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GEO-SPATIAL INVESTIGATION OF CLIMATE CHANGE IMPACTS ON IRRIGATION DEMAND OF DRY SEASON BORO RICE IN NORTHWESTBANGLADESH

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ABSTRACT

The present study is an attempt to assess the irrigation demand of the dry season Boro rice in the northwest regions of Bangladesh using climatic, soil and crop data. The FAO-56 Penman–Monteith method was applied to calculate reference evapotranspiration and irrigation demand of Boro rice has been estimated using CROPWAT model. Both the observed and downscaled Representative Concentration Pathway (RCP) climatic data were used in the study. The result reveals that there is no significant change in irrigation demand of Boro rice from 1975 to present. However, the demand will increase significantly in future. The study projects that future irrigation demand of Boro rice in climate change situation for RCP 8.5 will be increased by 180-220 mm in 2075. It is expected that the findings will contribute in devising appropriate agricultural and irrigation plan for the region.

Keywords: Climate change, RCP, Boro rice, Irrigation Demand, Bangladesh

INTRODUCTION

Bangladesh is identified as one of the most vulnerable countries to climate change. A World Bank study (2000) projects that by the year 2050, average temperature will increase by 1.8°C and precipitation will fluctuate 37 percent compared to 1990 in the dry season in Bangladesh. Agriculture is considered as the most vulnerable sector to changing climate since its productivity depends on climatic factors such as temperature, rainfall, light intensity, radiation and sunshine duration, which are predicted to be erratic. Irrigation water, which is an important determinant of agriculturalproduction, will face challenge due toclimate

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change (Rahman 2017). It is anticipated that irrigation water security will be a crucial matter to manage in the changing climatic condition of Bangladesh.

In recent years, human activities have augmented changes in the entire climatic system. Global surface temperature change is projected to likely exceed 1.5°C for RCP 8.5 by the end of the 21st century, relative to the average from 1850 to 1900 (Stocker *et al*., 2013). Besides global warming, climatic variables such as precipitation, solar radiation and wind speed will change. Although climate change is a global phenomenon but has significant regional impacts. As a result, hydrological system, ecosystem and agriculture system in many countries are adversely affected. Unique geographical location and unstable economy of Bangladesh have posed additional challenges for the agricultural sector of the country. Hydrologic changes are the most significant potential impacts of climate change in Bangladesh (Agrawala2003) and it is directly associated to agricultural sector. It has been predicted that due to climate change, there will be a steady increase in temperature and change in rainfall pattern of Bangladesh (Solomon 2007). Agriculture is the major source of earning livelihood of the fellow citizens, which is mainly dominated by rice. Boro rice is at present the highest growing rice of the country, which has replaced Aman rice. Introduction of Boro rice cultivation is a landmark for Bangladesh as it is helping the nation to achieve self-sufficiency in food grain production (Rahman *et al*., 2013). One of the remarkable effects of future climate change will be a threat to food security of the country, which can be overcome by efficient cultivation of Boro rice. Different studies showed that future food security would depend on Boro cultivation as the production of Aus has already decreased and that of Aman is on the way of decreasing. Likewise, effect of climate change will be more severe on these two varieties as they are rain fed varieties of rice.

Boro rice in Bangladesh, either HYV or traditional variety covering more than 4.5 million ha, is entirely irrigated production, mostly with underground water. For producing 1 kg of paddy, it is estimated that a farmer has to use 2,500 liters of water (Bouman 2009). However, farmers in Bangladesh use about 3,300 liters, not knowing the appropriate farming methods. Water resources are becoming scarce worldwide, and Bangladesh is of no exception. Generally, in Bangladesh irrigation is applied in dry season. Dry season rice (HYV Boro) is the main cultivable crop in the northwest region. As irrigation in rice field is the main sector of water use in northwestern Bangladesh, so the total demand of water required for Boro rice irrigation is important for water resources planning and management of the area.

Effective precipitation is the amount of precipitation that is actually added and stored in the soil. During dry periods, less than 5 mm of daily rainfall would not be considered effective, as this amount of precipitation would likely evaporate from the surface before soaking into the ground. The factors that influence which part of rainfall is effective and which part is not effective include the climate, the soil texture, the soil structure and the depth of the root zone (Brouwer and Heibloem 1986).There is a close relationship between the amount of total effective rainfall and irrigation water demand of crop in an area. Irrigation water demand is inversely proportionate to the amount of total effective rainfall. The more will be the amount of effective rainfall, the less will be the irrigation requirement of a region. It is assumed that higher evapotranspiration due to temperature rise may also demand higher amount of water for irrigation. On the other hand, higher temperature will change the crop physiology and shorten the crop growth period, which in turn will reduce the irrigation days (Shahid 211). These contradictory phenomena will change the total irrigation water demand, which is required to quantify for long-term water resources and agricultural planning.

The aim of the present study is to assess the change in irrigation water demand of dry season Boro rice in the northwest region of Bangladesh in the context of climate change. Specific objectives cover (a) assessment of the changes in effective rainfall of the study area as an important determinant of irrigation demand, (b) to find out past and present scenario of dry season rice irrigation demand, and (c) predicting its future trends with changing climate.The present work will consider all the possible factors by which climate change can influence the irrigation water demand of Boro rice. Such factors include water required for land preparation, evapotranspiration from rice field, effective precipitation etc. Acharjee*et al.*, (2017) investigated irrigation demand for Boro rice of northwest Bangladesh using model data only which was a limitation of that study because in many cases downscaled model data do not comply with observed climate situation. For instance, Rahman *et al.*, (2019) found different results in ET_0 calculation for observed and model data in Bangladesh. Shahid (2011) also used model data (MAGICC/SCENGEN) to predict future irrigation but the study did not consider historical data to get a localized picture of changing climate. The present study will contribute there by considering observed climate in assessing irrigation demand of dry season Boro rice. It is decidedly expected that the study findings will be able to show some directions of future irrigation and agricultural planning to overcome future crisis related to agricultural water security and relevant food productivity.

MATERIALS AND METHODOS

Description of the Study Area

The study area includes the northwestern region of Bangladesh, which consists of Rajshahi and Rangpur divisions. It is the area lying west of Jamuna River and north of Padma River, and includes the Barind Tract. Only six of the 16 administrative districts ofnorthwest Bangladesh have a weather station in the region. Five of these, namely Bogura, Rajshahi, Rangpur, Ishwardi (Pabna) and Sayedpur (Nilphamari) have been included in this study (Figure 1).

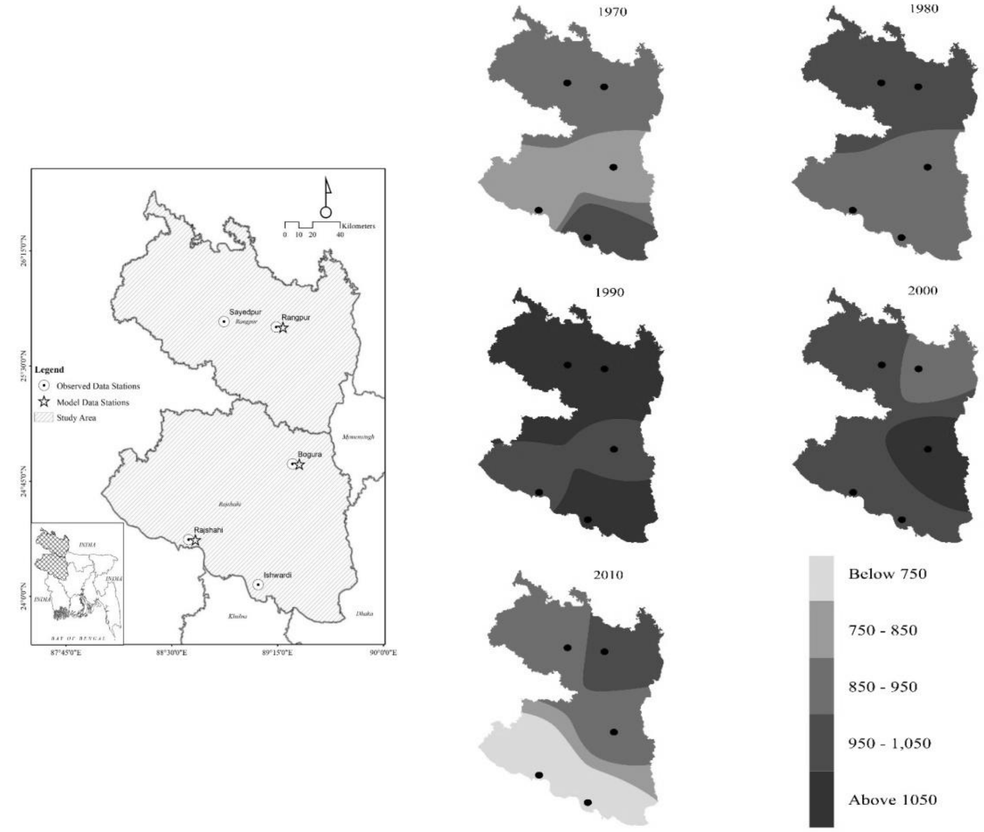

FIGURE 1: MAP OF THE STUDY AREA (LEFT) AND EFFECTIVE RAINFALL IN THE STUDY AREA FROM 1970-2010 (RIGHT).

The northwestern part of the country belongs to the sub-humid agro-climatic zone. This region is well known for its weather extremes. While temperature rises up to 40°Cduring summer, in winter it drops to almost freezing point (below 5°C sometimes). Temperature in the region usually ranges from 25°C to 40°C in the hottest season and 8°C to 25°C in the winter season (Shahid, 2011).The study area belongs to dry humid zone where annual average rainfall vary between 1,400 and 1,900 mm. The seasonal distribution of rainfall shows that almost 92.7% rainfall occurs during May to October. Less than 6% of rainfall occurs during the irrigation period of Boro rice (December to April). The rainfall also varies widely from year to year. Annual variability of non-monsoon rainfall in the area is more than 50% (Shahid, 2008). Meteorological drought is a very common phenomenon during the dry months in this region (Shahid and Behrawan 2008).Boro rice is the main cultivable crop in the area and is cultivated on more than 70% of the cultivated land from December to May (Acharjee*et al*., 2017).

Data and its sources:

Data used in the study were collected from different sources and were processed accordingly to fulfill the requirement of the analysis. Data used in the study can be divided into three major types:

Observed Climatic Data:

Data of different climatic variables namely maximum and minimum temperature, rainfall, humidity, wind speed and sunshine hour of last 40 years of relevant stations were collected from Bangladesh Meteorological Department (BMD).As mentioned in the section of study area description, five weather stations of BMD of northwest Bangladesh were purposefully selected in this study for observed climatic data. The reason of selecting five out of six stations of BMD is that these stations have about 40 years climatic data while the remaining one (Dinajpur) is not within the boundary of the study area.It is assumed that the data collected from the stations would be representative for the region’s climate.

Modelled Climatic Data:

Four General Circulation Models (GCMs) and two emission scenarios (RCPs) were used to construct future climate scenarios in this study.MarkSim web version for IPCC AR5 data (CMIP5) (http://gisweb.ciat.cgiar.org/MarkSimGCM) were used in this purpose. Maximum and minimum temperatures, rainfall, wind speed and sunshine hour for the year of 2025, 2050 and 2075 were prepared. The GCMs used were MIROC5 (Model for Interdisciplinary Research on Climate), IPSL-CM5A (Institut Pierre Simon Laplace Model CM5A), GFDL (Geophysical

Fluid Dynamics Laboratory) and HadGEM2-ES (Hadley Centre Global Environmental Model version 2) models. RCPs are greenhouse gas concentration trajectories adopted by IPCC for its fifth Assessment Report (AR5) in 2014. It supersedes Special Report on Emission Scenarios (SRES) projections in 2000. The RCPs are consistent with a wide range of possible changes in future anthropogenic greenhouse gas (GHG) emissions, and aim to represent their atmospheric concentrations. Two different emission scenarios, RCP 4.5 and 8.5 were usedin this study to project results in moderate to high level of climate change.

Crop and Soil Data

Some of the crop data were collected from Bangladesh Rice Research Institute (BRRI), and some others from previously published and authorized papers.
Rice growing period was divided as:

i. Nursery/Land preparation (seedling stage, 30 days)
ii. Initial stage (transplanting to seedling establishment, usually 20 days)
iii. Crop development stage (tillering to panicle initiation, 30 days)
iv. Mid stage (panicle initiation to 100% flowering, 20 days) and
v. Late stage (flowering to maturity, 20 days)

In addition to the above-mentioned data, Kc value (dry and wet), rooting depth, puddling depth, nursery area, critical depletion, yield response factor and crop height were needed. These data were collected from available published sources(Shahid 2011; Mainuddin and Kirby 2015; Acharjee*et al*., 2016).In Boroseason, farmers usually transplant Borovarietiesfrom the last week of December to middle ofFebruary and grow the crop under fully irrigatedcondition (Hossain*et al*., 2017). For simplification, 1stJanuary wasconsidered as a suitable transplanting date sincemost of the farmers' follow this practice in thestudy area. Maximum rooting depth of ricewas considered 45 cm in the present study.Soil data, available soil moisture, maximum rainfall infiltration rate, maximumrooting depth, initial soil moisture depletion, initial available soilmoisture, drainable porosity, critical depletion for puddle cracking, maximum percolation rate after puddling, water availability at planting and maximum water depth were standardized for amedium average soil for the study area from FAO standard soilparameter values.

Calculation of Reference Evapotranspiration (ETo)

The FAO-56 Penman–Monteith method (Eq. 1), recommended as the standard method for estimating reference evapotranspiration, was used in the study. CROPWAT 8.0 tool was applied in this regard. Islam *et al*., (2019) assessed design water demand of Boro rice in the case of Bangladesh also using the same tool. The input data required for calculating the potential evapotranspiration are minimum temperature (°C), maximum temperature (°C), sunshine hours (hrs), wind speed (km/day), relative humidity (%), latitude, longitude and altitude (m).The outputs given by CROPWAT model are Radiation (MJ/m^2/day), ET$_0$and potential evapotranspiration (mm/day).Penman-Monteith (Eq. 1) used in the study to compute ET$_0$.

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273}(e_s - e_a)}{\Delta + \gamma(1 + 0.34\mathrm{u}_2)} \qquad \text{(Eq. 1)}$$

Where,

ET_0 = Reference evapotranspiration (mm/day)
R_n= Net radiation at the crop surface (MJ m^2 /day)
G = Soil heat flux density (MJ m^2 /day)
T = Mean daily air temperature at 2 m height (°C)
u_2= Wind speed at 2 m height (m/s)
e_s= Saturation vapour pressure (kpa)
e_a= Actual vapour pressure (kpa)
$e_s - e_a$= Saturation vapour pressure deficit (kpa)
Δ= Slope vapour pressure curve (kpa/ °C)
γ = Psychrometric constant (kpa /°C)

Using this method,ET_0 of each weather stations were computed for relevant yearsand these havebeen further used for estimating irrigation demand of that region.

Calculation of Effective Rainfall

CROPWAT model considers four methods; fixed percentage, FAO/AGLW formula, empirical formula and USDA soil conservation service method to estimate effective rainfall. In this study, the USDA soil conservation service method (Pongpinyopap and Mungcharoen 2012) was used to estimate effective rainfall using Eq. 2-3.

$$P_{eff} = P\frac{(125 - 0.2P)}{125} for P \leq 250mm \qquad \text{(Eq. 2)}$$

$$P_{eff} = (125 + 0.1P) for P \geq 250\ mm \qquad \text{(Eq. 3)}$$

Here,
P_{eff}=effective monthly rainfall(mm),
P = total monthly rainfall (mm)

Calculation of Potential Crop Water Requirement (ET_C)

Crops require the water mainly to meet the evapotranspiration demand. The potential crop evapotranspiration (PET) or Potentialcrop water requirement (ET_C) was estimated using the following formula:

$$ET_c = ET_O \times K_c \qquad \text{(Eq. 4)}$$

Here,
ET_O = Reference evapotranspiration and
K_c= Crop co-efficient of Boro rice
In this study, The CROPWAT 8.0 model was used to estimate the crop water requirement.

Calculation of Irrigation Water Demand

CropWat model developed by FAO was used to estimate irrigation demand of Boro rice. It has been used extensively as a decision support toolin an international context to calculate regional irrigation requirements (Clarke *et al.*, 2001). Irrigation demand of Boro rice has been estimated in CropWat model for 5 weather stations using observed climatic data and 3 stations using statistically downscaled climate data from GCM outputs.

Equation used for computing irrigation demand of Boro rice:

$$Net\ Irrigation\ Demand = \sum ET_C - ER + PL + N\&\ LP \qquad \text{(Eq. 5)}$$

Here,
$\sum ET_C$= potential crop water requirements or total crop evapotranspiration,
ER= effective rainfall,
PL= amount of percolation loss, and
$N\& LP$= amount of water required for nursery and land preparation.
$\sum ET_C - ER$= potential irrigation requirement for cropevapotranspiration.

Irrigation requirements have been estimated for 3 districts and 2 sub-districts using historical observed climate data and for 3 districts at 2 RCPs (4.5 and 8.5) for 2025 (average of 2024-2025), 2050 (average of 2049-2051) and 2075 (averageof2074-2076).For the mapping of spatial extents of effective precipitation and irrigation demand, inverse distance weighting (IDW)interpolation method is used. Geo-statistical analysis tool of ArcMap10.5 developed by Environmental Systems Research Institute (ESRI) is used for thispurpose.

RESULTS AND DISCUSSION

Assessment of Effective Rainfall for last 40 years (1970-2010)

From the calculation of effective rainfall of the study area and reviewing its decadal changes, it is observed that effective rainfall tends to be erratic in the recent decades. For each of the station considered, increasing trends were observed from 1970 to 1990. In 1970, the area received 900.4 mm of effective rainfall on an average, whichincreased to 950.9 mm in 1980. In 1990, all the stationsshowedthe highest amount of effective rainfall.Thus, the amount of effective rainfall increased by 50.4 mm in 10 years. In 1990, the amount increased to 1126.5 mm, which was much higher than previous decade. It is anticipated that the changes in temporal distribution of rainfall has caused the increased amount of effective rainfall.However, during 2000 the amount decreased to 999.5 mm, which was further decreased as 824.7 mm in 2010. The reason of such decreasing trend was not investigated in the study and further studies are recommended to explore the reason behind that.Spatiotemporal changes in effective rainfall in the region could be revealed from Figure 1 (Right).

From the monthly distribution of effective rainfall of the study area, it is evident that it had been much erratic throughout the study periods but overall effectiverainfall has increased during the months of April, May and June. During the total study period, highest effective rainfall had been occurring in the months of May,June, July and August, which is about 144.12 mm on an average. Other months of the year experienced irregular distribution of effective rainfall. The lowesteffective rainfall was observed from November to January though anomalies were observed in the distribution pattern. December received very little or negligibleamount of effective rainfall most of the time. The reason behind it is that the region experiences little to no rainfall in December. However,the month received 20.2 mm of effective rainfall in 1980, which was unusual comparing to its normal trend. Monthly distribution of effective rainfall of the study area from 1970-2010 has been shown in Figure2.

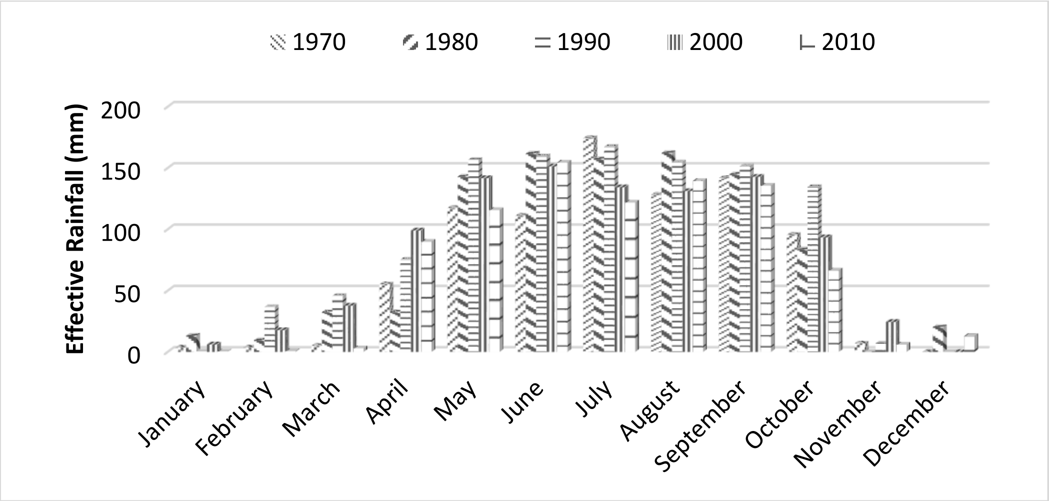

FIGURE 2: MONTHLY DISTRIBUTION OF EFFECTIVE RAINFALL OF THE STUDY AREA FROM 1970-2010

Present Situation of Effective Rainfall in the Study Area

Effective rainfall of the current period was calculated from most recent rainfall data of different weather stations of the northwest region. Based on the calculation, the area receives 1017.4 mm of effective rainfall annually on an average, which is 182.7 mm more than that of the year 2010. That means, an increasing trend of effective rainfall has been continued up to the current period. On the other hand, the amount of effective rainfall covers 53-60% of total rainfall occurred in a year which means there is almost 40-47% annual loss of rainwater which covers a huge percentage of water.Plants cannot use this lost amount of rainfall. If this amount of rainwater can be used by agricultural irrigation sector, we can save significant amount of money incurred by electricity or diesel cost for this purpose.Figure3(Left) represents the current effective rainfall of the study area.

Monthly distribution of effective rainfall of recent time shows that the area receives highest amount of effective rain during the month of August and no effective rain during the months of February, November and December. Comparing to the past effective rainfall data it is found that effective rainfall of the study area has been increased in the months of March, April and July, and decreased during June and September.

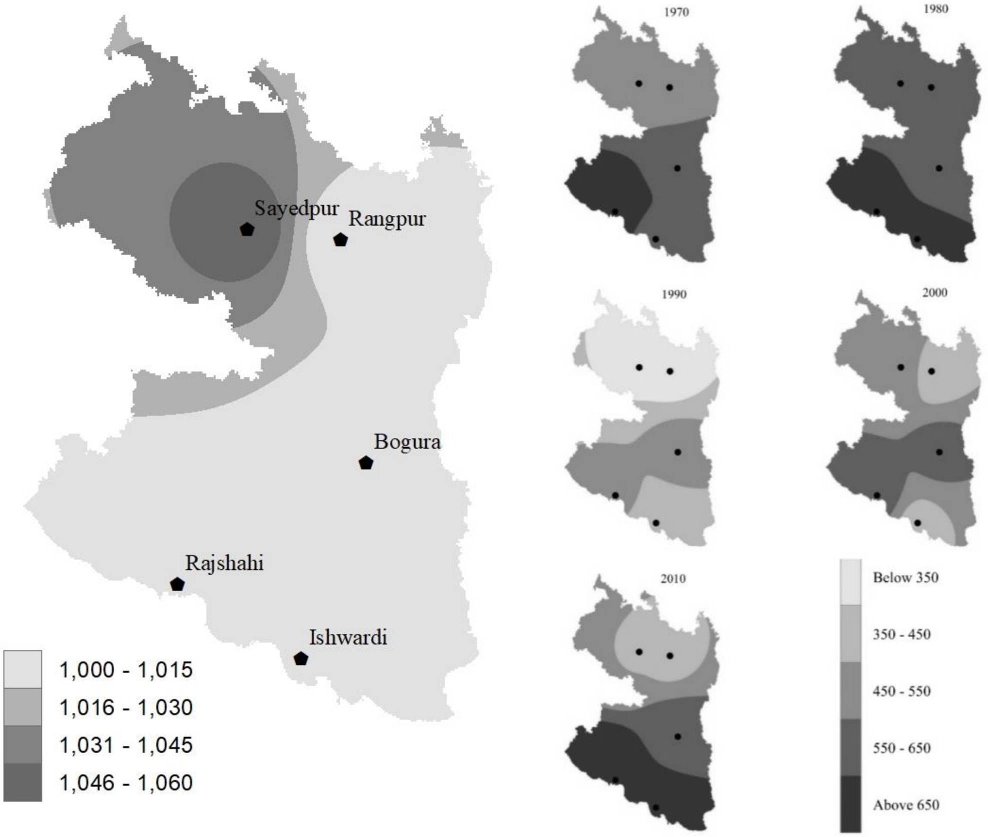

FIGURE 3: EFFECTIVE RAINFALL (MM) IN THE STUDY AREA (LEFT) ANDIRRIGATION WATER DEMAND OF THE STUDY AREA FROM 1970-2010.

The analysis of effective rainfall for crop water use and crop production constitutes a key element in developing strategies to optimize the use of rainwater for effective water management practices (Ali and Mubarak 2017).By analyzing past and present effective rainfall data of the study area, it can be concluded that the trend of effective rainfall is erratic in its temporal distribution. There is also a change in the seasonal variation of effective rainfall. Another crucial matter in terms of effective rainfall assessment is that there is a remarkable portion of rainfall, which remains ineffective every year. All the matters together can have a major impact on overall irrigation water management of the study area and future changes in effective rainfall distribution can change irrigation water demand of crops especially dry season crops of the area. It is also important to note that if rainfall increases during the rainy season, as predicted by IPCC and other researchers (Rahman *et al.*, 2017), effective rainfall (water stored by topsoil and can be used by plants) will not increase. However, the increased rainfall will ultimately contribute in runoff and will increase the chance of flooding of low lands. Thus, increased rainfall due to climate change during the rainy season may hamper the production.

Analysis of Historical Water Demand of Boro Rice of the Study Area (1970-2010)

In 1970, irrigation water demand of the study area were found 522.4 mm, 525.5 mm, 620.9 mm, 623.4 mm and 742.3 mm for Sayedpur, Rangpur, Ishwardi, Bogura and Rajshahi respectively. The highest water demand was recorded for Rajshahi whereas the lowest demand was calculated for Sayedpur. The average irrigation demand of the study area was 606.9 mm.In 1970s, irrigation sector was of great importance for agricultural advancement in Bangladesh especially for Boro cultivation. Promotion of the Green Revolution technology since the 1970s through provision of irrigation, subsidized inputs and credit,creation of irrigation water-user groups introduced the cultivation of modern Boro rice variety in the country (SayeedandYunus 2018). Boro rice, the major cultivated crop of this region which was mainly initialized in 1970s after the introduction of irrigation. The yearly production of Boro rice was nearly 10 million tones in 1970s (BBS 2006). Introduction of modern variety of Boro rice was a milestone for economic productivity of the northwest region which initialized first step in modernization of agriculture through the preface of irrigation system and modern rice variety.In 1980, irrigation water demand of the study area were found 562.9 mm, 563 mm, 586.1 mm, 692.3 mm and 729 mm for Rangpur, Sayedpur, Bogura, Ishwardi and Rajshahi respectively. The average irrigation demand of the study area was 626.7

mm, which had been increased by 20 mm, compared to the irrigation demand of 1970. 1980s period was also important in terms of Boro cultivation. Until 1980s, rice was dominated by Aman production. The introduction of irrigation made it possible to grow rice extensively in the Boro season. Area under Boro rice cultivation became 25.11 lac hectares in the last of 1980s which was 13.02 lac hectares at the first part of the era. The production also became 58.31 lac metric tons in this era which was almost one-third of the total rice production of the period (BBS, 2018). In 1990, the areas under the stations of Bogura, Rajshahi, Rangpur,Ishwardi and Sayedpur required 473.5 mm, 470.6 mm, 341.4 mm, 359 mm and 348.2 mm of irrigation water respectively which were much lower compared to the previous periods. In 1990, the area received the highest amount of effective rainfall. As irrigation water demand is directly linked with effective rainfall, so the area required minimum amount of water for irrigation in that year and much of it were supplied from direct rain water. Average irrigation demand of the area was 398.4 mm in 1990. The high amount of rainfall in 1990s caused devastating floods in the study area in 1993-94. During 1993-95, rice production declined as a result of natural disasters (particularly floods and droughts) in the region when the area is known as a surplus grain production region of the country. In 2000, the average irrigation water demand of the study area was 507.1 mm which was increased by 109.3 mm from the previous period. For areas under the stations of Bogura, Rajshahi, Rangpur, Ishwardi and Sayedpur irrigation demand were calculated as 558.2 mm, 584 mm, 423.4 mm, 444.1 mm and 525.7 mm respectively. As irrigation water demand increased during this period, farmers' production cost also increased somehow but it did not affect much on the gross production of Boro rice rather it increased both in terms of area and yield. Area under Boro cultivation reached up to 40.66 lac hectares and rice production rate was 139.75 lac metric tons which were much more than previous period. In 2010, averageirrigation demand of the entire study area remained as 597.5 mm which was 90.4 mm higher than previous period. For areas under the stations of Bogura, Rajshahi, Rangpur, Ishwardi and Sayedpur irrigation demand were calculated as 628.5 mm, 745.9 mm, 446.6 mm, 716.8 mm and 449.8 mm respectively. Although the irrigation demand increased but there was phenomenal growth in the area Boro rice production during this period. In 2001-02 season, the area was 3.77 million ha which had risen to 4.71 million ha in 2009-10 season. That time, 60% of the net cropped area was under Boro cultivation in the dry season (Mainuddin*et al.*, 2014).This overall helped ensuring national food security of the country.

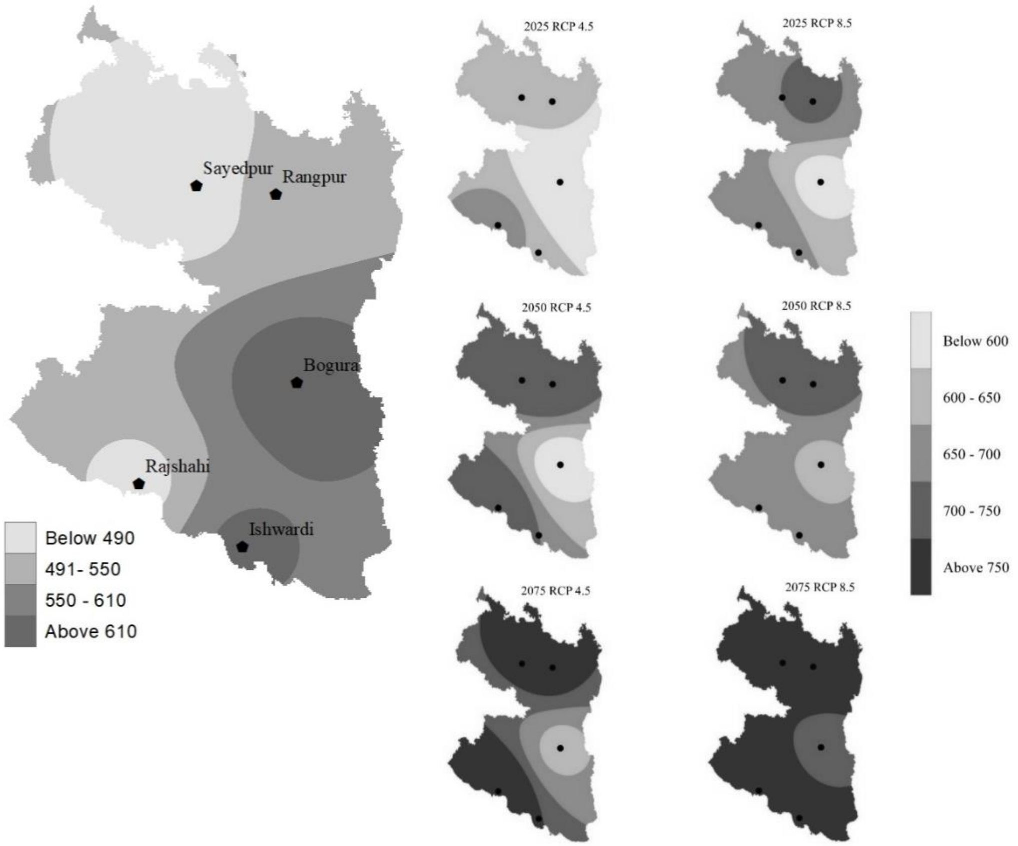

FIGURE 4: IRRIGATION WATER DEMAND OF THE STUDY AREA (LEFT) AND IRRIGATION WATER DEMAND OF THE STUDY AREA FOR DIFFERENT PERIODS AND CLIMATIC SCENARIOS

Bumper growth of Boro rice was driven by superfluous application of irrigation water and total irrigated area increased from 1.52 million ha to 5.7 million ha from 1981-82 to 2009-10 (BADC 2010).Irrigation demand of the study area for the time period 1970-2010 has been presented in Figure 3 (Right).

Analyzing the past trend of irrigation water demand of dry season Boro rice of northwest region of Bangladesh, it was observed that the demand of irrigation water mostly followed an increasing trend except the year 1990. In 1990, the region got sufficient amount of effective rainfall which eventually reduced the rate of water requirement for irrigation. However, in other cases the rate tended to enhance and the rate of increasing had remained as 70-75mm on an average. It cannot be said absolutely that the rate of irrigation demand is increasing and it will continue to increase but at least it can be said that the rate is being changed and is very much related to the changes of climatic variables;especially rainfall, and to be more specific, effective rainfall. If the rate of effective rainfall changes in the crop growing season the rate of water demand will change automatically. Present irrigation demand of Boro rice has been shown in Figure 4 (Left).

Future Irrigation Water Demand of the Study Area

Future irrigation water demand has been estimated for two climate change scenarios: RCP 4.5 (Moderate climate change) and RCP 8.5 (Increased climate change). As irrigation water demand of Boro rice is very much related to climatic variables (temperature, sunshine, wind speed, humidity, rainfall etc.), it is likely to be changed with future change of climate where all of these variables are supposed to be changed, particularly temperature. Irrigation demand of the study area has been calculated for three future years as 2025, 2050 and 2075 and for three stations;Bogura, Rajshahi and Rangpur as future climatic data are not available for other stations of the region.

In 2025, for RCP 4.5 (moderate climate change scenario), Irrigation demand of Bogura, Rajshahi and Rangpur will be 552.8 mm, 662.4 mm and 605.3 mm respectively and for RCP 8.5 the amount will be 585.6 mm, 694.9 mm and 705 mm correspondingly. The average irrigation demand of the study area in 2025 will be 606.8 mm and 662 mm for RCP 4.5 and RCP 8.5, respectively. Comparing to the present irrigation demand of the study area, the amount will be increased by 50-120 mm on an average. In 2050, for RCP 4.5 or moderate climate change scenario, Irrigation demand of Bogura, Rajshahi and Rangpur will be 578.4 mm, 742.8 mm and 735.1 mm respectively and for RCP 8.5 the amount will be 644.5 mm, 672.6 mm and 715.2 mm correspondingly. The average irrigation demand of the study area in 2050 will be 685.4 mm and 672 mm respectively for RCP 4.5 and RCP 8.5 respectively. Comparing to the present irrigation demand of the study area the amount will be increased by 130-150 mm on an average and comparing to 2025 it will increase by 10-80 mm. In 2075, for RCP 4.5, irrigation demand of Bogura, Rajshahi and Rangpur will be 640.5 mm, 798.2 mm and 765.9 mm respectively and for RCP 8.5 the demand will be 745.5 mm, 781.1 mm and 759.9 mm, correspondingly. The average irrigation demand of the study area in 2075 will be 734.9 mm and 762.2 mm respectively for RCP 4.5 and RCP 8.5 respectively. Comparing to the present irrigation demand of the study area the amount will be increased by 180-220 mm on an average and comparing to 2050 it will increase by 60-90 mm. Projected irrigation water demand of the study area for the year 2025, 2050 and 2075 and for RCP 4.5 and 8.5 is being shown Figure 4 (Right).

The additional irrigation demand of Boro rice will increase the need of water by 5832-10,648 liters. To extract this additional amount of water extra energy will be needed. The unit price of Boro rice in Bangladesh is also directly linked to energy markets. The irrigation cost of Boro rice is expected to reach to US$ 200 per hectare in 2030 (Dey*et al*., 2013) if the present trend of rising cost continued. As the genetic and agronomic scope for yield increase in rice is limited (Cassman*et al*., 2003), increasing irrigation costs will ultimately reduce farmers' net incomes.

CONCLUSION

Changing climatic condition in future will be a great challenge for the irrigation and agricultural sector of Bangladesh. Though science and technology has advanced a lot, most of the farmers of Bangladesh still follow traditional cultivation methods that has ended them being more reliable on weather and climate. The farmers cultivate crops following the crop calendar, which is totally based on seasonal behavior of the country. Irrigation water is very important for the cultivation of dry season Bororice, which is at present the major cultivated rice variety of the country. Irrigation water security is also under great threat in a climate change condition.The study projects that future irrigation demand of Boro rice in climate change situation for RCP 8.5 will be increased by 180-220 mm in 2075, which will create additional 10,648 liters of water use during crop growing season. Scarcity in irrigation water can lower the average Boro rice yield on which future food security of the country is largely reliant. Recently, Bangladesh has established itself as one of the self-sufficient nations in terms of food grain production in the world. To uphold this position in future on the face of climate change challenges, ensuring the availability of required water for cultivation is necessary. Therefore, the government as well as private sectors should work hand in hand to face the challenge successfully by performing their present responsibilities. It will be possible if present water misuse is prevented, new climate stress tolerant varieties are evolved in large number, farmers are properly trained by the state run organizations for efficient and safe cultivation practices, climate smart agricultural practices are largely accomplished and alternative sources of groundwater irrigation such as rainwater is introduced. Based on the findings of the present study it is reasonably expected that the study will contribute in devising a sustainable water management and irrigation policy that will help to cope with the changing climatic condition we are going to face in near future.

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REFERENCES

ACHARJEE T.K., HALSEMA G., LUDWIG F., AND HELLEGERS P. 2016. Declining trends of water requirements of dry season Boro rice in the northwest Bangladesh. *Agricultural Water Management,* **180**: 148-159.

ACHARJEE, T. K., LUDWIG, F., VAN HALSEMA, G., HELLEGERS, P., ANDSUPIT, I. 2017. Future changes in water requirements of Boro rice in the face of climate change in North-West Bangladesh. *Agricultural water management,* **194**: 172-183.

AGRAWALA, S., OTA, T., AHMED, A. U., SMITH, J., AND VAN AALST, M. 2003. *Development and climate change in Bangladesh: focus on coastal flooding and the Sundarbans*, Paris: OECD.

ALI, M. H., AND MUBARAK, S. 2017. Effective rainfall calculation methods for field crops: An Overview, Analysis and New Formulation. *Asian Research Journal of Agriculture,* **7(1)***:* 1-12.

BADC (2012) *Minor irrigation survey report 2012-2013*, Bangladesh Agricultural Development Corporation, Ministry of Agriculture, Government of Bangladesh.

BBS (2006). *Statistical Yearbook of Bangladesh*, Bangladesh Bureau of Statistics, Statistics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka.

BBS (2018). *45 years Agriculture Statistics of Major Crops (Aus, Amon, Boro, Jute, Potato & Wheat),* Statistics and Informatics Division, Ministry of Planning, Dhaka.

BROUWER, C., AND HEIBLOEM, M. 1986. *Irrigation water management: Irrigation water needs*. *Training manual,* ***3****.*

BOUMAN, B. 2009. How much water does rice use? *Management*, **69**:115-133.

CASSMAN, K. G., DOBERMANN, A., WALTERS, D. T., AND YANG, H. 2003. Meeting cereal demand while protecting natural resources and improving environmental quality. *Annual Review of Environment and Resources, **28***(**1**)**:** 315-358.

CLARKE, D., SMITH, M., AND EL-ASKARI, K. 2001. *CropWat for Windows: user guide*. IHE.

DEY, N. C., BALA, S. K., ISLAM, A. K. M. S., RASHID, M. A., AND HOSSAIN, M. 2013. *Sustainability of groundwater use for irrigation in northwest Bangladesh*. Policy Report prepared under the National Food Policy Capacity Strengthening Programme (NFPCSP). Dhaka, Bangladesh.

HOSSAIN, M. B., YESMIN, S., MANIRUZZAMAN, M., AND BISWAS, J. C. 2017. Irrigation Scheduling of Rice (Oryza sativa L.) Using CROPWAT Model in the Western Region of Bangladesh. *The Agriculturists,* **15(1):** 19-27.

ISLAM, A. T., SHEN, S., YANG, S., HU, Z., AND CHU, R. 2019. Assessing recent impacts of climate change on design water requirement of Boro rice season in Bangladesh. *Theoretical and Applied Climatology,* **138(1)**: 97-113.

MAINUDDIN, M., KIRBY, M., CHOWDHURY, R. A. R., SANJIDA, L., SARKER, M. H., AND SHAH-NEWAZ, S. M. 2014. *Bangladesh integrated water resources assessment supplementary report: land use, crop production and irrigation demand*. CSIRO: Australia.

MAINUDDIN M., KIRBY M., CHOWDHURY R.A.R, AND SHAH-NEWAZ S.M. 2015. Spatial and temporal variations of, and the impact of climate change on, the dry season crop irrigation requirements in Bangladesh. *Irrigation Sciences,* **33(2)**: 107-120.

PONGPINYOPAP, S., AND MUNGCHAROEN, T. 2012. Comparative study of green water footprint estimation methods for Thailand: A case study of cassava-based ethanol. *Environment and Natural Resources Journal,* **10(2)**: 66-72.

RAHMAN, N. M. F., HOSSAIN, M. I., AZIZ, M. A., BATEN, M. A., ANDKABIR, M. S. 2013. Prospects of Boro rice production in Bangladesh. *Advances in Environmental Biology,* **7(14)**: 4542-4549

RAHMAN, M. A. 2017. *Spatiotemporal variability analysis of temperature, precipitation, reference evapotranspiration and irrigation demand under changing climate of Bangladesh* [Unpublished doctoral dissertation]. Nanjing University of Information Science and Technology.

RAHMAN, M. A., YUNSHENG, L., SULTANA, N., AND ONGOMA, V. 2019. Analysis of reference evapotranspiration (ET 0) trends under climate change in Bangladesh using observed and CMIP5 data sets. *Meteorology and Atmospheric Physics*, **131(3)**: 639-655.

SAYEED, K. A., AND YUNUS, M. M. 2018. *Rice prices and growth, and poverty reduction in Bangladesh*. Food and Agriculture Organization of the United Nations, Rome.

SHAHID, S. 2008. Spatial and temporal characteristics of droughts in the western part of Bangladesh. *Hydrological Processes: An International Journal*, **22(13)**: 2235-2247.

SHAHID, S., ANDBEHRAWAN, H. 2008. Drought risk assessment in the western part of Bangladesh. *Natural Hazards*, **46(3)**: 391-413.

SHAHID, S. 2011. Impact of climate change on irrigation water demand of dry season Boro rice in northwest Bangladesh. *Climatic change*, **105(3-4)**: 433-453.

SOLOMON, S. 2007. IPCC (2007*): Climate change the physical science basis*. In Agu fall meeting abstracts (Vol. 2007, pp. U43D-01).

STOCKER, T. F., QIN, D., PLATTNER,G. K., TIGNOR,M.,ALLEN, S. K., BOSCHUNG,J., NAUELS,A., XIA,Y.,BEX, V., AND MIDGLEY, P. M. "IPCC, 2013." *Climate change* (2013).

VAN VUUREN, D.P., EDMONDS, J., KAINUMA, M., RIAHI, K., THOMSON, A., HIBBARD, K., HURTT, G.C., KRAM, T., KREY, V., LAMARQUE, J.F., AND MASUI, T. 2011. The representative concentration pathways: an overview. *Climatic change*, **109(1)**: 5-31.

WORLD BANK. (2000). *Bangladesh: Climate Change & Sustainable Development.* Report No. 21104 Bangladesh, Dhaka

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