity Index decreased in all stations.

TABLE 4: CHANGES IN METEOROLOGICAL PARAMETERS, REFERENCE EVAPOTRANSPIRATION AND DE MARTONNE ARIDITY INDEX IN THE ZAGROS REGION, WEST OF IRAN, IN RECENT YEARS (2000 – 2010)

	Piranshahr (1986-2009)	Saghez (1961-2009)	Khorram Abad (1961-2010)	Ramhormoz (1987-2010)	Yasuj (1987-2009)	Sad Doroudzan (1988-2010)
Mean Air Temperature (1961- 1999) (ºC)	11.8	11.3	17.1	26.1	15.1	17.5
Mean Air Temperature (2000- 2010) (ºC)	13.1	11.1	17.3	27	15.3	18
Air Temperature Changes (ºC)	+1.3	-0.2	+0.2	+0.9	+0.2	+0.4
Air Temperature Changes (%)	+11.3	-2.2	+1.1	+3.4	+1.1	+2.6
Mean Precipitation (1961- 1999) (mm)	670.9	498.7	515.7	343.4	838.6	509.2
Mean Precipitation (2000- 2010) (mm)	639.8	407.0	458.4	285.7	844.4	455.0
Precipitation Changes (mm)	-31.0	-91.7	-57.3	-57.7	+5.8	-54.2
Precipitation Changes (%)	-4.6	-18.4	-11.1	-16.8	+0.7	-10.7
Mean Relative Humidity (1961- 1999) (%)	52.7	51.6	46.1	38.2	45.5	42.3
Mean Relative Humidity (2000- 2010) (%)	49.2	53.4	44.1	34.9	42.2	38.3
Relative Humidity Changes (%)	-3.5	+1.8	-2	-3.3	-3.3	-4
Relative Humidity Changes (%)	-6.7	+3.4	-4.4	-8.6	-7.3	-9.4
Mean Wind Speed (1961- 1999) ($m.s^{-1}$)	2.6	2.3	1.7	2.0	1.3	1.9
Mean Wind Speed (2000- 2010) ($m.s^{-1}$)	2.7	2.8	2.5	1.9	1.6	2.2
Wind Speed Changes ($m.\ s^{-1}$)	+0.1	+0.5	+0.7	-0.1	+0.3	+0.3
Wind Speed Changes (%)	+2.5	+22.7	+42.5	-4.6	+30.9	+18.4
Reference Evapotranspiration (1961- 1999) ($mm.d^{-1}$)	3.8	3.7	4.0	6.1	4.5	4.1
Reference Evapotranspiration (2000- 2010) ($mm.d^{-1}$)	4.1	3.8	4.5	6.2	3.7	4.4
Reference Evapotranspiration Changes ($mm.d^{-1}$)	+0.3	+0.1	+0.5	+0.1	+0.2	+0.3
Reference Evapotranspiration Changes (%)	+8.0	+2.4	+13.5	+1.6	+5.5	+0.7
De Martonne Aridity Index (1961-1999)	30.8	23.4	19	9.5	33.4	18.5
De Martonne Aridity Index (2000-2010)	27.6	19.3	16.8	7.7	33.4	16.3

3.2. Total and Effective Precipitation

Background meteorological data recorded from 1961 to 2010 showed that average annual precipitation in the selected stations is 546 mm occurred in 63 wet days, i.e., averages 8.7 mm per wet day (Table 5).

TABLE 5: CHANGES IN TOTAL AND EFFECTIVE PRECIPITATIONS IN THE ZAGROS REGION, WEST OF IRAN, WITHIN THE THREE PERIODS

Station	Yearly precipitation (mm) effective precipitation (mm) + wet days			Mean daily precipitation (mm)		
	1961-2010	1961-2000	2000-2010	1961-2010	1961-2000	2000-2010
Piranshahr	658 $_{526}$ + **81**	671 $_{537}$ + **82**	640 $_{512}$ + **79**	8.2	8	8.4
Saghez	480 $_{384}$ + **78**	499 $_{399}$ + **77**	407 $_{326}$ + **82**	6.1	6.2	5.8
Khorram Abad	504 $_{403}$ + **70**	516 $_{413}$ + **73**	458 $_{368}$ + **60**	7.2	6.9	8.4
Ramhormoz	307 $_{254}$ + **40**	343 $_{275}$ + **42**	286 $_{229}$ + **37**	7.6	7.3	8.2
Yasuj	841 $_{673}$ + **63**	839 $_{671}$ + **68**	844 $_{675}$ + **57**	13.4	12.4	14.8
Sad Doroudzan	485 $_{387}$ + **46**	509 $_{407}$ + **50**	455 $_{364}$ + **42**	9.5	8.8	10.5
Mean	546 $_{438}$ + **63**	563 $_{450}$ + **65**	515 $_{412}$ + **60**	8.7	8.3	9.3

However, during the previous decade (2000-2010), the yearly precipitation and the total number of wet days decreased to 515 and 60 mm, respectively. Therefore, the amount of precipitation per wet days increased up to 9.3 mm. As well, in comparison with the period of 1961-2000, the recent decade received less precipitation with lower number of wet days. We separated the precipitation into five storm classes, very small (0–2.5 mm), small (2.5–7.5 mm), middle (7.5–15 mm), large (15–30 mm), and very large (>30 mm). Three out of six stations, Piranshahr, Ramhormoz, and Saghez, showed that the number of wet days with 0.1-2.5 mm in the recent decade significantly increased.

4. DISCUSSION

Our observations showed that long-term trends (1961-2010) of air temperature, precipitation, relative humidity, reference evapotranspiration were significant in 3, 1, 2, and 1 selective stations, respectively. The historical (1961-1999) mean values of the meteorological parameters of air temperature (16.5 ˚C), relative humidity (46%), wind speed (2.4 m s^{-1}), precipitation (563 mm), reference evapotranspiration (4.4 mm d^{-1}) in the six selective stations located throughout the Zagros region were observed. However, during the previous decade from 2000 to 2010, since oak decline gradually started appearing, the mean annual air temperature increased by 0.6 ˚C. Within this period, precipitation, relative humidity, wind speed, and reference evapotranspiration changed additionally by around -60 mm, -3 %, +0.4 m s^{-1}, and +0.25 mm d^{-1}. Exceptions were also noted; for example, mean yearly precipitation increased up very slightly from 838.6 mm to 844.4 mm in Yasuj.

Results indicate that all of the meteorological parameters were affected by global warming phenomena in the Zagros region as occurred in many regions. Literature reviews also shows that precipitation has declined in the tropics and subtropics since 1970 –e.g., Southern Africa, the Sahel region of Africa, southern Asia, the Mediterranean, and the U.S. Southwest are getting drier. Even areas that remain relatively wet can experience long, dry conditions between extreme precipitation events. ET_0, which is a nonlinear complex function of many parameters, increased in all stations, averaging 0.25 mm d^{-1}. Forest ET_0 is generally larger than those of other vegetation types such as grassland [21,22]. Forests cover about 30% of the total global land area, but ET_0 from forests accounts for 45% of the total ET_0 from the global land surface [22,23]. Changes in ET_0 will certainly affect the natural forest ecosystems in the Zagros region. The composition of the species, ecophysiological characteristics of the trees as well as the spatial distribution of the tree species may be threatened by changes in meteorological parameters. Climate change is predicted to affect forests by altering both forest processes [9] and biodiversity [24,25], resulting in changes in forest location, composition, and productivity [24].

Within the growing season the typically hot and dry wind results in more ET_0 from the surface relative to the cold wind during the non-growing season. Changes in ET_0 can have a thoughtful effect on agriculture, forests, and water resources in the Zagros region and this may put a pressure on existing water resources.

During the previous decade, both the amount of precipitation and the number of wet days decreased. Moreover, the number of precipitation events lower than 2.5 mm increased in three out of six stations. If this trend persists to the future, regarding to the amount of canopy water storage capacity of oak trees in the Zagros forests which is 1.6 mm for the growing season and 0.6 mm during the non-growing season [18], it is reasonable that these forests will experience reduction in the available water because of increased evaporative loss.

This study examined the hypothesis of possible effects of changes in meteorological parameters on oak decline in the Zagros forests. Our data showed that during the previous decade some parameters were changed drastically, for example wind speed 23% and precipitation 12%, however, the others fairly altered, e.g., air temperature 4.6%, relative humidity 7.3%. Combination changes in meteorological parameters increased the reference evapotranspiration up to 5.3%. The De Martonne Aridity Index also decreased down to 20.2 showing the Zagros region is getting drier and warmer. Oak decline in the Zagros forests is a multidisciplinary and complicated phenomenon depending on many factors. Removing the susceptible and stressful environmental factors is considered to be the most important solution for rehabilitation of this generous ecosystem. Great attention is now focused on climate change and its impacts on forest ecosystems [26-28] because forests are highly vulnerable to climate change and significant forest dieback can occur [27].

5. Conclusion

One of the prevalent hypotheses in the decline of the Zagros forests is variations in meteorological parameters. This introductory research on long-term trends of meteorological parameters and reference evapotranspiration in the Zagros regions of western Iran confirmed a significant linking between oak decline and changes in meteorological parameters. For example, yearly air temperature increased by approximately 0.5 °C and annual precipitation reduced by 50 mm in the Zagros region since 2000, coinciding with the emerging oak decline. To fully explain this assumption, however, more meteorological data should be analyzed.

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The Impact of Climate Change on Soil Organic Carbon in Iran Using LARS-WG and RothC Models

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Abstract

The changes of soil organic carbon and soil carbon decomposition are influenced by temperature and precipitation changes. In the current study, the changes of soil organic carbon under climate change scenarios is estimated by the Rothamsted Carbon model in different land-use areas in north and northeast of Iran. The simulated results of soil organic carbon illustrated that over the period 2010-2065, SOC will decrease in the study area. The simulation of soil organic carbon strongly suggests that SOC levels will decline due to temperature increase and decline on precipitation in the study area, particularly in cultivated lands. SOC is expected to have decreased under A2 climate scenario by 8.3 tC/ha and 13.36 tC/ha by the year 2030 and 2065, respectively. Likewise, under the B2 scenario, SOC will have decreased by 8.58 tC/ha and 13.81 tC/ha by the year 2030 and 2065, respectively. By simulating changes to soil organic carbon in the future, the impact of temperature and precipitation as the major factors on soil organic carbon in different geographical regions can be determined.

Keywords: Soil Organic Carbon; Scenarios of Climate Change; Land Use; RothC Model

1. INTRODUCTION

Soil organic carbon (SOC) is an important source of carbon in the biosphere. The amount of SOC as a total measure over soil depth is estimated as being from approximately 10 tC/ha to around 160 tC/ha in the top 30 cm of soil and at times up to 250 tC/ha in the case of rich soil in undisturbed locations [1]. Globally there are an estimated 1,400 gigatonnes of SOC, about double the quantity of carbon dioxide in the atmosphere, such that changes in SOC may have a great impact on CO_2 concentrations in the atmosphere [2,3]. There is a direct relationship between the functions of SOC and changes in temperature, precipitation and CO_2 concentration in the atmosphere [4]. Temperature and precipitation are acknowledged as being two of the most crucial climatic factors and their ability to change the rate of SOC decomposition, plant growth and microbiological activity has been noted [5]. Results from previous studies have shown that with higher temperatures and precipitation, organic material decomposition and CO_2 losses from soil have increased, and there is a lower amount of SOC in warm climatic conditions when compared to cold climates [3].

There are a number of models, as proposed by Falloon et al. [2], Guo et al. [6], and Zimmermann et al. [7], which can study carbon levels in soil over a time scale of years–to-centuries, including Century model, DeNitrification–DeComposition model (DNDC), Daisy and RothC models. As a simulation model, the RothC has become popular and been used in many parts of the world to calculate predicted SOC changes [8,9]. RothC is a well-established model for simulating long-term trends in SOC and has been very useful in the analysis of different types of land use, soil, and climatic regions. In China, the RothC model was used to evaluate increase and decrease of soil organic carbon based on climate change in upland and cropland soils [9] and also, this model was used in Zambia and Nigeria to estimate SOC turnover based on temperature function [10,11]. In Norway, Switzerland, and Ireland, RothC has also enabled estimates of changes in SOC in grassland and forest soils resulting from climate change [12,13]. Their results showed a positive correlation of measured data and modelled results for humified organic matter (HUM), microbial biomass (BIO) and decreases in SOC. In the current study, the evaluation of SOC under climate change was undertaken using the climate change scenarios organized by IPCC. Climate scenarios shown as Al, A2, B1 and B2 indicate varying demographic, social, economic, technological and environmental evolutions [14]. The A2 scenario represents a very heterogeneous world and the B2 scenario imagines a world that highlights the local solutions to social, economic and environmental sustainability.

The aim of this study is to simulate the SOC changes in different geographical regions in north and northeast Iran by using RothC model to determine how and to what extent climate change would influence soil organic carbon under scenarios A2 and B2. The Long Ashton Research Station-Weather Generator (LARS-WG) model simulated temperature and precipitation data for future based on A2 and B2 scenarios.

2. MATERIAL AND METHODS

2.1. The Study Area

The study area encompasses a range of climates. In the northeast it is dry whereas in the northern region of Iran it is very humid with heavier rains and dense tree and vegetation cover that extends between latitudes (defined as 38°N to 30°N and 48°E to 59°E) (Fig. 1). The study area comprises 19 climate stations across Iran and these stations were classified using De Martonne's method [15] (Table 1). Table 2 shows the information for each station, which was collected from the Meteorological Department of Iran.

$$I = \frac{P}{T+10} \tag{1}$$

where T is mean annual temperature (°C) and P is mean annual precipitation (mm). Seven out of nineteen stations are located in very humid and humid areas, three stations are in semi-arid regions and nine stations are in arid regions across the study area.

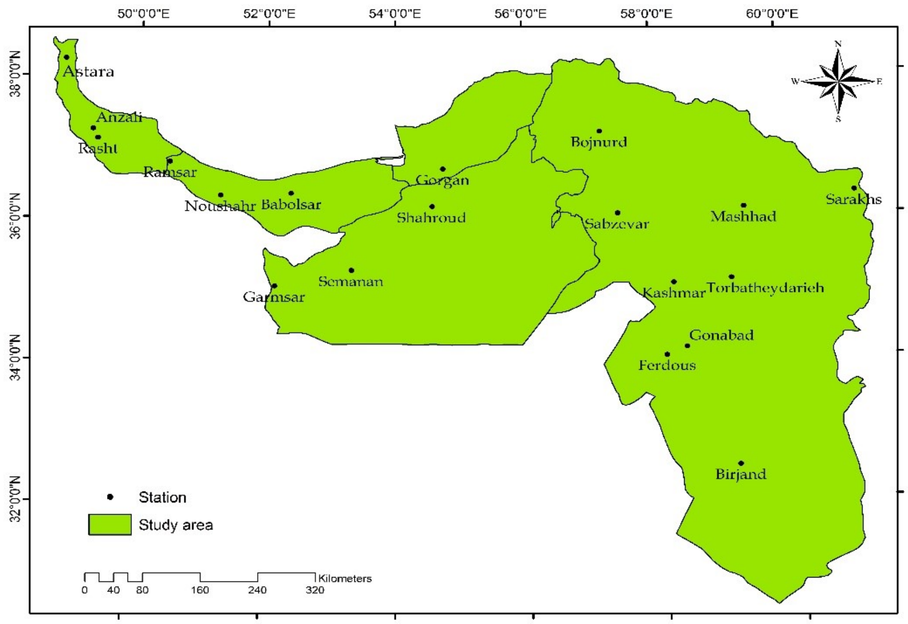

Figure 1: The study area and meteorological stations

TABLE 1: CLIMATE CLASSIFICATION ACCORDING TO THE DE MARTONNE METHOD.

Climate	I
Arid	< 10
Semi-Arid	10 - 19.9
Mediterranean	20 - 23.9
Semi-Humid	24 - 27.9
Humid	28 - 34.9
Very Humid	> 35

TABLE 2: LOCATION AND STATIONS UTILIZED IN THE STUDY AREA.

Stations	Latitude (˚N)	Longitude (˚E)	Elevation (M)	Climate
Anzali	37.28	49.28	-26.2	Very Humid
Astara	38.25	48.52	-18.0	Very Humid
Babolsar	36.43	52.39	-21	Humid
Birjand	32.52	59.12	1491	Arid
Bojnurd	37.46	57.31	1091	Semi-Arid
Garmsar	35.12	52.16	825.2	Arid
Gonabad	34.21	58.41	1056.0	Arid
Gorgan	36.51	54.16	13.3	Humid
Ferdous	34.1	58.10	1293	Arid
Kashmar	35.12	58.28	1109.7	Arid
Mashhad	36.28	59.6	999.2	Semi-Arid
Noushahr	36.39	51.3	-20.9	Very Humid
Ramsar	36.54	50.4	-20	Very Humid
Rasht	37.15	49.36	36.7	Very Humid
Sabzevar	36.12	57.43	977.6	Arid
Sarakhs	36.32	61.10	235.0	Arid
Semnan	35.35	53.33	1130.8	Arid
Shahroud	36.25	54.57	1345.3	Arid
Torbat Heydarieh	35.27	59.22	1450.8	Semi-Arid

2.2. Rothamsted Carbon Model

The Rothamsted Carbon Model (RothC) is used to get non-waterlogged topsoil from organic carbon, which determines the effect of soil type, moisture content, temperature and plant cover on the turnover process. It calculates the total organic carbon (t ha^{-1}), microbial biomass carbon (t ha^{-1}) and Δ14C on a years-to-centuries timescale based on monthly time step [8].

RothC is a model for the turnover of organic carbon in non-waterlogged topsoil. This model determines the soil carbon turnover process based on soil type, plant cover, moisture content and temperature. This model uses a monthly data to estimate total organic carbon, Δ14C and microbial biomass carbon from years to century timescale [8]. Based on the RothC assumptions, there are five main compartments. Carbon is transferred by a first order process from one compartment to the other via decomposition processes. The fractions comprise resistant plant material (RPM), decomposable plant material (DPM), humified organic matter (HUM), microbial biomass (BIO), and inert organic matter (IOM). The IOM are calculated from total soil organic carbon based on following equation [16].

$$IOM = 0.049 \times SOC^{1.139} \quad (2)$$

The concept of IOM, introduced as a mathematical construct, is necessary for calculating soil organic carbon content and Δ14 C of bulk soil data [2]. The quantity of inert organic matter is a major factor in the RothC model results. Inputs to the model are meteorological data (temperature [°C], rainfall [mm], potential evapotranspiration [mm]), soil clay [%], plant residue inputs and a soil cover factor. In this model open pan evaporation is calculated based on below equation.

$$\text{open pan evaporation} = \text{potential evaporation}/0.75 \quad (3)$$

In this study, the model assumes that all soil contains 20% clay. The ratio of DPM/RPM is set as 0.25 for forest regions, 0.5 for warm deserts and temperate steppes and 0.67 for cultivated land and temperate thorn steppes.

2.3. Soil and Land Use Data

We need to prepare an input file including soil and climate data to run the RothC model in different geographical area. We used ArcGIS to generate land use classification map. The basic soil unit in the 1:250,000 soil map was subgroup. Soil samples were collected from Soil and Water Research Institute of Iran for different sites (forest, agriculture, grassland and desert). During 2009 to 2010, soil samples were taken from the 0-30cm soil depth. The measured carbon fractions (%) were converted to tC ha^{-1} using known soil bulk densities with the same units as the output from RothC model. The distribution of the original 980 soil samples in the study area is shown in Fig. 2.

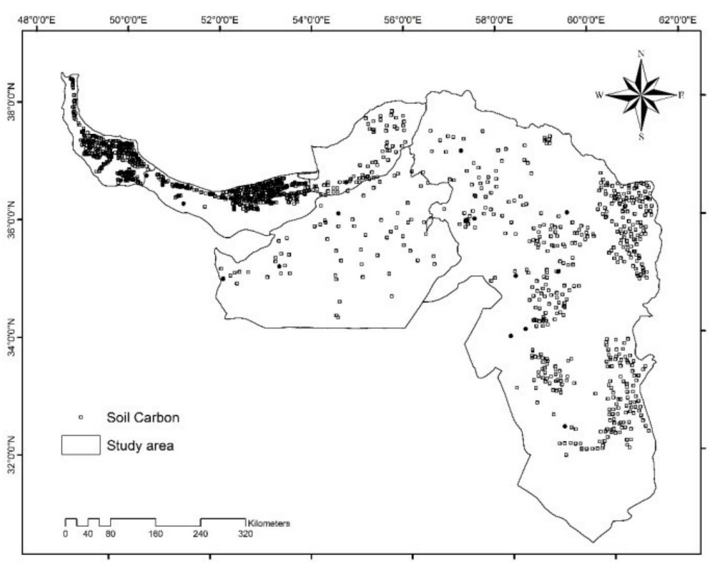

Figure 2: Soil sample distribution in the study area in different geographical zones

Due to various climate conditions, we divided the study area, into five different geographical zones: warm desert, warm temperate forest, cool temperate forest, temperate thorn steppe, and cultivated lands (Fig. 3). In this study, land use data was derived from the world vegetation dataset [17] and Holdridge's life zone classification. Monthly precipitation and temperature data for the five climatic zones of the study area were derived using the method proposed by Jenkinson and Rayner [18].

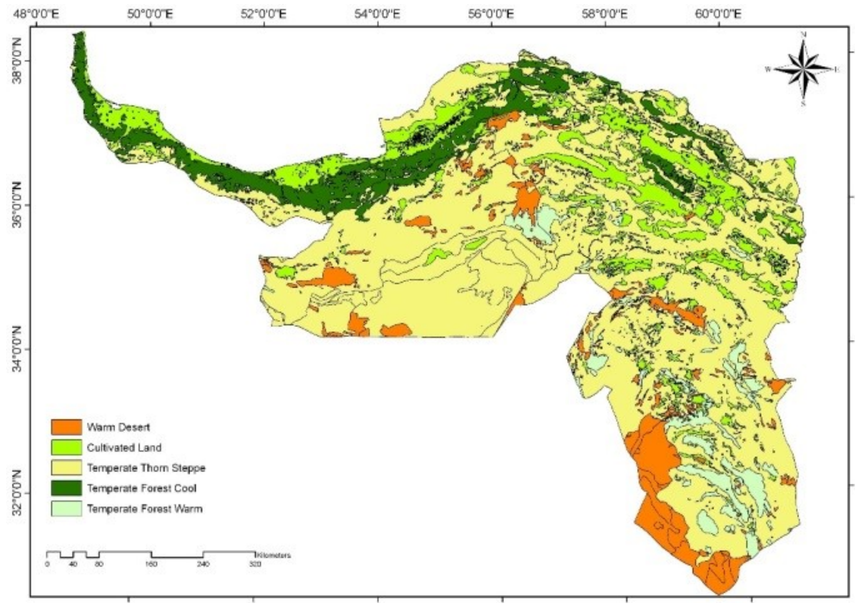

Figure 3: Land-use classification in the study area.

2.4. Climate Data

In order to determine future changes in the composition of the atmosphere and the resultant climatic changes, previous studies commonly constructed scenarios of greenhouse gas and sulphate aerosol emissions over a period of time yet to come, namely, the next 100 years and beyond [19]. Emission scenarios are developed and based on assumptions, which link into assumptions made about how society is likely to develop in the future [14]. In this study, the use of A2 and B2 emission scenarios enabled us to simulate the SOC changes under changes of temperature and precipitation in future conditions. The relative changes in precipitation and temperature data for A2 and B2 scenarios are listed in Table 3. The LARS-WG model was used to produce climate data in 50 km ×50 km grid resolution as an input for the RothC model [20].

TABLE 3: PRECIPITATION AND TEMPERATURE CHANGES UNDER A2 AND B2 SCENARIOS, COMPARED WITH THE OBSERVED DATA.

Stations	Baseline			A2			B2		
	P (mm)	T_{max} (°C)	T_{min} (°C)	P (rise mm)	T_{max} (rise°C)	T_{min} (rise°C)	P (rise mm)	T_{max} (rise°C)	T_{min} (rise°C)
Anzali	1773	18.9	13.7	13	1.5	0.5	4	1.3	0.2
Astara	1380.9	18.7	11.7	14.6	0.7	0.3	12	0.8	0.4
Babolsar	951.5	21.1	13.8	3.5	1.4	0.6	4.6	1.2	0.3
Birjand	169.8	24.3	8.2	-17.3	1.8	0.5	-16.2	1.5	0.8
Bojnurd	271.0	19.7	6.8	-15.2	1.3	0.7	-13.6	1.01	0.5
Garmsar	128.0	25.8	11.2	-20	0.9	0.1	-19.2	1.1	0.3
Gonabad	144.4	23.8	10.7	-9.6	0.6	0.1	-10.1	0.7	0.3
Gorgan	546.1	18.5	11.2	-5	1.2	0.7	-3.8	1.3	0.6
Ferdous	150.0	24.4	10.02	-17.4	0.8	0.3	-6.3	0.9	0.3
Kashmar	203.2	23.6	11.9	-11.5	1.2	0.5	-12.4	1.4	0.7
Mashhad	254.7	21.6	8.6	-18.3	1.6	0.5	-6.9	1.8	0.9
Noushahr	1318.7	19.6	12.8	-6.3	1.2	0.3	17	1.4	0.6
Ramsar	1216.9	19.4	13.5	17	1.1	0.6	15	0.9	0.4
Rasht	1363.8	20.6	12.1	10.4	1.3	0.4	9.5	1.5	0.8
Sabzevar	200.2	24.7	11.9	-9.6	1.8	0.9	-10.9	1.5	0.6
Sarakhs	193.0	17.9	11.13	-15.3	1.1	0.4	-14.2	1.4	0.5
Semnan	142.8	23.5	13.11	-16.3	1.4	0.3	-17	1.5	0.6
Shahroud	162.5	20.7	9.7	-18.2	1.3	0.9	-17.8	1.6	0.8
Torbat Heydarieh	278.3	21	6.9	-14	1.6	0.7	-13	1.5	0.3

3. RESULTS AND DISCUSSION

3.1. Soil Organic Carbon under Climate Change Scenarios

The total and annual input of SOC under different IOM are shown in Table 4. The model illustrated that the total carbon and carbon input are 106.2 tC/ha^{-1} and 6.58 tC ha^{-1} for all zones, respectively. The results illustrated that more than half (over 60%) of the total SOC is distributed between two zones, namely: cool temperate forest and cultivated lands. All the other zones collectively share less than 40% of the SOC. From the percentage of annual carbon input to soil, it can be noted that when the decay process is enhanced by temperature and precipitation, a higher amount of annual SOC is required to stabilize the carbon content in that area. For example, over 70% of the total annual carbon input to the soil is found in cultivated as well as cool temperate forest zones, while the remaining 30% is located in the other zones. These findings also illustrate that in the warm study areas (like deserts) the lowest amount of annual carbon input could maintain the total SOC content.

TABLE I. TOTAL SOIL CARBON AND CALCULATED ANNUAL INPUT OF CARBON OF SOILS.

Zone	Total C (tC/ha^{-1})	Carbon input (tC/ha^{-1})
Warm desert	3.9	0.26
Temperate thorn steppe	10.5	0.48
Temperate forest cool	41.7	1.02
Temperate forest warm	7.8	2.55
Cultivated lands	42.3	2.27
Total	106.2	6.58

The findings revealed that the total amount of soil carbon expected to be lost from the soil under scenario A2, in comparison to the observed SOC. The SOC decreased approximately 8.3 tC/ha^{-1} and 13.36 tC/ha^{-1} by 2030 and 2065, respectively (Table 5). Predictions strongly suggest that the total amount of SOC will drop to 97.9 tC/ha^{-1} by 2030 and 92.84 tC/ha^{-1} by 2065. The results showed that SOC declined mainly in cultivated land. The specific decrease of SOC was 2.5 tC/ha^{-1} and 4 tC/ha^{-1} by the year 2030 and 2065, respectively. Under the A2 scenario, SOC would decrease in temperate forest warm (1.26 tC/ha^{-1}) and temperate forest cool (2.2 tC/ha^{-1}) during 2030 compared with its basic level, while SOC showed predicted decreases of 2.06 tC/ha^{-1} and 3.6 tC/ha^{-1} in these area during 2030 and 2065, respectively. Fig. 4 shows the simulated future changes of SOC compared with its values during 2009-2010 under A2 and B2 scenarios.

TABLE 5: TOTAL SOIL CARBON VARIATION UNDER A2 SCENARIO.

Zone	Original SOC (tC/ha-1)	C 2030 (tC/ha-1)	C 2065 (tC/ha-1)	Original SOC -2030 (tC/ha-1)	Original SOC -2065 (tC/ha-1)
Warm desert	3.9	2.92	2.6	0.98	1.3
Temperate thorn steppe	10.5	9.14	8.1	1.36	2.4
Temperate forest cool	41.7	39.5	38.1	2.2	3.6
Temperate forest warm	7.8	6.54	5.74	1.26	2.06
Cultivated lands	42.3	39.8	38.3	2.5	4
Total	106.2	97.9	92.84	8.3	13.36

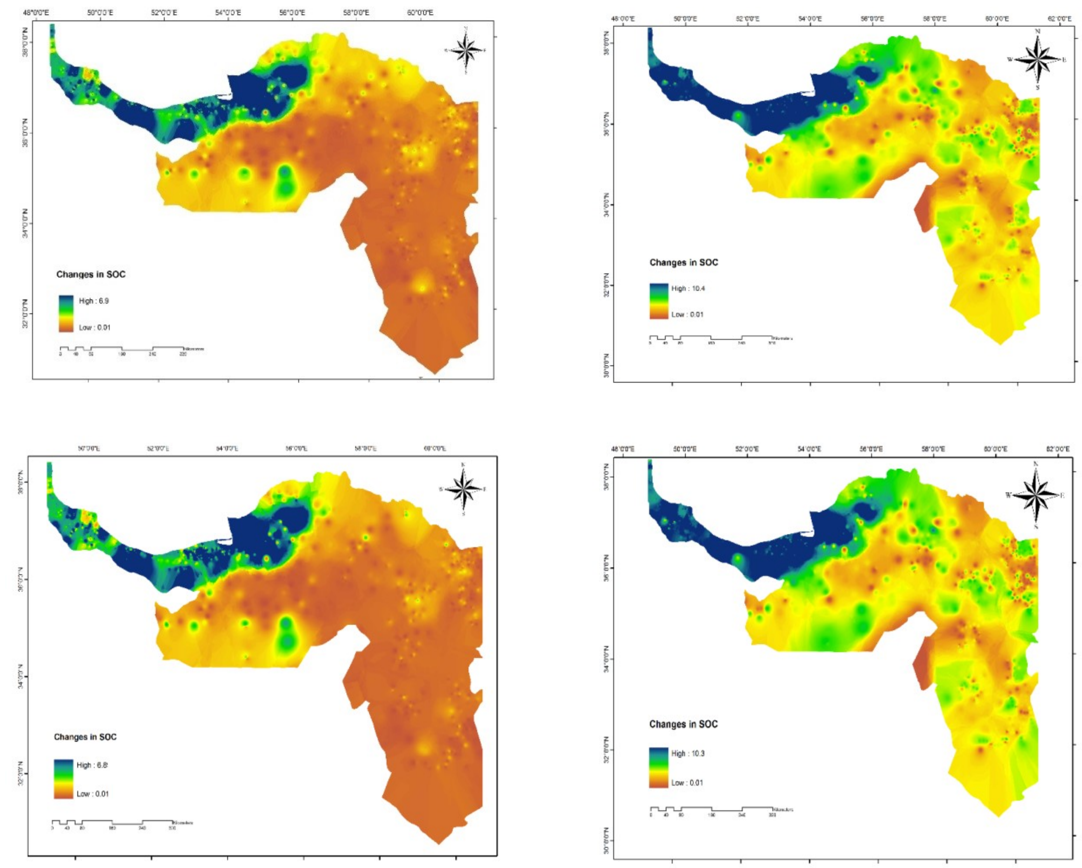

Figure 4: The change of soil organic carbon compared with observed data under A2 and B2 climate scenarios in north and northeast of Iran. (a) A2 2030, (b) A2 2065, (c) B2 2030, (d) A2 2065.

The trends of SOC change predicted under the B2 scenario were the same as those predicted under the A2 scenario; however, the rate of SOC change was greater under the B2 scenario. The changes of sSOC under the B2 scenario for 2030 and 2065 are shown in Table 6. The findings illustrate that the amount of SOC would decrease in comparison with original data under changing temperature and precipitation. The total SOC showed predicted decreases of 8.58 tC/ha^{-1} and 13.81

tC/ha^{-1} during 2030 and 2065, respectively. The overall amount reduction in SOC was also notable in cultivated land in 2030 (2.3 tC/ha^{-1}) and 2065 (3.6 tC/ha^{-1}) compared with basic data. The area with only a slight decrease in SOC was obtained 0.92 tC/ha^{-1} and 1.4 tC/ha^{-1} for warm desert during 2030 and 2065 compared with basic data, respectively. Under the B2 scenario, the trends in SOC change in 2065 were similar to those predicted for 2030, but the range of change was greater.

TABLE 6: TOTAL SOIL CARBON VARIATION UNDER B2 SCENARIO.

Zone	Original SOC (tC/ha^{-1})	C 2030 (tC/ha^{-1})	C 2065 (tC/ha^{-1})	Original SOC2030 (tC/ha^{-1})	Original SOC 2065 (tC/ha^{-1})
Warm desert	3.9	2.98	2.5	0.92	1.4
Temperate thorn steppe	10.5	8.7	7.79	1.8	2.71
Temperate forest cool	41.7	39.5	38.3	2.2	3.4
Temperate forest warm	7.8	6.44	5.1	1.36	2.7
Cultivated lands	42.3	40	38.7	2.3	3.6
Total	106.2	97.62	92.39	8.58	13.81

In general, modelling results showed that SOC decreased under A2 and B2 climate scenarios in the study area. The pattern of decrease of SOC was greater under B2 scenario compared to A2 scenario. Our findings are partially in agreement with previous studies in different parts of the world [21,22]. Changes in precipitation and temperature can, over time, lead to a reduction in the quantity of soil organic carbon in the soil. A rise in precipitation and temperature can speed up SOC decomposition whilst fluctuations in precipitation and temperature may influence the storage of SOC in any physiographic unit [21,23]. The study by Wan et al. [9] found that SOC decreases at a higher rate in northern China compared with Southern China. Usually the higher decrease of SOC happened under B2 scenario. Smith et al. [21] reported that climate impacts would reduce the mean grassland soil carbon stock by 6–10% of the 1990 level by 2080. Friedlingstein et al. [24] found that precipitation could offset the effect of temperature on SOC. Regarding the agricultural regions, apart from the effect of climatic factors, the loss of soil organic carbon was found to accelerate as a result of land misuse through, for example, biological activity and soil mismanagement, as commonly caused by humans. As a result, the soil organic carbon contents were reportedly lower than their potential levels in most agricultural soils. In these regions, respiration and decomposition processes take a lead on the process of productivity, causing negative feedback [25,26].

3.2. Impact of Climate Change in Different Land Use Areas

Fig. 5 revealed the results of the comparison between monthly temperature and precipitation, as observed data with A2 and B2 scenarios in different land use. The warm desert area showed that a slight increase in temperature in future. The maximum predicted temperatures reach 0.5°C and 0.9°C in scenarios A2 and B2, respectively. The results also showed that in the future precipitation will decrease. The possible explanation for this is that deserts can be characterised by low rainfall, dry air and incoming solar and outgoing terrestrial radiation, as well as high potential evapotranspiration. Therefore, desert areas generally experience less variability in precipitation and temperature. These findings are all in good agreement with the results of Modarres and Silva [27] and Sadeghi et al. [28]. In the cool temperate forest, the temperature will increase 0.5°C and 0.4°C under A2 and B2 scenarios in comparison with basic data, respectively. The maximum predicted temperature reaches 1°C in December under A2 scenario. Changes in the predicted temperatures are noticeably smaller in the warmer months. Additionally, the results show that precipitation will increase in this area in the future. The predicted precipitation will rise by about 11.2 mm and 10.8 mm in July and September, respectively. Regarding predictions for the area of warm temperate forest, temperature is likely to increase in both scenarios with a maximum rise of 0.9°C and 0.7°C in November and January, respectively. As for precipitation in this area, predictions suggest that in the future it will decrease during the cold seasons. Analysis of temperature trends showed that the maximum rise of precipitation occurs in the temperate thorn steppe region under A2 and B2 scenarios. Cool temperate forest and cultivated lands are regions most sensitive to increases or decreases in predicted temperature and precipitation in both scenarios. Under the monthly variation, the greatest increase in temperature occurred during the colder months.

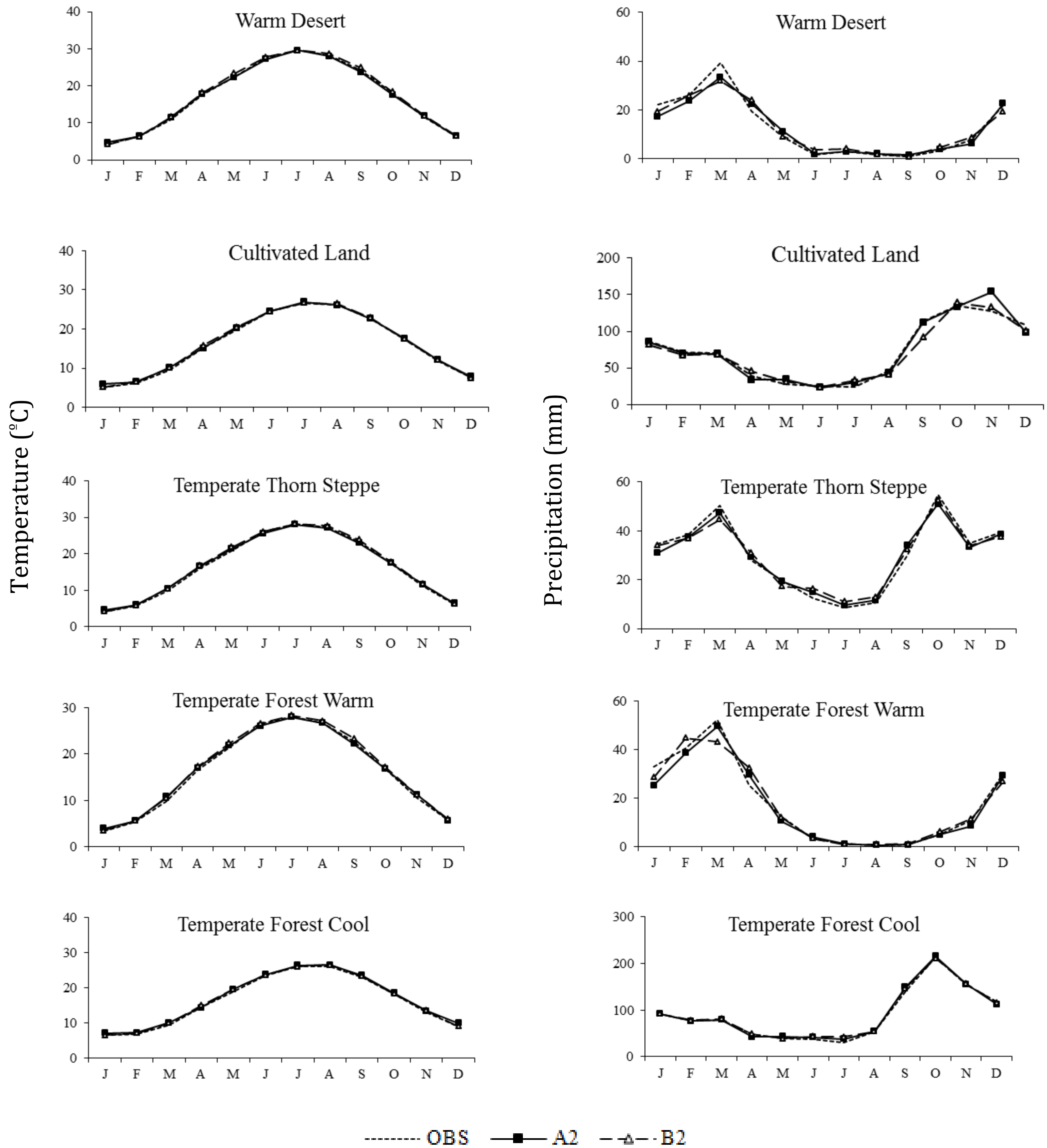

Figure 5: Monthly temperature and precipitation trends compared between observed with A2 and B2 scenarios in different land use

Temperatures are expected to increase in the future because in recent years, big cities have undergone very rapid urbanization. Population growth, local industries, transportation, and construction increased the temperature and created urban heat islands [29-31]. Undoubtedly, these changes can have serious consequences like affecting water resources as well as agriculture and causing prolonged drought. Limitations to using current climate models are that they do not make estimations of wind and humidity, two important factors particularly in hydrological, ecological, geomorphologic, and agricultural models [32].

4. SUMMARY AND CONCLUSIONS

This study demonstrated that RothC model is one of the most useful models for SOC simulation and prediction because this model required a limited number of input data such as climate (temperature, rainfall and evaporation), soil texture (clay content) and land management files. RothC is therefore a suitable tool for estimating soil organic carbon changes under different climate change conditions. The results indicated that increasing temperature and decreasing precipitation lead to a change of SOC in different land use. Based on modelling results, it can be said that soil organic carbon changes would decrease in the study area under A2 and B2 climate scenarios compare to basic data at the 0-30 cm depth by the year 2030 and 2065. The total soil organic carbon was 106.2 tC/ha^{-1} during basic year, while it was obtained 97.9 tC/ha^{-1} during 2030 and 92.84 tC/ha^{-1} during 2065 under A2 scenario. The total soil organic carbon was accounted 97.62 tC/ha^{-1} and 92.39 tC/ha^{-1} during 2030 and 2065 under B2 scenario, respectively. The decrease rate of SOC was higher in cultivated land under both scenarios. The minimal decrease of SOC occurred in warm desert area under A2 and B2 scenarios.

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Investigating the Effects of Climate Change on Wetlands Using Risk Assessment and Remote Sensing (Case Study: Choghakhor Wetland, Iran)

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Abstract

Climate changes result in altered temperature and precipitation patterns that affect wetland physical and ecological processes and poses risks for these ecosystems. Understanding the effects of a changing climate on wetland biotic and hydrologic processes in the form of climate risk assessment is necessary. This study uses a process of environmental risk assessment (ERA) to identify climate risks and responses within the framework of ecosystem-based approach. The paper aims to enumerate risks related to climate change impacts; prioritize risks that require further attention; and establish a process for ensuring that these higher priority risks are managed effectively. The proposed methodology was applied to Choghakhor international wetland, located in southwest of Iran. In order to assess the trends of changes in the study area, land use changes were investigated in a period of ten years (2003- 2013) using remote sensing (RS) technique. Two major variables of climate changes, temperature and precipitation, have been considered as the climate hazards which have impacts on the ecosystem and analyzed for a period of 31 years (1981- 2012). In the next level, climate risks on wetland ecosystems have been identified. In the characteristics step, risks are analyzed according to severity and probability of consequences. A Multi Criteria Decision Making (MCDM) method is used to prioritize these risks on the basis of experts' opinions. Finally, management strategies are proposed to deal with the risks. According to the results, high-ranking potential risks and management strategies were proposed for this wetland.

Keywords: Climate Change, Remote Sensing, Risk Assessment, Choghakhor Wetland, Iran.

1. INTRODUCTION

Wetlands are among the most valuable yet vulnerable habitats on Earth [1-3]. They are formed and sustained by hydrologic processes driven by climate, geology, and landscape setting [4,5]. Wetlands typically occur at low points in their watersheds, and the flow paths sustaining them integrate catchment-scale processes and environmental conditions. Close proximity of the water table and land surface makes wetlands susceptible to changing hydrologic, landscape, and climatic conditions [1,6]. Climate changes result in altered temperature and precipitation patterns that affect wetland physical and ecological processes. Understanding the effects of a changing climate on wetland biotic and hydrologic processes is challenging due to the spatial and temporal complexity of wetland habitats [1,6]. However, land management should be based on an understanding of wetland functional types.

There has been little attention to date given by conservation bodies to the relationship between climate change and the protection and management of wetland ecosystems. The projected changes in climate are likely to affect wetlands significantly in their spatial extent, distribution and function [7,8]. Conditions in the 21st century are expected to be substantially drier than during the past century, perhaps closer to what they were in the mid-1980s when explorers found much of the region to be too dry to warrant cropping [9]. The intergovernmental panel on climate change (IPCC) predicts that surface temperature around the globe could rise between 1.1 and 6.4 degree centigrade by 2100 [10]. Future precipitation patterns are more difficult to predict.

Although the effects of climate change are worldwide accepted the biological responses vary widely across species which can biologically respond against the potential climate related extinctions by moving or staying [11]. Coupled with climate change, habitat destruction is considered another major threat on global biodiversity, able to influence the distribution of suitable areas for many species, thus limiting their ability to migrate or adapt in response to climate variability [12]. The effect of climate variation on the distribution and availability of habitats are expected to be particularly severe on aquatic ecosystems [13,14], mainly related to changes in the quantity and quality of water supply due to the alteration in hydrological regimes and land use changes [1]. This can result in a reduction of their functional capacity or the shifting of their geographic location [15]. Thus, climate change poses risks for human and natural systems, climate risk assessment and management seems necessary. Climate risk management (CRM) is the systematic approach to considering climate related trends and events in development decision-making to minimize potential harms. Climate change is altering the nature of climate risk, increasing uncertainty and forcing us to re-evaluate conventional CRM practices [16].

Sousa and Morales [17] applied the environmental indicators to the impacts of climate change and aimed to do a multidisciplinary analysis. Erwin [15] discussed that wetland systems are vulnerable to changes in quantity and quality of their water supply and it is expected that climate change will have a pronounced effect on wetlands through alterations in hydrological regimes with great global variability. Acreman et al. [18] presented a simple framework that can be used for combining models and available data at a regional scale. The wetland model is based on broad conceptual understanding of wetland hydrology. The model combines climate changes, hydrological processes and ecological responses. Withey and Kooten [19] employed a linear regression analysis to determine the casual effects of climate change on wetlands with temperature, precipitation and SPI to predict the effect of potential climate change on wetlands.

In this paper, we explain how impacts and risks related to climate change for wetlands can be assessed and managed. Risk is generally defined as a combination of the likelihood of an occurrence and the consequence of that occurrence. In practice, neither likelihoods nor consequences are known with certainty. In the context of climate change risk assessment, uncertainty arises because, although we can be confident the climate is changing, we do not know precisely the magnitude of the changes or their associated impacts and in some regions it is not clear whether rainfall will increase or decrease. As well, uncertainty may arise because decision makers do not know the exact point (or threshold) at which a climate change impact has a particular level of consequence for their organization.

This paper provides a framework for managing the increased risk to wetlands due to climate change impacts. The paper aims to enumerate risks related to climate change impacts; prioritize risks that require further attention; and establish a process for ensuring that these higher priority risks are managed effectively.

2. METHODOLOGY

A framework was developed for assessing the effects of climate change on wetlands using a semi-quantitative approach. Semi- quantitative methods are used to describe the relative risk scale. For example, risks can be classified into categories like "very low" "low", "moderate", "high" and "very high". In semi-quantitative approach, different scales are used to characterize the likelihood of adverse events and their consequences. Analyzed probabilities and their consequences do not require accurate mathematical data [20]. In semi-quantitative methods, risk indicators and values are determined according to information on real available data as well as using judgments made by experts. Fig. 1 presents a structural illustration of the methodology applied to assess the effects of climate change on wetlands. This structure was formed with combination of risk assessment technique, climate change analysis and remote sensing (RS) tool. The method was according to the following steps:

Step 1: Assessment the trends of land use and climate changes; In order to assess the trends of changes in this study, land use changes and climate change parameters were investigated in a period of time, based on the available information. Stages of this step are described in the following:

- Using the Landsat-7 satellite images (ETM+) for wetland land use/cover change assessment.
- Applying the maximum likelihood classification and assessment of classification accuracy with kappa and overall accuracy in ENVI 4.7.
- Evaluating the trend of climate change factors such as the average amount of annual precipitation and temperature for wetland. Characterizing the drought degrees with the Standardized Precipitation Index (SPI) by data of effective stations in the study area.
- Analysis the environmental changes and pressures by considering the results of climatic trend and land use changes.
- Recognize how the wetland is under pressure from climate change.

Step 2: Identification of the climate risks; climate risk refers to the probability of harmful consequences or expected losses resulting from the interaction of climate hazards with vulnerable conditions [21]. Climate hazard refers to potentially damaging hydro-meteorological event or phenomenon that can be characterized by its location, intensity, frequency, duration and probability of occurrence. For this purpose, events with an identifiable onset and termination, such as temperature and precipitation are considered [22]. As can be seen in Fig. 2, these two major variables of climate change and their consequences have been considered as the climate hazards which have impacts on the wetland ecosystem. Based on these hazards, wetland climate risks have been identified.

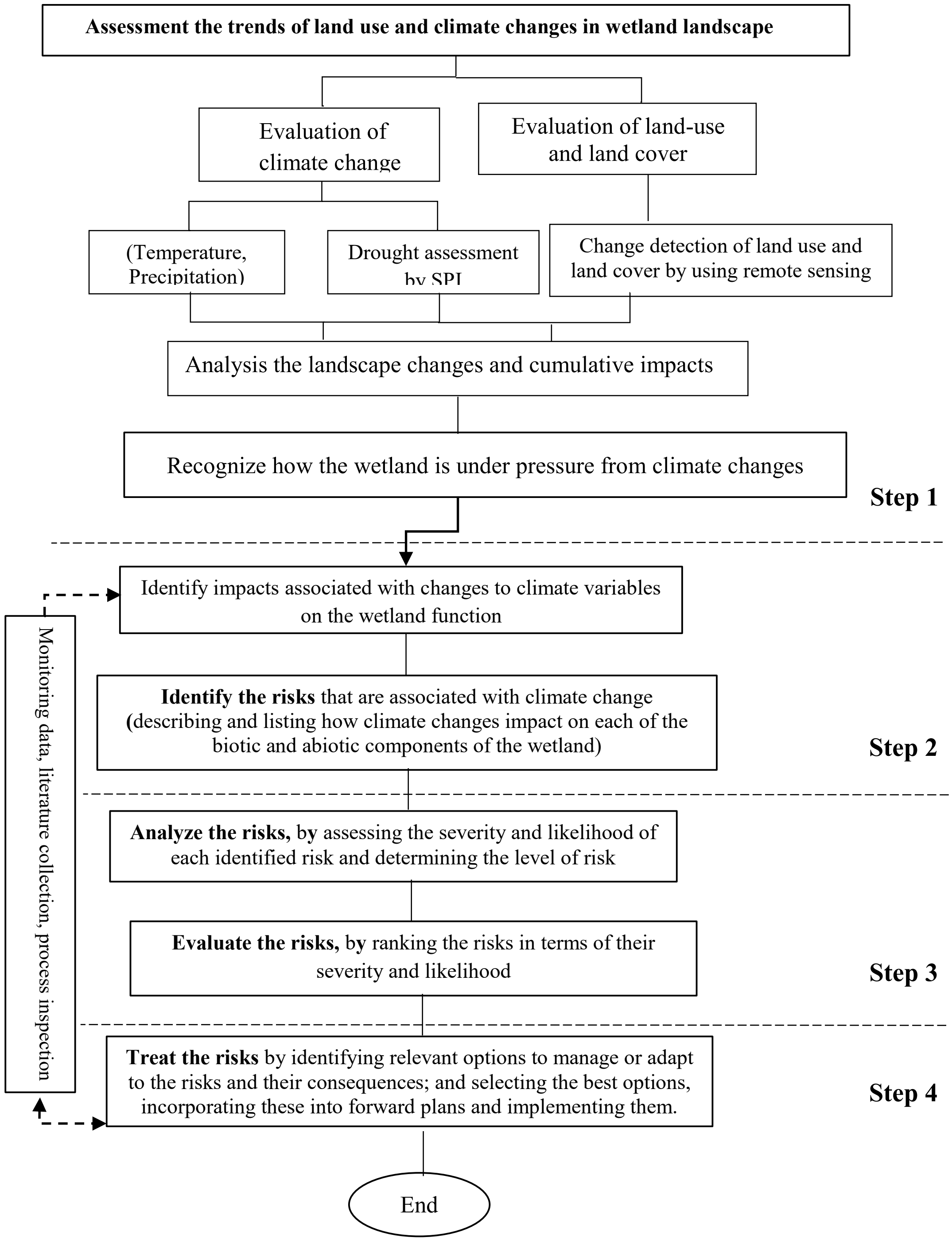

Figure 1: Process of investigating the effects of climate change on wetlands through environmental risk assessment

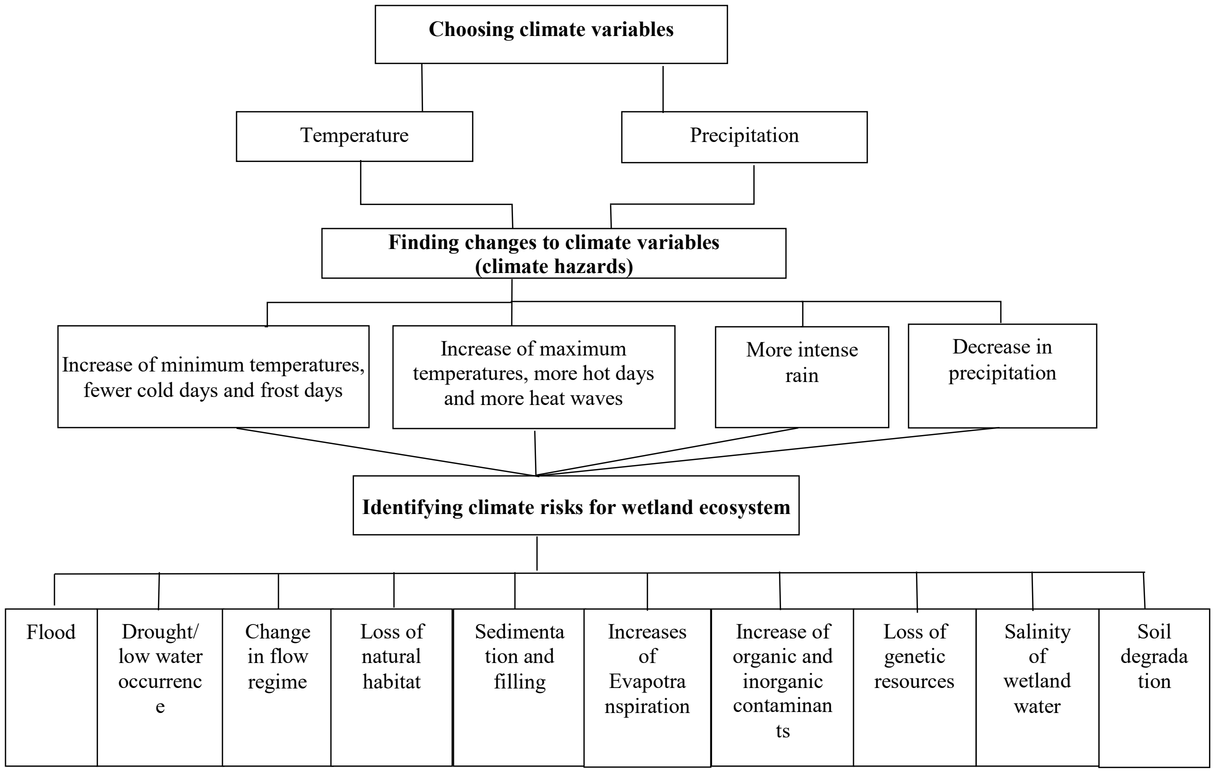

Figure 2: Structure for identification of risks imposed on wetlands in accordance with climate change hazards

Step 3: Climate risk assessment; in this step risks are analyzed according to severity, probability of the risks. A risk index is calculated by analyzing severity and probability in a semi-quantitative approach with Eq. (1).

$$Risk = Probability\ of\ the\ risk \times Severity\ of\ the\ risk \qquad (1)$$

In Tables 1–3, severity and probability of risks were classified by Malekmohammadi and Rahimi [23] from very low to very high with scoring according to that taken from a review of related literature, engineering judgments and information gathered from brainstorming sessions with a group of experts. The determined environmental risks are given a score for severity by applying an assessment of consequences of each potential risk. Expected consequences are identified through assessment of climate risk. In Table 1, classification and scoring of the severity of wetland risks are developed by cumulative impact assessment of consequences in the wetland. Summation of numbers in the first column is equal to 15. Classes of severity are ranked from very high (5) to very low (1) and each class is assigned a score up to 15.

The probability of a wetland climate risk is classified according to probability of the expected consequence (Table 3). By applying Eq. (1), amounts are given as an evaluation of each risk. Table 4 presents the range, classification and description of risks. The risks are prioritized on the basis of their importance. This can be done according to the classification of severity and probability of the risk. These criteria should be valued in risk assessment according to degree of importance and influence. Multi-criteria Decision Making (MCDM) is used to prioritize risks and effective indicators to estimate risk levels.

Step 4: Finally, risk management strategies will be provided for high-risk. The most effective risk management strategies are presented within wetland basin, because wetlands are associated and interacted with upstream and downstream processes.

TABLE 1: CLASSIFICATION AND SCORING OF THE SEVERITY IN THE WETLAND CLIMATE RISK ASSESSMENT [ADAPTED FROM 23]

Expected consequences	Scores range	Classes
Destroying the integrity and existence (5)	15-13	Very high (5)
Changes in the hydrological balance and regime (4)	12-10	High (4)
Disruption of the biological balances (3)	9-7	Moderate (3)
Changes in physical and chemical parameters (2)	6-4	Low (2)
Disruption of the biogeochemical cycles (1)	4<	Very low (1)

TABLE 2: CLASSIFYING OF THE PROBABILITY IN THE WETLAND CLIMATE RISK ASSESSMENT [ADAPTED FROM 23]

Expected consequences	The likelihood of the consequences	Classes
Certain (Risks occur continuously).	Very likely	Very high (5)
Common (Risks occur usually)	Greater than 50 percent	High (4)
Possible (Risks may occur from existing risks.)	Equal to 50 percent	Moderate (3)
Likely, but are low	Unlikely under normal conditions	Low (2)
Likely, but are very low	Impossible or remote under normal conditions	Very low (1)

TABLE 3: CLASSIFICATION AND DESCRIPTION OF THE RISKS IN THE WETLAND CLIMATE RISK ASSESSMENT

Risk range	Classification	Description
21-25	Very high	Unacceptable
20-16	High	Unacceptable
11-15	Moderate	Acceptance with conditional control
6-10	Low	Acceptable
1-5	Very low	Negligible

3. STUDY AREA

Choghakhor international wetland in Boroujen city of Chaharmahal-O-Bakhtiaryi province in southwest of Iran is in the upper drainage of the Karun River in the Zagros Mountains. This wetland with 1,600 hectares' areas and freshwater resources is located between 50° 52′ to 50° 56′E and 31° 54′ to 31° 56′N in height 2,270 meters above mean sea level (Fig. 3). The marsh floods in winter and spring to a maximum depth of about 2 meters. In year 2012, much of the wetland was dried and the remainder was almost entirely overgrown with emergent marsh vegetation. Large portions of the plains around the wetland are under cultivation of wheat. It is located in non-protected area in prohibited hunting zone that 2,500 ha proposed for refugee site [24,25]. Study area include three sub-basins namely Shalamzar, Ardal, Gandoman-Boldaji. In Ardal sub-basin a water transition project is under construction, therefore it's considered as source of process. Choghakhor wetland is located in Shalamzar sub-basin and there is a water transmission channel to provide water for down-land Boroujen plain. Gandoman-Boldaji sub-basin which accommodates an underground aquifer (Gandoman-Boldaji aquifer) plays role of a sink and storage site. Although, water doesn't remain there wholly, it's flowed to its down-land, but because an aquifer fed by delivered water, this sub-basin can be considered as intermediate sink. As presented in Fig. 3, a water transition project was considered from Sabzkouh river basin to Choghakhor wetland. It has started since 1997 for providing water demand of Choghakhor petrochemical industrials, agricultural activities, drinking water of Boroujen city, employment and prevents uncontrolled immigration [26].

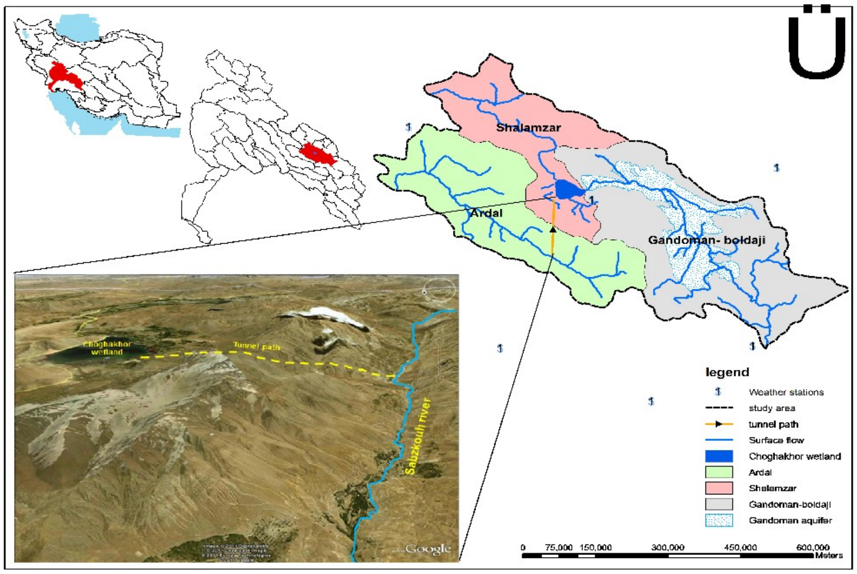

Figure 3: Location of Choghakhor wetland and related basin in Iran [27]

4. RESULTS AND DISCUSSION

The aforementioned steps were performed for Choghakhor wetland landscape. Detecting the land use and land cover changes in 2003 and 2013 indicate five distinct classes, including: pasture and forest (cultivated and non-cultivated), bare land, man-made (settlements and roads) and water (snow and water) results (Figs. 4 and 5). Data processing in this period represent increasing area in cultivated and man-made lands are 18 and 26.3 percent and decreasing in water body, pasture and forest and bare lands are 51.4, 4.2, and 2 percent. The results of classification accuracy measurement were estimated on 89% and 64% in 2003 and 93% and 68% in 2013 for overall accuracy and Kappa coefficient, respectively. The most effective meteorology data (Overgan station records) in wetland area in 2012 illustrated that the amount of standard precipitation index is -0.89, which confirmed a drought was occurred. The probability of drought occurrence is predicted by 41.7% which is in accordance with previous year records (Table 4). The investigation on climatic change elements showed an increasing trend in average annual temperature with a sharp and irregular fluctuation of rainfall in recent years (Fig 6).

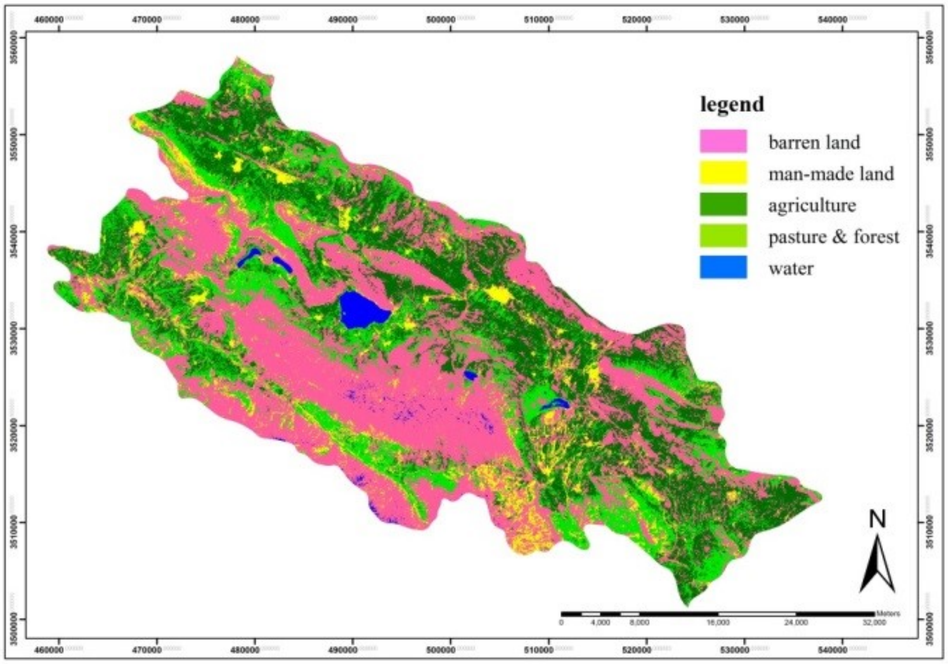

Figure 4: Classified image of study area in 2013

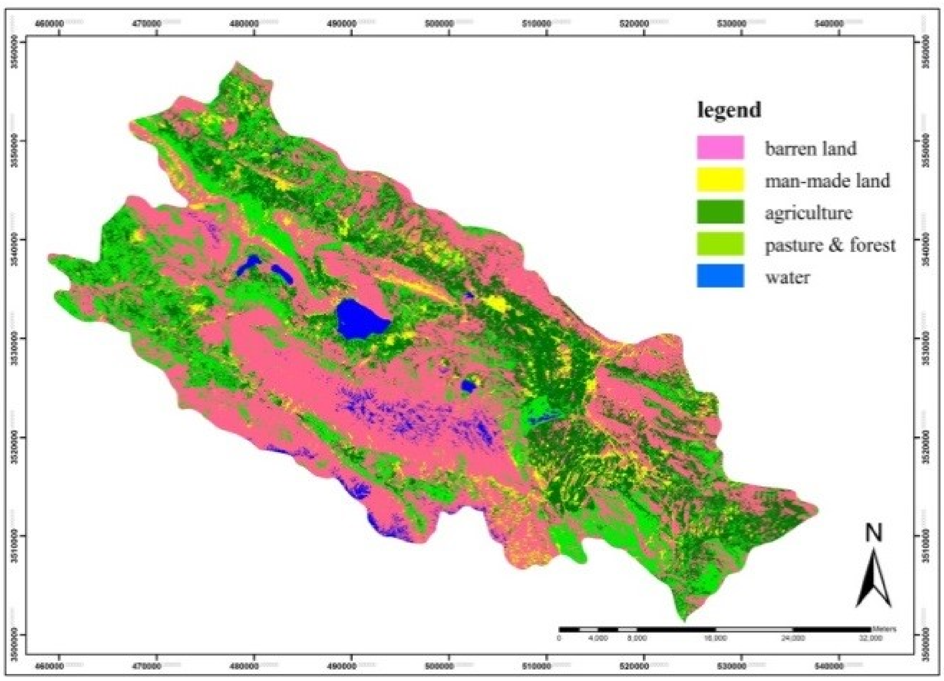

Figure 5: Classified image of study area in 2003

TABLE 4. PRECIPITATION, SPI INDEX AND FUTURE POSSIBLE STATUS IN WEATHER STATIONS OF CASE STUDY AREAS [27].

Weather station	Armand	Overgan	Behesht abad	Boroujen	Lordgan	Soolegan
Annual precipitation, 2011-2012, (Millimeter)	437	381	649	233	435	613
SPI index	0.01	0.92	0.04	0.42	0.89	0.92
Possible status	Dry to wet	Dry to wet	Normal to normal	Normal to wet	Dry to dry	Normal to normal
Probability of occurrence percentage	44.4	41.7	50.0	54.5	40.0	40.0

Investigation on the trend of thirty-year records of climatic elements and the obtained results by satellite monitoring of landscape illustrated 50% decline in water resources amount. Rainfalls declining, rise of a few degrees in the annual average temperatures in the region and the recent drought, as the remote sensing processing result were confirmed water shortage is in expanded trend. Despite, land use changes play an important role during water shortage period, the agriculture development has imposed enormous environmental pressures by excessive consumption of water, fertilizers and pesticides. Drying of springs, reduction of groundwater level, increase of organic and inorganic contaminants and finally enrichment and declining of dissolved oxygen in wetlands is a description of occurred situation due to cascading effects of land use change simultaneously with the climate change which could be effective on ecosystem functions of wetland such as water purification and regulation [27]. Risks and stressors imposed on this wetland were identified in accordance with climate hazard and climate risk.

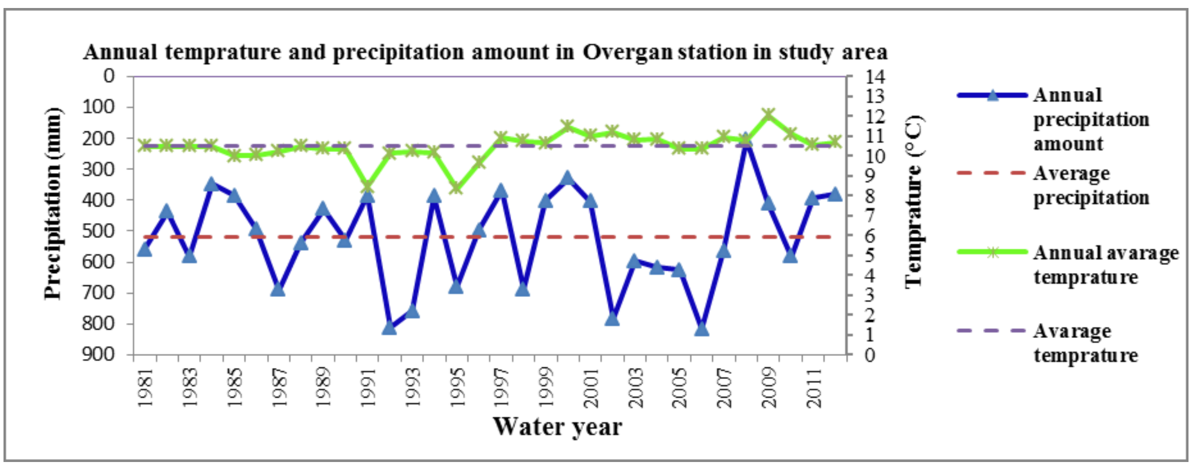

Figure 6: Climate factors trends in case study area [27]

TABLE 5: INVESTIGATE THE IMPACT OF RISK FACTORS ON WETLANDS AND DETERMINE THE SEVERITY OF THE CONSEQUENCES

Risk factor	Harmful potential effects	Severity of the risk					Total
		Destroying the integrity and existence of wetland (5)	Changes in the hydrological balance and regime (4)	Disruption of the biological balances of wetland (3)	Changes in physical and chemical parameters (2)	Disruption of the biogeo-chemical cycles of wetland (1)	
Flood	-Increases and/or decreases habitat space depending on species -Facilitates dispersal of isolated aquatic populations -Dilutes contaminants, suspended sediment, and plant material -Changes vegetative community over long-term -Decreases rate of photosynthesis	*	*	*		*	13
Drought/low water occurrence	-Reduction in productivity and survival of the wetland - Reduction of hydrological stability	*	*			*	10
Change in flow regime	-Reduces in water inflow -Reduces in water flow purification	*	*		*		11
Loss of natural habitat	-Increases evapotranspiration -Increases concentration of inorganic -Reduces habitat availability and suitability	*			*	*	8
Sedimentation and filling	-Depresses biological uptake, processing and photosynthesis -Diminishes species richness -Reduces groundwater recharge -Changes in sediment particle size -Increases surface runoff		*	*	*	*	11
Increase of Evapo-transpiration	-Increases rates of chemical and biological functions -Reduces species richness			*	*	*	6
Increase of organic and inorganic contaminants	-Diminishes species richness -Reduces photo-oxidation of some contaminates -Depresses denitrification, photosynthesis, and biological uptake -Effects on chemical adsorption depend on chemical			*	*	*	6
Loss of genetic resources	-Diminishes species richness -Reduces native diversity and production -Change in biodiversity at wetland and landscape scale -Decrease genetic material and evolution in wild plants and animals			*		*	4
Salinity	-Reduces denitrification, biological uptake and photosynthesis - Diminishes species richness -Enhances adsorption of some chemicals			*	*	*	6
Soil degradation	-Diminishes species richness -Increases erosion potential -Reduces hydrologic residence time		*	*		*	8

Table 5 describes harmful potential effects for each risk factor. The most important consequences by evaluation of risk factors were identified as destroying the integrity and existence of the wetland, changes in hydrological balance and regime, biological imbalance, changes in physical and chemical parameters and disruption of biogeochemical cycles of the wetland. The risk factors threatening Choghakhor wetland were analyzed according to the methodology and presented in Table 6. According to the severity index, drought /low water occurrence, change in flow regime, sedimentation and filling were evaluated as having the high level of risk. Also, increases in evapotranspiration, increase of organic and inorganic contaminants, and loss of genetic resources were evaluated as having low level of risk. Risk factors were prioritized by multiplying risk level and importance weight of each risk. Rankings of risks are shown in the last column of Table 6 and represent the priority of each risk factor. Based on these priorities, drought/low water occurrence factor has high ranking and loss of genetic resources has low ranking. Based on the results of risk analysis, strategies to manage and reduce the climate risks of Choghakhor wetland are abstracted in Table 7. The proposed management strategies for the wetland were determined by the above-mentioned ecosystem-based approach

TABLE 6: RESULTS OF CALCULATION OF THE CLIMATE CHANGE RISKS IN THE CHOGHAKHOR WETLAND

Risk factor	Severity	Probability	Risk level	Importance weight in AHP	Weighted risk	Risk ranking number
Drought/low water occurrence	High (4)	Very high (5)	High (20)	0.18	3.6	1
Change in flow regime	High (4)	Very high (5)	High (20)	0.16	3.2	2
Loss of natural habitat	Moderate (3)	High (4)	Moderate (12)	0.099	1.18	5
Sedimentation and filling	High (4)	High (4)	High (16)	0.14	2.24	3
Increases evapotranspiration	Low (2)	Very high (5)	Low (10)	0.094	0.94	6
Increase of organic and inorganic contaminants	Low (2)	High (4)	Low (8)	0.097	0.77	7
Loss of genetic resources	Low (2)	Moderate (3)	Low (6)	0.12	0.72	8
Soil degradation	Moderate (3)	High (4)	Moderate (12)	0.11	1.32	4

TABLE 7: MANAGEMENT STRATEGIES FOR REDUCING EFFECTS OF CLIMATE RISK FACTORS IN CHOGHAKHOR WETLAND

Risk factor	Risk level		Management strategies (control measures)
	Category	Rating	
Drought/low water occurrence	High	1	- Designing a drought monitoring network in the Shalamzar sub-basin
Change in flow regime	High	2	- Allocating the minimum of water rights - Restricting unauthorized exploitation of the water resources, especially in drought periods
Sedimentation and filling	High	3	- Avoid constructing projects near wetland - Restrict accessible areas and vehicle types - Require storm water management and/or sediment control practices. If necessary, physical removal of sediment
Soil degradation	Moderate	4	- Encourage reforestation and/or soil conservation activities on upland areas
Loss of natural habitat	Moderate	5	- Avoid or minimize disturbance of significant wetland areas - Avoid Or minimize wetland disturbance by applying wetland setback regulation

5. CONCLUSION

In order to protect and manage wetlands in a sustainable way, it is necessary to reduce risks that impact on the wetlands. According to the presented methodology, impacts and risks related to climate change can be identified and managed. This method focuses on identification of impacts associated with changes to climate variables on the wetland function. Results of this study for Choghakhor wetland reveal that the climate risk inflicted on the environment of this wetland causes adverse effects on characteristics of the wetland. Drought/low water occurrence, Change in flow regime, sedimentation and filling are the main climate hazard of this wetland. All of these factors are interrelated and due to the complexity of wetland ecosystems, it is difficult to separate the effects and consequences of these factors. For Choghakhor wetland, management strategies are suggested on the basis of the results of this research. Another important issue in wetland climate change risk assessment is the matter of vulnerability which refers to the potential for a system to be harmed by climate change. When assessing vulnerability, we need to recognize the hazard specificity of people's vulnerability; we understand vulnerability to be a function of a system's sensitivity and its adaptive capacity, so as one of the most important functions in climate risk assessment, it is suggested to estimate and assess a wetland ecosystem adaptive capacity in future studies. In many arid and semi-arid regions of the world, environmental water flows are declining due to the over-allocation of water for human use, particularly for agriculture; these trends are compounded by droughts and longer-term climatic changes. As a result, flows in many rivers and water volumes reaching downstream lakes and wetlands are greatly reduced, resulting in severe environmental, social and economic impacts. Salt- and dust-laden winds and degradation of lands are among the present consequences arising from the drying of wetlands, which are causing serious social, economic and health problems for the inhabitants of the basins. The main challenge behind these problems is the over-allocation and mismanagement of water resources. This can be seen through the recent combined impact of droughts, climate change and the consequences of the unsustainable management of water resources which has brought two of Iran's most precious wetlands, Lake Urmia and the Hamouns, to the brink of ecological catastrophe. Nor are these only wetland problems in Iran, some other wetlands have already completely disappeared and others are under immense threat [28]. The future studies can be focused on finding indicators for identifying wetland resiliency in terms of water resources and other related ecosystems functions under risk of climate change. Based on the abovementioned agenda, the future studies can be conducted to answer these questions. Is it possible to have positive resiliency in wetland ecosystems under risk of climate change? How can find some indicators to use in making decision in ability to renovate and ranking degree of resiliency of wetland ecosystems? How can develop an adaption management plan for reducing vulnerability and increasing resiliency under risk of climate change for wetland ecosystems?

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Climate Change and Air Quality in Iran: A Case Study Analysis for Tehran

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Abstract

Aerosol particles impact the planet's energy balance, the hydrologic cycle, atmospheric visibility, and public health. Areas with especially high vulnerability to the deleterious effects of particulate matter include urban areas such as Tehran, Iran, which has unfavorable topography that suppresses ventilation of pollutants from the city. Projections of future climate change suggest that dry areas such as Iran and the southwest part of North America will become dryer, which can lead to more dust emissions and wildfire emissions. This is problematic for urban areas such as Tehran that already are dealing with high levels of anthropogenic pollution on top of which these other forms of natural emissions become superimposed. This work serves as a baseline study for the period between 2000 and 2009 to characterize air quality characteristics in Tehran.

Keywords: Aerosol, Air Quality, Tehran, Dust

1. INTRODUCTION

Aerosol particles impact the planet's radiation balance, the hydrologic cycle, public health and welfare, and biogeochemical cycling of nutrients and contaminants. Aerosol particles, especially dust, act as carriers for potentially harmful contaminants and beneficial nutrients to ecosystems where their effects are felt after dry and wet deposition. The effects of particles in arid and semi-arid regions such as the Middle East that cover over a third of the global land area are especially of importance to understand as these regions exhibit high levels of airborne dust. Particulate matter has been extensively monitored in several major urban centers of the world such as Beijing, Mexico City, and Los Angeles, but one area that has received disproportionately less attention is the arid Middle East. The Middle East is a major center of dust and includes megacities such as Tehran, Iran, that are facing serious air quality issues. Projections indicate that dry areas will become dryer, which promotes more dust emissions and wildfires. As a result, it is critical to understand and improve air quality in areas such as Tehran that are exposed to significant anthropogenic pollution in addition to dust and biomass burning. The subsequent discussion is adopted from the work of Crosbie et al. [1].

Iran' capital city is Tehran, which covers an area over 2,300 square kilometers in the northern part of the country (Fig. 1). The population of the Tehran metropolitan area was reported to be 12.2 million in 2011 (United Nations Population Fund; http://iran.unfpa.org/). Air pollution problems are exacerbated in this major metropolitan area due to surrounding mountains, which extend to over 5000 m and inhibit ventilation of pollutants, especially during wintertime. The growing population and extensive anthropogenic emissions result in major air quality issues and uncertain effects on the region's microclimate and hydrological cycle. Visibility data from the last 50 years indicate a long-term trend in visibility reduction and suggest that worsening air quality is attributable to emissions rather than meteorological factors [2]. Vehicular emissions are of particular concern in the region owing to more than two million vehicles, many of which are more than two decades old [3]. Dust has a substantial impact on the region owing to internal sources [4–6], including numerous dry lakes (e.g., Daryacheh-ye Mamak) and the larger Dasht-e Kavir Desert, and external sources due to its location near the Arabian Peninsula to the south and the Euphrates and Tigris Basins to the west [6–9]. PM_{10} concentrations in parts of Iran can reach more than 5 $mg{\cdot}m^{-3}$, which consequently contribute to enhanced mortality [8]. It was reported that in the city of Zanjan, just to the northeast of Tehran, the dominant aerosol type was dust and that only 20% of all particles were smaller than 1 μm [10]. Dust has also been shown to be more abundant in parts of Iran during spring and summer, while motor vehicles are more influential during fall and winter and during weekdays [11].

Figure 1: Geographic locations of the ground-based meteorological monitoring stations

Due to limited availability of surface particulate matter data in the Tehran metropolitan area, satellite remote sensing data are valuable in examining spatiotemporal patterns of air pollution in this area [12]. Concerted efforts to combine satellite data with available surface measurements, air mass back-trajectory data, and chemical transport model results do not exist for the Tehran area and its surroundings, a fact that motivates the current study. The goal of this work is to report a multi-year (2000–2009) aerosol characterization for metropolitan Tehran and surrounding areas with an aim to extend upon previous studies examining air pollution characteristics in Iran. This work addresses the following questions: (i) what are monthly trends in aerosol-related parameters and others that potentially influence them such as meteorology and air mass source regions?; (ii) What is the role of precipitation in modulating aerosol-related parameters?; and (iii) can the datasets provide any indication of the weekly aerosol cycles and the relative strength of dust *versus* other aerosol types? In addressing these questions, we will determine the degree of correspondence between satellite data, chemical transport modeling, and surface measurements of visibility. Direct surface measurement data for aerosol particles are not publicly available for Tehran during the study period. In light of this limitation this study leverages a combination of remotely-sensed data, local meteorological observations and model data, the details of which are summarized by Crosbie et al. [1].

2. RESULTS

2.1. Meteorology

Local meteorological conditions are examined using surface station data at Tehran (Mehrabad) and compared with data from the nearby stations at Gharakhil and Semnan to understand the impact of local microclimatic variability within the context of the region (Fig.1). A summary of the monthly average surface station data at Mehrabad, Gharakhil and Semnan is shown in Fig. 2a–e. The region is characterized by a semi-arid climate, with hot and dry summers, cold winters, and mild conditions in the spring and fall. The annual cycle of ambient surface temperature is expectedly very similar at Mehrabad and Semnan ranging from as low as 3.7 °C in January to 32.2 °C in July and with monthly averages deviating by approximately 1 °C between the sites. Gharakhil has a slightly lower seasonal variability, because of its proximity to the Caspian Sea, with temperatures ranging from 7.2 °C in January to 26.6 °C in August. At Mehrabad, wind speeds at the surface are lowest in the winter months and peak in the spring and early summer. Semnan has comparable wind speeds during the summer but in the other seasons the wind speed is lower. Gharakhil has lower wind speeds overall with minimal seasonal variability. Precipitation accumulation at Mehrabad and Semnan is generally low throughout the year with minimal rainfall from May to October. April is the wettest month for both stations with 45 mm at Mehrabad and 30 mm at Semnan. Both of these stations receive 80% of their annual precipitation between November and April. Gharakhil experiences a markedly different precipitation regime with comparable totals during the early part of the year followed by a large upswing starting late summer and extending through the fall to early winter with precipitation peaking at 132 mm in November. The surface RH at Mehrabad and Semnan follows a very similar seasonal pattern with the driest conditions found during the summer months because of the high ambient temperatures. Gharakhil is humid throughout the year with little seasonal variability.

Monthly patterns in mixing layer height (Fig.2f) and columnar water vapor (CWV) (Fig. 2g) were calculated using the radiosonde data at Mehrabad in conjunction with the values derived from the NASA MERRA dataset at grid points near Tehran (35.50°N, 51.33°E), Semnan (35.50°N, 53.33°E) and Gharakhil (36.50°N, 52.67°E). There is a noticeable increase in the daily maximum mixing layer height during the summer compared with the winter and increased mixing layer heights are found on the south side of the mountains (Tehran and Semnan) consistent with expectations for a semi-arid sub-tropical climate. The diurnal cycle of the mixing layer (not shown) shows the characteristic maximum in the afternoon driven by solar heating at the surface and overnight surface inversion typical of desert environments. Gharakhil shows a similar diurnal pattern with slightly less variation and has the signature of the influence of afternoon sea breezes. CWV (Fig. 2g) is at a maximum during the summer at all locations, consistent with higher temperatures and hence higher saturation vapor pressures. The peak monthly values occur in July for all three locations reaching 20 mm at Tehran, 19 mm at Semnan, and 33 mm at Gharakhil.

The average visibility (Fig. 2e) at Semnan is highest in July at 13.9 km with a moderate reduction observed during the winter, reaching a minimum of 11.9 km in December. Mehrabad also follows the same annual pattern; however, the visibilities are systematically lower for all months with a considerable reduction during the winter with minima of 6.3 km in December and 6.8 km in January. In both cases, local aerosol emissions are trapped within the surface layer leading to higher surface concentrations and lower visibility in the winter. The contrast between the two stations highlights the magnitude of the local aerosol sources in Tehran, which strongly affect the Mehrabad data but have a smaller effect on Semnan. In complete contrast, the annual visibility profile at Gharakhil follows a different pattern with minimal variability throughout the year (range ~1.2 km *versus* ~3.8 km at Mehrabad). This is likely due to the different meteorological conditions north of the Alborz Mountains where reduced visibility may be associated with phenomena other than an increase in aerosol concentration, such as fog or rain.

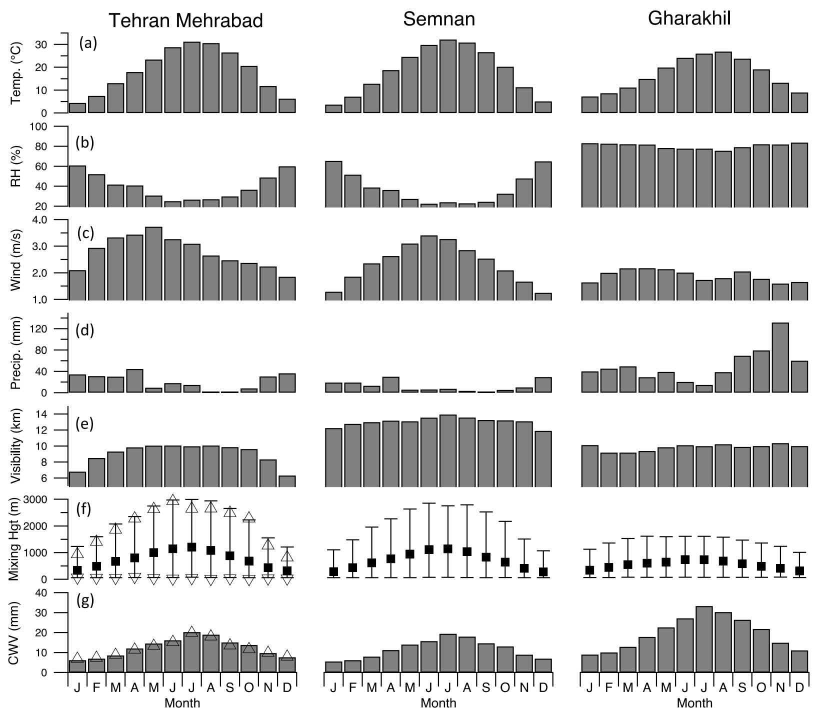

Figure 2. Monthly summary of surface meteorological data at three sites near Tehran (see Figure 1 for locations) between 2000 and 2009 for (a) dry bulb temperature (T), (b) relative humidity (RH), (c) wind speed, (d) accumulated precipitation, and (e) visibility. Monthly summary of upper air data for the same sites: (f) mixed layer height derived from Mehrabad radiosonde data (1980–2012; 00Z and 12Z soundings shown as triangle markers) and MERRA reanalysis data (2000–2009; square markers represent daily mean and whiskers represent average daily range) at grid points near Tehran (35.50°N, 51.33°E), Semnan (35.50°N, 53.33°E) and Gharakhil (36.50°N, 52.67°E); (g) Same as (f) except for average total column water vapor (CWV)

2.2. Air Mass Source Origin

An important factor governing aerosol characteristics in the greater Tehran area is the seasonal air mass transport pathways ending at this location. To determine air mass source origins impacting Tehran, five-day back-trajectories were computed using the NOAA HYSPLIT (Hybrid Single-Particle Lagrangian Integrated Trajectory) model [13], which was run using the NCAR/NCEP reanalysis data with the isentropic vertical velocity method. Six-hourly trajectories from 2000 to 2009 were obtained ending at Tehran (35.70°N, 51.42°E) at 500, 1000, and 3000 m above the surface. The HYSPLIT data were used to construct seasonal (DJF, MAM, JJA, SON) trajectory frequency maps for the 2000–2009 period, which present the most frequent transport pathways of air ending in Tehran. Trajectories are also classified by source region denoted by regions A–E (Fig. 3): A = desert region southwest of Tehran; B = Europe; C = Siberia/Russia; D = countries which are east of Iran; E = representation of local sources near Tehran.

Trajectories ending below 1000 m show qualitatively similar patterns with altitude (Fig. 3) and during the majority of the year, the most dominant source region is found to be in the desert regions to the west and southwest (Region A). In summer the circulation pattern of the region is significantly different and trajectories from Region C prevail at low levels. Low-level trajectories in winter (DJF) included a significant contribution from Region E (34%), which is indicative of stagnant low-level air. While HYSPLIT may not resolve these features entirely, the stagnation at the surface would be further enhanced by shallow mixing heights with stable air aloft which would trap air below the mountain tops. The least important source regions were from Regions B (northwest) and D (east). The importance of trajectories originating from the dust-rich region between the west and south of Tehran increased for the upper levels. At an ending altitude of 3000 m AGL, the air mass origins were in Region A for 57% of trajectories annually and reached a peak fraction during the spring (MAM) of 73%. For trajectories ending below 1000 m, there was no significant change in the attribution of source region when only surface influenced (<500 m) fractions of the trajectory were considered (not shown). Low-level (ending altitude 500 m AGL) trajectory density is presented as an average residence time (hours per trajectory) within each cell in a 0.5° × 0.5° grid to supplement the apportionment of source regions (Fig. 4). Consistent with Fig. 3, all seasons except summer (Fig. 4c) exhibit similar trajectory maps with air mass source regions in a quadrant from the south through to the west and a secondary source region to the northeast, although many of these trajectories were likely classified as Region E. The summer source region is predominantly to the north and northeast, which accounts for the abundance of Region C trajectories during these months.

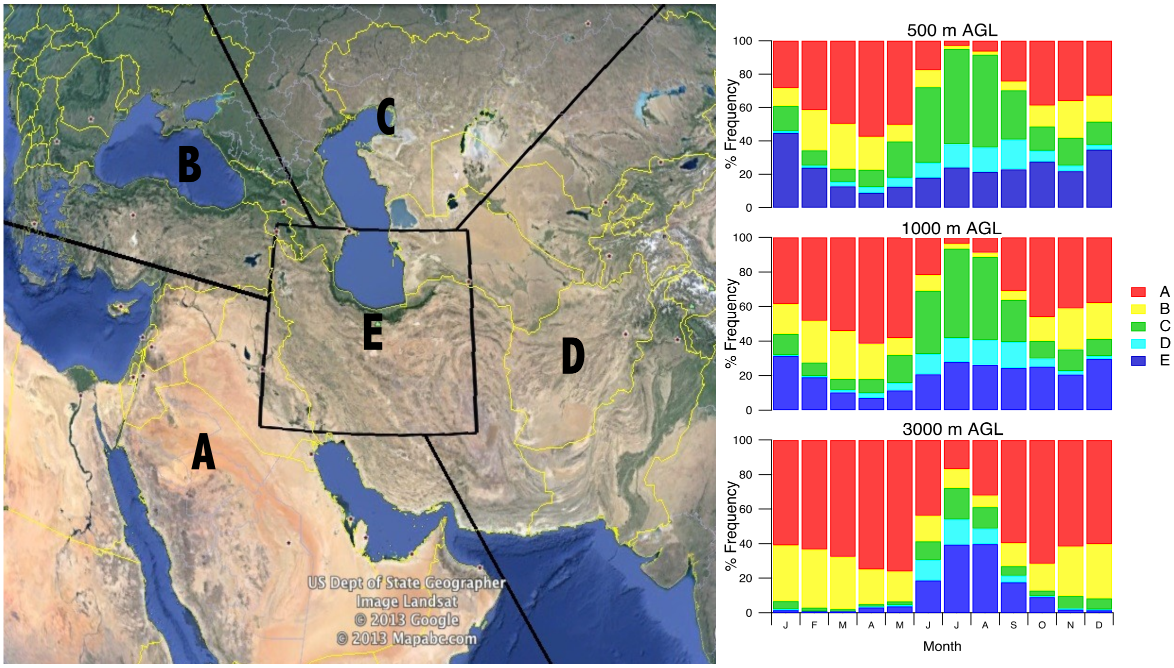

Figure 3: Monthly pattern in air mass source region as determined by analysis of daily HYSPLIT data between 2000 and 2009. Back-trajectories are classified by time spent in each region. The region totals are shown, by month, for end points at 500 m, 1000 m and 3000 m above ground level (AGL) (Right)

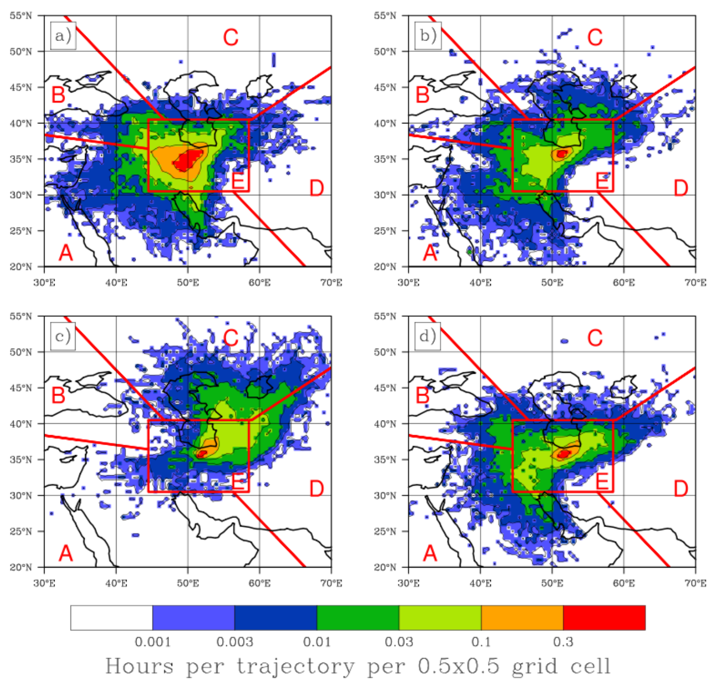

Figure 4: Decadal (2000–2009) summary of seasonal HYSPLIT five-day back-trajectory frequencies, ending at 500m above Tehran (35.70°N, 51.42°E) for (a) winter (DJF), (b) spring (MAM), (c) summer (JJA), and (d) fall (SON). Frequency is defined as the number of trajectory-hours spent in each 0.5° × 0.5° grid box divided by the total number of trajectories analyzed. Source regions, as illustrated in Figure 3, are overlaid

2.3. *Regional Fire Patterns*

Using the Moderate Resolution Imaging Spectroradiometer (MODIS) Fire Information for Resource Management System (FIRMS) data from 2000 to 2009, a fire radiative power (FRP) climatology has been developed for four seasons for a region spanning eastern Europe, central Asia and the Middle East (Fig. 5); FRP is related to the burn intensity of the fire pixel and is provided for each identified fire per overpass. FRP across the region increases in spring and summer. In particular, the region to the north of the Caucasus Mountains extending into Ukraine, southwest Russia and further northeast into Kazakhstan experiences a substantial number of fires during the summer. The fires in Ukraine and southwest Russia are predominantly associated with agricultural burning. During spring, there is a maximum in fire density shifted farther east into Kazakhstan. The number of fires during fall and winter is significantly lower than other seasons and is likely to have little impact on aerosol concentrations in the study region.

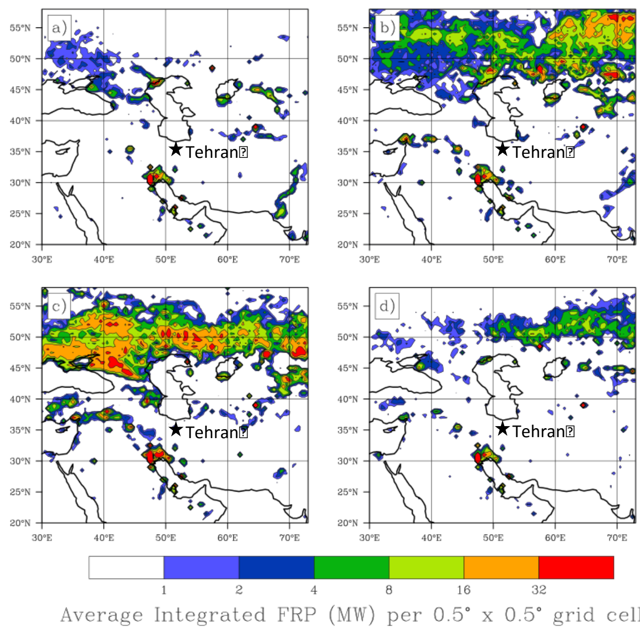

Figure 5: Seasonal patterns in Fire Radiative Power (FRP) derived from Moderate Resolution Imaging Spectroradiometer (MODIS) Fire Information for Resource Management System (FIRMS) data from 2000 to 2009. FRP is shown as integrated seasonal average power (megawatts per 0.5° × 0.5° grid box) for (a) winter (DJF), (b) spring (MAM), (c) summer (JJA), and (d) fall (SON)

2.4. *Remotely-Sensed Aerosol Data*

MODIS Deep Blue (Terra and Aqua) and Multi-angle Imaging Spectroradiometer (MISR) all show that aerosol optical depth (AOD) is largest between April and August (Fig. 6a). Although not presented quantitatively, the MODIS Angstrom Exponent (AE) monthly averages were also considered as a qualitative method of assessing coarse mode *versus* fine mode aerosol. Lower AE values are generally found in the spring and summer months, which suggests a shift towards coarser aerosol such as dust. This point is further supported by Fig. 6c where it is shown that the highest ultraviolet (UV) aerosol index (AI) values are observed in the spring and summer (May–July), especially for the Total Ozone Mapping Spectrometer (TOMS) sensor; note that UV AI is a representation of the relative abundance of absorbing aerosols (e.g. smoke and dust). However, there are two possible mechanisms for the significant upswing of UV AI levels during the summer: an increase in the abundance of absorbing aerosol (*i.e.*, dust and smoke) or a change in the column distribution of the absorbing aerosol. While an increase in overall dust concentration is the likely contributor to the increase in UV AI, it may also be driven by an increase in elevated dust and/or smoke layers. Some caution must be employed when considering the mean AOD and UV AI values during the winter, since during this time of year there were fewer data points available, because of cloud contamination. To qualitatively assess the significance of the seasonal cycle we evaluate monthly mean values against the standard deviation of interannual variability (shown as error bars on Fig. 6). Winter AOD is generally more variable than summer; however, in summer the range of variability is amplified, particularly for the TOMS data, in part due to extreme dust events, which occur in some years and not in others.

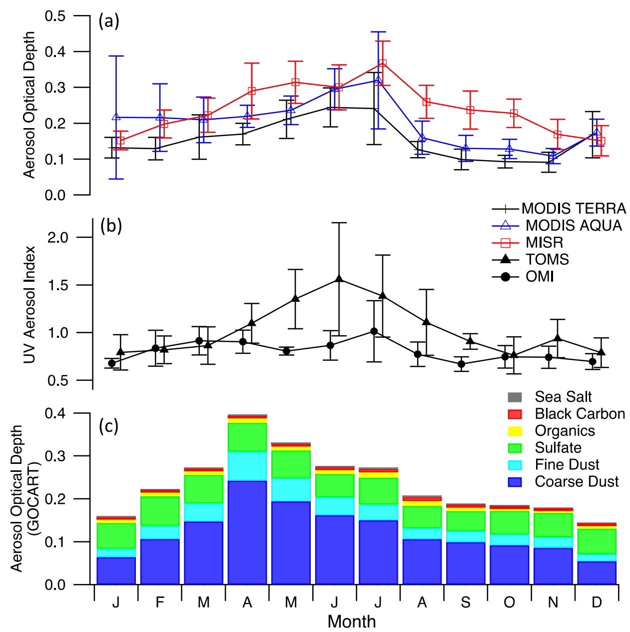

Figure 6: Monthly summary of remotely-sensed and model data for the greater Tehran area (see Table 1) for different satellite products (a and b): (a) aerosol optical depth (AOD) from MODIS Deep Blue (Terra and Aqua) and Multi-angle Imaging Spectroradiometer (MISR); (b) Total Ozone Mapping Spectrometer (TOMS) and Ozone Monitoring Instrument (OMI) ultraviolet aerosol index; (c) monthly summary of fractional AOD from Goddard Ozone Chemistry Aerosol Radiation and Transport (GOCART)

2.5. Goddard Ozone Chemistry Aerosol Radiation and Transport (GOCART) Model

Data from GOCART [14] simulations were used to quantify the relative importance of different aerosol constituents. The monthly average fractional AOD for fine and coarse dust, black carbon, organics, sulfate, and sea salt are shown in Fig. 6d. In examining these data, we focus on the relative fraction of the constituents and their seasonal trends instead of considering the absolute values to reduce sensitivity to model limitations.

Throughout the entire annual cycle, dust optical depth (which includes coarse and fine dust), accounts for the largest fraction of the total optical depth at 68% of the average annual aerosol with highest levels during April. Sulfate contributes the next highest fraction with an annual average of 25% with little variability through the year. Black carbon and organics are responsible for a relatively small fraction of the total AOD at 2.8% and 3.6%, respectively; however, the peak occurs during July and August and is suggestive of a biomass-burning source due to wildfires mainly in Ukraine, Russia and Kazakhstan. The peak AOD from GOCART occurs during spring, which is consistent with the influx of regional and local dust; however, the model may be under predicting the role of black carbon and organics associated with biomass burning due to uncertainties in the emissions inventory. In addition, GOCART does not include gas phase chemistry and hence cannot suitably model secondary production of aerosol that is not approximated at the source. Sea salt is also a very low impact contributor to the total AOD approximately 0.6% annual average) with the peak occurring during winter and early spring where upper air trajectories are from the west and southwest. The HYSPLIT trajectories suggest that sea salt aerosol sources include the Gulf and the Mediterranean Sea and perhaps the Caspian Sea, although its salinity is far lower. The high terrain and lack of local sea salt sources suggests that marine air intrusions do not affect the lower troposphere and this is confirmed by the contrast in meteorology at Mehrabad and Semnan as compared to Gharakhil and justifies the lack of sea salt aerosol.

3. DISCUSSION

3.1. Seasonal Climatology

Many of the patterns found in the surface data conform to the expected seasonal variability, which is characteristic of a sub-tropical desert environment such as temperature, humidity, and visibility. The observed meteorology at Mehrabad, Gharakhil and Semnan can be explained by the influence of local topography, land surface, urbanization, and large-scale atmospheric circulation pattern of the region. Further analysis of the data suggests mechanisms for variability in aerosol quantified using satellite-derived AOD and surface visibility. Since satellite AOD was available only on days with low cloud fraction, there was a potential sampling bias associated with the comparison of seasonal visibility and AOD cycles. However, the difference between the visibility statistics derived on days when satellite data were available and the entire dataset was found to be negligible, and so this bias was not relevant to this study.

Using the visibility data at Mehrabad as a proxy for surface-layer aerosol concentration reveals that the reduced visibility during winter is aligned well with recurring reports of hazardous air quality within the city being more prevalent during this season. MODIS Deep Blue and MISR data indicate that AOD is lowest during winter. For this to happen the distribution of aerosol through the column is more weighted towards the near-surface layer. The local meteorology supports this conclusion, since average mixing layer heights are far lower in winter and stable air above the mixing layer traps air below the mountains causing a high incidence of stagnant air at the surface, which is infrequently ventilated. In contrast, the summer exhibits a maximum in the satellite-derived AOD and the highest visibilities at Mehrabad. Mixing heights are highest mainly due to the high incident solar radiation, which vigorously mixes aerosol in the lower troposphere and helps to relieve the accumulation of aerosol near the surface. The AOD is highest during this season, which suggests a higher columnar aerosol concentration, and is likely attributed to dust transport in the mid- to upper-troposphere from source regions in the deserts to the west of Iran (Arabia, North Africa, and the Levant), although it is unclear exactly which dust source regions are most influential for Tehran. While data for AOD and perhaps TOMS and OMI UV AI indicate that dust is most important during spring and summer, the trajectory analysis only supports the argument for regional dust transport during spring. Nonetheless, there is evidence from individual cases that regional dust transport can contribute to extreme events during the summer. In addition, there is an abundance of local sources of dust within Iran, in relative proximity to Tehran, and these sources may be most impactful during summer due to higher surface wind speeds and potentially lower soil moisture. One possible method for isolating local and regional dust sources is the ratio of $PM_{2.5}$ to PM_{10}, with lower ratios suggestive of greater influence from local dust sources [15]; that study suggested 0.35 as a threshold value, above which data are contaminated by non-local dust sources. Results from [8] for $PM_{2.5}$ and PM_{10} concentrations measured at a site in western Iran during 2010, suggest a range of $PM_{2.5}$:PM_{10} between 0.18 and 0.32 (based on ratios of monthly-averaged values) indicating that local dust sources make a significant contribution.

Another mechanism for the enhancement of satellite-derived AOD during the summer may be the swelling of aerosol due to uptake of water vapor (*i.e.*, hygroscopic growth). Higher CWV in the summer (Fig. 2g) supports the occurrence of hygroscopic growth, and even though surface relative humidity values are suppressed (Fig. 2b), the relative humidity in the upper parts of the (deep) mixing layer (not shown) is sufficient for significant water vapor uptake. Later in the summer, upper air trajectories imply that air mass origins from the north are prevalent, which may indicate a contribution from biomass burning sources due to smoke from wildfires in Ukraine and Russia. Although the magnitudes are too small to be of major significance, if taken in a relative sense, GOCART generally supports this with an increase in black carbon optical depth during the summer.

3.2. Precipitation

The discussion above suggests that the combination of local and regional aerosol sources is stronger during the summer, however, the mechanism for the removal of aerosol can be equally as important. An essential mechanism for modulation of aerosol loading is the scavenging of aerosol by precipitation. Summer (JJA) rain in Tehran is rare, and the average interval between rain events at Mehrabad during 2000–2009 is 23.5 days compared with 4.5 days for winter (DJF), 5.0 days for spring (MAM), and 8.2 days for fall (SON). To understand the importance of this interaction for the climatology of Tehran, we investigate the difference in aerosol immediately before and after rainy days, which are defined as days with observed rainfall at Mehrabad. We focus only on the winter months, since this is the season with the most rain days and also is the most critical season in terms of aerosol effects on public health owing to a shallower mixing layer accumulating a higher concentration of pollutants near the surface. Fig. 7a shows the composite average change in visibility at Mehrabad between the mean visibility during the two days before and two days after rainfall stratified by the severity of the rainfall event and Fig. 7b shows the same comparison for AOD. Since the number of rain events is small and there is considerable loss of AOD data surrounding rain events due to cloud contamination, a "consolidated" AOD is generated using the three satellite products used in this study (MODIS Deep Blue (Terra and Aqua) and MISR). We take the available data from the three products, and for instances where more than one measurement exists, we take the (unweighted) mean. Consequently this alleviates the fact that each product is not available for the entire study period. There is a significant increase in visibility and concurrent reduction in AOD at all rain rates and furthermore, there is a general trend showing that the magnitude of the change in visibility and AOD increases as the severity of the rainfall increases. Overall, this finding suggests that rainfall events tend to have a beneficial impact on the extreme aerosol concentrations found in Tehran during the winter.

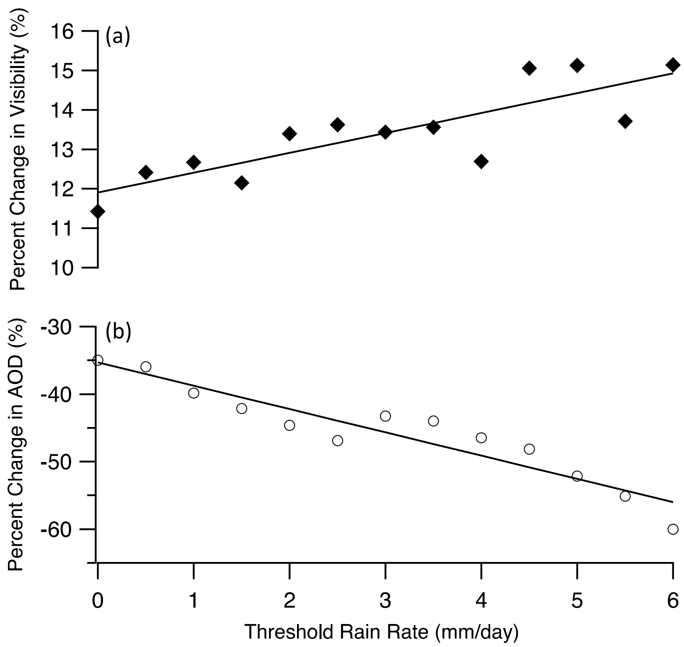

Figure 7: Change in (a) visibility and (b) satellite-derived AOD immediately before and after rain days. The plots show the composite average difference between the mean visibility/AOD during the two days after rain and the two days before rain. The composite is taken for rain events, which exceed the given threshold daily rainfall rate and is presented as a percentage with respect to the mean visibility/AOD before the rain

3.3. Weekly Cycle of Visibility

Another potentially important modulator of local aerosol concentrations is the weekly cycle of human activity, since anthropogenic emissions are expected to vary between workdays and weekends. It should be clarified that typically only Friday is the weekend in Iran; for some industries Thursday is also a reduced working day. Fig. 8 shows the average visibility anomaly at Mehrabad for each day of the week. The anomaly is calculated as the average deviation from the seasonal mean visibility for each of the four seasons, which allows an independent comparison of the weekly cycle to be made without incorporating the significant seasonal variability in visibility. In all seasons, Friday exhibits a strong increase in visibility, which is aligned with an expected reduction in anthropogenic emissions. In addition, the visibility on Thursday is also anomalously high which would be supported by reduced working hours. With minor exceptions, the other days show broadly consistent visibilities. Another notable feature in these data is that the increased visibility on Friday is stronger in winter and fall compared with spring and summer. If the weekly cycle were used as an indicator of the relative importance of local (anthropogenic) sources compared to regional and meteorologically driven sources (e.g., dust), then this result would support the conclusion that local sources are more important in winter and fall for modulating aerosol concentrations. Conversely, during the spring and summer, regional dust transport, local dust sources and possibly biomass burning overshadow local anthropogenic emissions, which are strongly mixed in the deep summer mixing layer and so the apparent importance of the weekly cycle is reduced. The weekly cycle was also analyzed for the satellite AOD data (not shown) and no significant pattern emerged. This further supports the argument that urban sources play a secondary role to regional transport and meteorology in modulating the column aerosol properties, even though they are an important local influence for conditions at the surface.

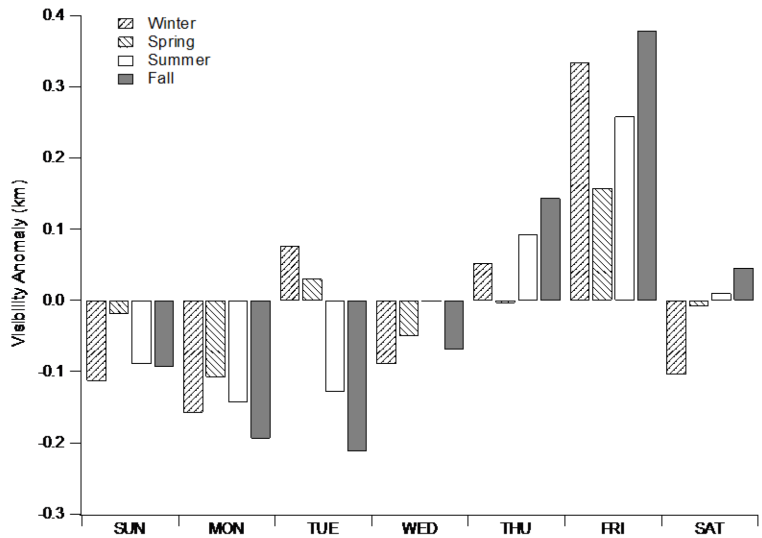

Figure 8: Average visibility anomaly in Tehran (Mehrabad) filtered by day-of-week for each season of the year. The visibility anomaly is calculated as the average deviation for each day-of-week from the climatological mean for each season. Note that the weekend in the study region is Friday, although some industries also observe Thursday as a reduced working day

4. Implications of Results

The results of the analysis by Crosbie et al. [1] highlight the importance of trying to mitigate emissions of pollutants and to adapt to the existing conditions. If emissions of dust and wildfires increase with climate change in future years, the city of Tehran will be exposed to even more pollution near the surface and aloft. While the impacts on public health and surface visibility are easier to predict, the question of how aerosol in the column above Tehran impacts the thermodynamic structure of the atmosphere, cloud formation, and precipitation is arguably much more unclear. Furthermore, deposition of dust on snow in areas of Iran such as the Alborz Mountains can potentially expedite the melting of snow, which has consequences for regional water planner. Therefore, addition research is warranted to examine these important effects in this vulnerable region.

Acknowledgement

This work was adopted from Crosbie et al. [1] and supported in part by Grant 2 P42 ES04940–11 from the National Institute of Environmental Health Sciences (NIEHS) Superfund Research Program, NIH, the University of Arizona Foundation and the Institute of the Environment at the University of Arizona. The authors gratefully acknowledge the NOAA Air Resources Laboratory (ARL) for provision of the HYSPLIT transport and dispersion model. Some of the analyses and visualizations used in this study were produced with the Giovanni online data system, developed and maintained by the NASA GES DISC. We also acknowledge the use of FIRMS data and imagery from the Land Atmosphere Near-real time Capability for EOS (LANCE) system operated by the NASA/GSFC/Earth Science Data and Information System (ESDIS) with funding provided by NASA/HQ.

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Tutorial on CHRS-UCI's Satellite Data Products

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Abstract

The G-WADI Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks – Cloud Classification System (PERSIANN-CCS) GeoServer has been successfully developed by the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California - Irvine collaborating with the UNESCO's International Hydrological Programme (IHP). The system employs state-of-the-art technologies in remote sensing and artificial intelligence to estimate rainfall globally from satellite imagery in near real-time and high spatiotemporal resolution. It offers graphical tools and data service to help the user in emergency planning and management for natural disasters related to hydrological processes. Recently a number of new applications for mobile devices have been developed by our students. The RainMapper has been available on App Store and Google Play for the near real-time PERSIANN-CCS observations. A global crowdsourced rainfall reporting system named iRain has also been developed to engage the public globally to provide qualitative information about real-time precipitation in their location which will be useful in improving the quality of the PERSIANN-CCS data. A number of recent examples of the application and use of the G-WADI PERSIANN-CCS GeoServer information will also be presented. This tutorial provides a brief introduction to CHRS's satellite precipitation data products. More details on the products can be found from our home page at http://chrs.web.uci.edu/ and the publications in the reference section.

Keywords: G-WADI, PERSIANN, Precipitation, RainMapper, iRain

1. PERSIANN AND PERSIANN CCS

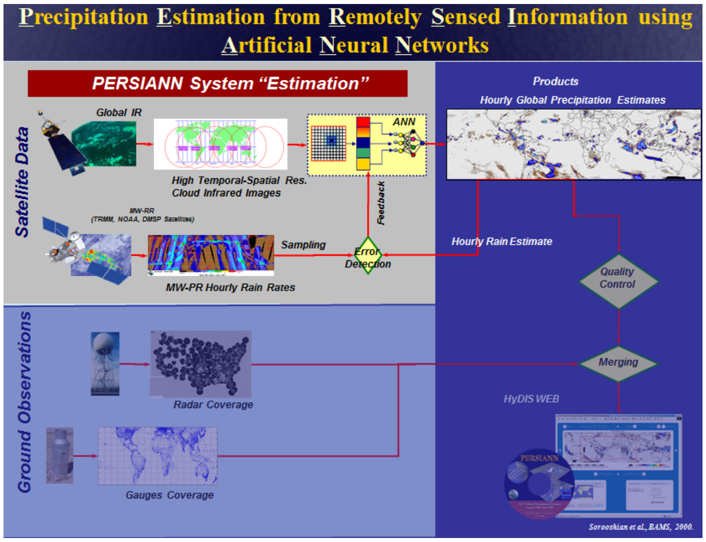

Figure 1: PERSIANN system. Details can be found at Sorooshian et al. 2000

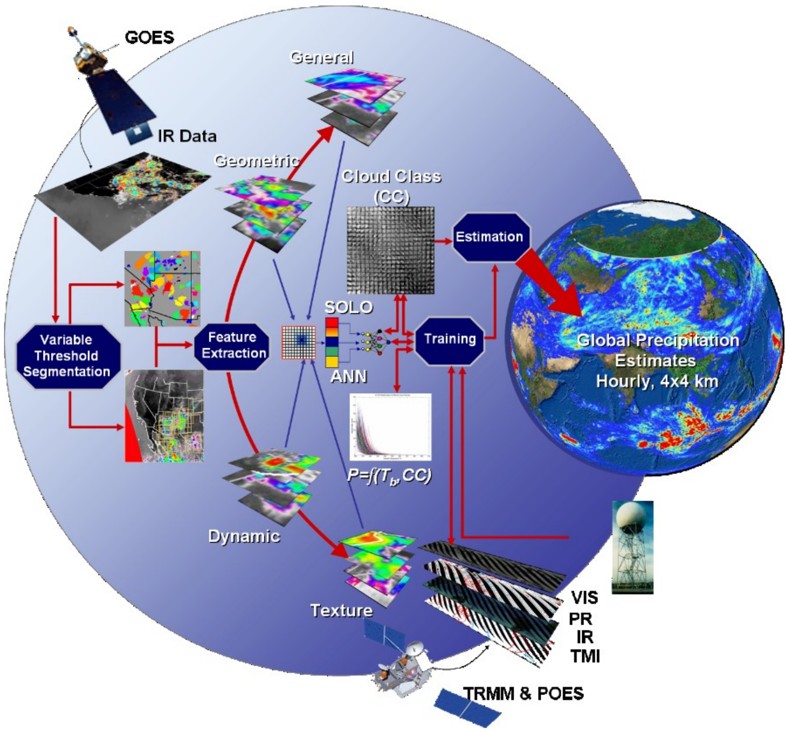

Figure 2: PERSIANN-CCS system. Details can be found at Hong et al. 2004

2. G-WADI PERSIANN-CSS GEOSERVER SYSTEM

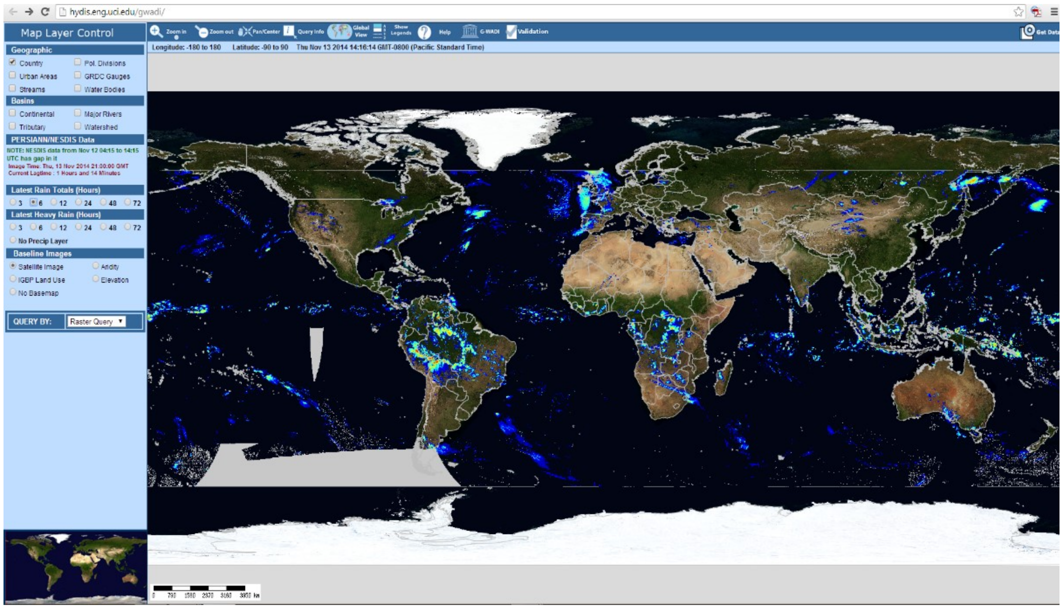

Figure 3: G-WADI PERSIANN-CCS GeoServer system (http://hydis.eng.uci.edu/gwadi/)

year:	#reqs:	#pages:	Tbytes
2010:	683850:	117685:	0.34
2011:	975998:	203044:	0.36
2012:	1388464:	302458:	0.38
2013:	2626889:	261192:	0.51
2014:	3858103:	387704:	1.02
2015:	1719533:	86179:	0.52

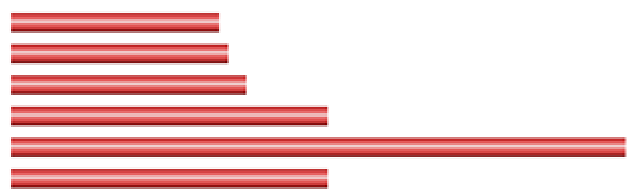

Figure 4: Statistics of G-WADI PERSIANN-CCS GeoServer usage (up to March 2015). Users are from more than 100 countries and territories

3. RAINMAPPER APPLICATION

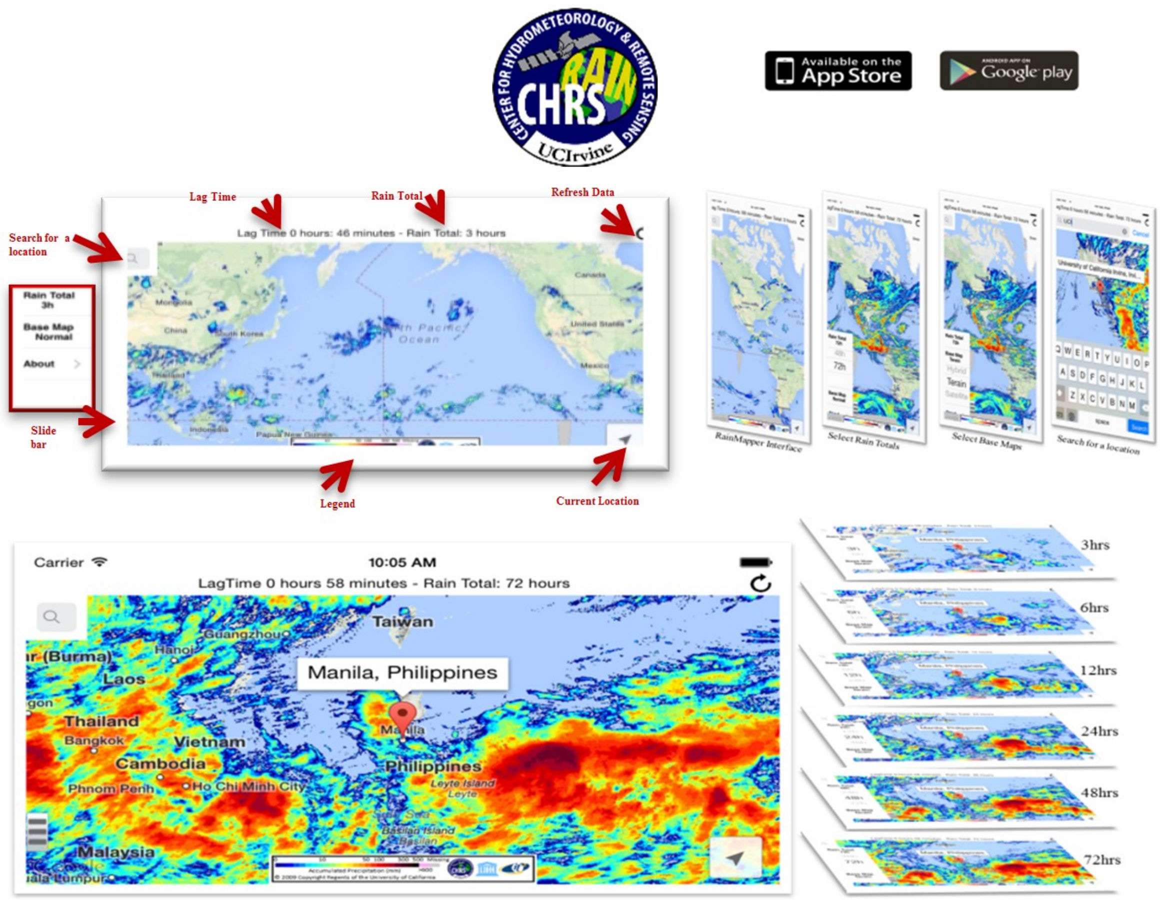

Figure 5: RainMapper application. Tracking the evolution of Typhoon Rammasun over the Philippines in mid July 2014 using RainMapper (lower panel)

4. Applications of G-WADI PERSIANN CSS GeoServer System for Natural HAzards Management

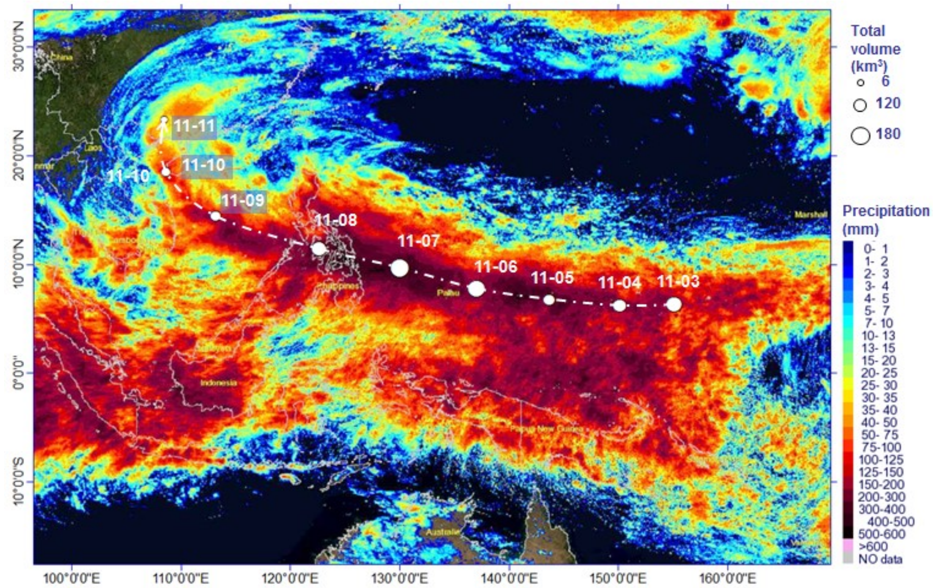

Figure 6: Monitoring Typhoon Haiyan over the Philippines in November 2013 using G-WADI PERSIANN-CCS GeoServer. More details can be found at Nguyen et al. 2014

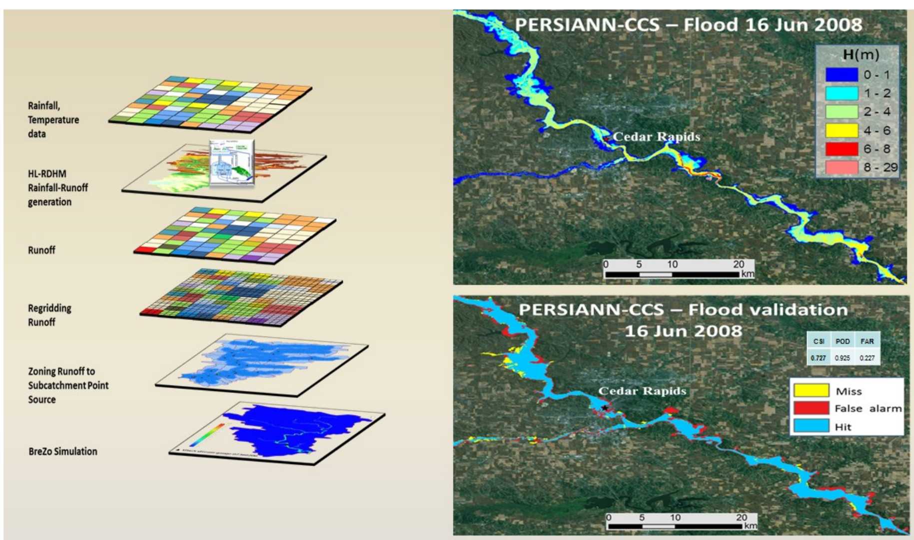

Figure 7: Simulation of Iowa Flood 2008 using coupled high resolution HiResFlood-UCI model (left) with PERSIANN-CCS real-time satellite precipitation data. More details can be found at Nguyen et al. 2015a&b

5. PERSIANN PRECIPITATION CLIMATE DATA RECORD (PERSIANN-CDR)

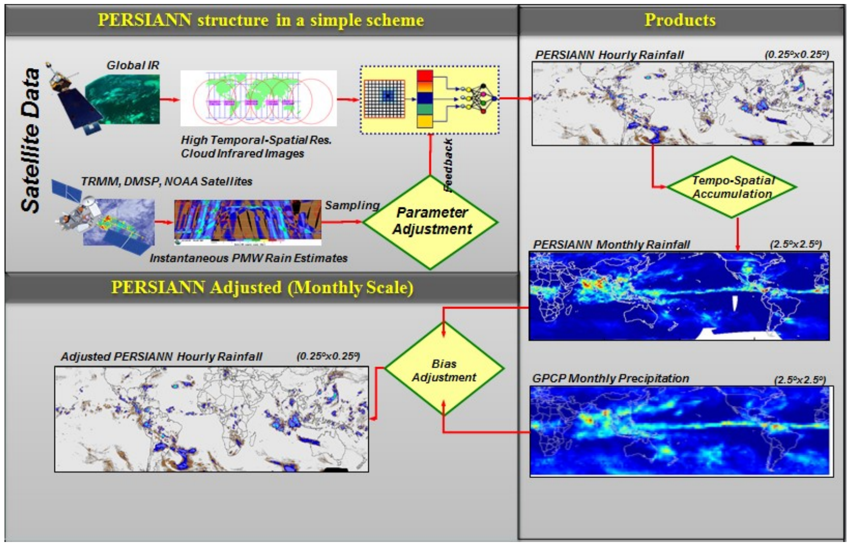

Figure 8: PERSIANN-CDR algorithm. More details can be found at Ashouri and Hsu et al. 2015

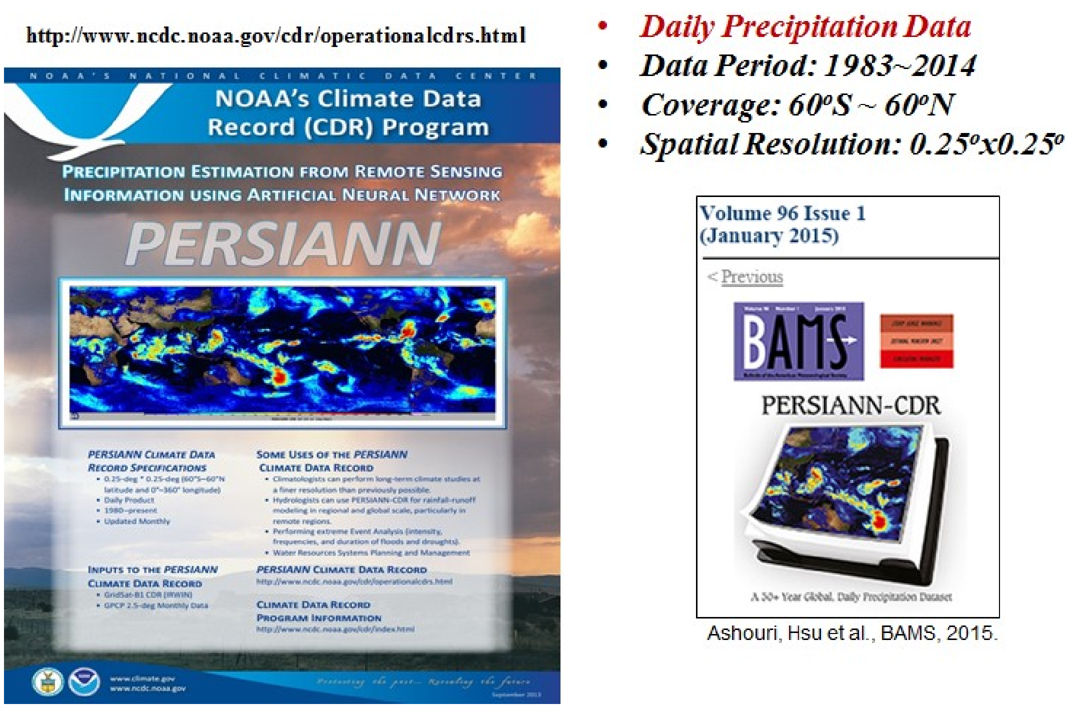

Figure 9: PERSIANN-CDR data product available from NOAA NCDC website (http://www.ncdc.noaa.gov/cdr/operationalcdrs.html). More details in PERSIANN-CDR algorithm can be found at Ashouri and Hsu et al. 2015

6. CHRS CONNECT – A GLOBAL EXTREME PRECIPITATION EVENT DATABASE

Figure 10: CHRS CONNECT system. More details can be found at Sellars and Nguyen et al. 2013

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U.S.-Iran Symposium on Climate Change: Impacts and Mitigation

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Irvine, California

Overview of Greenhouse Gases Emission Trends and Potentials for Mitigation in Iran: Case Study Cement Sector

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Abstract

Iran's demographic profile is sharply youth oriented and this upcoming generation's needs for employment, coupled with low-energy efficiency vectors and consumption patterns, has created a constant rise in energy demand and greenhouse gas (GHG) emissions in all economic sub-sectors, especially industry. Lack of new business opportunities on the one hand and low energy efficiencies on the other hand, leads the national economic development programmes towards investment in energy incentives in industries such as cement, iron and steel, aluminum and petrochemical.

This study first overviews the GHG emissions trend and mitigation potential in Iran, then as a case study, evaluates the twin impacts of switching to low carbon fuels and efficiency improvement on energy carriers' consumption and GHGs mitigation in the Iranian cement sector. For this purpose, the demand for energy carriers has been developed by applying end-use Long-range Energy Alternative Planning (LEAP) model in Business-as-Usual (BAU) and Mitigation scenarios.

Finally, aided by a Scenario-Based Approach, the impact of fuel switching and efficiency improvement in trends of energy demand and GHG emissions is assessed in Mitigation Scenarios. The results indicate that in the BAU scenario between 2005 and 2020, the energy demand and CO_2 equivalents emission in the cement industry increases with an annual growth rate of 6.82% and 7.48%, respectively.

Comparatively, if the fuel switching and energy efficiency programs are implemented, they will stimulate carriers' demand and CO_2 equivalents emissions growth rate decreases to 5.9% and 6.37%, respectively. This means that by applying the mitigation policies, the energy demand and GHG emissions in 2020 by Iran's cement industries will be reduced by 9.6% and 14.5%, respectively.

Keywords: Emission Reduction, Energy Efficiency, Fuel Switching, Energy Planning Model, Cement Industry

1. INTRODUCTION

Climate change is an issue of international concern. The increased levels of atmospheric greenhouse gases (GHGs) are produced overwhelmingly by emissions in the industrialized North, while tropical zones are more vulnerable to climate change. The UN Framework Convention on Climate Change therefore urges the industrialized regions to take the lead in the development of climate change policy [1]. Despite the fact that many countries have started to develop climate policies, scenario studies indicate that GHG emissions are likely to increase in the future in most world regions [2]. In developing countries, these expected increases in future emissions are associated with rapid economic and population growth. To ensure that carbon dioxide concentrations stabilize at a level to hold the increase in global average temperature below 2 °C above preindustrial levels, relatively large reductions in global emissions are needed [3]. Given the rapid economic growth in many developing countries, this will only be possible if the industrialized world reduces its emissions considerably.

It is also important to keep in mind that, as UN analysis shows, the emission reduction targets and actions announced in Cancun, although they are the most ambitious global effort to date, are inadequate in the longer term to keep the world under the agreed maximum global temperature rise of two degrees. It is therefore essential to keep raising the global level of ambition to reduce global greenhouse gas emissions [3].

To date a stabilization of greenhouse gas emissions from the industrialized world has not been realized, let alone a reduction. Meanwhile, it is also important that the developing world aims at the reduction of emissions trend from economic activities, especially in energy demand and the supply side. In this study, we first reviewed the GHG emissions trend in the energy and industrial process sectors of Iran and then, as a case study, focused on assessment of the emissions reduction potential for the cement sector.

2. GHG EMISSION TRENDS IN IRAN

The energy carriers' low price within Iran promoted an economic and industrial development pattern focused on energy intensive industries and therefore GHG emission trends increased rapidly during the last decade. GHG emission trends in Iran in recent years increased from 417 million tonnes in 1994 to 850 million tonnes in 2010, with an annual growth rate of 6.5%. At the same time, overall CO_2 emissions increased at an annual rate of 5.8%, increasing from 342 million tonnes in 1994 to 661 million tonnes in 2010, while CO_2 emissions from fuel combustion grew at a faster rate during the same period at annual growth rate of 7.1 % (Fig. 1). Also in 2010, the cement sector, with a total CO_2 emission of 49.5 million tonnes, comprising 7.5% of total CO_2 emissions in Iran [4,5].

On the other hand, the result of GHGs projection in Iran's energy sectors reveals that for a 3.5% annual economic growth rate, GHG emissions in the energy sector will increase with an annual growth rate of 8.3% in the BAU Scenario. This indicates that Iran's economy is carbon intensive and that more attention should be given to decarbonization of the economy in economic development plans [5].

Table 1 shows the GHGs emission projection in different *Scenarios* for energy sector between 2005 and 2020. As shown in the table, GHG emissions in BAU scenario increases from 423.7 million tonnes of CO_2 eq. in 2005 to 1,416 million tonnes in 2020, while in the mitigation scenario it falls to

678.6 million tonnes in 2020. This shows that there is a huge potential for mitigation of GHG emissions in Iran's energy sector (46% GHGs reduction).

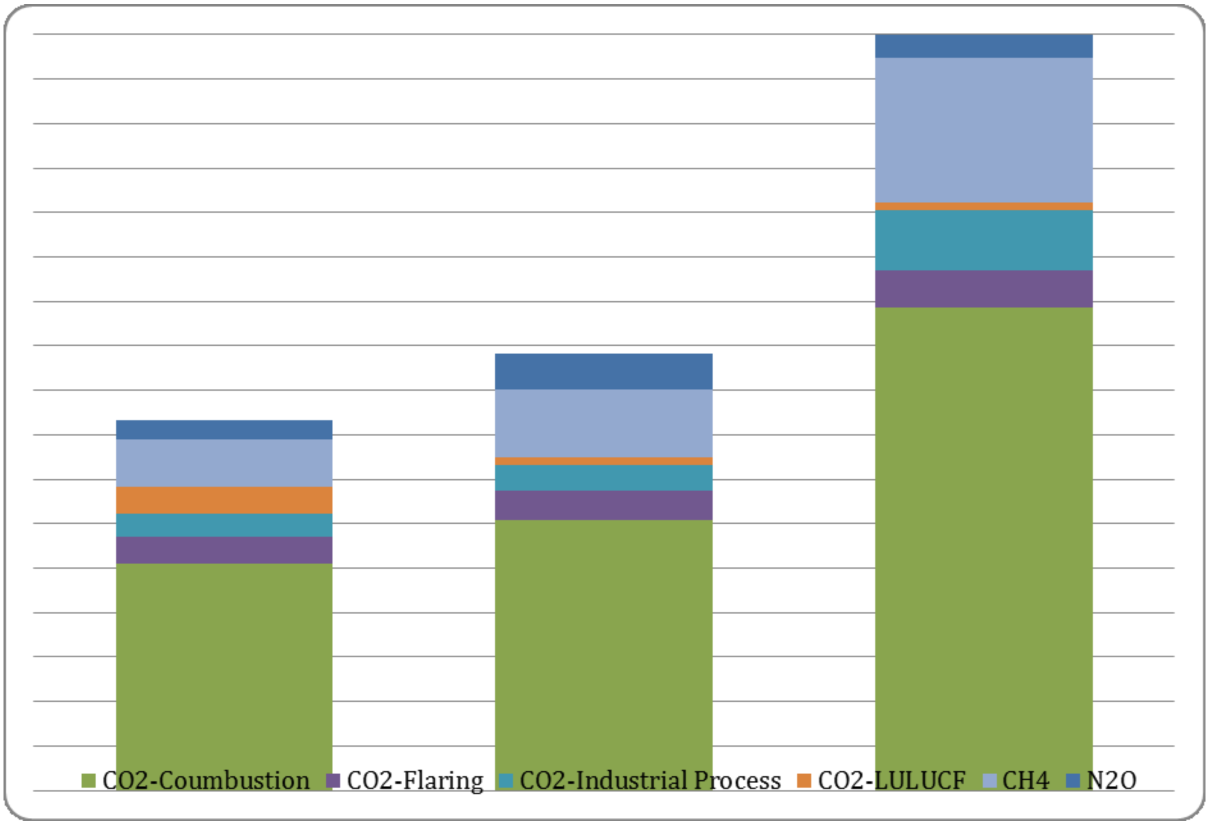

Figure 1: GHG emission trends in Iran's economic sub-sectors (1994-2010/million tonnes)
Source: Authors compilation of the GHGs emission inventory in Iran's Initial and Second National Communications [4,5]

TABLE 1: GHGS EMISSION PROJECTION IN DIFFERENT SCENARIOS FOR ENERGY SECTOR IN IRAN (MILLION TONNE)

Year*	2010	2015	2020
Business-as-Usual (BAU)	611.2	916.7	1,416.00
Official Development Scenario (ODP)	565.6	783.6	1,227.00
Mitigation Scenario	542.1	589.4	678.6
Mitigation Potentials in Non-electricity Sectors (%)	3	19	36.3
Mitigation Potentials in Electricity Sectors (%)	1.3	6.4	9.7
Overall Mitigation Potentials (%)	4.2	25	45

* Total GHG emissions in 2005 was 423.7 million tonne CO_2 eq.

3. METHODOLOGY AND MODELS FOR CASE STUDY

3.1. Introduction

The young population demographics and resultant employment pressures have created a constant upsurge in energy consumption in Iran. Given the limit of fossil energy resources and adverse impact of energy sector development and fuel consumption on the environment, a comprehensive analysis of the interactions between energy, economy, and environment is needed.

After the energy crisis in the 1970s, widespread research was performed to develop appropriate energy models to gain an accurate understanding on interactions between energy use and economic activity. In recent years, because of environmental problems induced by energy consumption, environmental issues and especially GHG emissions are included in the models. According to the United Nations Framework Convention on Climate Change (UNFCCC) resource guide, there are various models for GHGs mitigation assessment and policy making which were widely used in preparing of the National Communications to UNFCCC [6]. With respect to the structure, the energy models are categorised in two following types:

- Top to bottom models
- Bottom to top /End-use models

For GHG mitigation polices assessment in Iran's Initial National Communication to UNFCCC, a combination of top-to-bottom and end-use models was used [4]. In the Second National Communications to UNFCCC, a *Techno-Economic* combination model was used for mitigation assessment in the energy sector [5]. Another study in Iran evaluated the twin impacts of price reform and energy efficiency programs on energy carriers' consumption and GHG mitigation in the Iranian residential sector using the Long-range Energy Alternative Planning System (LEAP) model [7].

In this study, the impact of different policies and measures on GHGs emission reduction was assessed through the scenario development approaches by the Long-Range Energy Alternative Planning (LEAP) model.

3.2. Long-range Energy Alternative Planning (LEAP) System

The Long-range Energy Alternatives Planning system (LEAP) is a scenario-based energy-environment modeling tool. Its scenarios are based on comprehensive accounting of how energy is consumed, converted and produced in a given region or economy under a range of alternative assumptions on population, economic development, technology, price and so on. With its flexible data structures, LEAP allows for analysis as rich in technological specification and end-use detail as the user chooses.

With LEAP, the user can go beyond simple accounting to build sophisticated simulations and data structures. Unlike macroeconomic models, LEAP does not attempt to estimate the impact of energy policies on employment or GDP, although such models can be run in conjunction with LEAP. Similarly, LEAP does not automatically generate optimum or market-equilibrium scenarios, although it can be used to identify least-cost scenarios. Important advantages of LEAP are its flexibility and ease-of-use, which allow decision makers to move rapidly from policy ideas to policy analysis without having to resort to more complex models [8].

In LEAP, demand calculations are based on a disaggregated accounting for various measures of social and economic activity (number of households, vehicle-km of travel, tonnes of industrial production, commercial value added, etc.) These "activity levels" are multiplied by the energy intensities of each activity (energy per unit of activity). Each activity level and energy intensity can be individually projected into the future using a variety of techniques, ranging from applying simple exponential growth rates and interpolation functions, to using sophisticated modeling techniques [8]. In the model, total energy demand is estimated according to Eq. (1).

$$E_t = \sum E_i = \sum \sum A_{ij} * I_j \quad (1)$$

Where, E_t is the total energy demand in the energy system, E_i is energy demand in sector (i), A_{ij} is activity data in sector (i), sub-sector (j), and I_j is energy intensity in sub-sector (j).

3.3. Scenario Based Approaches for Mitigation Assessment

For assessing the impact of different policies and measures on GHGs emission reduction in the cement sector, first the energy demand and GHGs emission was estimated in BAU scenario for 15 years vision, between 2005 to 2020, with the first five years results (2005-2010) used for calibration of the model prediction. Then the impact of energy efficiency and switching to low carbon fuel on energy demand and therefore GHGs emission reduction was assessed in the Mitigation scenario. For this purpose, substantial amounts of data, including cement production capacity, energy intensity, fuel mix, type and age of the technology and theirtrends during the study horizon must be collected. The definitions of scenarios and their required information are as follows.

3.3.1. Business-as usual scenario (BAU)

In the business as usual (BAU) scenario, current trends of the cement industry continue in the future, and GHG emissions are predicted by projection of the trend of the main variables, such as cement production growth rate, type and rate of fuel consumption, rate of technological changes and energy intensity.

In this scenario, 2005 was selected as the base year and all relevant information for cement industry in the base-year was collected. Then, the BAU scenario was developed according to current plans as well as future policies, trend of variables such as cement production capacity, energy intensity, and fuel share and other factors in the cement industry during 2005-2020. The trend of key variables and its assumptions are as follows:

- *Production capacity*: According to Iran's Vision 2020 Development Plan, cement production capacity will increase from 32.6 million tonnes in 2005 to 92.6 million tonnes in 2020.
- *Fuel mix*: With respect to the trend of natural gas substitution instead of heavy oil in recent years, it is predicted that the share of natural gas will increase from 63.1% in 2005 to 80% in 2020, while the share of diesel oil and biomass will be constant at 0.7% and 0.0%, respectively [9].
- *Energy intensity*: For estimation of the energy intensity of the cement industry within the country, first the information for thermal and electrical intensity of different cement technology is collected [10]. Then the average intensity estimated according to Eq. (2).

$$I_t = \sum w_i I_i \tag{2}$$

Where, I_t is Average energy intensity of cement industry within the country, I_i is energy intensity of technology(i) in MJ/ton, and w_i is the share of technology(i) in the total cement production in the country (%).

Table 2 shows the share and energy intensity of the different cement technologies within the country. Based on Eq. (2) and Table 2 information, the thermal and electrical intensity of the cement industry are 836.4 Kcal/kg-cement (949.6 Kcal/kg-clinker) and 112.1 kWh/kg-cement in 2005, respectively. It is predicted that, based on current trends of energy efficiency programs in the cement industry, the thermal intensity will decrease to 784 Kcal/kg-cement, while the electrical intensity will remain at 112.1 kWh/kg-cement [11].

TABLE 2: ENERGY INTENSITY OF THE VARIOUS TECHNOLOGIES IN CEMENT INDUSTRY OF IRAN IN 2005

Technology	**Portion of Total Production (percent)**	**Production (ton/yr)**	**Capacity (ton/day)**	**Fuel Consumption Intensity (kcal/kg.clinker)**	**Electricity Consumption Intensity (kWh/ton)**
Dry high heater	5.14	1,600,500	4,850	1125	111
Dry pre heater	40.51	12,606,000	38,200	950	108
Dry pre heater and pre calcinatory	51.70	16,087,500	48,750	890	114
Mid dry pre calcinatory	0.64	198,000	600	1020	110
Wet process	2.01	627,000	1,900	2000	150
Total / Weighted average	100	31,119,000	94,300	949.6	112.1

Source: Ministry of Energy [10]

3.3.2. Mitigation scenario

In the mitigation scenario, employing different policies in order to reduce energy demand and mitigating GHGs emission are considered as input data to LEAP model. Then, the effect of different policies and measures is assessed through predicting the energy carriers' demand by fuel type and estimating GHGs and air pollutant emissions in BAU and Mitigation Scenarios. Finally, the overall energy demand and GHG emissions are compared in BAU and Mitigation scenarios which indicate the contribution of different measures on GHG emissions reduction. The policies that were surveyed in the study are fuel switching and energy efficiency.

The energy efficiency policy consists of a group of programs like waste heat recovery for power generation, waste heat recovery for preheating of the raw materials, energy efficiency through the renovation and rehabilitation of the old technology and utilizing state-of-art technology in new installed plants, while the fuel switching is focusing on increasing the share of natural gas and biomass in cement industry fuel mix. The trend of key variables and its assumptions are as follows:

- *Production capacity*: The trend of cement production in mitigation scenarios is the same as in the BAU scenario.
- *Fuel mix*: With respect to the government polices on promoting fuel switching from liquid fuel to natural gas in industry, it is assumed that the share of natural gas in cement fuel mix is increased to 85% in 2020, which is 5% more in comparison to BAU. This is the maximum available capacity for natural gas supply to the cement industry based on gas network capacity and availability. Also, with respect to availability of biomass resources, technical feasibility and economical viability, it is amused that the share of biomass in fuel mix of the cement industry is increased from 0% to 5% in 2020, in comparison to BAU scenario. Table 3 shows the share of different fuels in cement fuel mix for 2005 and 2020 in BAU and Mitigation scenarios.
- *Energy intensity*: It is assumed that the thermal energy intensity of cement industry is reduced from 836.4 Kcal/kg-cement in 2005 to 700 Kcal/kg-cement in 2020. While the electrical intensity remains at the same level. This means that the cement industry in *Mitigation Scenario* in 2020 is 10.7% more efficient than *BAU* Scenario. The energy efficiency potential in mitigation scenario is estimated based on following assumptions:

- *Replacement of old technology:* It is assumed that all cement production units older than 20 years are replaced with new and efficient technologies. With respect to the type of the technologies and its share of total national cement production capacity (35% of total), replacement of the old technology with state-of-art technology may improve the national energy efficiency of the cement industry by 7.7%.
- *Energy efficiency improvement programs:* In this measure, it is assumed that all cement production units that are 10 to 20 years old will carry out energy efficiency improvement plans. With respect to the share of these plants in the country total cement production capacity (25% of total), implementation of the energy efficiency programs may improve national energy efficiency of the cement industry by 3%.

Therefore, overall energy efficiency of cement industry in 2020 will be improved about 10.7% in mitigation scenario when compared to BAU scenario [11].

TABLE 3: CONTRIBUTION OF ENERGY CARRIERS IN CEMENT FUEL MIX IN BAU AND MITIGATION SCENARIOS (%)

Fuel	**Share of total demand in 2005**	**Share of total demand in 2020**	
		BAU Scenario	**Mitigation scenario**
Fuel oil	36.1	19.21	9.21
Natural gas	63.11	80	85
Diesel oil	0.79	0.79	0.79
Biomass	0	0	5

4. RESULTS AND DISCUSSION

The BAU scenario shows the projection of energy carriers' demand if the key variables like fuel type and production technology remain true to current trends. The results of energy demand forecasting in the BAU scenario (Fig. 2) show that total energy carriers' demand in BAU scenario will increase from 130 million Gj in 2005 to 340 million Gj in 2020, with annual growth rate of 6.82%.

During the same time, by replacing the high-aged cement plants with state-of-art technology and renovating the old units and implementation of energy efficiency programs, energy demand in 2020 is reduced from 340 million Gj in BAU to 310 million Gj in mitigation scenario, which shows a reduction of 9.65% in cement industry energy consumption (Fig. 2). Comparison of the demand growth rate in the BAU and mitigation scenarios shows that the demand annual growth rate between 2005-2020 decreased from 6.82% to 5.9%.

The impact of different mitigation options on global warming and GHG emissions was evaluated. Fig. 3 shows the direct CO_2 eq. emission in the cement industry and reveals that the CO_2 eq. emission in BAU is increased from 8 million tonnes in 2005 to 19 million tonnes in 2020, with an annual growth rate of 5.94%. Comparatively, the CO_2 eq. emission in mitigation scenario is increased from 8 million tonnes in 2005 to 15 million tonnes in 2020, with an annual growth rate of 3.8%.

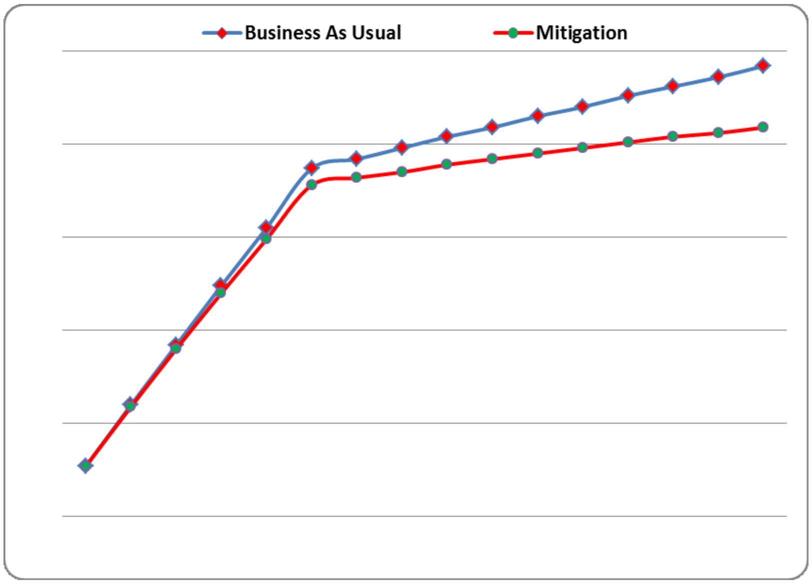

Figure 2: Energy demand in BAU and Mitigation scenario (million Gj)

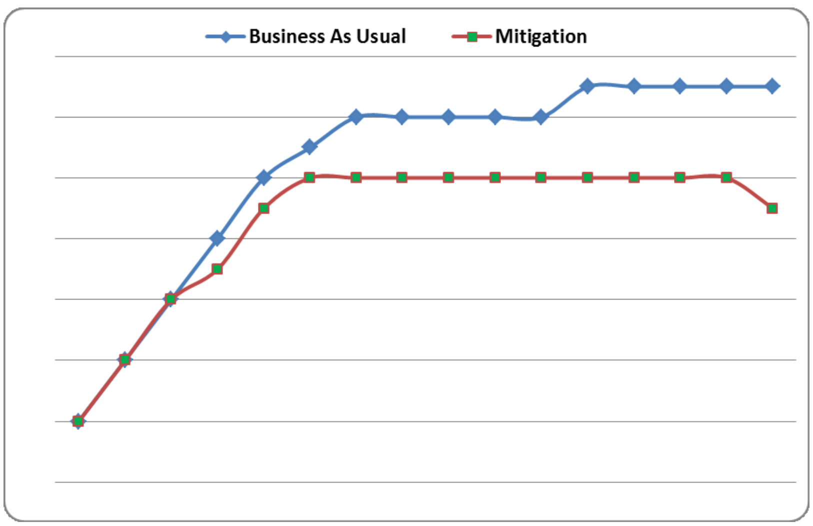

Figure 3: Comparison of GHG emission trend in different scenarios for cement industry (million tonnes-CO_2 eq.)

It is to be noted that the trend for CO_2 eq. emissions in Fig. 3 is just for the GHGs produced in cement units, while a much larger amount of GHGs is emitted by the power plants and refineries providing the electricity and fuels required by the cement industry. As described in Section 2.2, LEAP is a comprehensive energy model which develops the supply side and transmission and distribution system and estimates its environmental impact based on the demand side structures. Therefore, for each demand subsector, LEAP estimates the indirect GHG emissions in the fuel chain for providing the required energy carriers in demand side.

The direct and indirect GHG emissions for providing the demand to cement industry is estimated and shown in Fig. 4 and Table 4. Fig. 4 shows that the overall CO_2 eq. emission (direct and indirect) in BAU scenario increased from 21 million tonnes in 2005 to 62 million tonnes, with an annual growth rate of 7.48%. While, in mitigation scenario, the CO_2 eq. emission in 2020 is about 53 million tonnes, which shows an emission reduction of 14.5% in comparison to BAU scenario (Table 4).

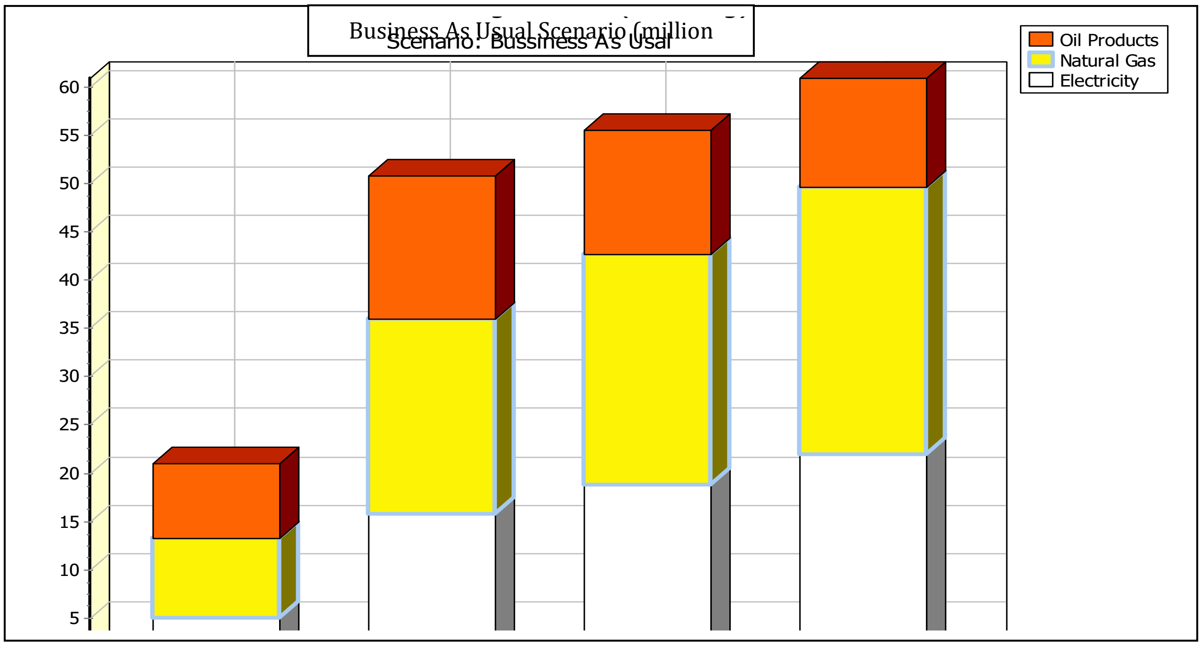

Figure 4: GHGs emission by fuel type in BAU scenario for cement industry (million tonnes-CO_2 eq.)

TABLE 4: COMPARISON OF THE IMPACT OF DIFFERENT MEASURES ON GHGS AND POLLUTANTS EMISSION REDUCTION IN CEMENT INDUSTRY AND FUEL CHAIN FOR THE YEAR 2010 (MILLION TON-%)

Pollutants emissions	**BAU Scenario**	**Fuel Switching**		**Energy Efficiency**		**Mitigation Scenario**	
CO_2 eq.	62	58	4.9%	55	9.8%	53	13.1%
NO_X	55	48	12.7%	49	10.9%	43	21.8%
SO_X	59	28	52.5%	52	11.9%	25	57.6%
CO	19	12	36.8%	14	26.3%	11	42.1%

Table 4 also shows the effectiveness of different mitigation options on GHGs and air pollutant emission reductions. As is shown in Table 4, in comparison to BAU scenario in 2020, implementation of fuel switching and energy efficiency programs resulted in CO_2 equivalent emission reductions of 4.9% and 9.8 %, respectively. This means that the energy efficiency policy is more effective than fuel switching in reducing CO_2 emissions, while the fuel switching is more attractive for air pollutant emissions.

On the other hand, the contribution of electricity in cement industry overall CO_2 eq. emission (inside and outside of the plants) in 2020 is 33% (Fig. 4). This means that cement-induced GHG emissions from electricity generation at power plants are the most important source of emissions in cement industries. Also, this reveals that the elasticity of emission reduction for electricity is higher than for other energy carriers; it is therefore recommended that cement industry energy efficiency programs are included in electricity consumption improvement.

5. CONCLUSION

The highly subsidized energy carriers and the young national population of Iran and its needs for employment have promoted the government and the private sector to invest in energy intensive industries like cement, iron and steel, resulting in a rapid increase in energy demand and GHG emissions in recent years.

In order to meet obligations of *International Treaties* and also *Iran's Low Carbon Economy Plan* (*Adopted by Board of Ministers, December 2014*) in combating climate change, it is necessary that the cement, iron and steel, and petrochemical industries prepare mitigation policies. For this purpose, the impact of energy efficiency and switching to low carbon fuels on GHG mitigation were assessed in different scenarios.

Energy efficiency policy was found to be more effective than fuel switching in CO_2 emission reduction, while for air pollutants emission, fuel switching is an attractive option. Therefore, for global environmental concern, it is recommended that the cement industries in Iran implement energy efficiency programs, while for local environmental issues, a fuel switching program will be more effective.

Also, with respect to the contribution of different energy carries in cement industry GHG emissions, it is recommended that to reach the emission reduction goal in Iran's Low Carbon Economy Plan, the cement industry should replace the substitutable part of electricity demand by other fuels or implement the waste heat recovery programs for electricity generation in the plants.

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Use of Solar and Alternative Energy to Reduce Emissions

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Abstract

To overcome the global warming catastrophe and mitigate its adverse (climate change) effects, the significant reduction of greenhouse gas emissions or effective conversion of carbon dioxide to its origins (C-based materials) is the urgent demand of the present world! To challenge this energy-related/environmental issue of the century, the application of solar-based or other renewable/clean energy sources is a promising route for doing water splitting process and storing the resulted H-atoms as carbon-free or carbon-containing hydrogen fuels, such as ammonia, oxygenates, etc. In this approach, using photon or other alternative energy sources, electrons are generated and synchronously utilized for the production of H atoms/radicals. These transient species are highly reactive and thus become consequently attached (bonded) to the atmospheric stable molecules such as CO_2 or N_2, and eventually converted to other useful materials, so-called food or fuel. This conversion of the atmospheric stable species can be artificially performed in particular photochemical/electrochemical reactors using sunlight and appropriate semiconductor materials with large surface area and great potency to adsorb CO_2 (N_2) species.

Keywords: CO_2 Conversion to Food/Fuel; Emission Balance; Water Splitting; Ammonia/H-Based Fuels; Oxidation/Respiration Processes; Biotic/Abiotic Activities; World's Energy Resources

1. INTRODUCTION

There is no doubt that the boundless dumping of CO_2 greenhouse gas into the atmosphere plays a crucial role in global warming and leads to climate change issues [1]. It is also obvious that the reduction of emissions or back-conversion of CO_2 into its origins (fuels) is a practical solution to mitigate the adverse effects of climate change.

Before focusing on the climate change problem, it is worth noting that the elements such as C, H, O and N are vital for living cells, for creation, proliferation and metabolism of them [2]. The method of entering these elements into the life cycle and their source in the Nature are summarized in Table I.

TABLE 1: SOME ESSENTIAL ELEMENTS IN LIVING CELLS

Elements	Main source	Method of entrance into life cycle
C	CO_2 [a]	Photosynthesis
H	H_2O	Water splitting/ photosynthesis
O	O_2 [a], H_2O, O-containing compounds	Aerobic/anaerobic respiration/methabolism
N	N_2 [a]	Nitrogenase enzyme, N-containing fertilizers (Haber-Bosch process)

[a] Available in the atmosphere

The table indicates that:

1. The main source of carbon on the globe is atmospheric CO_2. This greenhouse gas comes into the life cycle through its consumption by green plants or photosynthetic bacteria. During this process, CO_2 molecules are converted to carbohydrate compounds and the food of animals is naturally synthesized [3]. The byproduct of this photosynthesis process is the emission of oxygen gas, which is vital for aerobic creatures.
2. Water (H_2O) is considered as the major source of hydrogen in the world. Hydrogen atoms (radicals) are transiently produced via water splitting process during the metabolism of living cells [4], through auto-dissociation and proton reduction phenomena (reactions 1 and 2):

$$\boldsymbol{H_2O \rightleftharpoons H^+ + OH^-} \tag{1}$$

$$\boldsymbol{H^+ + e^- \rightarrow H} \tag{2}$$

These transiently generated H-atoms are highly reactive; so they can attach to other species even with chemically stable molecules such as atmospheric N_2 or CO_2. This high reactivity of H atoms (radicals) seems to be the essence of photosynthesis of carbohydrate compounds and bacterial production of ammonia occurring in the Nature.

3. Oxygen is widely found as diatomic O_2 gas. This element is also available in the other O-containing compounds, such as H_2O molecules. The entrance of O-atoms into living cells is continuously carried out through metabolic activities of cells, via aerobic or anaerobic respiration processes [2]; in the first process, the respiration occurs through donation of electrons into O_2 molecules, whereas in the second, the electrons are transported to other recipients (e.g. nitrate, sulfate, or …).
4. About 78% of the atmosphere is composed of diatomic nitrogen molecules. Because of the strong triple bond existing between the nitrogen atoms ($N \equiv N$), this molecule is chemically very stable and inert. Therefore, the natural entrance of atmospheric nitrogen into biotic systems is limitedly accomplished by particular bacteria having nitrogenase enzyme. Because of this matter, the atmospheric N_2 should firstly be converted to a more reactive compound. This is achieved through Haber-Bosch industrial process and ammonia becomes produced [**5**]; using this reactive starting material, N-containing fertilizers are synthesized. Since ammonia production reaction (Eq. 3) is industrially carried out under high temperature and pressure conditions (~500 K and 300 bar), the energy and hydrogen molecules required for Haber-Bosch process are traditionally provided by burning and reforming of fossil fuels.

$$\boldsymbol{N_2 + 3H_2 \rightarrow 2NH_3} \tag{3}$$

Therefore, a vast amount of CO_2 greenhouse gas is emitted during this paramount industrial process.

The objective of this paper is to provide a deep scientific/fundamental insight on the current energy-related/environmental issues, including energy sources in the world, bio-globe (earth and its living creatures) activities and energy provision by means of oxidation (burning or respiration) processes. In this article, we have focused on the strategic aspects to challenge the global warming issue and mitigate its adverse effects, through pointing the practical routes to achieve a balance between CO_2 production and back-conversion to its origins, i.e. carbohydrate food and fuels, using solar and alternative energy sources.

2. Energy Sources in the World and Bio-Globe Activities from Chemical Reaction/Energy Viewpoint

The energy sources in the world are diverse and can be classified into three major categories (Fig. 1); the classification is on the base of solar/nuclear activities, gravitational forces, and internal heat of Earth [6].

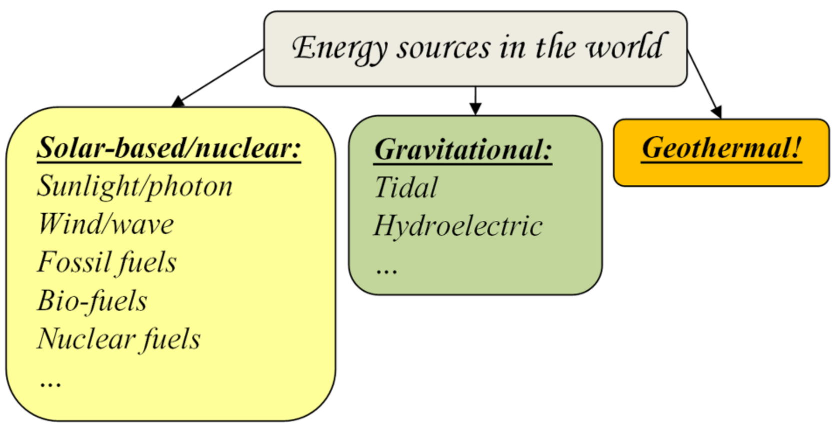

Figure 1: A classification of energy sources in the world

From chemical standpoint, however, the energy of the bio-globe (earth and its living creatures) is provided through the oxidation process of a fuel/food in a natural living cell or human-made reactor [7]; see Eq. 4:

$$\boldsymbol{fuel + oxidant \rightarrow products + energy} \qquad (4)$$

Fuel could be fossil, hydrogen, ammonia, alcohol, or any type of material which is capable to be oxidized naturally or artificially in a biotic or abiotic reactor/cell. For biotic reactions in living cells, the word *fuel* is often replaced by *food* or *substrate*.

In Eq. 4, *oxidant* denotes to oxygen molecules or other types of oxidizing agents, which are capable to accept electrons from the fuel/food material (e.g. Fe^{3+}, SO_4^{2-}, CO_2, N_2, etc). Products of this oxidation process (also it is referred to as burning/combustion) can be a variety of compounds including carbon dioxide, water, nitrous oxide, ammonia, alcohols, bio-molecules, etc. Depending on the type of electron transfer (direct or indirect through a medium) being taken place between fuel and oxidant, the energy of chemical bonds could be released in a controlled or un-controlled way, as heat, mechanical or electrical energies (see Table 2). It is generally concluded that such e-transport processes are the base of most energy-related chemical reactions occurring in the world, and Eq. 4 is the essence of all internal combustion heat-engines, fuel cells, living creatures (prokaryotes and eukaryotes), bioreactors, and so on!

TABLE 2: RELEASE AND MATERIALS PRODUCTION DURING FUEL/FOOD OXIDATION PROCESS BEING TAKEN PLACE IN VARIOUS NATURAL OR ARTIFICIAL CHEMICAL REACTORS

Category	Application	Type of e-transport	Type of energy release	Emissions/Products
Heat engines (internal combustion)	Transportation, automotives, jet turbines, power plants, traditional carbon-base heating devices/reactors, etc.	Direct	Heat/ mechanical	CO_2, H_2O, NO_X, SO_2, alcohols, synthetic gas and so on.
Fuel cells/ electrochemical power sources	Hi-tech industries including new generation of power plants, transportation, aerospace, eletrogenerative synthesis, etc.	Indirect, being transferred through external circuit	Electrical/heat	H_2O, CO_2, NH_3, etc.
Living cells/ Bioreactors	All type of biotic systems/microorganisms (simple or complex)/ metabolic activities/ biosyntheses, bioengineering	Indirect through respiration process, being mediated by the living cells (e.g. bacteria)	Heat/electrical/ mechanical/ light/etc.	CO_2, H_2O, NH_3, biogas, hydrogen, bio-molecules, etc.

3. CARBON DIOXIDE EMISSIONS AND BACK CONVERSION TO ITS ORIGINS: HUMAN-CAUSED IMBALANCE

As mentioned in the previous section, the energy of terrestrial creatures is chemically provided through fuel/food oxidation/respiration processes. In this regard, if a carbohydrate material is utilized as a fuel (food), the final product of this oxidation (respiration) process will be the release of energy, carbon dioxide and water molecules. In the life cycle, this CO_2 greenhouse gas is naturally re-consumed through back-conversion photosynthesis process (see Fig. 2), via sunlight and green plants or photosynthetic bacteria [8].

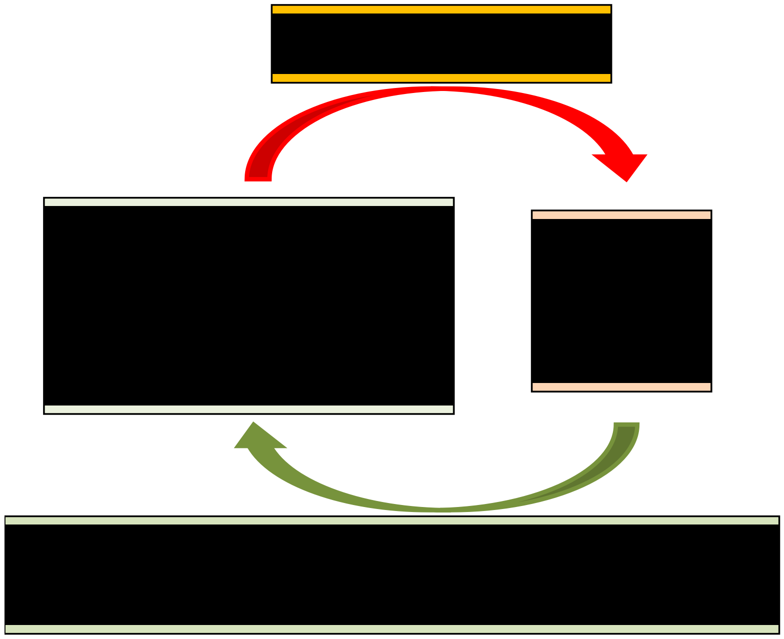

Figure 2: Carbon cycle: CO_2 emission and back-conversion to its origins!

Regarding to carbon cycle depicted in Fig. 2, the following results are deduced:

1. Since CO_2 is the major greenhouse gas, it is obvious that by keeping a balance between its production and consumption, the climate change issue will be controllable and the net emission eventually approaches zero!
2. To provide the world's energy demands, instead of burning the depleting fossil resources, we could alternatively use hydrogen fuels [6]. The byproduct of this non-carbon fuel is not CO_2 but fortunately water molecules!
3. Instead of utilizing the oxidation processes and emitting the vast amount of greenhouse gases into the atmosphere, we can employ other clean energy sources, such as solar photons, wind energy, hydroelectric/tidal power, geothermal heat, etc.
4. With photosynthetic reverse reactions, not only the level of CO_2 gas in the atmosphere becomes eventually (at least locally) decreased but the metabolism of other organisms can be also facilitated with the production of oxygen and synthesis of carbon-based foods (carbohydrates, starch, glucose, etc). Concerning this strategy, forestation programs could be effective; however, they do not seem to be sufficient alone, because, annually a huge amount of CO_2 gas is damped into the atmosphere. Therefore, artificial photosynthesis (through water splitting process, using sunlight and appropriate semiconductor materials [6]) or genetic manipulation of living cells could be an alternative solution to reduce and convert CO_2 greenhouse gas to other valuable compounds.

To reduce CO_2 emission, we need to globally identify its main sources in the world. As mentioned formerly, Haber-Bosch process (nitrogen fixation and ammonia production) is one of these sources, which plays a significant role on CO_2 dumping into the atmosphere. Concerning this fact, it should be noted that the amount of ammonia being annually synthesized is approximately 1.5 million metric tons and each ton is accompanied with the release of 1.87 tons CO_2 into the atmosphere [5]. Thus, to minimize CO_2 emission, the synthesis of ammonia using clean routes, under ambient conditions is highly on demand. By this new strategy and synthesis of carbon-free green fuels, we could resolve the explosive problem of the hydrogen gas and store it as a safe liquid ammonia fuel [9].

4. HYDROGEN SOLAR FUELS

As we know [10], hydrogen is the first element of the Periodic Table and the most abundant element in the universe [11]. Hydrogen is utilized as the fuel of most celestial power-generating nuclear-fusion reactors, in the sun and other stars [12]. The energy being released during these nuclear reactions is transmitted in free space as electromagnetic waves, so-called photons. The photons coming to the earth as clean/filtered energy are used by living organisms to power their metabolic activities [8]. This solar energy is utilized by green plants as well as photosynthetic bacteria, through natural photo-splitting process of water molecules to extract their hydrogen atoms for further recombination with the atmosphere CO_2 and supply foods and fuels of the world [3]. Oxygen is the byproduct of this biotic process and it is consumed again during the respiration process of aerobic creatures.

Hydrogen can be found in the world in three different oxidation states: +1, 0, and -1, which is known as proton, hydrogen atom (radical) and hydride, respectively. H-atoms/radicals can be transiently produced with consumption of energy via a *redox* process or bond cleavage of the H-containing compounds; see Fig. 3.

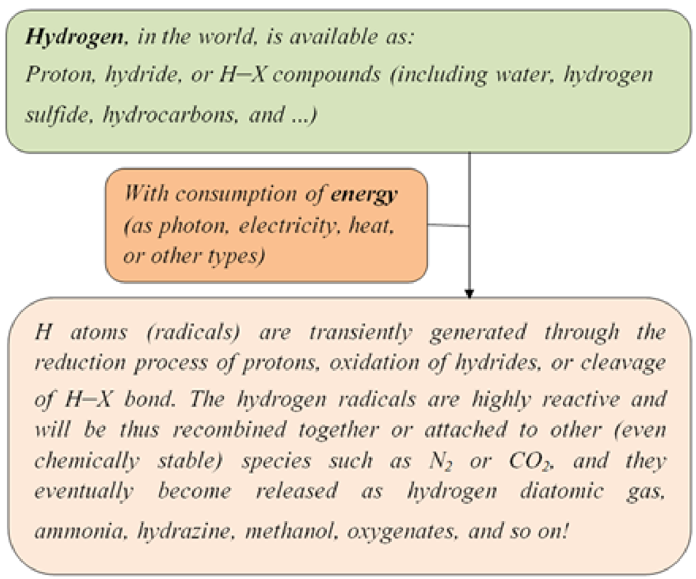

Figure 3: Hydrogen appearance in the world and production of H-based fuels.

These transiently generated hydrogen atoms are capable to recombine together or attach to other species (e.g. atmospheric CO_2 or N_2) and produce H-based fuels, such as oxygenates and ammonia [6]. The energy required for this chemical conversion is naturally supplied by the Sun, which is considered the main energy source of the world! This photosynthetic process could be also carried out in artificial water photo-splitting systems through a photon-to-electron conversion phenomenon, in the presence of appropriate narrow band-gap semiconductor materials [6]; therefore, H-based solar fuels could be artificially synthesized.

5. CONCLUDING REMARKS

To challenge the CO_2 issue and mitigate its adverse (climate change) effects, the following strategies are suggested:

1. Using sunlight or other clean energy sources, we can perform water splitting process by mimicking the Nature route in adjusting the level of atmospheric carbon dioxide through its conversion and production of hydrogen-based fuels.
2. The application of carbon-based energy carriers needs to be globally discouraged and replaced by those having no CO_2 emission, such as hydrogen or ammonia fuels.
3. Instead of burning fossil resources and wasting them as heat, CO_2, and other environmental toxins, we could directly utilize solar energy or other sustainable clean alternatives and produce electricity by means of photon-to-electron conversion phenomena.
4. We should identify the main sources of CO_2 in the world. Using these data, we could find a scientific route to achieve a global balance between CO_2 emission and its consumption to produce food/fuel.
5. Genetic manipulation of the microorganisms is another challenging strategy to generate living cells with accelerated metabolism (inhalation). These mutated bacteria could be employed as efficient biotic energy-convertor micro-machines to produce electricity or synthesize chemical compounds in microbial fuel cell reactors.

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Resilience Thinking for Adaptation of Cities to Climate Change

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Abstract

Climate change is an issue of enormous impact to society at local, regional and global scales. Cities are increasingly vulnerable to the direct and indirect effects of climate change; urban planners and decision makers are acting to reduce these effects. In this research, decisions made by city planners in Tehran, Buenos Aires, Delhi, Lagos and New York are evaluated. Results show that actions by these urban planners have had varying levels of success and generally lack a holistic strategy for minimizing adverse effects of climate change. Adaption of resilience thinking would be beneficial for organizing urban adaptation measures to better combat climate change impacts. In a resilience thinking approach, scientists and urban planners develop an integrated framework for adaptability, thereby reducing impacts and improving urban resiliency.

Keywords: Climate Change, Resilience Thinking, Adaptability, City, Urban Resiliency

1. INTRODUCTION

The world's population has become more urbanized in recent decades, from 28.3% in 1950 to 50% in 2010 [1]. Cities occupy less than 2% of the earth's land surface, yet consume 78% of the world's energy and are the source of more than 60% of all carbon dioxide as well as substantial amounts of other greenhouse gas (GHG) emissions, mainly through energy generation, vehicle use, and industrial activities. The high sensitivity of urban areas to impacts of climate change has prompted cities to begin exploring strategies for mitigation and adaptation [2].

Climate change exerts added stress on urban environments through increased frequency of extreme weather events (e.g. heat waves), which threaten the health of the elderly, the ill, and the very young; more frequent and intense droughts and inland floods, which threaten water supplies; and for coastal cities, sea level rise and storm surge, affecting both people and infrastructure [3]. At the same time, cities are responsible for a considerable portion of GHG emissions and are therefore crucial to global mitigation efforts [4,5]. Though cities are clearly vulnerable to the effects of climate change, they are also uniquely positioned to take a leadership role in both mitigation and adaptation because they are pragmatic and action-oriented; play key roles as centers of economic activity regionally, nationally, and internationally; and are often first in societal trends. There are also city-specific issues that are exacerbated as a consequence of climate change. These include the urban heat island effect, increased air pollution, increased population vulnerability along coastlines, and high population density and diversity.

Urban planners can play an active role in reducing the negative effects of climate change but, without the proper framework, their actions may not provide the greatest possible benefit. The direct and indirect effects of climate change that are already occurring in cities have caused uncertainties in urban management decisions. To move forward, a new review of urban policies, plans, and programs, based on ecological approaches, is warranted.

The concept of resilience is a flexible and new approach that is currently used in several fields of study. Resilience was originally suggested as a descriptive ecological term and refers to a basic capacity of an ecosystem to maintain desirable services while confronting natural and/or human-caused ecosystem disruption [6].

The application of the concept of resilience, especially in urban areas, is organized by a framework of resilience thinking. Resilience thinking, through the concept of multi-scale and selection of appropriate temporal and spatial scales, provides insight to consider an unpredictable future, the inevitability of change, and vulnerability of such systems [7,8]. Resilience thinking provides a structured method for taking into account the complexities, uncertainties, and interdependencies of systems and paves the way for new methods of planning and more efficient application of assessment and sustainability thinking [9].

The purpose of this study was to apply the concept of resilience thinking to evaluate the climate change mitigation and adaptation strategies of five megacities (Tehran, Buenos Aires, Delhi, Lagos, and New York). The measures adopted by each city are presented and critiqued using a resilience thinking framework to assess their efficacy to mitigation and adaptation efforts.

2. Adaptive Activities of Five Cities to Climate Change

The five cities selected for assessment were Tehran, Buenos Aires, Delhi, Lagos, and New York. These megacities are important national urban centers in their countries and they exhibit a range of socio-economic conditions and vulnerabilities to climate change. Using a resilience thinking framework, we evaluated the plans, policies and programs of each megacity for managing climate change impacts.

2.1. Tehran

Tehran is the political and financial capital of Iran. According to the public census in 2011, greater Tehran has over 12 million inhabitants, representing 16.21% of the population of the country. Tehran contains several sub jurisdictions that were added as the city expanded. Tehran has a setting characteristic due to its geographical location. Natural and topographic characteristic are well reflected in the elevation of the city above sea level which varies from 1,000 meters to 1,700 meters [10].

Tehran is a unique megacity in terms of geographic setting (non-coastal), being mountainous with an ever expanding urban area; hence it suffers from acute air pollution and heat wave episodes. The mean and maximum summer temperatures in Tehran have increased over the last fifty years. Temperature trends in Mehrabad (District of Tehran) over the last 60 years are shown in Fig. 1: annual mean temperature for the years 1950-2003 and summer mean daily maximum temperature for the last ten years (2004-2013). The mean summer (June, July, August) temperature has increased at a rate of +0.04 ºC/year over the last 60 years, while the summer mean daily maximum temperature has a steeper rise of +0.083 ºC/year for the last ten years. In addition, the rate of increase in mean annual temperature is about four to five times greater in Tehran than for the region, possibly due to urban heat island effect.

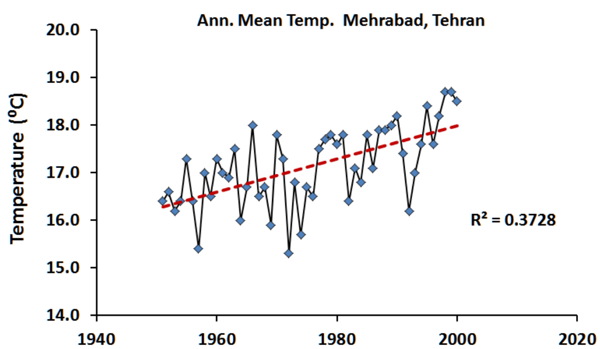

Figure 1: Surface air temperature trends for Tehran: a) summer mean temperature for Mehrabad station, Tehran and b) summer mean daily maximum temperature for Geophysics station [11]

In addition to the combined effects of population growth/urbanization, climate change may be an additional causal factor for the increasing temperature trend observed over the last 60 years in Tehran. An increase has also occurred for near surface ozone concentration, a potential hazard to public health and property. Recent air quality records (last 20 years) show increased pollutant concentrations with some low frequency variability (caused by chaotic atmospheric motions). Apart from the increase in pollutant emissions as a result of the city expansion, wind speed (often locally driven by mountains for about 85 percent of the year) has decreased as a result of the increase in aerodynamic surface roughness and probable decrease in the frequency of cyclones (recent finding of climate effects for the mid-latitudes) over the area [6]. Wind records for Tehran show a decrease in wind speed has occurred over the last 60 years (Fig 2a) and especially for the northerly wind component (katabatic wind) (Fig 2b).

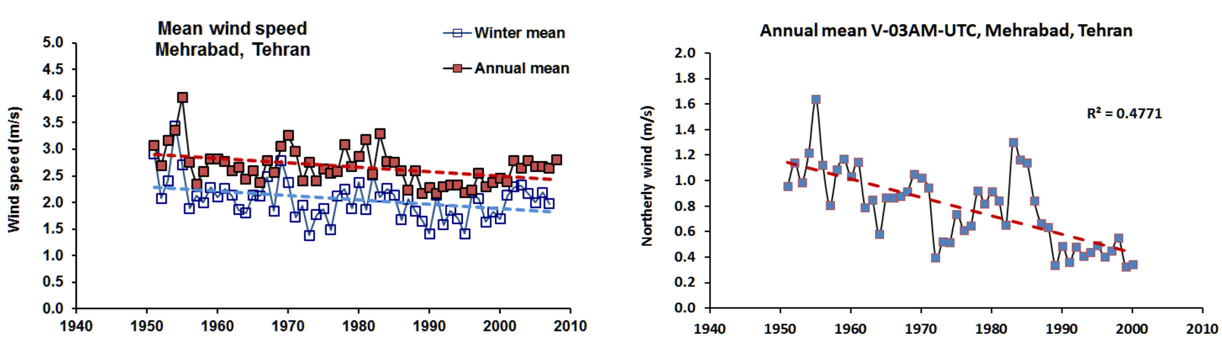

Figure 2: Wind speed (m/s) for the last 60 years in Tehran: a) annual mean and winter mean and b) annual mean of early morning northerly component of wind [11]

Mean annual winter wind speed has not only decreased but is lower than the annual average wind speed. Such slow winds cannot ventilate this populated area efficiently, leading to strong episodic air pollution periods, especially when the mid latitude jet stream is far from this area [12] in cold seasons. The northern mountain also plays an important role in local air circulation as well as air pollution distribution. Higher surface heat fluxes (mainly due to the reduction of surface albedo, anthropogenic heat, higher heat capacity of the building materials and lower green spaces) is expected to have increased the mixed layer height over the city. Although this is favorable for reducing some air pollutants such as CO, it has not reduced ozone or particulates. Built up areas and some industrial sites (often upstream of the prevailing winds) appear to have been often expanded, irrespective of weather and climate conditions, hence ventilation of the city is becoming an ever deteriorating problem. Emissions of pollutant gases and particulates have increased PM10 concentrations and have resulted in poorer visibility over the city. Fugitive dust has also become frequent due to the transport of dust from distant sources. Such events increase atmospheric particle concentrations by substantial amounts and have led to the closure of city activities at an increasing rate. long term trends of climate change and emissions have affected air quality conditions. Episodic acute air pollution periods have also increased leading to more frequent hampering of city activities. It has also been shown that occasional stagnation periods have led to the increase of air pollutants to alarming levels, leading to more frequent closures of major institutions in recent years [11]. It is also interesting that air pollutant concentrations appear to be better correlated with either the northern (nearer the mountains) or southern stations (more distant from the mountains) of the city and not between those of the north and those of the south, indicating that the northern mountains have a strong influence on distribution of air pollutants over the city (Fig.3).

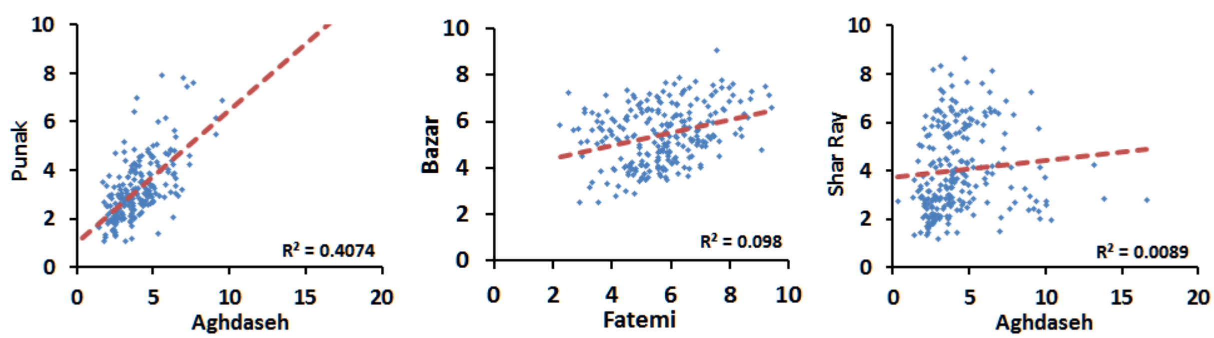

Figure 3: Correlations between CO concentrations (ppm) measured at different locations in Tehran: a) Ponak and Aghdasyeh (north, near mountain), b): Bazar and Fatemi (further south, away from mountain) and c): Ahdasyeh and Shahr Ray (One north and other south respectively). Data shown are daily winter CO concentrations for years 2002-2007 [11]

The Iranian government response to climate change and its local impacts, especially regarding GHG emissions and other types of air pollution has been to develop a set of policies, plans, and research programs that are implemented by various departments, offices and agencies. These efforts include: adjusting the Subsidiary Act in November 2008 (according to this law, the government is obligated to adjust the price of energy distribution), approving the Vehicle Technical Inspection Law, retiring older automobiles, developing bicycle routes, approving standards for maximum permissible pollutant emissions for different types of cars, adopting clean air standards for the years 2009, 2010, 2011 (approved by the High Commission on Environmental Protection), developing comprehensive plans for air pollution reduction in the city of Tehran, expanding public transportation fleets such as the BRT system (rapid bus transit provided 62% share of service in 2010), constructing a metro (underground subway) network with four major operational service lines (number of passengers was around 2.5 million per day in 2010), developing comprehensive plans for identification and assessment of water resources, and expanding urban green spaces from 14.3 % in 2001 to 16.5% in 2010.

The dry hydrologic conditions in the Tehran region (average precipitation of about 250 millimeters per year), accompanied by high population density, and a changing climate, have made water resources management complicated and challenging. The rate of groundwater extraction exceeds the rate of natural recharge, which has resulted in an acute drop (about 18 centimeters per year) of the water table. Mitigation measures taken in this regard include: formation of a groundwater resources committee in the environmental and sustainable development headquarters of the municipality of Tehran in 2003 to organize and regulate the qanats in Tehran, and development of a plan for identifying and assessing the potential for underground water resources (qanats) [10].

Most of the adaptability measures implemented so far in Tehran are related to developing plans for reducing air pollution. These efforts have been effective in reducing GHG emissions but the municipalities do not have an overall perspective on the effectiveness of these measures for mitigating climate change. The goal has been develop laws and standards to combat the effects of air pollution, without attention to the larger issue of climate change.

2.2. Buenos Aires

Based on the National Population Census Report in 2001, the Greater Buenos Aires Agglomeration (AGBA), which includes metropolitan Buenos Aires and several sub-jurisdictions, has over 12 million inhabitants and is the third largest city in Latin America. Increases in sea and river levels, rising temperatures and precipitation amounts, along with increased frequency of extreme events such as flooding and drought in this region are likely examples of consequences of climate change. in this region. The city has a humid subtropical climate with long hot summers, and with low precipitation in winters. There are strong south-southeast winds in the summer and autumn summer causing floods along the shores [13]. Occurrence of precipitation events of more than 100 millimeters within 24 hours has increased in this region and a quarter of the metropolitan area is susceptible to flooding [14].

The Argentinean government's response to these local impacts, likely caused by climate change, has been to develop a diverse series of policies, plans and research programs. These efforts include the Greenhouse Gases Reduction Program, Climate Change Unit in 2003, and the National Program on Climate Scenarios in 2005. Additional responses include flood monitoring, development of broader disaster management systems, and development of climate change mitigation and adaptation programs involving NGOs, the media, and citizen groups [15,16].

The roles and responsibilities of governmental agencies in regard to these climate change impacts have been fragmented, with mismatches in terms and scales and conflicts among plans from different jurisdictions. These weaknesses reduce the efficacy of climate change response plans at the city level [17-19].

2.3. Delhi

Metropolitan Delhi has over 16 million inhabitants. Delhi is a city of wide income contrasts, with most of the people living below the national poverty line and having low quality of sanitation, residing in slums and exposed to a high level of vulnerability. Delhi has three distinct seasons:

summer, winter, and monsoons with extreme temperatures and concentrated precipitation. Climate-induced hazards in this region are increases in temperature, precipitation, the Indian Monsoon, and sea-level rise [20]. It is predicted that drought-prone areas will become drier and flood-prone areas will experience a higher frequency of flooding. Because of these extreme events and the characteristics of Delhi's physical infrastructure, social services, and the hyper-dense nature of the slums make this region highly vulnerable to effects of climate change [19].

Projects in Delhi for mitigating these climate change impacts include carbon emission reductions and other environmental improvements. Dehli is establishing the world's largest fleet of compressed natural gas (CNG) vehicles and is improving vehicular emission standards. The "Bhagidari program" provided a context for public participation to enhance awareness and engagement for addressing climate change, adopting green building technology for reducing GHG emissions, installing compact fluorescent lamps and capacitor banks to increase energy efficiency, reducing demand for energy, developing a program that subsidizes electric vehicles and encouraging the introduction of the Reva car, as well as battery-operated two- and three-wheelers.A "Clean Development Mechanism (CDM)" project proposal is being developed. Greening programs like expanding forest cover is a part of CDM that is being conducted in collaboration with several stakeholders in the city [19].

The government of Delhi is developing projects to mitigate the effects of climate change. However, coordination between departments and among levels of government is generally lacking. They have not yet developed strategies for adaptation to climate change.

2.4. Lagos

Metropolitan Lagos, Nigeria, is one of the world's ten largest cities, with over 18 million inhabitants in 2010. There are dense slum populations in this region that are located on flood-prone lands. The climate of Lagos is affected by the Atlantic Ocean and atmospheric interactions. This region experiences relatively high to very high temperatures throughout the year and high to very high monthly rainfall between May and November, with extreme precipitation events in June. Climate-induced hazards in this region include: increasing monthly maximum temperature, decreasing monthly minimum temperature, increasing average temperature, increasing number of heat waves, decreasing total annual precipitation, and increasing coastal storm surge. Rising sea level is the most important impact in this region and has caused erosion along the Lagos coast, increased the salinity of both ground and surface water and has affected the slums [19,21]. Flat topography and low-elevation, high population, widespread poverty, and weak institutional structures make Lagos particularly vulnerable to the adverse effects of climate change.

Recently, the Lagos government has addressed the problem of flooding and coastal erosion through conducting research studies, building a sea protection wall, constructing primary and secondary drainage channels; cleaning open drains and gutters; upgrading slums, and developing educational programs and training workshops on climate change issues. These programs create awareness of climate change issues and can help the adaptation capacity. Some mitigation actions being pursued by the Lagos State government that related to issues of climate change are improving of solid waste dump sites that are notable point sources of methane emissions; establishing green technology for transportation; city greening projects, and proposed provision of three air-quality monitoring sites for the city [19].

Lagos does not yet have a comprehensive plan or perspective to address climate-induced hazards. The local mitigation measures and awareness efforts indicate that city managers currently lack a holistic approach for adaptation to climate change.

2.5. New York

Based on the report “The City of New York,” New York City is the largest coastal city in the USA both in population (8.2 million people) and in economic productivity [22,23]. New York City has a temperate, continental climate characterized by hot humid summers and cold winters. This relatively low elevation region, because of mid-latitude and tropical hurricanes and nor’easter storms, is susceptible to erosion of coastal wetlands. Climate-induced hazards in this region are causing a number of effects including sea level rise, increasing possibility of inundation during coastal storms, increasing heat waves and rising mean temperature, inland flooding (due to increasing intensity rain events) and droughts (because of increasing time period between rain events). Impacts of these climate hazards may affect the water supply, urban infrastructure, energy demands, air quality, human health, and areas of low per capita income.

New York has an active scientific research program on climate hazards, and is working closely with universities and other administrative bodies. For example, the Center for Climate Systems Research (CCSR) in the Earth Institute at Columbia University works with the New York City Department of Environmental Protection; they have developed a sector-specific climate assessment and action plan for New York City’s water system [24,25]. The NYC Climate Change Adaptation Task Force has developed a comprehensive, integrated climate change risk assessment and adaptation plan for the critical infrastructure of the metropolitan region. The New York Panel on Climate Change (NPCC), composed of various scientists and institutions, has the responsibility to provide expert guidance on climate change risks and adaptations needed to create actionable guidelines and plans [19]. The NPCC and the NYC Climate Change Adaptation Task Force have worked together to develop a set of definitions for adaptation assessment.

Such cooperation between decision-makers from all key departments in the city and numerous other sectors is providing climate information in a multidimensional and systematic framework for increasing urban resilience to climate change but these activities are not yet being implemented based in a strategic holistic orientation.

3. Resilience Thinking

The four key aspects of resilience thinking are the socio-ecological system (SES), adaptive cycle, panarchy, and adaptive capacity [26-28]. The utility of these concepts in promoting a holistic approach for developing adaptation measures to climate change is described below.

3.1. Socio-Ecological Systems

One of the most important concepts in resilience thinking is the socio-ecological system. This concept was created by scholars within the realm of resilience which includes cities. Socio-ecological systems are considered as the integration of nature and human society, with mutual feedbacks and interdependencies [29]. Influenced by resilience thinking, urban ecosystems are defined as the production of natural and social processes within which structure and performance are closely related [30-33]. Such thinking can help decision makers in considering all components of a city, emphasizing interdisciplinary studies and their relationships for increasing urban resiliency to climate change.

3.2. Adaptive Cycles

Socio-ecological systems are dynamic and follow distinct phases of a cycle, similar to what occurs in a natural ecosystem. The four phases in a natural ecosystem are rapid growth and exploitation (r), conservation (K), collapse or release of resources (Ω), and renewal and reorganization (∝) [34]. The evolution of these four phases over time is generally named the "Adaptive Cycle" [6]. When a system passes through these four phases, there will be some internal change or vulnerability toward disorder. The capacity of the system to suitably respond to a disturbance (e.g. climate change) varies depending on which phase of the cycle it is currently in. Examining the condition of the system and recognizing which phase of the adaptive cycle it is in will enhance our awareness and insight on choosing the type and timing for administrative involvement [26].

3.3. Panarchy

The term "Panarchy" is an anti-thesis of the term hierarchy. Whereas hierarchy means a top-down organizational structure, panarchy refers to an evolving hierarchical system with multiple interrelated elements. The term also emphasizes the unpredictability of relationships between elements of an ecosystem [6,34]. Decision makers recognizing the concept of panarchy are better able to consider appropriate temporal and spatial scales for assessment and planning, and correlation between different tiers of decision-making will be better considered [35]. Understanding the dynamics of a system at a specific management scale is quite difficult without properly including consideration of the higher and lower scales [34]. Utilizing the concept of panarchy helps to understand differences between scales (levels) through consideration of appropriate multi-dimensional time and space scales [26].

3.4. Adaptive Capacity

In resilience thinking, adaptive capacity is a measure of the willingness of actors (cities) to adapt to the impacts of climate change [19]. In the context of cities, adaptive capacity considers institutional attributes (institutional structure, caliber, resources, information, and analysis) and their actors (local governments and their constituent departments, private sector, civil society, NGOs, and academics) that determine the degree of its capability to respond to potential climate change impacts [19]. Specific characteristics of adaptive capacity include: test of experience, new strategies for ecosystem management, new approaches for cooperation, inter- and intra-organizational levels and staff in order to present new methods and to improve the flexibility and adornment of new organizations and administrations. By using these factors, a system can promote resilience through encouraging flexibility, integrity, variety and innovation [34].

Adaptive capacity that is organized within a resilience thinking framework provides a superior approach for maximizing urban resilience to climate change. Taken together, the four concepts of resilience thinking provide a framework (Table 1) for cities to better adapt to climate change.

TABLE 1. APPLICATION OF RESILIENCE THINKING FOR ADAPTATION OF CITIES TO CLIMATE CHANGE

Resilience Thinking Concept	Application of resilience concept to climate change
Social-ecological systems	• *Assessing the system as a whole and not as individual components* • *Understanding the relationships between social and ecological systems* • *Emphasizing multidisciplinary assessment studies*
Adaptive Cycle	• *Awareness and knowledge about the type and timing of management involvement*
Panarchy	• *Choosing appropriate time and spatial scales for adapting measures* • *Finding an incongruous and heterogeneous solution in relation to different tiers of decision-making* • *Attention to trends and future threats concerns the ability of prediction on the basis of current information*
Adaptive capacity	• *Clearance* • *Cooperative learning* • *Cooperation in national, regional, and local levels* • *Adapting the management plans with ecological scales* • *Using experiences from the past and requires the capacity to utilize the necessary knowledge to deal with similar conditions in the future*

4. RESULTS AND DISCUSSION

The four concepts of resilience thinking were used to evaluate the measures being taken to address climate change by the five case study cities. A summary of the analysis is provided in Table 2.

TABLE 2. COMPARING THE RESPONSE MEASURES OF FIVE CITIES TO CLIMATE CHANGE.

City	City Profile	Climate Condition	Hazards and Vulnerability	Response Measures
Tehran	*-High population density -Elevation diversity (from 1,000 to 1,700 meters)*	*-Mediterranean type -Varied climatic conditions due to difference of elevation*	*-Increase of air pollution -Increase of heat waves -Increase of mean temperature -Decrease of mean wind speed -Depletion of water resources*	*-Approving laws and standards for vehicles -Developing plans for optimizing transportation system - Developing plans for reducing air pollution - Developing comprehensive plans for water resources*
Buenos Aires	*-High population density -Low elevation urban areas -Increasing number of slums*	*-Humid subtropical climate -Long hot summers -Winters with low precipitation*	*-Increase of sea and river levels -Rising temperature and precipitation -Increasing frequency of flooding and droughts*	*-Greenhouse Gases Reduction Program -Developing various responsible agencies -Developing flood monitoring system -Developing system for public participation*
Delhi	*-High population density -Inhabitants with wide income contrasts -Hyper-dense nature of the slums*	*-Three distinct seasons: summer, winter, and monsoons; extreme temperatures and concentrated precipitation*	*-Increase of Indian monsoon, temperature, precipitation, and sea-level -Drought prone areas are becoming drier -Flood-prone areas will experience higher frequency of flooding*	*-Developing plans for carbon emission reduction -Developing green transportation systems -Improving vehicular emission standards -Adoption of green technologies -Developing systems for public participation -Expanding forest cover as a sink for GHG emissions*
Lagos	*-High population density - High density slum -Populations located on flood-prone lands -Flat topography -Widespread poverty -Weak institutional structures*	*-High to very high temperatures throughout the year -High to very high monthly rainfall (between May and November)*	*-Increase of monthly maximum temperature -Decrease of monthly minimum temperature -Increase of average temperature -Increase of heat waves -Decrease of annual precipitation -Increasing coastal storm surge -Rising sea level -Increasing flood prone areas -Coastal erosion -Increasing salinization of ground and surface water*	*Developing research studies Improving the solid waste dump sites Developing air-quality monitoring sites*
New York	*-High population density -Coastal city - Low elevation*	*-Temperate and continental climate -Hot and humid summers -Cold winters*	*-Susceptibility to coastal erosion -Increase of sea level -Increase of inundation during coastal storms -Increase of heat waves -Inland floods and droughts*	*- Developing an extensive body of research -Developing actionable guidelines and plans*

Most of the adaptation and mitigation response measures being undertaken by these five cities have in common the following traits:

- Mismatches between spatial scales and activities
- Orientation to specific project(s)
- Greater focus on mitigation activities instead of adaptation strategies
- Lack of coordination across sectors, institutions and within departments
- Lack of relationships between administration and scientific organizations
- Lack of a multi-dimensional approach to urban climate change resiliency
- Lack of awareness of position of urban system in the Adaptive Cycle for understanding the vulnerability of the city
- Lack of attention to mutual decision tiers (top-down and bottom-up)

Comparison of current measures being taken by the five case study cities with the key components of "resilience thinking", leads to the conclusion that there is a general lack of integrated approaches or holistic perspectives for developing mitigation and adaptation measures to climate change. Based on resilience thinking, an integrated framework is proposed to increase adaptive success of cities against the negative effects of climate change (Fig. 4).

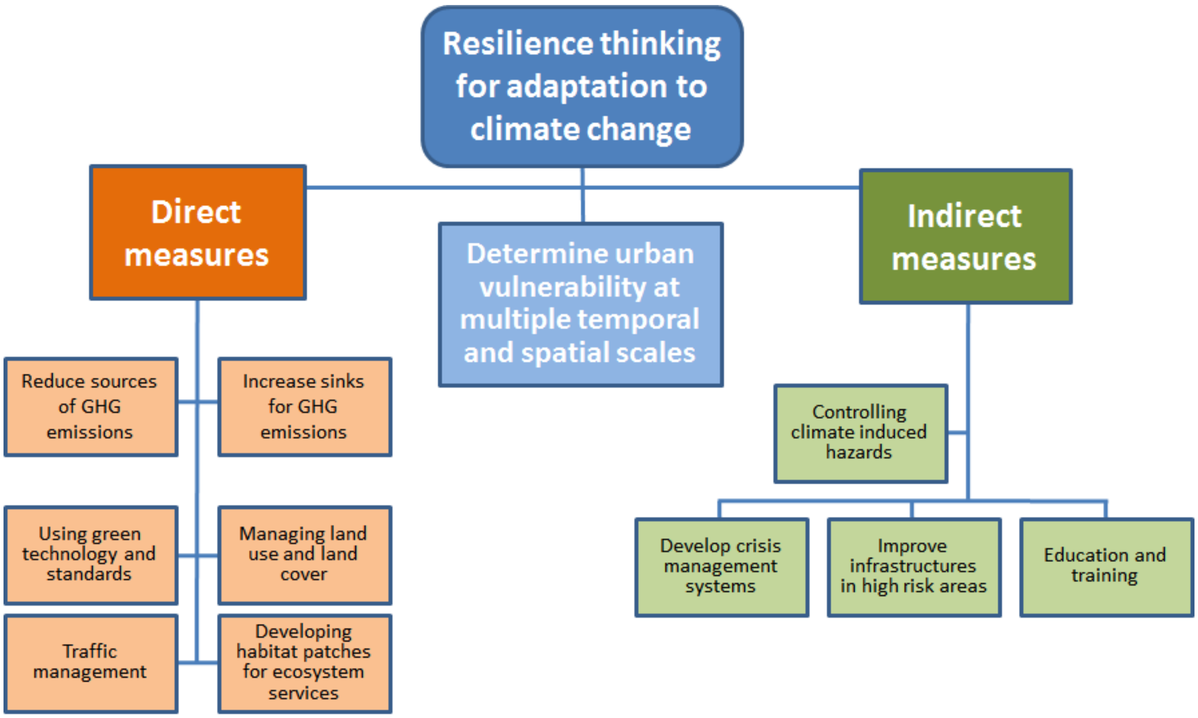

Figure 4: A proposed integrated framework based on resilience thinking for adaptation of cities to climate change

The proposed framework contains three main components: 1) assessment of vulnerability, 2) direct measures, and 3) indirect measures that can be taken to increase adaption to climate change. Decision makers and urban planners using this framework must be aware of the sensitivity and vulnerability of their urban area to the direct and indirect effects of climate change.

5. Conclusion

In this study it has been shown that climate change mitigation and adaptation policies and initiatives being undertaken by the five case study cities are discrete due to the lack of consensus in the scientific community on the subject of climate change and lack of integrated planning frameworks. Some world organizations are taking actions in this area, but most are limited to controlling GHG emissions and adding GHG emission sinks such as urban green space.

As noted earlier, because of increasing urbanization high population density, cities are the center of attention on issues related to climate change. Cities are not only large sources of GHG emissions but are also strongly impacted by primary and secondary effects of climate change. City managers, to comply with international measures, are conducting actions to reduce the effects of climate change. As illustrated in the case studies mentioned, these actions are specific project-based, dispersed, and generally lacking an integrated holistic framework. As a result, the efficiency and effectiveness of such measures to control GHG emission sources, promote adaptability, and reduce climate-induced hazards is suboptimal. The resilience thinking approach, with an emphasis on attention to all levels of urban decisionmaking, temporal-spatial scales, public participation, learning by doing, monitoring, and attention to position of the system in the adaptive cycle, uncertainties, and a holistic perspective can create an integrated framework for adaptability, reducing climate change impacts and improving urban resiliency. The following specific recommendations should be considered:

- Developing a systematic and multidimensional approach to climate change adaptation
- Establishing an interdisciplinary scientific group which can develop the criteria for assessing the efficiency of measures related to urban climate change (national and international level)
- Establishing a framework of Urban Strategic Environmental Assessment for assessing the adverse impacts of urban policies, plans and programs (with a focus on climate change)
- Considering all levels of urban decision-making and their functionality and efficiency for adapting to climate change
- Considering the urban structure and function and their interactions in different scales

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Wildlife Corridor as Conservation Management Tool to Mitigate the Impacts of Climate Change (Case Study: Maintaining Habitat Connectivity in Isfahan Province, Iran)

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Abstract

The combined effects of climate change and existing human-caused stresses to natural systems, such as habitat fragmentation and land use change are the most important conservation challenge we face. Maintaining connectivity is the most recommended strategy for conserving species in onset of climate change. Improving connectivity is not only strategically smart, but a proven method to enable species to migrate with their climatic niche and move in response to environmental change. Therefore, taking a flexible management approach to increase the resilience of protected areas to overcome the adverse effects of climate change by identifying and protection of corridors seems crucial. In this study, we identified and evaluated migration corridors for two vulnerable ungulate species, the Isfahan wild sheep (*Ovis orientalis isphahanica*) and the goitered gazelle (*Gazella subguterrosa*) between Mooteh and Ghamishloo wildlife refuges in Isfahan province, Iran. Migration of goitered gazelle and wild sheep between these wildlife refuges is related to seasonal change in environmental conditions. To identify migration corridors, two connectivity models were used, Least-Cost Corridor (LCC), and Circuit Theory. Using LCC, two corridors were selected for each target species. Circuit theory also identified several bottlenecks and paths which were of high importance for maintaining the continuity of connectivity along the corridors. We conclude that protecting and incorporating the remaining suitable migration corridors into the existing protected areas network of Iran is an urgent need in order to secure the survival of the migratory species in the future under changing climate and environmental conditions.

Keywords: Climate Change, Wild Sheep, Goitered Gazelle, Corridor, Least Cost Modeling, Circuit Theory

1. INTRODUCTION

Climate change is predicted to have substantial negative impacts on biodiversity for a wide variety of taxa across many regions of the world [1]. Observed and predicted impacts include the contraction of suitable habitat for species [2], pole ward and shifts toward high altitudes in occurrence [3]. Anthropogenic climate change poses a challenge to the conventional approach to biodiversity conservation, which relies on fixed protected areas. Because of the static boundaries for most protected areas, species may shift out of reserves where they are protected in response to climate change. Hence, the focus for new conservation reserves has dramatically shifted to increasing the connectivity between reserves through migration corridors, to enable species to migrate with their climatic niche. Corridors are regions of the landscape that facilitate the flow or movement of individuals as compared to the surrounding landscape. Large-scale corridors that span climatic gradients can enhance the capacity of species to shift to new, more climatically favorable areas, allowing species to respond to shifting climates through natural dispersal rather than requiring active intervention. Although climate change may alter the distributions of many species, land use changes may compound these effects through fragmentation of suitable habitats and reducing the permeability of landscape matrix, which in turn hinders movement of species between protected areas.

Conservation and management of wildlife populations in Iran have mostly relied on protection of areas where the species of interest occurs [4]. This approach has resulted in delineating protected areas which include major proportions of wildlife populations and their main habitats. Due to limited financial and human resources, conservation and management actions mainly focus on these areas, and little effort has been allocated to ensuring connectivity between appropriate habitat patches to support seasonal movements and movements in response to climate change in the future. Furthermore, expansion and intensification of human activities in the vicinity of protected areas has hampered or even destroyed many migration corridors. These developments are still going on and threatening the few remaining corridors. In Iran several ungulate and carnivore species of high conservation move between protected areas due to seasonally unsuitable habitat conditions and in some cases for mating. Loss of habitat corridors and increasing isolation of the populations will have serious impacts on the survival of these migratory herbivores and carnivores originally operating at large scales and would reduce their ability to cope with the adverse effects of climate change in the future. Hence protecting and incorporating of the remaining suitable migration corridors into the existing protected areas network of Iran is an urgent need in order to secure the survival of the valuable migratory species in future. In the present study, we identified and evaluated migration corridors for two vulnerable ungulate species, the Isfahan wild sheep (*Ovis orientalis isphahanica)* and the goitered gazelle (*Gazella subguterrosa)* in Isfahan province. For this purpose, we first produced the suitability maps for the target species using Habitat Suitability Index Model (HSI) and used them as main inputs for two connectivity models, Least-cost modeling (LCM) [5] and circuit theory [6]. The results of these connectivity models could provide useful information, guiding toward an effective conservation planning for these valuable migratory species in this area and also to reduce the effects of climate changes on these species. Furthermore, the methods may be adapted to be used for conservation management of other threatened species in Iran.

2. METHODS

2.1. *Study Area*

The unprotected study area is located between Mooteh and Ghamishloo wildlife refuges, in northwest of Isfahan province-Iran, covering an area of about 2,100 km^2. The elevation ranges from1,600-3,000 m above sea level (Fig.1). The three main topographic features found in the area include: flat plains, rolling hills and rocky mountain ranges. Dominant vegetation cover include: *Artemisia siberie*, *Artemisia aucheri*, *Scariola orientalis* and *Astragalus spp*. The boundaries of the study area are well marked by roads and there are no paved roads inside it. Human activities found within the region include livestock grazing, crop cultivation such as wheat and illegal hunting. The agricultural fields are few and dispersed in the eastern part of the study area. Alavijeh City and industrial park (established in 1992) were both established outside the study area, in close proximity to the southern road-between Ghamishloo wildlife refuge and the study area. Mooteh and Ghamishloo wildlife refuges are among the most important protected areas in Iran. Some of the highest numbers of goitered gazelle and Wild sheep in Iran live in Mooteh wildlife Refuge [7]. Ghamishloo wildlife Refuge also harbors significant numbers of both species in Isfahan province. Migration of goitered gazelle and wild sheep between these wildlife refuges is related to seasonal change in environmental conditions. During the winter months the animals migrate from Mooteh to Ghamishloo. During winter, thick snow cover prevents ungulates' access to forage in Mooteh and force them to move toward Ghamishloo located at lower elevation and with moderate weather conditions [8]. At lower elevations, there is usually less snow, and the animals are able to dig through the snow to access ground level vegetation. In summer, migration from Ghamishloo back to Mooteh is associated with low precipitations in the previous spring [8].

2.2. *Habitat Suitability Models*

Habitat Suitability Modeling (HSM) aims at defining for any chosen species, the envelopes that best describes its spatial ranges limits by identifying those variables that limits its distribution.

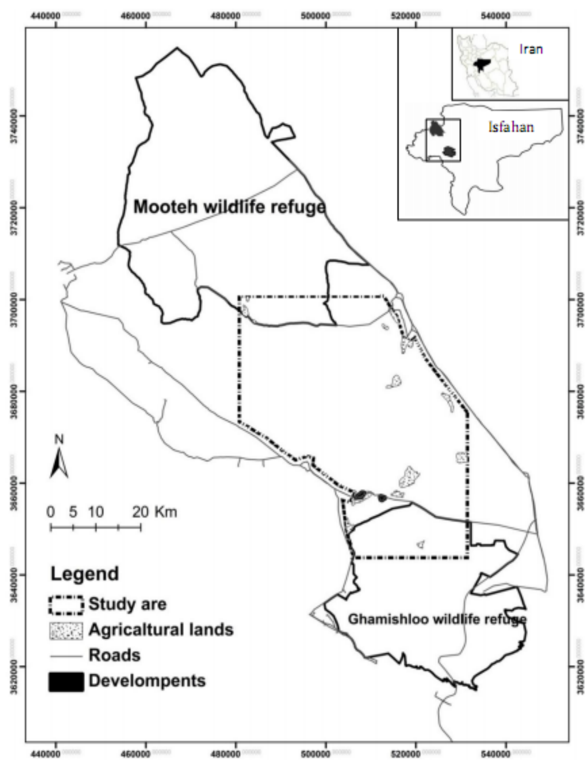

Figure 1: Geographic location of the study area, between Mooteh and Ghamishloo wildlife refuges, North-West of Isfahan province, Iran

Habitat Suitability Index (HSI) models are based on functional relationships between wildlife species and habitat variables. In these models, value of habitat variables are related to habitat quality on a Suitability Index (SI) ranging from 0 (no habitat) to 1(maximum habitat suitability). To develop HSMs, first habitat variables most likely to influence the movement of ungulates were determined through reviewing relevant literatures [9], field observations and expert's opinions. These variables included: elevation, slope, vegetation cover and land cover (agricultural lands and developed areas). Then to generate habitat suitability maps using HSI model, each variable was classified and a quality value was assigned to each class. For each species, suitability maps were produced by assigning a quantitative value to each class as suitability index [9].The SI ranged from 0.01 to 1, representing the minimum and maximum relative suitability of each class. To calculate the overall HSI, two mathematical formulas representing hypothesized relationship among the individual suitability indices for goitered gazelle and Wild sheep were used [9]. The formulas used for goitered gazelle and Wild sheep were as follow:

$$HSI = \frac{min(SI_2 \times SI_3) + SI_1}{2} \times SI_4 \qquad (1)$$

$$HSI = \frac{\left(SI_1 + SI_2 + SI_3 \right)}{3} \times SI_4 \qquad (2)$$

Where $SI_{1,}$ SI_2 SI_3 represent required habitat variables including elevation, slope and vegetation cover, and SI_4 represents any variable which leads to avoidance by the species. Here it included land cover classes (agriculture and human developments).

2.3. Connectivity Models

Both least-cost modeling and circuit theory operate on a resistance (cost) surface of the landscape. Landscape resistance maps depict the difficulty or resistance for movement through any location in the landscapes, as a function of landscape features of that cell [10]. High quality habitats are assumed to be more permeable to movement than low quality habitats in the other word, landscape resistance to movement is inversely correlated to habitat quality. Accordingly, the resistance or cost maps of the study area for target species were derived as inverse function of HSI values using the following equation:

$$"(("Fac" - Z\_ Max) * -1) + Z\_ min" \tag{3}$$

where Fac is the suitability map and Z_ Max and + Z_ min are the maximum and minimum pixel values of the suitability map.

To identify migration corridors, Least-Cost Corridor (LCC) Modeling was used. First the cost-weighted distance maps were produced using Arc GIS 9.3 Cost Distance function. These maps represent the least cumulative cost needed to move from each pixel to a specific source [11]. Considering both wildlife refuges as core wild land block, two cost- weighted distances were produced for each target species provided the relative accessibility from each pixel in the study area to the wildlife refuge [11]. Then, the costs-distance maps of each species were combined using Corridor function to produce least-cost corridor. The results were total cumulative cost-distance or permeability maps showing the relative values of each pixel in providing connectivity between wild life refuges [11].

To assess the connectivity for target species, we applied circuit theory as well, and measured the current using Circuitscape program [12]. Circuitscape measures habitat connectivity by calculating the cumulative current that flows through each cell of a resistance map between a given set of nodes [6]. The resulting map represents the current density or a probability of movement across each pixel of the landscape. Areas with higher suitability were assumed to better allow for current flow and so were more likely to support successful movements of the species.

3. RESULTS

3.1. Cost Maps

Combination of the habitat variables using the formulas resulted in habitat suitability maps ranging from 0.01-100 and 0.17-100 for goitered gazelle and wild sheep, respectively. Suitable habitats for the goitered gazelle were manly found in the east and for wild sheep in the central and north-west parts of the study area. These ranges for wild sheep had more area than goitered gazelle (about 3000 km^2 for the wild sheep compare to 1041 km^2 for the goitered gazelle). The values of Cost layers derived from equation (3) for the target species were exactly inverse of the values of the suitability rasters (Fig. 2).

3.2. Connectivity Models

For each target species we extracted two least-cost corridors (Fig. 3 and Fig. 4.) from the permeability layers. The first least-cost corridors for the species included habitats of highest quality (lowest resistance) which stands for the minimum costs for movement. Theses corridor for giotered gazelle covered about 158 km^2 (7.5% of the total area) and the one for Wild sheep covered 151 km^2 (7.2% of the total area). The corridor for goitered gazelle crossed mostly plain area with slope of 0-12%, while the corridor of Wild sheep supported areas with dominant slope range of 0-20% and elevation between 1,900-2,300m. For both species the corridors include narrow sections. For goitered gazelles, these bottlenecks were found at points where the corridor passed through high elevation areas (>2100m) and climbed steep slopes (>20%).

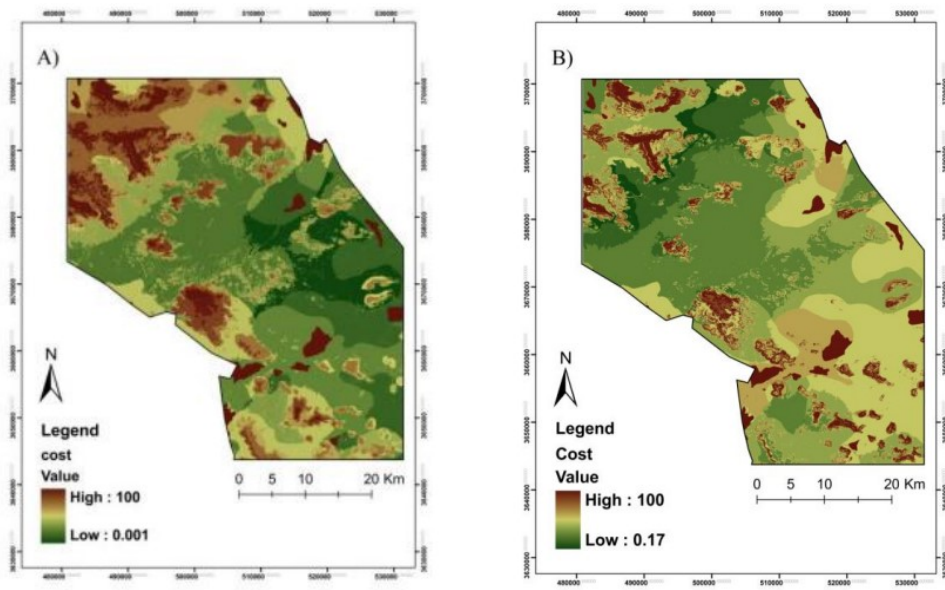

Figure 2: Cost maps for A) giotered gazelle and B) wild sheep

For wild sheep, the most pronounced bottleneck (only 320m wide) is seen in the southern half of the corridor due to expansion of human developments and agricultural lands. This bottleneck is then followed by a narrow valley flanked by high mountain ranges (>3000m) with steep (>50%).The second least cost corridors were about 480 km^2 (23%) and 382 km^2 (19%) for wild sheep and goitered gazelle respectively. They covered additional suitable ranges for the target species, more plain areas for the goitered gazelle and better coverage of the high quality habitats in the north-western and central parts of study area for the wild sheep (Fig. 4). Results of circuit theory were the current maps for the target species (Fig. 5.) In the current map for the goitered gazelle, maximum probability was observed in the eastern part of the study area. Following the high current in the central and northern parts near Mooteh wild life refuge, revealed the visual conception of the corridors between wild life refuges. In south near Ghamishloo, however, current became diffuse and prevented the formation of any obvious corridor toward the wild life refuge.

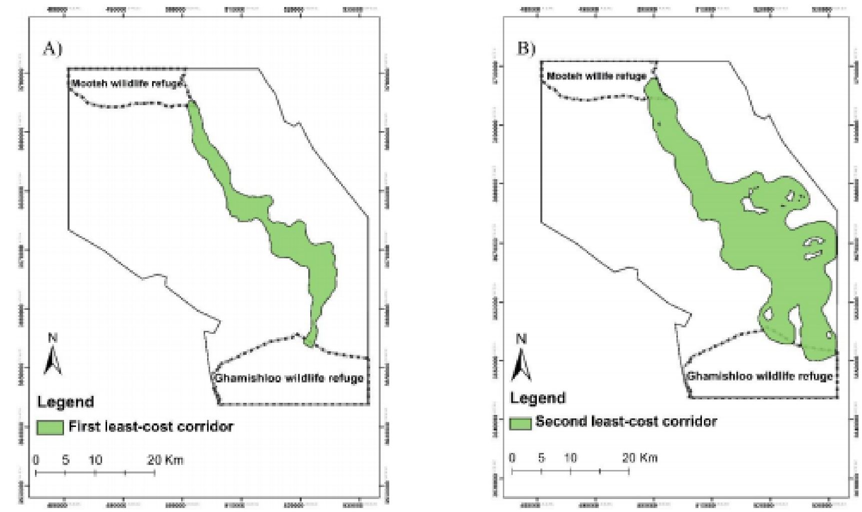

Figure 3: A) First and B) second least-cost corridors selected for goitered gazelle

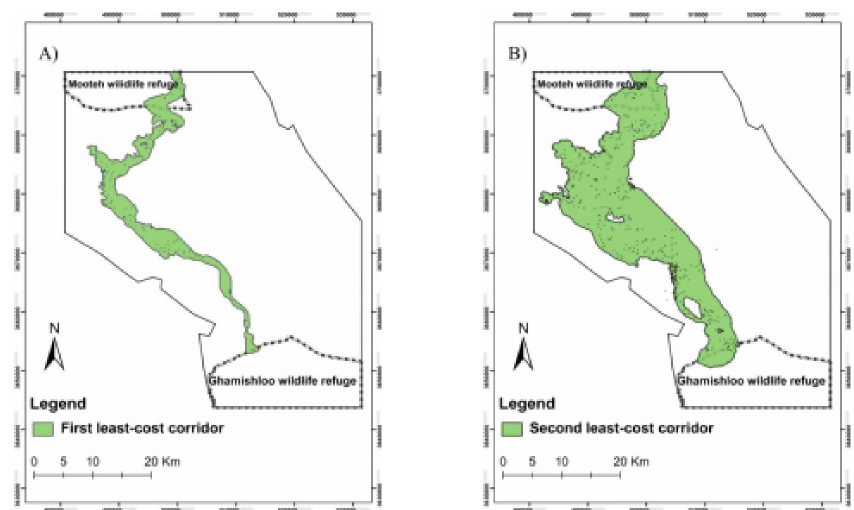

Figure 4: A) First and B) second least-cost corridor for Wild sheep

For goitered gazelle maximum connectivity is most pronounced in the central part of the area (depicted in yellow color) with the highest habitat suitability (lowest resistance). Continuity of the high current path at south-west near Ghamishloo wild life refuges is identifiable, but following that current strength decreased and again near Mooteh wild life refuges increased because of funneling through narrow areas. Main barriers to movement (depicted in blue, Fig. 5) for both species included human land use and unsuitable topography. Differences in the extent of these barriers for the species were well reflected in the pattern of current flow. As in the case of goitered gazelle, these barriers were strongly reducing current strength and thus limiting flow across the study area. Presence of narrow areas with high current especially in the map for goitered gazelle is notable.

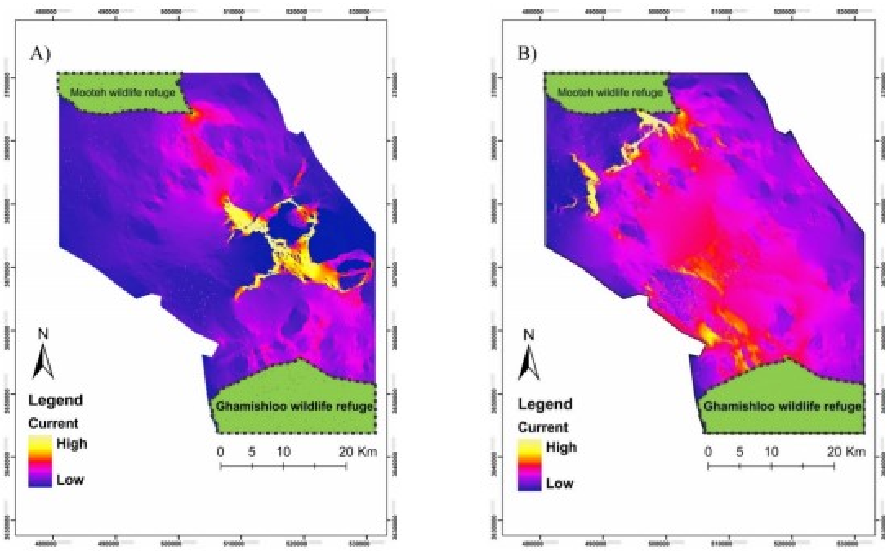

Figure 5: Current maps for A) goitered gazelle and B) Wild sheep

4. DISCUSSION

Extensive shifts in species' geographical distributions have been the most important mechanism through which plants and animals coped with large-scale climate changes. Consequently, many advocate the need for conservation corridors and linkages as a means to support species' range shifts [13]. Corridors have a role in countering climate change by interconnecting existing reserves and protected areas in order to maximize the resilience of the present conservation network. Those corridors that maintain large contiguous habitats or that maintain continuity of several reserves along an environmental gradient are likely to be most valuable in this regard .The impacts of climate changes are exacerbated by fragmentation through reducing the resilience of species populations, habitats and ecosystems to the effects of climate change. While fragmentation might increase species' vulnerability to climate change in many ways, it is likely that a major impact will be on species attempting to track shifting climate envelopes. The ability of species to track these changes depends on the availability of suitable habitats within transitional and new ranges, and their ability to reach them.

In this study we used two connectivity model, least-cost corridor (LCC) modeling and circuit theory to identify migration corridors for vulnerable ungulates in Isfahan province. Although the identified corridors in this study are currently used for round migrations between Mooteh and Ghamishloo wildlife refuges, they are most likely to be served as one way migration corridors from Ghamishloo to Mooteh protected area assisting the species to shift their ranges in response to climate change in an immediate future. Climatic conditions in Mooteh compared to Ghamishloo in terms of annual rainfall (249.16 mm in Mootieh in compared to 180.9 mm in Ghamishloo) and minimum average temperature (-8.5C in Mooteh compared to -1.6 C in Ghamishloo) indicates that Mooteh wildlife refuge will be used as a refugia to buffer these ungulates from the impacts of drought and climate change in this region [15]. Likely Mooteh wildlife refuge is already under legal protections but the main concern is about the corridors connecting Mooteh and Ghamishloo that should be protect to secure the safe passage of the species if they are about to come over the adverse effects of climate change. Currently, illegal hunting is a major threat in the study area greatly prevents migrants to move between the wildlife refuges while the corridors still exist intact. More importantly, although considerable portions of the study area is intact, with the present pace of human activities expanding (particularly for agricultural use) across Isfahan province and inside the study area, the corridors found in this study are likely to disappear in near future.

5. Conclusion

In this study we used two connectivity model, least-cost corridor (LCC) modeling and circuit theory to identify migration corridors for vulnerable ungulates as the first effort in Iran. Least cost corridors revealed in the study area with the highest probability of movements. As the study area is not protected at present and is very likely to be developed in near future, it is very important identifying the areas with the easiest movement routes for future conservation which, if conserved, provide the easiest movement routes assisting species in the face of climate change. Furthermore land-use planning in Isfahan province should ensure that habitat connectivity at the landscape scale needed for climate change adaptation are taken to increase the ability of the species populations to move between protected areas, rather than preservation wildlife and their habitats within existing protected areas with fixed boundaries. Improving connectivity is not only strategically smart, but a proven method of allowing wildlife to move in response to rapid environmental change.

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U.S.-Iran Symposium on Climate Change: Impacts and Mitigation

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Mitigating the Effects of Climate Change on Power Generation through Modification of Reservoir Operation Policies

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Abstract

The focus of this study is to see how much the negative impacts of climate change on the hydropower production potential in multireservoir systems could be avoided by modifying reservoir operation policies. For this purpose, in this study, Stochastic Dual Dynamic Programming (SDDP) has been used as an optimization tool to formulate optimal operation policies for Karkheh River-Reservoir system with two Karkheh and Seymareh Reservoirs in Southwest Iran. Three different operation policies have been developed for historical inflows and climate scenarios SRES A2 and B2. For this purpose, HadCM3 AOGCM predictions for the period of 2030-2100 have been converted to streamflow series utilizing GUO monthly water balance models calibrated for different sub-basins of the study area. Comparison between the performance of the operation policies developed for the historical flows and those for the future scenarios have shown that in Karkheh-Seymareh System, up to 65% of the negative impacts of climate change on hydropower production can be avoided.

Keywords: Climate change, Reservoir operation policy, SDDP, Adaptation strategy.

1. INTRODUCTION

Hydropower is an important source of renewable energy which is highly dependent on the availability of water and as such is under the direct impacts of climate change. In order to analyze the impacts of climate change on hydropower systems, both seasonal availability of water and operation policies of the hydropower systems, should be taken into account. Schaefli et al. [1] argues that most studies have analyzed the direct effects of climate change on water cycle rather than assessing the impacts of climate change on water management strategies.

Garr and Fitzharris [2] analyzed the effects of climate change on the annual power production of power plants in New Zealand. Similar studies were carried out by Robinson [3] and Westaway [4] to analyze the effects of climate change on the annual power production of power plants in the

United States and Switzerland, respectively. Bergstrom et al. [5] proposed water resources management scenarios with a focus on hydropower production and dam safety based on a study on the effects of climate change in six major basins in Sweden.

In some similar studies, optimization models have been used as a tool for assessing climate change impacts. Tanaka et al. [6] used a large scale economic-engineering optimization model, namely CALVIN, to study the effects of climate change scenarios on the performance of California's water system. Vicuna et al [7] utilized a linear programming model in order to analyze the potential impacts of climate change on high elevation hydropower systems in California. Madani and Lund [8] proposed an Energy-Based Hydropower Optimization Model (EBHOM) to examine the effects of climate change on high-elevation hydropower systems.

In this study, we have utilized an optimization model, namely Stochastic Dual Dynamic Programming (SDDP), to examine the effects of climate change on the hydropower systems and to see to what extent these effects could be avoided through modification of the reservoir operation policies. Karkheh River Basin located in southwest Iran, the third largest river in Iran in terms of long-term average annual streamflow, is the case study of this research. Five large storage hydropower plants have been planned to be built on this river, two of which have already been constructed. The importance of hydropower generation to the national electric system alongside with the large impacts of climate change on the streamflows, makes it necessary to develop adaptive operation policies to climate change scenarios. Karkheh River Basin has experienced significant decline in the amount of the inflows in the past two decades and part of this decline is associated with climate change. The surface runoffs of different sub-basins in the study area have been decreased to less than half of the long-term averages during the period of 1998-2009.

The rest of this paper is organized as follows. In Section 2, the optimization model is represented and SDDP algorithm is briefly described. Section 3 represents the Karkheh River system. The results of optimization and simulation models are provided in Ssection 4. Conclusions are given in Section 5.

2. STOCHASTIC DUAL DYNAMIC PROGRAMMING (SDDP)

SDDP is an extension of stochastic dynamic programming (SDP). It is specifically developed to circumvent the well known problem of curse of dimensionality in SDP. Successful implementation of the technique has been reported in [9].

Rather than estimating the expected value of objective function of the next stage on a grid of state variables like ordinary SDP, in SDDP, the expected objective function of the next stage is approximated using some hyperplanes. These hyperplanes are estimated on some trial points based on duality theorem. The algorithm continues to generate new hyperplanes in an iterative manner until the convergence criterion is met. In order to the duality theorem to be applicable, the problem should be a convex.

Formulation of one-stage optimization of SDDP for multireservoir hydropower systems, with the objective of hydropower generation maximization is shown by Eqs. (1) to (6).

$$\max F_t = \sum_{j=1}^{J} G_{j,t} + F_{t+1}^{*} \tag{1}$$

$$\textbf{subject to: } \mathbf{s}_{t+1} - \mathbf{C}^{R}(\mathbf{r}_t + \mathbf{x}_t) - \mathbf{C}^{w}\mathbf{w}_t = \mathbf{s}_t + \mathbf{q}_t \tag{2}$$

$$\begin{cases} F_{t+1}^{*} \le \boldsymbol{\alpha}_{t+1}^{1}\mathbf{s}_{t+1} + \sum_{j=1}^{J}\boldsymbol{\beta}_{t+1,j}^{1}\mathbf{q}_{t+1,j}^{[His]} + \boldsymbol{\chi}_{t+1}^{1}\mathbf{y}_{t+1} + \delta_{t+1}^{1} \\ \vdots \\ F_{t+1}^{*} \le \boldsymbol{\alpha}_{t+1}^{h}\mathbf{s}_{t+1} + \sum_{j=1}^{J}\boldsymbol{\beta}_{t+1,j}^{h}\mathbf{q}_{t+1,j}^{[His]} + \boldsymbol{\chi}_{t+1}^{h}\mathbf{y}_{t+1} + \delta_{t+1}^{h} \\ \vdots \\ F_{t+1}^{*} \le \boldsymbol{\alpha}_{t+1}^{H}\mathbf{s}_{t+1} + \sum_{j=1}^{J}\boldsymbol{\beta}_{t+1,j}^{H}\mathbf{q}_{t+1,j}^{[His]} + \boldsymbol{\chi}_{t+1}^{H}\mathbf{y}_{t+1} + \delta_{t+1}^{H} \end{cases} \tag{3}$$

$$\underline{\mathbf{r}}_t \le \mathbf{r}_t \le \overline{\mathbf{r}}_t \tag{4}$$

$$\underline{\mathbf{s}}_{t+1} \le \mathbf{s}_{t+1} \le \overline{\mathbf{s}}_{t+1} \tag{5}$$

$$\underline{\mathbf{w}}_t \le \mathbf{w}_t \le \overline{\mathbf{w}}_t \tag{6}$$

where J is the number of reservoirs, T is the number of stages, $\mathbf{s}_t$ is the $(J \times 1)$ matrix of the storages at the beginning of stage t (m^3), $\mathbf{w}_t$ is the $(D \times 1)$ matrix of the agricultural allocations to different demands in the stage t (m^3), $\mathbf{r}_t$ is the $(J \times 1)$ matrix of the reservoir releases in the stage t (m^3), $\mathbf{q}_t$ is the $(J \times 1)$ matrix of the reservoir inflows in stage t (m^3), $\mathbf{u}_t$ is the $(J \times 1)$ matrix of the spills in the stage t (m^3), $\overline{\mathbf{r}}_t$ and $\underline{\mathbf{r}}_t$ are the lower and upper bounds of reservoir releases in the stage t (m^3), $\overline{\mathbf{s}}_{t+1}$ and $\underline{\mathbf{s}}_{t+1}$ are the lower and upper bound matrixes of reservoir storages at the end of stage t (m^3).

F_{t+1}^{*} is the approximation of $E[F_{t+1}]$ given by the hyperplanes. $\boldsymbol{\alpha}_{t+1}^{h}$ $(1 \times J)$, $\boldsymbol{\beta}_{t+1,j}^{h}$ $(1 \times E)$ and δ_{t+1}^{h} in Eq. (3) are the parameters associated to the h^{th} hyperplane and $\mathbf{q}_{t+1,j}^{[His]}$ $(E \times 1)$ is the history of inflows at the start of stage $t+1$, i.e. the inflow state variable.

Stochastic nature of inflows is modeled in SDDP by using synthetic flow series generated by statistical time series models such non-seasonal Autoregressive (AR) or periodic AR (PAR) models. Gjelsvik et al. (2010) argued that AR(1) is suitable for SDDP applications. Application of PAR(1) model in SDDP is also reported by Tilmant et al. [9]. In the case of using an order one AR or PAR model, the inflow in the stage $t+1$ depends solely on the inflow of the earlier stage and hence we have $\mathbf{q}_{t+1,j}^{[His]} = \mathbf{q}_t$.

$\mathbf{C}^R$ is a $(J \times J)$ matrix which shows how the reservoirs are connected in the multireservoir system. If reservoir j_1 receives the released water from reservoir j_2 then $C^R(j_1, j_2) = 1$ and obviously $C^R(j, j) = -1, \forall j = 1,\ldots, J$. Also $\mathbf{C}^w$ is a $(J \times D)$ matrix which shows the connectivity between agricultural demand sites and reservoirs. If the reservoir j receives the return flows from agricultural demand site d then $C^w(j, d) = \omega_d$ where ω_d is the percent of water allocation to the demand site d that drains back to the system.

The SDDP algorithm consists of two main phases: (1) Backward recursion and (2) Forward simulation. Backward recursion starts from the last stage and moves in the backward direction and is responsible for generating new hyperplanes for approximation of the expected objective function. These hyperplanes are generated assuming some trial state variables at the start of the stage. Forward simulation then uses these hyperplanes to solve the one-stage optimization problems shown in Eqs. (1) to (6) in the forward direction. After finishing the forward simulation, the convergence criterion is controlled and if the algorithm is not converged, the state variables from the forward simulation are used as the new trial decisions to carry out a new backward recursion. This algorithm continues until the convergence criterion is met. A comprehensive description of the SDDP algorithm and the equations to estimate the hyperplane parameters is available in [9].

3. KARKHEH MULTI-RESERVOIR SYSTEM

Karkheh River is the third largest river with respect to the long-term average streamflows in Iran. The area of the river basin is 51,643 km^2 with an annual discharge of 6,829 million m^3. Karkheh River system is the third largest potential for hydropower generation in Iran. Five hydropower plants are planned to be built on this river, two of which, namely Karkheh and Seymareh, are currently under operation. The location map of the Karkheh River and the schematic of the future and current conditions of the system are shown in Fig. 1. Furthermore, the specification of the Seymareh and Karkheh Reservoirs are given in Table 1.

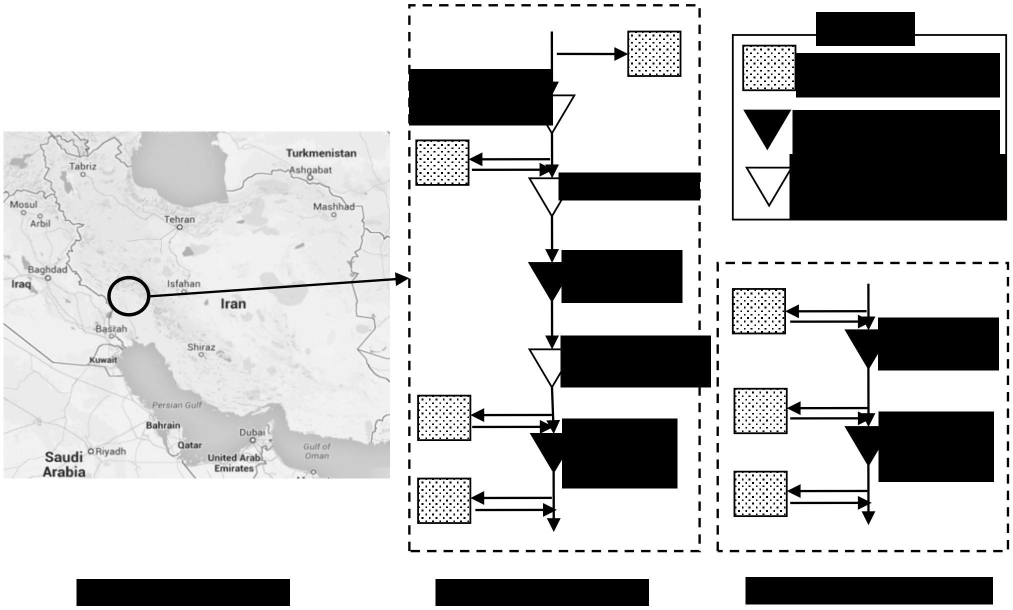
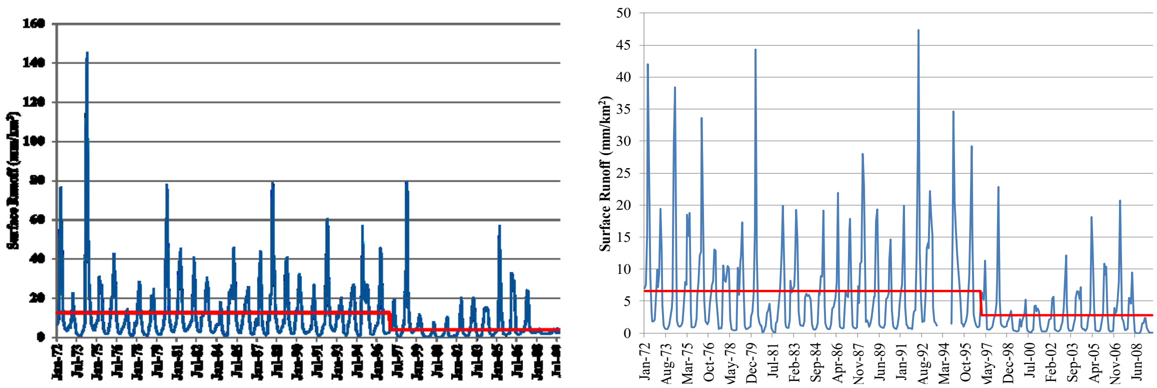


Figure 1: (a) Location map of the Karkheh River Basin Hydropower System (b) Future development of the system (c) Current status of the system

TABLE 1: GENERAL SPECIFICATIONS OF THE SEYMAREH AND KARKHEH RESERVOIRS

Dam	Installed Capacity (MW)	Normal water level (masl)	Maximum Storage ($10^6 m^3$)	Predicted inflows under SRES B2 (2030-2100) ($10^6 m^3$/month)	Predicted inflows under SRES A2 (2030-2100) ($10^6 m^3$/month)	Historical inflows (1982-1998) ($10^6 m^3$/month)
Seymareh	480	720	3250	314.5	331.5	381.4
Karkheh	400	220	5346	139	139.5	160

The surface runoffs in Karkheh River basin have been decreased significantly after late 90s due to different direct and indirect human interventions in the hydrologic cycle of the basin. Significant groundwater drawdown in several areas in the basin and extensive agricultural development as well as climate change have been among the main reasons behind the decreasing trend of the surface runoffs in the basin. Zahraie [10] studied impacts of climate change on surface runoffs in Karkheh River basin to assess the share of climate change in the observed changes in temporal and special variability of surface runoffs. For this purpose, the Karkheh River basin was divided into seven sub-basins namely Gamasiab, Ghourbaghestan, Poledokhtar, Polechehr, Tange-Sazbon, Payepol, Abdolkhan. Fig. 2 shows the time series of observed historical streamflows in two of these sub-basins. As it can be seen, 57 percent reduction in long-term average of streamflows has been observed in Gamasiab basin after 1997 while only 4 percent reduction of long-term average of mean areal precipitation has been observed in this period. In Ghourbaghestan Basin, 51 percent reduction in streamflows and 16 percent reduction of average areal precipitation have been observed after 1997. Zahraie [10] used three Fixing-Changing (Wang et al. [11]), Double Mass methods (Zhang [12]), and Climatic Elasticity (Zheng et al. [13]), to estimate share of climate change in the long-term variations of surface runoffs in the sub-basins of the Karkheh River watershed. The results have shown that share of climate change varies between 6% in Poledokhtar to 36% in Ghourbhghestan sub-basins. These results have been used along with the surface runoff predictions using statistically downscaled outputs of HadCM3 AOGCM model for SRES A2 and B2 scenarios to estimate time series of inflows to Seymareh and Karkheh Reservoirs in the period of 2030 to 2100. Long-term average values of the estimated inflow series are shown in Table 1. It should be noted that the inflows have been naturalized by omitting the effects of water withdrawals from headwaters.



a)Gamasiab Sub-basin b)Ghourbaghestan Sub-basin

Figure 2: Time sequence plot of observed historical streamflows in Gamasiab and Ghourbaghestan sub-basins (red lines indicate long-term average in 1972-1996 and 1997-2008 periods)

4. Results

The objective function of the SDDP model developed in this study is to reach the maximum power generation over a time horizon of 25 years with monthly time steps. Minimum acceptable level of water supply to agricultural lands has been assumed to be 70% in each month. In order to analyze the extent of adaptation to the effects of climate change in Karkheh-Seymareh system by modifying the operation policies, we have built three different SDDP models based on the available history of the inflows and predictions of the inflows to the to the reservoirs under two SRES A2 and SRES B2 climate change scenarios. For this purpose, three different PAR(1) models have been calibrated based on the historical and A2 and B2 inflow predictions.

In all three SDDP models for historical inflows, and inflow predictions under A2, and B2 scenarios, 50 inflow scenarios have been generated for forward simulation in each iteration of SDDP, and 10 trial state variables are considered in the beginning of each stage for backward recursion in each iteration. Furthermore, 10 realizations of inflow to the reservoirs are generated for each stage in backward recursion in each iteration and for each trial state.

Three following sets of operation policies have also been developed using SDDP model:

- Policy historic: optimal operation policies without considering the effects of the climate change
- Policy_A2: optimal operation policies developed based on the synthetic inflow series generated by PAR(1) model calibrated for SRES A2 climate condition.
- Policy_B2: optimal operation policies developed based on the synthetic inflow series generated by PAR(1) model calibrated for SRES B2 climate condition.

After deriving the aforementioned policies, the following simulations have been carried out to analyze the effects of climate change on the system:

- Simulation 1: Simulation of the system based on the historical inflows from 1982-2007, using policy_historic, policy_A2 and policy_B2.
- Simulation 2: Simulation of the system considering the streamflows estimated based on the SRES A2 scenario, using policy_historic and policy_A2;
- Simulation 3: Simulation of the system considering the streamflows estimated based on the SRES B2 scenario, using policy_historic and policy_B2;

The results of simulation 1 are represented in Table 2. The 1998-2007 period is characterized by the high impact of human activities on the inflows to the system. As stated earlier, in this period, the average annual inflows to the system have decreased by about 50 percent compared to the average annual inflow in the 1982-1998 period.

Comparison between the annual power generation in the 1998-2007 and 1982-1998 periods shows that the annual power generation has decreased dramatically for all three sets of policies. The percentage of the decrease is 50%, 35% and 35% respectively for policy_historic, policy_A2 and policy B2. Policy_B2 and policy_A2 have both performed better than the historical policy in the 1998-2007 period, while the results of policy_B2 have been slightly better than policy_A2. This implies that modification of the optimal operation policies based on the climate change effects can considerably assist in adaptation to the negative impacts of the climate change on the power generation potential of the system. Same conclusion can be drawn for the results of Simulation 2 shown in Table 3. The simulated monthly storage levels corresponding to the policy_historic and policy_A2 in the period of 2076-2100 are shown in Fig. 3.

TABLE 2. RESULTS OF SIMULATION 1

Period	Policy	Reservoir	Average annual power generation (GWH)	Total annual power generation of the system (GWH)
1982-1998	***policy_historic***	***Seymareh***	1212.1	2490.3
		Karkheh	1278.2	
	policy_A2	***Seymareh***	1185.8	2444.8
		Karkheh	1259.0	
	policy_B2	***Seymareh***	1188.0	2445.8
		Karkheh	1257.8	
1998-2007	***policy_historic***	***Seymareh***	664.8	1244.0
		Karkheh	579.2	
	policy_A2	***Seymareh***	692.6	1567.7
		Karkheh	875.1	
	policy_B2	***Seymareh***	697.0	1575.9
		Karkheh	878.9	

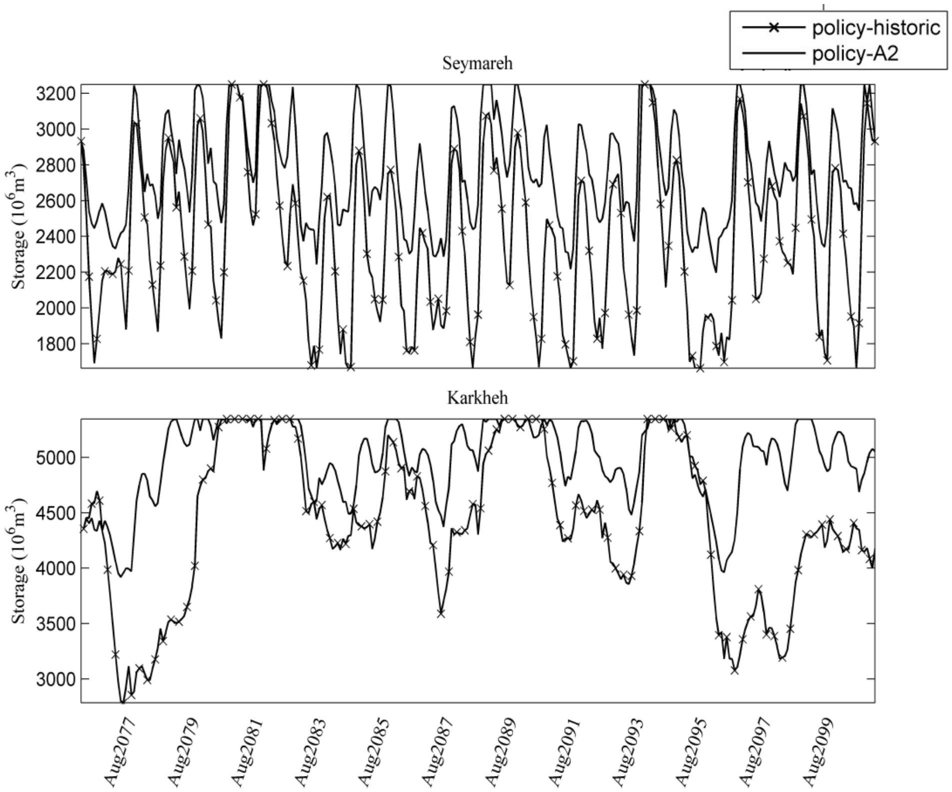


Figure 3: Simulated storage levels in simulation 2

Simulation based on policy_A2 has resulted in higher storage levels in both of the reservoirs and almost in all time stages throughout the planning horizon. This in turn has resulted in more spill from the reservoirs. The simulated average annual power generation with the policy_historic is 4.5% less than the simulated average annual power generation with policy_A2.

The average annual power generation and the simulated storage levels in simulation 3 are shown in Table 3 and Fig. 4, respectively.

TABLE 3- RESULTS OF SIMULATION 2 AND SIMULATION 3

Simulations	Policy	policy_historic		policy_A2		Policy_B2	
		Seymareh	***Karkheh***	***Seymareh***	***Karkheh***	***Seymareh***	***Karkheh***
Simulation 2	**Average annual power generation (GWH)**	1119.4	1205.2	1177.2	1254.4	-	-
	Average annual spill ($10^6 m^3$)	15.9	240.91	78.4	355.9	-	-
Simulation 3	**Average annual power generation (GWH)**	1083.6	1174.1	-	-	1148.2	1247.8
	Average annual spill ($10^6 m^3$)	9.4	171.4	-	-	63.3	300.1

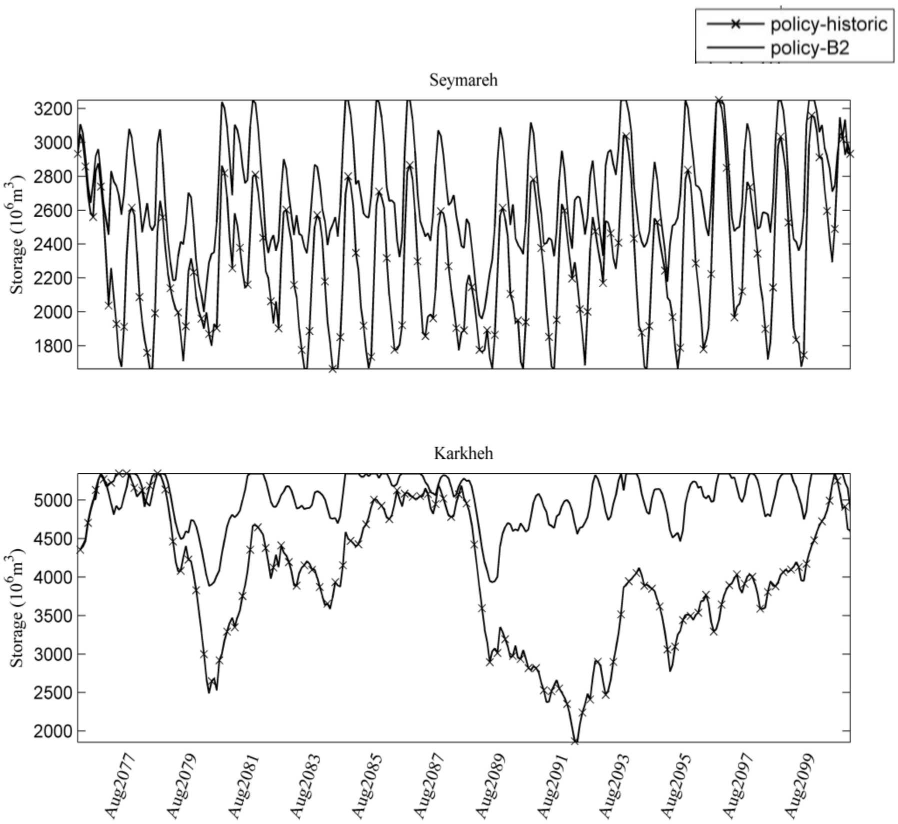


Figure 4: Simulated storage levels in simulation 3

The results show that for SRES B2 scenario, simulation with the historical policy leads to a decrease of 6% in average annual power generation. Similar to the simulation 2, policy_B2 have resulted in higher storage levels in both reservoirs and almost in all time stages throughout the planning horizon.

5. CONCLUSIONS

Utilizing an optimization model, SDDP, in this study we analyzed the effects of climate change on the power generation potential in the Karkheh River-Reservoir system in Iran. The goal was to see to what extent the negative impacts of climate change using predictions based on HadCM3 and two SRES A2 and B2 scenarios could be avoided by modifying reservoir operation policies. The results indicated that using operation policies developed based on the historical inflows can result in 6.6% and 9.3% decrease in average annual power generation for SRES A2 and B2 conditions (compared to the average annual power generation in period 1982-1998), respectively. By using the modified operation policies, the average annual power generation decreases are estimated to be as low as 2.3% and 3.7% for SRES A2 and B2 conditions, respectively. The main operation policy change appears to be keeping higher storage levels in both reservoirs throughout the year which in turn results in higher spill volumes. This conclusion should certainly be validated by predictions of other AOGCMs and climate change scenarios.

ACKNOWLEDGEMENTS

Some of the results presented in this study have been produced in the research project carried out by Zahraie [10] to study "The Impacts of Climate Change on Karheh River Basin Surface Runoffs" which was funded by the Khuzestan Water and Power Authority. Valuable contributions of the graduate students of the University of Tehran including Ardalan Tootchi, Vahid Espanmanesh, Amin Mehdipour Varnousfaderani, Leila Forouhar, and Mehdi Ghobadi-dana are hereby acknowledged.

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Grand Science Challenges in Climate Research - Climate Information for Decision Makers

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Abstract

Over the past several years, the three major sponsors of the World Climate Research Programme (WCRP), i.e. the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Committee (IOC), and the International Council for Science (ICSU), have underdone considerable strategic planning such as WMO's World Climate Conference-3 leading to the Global Framework for Climate Services, IOC's Ocean Obs '09 and subsequent framework for global sustained ocean observations, and ICSU's Visioning exercise leading to the formation of Future Earth. Emerging themes include the need for more flexibility and agility to respond to expanding user needs that include information at the regional scale, for key sectors of the global economy, and for adaptation, mitigation, and risk management.

In response, the Joint Scientific Committee (JSC) of the WCRP embarked on a series of consultations with its sponsors, stakeholders and affiliate network of scientists culminating in the WCRP Open Science Conference: Climate Research in Service to Society in Denver, Colorado during October 2011. The WCRP Grand Science Challenges have emerged as a result of this deliberative process. As such, the Grand Challenges represent major areas of scientific research, modelling, analysis and observations for the physical climate system in the ensuing decade.

This presentation will provide an overview of the following Grand Challenges in research on the physical climate needed to support and underpin the provision of climate information and services:

- Clouds, Circulation and Climate Sensitivity
- Cryosphere in a Changing Climate
- Science Underpinning the Prediction and Attribution of Extreme Events
- Regional Climate Information
- Sea-Level Rise and Regional Impacts

THE UNIVERSITY OF ARIZONA · NATIONAL ACADEMY OF SCIENCES · NATIONAL ACADEMY OF ENGINEERING · INSTITUTE OF MEDICINE OF THE NATIONAL ACADEMIES · The Academy of Sciences Islamic Republic of Iran · INSTITUT DE FRANCE Académie des sciences

Current and Future Impacts of Climate Change, with an Emphasis on Developments in Iran

Scientists from U.S., Iran, and France: A Workshop at Les Treilles, October 19-23, 2015

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Preface

Twenty scientists, including five early-career scientists, discussed adverse developments in the world, including Iran, driven in part by climate change, and particularly declining access to water. Global concerns over climate change provided a context for considering current and future activities to reduce adverse changes in the physical and human landscape of the country. The global discussions and programs directed to reducing adverse environmental trends provided a context for the technical sessions of the workshop. During the final workshop session, the participants offered their personal recommendations for steps that could be considered by different organizations, in collaboration with the international community, to reduce adverse trends linked to climate change. They also identified technical uncertainties that could be addressed through new research efforts.

Keywords: Climate Change, Iranian Environment, Water Shortages, Water Evaporation, Air Pollution, Dust Storms, Iranian Research Priorities, Protected Areas, Forests, Wetlands, Temperature Variations, Greenhouse Gases, Atmospheric Modelling, U.N. Environmental Programs.

The twenty participants in this workshop included a wide range of specialists, given the extensive reach of causes and impacts of climate change. The Iranian group was comprised of four early-career scientists, several mid-career scientists, and one senior scientist. The French participants were senior scientists with long careers at universities and at the Academy of Sciences of France. The American group included senior scientists in a number of fields and one early-career scientist who has important environmental publications.

The initial session was devoted to a broad-ranging discussion of the context for addressing climate change. Updates on the activities of the International Panel on Climate Change and its forthcoming meeting in Paris were highlighted. Discussions concerning the environmental interests of the U.N. agencies in Iran, and particularly programs that address wetlands and other water-related problems, included an audio-visual presentation prepared for the workshop by the U.N. office in Tehran. Representatives of the academies of science of the United States, France, and Iran provided overviews of relevant international interests and activities of their academies. The findings of a related U.S.-Iran workshop in California in 2015 were considered, with an emphasis on the opportunities identified at that workshop for future collaborative efforts—particularly joint efforts related to water issues.

The initial technical session addressed evidence of change and the role of atmospheric sciences. Dispersion, chemical transformations, effects of winds, and dispersion patterns were highlighted. Climatology of desert-related events in Iran and the use of synoptic and spectral analysis were considered. The participants agreed that emphasis should be given to series analyses of surface air temperatures.

A technical session then focused on historical evidence of climate change. The decline of oak forests and investigations of neo-proterozoic glaciation attracted considerable interest. Suggestions for further exploring these developments, and particularly on-the-ground efforts to save the forests of Iran, were considered.

Impacts of air pollution and dust storms both on human health and on climate change, fuel desulfurization, geological investigations in the Arctic and Antarctic regions, resiliency of populated areas, and monitoring of greenhouse gases were on the agenda of the next session.

Biological impacts of climate then came into the foreground. Protected areas, protected pathways between separated areas, and attendant land-use changes were described. The profound implications of climate change for agriculture were highlighted, including the many linkages of the entire food supply system to climate change.

A separate session was devoted to early education, with suggestions that included but extended far beyond climate change. The topic of education is so broad that it deserves consideration at a series of workshops, not just during one session of a single workshop.

The technical sessions concluded with recognition of the grand challenges confronting all countries in considering climate change. While addressing the problems of today and tomorrow is important, the fundamental long-term changes linked to climate change cannot be underestimated. A particularly important step is to address specific regional and local problems. Only then will broad concepts be transformed into actionable initiatives. For example, workshop participants viewed an Iranian film on the shrinkage of Lake Urmia during the past two decades. And a discussion of future problems of the Chesapeake Bay raised new concerns.

During the final session the participants discussed future steps that academies and institutions of the countries could take to expand collaboration. Also, each participant offered suggestions as to steps that could be taken by governments and non-governmental organizations, individually and collectively, to improve the prospects for reversing the decline in the quality of life associated with climate change. These suggestions will be catalogued in the overall compendium of documents considered during at the workshop, which should be available at the beginning of 2016.

ACKNOWLEDGEMENTS

The Fondation des Treilles in Paris provided its beautiful estate and excellent administrative and culinary staffs located near Tourtour in southern France as the venue for this gathering of leading experts from Iran, France, and the United States. The Fondation's extensive network of comfortable villas together with excellent meeting facilities promoted uninhibited discussions among both senior and early career scientists in addressing some of the most critical issues confronting the world community for the indefinite future.

The U.S. National Academies of Sciences, Engineering, and Medicine, the Academy of Sciences of the Islamic Republic of Iran, and the Academy of Sciences of France were strong supporters of the meeting. Their selection of Yousef Sobouti, Yves Quere, and Michael Clegg as co-chairmen of the sessions ensured that the discussions would be carried out in an objective and unconstrained manner, with new ideas welcomed during discussion of every agenda item. The U.S. National Academies played a particularly important role in initiating and arranging the event. The University of Arizona was very helpful in communicating with interested universities and research centers to ensure a balanced representation of specialists from many disciplines and also took the lead in preparing this report.

Suggestions by Participants in Climate Change Workshop

1. Undertake dendrochronological studies that are useful for reconstruction of missing data.
2. Emphasize “regional” modeling for Iran and its geographical neighbors.
3. Promote collaboration between U.S. and Iranian universities on designing urban areas that can effectively cope with impacts of climate change.
4. Establish summer schools in technical fields such as observation and modelling that involve post-doctoral scientists and graduate students. Such schools could be held near Ecole Polytechnique in Paris and emphasize technical analyses and modelling studies.
5. Prepare a “new directions” article for *Science* or *Nature* that summarizes the outlook on climate change issues and suggested strategies for Iran.
6. Provide exemptions from sanctions that would enable U.S. and French scientists to work with Iranian counterparts in encouraging student and sabbatical exchanges that promote capacity-building in Iran.
7. Encourage Iran-France collaboration in building on French experience in improving science education for children in collaboration with scientists, possibly by focusing on climate change in an interested province in Iran.
8. Install water catchment tanks in mountains and valleys in wildlife parks and protected areas to catch winter/spring runoff, thereby saving costs of importing water for animals by tankers.
9. Work with U.N. office in Tehran in creating entities for specific environmental programs that are well-suited for management by institutions
10. Establish joint centers to conduct research on renewable energies such as biofuels.
11. Increase international conferences in Iran on climate change topics.
12. Collaborate in improving desulfurization technologies.
13. Create an association for climate change in Iran as an important focal point for discussions with government officials about climate change impacts.
14. Provide grants for Iranian students who prepare their master/doctoral theses on selected aspects of climate change.
15. Conduct pilot studies on selected techniques to preserve and/or restore wetlands.
16. Organize summer schools on selected aspects of climate change.
17. Develop a pilot project on selected features of solar energy.
18. Investigate controlled environmental agriculture (greenhouses) by Iranian scientists.
19. Develop demonstration project for recycling waste water through infiltration basins.
20. Encourage international organizations to undertake pilot projects at Lake Urmia that reduce agricultural water demands while transferring saved water to meet environmental demands.
21. Encourage the Iranian government to support a broadly based climate assessment of current and future conditions of a selected region in Iran, to be carried out by Iranian scientists in cooperation with international scientists who are familiar with similar efforts in other countries.
22. Work with countries in northern and other latitudes where supplies of water are stable or increasing for sharing with water deficit areas such as Iran and other arid countries
23. Develop new international approaches for water distribution across boundaries of water-adequate countries into water-deficit countries.

Time series analysis of Iranian surface air temperature data recorded in synoptic stations

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Abstract

Surface temperature records all over the world are characterized by short-term and long-term periodic and non-periodic variations. The exact causes of most of these changes remain the subject of debate. Temperature variations on the Earth's surface originate from natural and anthropogenic activities, and are observed in global, regional and local scales. In climate variation studies, the crucial question is to identify and to estimate the amount of contributions by natural causes. In this research we are interested in periodic variations of surface temperature data recorded in the Iranian synoptic stations. Identification of these periodicities and evaluation of their contribution in temperature variations of the Iranian region is the main objective of this study.

We used in this research the monthly mean surface air temperature data series recorded in the Iranian synoptic stations delivered by Islamic Republic of Iran Meteorological Organization (IRIMO). The minimum length of these records is 40 years in 42 stations up to 2010. There are some data gaps in certain stations. We used the Least Squares Spectral Analysis (LSSA) method developed by P. Vaníček in the 1970s as an alternative to the classical Fourier method.

Considering a unit weight matrix, the least squares spectra of all the time series have been estimated. The choice of the unit weight was because of the lack of any quality indicator of the data. Numerous statistically meaningful peaks are distinguished in the spectra in 95% confidence level and we computed the amplitude of their corresponding harmonic components. Spectral analysis revealed the following observations:

1. Statistically meaningful peaks corresponding to annual, 6 month, 4 month and 3 month periods are observed for all the stations. This is clearly due to the annual temperature variations. The amplitudes of this periodicity vary annually up to 14.4±0.2°C in Jolfa in NW of Iran. Coastal regions of Oman Sea experience 5-7°C annual temperature variations. The minimum value is 5.4±0.1°C for Chabahar in extreme SE of Iran. According to our estimation, the mean value of Iranian annual temperature variations is 11.7°C.
2. 95 percent of stations (total of 42) show statistically meaningful components on the quasi-biennial time scale (2-3 year). It has been observed that the amplitudes of this periodicity behave differently in southern coastal regions of Iran compared to northern parts. The maximum and minimum amplitudes of this periodicity are 0.9±0.2°C and 0.1±0.1°C respectively, and the corresponding mean value is 0.4°C.
3. Statistically meaningful spectral peaks with 3-5 year periods have been observed in all the spectra. We observe a distinction of amplitudes of this periodicity in southern coastal region comparing to other parts of Iran. The maximum and the minimum values of these inter-annual periodicities are 0.6±0.2°C and 0.2±0.1°C, respectively, and the mean value is 0.4°C.

4. Considerable spectral power concentration is observed in the quasi-decadal band (8-12 years) for all the stations (out of 42). The corresponding amplitude of these variations varies from 0.1±0.1°C in SE to 0.7±0.2°C in NW. The mean value of this periodicity is 0.3°C.

For periods longer than about 20 years, all the spectra show considerable high spectral values, but the spectral behavior of individual stations is not the same. Because of the short time span of our data set, long wavelength periodic phenomena and the eventual (linear/non-linear) trend(s) are not distinguishable in the low frequency part of the spectra. At the same time, the spectral leakage deteriorates the quality of the spectrum in this near zero frequencies. Therefore, we do not make any conclusion about the long term behavior of the data. The ensemble average of the residual time series shows considerable consistency with the mean global surface temperature time series published by international organizations like IPCC. However, the effect of non-detected long term periodicities mentioned above is clearly seen in the ensemble average of residuals.

The cumulative amplitude of periodicities introduced above has an average of 0.8°C, its maximum value is 1.4±0.3°C in the NW and its minimum value is 0.2±0.2°C in the SE of Iran. It is therefore probable to observe variations in these ranges in the Iranian surface air temperature during a decade because of periodicities introduced in this paper.

Climate Change Impacts on Desert Ecological Systems of Iran (Case Study: Yazd)

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Abstract

Today our human communities and natural resources are at risk of climate change. Now we observe the first signs and symptoms of this horrible phenomena. We must be ready for more changes that will occur in the future. Iran is climatically part of the Afro-Asian belt of deserts, which stretches from the west of Africa to the east of Asia. Approximately 85% of the country has arid, semi-arid or hyper arid environment. Iran's geography consists of a plateau surrounded by mountains and is considered to be one of the driest countries of the world. In this research we examine the impacts of climate change on two desert ecological system of Iran. Firstly, the impacts of climate change on Syahkooh National Park in central Iran are examined. Syahkooh National Park provides a good example of the desert regions of Iran. Syahkooh is located between Yazd and Isfahan provinces near the city of Ardakan. A chain of low rocky mountains and alluvial plains form the backbone of this region. Altitudes range from between 800 and 2,050 meters. The biota in the Syahkooh desert are at the limit of conditions that allow growth and survival and show very specialized adaptations to aridity and heat. Vegetation is very sparse and large areas appear to be barren during periods of prolonged drought. The biomass of plants and animals is low; however, Syahkooh have a significant species richness and a high endemism. Many kinds of important species like Asiatic Cheetah, wolf, wild sheep, Persian Ibex, gazelle(Jebir), Houbara Bustard and Hare and Chukar Parteidge lives in Syahkooh National Park. Unfortunately Syahkooh is likely to become even more extreme if climate changes happen as projected by current scenarios. The Syahkooh desert is expected to become significantly hotter and drier. If changes in the frequency or intensity of rainfall events occur, they are likely to cause changes in the flora and fauna of this national park. Unfortunately for many kind of species in this national park there is no option to migrate or go to other protected areas because Syahkooh is like an island located between the extreme hot and dry deserts and salt lake.

In the second case study we examine impacts of climate change on the social ecological system of Yazd city. In central Iran, most of the cities and villages are usually located along the border of deserts close to mountains. The reason for this site selection is the presence of ecological services such as water and fertile soil belonging to closed water basins of arid zones. These ecological services are highly dependent on the *arrangement of structural pattern of patches, corridors and a matrix that constitute a landscape. Unfortunately these landscapes are under the degradation due cumulative impacts of uncontrolled human development and climate change.* Yazd is one of the ancient cities (with 3000 year long history) that located in center of Iran in arid zone. The arid landscape of Yazd have some characteristics like lack of water, high levels of solar radiation, and strong dusty winds. Traditional Yazd, has been formed based on environmental and weather conditions. But unfortunately development of Yazd in last decades did not consider the arid environmental conditions. Urban landscapes developed like cities with high rain or in temperate climate. Based on the IPCC projection, climate change will lead to increased frequency, intensity, and/or duration of extreme weather events such as shortage of rainfall, warm weather and heat

events, drought, and intense storms. Based on these projections the existence condition of new Yazd city does not comply with these changes and cannot be sustainable in the future……… to be continued.

Zinc nanoparticles immobilized into MCM-41 pores, an adsorbent for hydrogen sulfide from crude oil

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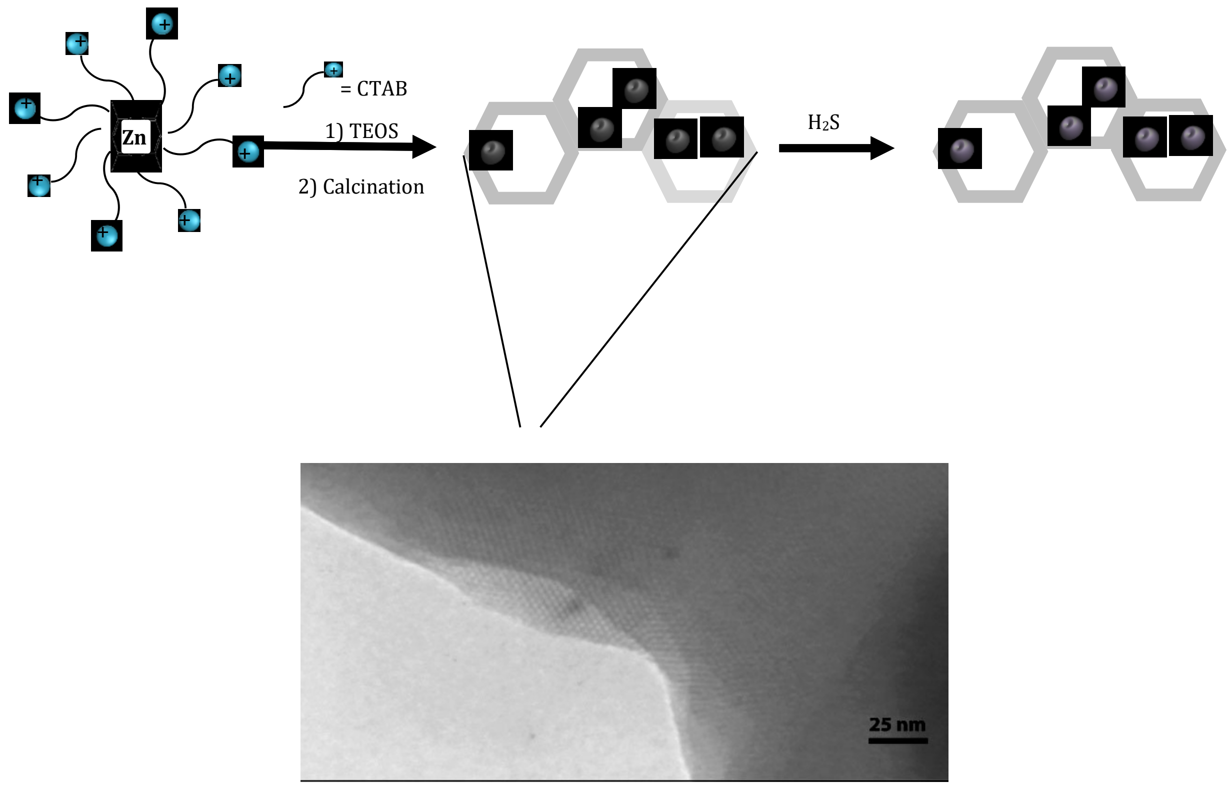

Keywords: ZnO, MCM-41, Adsorption, H_2S, Crude Oil

In recent years, the preparation and application of nano-sized materials due to their large surface areas have received increasing attention in various areas of research. Nano-ordered MCM-41 has great uses in many fields such as catalysis, separation, medicine, and hydrogen sulfide removal.

Pure siliceous MCM-41 has had limited applications. Though, an active substance can be prepared with the modification of silicate framework of MCM-41 by inorganic elements or organic functional groups. Different methods for inorganic functionalization of mesoporous silica have been considered. In order to achieve inorganically modified mesoporous silica, some studies have been accomplished in recent years.

One of the main applications of metal-containing mesoporous silica is adsorption of hydrogen sulfide (H_2S). Adsorption is one of the most interesting areas of research for lowering H_2S, especially in oil industry. As a result of environmental issues regarding the sulfur content, refiners have to produce clean petrochemical products.

H_2S is a naturally occurring toxic and malodorous gas contained in many of the world's crude oils. It harms product value, compromises environmental and safety compliance, damages infrastructure integrity from corrosion attack, produces odors, and more. That is why managing H_2S content is a challenge at every stage of hydrocarbon processing, refining, and transportation. In different industries, H_2S can be removed using a variety of physical-chemical or biological methods, including Claus process, chemical oxidants, caustic scrubbers, H_2S scavengers, liquid amine absorption, liquid-phase oxidation, physical solvents, membrane processes, biological methods and adsorption. MCM-41, because of its high specific surface area, uniform pore size distribution and reactive surface for functionalization with many functional groups, is a good candidate as a H_2S adsorbent. After the work of Westmoreland and Harrison, studies were concentrated on zinc, copper, iron, and calcium oxides as suitable metals due to their sulfur removal efficiencies and thermal stabilities. From the thermodynamic analysis, it can be shown that zinc oxide (ZnO) is a good adsorbent having high sulfur removal efficiency because of high equilibrium constant. Furthermore, ZnO is considered a cost-effective and stable sorbent compared to other metal oxides.

Herein the well-ordered Zn-MCM-41 was synthesized by a direct hydrothermal method using cetyltrimethylammonia bromide as the structure-directing agent in an ammonia aqueous solution. Zinc acetylacetonate was inserted into the structure-directing agent's loop during the synthesis which was converted to ZnO after calcination. ZnO functionalized mesoporous silica samples were characterized by X-ray diffraction, high-resolution transmission electron microscopy, and nitrogen adsorption–desorption isotherms. The results show presence of ZnO in highly-ordered MCM-41's pore and the material maintained ordered mesostructure of MCM-41. The materials possessed high specific surface area (1114–509 $m^2\ g^{-1}$) and large pore diameter (4.03–3.27 nm). A remarkable difference between the present approach and the typical in-situ pathways is the precursor's behavior in the solution. In this process $Zn(acac)_2$ was located inside the hydrophobic micelles which were arranged by surfactant (before adding silica source) and after the calcination zinc oxide nanopaticles were anchored onto silica walls. Although in this synthesis the metal precursor was added in the synthesis medium, the introduced metal in silica's body is less than other in-situ methods. Notably, the characterization techniques showed considerably high specification for all of the samples mentioned. Additionally, in comparison to the previous work and this study, in the same experimental conditions, the synthesized samples in this work showed more ability than the other where the only difference is "synthesis method."

The obtained results from adsorption of H_2S in a lab-made set up showed superior ability of all the materials and an increase in adsorption upon increasing ZnO amount.

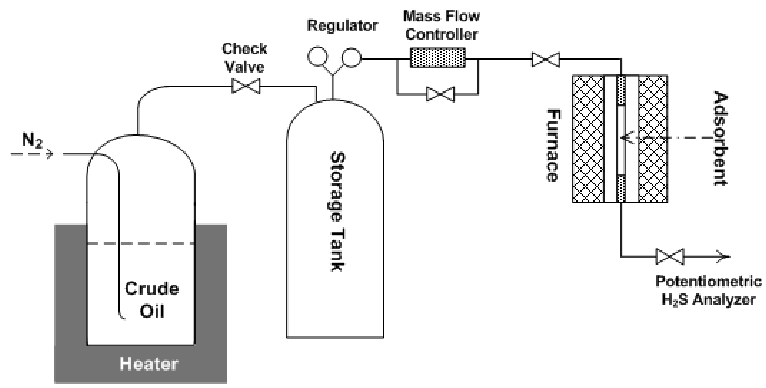

Figure 1: Schematic diagram of experimental set-up.

In conclusion we offer strongly this new generation of adsorbent as a good replacement for convenient methods of desulfurization of oil derivatives as a way of climate change mitigation caused by sulfur emission of petroleum-based fuels combustion.

Climate Change: Some Implications for Agriculture

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Abstract

Increasing global food production is essential to meeting human food security challenges and avoiding societal disruptions over the next 75 years. Continued population growth coupled with climate change pose major challenges for the UN Sustainable Development Goals (SDGs) of insuring food security for all peoples. Most experts believe we have the technological capability to feed roughly 10 billion people, but this will require the invention of new technologies and the effective implementation of existing technologies, such as the suite of tools that constitute biotechnology. When population growth is coupled with climate change, the challenge of feeding the world's peoples over the next 75 years becomes even more daunting. Agricultural activities and forestry are themselves major contributors to greenhouse gases, so significant policy reforms and new efficiencies will be crucial. The challenge can only be met by expanded investments in public sector research and by the implementation of public policies that reduce carbon emissions and that insure greater equity among the world's peoples.

Keywords: Agriculture, Climate Change, Population Growth, Biotechnology

1. INTRODUCTION

Human history is a continuous story of technological transformation. It is arguable that the most transforming change in human history came from the invention of agriculture, an innovation that appears to have been catalyzed by climate change [1,2]. The first clear evidence of plant domestication comes from the Fertile Crescent beginning around 11,500 YBP, but a remarkable feature of this innovation is that it appeared independently at several places around the globe at roughly the same time (Mexico about 10,000 YBP; China about 10500 YBP). What accounts for the simultaneous appearance of agriculture in such widely separated parts of the globe? The most plausible explanation is that humans of the late Pleistocene era were forced to adapt to new climatic environments during a period of dramatic climate change driven by the end of the glaciation.

Once humans had adopted agriculture they set about domesticating plants and animals with a vengeance. National Research Council publications on the lost crops of Africa and of South America document hundreds species of plants domesticated by Neolithic peoples [3-6]. But modern humans no longer cultivate most of these species, as we have come to depend on a very small number of cereal grain and vegetable species for human sustenance. An important consequence is that agricultural systems are more vulnerable to pests and disease epidemics and to climate variability, because dependence on a very small number of crops for much of our food supply makes catastrophic failure more probable. Beyond domesticating a wide range of plant species, Neolithic humans also developed irrigation, crop rotation practices and fertilization to enhance crop yields and productivity. Taken together these innovations allowed the support of much larger human populations and promoted early urban civilizations.

The pace of agricultural innovation accelerated in the last century and a half with the development of the steel plow, the substitution of animal and human labor by machines, the introduction of chemical fertilizers and the development of modern genetic approaches to plant and animal improvement. These innovations, together with advances in public health, have allowed human populations to increase at a super exponential rate. According to the United Nations Population Fund the human population passed 1 billion in about 1800, it took another 127 years to grow to two billion, three billion was reached 33 years later, 4 billion in only 14 years, 5 billion in another 13 years, 6 billion 12 years later, and 7 billion was achieved in 2011 after another 12 years. Human population growth is predicted to reach 8 billion in 2025, 9 billion in 2043 and 10 billion in 2083. While the rate of growth is slowing the human population is projected to increase by about 2.8 billion or more than 35% over the next 75 years or so.

2. The Challenge of Feeding a Growing Human Population over the Next Seventy-Five Years

2.1. Can we feed the growing human population over the next seventy-five years, even without factoring in the complications of climate change?

Most experts agree that we have the knowledge, technologies and resources to feed the human population over the next seventy-five years, despite a projected further population growth of more than 35% [7-9]. But the picture becomes more complex when viewed on a regional scale. About 90% of human population growth will occur in the poorest regions of the world [10] and urbanization will accelerate from the current level of about 50% urban dwellers to about 70% of the global population living in large cities. So for example, population is projected to double in sub Saharan Africa, while actually declining in Russia, Japan, Italy and a number of other advanced countries. A higher level of urbanization is a mixed blessing. It facilitates more efficient use of some resources and increases the effectiveness of food distribution systems. But, it will make human disease management a greater challenge by concentrating many people into small areas [10].

In 1950 there were about 0.5 hectares of arable land per person on earth, that ratio will decline to somewhere between 0.21 and 0.14 by 2050 depending on actual population growth. So the option used by our recent ancestors of bringing more arable land into production is now largely foreclosed. Only about 5% of agricultural production increases over the next half-century will come from increases in arable land [11].

An interesting outcome of economic growth in China, India and many other countries will be a growth in demand that substantially exceeds population growth, because wealthier societies consume more. So the demand for food products will grow much faster than population. This will place a strain on food production systems and there is no guarantee that markets will work to provide adequate food for the world's poorest inhabitants.

2.2. One of the great achievements of 20th century agricultural science was the introduction of the suite of technologies known collectively as the "Green Revolution"

The Green Revolution combined modern genetic methods with high inputs of nitrogen fertilizers to bring about large increases in agricultural productivity in countries such as India that were previously threatened by hunger. But, the rate of increase in productivity is declining because most of the innovations latent in the green revolution have been fully exploited. So it is estimated that average crop yields will increase at only about half the rate experienced over the past half century, declining from about 1.7% per year to 0.8% per year for cereals (FAO, 2009). Moreover, some current practices are clearly unsustainable in the future, such as over fertilization or subsidies for excess water withdrawal.

2.3. The prospects for enhanced yields from the application of biotechnology appear to be very good

But here too there are uncertainties. One uncertainty arises from strong and entrenched opposition to the techniques of genetic engineering. It is still not clear how the political opposition to GMOs will play out in important regions like Europe and Africa. A second uncertainty arises from the unpredictable nature of basic research. We can be quite certain that over the long term we will be able to engineer genomes to accelerate adaptation to extreme environments and to substantially increase productivity, but we cannot be certain how long it will take to overcome unanticipated obstacles to research progress.

Another challenge is the management of water resources. Plants and animals are absolutely dependent on water for survival and for optimal productivity. It is estimated that irrigation will increase by about 28% (largely in developing countries) and water withdrawals will increase by 11%. This will put severe strains on renewable water resources. Governments will be challenged to adopt new legal approaches to water management and to eliminate incentives that support wasteful practices [11].

The FAO [11] projects that aggregate food demand will increase about 70% by 2050 over today's levels. We currently consume 2.1 billion tons of cereal grains and this will increase to 3 billion tons by 2050. But the projections are complicated by the unknown amounts that may be consumed for biofuel production.

So the picture with respect to food availability is one of a difficult, but potentially manageable 50-year time horizon. We will have to do more on a limited arable land base, but biotechnology and more efficient management techniques should provide a route to increased productivity, assuming public acceptance is improved. Managing water resources will be a challenge, but we have the technical knowledge to do a better job, provided we can overcome outdated subsidies and outmoded legal systems. However, the regional picture is more disquieting, most population growth will occur in poorer regions of the world and it is not clear that market systems will lead to adequate allocation of food to poor peoples. We rely on a very small number of crop species that can be vulnerable to extreme events and to new diseases. So, risks of catastrophic failures may increase. Still taking all that we currently know into account there is good reason to believe that we can feed nine or perhaps even ten billion people [9].

3. How will Climate Change Impact our Ability to Feed the World over the Next Fifty Years

3.1. Greenhouse Gases

The first thing to note is that contemporary agriculture is a major contributor to green house gases (GHGs), so global strategies for reducing GHGs will have to include both reforms to current agricultural practices and new technologies [12]. At least 12% of GHG emissions can be traced to agricultural practices, such as the high-energy inputs employed in industrial agriculture and methane emissions from animal agriculture. This figure doubles to about 24% when the impacts of forestry are added to those of agriculture. Agriculture is the world's largest source of non CO_2 GHGs [13]. So, it is imperative to reduce the impact of agriculture and forestry on GHG production.

3.2. Experts divide the opportunities for reducing GHGs from agriculture into demand side and supply side approaches

On the demand side a huge issue is loss of food owing to spoilage and waste. The FAO [14] estimates that about one-third of global food production is lost or wasted and this amounts to about 1.3 billion tons per year. An implication is that one-third of all the GHGs invested in agricultural production are expended for no gain. Much more food is wasted at the consumption level in the developed world. The FAO report cited above calculates that 95 – 115 kg/yr of food are wasted per capita in Europe and North America compared to 6 – 11 kg/yr in sub-Saharan Africa and South/Southeast Asia. Another demand side issue involves changing dietary practices. Meat consumption uses much more energy than the consumption of plant products, but as income levels raise so too does the tendency to consume meat, accounting in part for the fact that growth in agricultural demand will out pace population growth. There are several supply side opportunities.

These include sequestration of carbon stocks in soils, biomass, management changes in land and live stock and substitution of fossil fuels by biomass. Most of the supply side opportunities will benefit from additional research and technological innovation.

3.3. Plants require CO_2 for photosynthesis

At first blush it might be assumed that increasing CO_2 levels would also increase plant yields, but the negative impacts of Ozone and higher temperatures more than offset the gain from increased CO_2. Fig. 1 [15] shows that the impact of climate change on agricultural productivity is strongly dependent on the extent of temperature increase.

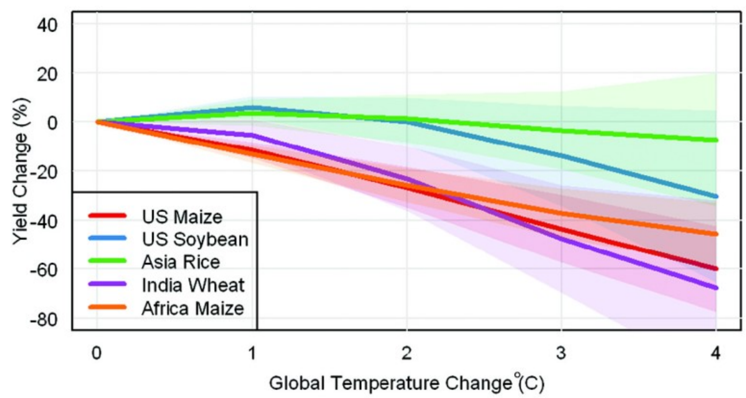

Figure 1: Depicts changes in yield for corn in the United States and Africa, wheat in India, U.S. soybeans and Asian rice as a function of degree centigrade global warming

According to Fig. 1, we can expect a small increase in yields for rice and soybeans for the first 1 – 2 degree C of warming, followed by a marked decline as temperature increases exceed 2 degree C. Corn and wheat show decreases in yields over the entire range of temperatures studied. Two important conclusions follow. First, warming of greater than 2 degree C poses a substantial risk to agricultural productivity, and hence to food security, and the risks become large after 3 degree C. Second, the negative impacts will be largest in Africa and Asia.

3.4. Other threats to agricultural productivity

There are other threats to agricultural productivity beyond simple temperature increases, although these threats are themselves a function of temperature. For example, as global temperature increases the variance in storm intensity, drought and other climate-linked extremes, will increase, and as a consequence, the frequency of extreme events is expected to grow. Extreme events impact agricultural productivity because they briefly impose environmental conditions that exceed the range of adaptation of domesticated plants and animals, thereby causing substantial crop losses. A second consideration is the impact of global warming on water supplies. Agriculture is absolutely dependent on water availability and global water supplies are expected to come under increasing stress [5]. Finally, it is important to recognize that agriculture operates in a systems context. Agricultural productivity is strongly influenced by the health of nutrient cycling, soil microbiota, and rates of waste decomposition among other factors. The impact of climate change on these ecosystem properties are likely to negatively affect agricultural productivity.

3.5. Food shortages can impact social stability and induce large-scale human migrations.

These disruptive processes also undermine agricultural systems because they disrupt supply chains, induce price volatility and increase investment uncertainty, thereby creating a feed back loop that further undermines the stability of social and agricultural systems.

4. What can be Done?

4.1. First and foremost take actions now to avoid unacceptable social and economic costs.

The UN Conference of Parties (COP 21) process that will culminate in December in Paris provides an opportunity to begin to slow the rate of accumulation of atmospheric CO_2. Recent announcements by China, India and the United States provide some basis for modest optimism. But these agreements, if they hold, are relatively late in coming, so a significant amount of global warming is already foreordained. Moreover, the regions of the world in greatest jeopardy are sub Saharan Africa and parts of Asia that are least able to cope with the disruptions caused by reduced food security and other climate related disasters. As noted above, most of the people born in the next fifty years will arrive in these regions of the world so, policy makers will have to devise better systems for equity, if we are to avoid political instability and mass human migrations.

As emphasized in the introduction, agricultural history can be seen as a long, although episodic, story of technology development and innovation. Unfortunately, we are witnessing a long-term trend of decreasing public investment in agricultural research [5]. It will be important to reverse this trend and to increase investments in basic and applied research aimed at agricultural improvement in order to fully harness the uniquely human capacity for knowledge creation and innovation. There is ample scope for advancements in the breeding of more heat tolerant crops, for scientific improvements in water management and for improvements in our understanding of the ecosystem dependencies of agricultural systems, to name just a small number of opportunities.

Successful human adaptation to a warmer future rests in part on technological innovation and in part on wise public policy implementation. The scale of research investment will need to be increased over current levels, especially in the public sector where most fundamental research is supported, in order to meet the challenges of climate change. The rapid rate of both population growth and of global warming provides very little time for new technologies to be developed and put into practice. A failure to make modest investments now, is likely to impose much larger future costs.

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Evidence for late Neoproterozoic glaciation (ca. 560 Ma) in oldest sedimentary exposures of northern Iran (Kahar Formation)

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Abstract

Climate is variable over time. When climatologists look backward in time and piece together evidence of Earth's past climate, they discover that during the great expanse of Earth history, and long before humans were roaming the planet, there were many shifts from warm to cold and back again due to natural variations [1, 2]. Indeed, the geologic record is a storehouse of data that confirm this fact. Although these days all climate news are about global warming but scientists have determined through proxy evidence that global freezing was the biggest climate worry in Earth's distant past. What is important is that the Planet Earth has been able to escape from its extreme climate events.

Proxy evidence from paleocontinents supports that Neoproterozoic Earth (1000-542 Ma) experienced several exceptional climate state fluctuations between 'icehouse' and 'greenhouse' conditions [3] the severity of which possibly influenced biological evolution prior to the Cambrian "explosion". Iran's earlier Neoproterozoic evolution is poorly understood, due to difficulties determining age in what have been considered oldest basement exposures. Many of Iran's stratigraphically lowest and highest metamorphic grade rocks occur in tectonostratigraphic terranes that have experienced complex thermal histories and metamorphism associated with one or more orogenic events. The late Neoproterozoic siliciclastic-dominated Kahar Formation, originally described in the Kahar Mountain type locality, central Alborz Ranges, is the oldest exposed sedimentary succession in northern Iran. Although the Kahar Formation has been studied paleontologically and sedimentologically, the unit has received little geochronologic or chemostratigraphic study, and glacial deposits have not been previously reported. Herein we focus on possible glaciogenic strata exposed near the base of the Kahar Formation from two different anticlinorial exposures, Kahar Mountain and Sarbandan (~120 km apart), in the central Alborz Mountains. Integrated field investigation, petrographic study, high precision U–Pb detrital zircon geochronology, in conjunction with elemental and isotopic (δ13C and 87Sr/86Sr) analyses of carbonate units (particularly those bracketing basal diamictites) provide new data bearing on the age and origin of Kahar diamictites in northern Iran. Our findings improve understanding of northern Iran's oldest sedimentary basement exposures and may also be useful in reconstructing of ancient cold climate belt.

In our studied localities the Kahar Formation consists of about 1000 m of siliciclastic sedimentary strata, with minor carbonate, which were deposited along the Peri-Gondwanan margin of Iran. Distinct diamictite units occur near the base of studied sections and are consistent with glaciogenic deposits on the basis of (1) textural and compositional characteristics, (2) geometry, (3) widespread lateral continuity, (4) sharp erosional basal contact, and (5) occurrence of glacial

striations. These glacial units, similar to many Neoproterozoic glacial deposits, are capped by distinct carbonate intervals (9 to 17m thick), with negative δ13C compositions (-1.0 to -5.4 ‰) and 87Sr/86Sr values between 0.70867 and 0.70884 (Kahar Mountain locality). These stromatolitic carbonates indicate an abrupt change from glacial to apparently tropical conditions. These carbonate intervals are overlain by siliciclastics which display a number of primary sedimentary structures such as round crested and symmetrical ripple marks, ripple cross laminations mainly in the form of climbing ripples, flaser, wavy and lenticular laminations, trough and bidirectional cross stratifications, and plane parallel laminations. Such structures indicate open water body (no ice) and relatively shallow water depth. Moreover, the Kahar Formation at both studied sections is overlain by the Soltanieh Formation, which contains abundant fossils and represents biological evolution at the terminal Neoproterozoic of this region. Integration U-Pb ages with δ13C and 87Sr/86Sr reference curves indicate that the Kahar diamictites in studied sections have a late Ediacaran (ca. 560 Ma) minimum age. Moreover, these C and Sr isotopic compositions are consistent with the rapid increase in 87Sr/86Sr during the late Ediacaran recovery from the Shuram negative δ13C excursion. These data allow us to correlate the Kahar–Soltanieh succession in Iran with the Buah and Ara formations of the Nafun Group in Oman and the upper Doushantuo and Dengying formations in South China. The combined data imply that the Kahar diamictites possibly show a picture of past glacial activity and represent a late Neoproterozoic glaciation (ca. 560 Ma), definitely younger than the 582 Ma Gaskiers glaciation. Prospective glaciogenic strata of Neoproterozoic age have also been reported from central Iran in the Rizu Formation [4] and Bafq mining district [5]. This result, together with several examples of late Ediacaran glacial deposits which have been reported from other localities around the world [6], support the suggestion that multiple glaciations may have occurred in late Neoproterozoic time.

Keywords: Neoproterozoic; Ediacaran; Alborz; Kahar; Diamictite.

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Securing Protected Areas in Iran in the Face of Climate and Land use Change

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Abstract

The protected areas system in Iran is faced with many challenges even without climate change. The combined effects of climate change and land use change are the most important conservation challenge we face. As a background to this work, we summarize information on the current situation in Iran with respect to the distribution and efficacy of protected areas, and the ancillary threats facing biodiversity, such as habitat fragmentation and isolation, drought, and human activities. Climate change projections suggest generally warmer and drier conditions in Iran that will intensify the already significant water stress across the region and impact on biodiversity and human wellbeing. Consequently, many protected areas are likely to lose species through extinctions and migrations. Indigenous freshwater species and ecosystems are at risk from future drying. In this paper we present ecological impacts of climate and land use change on Lorestan newt (*Neurergus kaiseri*) as an endemic species to the southern Zagros Mountains in Iran, and critically endangered species in IUCN red list, and will provide climate change-integrated conservation strategies to help biodiversity survive climate change. As the first part of this study, habitat suitability of *Neurergus kaiseri* was evaluated using a MaxEnt modelling approach using environmental and climatic parameters such as elevation, slope, aspect, land cover, distance to the streams, village density, and 19 thermal and precipitation parameters. Based on the results derived from the MaxEnt model, the most important predictor parameters were related to Annual Precipitation, Precipitation Seasonality, Annual Mean Temperature, Elevation and Land Cover. The results showed that climatic parameters are very important for this species and according to upcoming climate change it is necessary to develop comprehensive conservation planning in the study area. Analysis of seven climatic parameters in 31 years (1980-2010) revealed that minimum temperature increased 2.2°C and relative humidity decreased 9%. This climate change might have direct and indirect impacts on Lorestan Newt populations. Direct consequences of climate change can be expected because amphibians are extremely sensitive to small changes in temperature and moisture due to their permeable skin, biphasic lifecycles and unshelled eggs, In addition, the indirect effects of climate change such as the availability of water, will likely be more deleterious than the effects of temperature alone.

In the second part of this paper, we consider the most recommended strategy for conserving species in onset of climate change which is maintaining connectivity. Improving connectivity is not only strategically smart, but a proven method to enable species to migrate with their climatic niche and move in response to environmental change. Individual sites should also be seen as part of an expanded network that can accommodate shifts in species' distributions. This network should improve the opportunities for dispersal of species. Due to the static boundaries for most protected areas, species may shift out of reserves where they are protected in response to climate change. Hence, the focus for new conservation reserves has dramatically shifted to increasing the connectivity between reserves through migration corridors, to enable species to migrate with their climatic niche. Conservation and management of wildlife populations in Iran have mostly relied on protection of areas where the species of interest occurs .This approach has resulted in delineating

protected areas which include major proportions of wildlife populations and their main habitats, and little effort has been allocated to ensuring connectivity between appropriate habitat patches to support seasonal movements and movements in response to climate change in the future. In this study, we exemplify identifying migration corridors for two vulnerable ungulate species, the Isfahan wild sheep (*Ovis orientalis isphahanica*), and the goitered gazelle (*Gazella subguterrosa*) between Mooteh and Ghamishloo wildlife refuges in Isfahan province, using Least-Cost Corridor (LCC), and Circuit Theory. Although the identified corridors in this study are currently used for round migrations between Mooteh and Ghamishloo wildlife refuges, they are most likely to be served as one way migration corridors from Ghamishloo to Mooteh protected area assisting the species to shift their ranges in response to climate change in an immediate future. Climatic conditions in Mooteh compared to Ghamishloo in terms of annual rainfall (249.16 mm in Mootieh in compared to 180.9 mm in Ghamishloo) and minimum average temperature (-8.5C in Mooteh compared to -1.6 C in Ghamishloo) indicates that Mooteh wildlife refuge will be used as a refugia to buffer these ungulates from the impacts of drought and climate change in this region.

We conclude that climate change as an integral factor in systematic conservation planning should be considered to ensure persistence of biodiversity.

Decline of Oak Forests: Convincing Evidence for Climate Change Impacts in the West of Iran

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Abstract

Over the last few years, millions of oak trees in the world have been affected by a complex disease known as oak decline, oak dieback or oak mortality, depending on the area and the particular case taken into consideration. There are a lot of interacting factors influencing over each particular situation and this fact makes difficult the search for explanations and possible solutions to the problem. Similarly, decline of the oak forests well-known as Zagros forests of western Iran, with an area of 5.5 million hectare and dominated by Persian oak (Quercus brantii) trees has been occurring since 2000. Forest managers in Iran believe there is no single reason responsible for the decline of oak forests. Not surprisingly, forest degradation, frequent droughts, overgrazing, suspended particles and dusts originated from neighboring countries coupling with changes in meteorological parameters in recent years assumes to impair the ability of the ecosystem to combat environmental stresses. The present research is aimed firstly at observing the long-term trends of meteorological parameters and reference evapotranspiration (ET_0) in the Zagros region where the average annual precipitation varies with approximately 250 mm to 800 mm and the mean annual air temperature differs from 9 °C to 25 °C. The second goal of this study was to estimate ecohydrological parameters highly affected by climate change and related to the rainfall interception (I) process (i.e., canopy storage capacity (S), the ratio of mean evaporation rate from the wet canopy to the mean rainfall intensity (E/R), and the free throughfall coefficient (p)). We also quantified a renowned potential of oak trees to intercept dust and particles. Long-term (1961-2010) data of air temperature, relative humidity, precipitation, and wind speed were obtained from six synoptic meteorological stations located all over the region. The Penman-Monteith equation was applied to calculate the ET_0. To measure gross rainfall (GR), rain gauges were fixed in an open space nearby to the oak trees and throughfall (TF) was measured using the gauges randomly placed underneath the trees canopy cover. I was computed as the difference between GR and TF. The results indicated that after 2000, coinciding with emerging oak decline, some of the meteorological parameters and ET_0 changed dramatically, i.e., air temperature: +0.6 °C; precipitation: -60 mm; relative humidity: -3 %, wind speed: +0.4 m s^{-1}, and ET_0: +0.25 mm.d^{-1}. Two out of six stations exhibited statistically significant positive and negative trends ($P < 0.05$) for the annual air temperature time series. Event-based relative interception (I:GR) was estimated at 40% and 25% during the in-leaf and leaf-less periods, respectively. During the in-leaf period, the mean values of S, E/R, and p were roughly estimated to be 1 mm, 0.22, and 0.23, respectively. These values were corresponded to 0.6 mm, 0.09, and 0.63 during the leafless period. Our data suggested that the number of precipitation events lower than 2.5 mm increased after 2000. If this trend persists to the future, regarding to the amount of canopy water storage capacity of oak trees in the Zagros forests which is 1 mm for the in-leaf period and 0.6 mm during the leaf-less period, it is reasonable that these forests will experience reduction in the available water because of increased evaporative loss. We estimate that each typical oak tree, i.e., diameter at breast height, DBH 30 cm; crown diameter, Cd 6 m; height h 7 m; plant area index, PAI, 2; crown projection area, CPA 30 m^2, is talented to intercept roughly 100 gr dust leached by a rainfall event with approximate size of 8 mm if the tree is exposed to no less than one dusty day. Moreover, moving the small size particles; PM_1, $PM_{2.5}$, and

PM_{10}; into oak trees through stomata aperture is likely since the pore length and width of stomata in oak trees were measured to be 15 and 3.3 micrometer, respectively. Dusts and particles intercepted by oak trees definitely disrupts exchanging oxygen and carbon dioxide and will affect tree ecophysiology. Although this preliminary research confirmed the significant linking between oak decline and altering the meteorological parameters, full datasets recorded in different parts of the Zagros regions are essential for a detailed and reasonable research to fully explain this hypothesis. Forest managers should necessarily think of the expected changes in meteorological parameters and evapotranspiration owing to global warming while proposing the preventative actions to mitigate oak decline in the Zagros region.

***Keywords**: Dusts and Particles, Ecohydrological Parameters, Evapotranspiration, Meteorological Parameters, Oak Decline, Rainfall Interception, Zagros Forests,*

Atmospheric issues, including dispersion, chemical changes, effect of winds

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Abstract

Air pollution comprises gases and aerosol particles stemming from both anthropogenic and natural sources. While greenhouse gases warm the planet, aerosol particles have a net cooling effect for two reasons: (i) they directly interact with solar radiation thereby reducing the amount of incident solar radiation at the planet's surface; and (ii) they indirect help scatter light via their role in producing cloud droplets. Understanding how particles impact climate, clouds, the hydrologic cycle, public health, and visibility is a major challenge owing to the short residence time of particles (~ days) in the atmosphere relative to gases, the changes that occur to the radiative properties of aerosols during their transport, and a lack of knowledge of how particle interact with clouds. Future climate change is expected to alter the emissions of particles, especially from deserts and wildfires. Thus, it is critical to be able to improve knowledge of exactly what these changes will be in the future and how they will impact the environment and public health.

Air pollution differs from other medium by which pollutants can move (e.g., water, soil, biota) in that it covers the largest spatial scale (~global) and occurs on the shortest time scale. With regard to the global spatial scale of transport, a prime example is how Asian emissions significantly impact North American air quality within a matter of a few days. This is clearly evident when large dust plumes advect eastwards to the western United States and subside leading to drastic degradation in surface air quality. Dust plumes from the Saharan Desert also regularly reach the southeastern part of North America. Biomass burning plumes also are transported between continents. Therefore, understanding how a particular region's air quality and microclimate will respond to future emissions requires a broad view of the entire planet as pollutants from a distant region can impact another area's surface pollution and overlying columnar thermodynamic structure, which in turn affects cloud formation and precipitation.

Dust and wildfire emissions are of particular importance in this presentation. Climate model projections predict that some parts of the world will become drier leading to more dust emissions and wildfires. Dust particle pose adverse health effects for people in this region and the other semi-arid and arid regions that cover over a third of the global land area. Dust can carry contaminants from one area to another. For example, valley fever is a disease endemic to arid regions, especially the southwestern part of North America ("Southwest"). The disease is caused by a soil-dwelling fungus, Coccidioides Immitis, that is associated with wind-blown soil dust. Dust aerosol can also transport a variety of allergens and pathogens, and consequently lead to respiratory diseases. An emerging concern is a suite of toxic metals and metalloids that are known to be abundant in dust aerosol in Southwest, and likely other regions. There has been a proliferation of news reports locally and nationally documenting this growing concern in Arizona. Article titles such as "How Global Warming is Spreading Toxic Dust" (http://www.scientificamerican.com/article.cfm?id=how-global-warming-is-spreading-toxic-dust) in a recent issue of the Scientific American provide an indication of the seriousness of the alarm being brought to the attention of those living in the region. Aside from health impacts, more dust emissions in the region will affect the microclimate of the region and the rate of snowmelt in high-altitude terrain such as with the Rocky Mountains because of the ability of this particle type to absorb light.

The western United States is becoming increasingly vulnerable to the effects of wildfires owing to both a warmer climate and fire-control strategies over past decades resulting in conditions that

promote larger and more frequent fires. Biomass burning leads to emissions of various gaseous (e.g., nitrogen oxides (NOx), ozone (O3), carbon monoxide (CO), volatile organic compounds (VOCs)) and particulate species (e.g., elemental carbon (EC), organic carbon (OC), inorganics), but also soil emissions due to mixing near the flames. The physicochemical properties of particles stemming from biomass burning have been extensively characterized in various past works, but much is still being learned due to new methodologies applied and varying results depending on the fuel type and burning condition being examined. Better knowledge of the nature of the emissions of wildfires and how their properties change with aging in the atmosphere is needed to improve model predictions of future climate change.

Grand Science Challenges in Climate Research - Climate Information for Decision Makers

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Abstract

Over the past several years, the three major sponsors of the World Climate Research Programme (WCRP), i.e. the World Meteorological Organization (WMO), the Intergovernmental Oceanographic Committee (IOC), and the International Council for Science (ICSU), have underdone considerable strategic planning such as WMO's World Climate Conference-3 leading to the Global Framework for Climate Services, IOC's Ocean Obs '09 and subsequent framework for global sustained ocean observations, and ICSU's Visioning exercise leading to the formation of Future Earth. Emerging themes include the need for more flexibility and agility to respond to expanding user needs that include information at the regional scale, for key sectors of the global economy, and for adaptation, mitigation, and risk management.

In response, the Joint Scientific Committee (JSC) of the WCRP embarked on a series of consultations with its sponsors, stakeholders and affiliate network of scientists culminating in the WCRP Open Science Conference: Climate Research in Service to Society in Denver, Colorado during October 2011. The WCRP Grand Science Challenges have emerged as a result of this deliberative process. As such, the Grand Challenges represent major areas of scientific research, modelling, analysis and observations for the physical climate system in the ensuing decade.

This presentation will provide an overview of the following Grand Challenges in research on the physical climate needed to support and underpin the provision of climate information and services:

- Clouds, Circulation and Climate Sensitivity
- Cryosphere in a Changing Climate
- Science Underpinning the Prediction and Attribution of Extreme Events
- Regional Climate Information
- Sea-Level Rise and Regional Impacts
- Changes in Water Availability

The Use of Synoptical Analysis for Classification of Dust Events in South Western Parts of Iran

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Abstract

Dust storms have significant impacts on the earth's atmospheric system. The mineral dust particles can alter the atmospheric heating and stability, influence the chemical and biological ecosystems, and affect the air quality and human health [1]. Dust particles may either absorb or scatter radiation, resulting in radiative forcing and cause remarkable reduction in visibility [2,3]. Radiative forcing due to dust aerosols is one of the largest sources of uncertainties in global and regional climate change. Thus, identifying physical, chemical characterization of dust aerosols and the forcings leading to dust genesis is the first step in understanding the effects of dust aerosols in climate change research [4-6].The mineral dust in Asia exerts great influence on regional air quality, hydrological and energy cycles, and ecosystems [7]. Dust storms may cause a variety of problems. Remarkable reduction in visibility, leading to the limitation of various activities and increasing traffic accidents, is considered the biggest problem [8–11]. Reduction in soil fertility and damage to crops, telecommunications and mechanical systems, dirt, air pollution and an increase in respiratory diseases are considered to have other important environmental impacts [12–14]. Moreover, dust fertilization, which includes the iron and phosphorus of poor nutrient marine environments, can increase the formation of phytoplankton, influencing the global cycle of carbon [15]. Detection of these highly variable aerosol events is challenging because of: episodic features, short life times, multiple-scales, and strong interactions with local surface and meteorological conditions [16]. Dust storms and suspended dust pose serious environmental problems in south-west Asia and natural hazards in the Middle East region. The Middle East is famous for its persistent and severe sand and dust storms, including arid and semi-arid environments, and is most affected in the world, next to Africa, by these phenomena [17]. Saudi Arabia has been recognized as one of five world regions allocated intensive dust storm genesis [18]. In this paper, the study area is the west and southwest of Iran, which consists of Zanjan, Hamdean, Kordestan, Kermanshah, Lorestan, Ilam, Chaharmahal va Bakhtiari, Kohkiloyeh va Boyerahmad, Khoozestan, Bushehr and Fars Provinces. These areas are bound between about 27° N and 37° N and 45° E and 54° E. There are 35 national synoptic meteorological stations with continuous observations in the region. The majority of dust storms affecting the mentioned areas are originated from Iraq, Kuwait, Saudi Arabia, and Syria. In these countries, the climate is dry with very low annual rainfall, except for the northeast of Iraq. The southern part of this region has a desert climate with hot and dry summers and mild winters [19]. In the western regions of the Zagros Mountains, winters can be harsh with frost and heavy snow fall, while the southern part of this region has a desert climate with hot and dry summers and mild winters. Generally, climate conditions in southwestern Iran are identified as semi-arid to semi-humid, leading to experience dust phenomena as one of the major natural hazards in the region. In order to categorize the influence of synoptic systems on dust genesis and its dispersion, GrADS software and NCEP-NCAR (National Centers for Environmental Prediction/ National Center for Atmospheric Research) data were applied to depict the meteorological charts at pressure levels of

the sea surface, 500 hPa and 850 hPa leading to introduce 3 main synoptical patterns. The NCEP/NCAR assimilated data are available from the NOAA website: http://www.esrl.noaa.gov. The categorization was based on the dust intensity, time of occurrence, affected areas and types of pattern revealing the most frequent ones occur in summer. Classification of dust frequency has been undertaken according to visibility reduction, and the relation between seasonal variations of blowing dust activity and strong wind velocity has been evaluated. This study explains the important role of dust frequency long term variability as an index for a more advantageous interpretation of climate change in the region. In this regard, several severe dust phenomena that occurred over Iran during the years 2000-2009 were studied. The results indicate that the prevailing synoptic systems leading to dust genesis in May, June and July are caused by the domination of Saudi Arabian and Pakistani thermal lows and sub-tropical highs in the region. The study confirms that the Shamal dust storm incorporates anticyclones over northern Africa to Eastern Europe and the monsoon trough over Iraq, south of Iran, Pakistan and the Indian subcontinent. The monsoon trough is considered the main low pressure system influencing the formation of devastating dust storms in the region in summer. Shamal dust storms occur across Iraq, Kuwait, and the Arabian Peninsula. They generate a tremendous amount of dust in the atmosphere. Shamal systems produce an impressive satellite image and severely reduce visibility at the surface. The winds travel across central and southern Iraq, picking up most of their dust load from source areas in the southern portion of Iraq between the Tigris and Euphrates Rivers [20].The synoptic feature that creates the potential for the summer shamal is a zone of convergence between the subtropical ridge extending into the northern Arabian Peninsula and Iraq from the Mediterranean Sea, and the Monsoon Trough across southern Iran and the Southern Arabian Peninsula. The pressure pattern tends to be extremely flat across the Arabian Peninsula. The zone of convergence between systems is caught between the pressure systems and the Zagros Mountains of western Iran, the orientation of which tends to force an acceleration of the northerly low-level winds across southeastern Iraq, the western Khuzistan Plains of Iran, Kuwait, and the northern Persian Gulf, and into the northeastern Arabian Peninsula [21]. In the spring pattern of dust event, low pressure systems over the Mediterranean Sea in western Iraq will lead to instability accompanied by the existence of subtropical high in atmospheric mid level over the southwest of the country that play a remarkable role in dust formation. In this pattern, due to the low pressure system over the Mediterranean Sea, instability will be intensified over the deserts of Iraq. The establishment of a Mediterranean low pressure system in the West and South-West of Iran with the effects of subtropical high and wind parameter lead to dust genesis in the area.

Keywords: Dust, Synoptic Patterns, Southwestern Iran

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Understanding climate change and its consequences: a challenge for education

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Abstract

Basic science education (K-9) has been the subject of great attention from the scientific community, including eminent scientists, international organizations and science Academies. Many successful pilot projects emerged worldwide since the 1990s, developing the concept of Inquiry Based Science Education (IBSE). Today, the threat of climate change poses a new challenge to education, in order to prepare the young generations for the profound changes they will have to meet with understanding and responsibility, IBSE has to evolve.

Keywords: Inquiry, Science Education, Sustainable Development, System Complexity

1. INTRODUCTION

In 2004, UNESCO published a report entitled *Science education in dange*r [1]. This warning was not entirely ignored by the scientific community, neither by the responsible authorities in various countries. Already, ten years before this publication, the Nobel laureate in physics, Georges Charpak, had launched in France, then in Europe with many other countries showing interest, a movement to transform the classical pedagogy with which science was taught in primary and middle schools : it was the birth of *La main à la pâte* [2]. An inquiry pedagogy progressively rallied consensus to make students interested in science and happy to practice it, while teachers being helped became more able to convey this vision of science.

In 2015, the global warming of the Earth due to an excess man-produced greenhouse gases, and its possible mitigation, have become an essential part of the political and economic agendas: a world 2°C or 3°C warmer, oceans higher by 1-meter or more, animal species disappearing by tens of thousands, 80 % of the world population living in cities, 1 billion people living in extreme poverty?

Should this future also become part of the education agenda in all nations, both developing and developed? And if so, why and how? Is inquiry pedagogy still the best way to prepare students to their future: These are the questions much too briefly addressed here.

2. THE DEVELOPMENT OF INQUIRY BASED SCIENCE EDUCATION

2.1. The Principles

The principles of an inquiry pedagogy for science basic education (K-9) are quite independent of the detail of a specific curriculum in a given national or local educational system. They have been thoroughly explored and defined in the last two decades [3-6], and can be briefly summarized as follows:

- An active participation of students to the construction of their scientific understanding and knowledge, based on observation, questioning, experiments, hypothesis, argumentation and expression in common language.

- Natural phenomena to observe and simple experiments to carry are proposed by teachers to students.
- Understanding science begins with *small ideas*, and progresses toward *big ideas*, which have a broader explanatory power, introducing more abstraction and quantitative content.

Fig. 1 gives an example of a very successful IBSE lesson, carried in many countries. IBSE pedagogy represents a profound rupture with the classical, more vertical way of teaching elementary science. The main challenge there is to properly prepare teachers, both for primary and middle school. This is a process taking time and requiring to coach the teachers, providing them with support, resources for the class and using distance help with Internet.

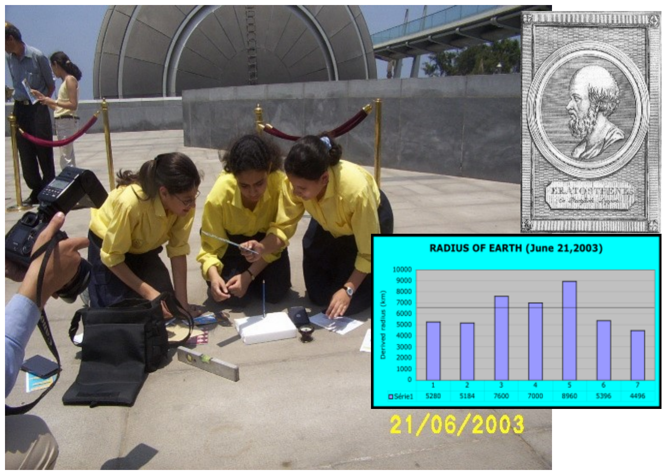

Figure 1: An IBSE lesson. Primary school students repeat the measurement of Eratostenes, on a solstice day, at the Library of Alexandria, and derive the radius of the Earth by coupling their measurements with an other group located in Assouan (from ref. A)

It is worth mentioning here the collaborative efforts undertaken between the French Academy and Iran. After an extensive visit made in 2004 by the author (Fig. 2), several training sessions of teachers were organized in 2005 and 2006 in Teheran, translation of IBSE resources in farsi was undertaken but unfortunately not implemented in schools (to the present knowledge of the author). Yet, Iranian colleagues, including Prof. Tahereh Rastegar from Teheran, attended several of the yearly International Seminar organized by *La main à la pâte* in Paris since 2009. In 2015 Iran participated to an ECO-Science Foundation Workshop on science education in Kazakhstan. An International Conference on science education was held in Kish Island (Iran) in 2010, but the present author could not find reference to its achievements.

Figure 2: Transit of the planet Venus in front of the Sun, at Maragheh Observatory, near Tabriz. Over 1500 students gathered to observe this event at the initiative of the French Embassy and the Ministry of education of Iran (Photograph by P. Léna)

2.2. The Achievements

After 20 years of intense international collaborations, IBSE pilot projects have been developed in a great number of countries – probably close to 100 –, both developed, emerging and developing. The basic principles are now well understood and implemented in these projects, while their size can vary from a few schools to a significant fraction of schools in a whole country. The projects have more covered primary than middle schools. Yet, curricula do not generally implement IBSE as a rule, given the slow penetration of IBSE concepts into education authorities and the lack of large scale teacher training, which is costly and time consuming. Overviews of international developments can be found in [7,8].

2.3. The Role of Scientists

Wherever IBSE has penetrated significantly an education system and produced significant results in term of student motivation, knowledge acquisition and teachers' changes appears strongly related to the involvement of the scientific community alongside the education authorities and the teachers: high repute scientists, science Academies, researchers and engineers convey the spirit of science, the understanding of its process, the sense of experimenting and discovery (Fig. 3).

Figure 3: A gallery of high-repute scientists who played a decisive role in their country, their region or even worldwide to develop IBSE principles, practice and research. Charpak, Lederman, Lee and Molina have received the Nobel prize for physics or chemistry. Wei Yu has been vice minister of education in China. Alberts, a molecular biologist, has been president of the National Academy of Sciences. Hahne has created the African Institute for Mathematical Sciences network. Samroo is president of the ECO-Science Foundation for Central Asia countries and has developed science education in Pakistan.

3. Does Climate Change Imply Changes in Science Education?

The main goal of IBSE is to introduce the students to the beauty of natural sciences, to develop their abilities to observe and to reason. Doing so, they become able to progressively construct a creative, rational and critical mind, which will help them to tackle with the situations they will encounter in their daily life, either personal, professional or social. But today and in the decades to come, humans are and will be confronted with new and very difficult issues, related to global warming, loss of biodiversity, energy crisis. Global warming and climate change will shape the next 50 years, implying profound and vital changes in economy, way of life, consumption of resources, migrations, megapoles, etc. It is unlikely that these changes can happen without a general adhesion of the people themselves. Therefore, one may doubt whether this adhesion will be possible if education does not prepare the young generation for a new set of mind, including indeed some understanding of science and technology, but also moral virtues of solidarity and frugality. Can the school carry these? Can IBSE pedagogy alone suffice? These are profound questions, requiring a much deeper analysis than this short abstract [9-11].

3.1. A New Responsibility for Schools

If one expects that the whole population needs to act and cooperate for implementing the needed changes, in developed as well as in developing countries, school has to change. *Business as usual* is no longer possible, as often claimed, neither *school as usual*. Climate, biodiversity, epidemics, agrcultural changes are all related in a complex manner. Dealing with them implies a systemic approach. Complex systems, implying many variables, multiple scales, non-linearities, phase transitions and instablities are more difficult to describe, to modelize and understand, to predict and to modify than the more simple situations currently encountered when teaching physics, chemistry, geology, biology (Fig. 4). Analytical methods, as encountered in specialised disciplinary fields, are no longer sufficient to treat such systems. Implementing, with IBSE method and pedagogy, a practice of interdisciplinarity, an understanding of complexity is a real challenge for the current education curricula. Adding to these scientific aspects a moral, or rather ethical dimension, is even more challenging, as the goal is indeed not to “format“ the mind of the students with ideology or ready-to-wear opinions, but to make them knowledgeable and responsible persons.

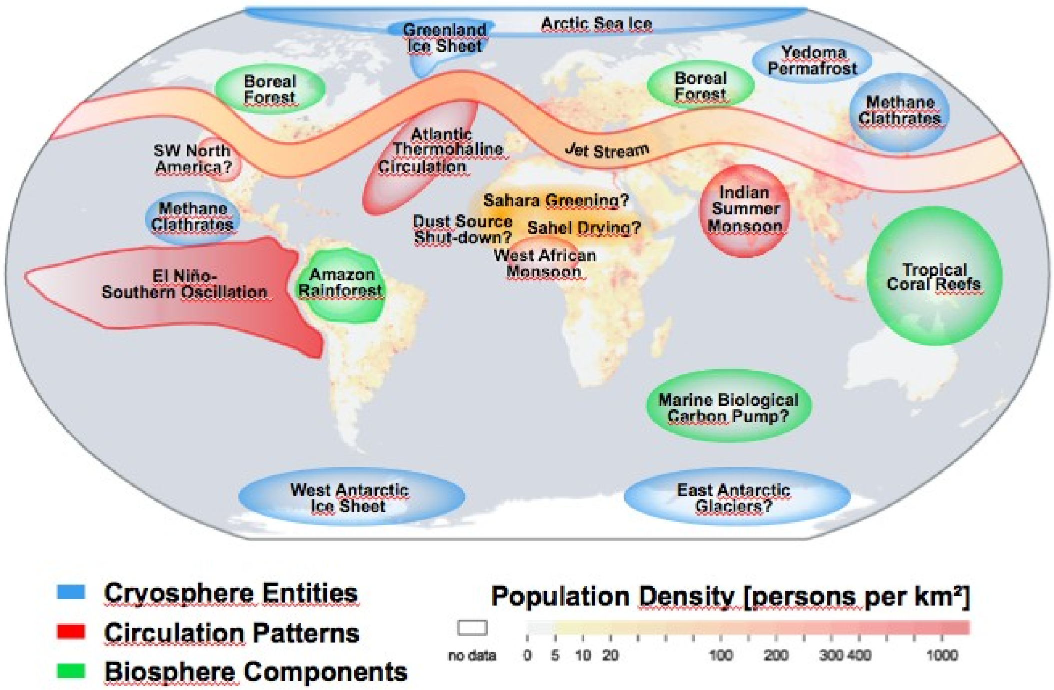

Figure 4: Some aspects of the Earth climatic system. This represents the various kinds of local instabilities which global warming may trigger in the future, at different scales, depending of the average temperature rise. After Lenton et al (2008), quoted by Schellnhuber & Martin [13] (2014)

3.2. Examples of Implementation

La main à la pâte has attempted to address this when exploring the themes of climate change and global warming, proposing to teachers (primary and middle schools) resources for the classroom, which *a)* are entirely consistent with an IBSE pedagogy and *b)* attempt to introduce interdisciplinary and some understanding of complexity (Fig. 5). An example is given on Fig.6, where ten year old students explore solar energy to heat water. This sequence has been practiced by over 250 000 thousand students of Grade 4 and 5 in France, over the four last years. Another example, relative to natural disasters, is given in Fig. 7. We are still far from introducing adequately the ethical dimensions in such resources.

Figure 5: Classroom resources produced for teachers by La main à la pâte in France [A]. Each includes scientific knowledge for the teacher, detailed implementation in the class, including experiments, and pedagogical analysis of the progression of the students. Subjects of these modules are all related to climate change and related issues of sustainable development (energy, biodiversity, fishing, housing). Some of these modules are also published in English

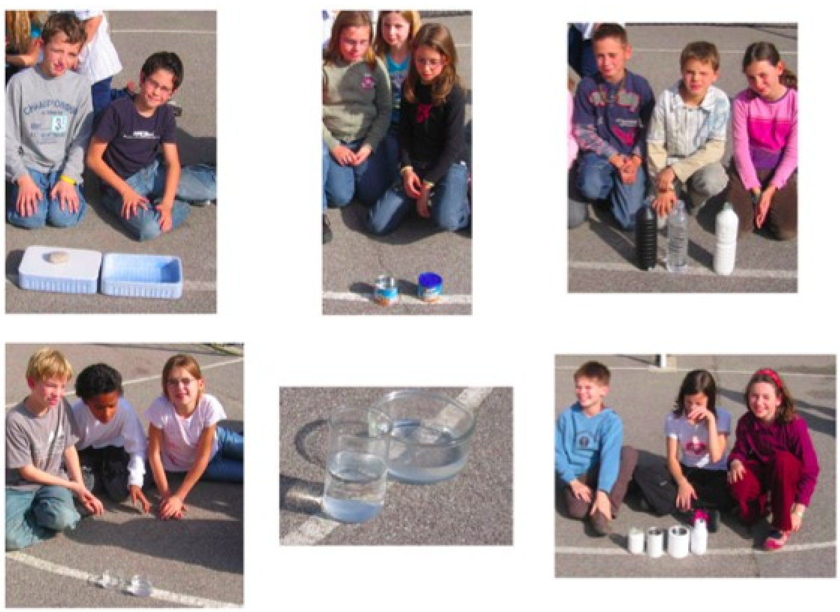

Figure 6: IBSE practice on energy .Ten years old students investigate various parameters to heat water with solar energy : insulation/ conductive material ; open/closed container ; light/dark coloured surface ; orientation ; compactness, etc. Ultimately, they will combine the parameters to make a solar heater. (From Ref. 9)

Figure 7: Natural disasters and extreme events are one of the consequence of climate change, and must be explored with a systemic and interdisciplinary approach. The resource When the Earth rumbles (here in English) has been developed by La main à la pâte in the same spirit as the previous resources. Here the students explore the resonance phenomena and the reinforcement of walls by bracing the material [9]

3.3. A Series of New Questions

As it appears slowly but progressively that global warming and its consequences, at various scales and in many aspects of human life, begin to be taken seriously by the economic and political world (cf. Paris COP21 Conference and the limited, but real progress achieved there), education and school systems will not avoid to address its responsibility. In fact the motto "educating for sustainable development" is already claimed. It remains to be seen what is the best way to implementation. Curricula in France, with the K-9 reform of 2015, or in Taiwan with its K-12 reform for 2017, are exploring how science education should evolve to best prepare the children to the world they will have to live in. Let mention here the notion of *Big Ideas*, born in the United States in 2001 with the *Project 2061*. It is an attempt to define a limited (about ten) ideas *about* science, for K-9 education, which progressively encompass a broader group of phenomena. These *big ideas* are more abstract, more powerful to explain and provide adequate models [12]. In addition, they include a few ideas *on* science, which allow to examine how science proceeds (i.e. the nature of science) and how it is (or not) related to human activities and ethics.

So, the new school will have to intertwine ethics with science, and to find how to assess the new skills required from students – this implying some drastic changes from the usual examination system.

4. CONCLUSION

After twenty years of exploration and experiments, the inquiry pedagogy for science education seems to have reached a good level of understanding, enriched practices and evaluation. The new challenges that the world is facing can be perceived on local scale by the students (for example drought, extreme events, loss of biodiversity), but require global actions, which also need to be understood. Preparing the schools, hence the teachers and the curricula, becomes a necessity, and this implies IBSE to evolve. Some of the perspectives of the future may seem grim, but one should not doubt of the extraordinary capability of the youth, if properly educated by families, schools and communities, to prepare this future with energy and hope.

Acknowledgement

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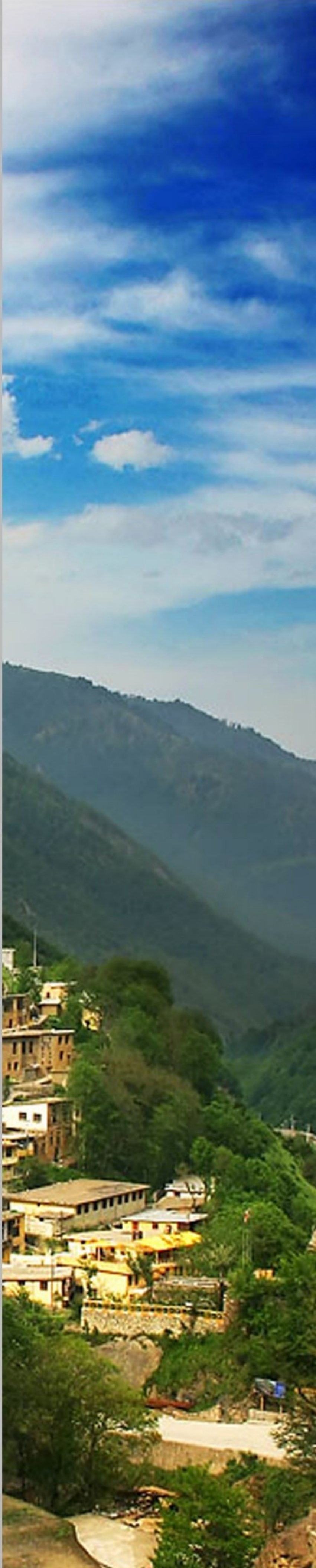

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