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Water-Table Dynamics, Its Trend and Sustainability Considerations at Two Upazila of North-Western Bangladesh

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Abstract:
The study aimed to determine the long-term trend of the groundwater table and to forecast the future situation of north-western part of Bangladesh. Using a non-parametric technique (through MAKESENS software), the trend was examined. The patterns of the yearly maximum and minimum depth to Water Table (WT) showed that the magnitude between the maximum and minimum is dwindling over time, implying a decreasing recharge rate. The depth to WT would be almost 1.5 times greater in 2050 and nearly twice as much in 2075, according to the projected scenario for WT. The "Discrete Space-State model" was also used to forecast the WT. Both models generally yielded findings that were quite close. If the decline of the water table is allowed to last for an extended period of time, the ecology and the sustainability of agricultural output, which is crucial for the nation's food security, could be significantly threatened. The necessary actions should be taken to sustain water supplies, which will then maintain agricultural production. Demand-side management and alternative agricultural practices (such as the introduction of crops with lower water requirements) seem to be workable alternatives for the area.

Keyword: Water-table dynamics, non-parametric method, Discrete Space-State model, sustainability

INTRODUCTION

In recent years, the primary policy goal in farm management, particularly in nations with limited water and land resources, has been the growth in food production while using less irrigation water (FAO, 2021). Since its liberation, food security has been a persistent problem in Bangladesh, one of the world's most densely populated nations. In Bangladesh's agriculture over the past 25 years, the extension of irrigated cropl and primarily accomplished through groundwater irrigation, has likely been the most significant change. The contribution of groundwater has grown from 41% in 1982–1983 to 79% in 2016–2017 (BBS 2017). In Bangladesh's north-western districts, as opposed to other regions of the nation, a far higher proportion of groundwater than surface water is used. With an average annual rainfall ranging between 1,400 and 1,900 mm, this region is classified as a dry humid zone by the climate. Less than 6% of this rainfall falls during the irrigation period for rice farming's dry season (November to April), and almost 94% rainfall occurs during May to October (Ali et al., 2021a). In order to meet the need for farming crops, particularly for Boro rice, during the dry season, all of the rivers and canals dry up, leaving the population entirely dependent on groundwater (Hossain and Mojid, 2022)

Although groundwater accounts for the majority of the area that is irrigated, excessive resource extraction in the northwest region has put the groundwater's quantity sustainability at jeopardy (Zaman et al., 2019; Ashraf and Ali, 2015). The primary causes of the current issue, according to researchers, are excessive groundwater extraction for irrigation due to ignorance, cultivation of water-intensive crops, irrational irrigation management, indiscriminate pump installation, and a lack of modern technologies (Reza et al., 2020; Adhikary et al., 2013).

According to several studies, the groundwater table in some parts of the Barind tract of the northwest region has decreased by at least 10 meters during the past 14 years (Ali et al., 2021b). Groundwater decline poses a threat to future water resources if it is not refilled on a regular basis by seasonal rainfall, with strong declining trends (0.5-1.0 meters/year) in the country's central region and moderate declining trends (0.1-0.5 meters/year) in the west, north west, and north-eastern regions during dry season.

The considerable reduction in groundwater levels over the past ten years has threatened both the ability of this region to sustainably use water for irrigation and how it is affecting other businesses (Jahan et al., 2010; Ali et al., 2011). The environment, society, and the economy are all negatively impacted by persistent water shortages (Islam et al., 2013). If this usage persists, it might cause exhaustion within a few years, which would have a significant impact on the country's agriculture-based economy.

The water resources in all sectors and the water demand during dry periods were estimated and forecasted in the National Water Management Plan 2001 for a 25-year timeframe (NWMP, 2001). According to the study, water supply for domestic and commercial use in urban and rural areas will be more than twice as large as it is now, and demand for irrigation is predicted to rise by as much as a quarter (1/4) during the next 25 years. Integrated surface water and groundwater model study in the Barind area which covers 25 Upazilas of Rajshahi, Chapainawabganj and Naogaonditricts was carried out by IWM (2006). MIKE, SHE integrated with MIKE 11 Modelling system having 1000m x 1000m grid size covers about 7500 sq. km of study area. Based on available data up to 2005, study found the 11 Upazilas (out of 25) have less groundwater resources create some problem to meet the present water demand of Boro crops (IWM, 2012).

According to research by the Barind Multi-Purpose Development Authority (BMDA) (IWM, 2006), the northwest region's groundwater table varies from 1 to 13 meters below ground level during dry seasons. In some study sites, it has been observed that the groundwater level may additionally decrease by between 0.5 and 1.0 meters as a result of climate change.

Recent data on the resource and optimization for the region's sustainable agricultural development are required for the long-term usage of this important and precious resource in the Barind region. In order to assess the long-term trend of the groundwater table (GWT) in the Barind region of Bangladesh, the study was undertaken.

METHODOLOGY

Description of The Study Area

Niamatpur Upazila under Nawgaon district and Nachol Upazila under Chapai Nawabganj district are two study areas which is from $89^{\circ}18'$ to $89^{\circ}22'$ East and $24^{\circ}22'$ to $24^{\circ}51'$ North and illustrated in Figure 1.

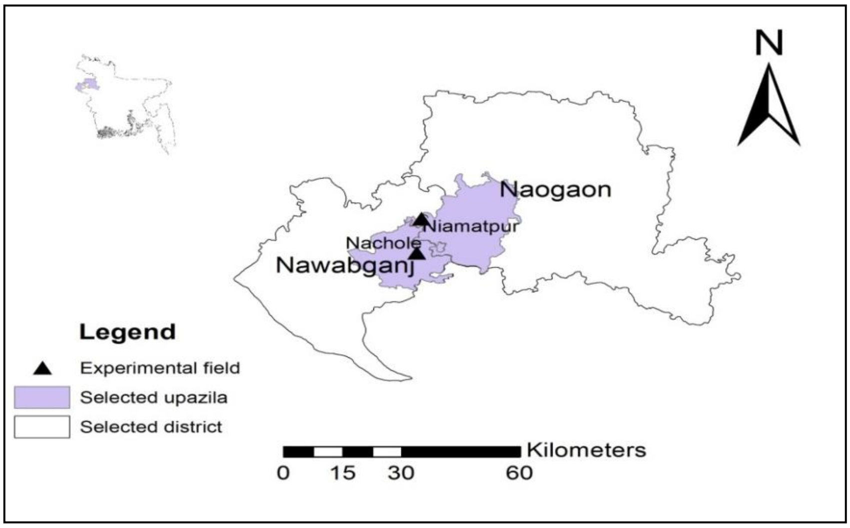


Figure 1. Location map of the study areas (Nachol and Niamatpur)

Hydro-Geological Features of The Study Area

Two separate landforms make up the geography of the area: (a) the dissected and undulating Barind tract; and (b) the floodplains. Due to the clayey and semi-to-impermeable Barind clay and high surface runoff, the elevated Barind tract has less infiltration. Three geological units make up the region's morpho-stratigraphy: (1) Barind clay residuum, which is alluvium that was developed over Pleistocene alluvium, (2) Holocene Ganges flood-plain alluvium, and (3) Active channel deposits of the Ganges and its distributaries (modern alluvium). Alluvial sand, alluvial silt, Barind clay residuum, Marsh clay, and peat are among the lithology categories (Alam et al., 1990). When it comes to hydrogeology, the region is characterized by single to multiple layered clay-silt aquitard of the Recent-Pleistocene age (thickness 3.0 - 47.5 m) (Jahan et al. 2005).

Rainfall Pattern of The Study Location

The graph in Figure 2 shows the monthly rainfall pattern from 2001 to 2020 (which was collected from BMDA Nachol office). The months from May to September is known as monsoon season, when most of this rainfall falls.

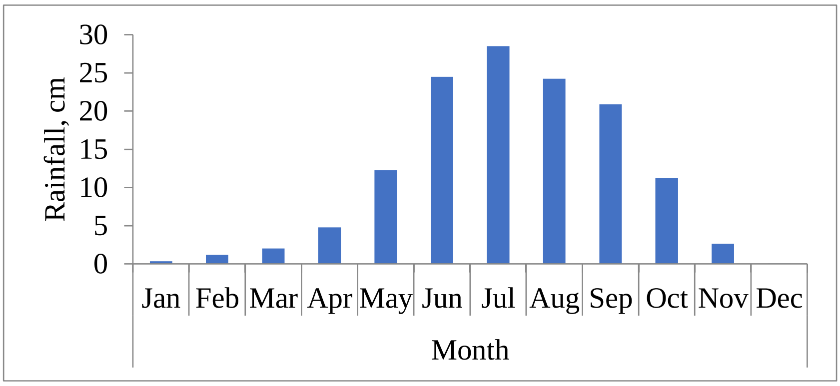


Figure 2. Monthly rainfall pattern in the study area

Water-Table Dynamics

The water-table (WT) data were collected from Bangladesh Water Development Board (BWDB) and also from Barind Multipurpose Development Authority (BMDA). To better understand the dynamics of the groundwater system, graphical representations of the seasonal and long-term patterns of WT fluctuations are provided. The long-term trend is determined using the yearly maximum depth to the water table.

Water-Table Trend Analysis by MAKESENS Model

Trends were estimated using the "MAKESENS" software. The non-parametric Mann-Kendall test for trends and the non-parametric Sen's approach for trend magnitude are the foundations of this software (Salmi et al. 2002). The non-parametric approach has the benefit of working with missing data and applying to both monotonic and non-monotonic trends.

The model also makes use of Gilbert's "S statistics" and "Z statistics" (the normal approximation) (Gilbert, 1987). The *S* test is applied to time series with less than 10 data points; the *Z* test is applied to time series with 10 or more data points.

Mann-Kendall Test

The Mann-Kendall test is applicable in cases where the data values x_i of a time series can be assumed to obey the model

$$x_i = f(t_i) + \varepsilon_i \tag{1}$$

in which, f (t) is a continuous, monotonic, increasing or decreasing function of time, and where ε_i is a set of residuals that may be assumed to come from the same distribution as the sample as a whole and have a mean of zero. The variance of the distribution is consequently thought to be constant throughout time.

The examined data series' n stands for the number of yearly values. The Mann-Kendall test statistic S is computed using the following formula when the number of data values is less than 10:

$$S = \sum_{k=1}^{n-1} \sum_{j=1}^{n} \operatorname{sgn}(x_j - x_k) \tag{2}$$

When j > k, xj and xk are, respectively, the yearly values in the years j and k; and

$$\operatorname{sgn}(x_j - x_k) = \begin{bmatrix} 1 \; if \;\; x_j - x_k > 0 \\ 0 \; if \;\; x_j - x_k = 0 \\ -1 \; if \;\; x_j - x_k < 0 \end{bmatrix} \tag{3}$$

The theoretical distribution of S developed by Mann and Kendall is directly compared with the absolute value of S if n is 9 or fewer (Gilbert, 1987). The two-tailed test is applied in MAKESENS for four distinct significance levels of: 0.1, 0.05, 0.01 and 0.001.

Salami et al. (2002) provided further information on the MAKESENS model. The formula used to forecast the WT conditions is:

$$\text{WT (m)} = \text{B} + \text{Q} \times (\text{Simulation year} - \text{Base year}) \tag{4}$$

Where, as determined from model output, B is the intercept and Q is the slope of the trend line. The simulation years 2050, 2075, and 2100 were chosen. The year 1981 served as the base year (the first year of the data set) of our study.

WT Prediction by Discrete Space-State Model

The Discrete Space-State model was used to predict WT for several wells. This model is created by dividing the original time series data into identification and validation data. Then, the model is used to predict WT for the future time period (Roy et al., 2021).

RESULTS AND DISCUSSION

Groundwater Dynamics

The seasonal maximum and minimum water-table patterns (1981-2019) for Nachol and Niamatpur are shown in Fig. 3.1 and Fig.3.2, respectively. The water table is gradually dropping, and it has been doing so at a rate of 0.43 m/year in Nachol and 0.33 m/year in Niamatpur.

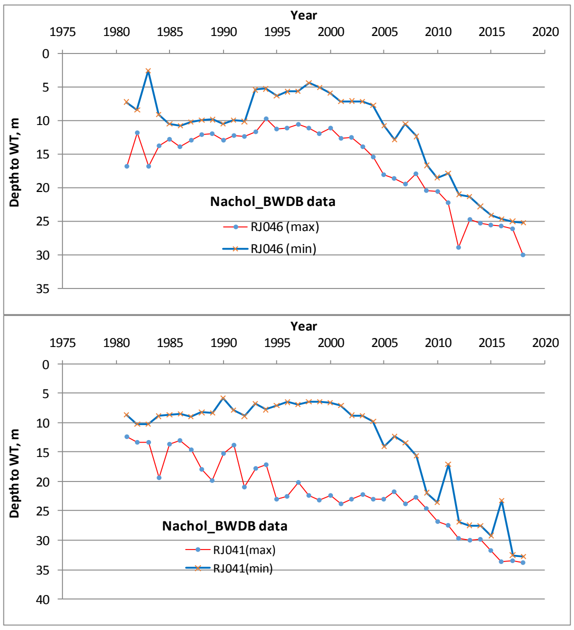


Figure 3.1. WT pattern of two wells at Nachol

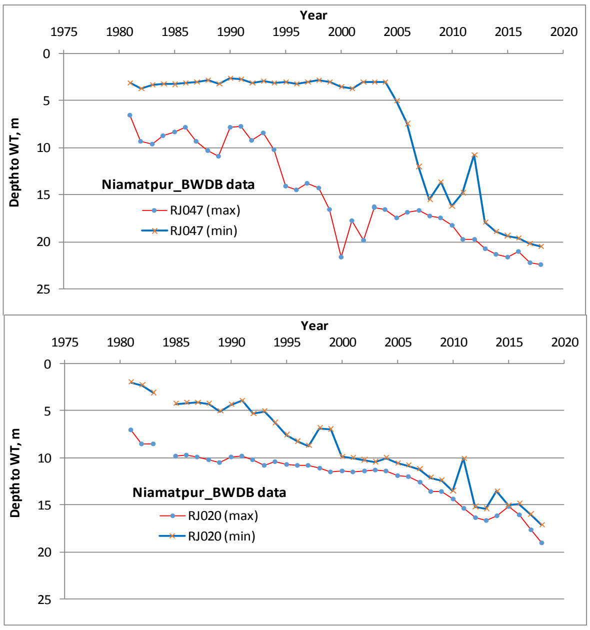


Figure 3.2. WT pattern of two wells at Niamatpur

Output of MAKESENS Model

The position of water-table (both maximum and minimum) in different wells of Nachol and Niamatpur in 1981and 2018, and the predicted scenario for 2025, 2050, 2075 and 2100 are tabulated in Table 3.1. In 2050, it is predicted that the water table will be about 1.5 times deeper. In 2075, it is predicted that the water table will be nearly twice as deep in 2018.

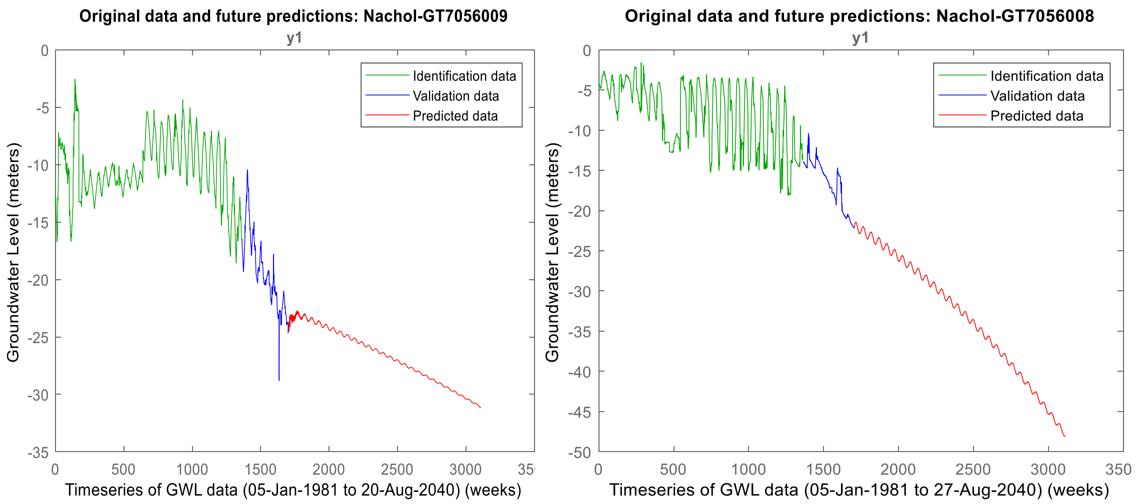
Table 3.1. Position of maximum WT depth in the past and simulated scenario for future, using MAKESENS software at Nachol and Niamatpur Upazilla.

Upazilla	Well no	WT depth (m) in year		B	Q	Predicted WT depth (m) in year				Significance level of trend
		1981	2018			2025	2050	2075	2100	
Nachol	GT7056006	12.3	33.45	12.38	0.523	35.39	48.49	61.57	74.66	***
	GT7056007	11.72	33.52	13.53	0.469	34.16	45.90	57.63	69.36	***
	GT7056008	4.82	25.1	5.80	0.490	27.36	39.61	51.86	64.11	***
	GT7056009	16.72	26.00	8.63	0.410	26.67	36.94	47.19	57.45	***
	GT7056011	7.37	29.69	11.30	0.518	34.09	47.06	60.01	72.97	***
Niamatpur	GT 29	8.46	19.05	7.91	0.213	17.28	22.57	27.89	33.20	***
	GT 30	9.28	21.3	7.06	0.419	25.49	35.98	46.45	56.93	***
	GT 31	7.02	13.44	6.72	0.215	16.18	21.55	26.93	32.30	***
	GT32	9.25	26.8	6.18	0.587	32.00	46.68	61.36	76.03	***

Note: B = Intercept of linear regression equation; Q = Slope of linear regression equation and *** trend is significant at α = 0.001; ** trend is significant at α = 0.01; * trend is significant at α = 0.05; + trend is significant at α=0.1.

Output of Discrete Space-State Model

Predicted WT of some of the wells by 'Discrete Space-State model' are tabulated in Table 3.2 along with MAKESENSE output, and also presented in Fig.3.3. Except one well (GT6459030), both the models produced almost similar results. For GT6459030 well, the prediction by Discrete Space-State model is not logical according to the base data (Fig.3.3).



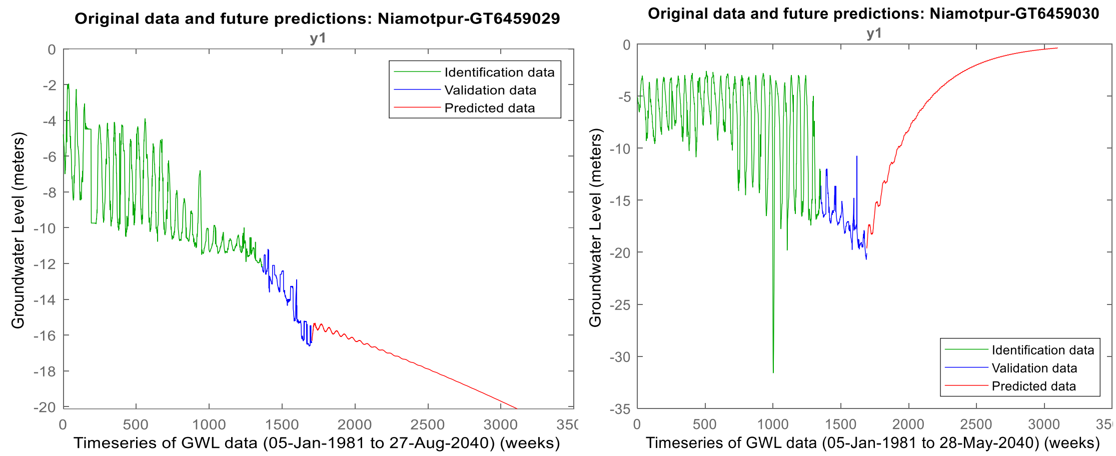


Fig.3.3. WT time series along with Predicted WT

Table 3.2 Comparative evaluation of predicted WT by Steady-State model and MAKESENS model

	Well No.	Predicted WT(m) by Steady State model		Predicted WT(m) by MAKESENS model	
		Year 2025	Year 2040	Year 2025	Year 2040
Nachol	GT7056008	30.91	47.97	27.36	34.71
	GT7056009	26.13	31.15	26.67	32.82
Niamatpur	GT6459029	17.34	20.13	17.28	20.47
	GT6459030	3.36	0.37	25.49	31.78

Discussions

The study found that groundwater usage has outpaced groundwater recharge, meaning that the water table is slowly decreasing. If this trend continues, many wells' water table depths will be roughly 1.5 times what they are now by 2050, and in virtually all cases, they will have doubled by 2075. This could lead to higher irrigation water costs, which would affect crop production. Groundwater is a valuable resource, but it can't be regenerated on a large scale. So, we need to make sure that we use it sustainably so that we don't extract too much from the aquifer over time. This is called sustainable groundwater utilization. If groundwater levels are falling over time, this means that we're using too much groundwater and it's not being replenished fast enough. The groundwater level is dropping, and this could lead to a number of environmental and ecological disasters. If we don't take measures to prevent groundwater mining, these disasters could become permanent obstacles to the region's socioeconomically sustainable development. So, measures should be taken to prevent groundwater mining. We can do this by using management techniques like demand-side planning (e.g., cultivating low water-demanding crops, efficient irrigation management, converting to natural rainfall-matching cropping pattern – such as Aus rice) and looking for surface water sources, which would reduce our dependence on groundwater. There is also an urgent need to change the monopoly of rice-based cropping patterns.

CONCLUSION

The MEKESENS software is used to predict the future and take into account how much water is being taken out of the ground each year. If the rate of water withdrawal continues at the same pace, the ground will be lowered by 1.5 times by the year 2050. This could have many negative consequences, including less water for plants and animals, higher pumping costs, and environmental damage. So, preventive measures should be taken to avoid undesirable circumstances.

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REFERENCES

Adhikary S.K., Das S.K., Saha G.C. and Chaki T. (2013). Groundwater Drought Assessment for Barind Irrigation Project in Northwestern Bangladesh. 20th International Congress on Modelling and Simulation, Adelaide, Australia, 1–6 December 2013. www.mssanz.org.au/modsim2013

Ali, M.H., M. Hassanuzzaman, P. Biswas (2021a). Groundwater resources management for sustainable crop production in northwest hydrological region of Bangladesh (BINA Component). Bangladesh Institute of Nuclear Agriculture, Project Completion Report, p.125

Ali, M. H., Zaman, M. H., Islam, M. A., Biswas, P., Karim, N. N., & Kader, M. A. (2021b). Recent Trend of Precipitation and Crop Planning in Rajshahi Region of Bangladesh. *Asian Journal of Advances in Agricultural Research*, *16*(4), 28-39. https://doi.org/10.9734/ajaar/2021/v16i430183

Ali, M. H., A.A. Sarkar, M.A. Rahman (2012). Analysis on groundwater-table declination and quest for sustainable water use in the North-western region (Barind area) of Bangladesh. J. of Agril. Sci. and Applications. 1(1):26-32

Ali, M. H., I. Abustan, M.A. Rahman, A.A.M. Haque (2011). Sustainability of Groundwater Resources in the North-Eastern Region of Bangladesh. Water Resour. Manage. 26:623–641

Asraf, T., M. H. Ali (2015). Water-table dynamics and trend in three Upazilas of Rajshahi district (Barind area), Bangladesh. Asian Academic Research Journal of Multidisciplinary, 2(6): 286 -310

BBS (Bangladesh Bureau of Statistics), 2017. Yearbook 16, Series 28. Statistics and Informatics Division (SID), Ministry of Planning, Government of the People's Republic of Bangladesh, Dhaka, Bangladesh.

FAO (Food and Agricultural Organization of the United Nations). 2021. The state of the world's land and water resources for food and agriculture – Systems at breaking point. Synthesis report 2021, Rome. https://doi.org/10.4060/cb7654en

Gilbert (1987) Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold, New York.

Hossain, M.A. and Mojid, M.A. 2022. Groundwater Withdrawal Trend and Management Considerations in an Intensive Groundwater Irrigation Region in Bangladesh. Journal of Bangladesh Agricultural University, 20(1): 79–87. https://doi.org/10.5455/JBAU.140654

Islam M.S. (2013). Estimation of Aquifer Parameter of Pabna District, Bangladesh. Global Journals Inc. (USA), Volume 13 Issue 4 Version 1.0 Year 2013.

IWM (2012). Groundwater Resources Study for Barind Integrated Area Development Project, Phase-III Volume-1, Final Report.

IWM [Institute of Water Modelling] (2006). Groundwater Model Study for Deep Tube Well Installation Project in Barind Area. Final Report. Dhaka, Bangladesh.

Jahan CS, Islam MA, Mazumder QH, Asaduzzaman M, Islam MM, Islam MO, Sultana A. (2005). Evaluation of depositional environment and aquifer condition in the Barind area, Bangladesh, using gamma ray well log data. *J. Geol. Soc. India*, 70: 1070-1076.

Jahan, C.S., Mazumder, Q.H., Islam, A.T.M.M. and Adham, M.I. (2010). Impact of irrigation in barind area, NW Bangladesh-an evaluation based on the meteorological parameters and fluctuation trend in groundwater table. Journal Geological Society of India.

NWMP [National Water Management Plan] (2001). Main Report, Volume 2, Ministry of Water Resources. Government of Bangladesh.

Reza, M.S., M.I. Hossain, M.E. Hossain, 2020. Environmental Challenges and the Measures Taken by the BMDA for Sustainable Agriculture and Environment in the Barind Tract, North-West of Bangladesh. International Journal of Agricultural Economics. Vol. 5, No. 5, 2020, pp. 197-209. doi: 10.11648/j.ijae.20200505.17

Roy DK, Biswas SK, Shaha KK, Murad KFI (2021). Groundwater level forecast via a discrete space-state modelling approach as a surrogate to complex groundwater simulation. Water Resources Management, DOI: 10.1007/s11269-021-02787-6

Salmi T, Maatta A, Anttila P, Airola TR, Amnell T (2002) Detecting trends of annual values of atmospheric pollutants by the Mann-Kendal test and Sen's slope estimates – The Excell Template Application MAKESENS. User manual, Publication on air quality, Finish Meteorological Institute, p.35

Zaman, M.H.; Ali, M.H.; X. Song (2019). The nature of groundwater dynamics under intensive dry-season Boro rice cultivation: A case study in Bogra district, northwest region of Bangladesh. J. of Agril. Engg., The Inst. of Engrs., Bangladesh, 42/AE (1): 33-44