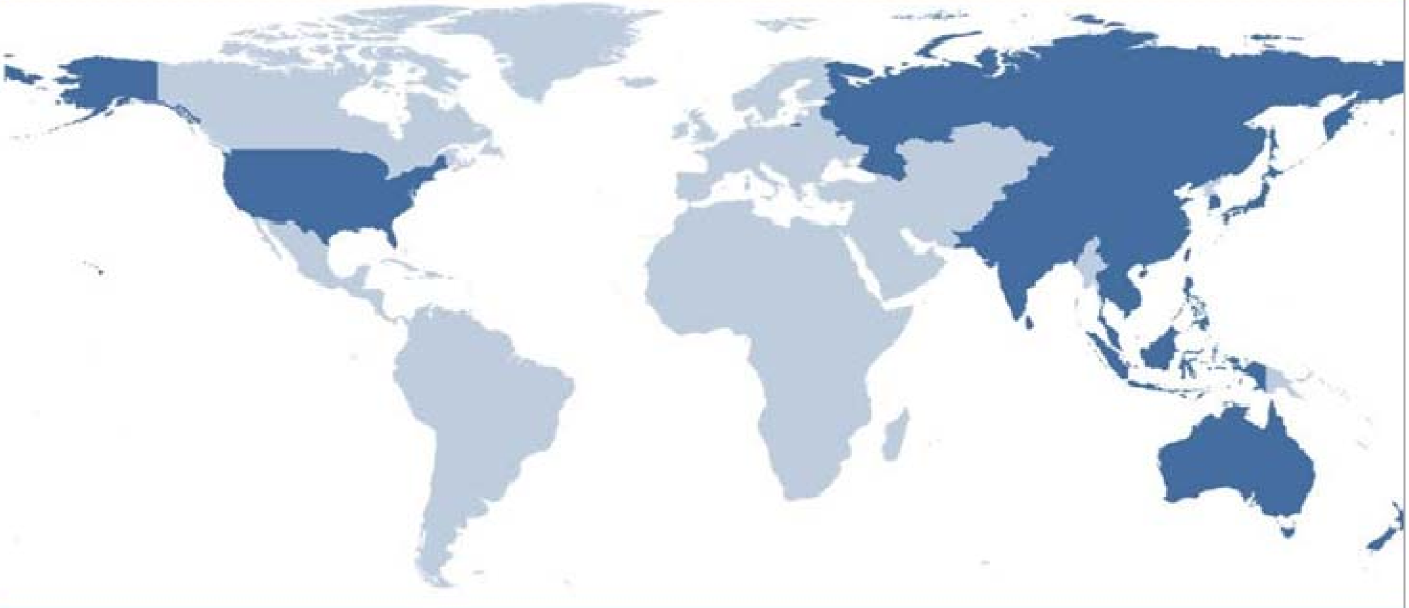
ASIA-PACIFIC NETWORK FOR
GLOBAL CHANGE RESEARCH

Project Reference Number: ARCP2013-25NSY-Shahid

Climate Change Vulnerability and Adaptation in Groundwater-dependent Irrigation System in Asia-Pacific Region



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Final Report Submitted to APN

Part One: Overview of Project Work and Outcomes

Non-Technical Summary

Many Asian countries are among the highest users of groundwater for irrigation in the world. Groundwater uses in irrigation is still increasing both in absolute terms and in percentage of total irrigation, especially in densely populated Asian countries. As the agriculture sector contributes a major portion of GDP and total employment generation, groundwater is considered as a major component of food security and poverty alleviation in many of those countries. Despite huge significance, groundwater based irrigation is heading for a crisis in many Asian countries and needs urgent understanding and attention. Rapid expansion of groundwater based irrigated agriculture to feed the growing population and inappropriate irrigation practices have caused overexploitation of groundwater in India, China, Pakistan and Bangladesh at an alarming rate. It is anticipated that climate change will pose another major threat to groundwater based irrigation system in near future. Increasing shortage of groundwater resources due to climate change and ever increasing consumption in agriculture could undermine the irrigation-based economy in many regions if adequate countermeasures are not taken. The goal of the project was to develop a long term regional cooperation among South, Southeast, and East Asian countries to exchange knowledge of the impacts of climate change and increasing consumption on groundwater resources as well as adaptation measures in order to achieve sustainability in groundwater based irrigation system. The project was successful to provide a knowledge-base about climate change impacts and adaptation to groundwater-dependent irrigation system.

Keywords

Climate change, groundwater dependent irrigation, groundwater level drop, Irrigation demand, adaptation

Objectives

The major objective of the collaborative research project was to foster regional cooperation to improve knowledge of the impacts of climate change and unsustainable human interventions on groundwater based irrigation system for formulating adaptation measures in order to achieve sustainability and improve the livelihood of the people of Asia.

Amount Received and Number of Years Supported

The Grant awarded to this project was:

US $ 40,000 for one and half years: to technical assistance for scientific meeting and policy workshop, and development of simulation tool.

Activity Undertaken

- ✓ Arrangement of two workshops, one for development of regional cooperation among the scientists working on groundwater dependent irrigation system in South, Southeast, and East Asian countries, and another for analysis of results and identification of suitable adaptation measures.
- ✓ Secondary data collection and analysis to measure the impacts of climate change on groundwater-based irrigation using existing tools
- ✓ Development of a tool to simulate the changes in groundwater dynamics in response to climate change and increasing abstraction of groundwater for irrigation
- ✓ Assessment of historical and current processes of adaptation measures

Results

The major outcome of the study is the quantification of climate change impacts on groundwater level and possible adaptation measures to sustain groundwater based irrigation system. The absence of groundwater level within the limit of suction lift of shallow tube wells during irrigation period is a major concern in many highly populated Asian countries. Changes in precipitation pattern and increased surface temperature have exaggerated the situation in recent years. The results obtained from two study sites located in Northwest

Bangladesh and Northeastern Punjab province of Pakistan show increase of groundwater level by 0.052% for every increase of rainfall by 1%, and decrease in groundwater level by 1.03% for every increase in mean temperature by 1% in Northwest Bangladesh, which is considered as a bench-marked area for study. The absence of groundwater below the suction lift of shallow tube-wells during dry season irrigation period is a major concern in the region.

Statistical downscaling results from ensembles of nineteen Coupled Model Intercomparison Project Phase 5 (CMIP5) simulations under four representative concentration pathways (RCP) scenarios, namely RCP2.6, RCP4.5, RCP6.0 and RCP8.5 indicate that temperature in the study area will increase in the range of 2.1-3.4°C and rainfall in the range of 8.7-12.6% in the end of this century. However, increased rainfall will not cause elevation of groundwater level. Rather increased temperature and changes in precipitation pattern will cause declination of groundwater table during the months of irrigations and elevation of groundwater level during monsoon months. Declination of groundwater level during peak irrigation months will affect the groundwater based irrigation system in the region. On the other hand, elevation of groundwater level near to the surface during monsoon months will make the aquifer more vulnerable to pollution.

Analysis of adaptation measures revealed that two measures can be adopted to reduce groundwater level declination namely, reduction of groundwater extraction of irrigation and crop rescheduling. Simulation of groundwater level showed that it is possible to keep the groundwater level always above the suction lift of shallow tube-well by reduction of groundwater abstraction by 28% and shifting groundwater irrigation period by 30 days by rescheduling harvesting date. Therefore, the study proposes reduction of groundwater extraction by reducing overuse of irrigation through development of awareness among the farmers, changing cropping pattern, increasing irrigation efficiency and development of surface water resources. The study also proposes that advantage of rainfall can be taken by rescheduling the cropping period.

As the assessment of impact and identification of possible adaptation measures are the main aspects of mitigation planning, it is hoped that the study in general will help various authorities, especially in terms of those interventions aimed at irrigation water supply augmentation in the region. It is also expected that the study will be beneficial to a number of stakeholders in the region, particularly water development authorities, agricultural organizations, development, and planning authorities to improve their understanding on climate change impacts on groundwater resources in Asian region.

Relationship to the APN's Third Strategic Plan (2010-2015)

The project is relevant to all core strategies of APN viz. to promote research that can improve understanding of global change and its implications for the regional policy formulation and decision making; to promote and encourage activities that will develop scientific capacity and improve the level of awareness on global change issues specific to Asia-Pacific; and to identify present and future needs and emerging issues.

Science Agenda: The project is relevant to the science agenda of APN to improve understanding of the change for adaptation and mitigation decision-making in the area of resources utilisation and pathways for sustainable development. The project is an initiative from developing countries to conduct site-specific integrative research where interdisciplinary analyses of climate change effects and human interventions to natural resources are carried out to identify potential coping strategies pertinent to Asian region.

Institutional Agenda: The project is relevant to the institutional agendas of APN viz. to encourage member countries' representatives to play an active role in promoting the APN programmes at the national, regional and international levels; to enhance year around communications among all APN stakeholders; and to assist member countries in facing the challenges presented by global change.

Self-Evaluation

The first workshop was conducted on August 11-13th, 2014, in Universiti Teknologi Malaysia (UTM), Johor Bahru Campus (Skudai, Johor Bahru, Malaysia). Collaborators from participating countries (Bangladesh, China, India, Indonesia, Malaysia and Pakistan) attended the meeting. The meeting was successful to foster a long-term collaboration among the scientists in the region working on groundwater dependent irrigation system.

The second workshop was conducted in September 08-10th, 2015, in UTM Johor Bahru Campus, Malaysia. Obtained results from bench-marked study areas were shared. A brainstorming discussion was conducted to identify the suitable adaptation measures.

The project is successful in term of development of collaboration among the scientists working on groundwater dependent irrigation system in South, Southeast, and East Asian countries. The project is also successful to provide a knowledge-base about climate change impacts on groundwater-dependent irrigation system and the processes of adaptation to achieve sustainability in groundwater-depended irrigation in South and Southeast Asian countries.

Potential for Further Work

Secondary data available from two locations namely, northwest Bangladesh and Faisalabad-Pakistan were used to conduct the study. Knowledge gathered from the project can be used to initiate new research projects in other collaborating countries. Only two adaptation measures were evaluated to mitigate the climate change impacts on groundwater level and sustain groundwater based irrigation system. In future data can be collected through field survey for assessment of other adaptation measures. A conference can be arranged to disseminate the gathered knowledge to aware scientific community and policy makers about climate change impacts and adaptation to groundwater-based irrigation system.

Publications

- Shahid, S., Wang, X.-J., Keramat, M., Akhter, G., Farooq, S.H., Lubis, R.F. (2014): Vulnerability and Adaptation to Climate Change in Groundwater-dependent Irrigation Systems in Asian Countries. APN Science Bulletin 2014 (4), 124- 126
- Shahid, S., Alamgir, M., Wang, X.-J., Eslamian, S. (2016) Chapter 6: Climate Change Impacts and Adaptation to Groundwater. In: Handbook of Drought and Water Scarcity (edited by S. Eslamian). Vol. 2: Environmental Impacts and Analysis of Drought and Water Scarcity. Francis and Taylor Publishers.
- Wang, X. J., Zhang, J. Y., Shahid, S., Guan, E. H., Wu, Y. X., Gao, J., & He, R. M. (2016). Adaptation to climate change impacts on water demand. Mitigation and Adaptation Strategies for Global Change, 21(1), 81-99. 10.1007/s11027-014-9571-6

Acknowledgments

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Preface

Groundwater is the lifeline of irrigated agriculture in many Asian countries. Climate change may pose a serious threat to already stressed groundwater-dependent irrigation system in the region. Rising temperature and changes in spatio-temporal pattern in precipitation may change groundwater recharge and groundwater abstraction rate to meet the changing demand, and consequently groundwater level drop. It may also affect the irrigation return flow and would play a vital role in groundwater storage. The major objective of this collaborative research project was to foster regional cooperation to improve knowledge on impacts of climate change and unsustainable human interventions on groundwater based irrigation system and identification of adaptation measures in order to achieve sustainability and improve the livelihood of the people of Asia. A software tool was developed to simulate the changes in groundwater level in response to climate change and irrigation abstraction. The tool was also used to simulate the changes in groundwater level under projected climate in two bench-marked regions located in Bangladesh and Pakistan. The simulated model was finally used to assess the effectiveness of two adaptation measures namely, crop scheduling and reduction of groundwater abstraction for irrigation in order to keep the groundwater level within the limit of suction lift of shallow tube-well. The study provided a knowledge-base about climate change impacts on groundwater-dependent irrigation system and possible adaptation measures to achieve sustainability in groundwater-depended irrigation in densely populated Asian countries.

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1.0 Introduction

Many Asian countries are among the highest users of groundwater for irrigation in the world. Groundwater use in irrigation is still increasing both in absolute terms and in percentage of total irrigation, especially in densely populated South Asian countries. Groundwater based irrigated agriculture has grown over 500% in India in the past three decades. In China, groundwater extraction has increased by about 2.5 billion-metre^3 per year in recent decades to meet irrigation needs. The total number of mechanized wells has increased from barely a few thousands in 1960 to half million in 2000 in Punjab province of Pakistan. The contribution of groundwater to total irrigated area has increased from 4% in 1971 to 85% at present in Bangladesh. As the agriculture sector contributes a major portion of GDP and total employment generation, groundwater is considered as a major component for food security and poverty alleviation in many Asian countries. Groundwater has the capacity to balance large swings in precipitation and associated increase of demands during drought. Consequently, many Asian countries are gradually shifting to groundwater based irrigated agriculture for food security. For example, Malaysia has planned to increase the share of groundwater to total water consumption from less than 3% at present to about 20% in the year 2020. After introduction of groundwater based irrigation in Java Island of Indonesia, groundwater use has increased steadily in last forty years. Therefore, it can be remarked that groundwater based irrigation is playing a crucial role or going to play an important role in Asia in their agro-economy and people's livelihood.

Despite huge significance, groundwater irrigation is heading for a crisis in many countries and needs urgent understanding and attention. Rapid expansion of groundwater based irrigated agriculture to feed the growing population and inappropriate irrigation practices have caused overexploitation of groundwater in India, China, Pakistan and Bangladesh at an alarming rate. Over-extraction has caused lowering of groundwater table, decrease in well yield, increase of pumping cost, and consequently, increase of crop production cost. This has seriously affected the benefit and livelihood of farmer. It is anticipated that climate change will pose another major threat to groundwater based irrigation system in near future. A number of studies carried out in recent years show that increased temperature and changing rainfall pattern will significantly affect groundwater recharge and storage. Furthermore, changes will occur in crop-water use due to increased temperature and CO_2 concentrations.

Groundwater demand for irrigation is also likely to increase because of the need to offset the substantial declines in surface-water availability due to climate change.

Increasing shortage of groundwater resources due to climate change and ever increasing consumption for agriculture could undermine the irrigation-based economy in many Asian countries if adequate countermeasures are not adopted. However, research in this field is still at infancy and many questions are not answered yet. More data, in terms of field information are needed to understand the multi-dimensional impacts of climate change and coupled human activities on groundwater resources and dependent irrigation. Case studies from different countries in a range of hydrogeologic settings, climate regions and socio-economic conditions can provide a good understanding of impacts at local and regional scales. International collaboration across geographical regions is therefore very urgent to advance the knowledge and adopt adaptive solutions.

2.0 Climate Change and Groundwater Resources

Climate change has already altered, and will continue to alter, the water cycle. Impacts of climate changes in hydrological process are already evident. As a part of hydrological cycle groundwater system will also be affect by climate change. Groundwater bodies are naturally protected from the earth surface by geological environment and therefore, less vulnerable and more resistant than surface water to external impacts. Therefore, the climatic effect on groundwater is usually low and slow. Groundwater is also less vulnerable to other extreme weather events, such as, flood and tsunami. However, groundwater is a part of hydrological cycle. Therefore, long term change in climate will certainly affect groundwater resources.

2.1 Climate Change Challenges and Opportunities to Groundwater Resources

It has been projected that water demand will continue to grow across the world due to climate and other environmental changes (Hasan et al. 2013). It can be anticipated that groundwater will play a major role to adapt with growing pressure on surface water resources in the context of global change. Groundwater resources management to ensure continuous supply in order to meet the increasing demand will be the biggest challenge in near future. Though development of groundwater resources is more expensive compared surface water, it has number of advantages over surface water, which have made groundwater as a major source of water supply in many countries of the world. Groundwater resources are relatively more robust to increased climate variability, and therefore, it is believed that the use groundwater will increase to ease the freshwater crisis in the context of climate change. Opportunity to use groundwater in the context of climate change is supposed to make this resource more important in near future.

2.2 Possible Impacts of Climate Change on Groundwater Resources

Rising temperature and changing precipitation pattern will directly affect groundwater recharge, discharge, level and storage. On the other hand, changes in vegetation cover, water demand for irrigation, sea level rise, etc. can affect groundwater quantity and quality indirectly. Number of studies has been carried out to assess the impacts of climate change on groundwater in different parts of the world in recent years (Mahmoodzadeh et al. 2014; Banerjee et al. 2009; Shahid 2008; BADC 2005; Nikolos et al. 2008; Coppola et al. 2003; Gaitan et al. 2013). The studies revealed that increasing evapotranspiration due to rising temperature and changing precipitation pattern will directly affect groundwater system. A review of recent studies on direct impacts of climate change on groundwater resources is given below.

Groundwater recharge: Recent research showed that changing climate will affect surface runoff, surface water bodies, and consequently groundwater recharge (Faye et al. 2009; Liu 2011). Rising temperature will cause increase air moisture holding capacity which in turn will increase precipitation. Increased precipitation, in general, will cause an increase in surface runoff and groundwater recharge. However, groundwater infiltration will not increase proportional to increased rainfall and runoff. Döll and Florke (2005) estimated that average global groundwater recharge will increase by 2% in 2050, which is less than the projected increases of 4% and 9% of global annual precipitation and runoff, respectively. Besides that changes in groundwater recharge will vary widely across the globe. In many cases, increase precipitation may reduce groundwater recharge due to changes in precipitation intensity and distribution. Even total annual groundwater recharge may decrease in the region where annual rainfall is projected to increase only due to increase of rainfall intensity. Similarly, changes in rainfall distribution may affect groundwater recharge. Less rainfall in the vicinity of recharge zone due to changes in precipitation pattern may reduce groundwater recharge in the region where rainfall has been projected to increase. Shahid et al. (2015) reported that increase evapotranspiration under higher temperature will offset the advantage of increased increased rainfall and therefore, no appreciable change in groundwater recharge in Northwest Bangladesh. Number of studies also suggested that groundwater resources will be less recharged from rivers and may lose more in the context of climate change (Liu, 2011; Samper et al., 2014).

Groundwater storage: Shallow groundwater systems, particularly those are located in unconsolidated sediment or fractured bedrock is highly sensitive to climate variability (Kundzewicz and Döll 2008). Overall, groundwater storage will increase in the region where groundwater recharge will increase more compared to groundwater discharge. As groundwater recharge is projected to increase in most parts of tropical and semi-arid regions, it is expected that groundwater storage may increase in these regions. However, it may decrease in tropical region too. Hsu et al. (2007) used a numerical modeling approach to investigate the response of groundwater system to climate variability in southwestern Taiwan and reported decrease of available groundwater due to climate change. Nayak et al. (2015) investigated the impact of climate change on groundwater storage in Satluj basin of India and reported that significant change in groundwater storage at higher infiltration rate.

Groundwater level: Higher temperatures will cause higher evaporation and plant transpiration rates, hence more drying up of soils. This will entail higher losses of soil moisture and lowering of shallow groundwater table. This may also cause shifting of groundwater availability within the exploitable limit. Seasonal variation in groundwater recharge may cause a wide variation in groundwater level. Therefore, increased recharge may not be helpful to elevate groundwater level for the whole year. Some studies revealed that groundwater level will go down further during dry irrigation period due to higher increase of temperature due to climate change. Decrease of groundwater level during dry month may cause more frequent and severe groundwater droughts in many regions across the world.

Groundwater quality: Increased precipitation in wet seasons may take the groundwater level to near surface and make it more vulnerable to pollution. Therefore, climate change can deteriorate the groundwater quality in many regions. Increased infiltration due to increased precipitation can mobilize intrusion of pollutant in the vadose zone (Gurdak et al. 2007). In areas where rainfall intensity is expected to increase, pollutants like pesticides, organic matter, heavy metals etc. will be increasingly washed from soils to water bodies (IPCC. 2007). Where recharge to aquifers occurs via these surface water bodies, groundwater quality is likely to decline. Water quality may also decrease in the region where recharge is projected to decrease due to the lowering of dilution (IPCC. 2007). It may also lead to intrusion of poorer quality water from neighboring aquifers in some cases. During drought periods, groundwater quality may decrease due to increase of salt content. Therefore, changes in recharge and discharge are likely to change the vulnerability of aquifers to diffuse pollution.

Changes in groundwater dependent irrigation demand: Compared to direct affect, groundwater might be more affected indirectly due to climate change. As the surface water will be severely affected by climate change, groundwater is likely to play a greater role under such conditions (Essink et al. 2010). Exploitation of groundwater will be high in the dry season when surface water will be scarce. Overexploitation of water will cause negative impacts on this precise resource in long term. Shahid (2011) assessed the impact of climate change on irrigation water demand in northwest Bangladesh and reported that there will be an increase in daily use of water for irrigation. As groundwater is the main source of irrigation in the region, higher daily pumping rate in dry season may lower groundwater level and aggravate the situation of groundwater scarcity in the region. Furthermore, changes in vegetation cover due to climate change may change soil moisture condition, groundwater recharge and groundwater depth.

3.0 Climate Change and Groundwater Resources in Collaborating Countries

Declination of groundwater level is a major problem in populated Asian countries where a major portion of agriculture depends on groundwater for irrigation. Groundwater resources in the context of climate change in six Asian countries participated in the project is briefly discussed in following section. Locations of collaborating countries are shown in Figure 1.

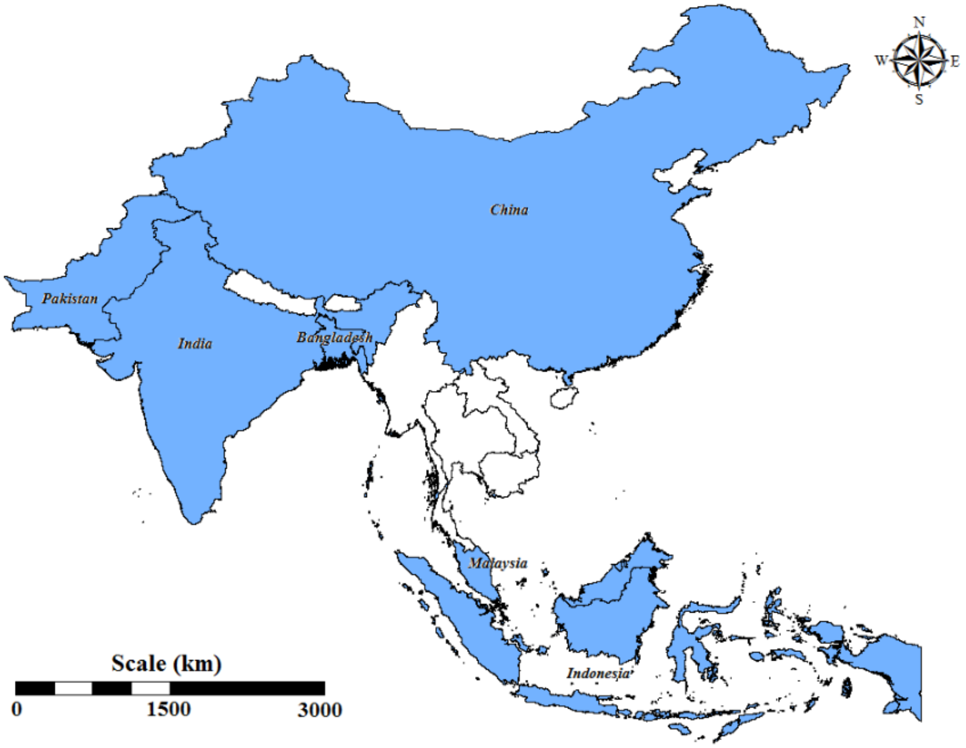


Figure 1. The collaborating countries of the project

3.1 Bangladesh

Groundwater use for irrigation in Bangladesh has increased greatly over the last few decades (Mainuddin and Kirby 2015). Increased use of groundwater for irrigation has caused declination of groundwater level, particularly in Northwest Bangladesh (Kirby et al. 2015). Future availability of groundwater in the region will depend on level of groundwater use, river runoff, and climate change. Temperature has been projected to increase in Bangladesh; however, the change in rainfall is less certain (Masood et al. 2015). Projected increase in temperature will affect irrigation demand and recharge to groundwater. Recharge will also be affected by changes to rainfall, irrigation return flow, and flood extent and duration. It has been projected that recharge may decline, as the rainfall is expected in fewer, more intense storms with greater runoff and shorter periods for recharge (Shamsudduha et al. 2011). This may exacerbate the condition of declining groundwater levels in some parts of Bangladesh, particularly in Northwest Bangladesh (Shamsudduha et al. 2009; Shahid and Hazarika 2010; Kirby et al. 2013).

3.2 China

Water shortages along with increasing water demands for industry, agriculture and residence has put tremendous pressure on water resources in China (Burke, 2000; Candela et al., 2009). Therefore, overexploitation of groundwater to meet increasing demand has caused rapid declination of groundwater level in some parts of China. It has also caused deterioration of groundwater quality. It has been projected that climate change will increase water demand in agriculture, the major water using sector of China, which will put more pressure on available water resources. Therefore, sustainable management of groundwater resources is a major concern in the country. China has taken integrated groundwater management investment plan to improve the groundwater resources management. Groundwater exploitation has already been restricted, some cases completely prohibited to revert the groundwater level.

3.3 Pakistan

Agriculture in Pakistan is highly dependent on irrigation. More than 80% of all arable land in Pakistan requires irrigation for agricultural production (Government of Pakistan, 2008). Groundwater plays a major role in irrigated agriculture in Pakistan (Qureshi et al 2004). The number of tube wells increased from 10,000 in 1960 to 0.6 million in 2002 (Qureshi et al 2003) and more than 1 million in 2007 (World Bank 2007). The total groundwater abstraction from these tube wells is estimated at 51×10^9 m^3 against a recharge of $40–60\times10^9$ m^3. Therefore, any changes in irrigation demand or groundwater resources due to climate change or human interventions may lead to serious challenges to food security and people’s livelihood.

3.4 India

Use of groundwater has increased tremendously in India over the past few decades. At present more than 19 million water wells are used for groundwater abstraction in India compared to 150,000 in 1950. Huge exploitation of groundwater has caused overdraft in many places. Declining of the groundwater table has been observed at a rate of about 0.15 m/year in the western Ganges plains and in some places as high as 0.35–0.4 m/year over the period 1994–2005 (Samadder et al. 2011). Rodell et al. (2009) estimated a depletion rate of the groundwater aquifer at 4.0 +1.0 cm/year over the period 2002–2008 in the states of Rajasthan, Punjab and Haryana. Shah (2009) reported that India may face food scarcity if the current trend continues. Number of studies reported that future climatic change will have severe impacts on water resources including groundwater resource and therefore, agrarian economy of India. Several studies projected an increase in temperature of 2–4 °C, a decrease in winter precipitation by 5–25% and an increase in summer precipitation by 10–20% in India in the end of this century (Rupa Kumar et al., 2006; Met Office, 2011). It has been reported that the combined effect of temperature increases and changes in precipitation may change groundwater recharge rates, mainly due to increased evapotranspiration under higher temperature and altered precipitation patterns (Bovolo et al., 2009; Shah, 2009).

3.5 Malaysia and Indonesia

Groundwater is relative less used for irrigation in Malaysia and Indonesia. However, groundwater based irrigated agriculture is gradually increasing in both the countries. Malaysia has planned to increase the share of groundwater to total water consumption from less than 3% at present to about 20% in the year 2020. Groundwater use in Indonesia has also increased rapidly in last few decades. It can be anticipated from the present trend that groundwater based irrigation may be a significant component of food production and people’s livelihood in some Southeast Asian countries.

3.6 Study Locations

The study was conducted in two intensive groundwater irrigated areas: one located in Northwest Bangladesh and another in Northeastern region of Punjab Province of Pakistan. Secondary data related to groundwater level, climate, irrigated land, crop and soil types were obtained from national and local authorities of the corresponding countries. Locations of study areas in Bangladesh and Pakistan are shown in Figures 2 and 3, respectively.

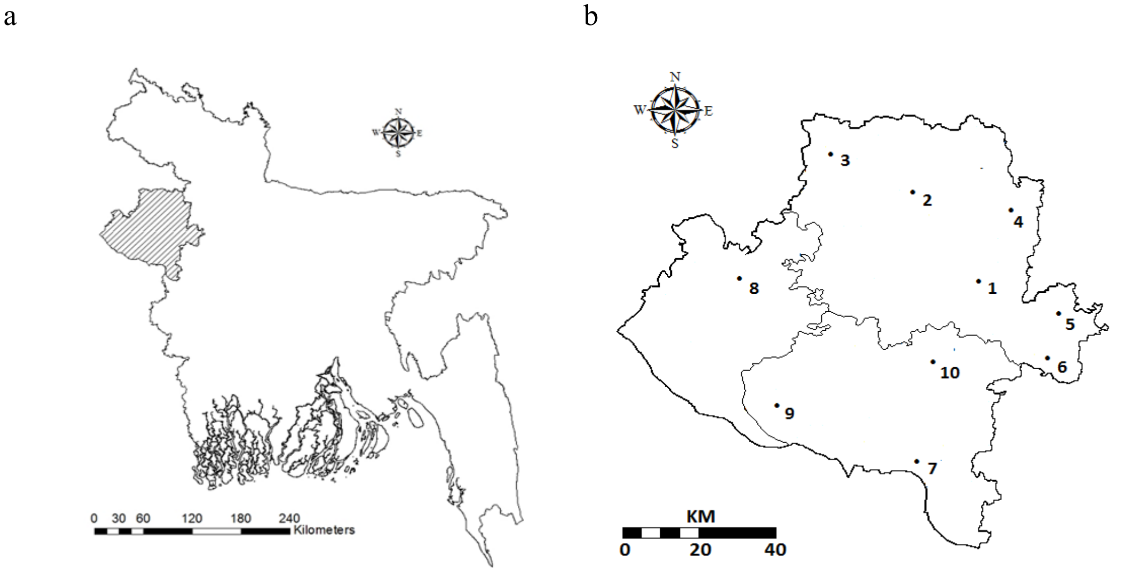


Figure 2: (a) Location of study area in Bangladesh; (b) location of groundwater sampling points

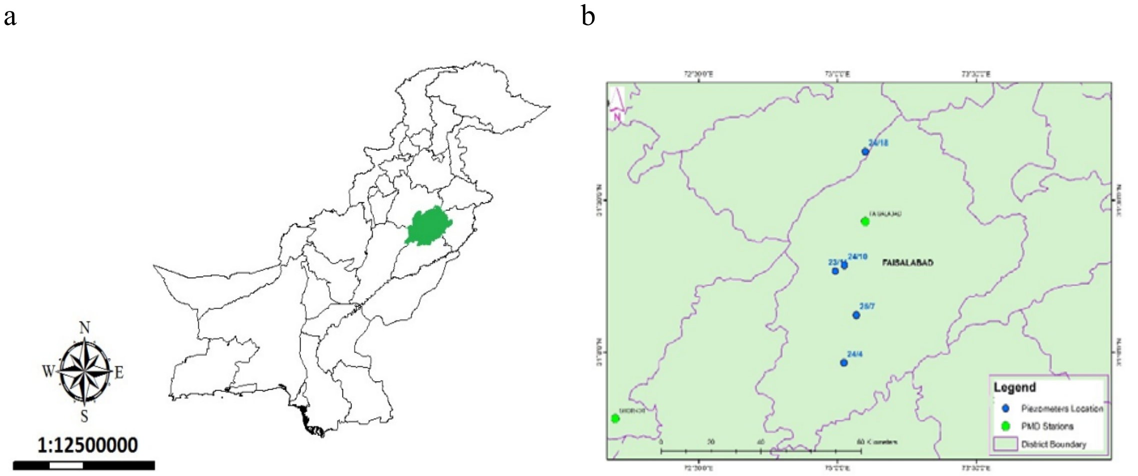


Figure 3: (a) Location of study area in Pakistan; (b) location of groundwater sampling points

4.0 Methodology

Many conceptual and process-based modelling techniques have been developed for simulating groundwater level in a variety of hydrogeological settings (Coppola et al. 2003; Coppola et al. 2005; Coulibaly et al. 2001; Daliakopoulos et al. 2005). These models are being used successfully during past several years for simulation and analysis of groundwater systems (Coppola et al. 2003). However, physical based models are very data intensive, which often hinder development of such model in data scarce region (Coulibaly et al. 2001). Rapid development of computer system and enhanced capability of computer programming encouraged hydrologist to develop empirical models to overcome the difficulties of physical based model. Support vector machine (SVM) models are such models, which are treated as universal approximations and are very much suited to dynamic nonlinear system modelling (ASCE. 1990). SVM learns the system's behaviour from representative data and therefore, do not require explicit characterization and quantification of physical properties and conditions of the system under investigation (Mohanty et al. 2010). Therefore, SVM was used to model groundwater level due to change in climate and groundwater abstraction. Rainfall, evapotranspiration, groundwater abstraction, and irrigation return flow were used as input to SVM model. The model was calibrated and validated with historical data, and then used to simulate future changes in groundwater level due to climate change. The study was conducted by following the steps given below:

1. Evapotranspiration was computed from temperature data using FAO Penman-Monteith method.
2. The amount of groundwater extraction for irrigation was estimated from crop water requirement in paddy field.
3. Irrigation return flow from paddy field was estimated from soil properties.
4. A support vector machine (SVM) model was developed to simulated groundwater level from rainfall, evapotranspiration, groundwater abstraction, and irrigation return flow data.
5. Climate in the study area was downscaled and projected under four RCP climate change scenarios.
6. Projected climate was incorporated in SVM model to projected future change in groundwater level assuming that irrigation water demand and irrigation return flow will not change in the area.

7. Wilcoxon signed rank test (Wilcoxon 1945) was used to reveal significant changes in groundwater level.

Methods used in the present study are discussed below in details.

4.1 Calculation of Evapotranspiration

The FAO Penman-Monteith methods was used to estimate evapotranspiration which is the Penman-Monteith method combine to the aerodynamic and surface resistance,

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma\frac{900}{T + 273}u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)} \qquad (1)$$

Where ET_o is the reference evapotranspiration [mm day-1], R_n is the net radiation at the crop surface [MJ m-2 day-1], G is the soil heat flux density [MJ m-2 day-1], T is the mean daily air temperature at 2 m height [°C], u_2 is the wind speed at 2 m height [m s-1], e_s is the saturation vapour pressure [kPa], e_a is the actual vapour pressure [kPa], $e_s - e_a$ is the saturation vapour pressure deficit [kPa], D is the slope vapour pressure curve [kPa °C-1], g is the psychometric constant [kPa °C-1].

4.2 Estimation of groundwater extraction rate

Irrigation water requirement in crop field was calculated from crop evapotranspiration as,

$$ET_{crop} = K_c \times ET_{ref} \qquad (2)$$

Where, K_c is the crop coefficient, and ET_{ref} is the reference evapotranspiration

Crop coefficient values proposed by FAO at different growing stages of rice were used for the calculation of crop evapotranspiration. As the groundwater is extracted for irrigation in paddy field in the study area, groundwater extraction rate is computed from irrigation water demand in rice field.

4.3 Irrigation return flow

Total water loss through percolation from the crop field was calculated from soil data. It was considered that percolation loss for a sandy soil is 8mm/day, for clay is 4mm/day, and for loom is 6mm/day. Percolation and seepage losses through a particular soil class were calculated according to the percentage of sand, clay and loom exists in that soil class.

4.4 Support Vector Machine (SVM)

In a regression SVM, the functional dependence of the dependent variable y on a set of independent variables x are estimated as,

$$\int(x) = W.\emptyset(x) + b \tag{3}$$

Where, W and b are weight vector and bias, respectively; ϕ denotes nonlinear transfer function that maps the input vectors (x) into a high dimensional feature space in which theoretically a simple linear regression can cope with the complex nonlinear regression of the input space.

SVM solves the nonlinear regression function using optimization problem with an ε-insensitivity loss function,

$$\frac{1}{2}w^T w + C\sum_{i=1}^{N}\xi_i + C\sum_{i=1}^{N}\xi_i^* = 0 \tag{4}$$

Where, ξ_i and ξ_i^* denote slack variables which are the distance of the training data set points from the region to an error tolerance ε; W is the vector of coefficient; b is the constant; and y_i is the independent variables. In the present study, SVM based model was trained with 70% of data and then validated with rest 30% of data.

4.5 Climate Downscaling

Coupled Model Intercomparison Project Phase 5 (CMIP5), a globally coordinated set of GCMs experiments from 20 different modelling groups provides historical and future simulations (Taylor et al., 2013). The monthly data from nineteen GCMs for historical simulations and future projections were used in this study. The name, modeling centers and resolutions of selected models obtained from (http://cmip-pcmdi.llnl.gov/cmip5/) is given in Table 1.

Table 1. List of CMIP5 models used in the project

No	Modelling centre	Model	Resolution (Lon x Lat)
1	Beijing Climate Center China	BCC-CSM1-1	2.8 x2.8
2	Canadian Centre for Climate Modelling and Analysis, Canada	CanESM2	2.8 x2.8
3	NASA/GISS (Goddard Institute for Space Studies) USA	GISS-E2-H	2.5 x 2.5
4	Met Office Hadley Centre, UK	HadGEM2-ES	1.87 x 1.25
5	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	MIROC5	1.4 x 1.4
6	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	MIROC-ESM	2.8 x 2.8
7	Atmosphere and Ocean Research Institute (The University of Tokyo), National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology, Japan	MIROC-ESM-CHEM	2.8 x2.8
8	Bjerknes Centre for Climate Research, Norwegian Meteorological Institute, Norway	NorESM1-M	2.5 x 1.9
9	Bjerknes Centre for Climate Research, Norwegian Meteorological Institute, Norway	NorESM1-ME	2.5 x 1.9
10	Max Planck Institute for Meteorology ,Germany	MPI-ESM-LR	1.87 x 1.86
11	Max Planck Institute for Meteorology Germany	MPI-ESM-MR	1.87 x 1.86
12	Beijing Climate Center China	BCC-CSM1.1(m)	2.8 x2.8
13	Centre National de Recherches Météorologiques, Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique France	CNRM-CM5	1.4 x 1.4
14	National Institute of Meteorological Research, Korea Meteorological Administration South Korea	HadGEM2-AO	1.87 × 1.25
15	National Center for Atmospheric Research, USA	CCSM4	1.25 × 0.94
16	Commonwealth Scientific and Industrial Research Organization/ Queensland Climate Change Centre of Excellence, Australia	CSIRO-Mk3.6.0	1.86 × 1.87
17	Russian Academy of Sciences, Institute of Numerical Mathematics, Russia	INMCM4.0	2.0 × 1.5
18	Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy	CMCC-CM	0.75 × 0.75
19	Centro Euro-Mediterraneo sui Cambiamenti Climatici, Italy	CMCC-CMS	3.75 × 3.71

Observed monthly rainfall data at the locations of interest was used for statistical downscaling of rainfall and temperature from an ensemble of nineteen CMIP5 GCMs under four representative concentration pathways (RCP) scenarios, namely RCP2.6, RCP4.5, RCP6.0 and RCP8.5 in order to assess future changes in rainfall and temperature. Stepwise regressions of GCM precipitations of 42 grid points surrounding the study locations were used as predictors. SVM was used for capturing highly nonlinear relationship between coarse resolution GCM predictors and local climatic variables. Quantile mapping (QM) method was used to adjust the simulated precipitation/temperature against the observed one in order to remove the bias in GCMs.

4.6 Assessment of Climate Change Impacts on Groundwater Level

Climate change impact on groundwater was evaluated by incorporating downscaled climate in calibrated and validated SVM model as inputs. Other inputs of the model were considered constant over the projection period. The groundwater levels simulated by SVM under future climate change scenarios were compared with observed groundwater level data (1986-2007). In the present study, projected groundwater level data were divided into two epochs namely, 2010-2039 and 2040-2069. Performance of the developed SVM model was assessed using root mean square error (RMSE), correlation coefficient (R), and the Nash-Sutcliff efficiency (NSE).

4.7 Significance of groundwater level change

The non-parametric Wilcoxon Signed Rank test (1945) was used to test the change in groundwater level over the time periods. The Wilcoxon signed rank is one of the best and widely used non-parametric methods for conducting null hypothesis of difference in median between paired samples. This method uses the ranks of the sample data, instead of their specific values, to detect the significance. This allows this test to be particularly robust against outliers, non-normal distributed and auto-correlated data (Souvignet et al. 2011). The test was conducted for months of a year. In this study, we defined the hypothesis as:

H_0: Groundwater mean is same for both the periods

H_1: Groundwater mean of one period is different from another.

4.8 Uncertainty in projection

Confidence intervals of the projected monthly mean groundwater level were measured using bootstrapping method (Efron and Tibshirani 1993). The bootstrap method generates a large number of samples randomly drawn with replacements from the original dataset known as pseudo-samples to generate confidence interval (Dibike et al. 2008). In the present study, one thousand samples are generated to compute the confidence intervals of means.

5. Results and Discussions

5.1 Model Calibration and Validation

The SVM model was calibrated and validated with 70% and 30% of observed time series data, respectively. Figure 4 shows the relationship between the observed and predicted groundwater level during model calibration and validation at three locations in Northwest Bangladesh. The figures show that the observed and predicted groundwater levels matches very well during both model calibration and validation.

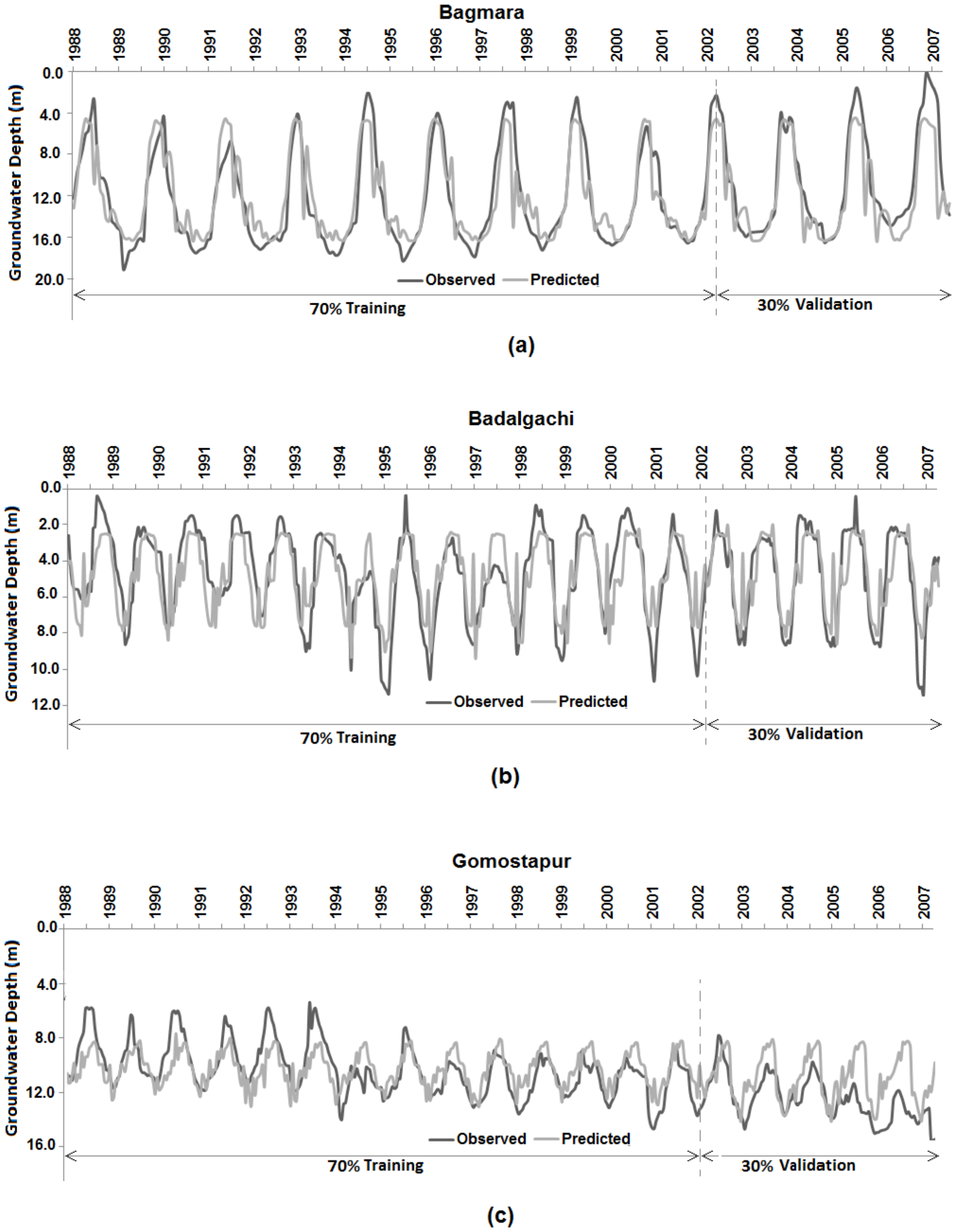


Figure 4: Observed and simulated groundwater level during model calibration and validation at three locations in Northwest Bangladesh

5.2 Downscaling of climate

One of the major challenges in climate downscaling is to select the appropriate predictors. In the present study, the GCM projected rainfall and temperature (maximum and minimum) at 42 GCM grid points surrounding the study areas were used to develop the downscaling model. Monthly rainfall and temperature data for the periods 1961–1990 and 1991–2000 were used for calibration and validation of SVM model respectively. Probability distribution functions (PDF) curves for observed and downscaled rainfall/temperature were compared to assess the capability of downscaling model to downscaling climate at a study location. PDFs for observed and CMIP5 GCM annual precipitations downscaled by SVM model at Rajshahi station, located in Northwest Bangladesh is shown in Figure 5 as an example. The Figure shows good match between the PDFs estimated from observed and downscaled rainfall projected by different models. This indicates that the downscaling model was able to downscale CGM rainfall at all the stations perfectly and therefore, it can be used for projection of future climate in the study area.

Calibrated and validated downscaling models were used to project future changes in rainfall and temperature at study locations under four RCP scenarios. Ensemble mean of nineteen GCMs projections under each RCP scenario are presented in Figure 6. The upper graph in Figure 6 shows the mean projection of rainfall at Northwest Bangladesh under three climate change scenarios namely, RCP2.6, RCP4.5 and RCP8.5. Simulations of rainfall under RCP6.0 scenarios are not available for many GCMs, therefore, only those three RCP scenarios were used for projection of rainfall. The lower two graphs in Figure 6 shows the ensemble mean projections of maximum and minimum temperature under different RCP scenarios in Northwest Bangladesh.

The downscaled rainfall shows an annual increase of rainfall in Northwest Bangladesh. However, the changes are not very much significant under all scenarios. Analysis of results revealed that rainfall will increase in the range of 8.7 to 12.6% in the end of this century. RCP8.5 showed the highest increase in rainfall (12.6%) and RCP2.6 showed the lowest increase of rainfall (8.7%).

The downscaled maximum and minimum temperatures reveal (Figure 6) increase in both minimum and maximum temperatures in the range of 2.1 to 3.4°C. The increase will be much higher in the last part of the century compared to first half of the century. Highest increase in temperature (3.4°C) was projected under RCP8.5 scenario and the lowest (2.1°C) under RCP2.6 scenario. Overall, all the scenarios projected increase in both rainfall and temperature in Northwest Bangladesh.

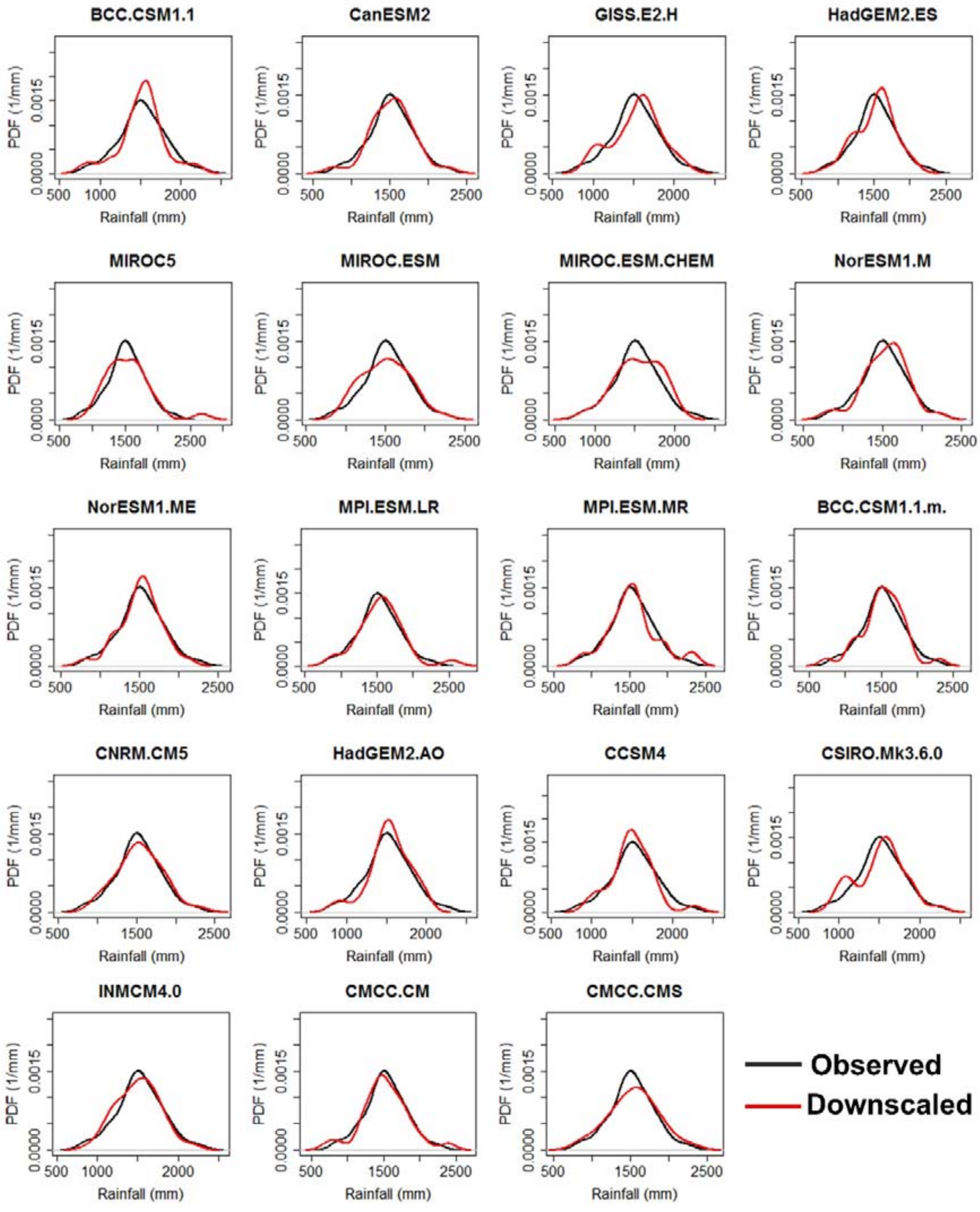


Figure 5. PDFs for CMIP5 GCM annual precipitations downscaled by SVM model at a meteorological station (Rajshahi) in Northwest Bangladesh

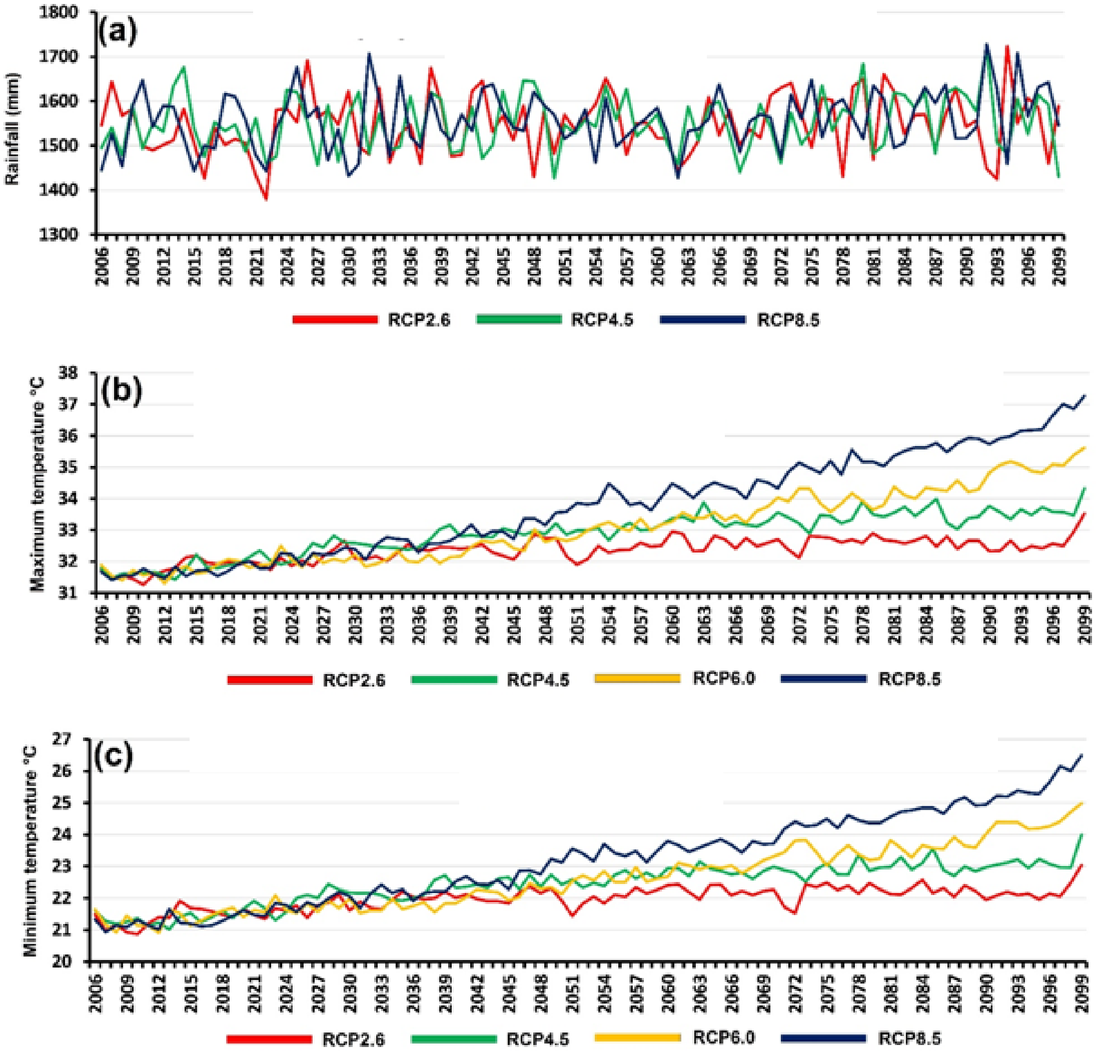


Figure 6: Future projection of ensemble mean of (a) rainfall; (b) maximum temperature; and (c) minimum temperature at a station (Rajshahi) located in Northwest Bangladesh

The downscaling model was also used to downscaling and projection of rainfall and temperature in Faisalabad station located in Pakistan. Ensemble mean of projected monthly rainfall at the station under four RCP scenarios are shown in Figure 7.

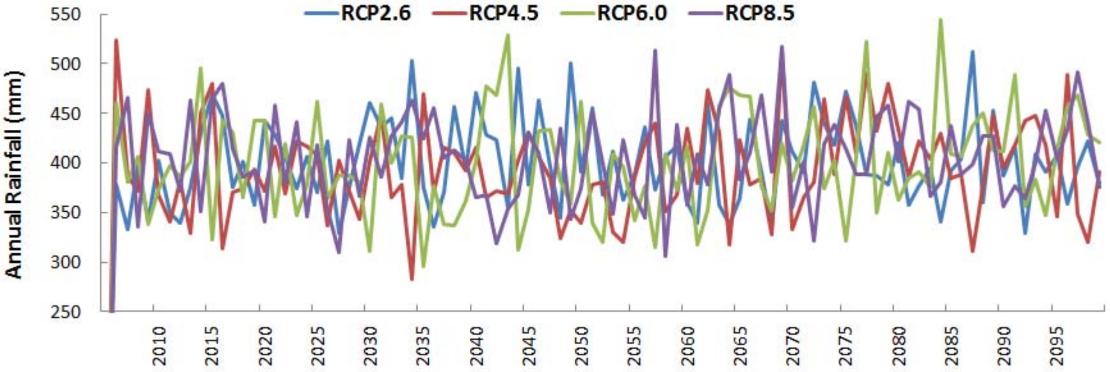
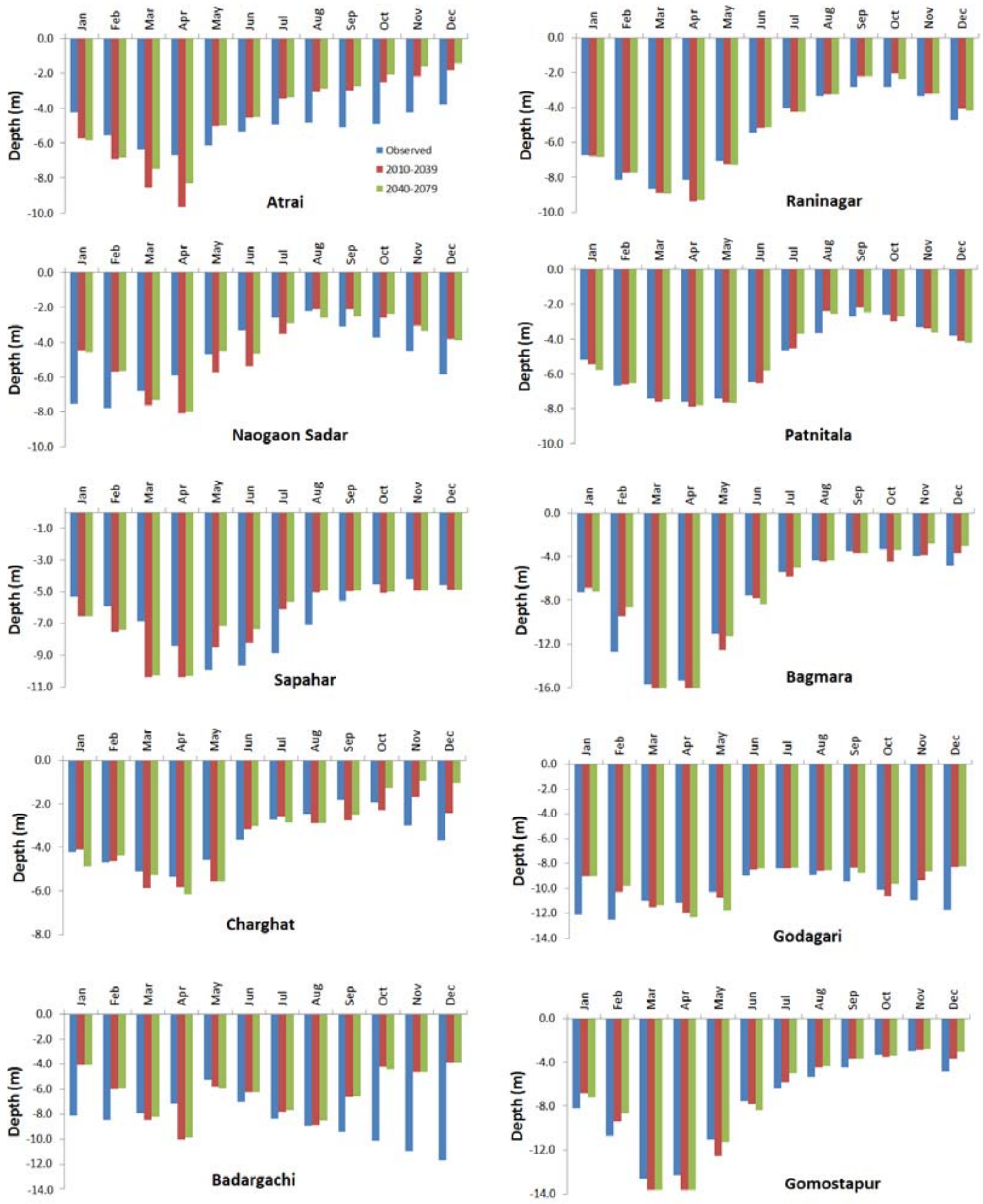


Figure 7: Future projection of ensemble mean rainfall under four RCP scenarios at a station (Faisalabad) located in Punjab province of Pakistan.

5.3 Climate Change impacts on Groundwater level

The projections of groundwater level under climate change scenarios was divided into two epochs namely, 2010-2039 and 2040-2069 for comparison. Changes in groundwater level during different months of the years for the observed period (1986-2007) was compared with that projected for the years 2010-2039 and 2040-2069. The obtained results at Northwest Bangladesh are presented in Figure 8.

Groundwater level data during base period and projected periods are compared using Wilcoxon signed rank test to reveal the significance in the change. The comparison was conducted for every months of a year. The obtained results at three stations are given in Table 2. The underlined numbers in the table indicate significant change at 95% level of confidence. It can be seen from the table that changes in groundwater level is significant in most of the months. Similar results were obtained in other stations. Therefore, it can be remarked that climate change will cause significant change in groundwater level in the study area.



Figures 8: Observed and projected seasonal variations of average groundwater tables at different locations in Northwest Bangladesh under RCP4.5 scenario.

Analysis of the projected seasonal variations of groundwater depths revealed that in all the cases, groundwater level will go down further during the pre-monsoon season, when groundwater is required for irrigation. Lack of sufficient rainfall and heavy groundwater extraction for the irrigation causes the groundwater scarcity in many parts of the study area which normally last until beginning of monsoon. The study indicates that groundwater will go further down during this period, which will make the groundwater more inaccessible in the study area.

Table 2: Significance levels (*p*-values) of the Wilcoxon Signed Rank test between observed and projected groundwater levels at three stations at 95% confidence level.

Month	Bagmara		Badalgachi		Gomostapur	
	2010-2039	2040-2069	2010-2039	2040-2069	2010-2039	2040-2069
January	0.02	>0.01	>0.01	>0.01	>0.01	>0.01
February	>0.01	>0.01	>0.01	>0.01	>0.01	>0.01
March	>0.01	0.01	0.06	>0.01	0.09	0.09
April	>0.01	>0.01	>0.01	>0.01	0.31	0.33
May	>0.01	>0.01	>0.01	>0.01	0.13	0.14
June	>0.01	0.92	>0.01	>0.01	>0.01	>0.01
July	0.12	>0.01	>0.01	>0.01	>0.01	>0.01
August	>0.01	>0.01	0.94	0.23	>0.01	>0.01
September	>0.01	>0.01	>0.01	>0.01	>0.01	>0.01
October	>0.01	>0.01	>0.01	>0.01	0.11	0.13
November	0.09	0.06	>0.01	>0.01	0.31	0.28
December	0.02	0.22	>0.01	>0.01	0.01	0.01

The groundwater level reaches near to surface in the end of monsoon after recharging by monsoon rain. Rain-fed agriculture is grown during monsoon. Therefore, groundwater abstraction during monsoon is insignificant. The graphs in Figure 8 show that climate change will bring the groundwater level more close to surface during post-monsoon months. It has been found that groundwater table will come within a meter to the surface. Groundwater in the study area is contaminated with different chemicals originated due to anthropogenic activities. It can be remarked that climate change will make the groundwater much more vulnerable to pollution in the study area.

The 95% confidence interval of groundwater level change, estimated using bootstrap method are also shown in Figure 9. The negative bars indicate lowering of groundwater level compared to base year and vice versa. The figure shows that the lower bound of confidence interval was always negative in peak irrigation months. On the other hand, the upper bound of confidence interval was found to exceed more than 3 meters in some dry months. The lower bound of groundwater level change was found always positive during most of the post-monsoon and winter months. The upper bound was found to reach near to 4 meter in some months. It is very clear from the above study that groundwater level will change significantly due to climate change. It can be remarked at 95% level of confidence that groundwater level will go down during pre-monsoon irrigation period and rise up near to surface during post-monsoon months.

5.4 Sensitivity of Groundwater Level to Climate

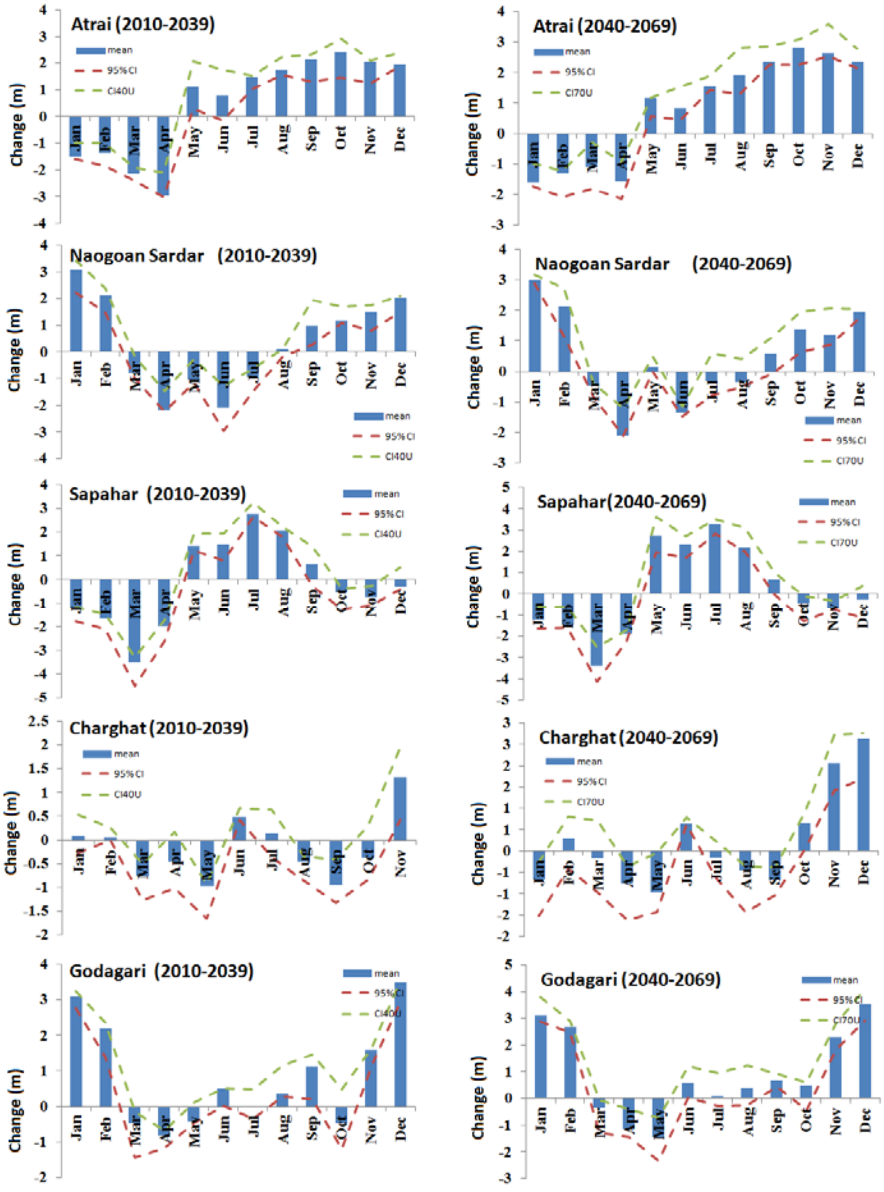
The obtained results were used to assess the sensitivity of groundwater level to rainfall and evapotranspiration (Table 3). The results show increase of groundwater level by 0.052% for 1% increase in rainfall and decrease in groundwater level by 1.03% for an increase in mean temperature by 1%. It indicates that shallow groundwater in the study area is most sensitive to evapotranspiration.

Table 3: Impacts of rainfall and temperature in groundwater level in Northwest Bangladesh

Changes in climate (%)	Changes in groundwater level (%)
1% change in rainfall	0.052%
1% change in temperature	1.03%

5.5 Assessment of Adaptation Measures

The model was finally used to assess the effectiveness of different adaptation measures to stop declination of groundwater level. Analysis of possible adaptation measures revealed that two adaption measures can be adopted to reduce groundwater level declination namely, reduction of groundwater extraction for irrigation and crop rescheduling. Simulation of groundwater level based on adaptation measures are shown in Figure 10. The result shows that it is possible to keep the groundwater level always above the suction lift of shallow tube-well by reduction of groundwater abstraction by 28% and shifting groundwater irrigation period by 30 days by rescheduling harvesting date. Therefore, the study proposes reduction of groundwater extraction by reducing overuse of irrigation through development of awareness among the farmers, changing cropping pattern, increasing irrigation efficiency and development of surface water resources. The study also proposes that advantage of rainfall can be taken by rescheduling the cropping period.



Figures 9: Changes in groundwater level with 95% confidence interval at five stations in Northwest Bangladesh

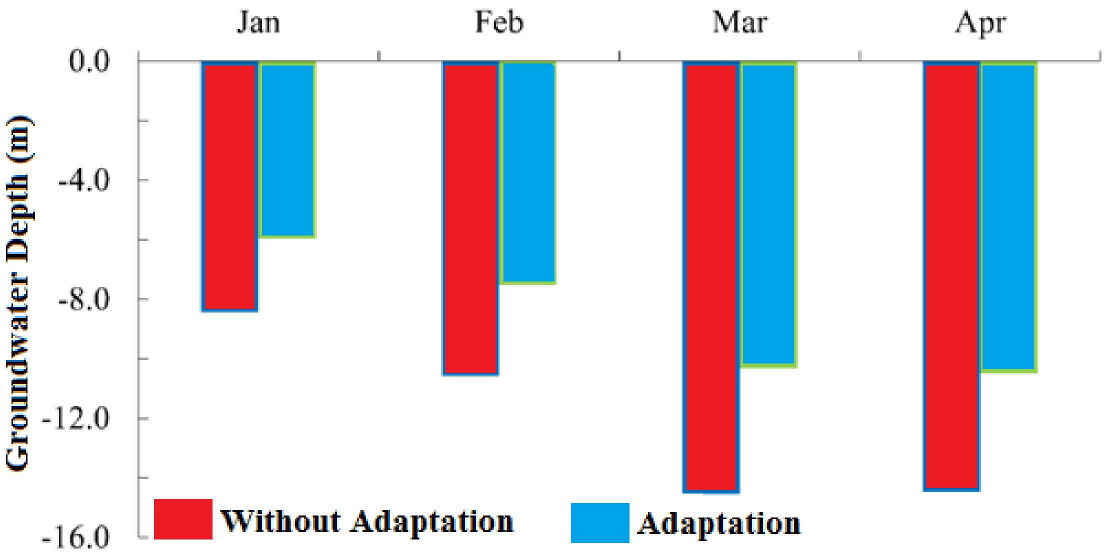


Fig 10: Uplift of groundwater level during irrigation period by considering adaptation measures

6.0 Adaptation Measures to Mitigate Climate Change Impacts on Groundwater

Groundwater in densely populated Asian countries is already under stress. Groundwater level during irrigation period is goes down in irrigated areas in most of the collaborating countries due to huge abstraction of groundwater to meet the irrigation demand in expanding groundwater based irrigated agriculture. The present study indicates the groundwater scarcity during crop growing period will be aggravated more due to climate change. The adaptation measures that have been taken in Northwest Bangladesh to mitigate the water scarcity are reviewed below as a case study.

6.1 Review of Adaption Measures

A number of measures were taken by government, local agencies and non-government organizations to build resilience to water scarcity under changing environment. The measures being adopted include water harvesting, special irrigation methods, growing awareness among farmers on over use of water for irrigation, improve irrigation efficiency, etc. By the year 2010, eleven thousand irrigation water distribution systems were developed to reduce the distribution loss and improve crop water productivity. Harvesting of rainwater was encouraged by excavation of mini ditch/pond and using the same for supplemental irrigation on farmlands having no source of irrigation. Training programs were organized and about hundred thousand farmers were trained about soil water conservation, water productivity, irrigation practices, crop diversity, etc. It has been learnt from government report that the average rice water productivity in the study area has increased from 0.392 kg/m^3 to 0.473 kg/m^3 between 1990 and 2008.

Overall, the policies and strategies have resulted in significant irrigation expansion, especially through intensified groundwater utilization, which has helped to achieve the country's primary objective of self-sufficiency in food production. However, the measures were not enough to maintain the sustainable groundwater yield due to extensive use of groundwater, extension of agricultural land and changes in climate in the region. Therefore, the groundwater level in the area has declined steadily over the last decade.

6.2 Streamlining of Adaptive measures

To reduce the growing pressure on ground water in the area, supplemental irrigation as well as to contribute to the recharging of groundwater to maintain better hydrologic cycle is required. The concept of integrated water resources management (IWRM) can be adopted to increase adaptive capacity to climate change.

Rainfall could be utilized more beneficially if it is stored and managed properly. Bangladesh Rice Research Institute (BRRI) reported that 90% of the total rainfall can be conserved in the paddy fields by constructing and maintaining 15 cm levees around the fields. This technique of rainwater harvest is sufficient to stabilize rice yield in moderate drought scenarios. It has been reported that in drought-prone areas, construction of farm pond in 5% of the land areas with 2 m deep is sufficient for supplemental irrigation to stabilize rice yield. This is economically viable even if there is a drought once in five years.

Farmers should be encouraged to change their irrigation practices to improve the water productivity. According to Bangladesh Rice Research Institute (BRRI), 1500 litres of water is enough to produce one kilogram of rice, but farmers generally apply 3000 to 5000 liters to grow a kilogram of rice. A technology called Alternative Wetting and Drying (AWD) to grow rice requires 20% to 25% less irrigation can be adopted for sustainable yield of groundwater in the region. Traditional practices such as moisture conservation through mulching by straw, water hyacinth, rice husk, polythene etc. should also be encouraged.

Steps are required to regulate the extraction of water in the area for sustaining rechargeable groundwater aquifers with full public knowledge. Accurate estimation of groundwater recharge is essential for this purpose. Quantitative information about groundwater recharge and groundwater management based on sustaining rechargeable groundwater aquifers may help in reducing groundwater scarcity in the region.

Climate forecasting system should be improved and the forecasting system should be used properly for water management. Groundwater level forecasting system based on rainfall and river water discharge can be developed. At the same time the forecasting and suggestion for crop adjustment should be made widely available to community. For example, low rainfall in a year may cause depletion of groundwater level in the next year. As the irrigation machines cannot pump properly due to the drop of water level, rice cultivation in the dry period may be hampered. In that cases rice growers can be recommended to cultivate other crops like wheat, maize and pulses that are relatively less dependent on irrigation. A pragmatic strategy is also needed to transform some parts of the region into a non-rice crop-growing zone particularly in the dry season.

Sustainable implementation of viable adaptation options depends heavily on disseminating climate information in a usable format. Mass media can play an important role in disseminating weather and climate information to farmers, farmer groups and community associations at the local level. This information should provide in easily understandable or usable formats to allow the farmer to make pro-active decisions.

7. Conclusions

A study has been carried out to assess the impacts of climate change on groundwater level as well as the effectiveness of different adaptation measures to mitigate the negative impacts of climate change on groundwater level in order to sustain the groundwater based irrigation system. The study was conducted to two intensively groundwater based irrigated regions, one located in Northwest Bangladesh and another in Northeastern Pubjab province of Pakistan. Absence of groundwater below the suction lift of shallow tube-wells during irrigation period is a major concern in those areas like many other groundwater dependent irrigated land in densely populated Asian countries. Therefore, it is expected that the results obtained from these two locations will help to mitigate the problem of declining groundwater level in other regions.

Analysis of the projected seasonal variations of groundwater depths under different climate change scenarios revealed that, groundwater level will go down further during irrigation season, which will make the groundwater more inaccessible. Two adaption measures: (i) reduction of excess groundwater abstraction; and (ii) shifting of groundwater abstraction period have been assessed in this study. Simulation of groundwater level show that it is possible to keep the groundwater level always above the suction lift of shallow tube-well by reduction of groundwater abstraction by 28% and shifting groundwater irrigation period by 30 days by rescheduling harvesting date. The elevation of groundwater level by adopting those measures can also reduce irrigation cost in the region significantly.

The study generated knowledge on possible impacts and adaptation to climate change impacts on groundwater level, which in turn will help to reduce irrigation cost and increase farmer's profit. It is expected that the study in general will help various authorities, especially in terms of those interventions aimed at water supply augmentation in the region.

8.0 Future Directions

The model used in the present study to simulate groundwater level is based on the assumptions that groundwater level in the region depends on rainfall, temperature, groundwater abstraction and irrigation return flow only. There are many other geological and soil features that influence groundwater level, which are not considered in the present study due to unavailability of reliable data at different sites. Similarly, irrigation cost in the region partially depends on some other factors besides the cost of electricity such as, fuel (mobile) price, equipment maintenance cost, etc., which are also ignored in the present study. Study can be repeated in future by considering all those factors for precise estimation of groundwater level and irrigation cost. Further research can also be conducted to assess the impacts of climate change on groundwater level in the region, which is considered highly sensitive to climate change from hydrologic point of view.

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