CLIMATE CHANGE PROJECTION AND DROUGHT CHARACTERIZATION IN BANGLADESH

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While most are dream about success, winner wake up and work hard to achieve it

To Beloved Our Mother

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ABSTRACT

One of the biggest threats of the climatic change is aberrant pattern or distribution of rainfall that results to drought. The main objective of this research was to develop a methodological framework to assess the impacts of climate change on seasonal drought characteristics with uncertainty. Bangladesh, one of the most vulnerable countries in the world to climate change was considered as the study area for implementation of the framework. An ensemble of general circulation models (GCMs) of Coupled Model Intercomparison Project phase 5 (CMIP5) were used for downscaling and projection of rainfall and temperature under different Representative Concentration Pathways (RCP) scenarios. Two state of art data mining approaches known as Random Forest (RF) and Support Vector Machine (SVM) were used for the development of downscaling models and Quantile Mapping (QM) approach was used to remove biases in GCMs. The observed and future projected rainfall data were used to characterize the seasonal droughts using Severity-Area-Frequency (SAF) curves developed for different climatic and major crop growing seasons. The results revealed superior performance of SVM in downscaling rainfall and temperature in tropical climate in terms of all standard statistics. Downscaling of CMIP5 GCMs projections revealed a change in annual average rainfall in Bangladesh in the range of -8.6% in the northeast to +11.9% in the northwest, which indicates that spatial distribution of rainfall of Bangladesh will be more homogeneous in future. The maximum and minimum temperatures of Bangladesh were projected to increase in the range of 0.8 to 4.3ºC and 1.0 to 4.8ºC, respectively under different RCPs. Future projection of droughts revealed that affected areas will increase for higher severity and higher return period droughts. Overall, the country will be more affected by higher return period Kharif (May-October) and monsoon droughts, and lower return period pre-monsoon and post-monsoon droughts due to climate change.

ABSTRAK

Satu daripada ancaman perubahan iklim ialah corak yang tidak menemtu atau distribusi hujan yang mengakibatkan kemarau. Objektif utama kajian ini adalah untuk membangunkan satu rangka kerja metodologi untuk menilai kesan perubahan iklim ke atas ketidakpastian ciri-ciri musim kemarau. Bangladesh adalah salah satu negara yang paling terdedah di dunia dengan perubahan iklim telah dipertimbangkan sebagai kawasan kajian bagi pelaksanaan rangka kerja ini. Kombinasi General Circulation Models (GCMs) dari Coupled Model Intercomparison Project Phase 5 (CMIP5) telah digunakan untuk penskalaan dan unjuran hujan serta suhu di bawah senario Representative Concentration Pathways (RCP). Dua pendekatan pemeriksaan data yang berbeza dikenali sebagai Random Forest (RF) dan Support Vector Machine (SVM) telah digunapakai untuk pembangunan model penskalaan manakala pendekatan Quantile Mapping (QM) telah digunakan untuk menghilangkan berat sebelah di dalam GCMs. Data hujan yang direkodkan dan diunjurkan digunakan untuk menentukan ciri-ciri musim kemarau menggunakan lengkung Severity-Area-Frequency (SAF) yang dibangunkan untuk iklim dan musim pertumbuhan tanaman utama yang berbeza. Hasil kajian menunjukkan prestasi SVM adalah yang terbaik dalam penskalaan hujan dan suhu dalam persekitaran iklim tropika dari segi semua piawaian statistik. Unjuran penskalaan CMIP5 GCMs mendedahkan perubahan purata hujan tahunan di Bangladesh adalah dalam julat -8.6% di timur laut hingga +11.9% di barat laut, yang menunjukkan bahawa taburan hujan Bangladesh akan lebih homogen pada masa depan. Suhu maksimum dan minimum di Bangladesh diunjurkan meningkat masing-masing dalam julat 0.8 hingga 4.3ºC dan 1.0 hingga 4.8ºC. Pengunjuran kemarau pada masa depan menunjukkan bahawa kemarau kawasan yang terjejas akan meningkat pada paras melampau dan pada tempoh kala kembali yang lebih tinggi. Secara keseluruhan, negara ini akan lebih dipengaruhi oleh tempoh kala kembali Kharif (Mei-Oktober) dan kemarau monsun yang lebih tinggi, dan pengurangan kala kembali pra-monsun dan selepas musim monsun kemarau disebabkan oleh perubahan iklim.

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LIST OF ABBREVIATION

AMS	-	Annual Maximum Series
ANN	-	Artificial Neural Network
AR5	-	Fifth Assessment Report
BB	-	Bayesian Bootstrap
CF	-	Change Factor
CMIP5	-	Coupled Model Intercomparison Project Phase 5
CRU	-	Climatic Research Unit
EM	-	Expectation-maximization
GCM	-	General Circulation Model
GIS	-	Geographical Information System
IPCC	-	The Intergovernmental Panel on Climate Change
K-S	-	Kolmogorov–Smirnov
MBE	-	Mean Bias Error
Md	-	Modified Index of Agreement
NCEP	-	National Centers for Environmental Prediction
NSE	-	Nash-Sutcliffe Efficiency
PDF	-	Probability Distribution Function
QM	-	Quantile Mapping
R^2	-	Coefficient of Determination
RCM	-	Regional Climate Model
RCPs	-	Representative Concentration Pathways
RF	-	Random Forest
RMSE	-	Root Mean Square Error
SAF	-	Severity- Area- Frequency
SDSM	-	Statistical Downscaling Model
SNHT	-	Standard Normal Homogeneity Test
SPI	-	Standardized Precipitation Index
SVM	-	Support Vector Machine
WMO	-	World Meteorological Organization

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CHAPTER 1

INTRODUCTION

1.1 Background

Climate change due to global warming is the most serious environmental challenge the world facing today (Trenberth et al., 2014, Wang et al., 2016a, Shahid et al., 2016). Increased temperature due to global warming has enhanced evapotranspiration and atmospheric water storage and thereby intensified the hydrological cycle. This eventually has changed the magnitudes, frequencies and intensities of rainfall as well as its spatio-temporal distribution (Scherer and Diffenbaugh, 2014, Wang et al., 2015, Diffenbaugh et al., 2015, Wang et al., 2016b, Swain et al., 2016). Ecology near to tropics is sensitive even to insignificant changes in climatic characteristics (Chase et al., 2000, Wassmann et al., 2009, IPCC 2014). Therefore, tropical and sub-tropical regions are considered as more susceptible to climate change (Liu et al., 2009; Mishra and Lui, 2014). The changes in climate are already found significant in many tropical countries (Shahid, 2011; Shahid, 2012; Mayowa et al., 2015). Number of studies suggested severe implications of these changes in different sectors particularly agriculture and economy in tropical regions (Fernandez-Gimenez, 2012, Shahid et al., 2016; Khalyani et al., 2016, Beniston, 2016).

More frequent and severe hydrological disasters are one of the primary impacts of global climate change (Favre et al., 2004, McMichael et al., 2006, Oki and Kanae, 2006, Wagener et al., 2010, Lopes et al., 2016). Small changes in mean and variability in climate can cause significant changes in extreme events (Easterling, 2000, Tilman et al., 2001, Schuur et al., 2008, Watanabe, 2010, Seinfeld and Pandis, 2016). Therefore, changes in rainfall distribution due to global climate change may cause frequent droughts and floods. Number of studies suggests an increasing trend in drought frequency and intensity in recent decades across the world (Dulamsuren et al., 2010, Dai, 2011a, Dai, 2011b, Ahmed et al., 2016). Dai (2011a) reported that the percentage of global dry areas increased by about 1.74% per decade during 1950-2008. The major increase in dry areas has been found over Africa, East Asia and South Asia. Increasing frequency and severity of droughts has severely affected the agriculture, people's livelihood and national economy in many of these regions (Zahid and Rasul, 2012, Wang et al., 2013, Liu and Hwang, 2015). Intergovernmental Panel on Climate Change (IPCC, 2007) reported that increased water stress attributed to a combination of increasing temperatures and dry spells has caused declination of food grain production in many Asian countries in recent decades (Bates et al., 2008). It has been projected by most of the climate models that the frequency and severity of droughts will continue to increase in the forthcoming years (Dai, 2011b, Nam et al., 2015, Touma et al., 2015). This can have a devastating effect on the livelihood and economic activities in developing countries, if necessary measures are not taken (Osbahr et al., 2008, Ahmed et al., 2016).

1.2 Problem Statement

Increasing frequency and intensity of droughts caused by global warming will certainly exacerbate the condition of water stress in the coming years (Halim, 2010, OECD, 2012, Kim and Chung, 2012, Wang et al., 2014). About one-third of the global population are living under water stress at present which is projected to reach 52% by 2050 (IFPRI, 2012, Wang et al., 2016a). Therefore, understanding possible future changes in the climate and their impacts on droughts is essential for adaptation and mitigation planning (Pahl-Wostl C., 2007; Batisani and Yarnal, 2010, Shahid et al., 2016).

The destructive droughts do not coincide with severe droughts if they do not occur during the crop growing season (Rahman, and Rahman, 2009; Mishra and Cherkauer, 2010) and therefore, characterization of seasonal droughts, particularly the droughts during crop growing seasons is highly required. For future projection of droughts, coarse resolution general circulation model (GCM) projections of climate are downscaled at local scale mostly using statistical downscaling methods (Wilby and Wigley, 1997, Widmann et al., 2003, Dibike and Coulibaly, 2006, Chen et al., 2012). However, the relations between local climate and large-scale circulation parameters in tropical region are highly non-linear and often ambiguous (Masiokas et al., 2006, Tabor and Williams, 2010, Ahmed et al., 2015). This has made statistical downscaling of climate in tropical region an extremely difficult task (Wilby and Wigley, 1997, Wang an Swail, 2001, Maraun et al., 2010, Pour et al., 2014, Seinfeld and Pandis, 2016) and emphasizes the need of development of sophisticated downscaling models. Furthermore, the downscaled climate projections are highly uncertain (Braga et al., 2013, Zhang and Huang, 2013, Schnorbus and Cannon, 2014, Shashikanth et al., 2014, Rashid et al., 2015) and therefore, quantification of the uncertainty in future drought characteristics is required for adaptation and mitigation planning.

1.3 Objectives of the Study

The major objective of this research is to develop a methodological framework for the assessment of the impacts of climate change on seasonal droughts characteristics with associated uncertainty. The specific objectives of the research are:

i. To develop statistical downscaling models for reliable downscaling and projections of climate in Bangladesh.

ii. To assess the spatial and temporal changes in climate under different climate change scenarios using ensemble of general circulation models.

iii. To characterize the seasonal meteorological droughts through the analysis of frequency distribution of drought index during different climatic and crop growing seasons.

iv. To assess the future changes in drought characteristics with uncertainty under different climate change scenarios.

1.4 Scope of Study

A methodological framework is developed in this study to assess the impacts of climate change on seasonal droughts characteristics with associated uncertainty. Bangladesh is used as the study area to implement the framework. Therefore, the historical seasonal droughts of Bangladesh are characterized, climate at different meteorological stations of Bangladesh are downscaled and projected, and possible future changes in drought characteristics of Bangladesh along with associated uncertainty is assessed with the framework developed in this study.

Bangladesh has four major climatic and two crop growing seasons. Therefore, historical seasonal droughts are characterized only for those six seasons. Numerous indices have been proposed in literature for characterization of droughts. A rainfall based index which can characterize the severity and frequency of droughts with various temporal scales is used is this study.

Though numbers of GCMs are available, nevertheless nineteen GCMs are used in this study for the projection of rainfall and eight GCMs are used for the projection of temperature. The GCMs are used to project future rainfall under three representative concentration pathway (RCP) scenarios and temperature for four RCPs. The GCMs and RCP scenarios are selected based on the availability of data by the GCMs for the RCP scenarios in Bangladesh.

Various linear and non-linear methods have been proposed for downscaling precipitation and temperature. In the present study, two robust state of art data mining methods are compared to find the best method for downscaling climate in tropical region.

Various parametric methods that assume a normal distribution of data and non-parametric methods that can handle any distribution of data have been suggested for assessment of model performance. In the present study, mostly non-parametric methods are used for evaluation of model performance and analysis of uncertainty considering that climatic data follows non-normal distribution.

1.5 Significance of the Study

This study attempted to develop a framework to facilitate the assessment of future changes in drought characteristics due to climate change. The novelty of the research lies in robustness of the developed framework in reduction of uncertainty in downscaled climate and ability to project future changes in drought characteristics during different crop growing seasons with credible uncertainty interval.

Uncertainty in downscaled climate adds uncertainties in impacts. Consequently, development and planning activities based on projected climate suffer from high risk of failure. It is expected that the use of several GCMs, and statistical downscaling scheme based on two sophisticated models will reduce uncertainty in downscaled climate.

Most of the drought indices characterize droughts generally without giving any indication of drought risk during different seasons or cropping periods. A methodology is proposed for easy assessment of droughts during different cropping seasons from only rainfall data. It can help in assessment of drought risk to crops as well as agricultural and water resources development and planning.

According to Climate Change Vulnerability Index (CCVI, 2011), Bangladesh is one of the most vulnerable countries to climate change. However, very little information on possible changes of climate and their impacts on droughts are available for Bangladesh. Drought is considered economically costlier to other natural hazards in Bangladesh. Therefore, information generated in the present study will help in climate change adaptation and mitigation planning of this highly vulnerable country of the world.

1.6 Thesis Outline

This thesis is divided into six chapters. Descriptions of the chapters are given below in brief.

Chapter 1 gives a general introduction of the study including background of the study, problem statements, research objectives as well as the scopes and significance of the study.

Chapter 2 provides a general review of relevant literature of previous studies on climate modeling, downscaling of GCM outputs, drought characterization, climate change, and uncertainty in climate projections.

Chapter 3 presents the methods used in the study. The methodological framework developed in the study is described in details which includes climate downscaling and projection, characterization of seasonal droughts, assessment of future changes in seasonal drought characteristics, performance evaluation and uncertainty analysis. Furthermore, the chapter describes the study area and the data used for the study.

Chapter 4 and 5 present the results obtained from the study. Chapter 4 presents the results of climate downscaling and projections, while Chapter 5 presents the results of seasonal drought characterization and possible future changes in drought characteristics with uncertainty.

Chapter 6 gives the conclusions made from the results presented in Chapters 4 and 5. The future research that can be envisaged from the present study is also given in this chapter.

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