SPATIAL AND TEMPORAL MODELING OF REGIONAL GROUNDWATER LEVEL IN CONTEXT OF CLIMATE CHANGE

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Specially dedicated to my parents, wife and daughter, for their love and support

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ABSTRCT

The accurate prediction of groundwater resources as the sole source of drinking and irrigation based agriculture in the northwestern part of Bangladesh is important for the sustainable use and management of this already stressed precious resource**.**Groundwater level data collected from 130 sites across 25 Upazilas (sub-district) of three northwest districts of Bangladesh were used in this study to access the impacts of climate change on groundwater resources in the region. Several geostatistical and determistic interpolation methods as well as data mining techniques such as, Support Vector Machines (SVM) and Artificial Neural Network (ANN) were investigated for spatial and temporal modeling of groundwater level. The study revealed that co-kriging gives the best estimation of spatial distribution of water table when soil infiltration information is provided. On the other hand, Artificial Neural Network (ANN) was found to model groundwater table fluctuation more accurately compared to other data mining approaches. Therefore, ANN was used to project the changes in groundwater level under projected climate data obtained through statistical downscaling of global circulation model outputs. Groundwater drought situations during base year and under projected climate were investigated using the Cumulative Deficit approach in a geographical information system. The study revealed that groundwater scarcity in at least 27% of the study area will be an every year phenomenon in the region due to climate change. Analysis of climate change and groundwater hydrographs reveals that no appreciable change in precipitation, but increases in temperature as well as increase in groundwater extraction for irrigation in the dry season are the causes of groundwater scarcity in the region.

ABSTRAK

Ramalan tepat sumber air bawah tanah sebagai sumber tunggal minum dan pertanian berasaskan pengairan di bahagian utara-barat Bangladesh adalah penting untuk penggunaan berterusan dan pengurusan yang telah menegaskan sumber air bawah tanah. Data jadual air bawah tanah harian yang dikumpul daripada 130 tapak, di seluruh 25 Upazilas (sub-daerah) di tiga daerah di barat laut Bangladesh telah digunakan dalam kajian ini. Beberapa kaedah interpolasi geostatistik dan determistic didapati dalam “Geographic and Information System” (GIS) dan teknik perlombongan data seperti, “Support Vector Machines” (SVM) dan “Artificial Neural Network” (ANN) telah disiasat untuk pemodelan ruang dan masa paras air bawah tanah. Kajian ini mendedahkan bahawa bersama 'kriging' memberikan anggaran terbaik taburan spatial aras air apabila maklumat penyusupan tanah disediakan. Sebaliknya, “Artificial Neural Network” (ANN) didapati memodelkan air bawah tanah turun naik jadual dengan lebih tepat melaui tempoh kalibrasi dan validasi. Oleh itu, ANN telah digunakan untuk projek perubahan dalam jadual air bawah tanah di bawah data iklim dijangka diperolehi melalui “Statistical Downscaling”. Keadaan air bawah tanah ketika kemarau dalam tahun asas dan bawah iklim diunjurkan telah disiasat menggunakan pendekatan “Cumulative Deficit”. Kajian ini menunjukkan bahawa kekurangan air bawah tanah dalam sekurang-kurangnya 27% daripada kawasan kajian akan menjadi satu fenomena setiap tahun di rantau ini. Analisis perubahan iklim dan air bawah tanah hidrograf mendedahkan bahawa kekurangan dalam hujan dan kenaikan suhu dan juga peningkatan dalam pengekstrakan air bawah tanah untuk pengairan pada musim kemarau yang menyebabkan penurunan paras air bawah tanah di rantau ini

TABLE OF CONTENTS

LIST OF TABALES

LIST OF FIGURES

LIST OF ABBREVIATION

ANN	-	Automated Neural Network
CET	-	Crop Evapotranspiration
CD	-	Cumulative Deficit
ET	-	Evapotranspiration
Eq.	-	Equation
GIS	-	Geographic Information System
GPI	-	Global Polynomial Interpolation
GWT	-	Groundwater Table
GWL	-	Groundwater Level
IDW	-	Inverse Distance Weighted
IWM	-	Irrigation Water Demand
LPI	-	Local Polynomial Interpolation
MPL	-	Multilayer Perceptron
MLR	-	Multiple Linear Regressions
PET	-	Potential Evapotranspiration
PMML	-	Predictive Model Mark-Up Language
RBF	-	Radial Basis Function
RMSE	-	Root Mean Square Error
RPDM	-	Rapid Deployment of Predictive Models
SVM	-	Support Vector Machines

LIST OF SYMBOLS

%	-	Percent
k°	-	Kelvin
°C	-	Centigrade
g	-	Gram
m^2	-	Square meter
ml	-	Milliliter
m	-	Meter
min	-	Minute
T_m	-	Daily Mean Air Temperature
$T_{\max}$	-	Daily Maximum Air Temperature
$T_{\min}$	-	Daily Minimum Air Temperature
R_a	-	Extra-terrestrial Radiation

CHAPTER 1

INTRODUCTION

1.1 Background of study

Agriculture is one of the most important sectors of Bangladesh's economy in which about 84% of the 145 million people of country are directly or indirectly engaged in a wide range of agricultural activities (Rahman, 2004). Groundwater is the main source of irrigated agriculture in Bangladesh. Groundwater use in irrigation has increased both in absolute terms and in percentage of total irrigation due population growth, which is growing by two million every year and projected to increase by another 24 million over the next 12 years (Bangladesh Bureau of Statistics 2003). Therefore, groundwater has emerged as an important factor for food security and poverty alleviation in Bangladesh in recent years (Shahid and Hazariak, 2010). At the same time, stress on groundwater of Bangladesh is increasing to meet the demand of growing population for sufficient food and water as a basic requirement to improve livelihood.

In the context of climate change, Bangladesh is one of the most vulnerable countries in the world (Intergovernmental Panel on Climate Change, 2007). Hydrologic changes are the most significant potential impacts of global climate change in Bangladesh (Organization for Economic Co-operation and Development, 2003). Due to climate change, it has been predicted that there will be a steady increase in temperature and change in rainfall pattern in Bangladesh (Intergovernmental Panel on Climate Change, 2007). These will results to higher evapotranspiration due to temperature rise, which will demand higher amount of water for irrigation. At the same time, the higher temperature will change the crop

physiology and shorten the crop growth period, which in turn will reduce the irrigation days. These contradictory phenomena will change the total irrigation water demand, which is required to quantify for long-term water resources planning and management. A study has been carried out in this research to predict thegroundwater table fluctuation under projected climate over the time period 2010-2089 as well as to investigate the changing scenarios of groundwater scarcity and drought risk in the context of climate change.

1.2 Problem Statement

Northwest part of Bangladesh is one of the most vulnerable regions in the country due to high climate variability. Droughts and water scarcity are common phenomena in the region (Shahid 2008; Shahid and Behrawan, 2008). History shows that in last 40 years the area was suffered eight droughts of major magnitude (Paul, 1998). From 1980–2000, groundwater irrigation coverage rose from 6% to 75% in Bangladesh (BADC, 2002). The overexploitation of groundwater resources in the area has caused the groundwater level to falls to the extent of not getting fully replenished in the recharge season. This causes a prolonged absence of groundwater within the range of shallow tube wells, particularly during dry season, which is a very serious problem for the groundwater-based irrigation system in the area (Shahid et al, 2010).

A number of research works have been carried out on the hydrogeology of the region (Ahmed and Burgess, 1995; Begum et al., 1997; Islam and Kanungoe, 2005), such as, groundwater occurrence potentials (Haqueet.al. 2000; Azad and Bashar, 2000), groundwater dynamics (Shwets et al., 1995; Jahan and Ahmed, 1997; Rahman and Shahid, 2004), etc. Shahid and Hazarika (2010) investigated the causes of groundwater level declination and droughts of the study area. However, no study has been carried out so far to assess the possible changes ingroundwater table, groundwater scarcity and drought in the context of changing environment, though it is very crucial for the sustainable utilization and management of this vital resource. In this research, the spatial and temporal variations of groundwater level in the

northwest districts of Bangladesh in the context of climate change were investigated using various statistical and soft computing techniques. The cumulative deficit approach was used to compute the changes in the severity of the groundwater droughts over the period 2010 to 2090. It is expected that the study will help local water resource management and agricultural organizations as well as the development/planning authorities to implement new reforms of sustainable water resources management in the region.

1.3 Objectives of the Study

The major objective of the present study is to understand the impacts of climate change on groundwater resources in northwest districts of Bangladesh. The specific objectives are:

i. To compare various data mining, deterministic and geo-statistical interpolation methods in order to identify the most suitable method for predicting the spatio-temporal variations of groundwater depths
ii. To use cumulative deficit approach and the best interpolation method to map the status of groundwater drought/scarcity in the area
iii. To predict the groundwater table fluctuations and drought potential in the study area in the context of climate change using climate downscale outputs and suitable interpolation methods.

1.4 Scope of the study

The scopes of the study are:

i. The study was conducted in three northwestern district of Bangladesh.
ii. Available data of groundwater, rainfall and geological information were used for the study.

iii. Data mining techniques were used to predict the regional groundwater table fluctuations in the study area for the period 2010 to 2089 from downscaled climate projection.

iv. Groundwater drought in the study area was modeled for the projected duration of this study using the cumulative deficit approach.

v. The severity of the groundwater droughts were estimated from a threshold groundwater level of 5%, 20% and 30%.

vi. Geographical information system (GIS) was used for the interpretation of the hydro-geological information, preparation of drought potential maps and assessment of groundwater condition of the study area.

1.5 Significance of the Study

Drought is one of the most frequent natural disasters in Bangladesh (Shahid and Hazarika, (2011). Despite its recurrent and devastating nature, it has attracted far less scientific attention in the world than floods or cyclones. Due to climate and land use changes within the country, Bangladesh has already shown an increased frequency of droughts in recent years. It is expected that climate change due to global warming will further aggravate the situation in near future. In northwestern part of Bangladesh, Droughts are recurrent phenomena which may although occur at any time of the year, therefore complete analysis of drought requires study of its spatial and temporal extents. The impact of droughts during the pre-monsoon period is more severe in the northwestern districts of Bangladesh. The country has suffered from nine droughts of major magnitude since independence in 1971 (Paul, 1998). The impact of droughts was higher in the northwestern part of the country compared to other parts. In recent decades, the hydro-climatic environment of area has been aggravated by environmental degradation and cross-country anthropogenic interventions (Banglapedia, 2003). Scientists have become increasingly concerned about the frequent occurrence of drought in the northwestern districts of Bangladesh. Thus, this study becomes very important because the output may be used to plan for mitigation measures to ensure the effectiveness on utilization and management of the groundwater resource in the study area.

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