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Statistical Evaluation of Groundwater Table Changes in Jashore District of Bangladesh for Sustainable Use

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Abstract: Groundwater (GW) sustainability is a key concern for the high dependency on groundwater for agricultural and domestic uses in the southwestern region of Bangladesh. So, this study intends to analyze the pattern of current and predicted changes in the water table for future development. It is based on selected wells in the Jashore district's eight Upazilas. MAKESENS has been used to analyze the dynamics of GW levels for long-term prediction, and Geographic Information System (GIS) is utilized to visualize the results. This study reveals the annual water table (WT) depth lowering with a decreasing rate of maximum and minimum 0.17 and 0.04 m/year, respectively. The suction limit is considered 8m because shallow tube wells utilize atmospheric pressure to lift water. The standard atmospheric pressure is 1.034 kg/cm^2, equivalent to 10.34m (maximum theoretical lift) of the water column, which reduces to 8m due to frictional head losses in the pipe. It is anticipated that the WT of some of the study area's locations will be lowered beyond the suction limit by 2030 if the declining trend continues. This research's findings may be useful in understanding the GW situation, GW management, and GW related activities in the study area.

Keywords: *Groundwater Dynamics, MAKESENS, Water Table, ArcGIS, STW*

Introduction: Groundwater is a valuable resource, considering a dependable water supply for agriculture, residential, and industrial usage. Rise in population, food shortages, growing economies, and ineffective water management are putting unprecedented pressure on the world's water sources [1]. Due to the limitation of surface water resources, groundwater is the most crucial condition for improving crop yields and assuring the sustainability of agricultural growth. Irrigation is critical to food security in many parts of the world, and groundwater use has increased to become a major source of irrigation water, particularly in China and South Asia [2,3]. Each year, a substantial amount of water is pumped through various water-lifting devices, primarily for irrigation, domestic, and industrial usage. In Bangladesh, agricultural production has greatly risen due to the availability of groundwater. During the dry season, most of the region's rivers and canals have dried up, and people have switched their water supply from surface to groundwater [4–6]. Shallow tube wells (STW's) are the principal source of irrigation, and their number has expanded from approximately 100,000 in the early 1980s to more than 1.5 million now [7]. Groundwater depletion has been accelerated to the point that it is not entirely replenishing during the rainy season in certain areas due to drastic reduction of the previous surface along with the over-extraction of groundwater for agriculture, industrial, and household uses during the dry season. Groundwater resource assessment and environmental protection studies are required to improve and intelligently exploit groundwater resources, as well as to develop water protection and conservation rules for the government. Groundwater management practices must be used sustainably to ensure their conservation and restoration for future generations [8].

Some researchers have studied the Water table depth dynamics and long-term trend for the northeastern Mymensingh district [9], the northwestern Bogra District [10], the northwestern Joypurhat district [11], and the Chapai-Nawabganj, Naogaon, district [12] of Bangladesh using the MAKESENS model.

Realizing the significance, a thorough examination is conducted with a focus on groundwater well monitoring in Jashore district, Bangladesh. The research area is located in the southwest region of Bangladesh, suffering from insufficient rainfall and high salinity in surface water. The aim is to evaluate the temporal changes in groundwater level in observed wells to get further insight into the confidence level of their trend test and residual distribution for the Sen's slope. The groundwater level dynamics of the region, the current trend, and the prediction would be useful in future planning for the sustainability of groundwater. In alignment with the above discussion, the objectives were set to study the variation of groundwater table trends from 2011 to 2020 using monitoring wells in the Jashore district, determine the significance of changes in GWT using the MAKESENS model and ArcGIS for further development of GWT patterns for the future, and realize sustainable groundwater use in the region.

Materials & Method : Site Description: Jashore district is bounded by Jhenaidah district to the north, Narail and Magura districts to the west, Khulna and Sathkhira districts to the south, and India to the west. The district has a total area of 2606.94 square kilometers (1006 Square Miles), of which 23.39 square kilometers (9.03 square miles), is reserved for riverine [13]. The district

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is located between the latitudes of 22°48' and 23°22' north and the longitudes of 88°51' and 89°34' east. Maximum and minimum annual temperatures range from 37°C to 11°C. Annual rainfall is 1537 mm. The Jashore region includes the mostly highland and medium highland western section of the Ganges River floodplain. Dark grey floodplain grounds and calcareous brown floodplain grounds are the two predominant soil types. Brown ridge soils have a lower organic matter level than dark grey soils. As a result, the PH of soils is quite alkaline and the general fertility level is low [13]. This region is suitable for agricultural crop production, especially cereals and vegetables. Compared to other regions of the country, the amount of farming is substantially higher here [13]. Modern Boro rice cultivation in the region is generally limited by its low water-holding ability. Water stagnation is also a problem in some specific locations. The whole area holds comparatively drier weather than the other parts of the country [13]. The wells are chosen accordingly since the entire Jashore district is intended to be covered. The present study consists of 8 sub-districts called "Upazila". A location map of the study area is shown in Fig. 1.

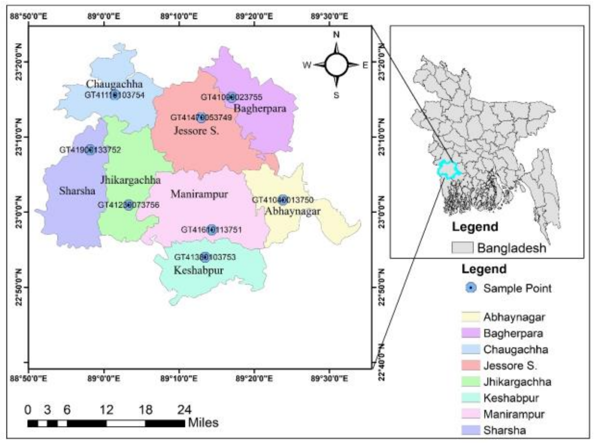

Fig. 1: Location of the study area and groundwater monitoring wells.

Data Collection and Analyses: The long-term (10-year) WT depth data, from 2011 to 2020, were collected from BWDB (Bangladesh Water Development Board). Eight observation wells have been used in the region to monitor groundwater levels. The elevation, position, and well ID of each well located in the Upazilas of Jashore district are displayed in [Table 1.]. Around 10 years of monthly meteorological data were collected from the Bangladesh Meteorological Department (BMD). MS Excel and the MAKESENS model (developed by the Finnish Meteorological Institute, 2002) are used to analyze the data. Additionally, Arc GIS 10.5 software was used for image processing.

Table 1. Location and well ID of the study area.

No.	Upazilla	Well No.	Elevation (m)	Latitude	Longitude
1	Jessore Sadar	GT41470053749	42.68	23.21	89.216
2	Abhaynagar	GT41040013750	27.84	23.027	89.3967
3	Manirampur	GT41610113751	39.02	22.961	89.239
4	Sharsha	GT41900133752	28.04	23.138	88.97
5	Keshabpur	GT41380103753	30.55	23.4696	88.777
6	Chaugachha	GT41110103754	32.93	23.322	88.802
7	Bagherpara	GT41090023755	25.16	23.255	89.283
8	Jhikargachha	GT41230073756	12.82	23.016	89.055

Rainfall pattern and WT dynamics of the study area: The average long-term WT depth fluctuation is seen as significant in the study area, and the trend from 2011 to 2019 is downward Fig. 2. In addition, during the same period, the study region's annual rainfall varied from 1361 to 1533 mm. It is observed that except for the years 2015 and 2017, the annual rainfall pattern is trending downward (Fig. 2). The result illustrates the necessity of groundwater use in that region.

Additionally, as seen in Fig. 3, the major portion of rainfall happens during the monsoon season (June-September), and as groundwater replenishment is crucial, this water frequently finds its way into rivers. In contrast, little to no rainfall is observed during the dry season (December-February, from the year 2011 to 2019) when the rice variety Boro crop, needs a substantial quantity of water (Fig. 3), That in turn increases the necessity of groundwater abstraction for drinking and household purposes.

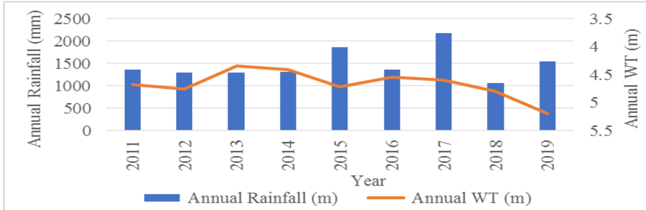

Fig. 2: Annual rainfall and water table change pattern of the study area.

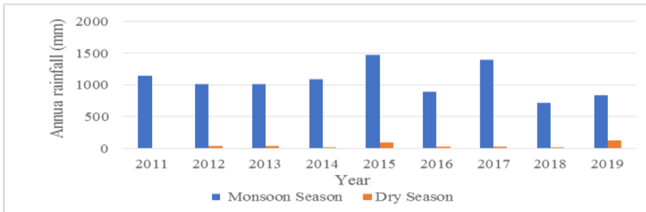

Fig. 3: Rainfall pattern for Dry and Monsoon Season.

WT Dynamics: The groundwater level's dynamic behavior is explained by the graphical presentation of the long-term WT depth patterns. The trend of meteorological and hydrological data has been analyzed using a variety of techniques, including non-parametric and parametric (linear regression) methods. Widely used time-series analysis, such as the Mann–Kendall trend test and Sen's slope estimator in the hydrological analysis has been applied [14–17]. The "MAKESENS" model is used to detect and estimate the simulated trends of the maximum WT depth, [18], which is based on the non-parametric Mann–Kendall test for trends and the non-parametric Sen's method for the magnitude of the trend [19]. It has the ability not only to identify any potential trend in temperature or hydrological series- but also asses if such patterns are statistically significant. This test compares the null hypothesis of no trend to the alternative hypothesis of either an increasing or decreasing trend. Moreover, normal distribution of the data is not necessary for this test. Nonparametric tests, in general, necessitate less restrictive data assumptions. These tests should also be used because of the ability to examine ranked and categorical data. The non-parametric method has the benefit of suitability for monotonic trends and does not require any missing data. The normal approximation or Z statistics and the so-called S statistics are also utilized by the model [20]. The S test is used for a time series with fewer than ten data points; the Z test is used for a time series with ten or more data points. The Mann-Kendall test is valid when the data values x_i (eq. 1) of a time series are assumed to obey the following model.

$$X_i = f(t_i) + \varepsilon_i \quad \text{(eq. 1)}$$

Where f(t) is a continuous monotonic increasing or decreasing function of time and the residuals ε_i are assumed to be from the same zero-mean distribution.

When data values are 10, the number of annual values in the studied data series is denoted by n, and the Mann-Kendall test statistic (S) is calculated (eq. 2) because the Mann-Kendall test is valid.

$$S = \sum_{k-1}^{n-1} \sum_{j-1}^{n} sgn(x_j - x_k) \quad \text{(eq. 2)}$$

Where x_j and x_k are the annual values in years j and k, respectively, ($j > k$), and

$$sgn(x_j - x_k) = \begin{vmatrix} 1\, if (x_j - x_k) > 0 \\ 0\, if\, (x_j - x_k) = 0 \\ -1\, if\, (x_j - x_k) < 0 \end{vmatrix} \quad \text{(eq. 3)}$$

The minimum values of *n* with which these four significance levels can be reached are derived from the probability table [Table 2.] for S as follows.

Table 2. Minimum values of n for each significance level.

Significance level, α	Required n
0.1	≥4
0.05	≥5
0.01	≥6
0.001	≥7

When the value of *n* is 9 or less, the absolute value of *S* is compared with the theoretical distribution of *S* derived by Mann and Kendal [20]. The significance levels tested in MAKESENS are 0.1, 0.05, 0.01, and 0.001. Further details about the MAKESENS software can be found in [19]. The WT depths were projected [18] in (eq. 4) as

$$\textbf{WT depth (m)} = \textbf{B} + \textbf{Q} \times \textbf{(Simulation year - Base year)} \qquad \text{(eq. 4)}$$

The projections were made for 2026, 2028, and 2030, where B is the intercept and Q is the slope of the trend line. The year 2011 is selected as the starting point.

Results of the Historical Data Analysis

Long-term pattern of yearly data: The long-term (2011-2020) annual WT depth trends under observed wells are shown in [Fig. 4]. Although WT depths in this figure are within the suction limit in many scenarios, the well's current yearly WT depth is typically near to the suction limit (8 m). Six out of eight wells were showing decreasing tendencies, with a maximum decreasing rate of 0.17 m/year in contrast to a maximum growing rate of 0.04 m/year. Wells in Jashore Sadar Upazila (GT41470053749) and Abhaynagar Upazila (GT41470053750) are the most vulnerable. At Jashore Sadar Upazila, WT depths were declining within the range of 4.90 m to 6.38 m at a rate of 0.17 m per year. At Abhaynagar Upazila, the decreasing trend was showing at a rate of 0.12 m/year, within the limit of 5.10 m to 6.25 m.

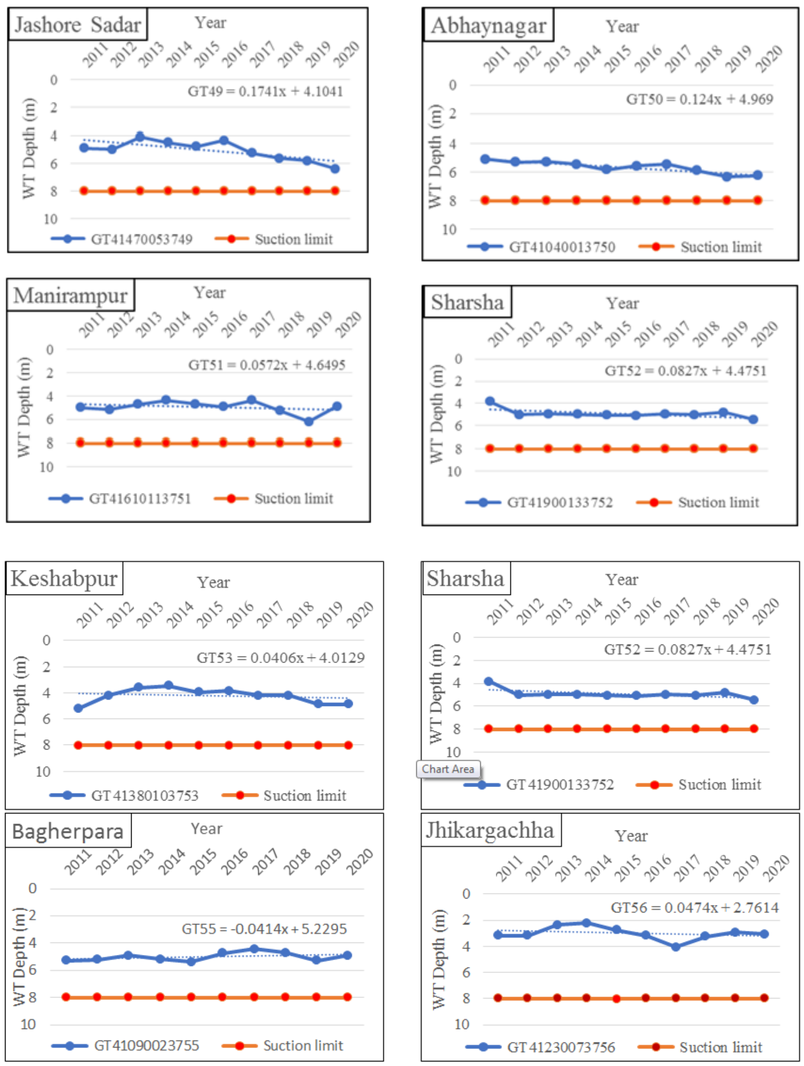

Fig. 4: Long-term Maximum WT depth fluctuation scenario for the study area.

A comparatively better scenario was seen in wells located at Chaugaccha (Well No.-GT41110103754) and Bagherpara (Well No.-GT41110103755), which were increasing at 0.05 m/year and 0.04 m/year, respectively. Although there was a growing tendency, the rate of increase was not statistically significant [Fig. 4]. Wells in Manirampur (Well No.- GT41470053751), Sharsha (Well No.- GT41470053752), Keshabpur (Well No.- GT41470053753), and Jhikargachha (Well No.- GT41470053756) were likewise declining at 0.05 m/year, 0.08 m/year, 0.04 m/year, and 0.047 m/year, respectively.

According to [Fig. 4], the WT depth in Jashore Sadar and Abhaynagar Upazila was drastically declining as compared to the other upazilas in that area. This occurred as a result of these two upazilas having substantially higher land use and land cover (LULC) than the other upazilas [21]. In addition, compared to the other Jashore upazilas, Jashar Sadar upazila is more urbanized. These two locations' soil permeability is likewise less rapid than it is throughout the district [21]. These reasons seemed to be the most likely causes of the other upazilas' significantly higher GW recharge than that of Jashore Sadar and Abhaynagar Upazila. [Fig. 4] also demonstrates that all of the wells, with the exception of GT 49 and GT 50, do not exhibit a discernible rise or fall because of the high permeability and low LULC of these regions. Because of this, these areas have higher groundwater recharge rates than Jashore Sadar and Abhaynagar Upazila.

Furthermore, throughout the entire study area, the data reveal reasonable spatial-temporal variance in maximum WT depth. In 2011 and 2020, it ranges from 3.19 to 5.28 m (mean: 4.67) and 3.09 to 6.38 m (mean: 5.01), respectively [Fig. 5]. It indicates a long-term decline.

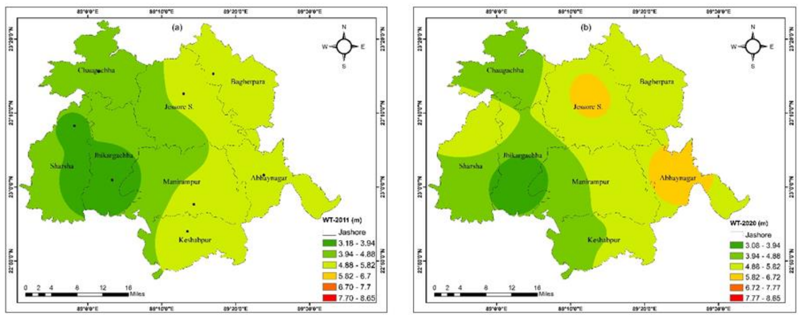

Fig. 5: WT depth distribution (a) maximum in 2011 (b) Maximum in 2020 (using the same legend).

Future Projection: The "MAKESENS" model was used to estimate the simulated WT depth fluctuation values for 2011–2020. [Fig. 6] depicts the distribution of simulated WT depth values at 95% and 99% confidence levels, and the residual distribution of the wells. The wells at Chaugaccha (Well No.-GT41110103754) and Bagherpara (Well No.-GT41110103755) reveal a negative trend, indicating that the aquifer is replenished more in this region than in the rest of the research area. Except for the observation wells in Jashore Sadar Upazila (Well No.-GT41470053749) and Abhaynagar Upazila (Well No.-GT41470053750), the WT depth in other wells was seen rising gradually. Following the present trend of simulated values, the WT depth for the years 2026, 2028, and 2030 were estimated [Table 3.]. If this trend continues, wells in Jashore Sadar and Abhaynagar will exceed the suction limit (8m) by 2030.

Table 3. Position of WT depth at present and in simulated scenarios for the future.

Upazila	Well No.	WT depth (m) in year		B	Q	Predicted WT depth(m) in year			Significance
		2011	2020			2026	2028	2030	
Jashore Sadar	GT41470053749	4.90	6.38	3.74565	0.25794	7.61	8.13	8.65	*
Abhaynagar	GT41040013750	5.10	6.25	5.09268	0.12166	6.92	7.16	7.40	**
Manirampur	GT41610113751	5.02	4.88	4.725	0.025	5.10	5.15	5.20	
Sharsha	GT41900133752	3.85	5.47	4.89453	0.03367	5.40	5.47	5.53	
Keshabpur	GT41380103753	5.20	4.87	3.58989	0.09440	5.01	5.19	5.38	
Chaugachha	GT41110103754	4.86	4.28	5.01449	-0.07083	3.95	3.81	3.67	
Bagherpara	GT41090023755	5.28	4.90	5.25687	-0.04021	4.65	4.57	4.49	
Jhikar-gachha	GT41230073756	3.19	3.09	3.03620	0.01285	3.23	3.25	3.28	

Notes; **B** = Intercept of linear regression equation; **Q** = Slope of linear regression equation; *** 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; If the cell is blank, the significance level is greater than 0.

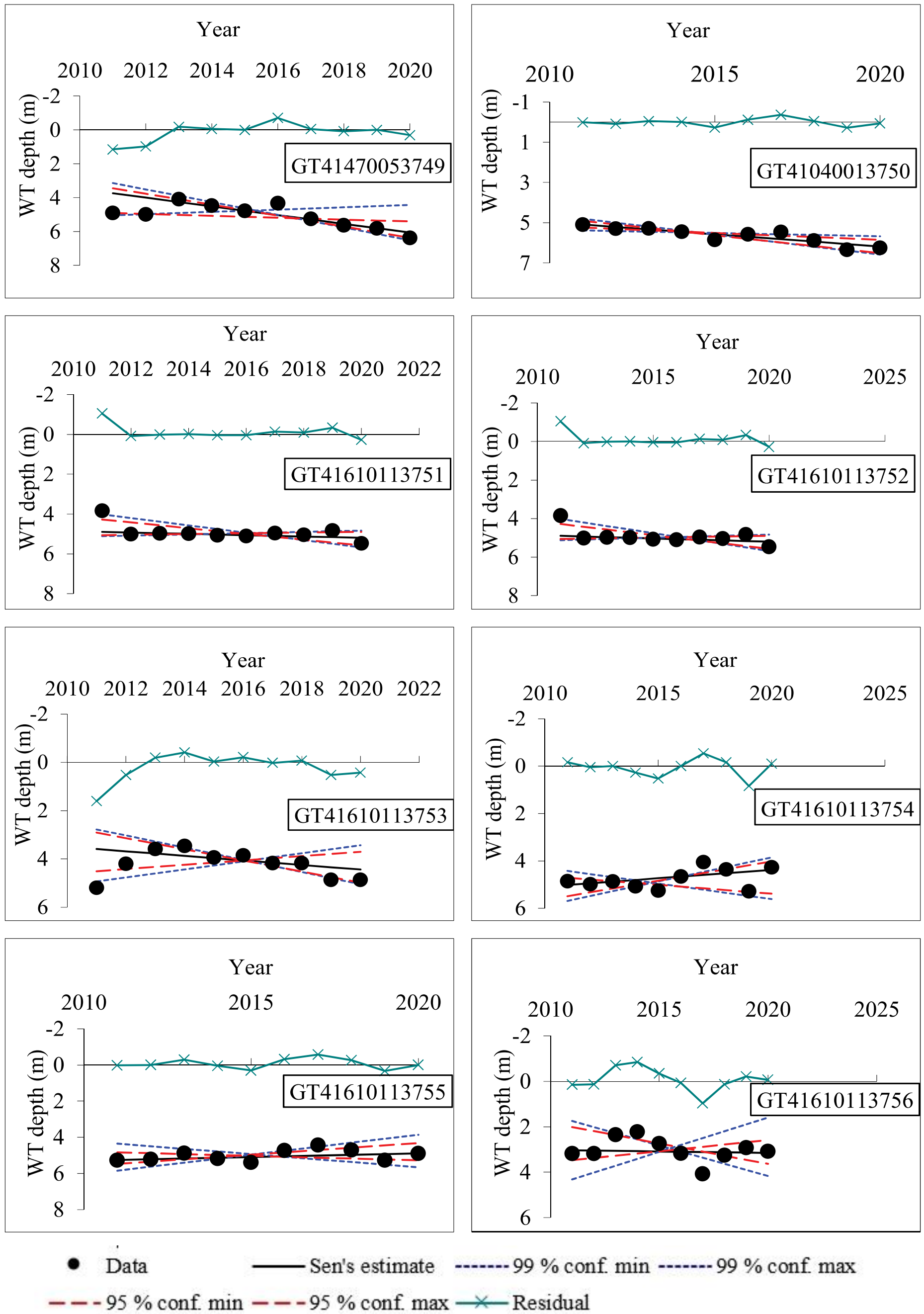

Fig. 6: Trend of maximum fluctuation of water table depth of the observation well.

In Fig. 6, the residual distribution fluctuated in all the wells. This happened because the MAKESENS, like any other statistical or predictive model, makes certain assumptions while examining trends (such as linearity or seasonality). Residuals are the differences between observed data and model-predicted values; a negative residual means that the predicted WT depth is greater than the observed WT depth. The negative residual values in the MAKESENS are most likely caused by variations between expected and observed GWT depths. According to Gilbert (1987), residuals can be both positive and negative, indicating variability around the trend line [20].

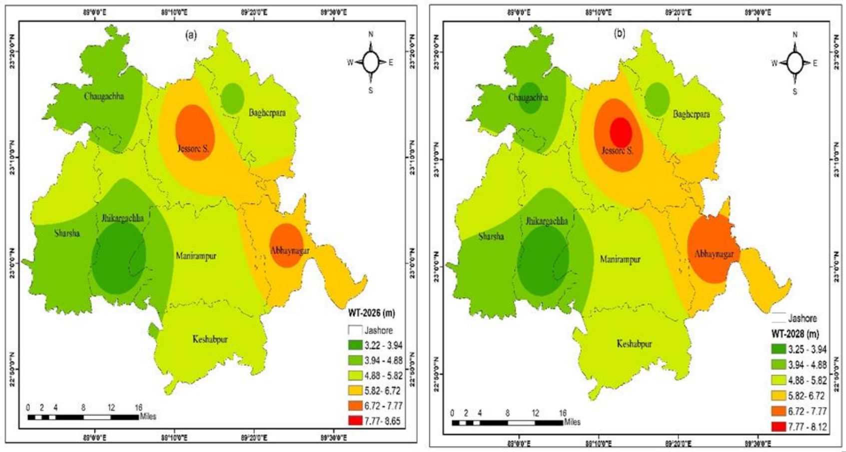

Fig. 7: Continued.

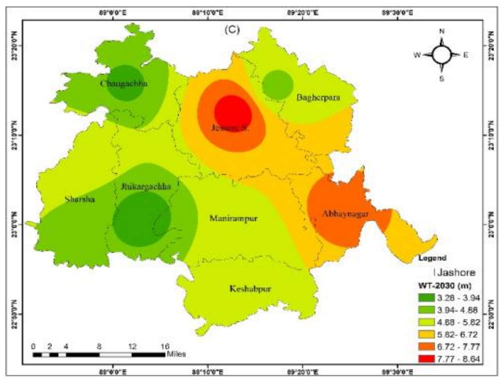

Fig. 7: Simulated Scenario of WT depth for (a) 2026 (b) 2028 (c) 2030.

Fig. 7 displays the simulated maximum WT depth spatial distributions for 2026, 2028, and 2030. This indicates that the maximum WT depth in 2026, 2028, and 2030 will differ from 3.23 to 7.61 m (mean: 5.23 m), 3.28 to 8.13 m (mean: 5.34 m), and 3.28 to 8.65 m (mean: 5.45 m), respectively, if the current trend continues.

Model Validation: To determine whether or not the MAKESENS model produces actual outcomes, an analysis is conducted using actual annual WT depth data ranging from 2011 to 2018, and a projected scenario is computed for 2020. As illustrated in [Fig. 8], the simulated result is quite satisfactory compared to the actual yearly WT of 2020. It makes sure the MAKESENS model is functional.

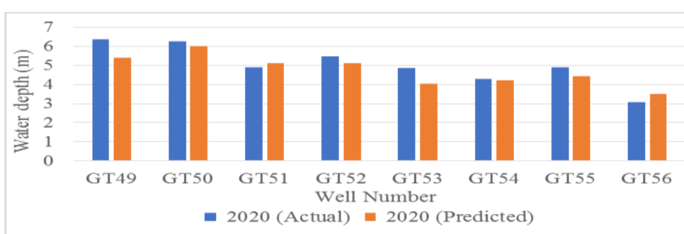

Fig. 8 “MAKESENS” model validation.

Discussion: The availability and necessity of water is an essential component in the social, economic, and cultural evolution of human activity. The burden of water supply will increase with the rising population in Bangladesh. Surface water, such as river flow, and groundwater make up Bangladesh's water supply during the dry season. Groundwater is a resource that must be sustainable because it cannot be massively artificially replenished. In short, sustainable groundwater utilization dictates that the typical long-term recharge of a groundwater reservoir should not exceed the withdrawal limit over time. Declining groundwater levels over time indicate unsustainable withdrawal or over-pumping. According to this study, groundwater is not recharging accordingly with increased groundwater use. By 2030, WT depth will frequently surpass the suction limit or drop below it. If this pattern persists, the cost of producing agricultural products will rise. The fall in groundwater levels could lead to ecological and environmental disasters, which could affect the region's ability to prosper economically and sustainably. There is a substantial amount of groundwater needed for both irrigation and domestic purposes all year round. During the dry season, more groundwater is extracted than in any other period of the year. As a result, it will increase the cost of irrigation and affect household water supply and crop productivity.

Comparison: This study uses "MAKESENS" model to show variations in WT depth in the Jashore district (southwestern region of Bangladesh) between 2011 and 2020. The model predicts continuous unpredictability and possible environmental instability by the year 2030. This study is in line with the research conducted in other regions of Bangladesh. Observing a decreasing WT trend in the drought-prone Barind area between 1991 and 2010 projects significant depletion by 2050 if present practices continue [12] Similarly, in Bogra district, WT depth declined between 1981-2013, particularly during dry seasons, and projects an additional drop that threatens the functionality of the pump [10]. Both studies highlight the importance of managing groundwater sustainability, as does this study. Focusing in Dhaka (the capital city of Bangladesh), showing a dramatic WT decline (up to 46m over 17 years) with predictions of further decreases by 2025, posing a severe risk to urban water supply. While this study provides comparatively short-term regional projections, the other studies extend their analysis over longer periods or different contexts (urban vs. rural). All studies highlight the urgency of addressing groundwater over-extraction to prevent environmental and socio-economic crises [22,23].

Limitations of The Study: Jashore district's eight upazilas are included in the study. The total number of monitoring wells in the study area is 18, among them 8 monitoring wells' weekly data is collected. Additionally, Bangladesh Water Development Board (BWDB) has data on these monitoring wells ranging from the years 1981 to the present. However, because of a shortage of funding, the data is collected only from 2011 to 2020. The study acknowledges the limitation of taking records for eight wells with limited data over 10 years. Whereas, conducting all 18 wells in Jashore with long-term data since installation could infer more accurate results.

Conclusion: Using "MAKESENS," water-table (WT) data from eight observation wells spread across eight different Jashore region Upazilas were analyzed to assess long-term fluctuation patterns and trends from 2011 to 2020. The results show a considerable amount of depth fluctuation over the projected timeframe, with both increasing and decreasing tendencies. Groundwater extraction exceeds the recharge thereby indicating unsustainable withdrawal. As a result, the depth to GWT of almost all the wells is increasing, and the mean GW level decline between the periods of 2011 and 2020 is 4.67m and 5.01m respectively. If the present trend continues, the depth of GWT may increase by almost 8.7% of present GWT by the year 2030. The primary cause of groundwater level instability is the WT's ongoing decline. Once this instability reveals itself, it will result in the appearance of several socio-environmental disasters. Groundwater should be used less frequently. Drip irrigation can significantly reduce water usage by over 50%. Resource managers must address groundwater usage and regulate irrigation practices. Encourage rainwater gathering in ponds and small canals for irrigation purposes. Alternative sources of water should be identified to meet irrigation demand. The usage of surface water should increase. As surface water demand increases, it is necessary to close more STWs and DTWs. To enhance sustainable groundwater use, avoid installing additional STWs, DTWs, and PPs. The findings also suggest that groundwater uses should be limited and monitored for sustainable uses. Although projection using trends showed an increment in depth in a few places, it can be further investigated with other scenarios of water use patterns. The present study evaluates the current practices and frames to analyze future GW trends in the Jashore district that might help adopt a necessary management plan for the sustainable use of groundwater resources in the area.

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