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Machine Learning-based Groundwater Level modeling in the Northwest region of Bangladesh: A review

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Abstract

This paper offers a review of machine learning techniques for modelling and predicting groundwater levels (GWL) over the northwestern region of Bangladesh. It offers a concise rundown of three widely used ML techniques in addition to an extensive bibliographical assessment of the authors' prior work. Additionally, it examines and contrasts the findings from the literature under this study. In 23 journal publications that were published between 2009 and 2022, the characteristics and capacities of the modelling approaches, consideration of the input data, prediction time, area of study, research duration, etc., were therefore reviewed throughout this paper. Numerous general and incomplete findings from the examined articles can be used as recommendations for the future researchers.

Keywords: *Groundwater modeling, Machine Learning, Northwest region of Bangladesh.*

1 Introduction

The Ganges-Brahmaputra-Meghna (GBM) Delta's surface water systems dominate Bangladesh. The availability of groundwater in Bangladesh plays a vital role in ensuring household consumption requirements and supporting dry-season irrigation for crop cultivation, which is essential for ensuring food security in the country (Hodgson et al., 2018). Groundwater is the primary water source for irrigated agriculture in Bangladesh. Approximately, groundwater fulfils the demand of 97% of the irrigation water. In this region, the primary mechanism for replenishing groundwater is rainfall, which is also the least abundant in comparison to other regions. Consequently, the utilization of groundwater in the Barind region has surpassed the rate of replenishment, leading to a gradual decline in groundwater levels over time.

2 Study Area

The primary focus of this study is the northwestern region of Bangladesh, which is consisted of Rangpur and Rajshahi division administratively. The geographical boundaries of these districts span longitudinally from 88°0'E to 89°50'E and latitudinally from 23°45'N to 26°45'N. The majority of the northwestern region is located within the Jamuna River basin, with a small fraction being in the Ganges River basin. The geographical region of Bangladesh is delineated by the utilization of six distinct hydrologic and hydrodynamic regional models. The groundwater is an important irrigation resource in the studied area. Furthermore, the northwest region is recognized as a drought-prone area, mostly as a result of the progressive decline in groundwater levels.

3 Methodology and Data Collection

In this study 23 research papers were collected from renowned journals available in the internet using keywords. Those papers were published in various journals such as Theoretical and Applied Climatology, Hydrology, Water, Scientific Reports, Environmental Challenges, Environmental Monitoring and Assessment, Environment, Development and Sustainability, International Journal of Statistical Sciences , Natural Resources Research, Groundwater for Sustainable Development, Hydrology and Earth System Sciences, Journal of Mechanical and Civil Engineering, Journal of the Geological Society of India, Australia's National Science Agency, Hydrological Research Letters, Sustainable Water Resources Management from 2009 to 2022.

4 ML based GWL modeling

4.1 Bibliographic Review

To effectively assess the virtual contributions of basic causes to GWL fluctuation, a hybrid collaborative modelling approach used locally weighted and multiple Gaussian process regressions (Elbeltagi et al., 2022). The groundwater potential zone was described using a fuzzy AHP-based GIS approach in the current study area of this research (Sresto et al., 2021). The groundwater table is gradually changing in Bangladesh's North-West hydrological area (Mojid et al., 2019). With the widely utilized weighted linear combination (WLC) geospatial approach, potential recharge was determined (Nowreen et al., 2021). Another study analyzed the spatiotemporal patterns and magnitudes of groundwater levels during the years 1981–2017 (Salam et al., 2020). GIS and the Mann-Kendall-Sen (MAKESENS) model have both been used to evaluate the dynamics of groundwater levels (Hasanuzzaman et al., 2017). The Thiessen polygon method was used to estimate the yearly groundwater inflow and outflow (Reza et al., 2013). The Autoregressive Conditional Heteroscedasticity models were introduced (Khalek & Ali, 2016). A variety of ML methods were trained to understand the complex interactions (Zzaman et al., 2022). To model groundwater level (GWL), the ANN approach was improved (Hasda et al., 2020). A nonparametric decomposition technique was used to observe the weekly groundwater levels (Shamsudduha et al., 2009). An integrated GW-SW model was created using MIKE-11 and MIKE-SHE (Islam et al., 2014). The spatial development potential of groundwater had been evaluated using a recharge-abstraction balance method (Shahid et al., 2015). Another study involved ANN and linear regression methods to model groundwater level (Kamal et al., 2022). MIKE 11 and the NAM rainfall-runoff model was used to conduct a new analysis (Karim et al., 2021). A summary of the reviewed papers is illustrated in Table 1 including the publication year, journal title, study area, range of used data, inputs for modeling, and the techniques used.

4.2 Results

When compared to the PUK model, the LWLR-GPR model performed better, showing an improvement in accuracy that ranged from 10% to 50% throughout the training period and 20% to 70% in the testing period (Elbeltagi et al., 2022). Approximately 1209.53 square kilometers (35.12%) of Dinajpur is estimated to have a very low potential, whereas just 208.36 square kilometers (6.05%) are deemed to have a very high potential (Islam et al., 2014). The groundwater model's capacity for prediction had been verified by the AUC of ROC (Sresto et al., 2021). 15% of the monitoring wells in the districts of Chapai Nawabganj, Naogaon, Rajshahi, and Joypurhat maintained GWTs below 6 m for the whole year (Mojid et al., 2019). The Barind Tract, on the other hand, particularly the southwest and south-central portions, exhibits "very low" groundwater possibility (Nowreen et al., 2021). The findings indicated that the aquifer in the study area exhibits a higher rate of groundwater recharge in Porsha Upazilla compared to Sapahar Upazilla. Additionally, the aquifer in Porsha Upazilla demonstrated a significant capacity for groundwater storage (Reza et al., 2013). The seasonal wavelet-ARIMA and GARCH models showed the best level of fit, as measured by goodness of fit (Khalek & Ali, 2016). The overuse of groundwater for dry-season rice farming was the main contributor to groundwater loss (Shamsudduha et al., 2009). In fact, there is a surplus of water present (Islam et al., 2014). Moreover, within the northwest region of Bangladesh, groundwater extraction had reached a critical state in fourteen out of twenty-six sub-districts (Shahid et al., 2015). The ANN model did better when estimating groundwater level (GWL) based on groundwater storage (GWS) and other relevant data (Kamal et al., 2022). In comparison to Rajshahi (76 mm/year) and Chapai Nawabganj (203 mm/year), the districts of Dinajpur, Naogaon, and Pabna show a drop in precipitation of between 30 and 35 mm/year (Karim et al., 2021).

5 Results and Discussion

Based on the literature, where rainfall was cited in 10 studies, groundwater level data were used as input in 15 papers. In 10 articles, the only univariate input was groundwater data. There have been 9 studies on Bangladesh's northwest region, 4 focused on Rajshahi, 3 on the Barind Tract, and others on Naogaon, Chapai Nawabganj, Rangpur, Bogura, Dinajpur, and Pabna among the 23 papers. Despite being widely acknowledged as being good at forecasting and prediction, black-box AI solutions do not make use of understanding of the fundamental processes of nature. The primary goal of this form of modelling is to produce precise projections; understanding the underlying dynamics is not required. Figure 1 shows the inputs used in the reviewed papers and the locations where the studies were conducted.

Table 1. Summary of the reviewed papers in which AI modeling techniques were used to simulate the GWL.

No.	Author (year)	Study area	Techniques used	Best technique	Journal	Range of data	Input variables
1	(Elbeltagi et al., 2022)	NW of Bangladesh	Hybrid LWLR-GPR-PUK	LWLR and GPR	Theoretical and Applied Climatology	1993–2018	Rainfall, Temperature, Population Growth Rate, Soil Moisture (SM), Nina3.4, Indian Ocean Dipole (IOD), Southern Oscillation Index (SOI), Normalized Difference Vegetation Index (NDVI)
2	(Iquebal Hossain et al., 2020)	Joypurhat	MIKE SHE	MIKE SHE	Hydrology	1995-2006	Groundwater Level Data
3	(Sresto et al., 2021)	Rangpur Division	FAHP	FAHP	Environmental Challenges		Landsat 8, DEM, Soil Data, Geology Data, Geomorphology, Rainfall Data, Groundwater Level,
4	(Mojid et al., 2019)	NW of Bangladesh	MAKESENS	MAKESENS	Water	1985–2016	Groundwater Level Data
5	(Nowreen et al., 2021)	NW of Bangladesh	WLC	WLC	Environmental Monitoring and Assessment	1993–2017	Rainfall, Slope, Soil, Drainage Density, Lithology, Land Use and Land Cover (LULC), Lineament Density, Geomorphology
6	(Salam et al., 2020)	NW of Bangladesh	ARIMA	ARIMA	Environment, Development and Sustainability	1981–2017	Groundwater Level Data
7	(Hasanuzzaman et al., 2017)	Bogura	MAKESENS	MAKESENS	Water	1981-2013	Groundwater Level Data
8	(Reza et al., 2013)	Naogaon	Water Balance Model	Water Balance Model	Rajshahi University Journal of Science	1991-2000	Groundwater Level Data
9	(Khalek & Ali, 2016)	Rajshahi	Hybrid Wavelet-GARCH	Wavelet-ARIMA GARCH	International Journal of Statistical Sciences	1991-2016	Groundwater Level Data
10	(Zzaman et al., 2022)	NW of Bangladesh, Bangladesh	RF, SVM	RF	Natural Resources Research	2018	Groundwater Level Data
11	(Hasda et al., 2020)	Barind Tract	NARX	NARX	Groundwater for Sustainable Development	1980-2017	Rainfall, Temperature, Humidity, Evaporation
12	(Shamsudduha et al., 2009)	NW of Bangladesh, Bangladesh	Non-parametric STL	Non-parametric STL	Hydrology and Earth System Sciences	1985–2005	Groundwater Level Data

No.	Author (year)	Study area	Techniques used	Best technique	Journal	Range of data	Input variables
13	(Islam et al., 2014)	NW of Bangladesh	MIKE SHE	MIKE SHE	Journal of Mechanical and Civil Engineering	2003-2009	Groundwater Level Data
14	(Shahid et al., 2015)	Naogaon, Rajshahi, Chapai Nawabganj	WTF	WTF	Journal of the Geological Society of India	1971-2010	Groundwater Level Data
15	(Kamal et al., 2022)	NW of Bangladesh, Bangladesh	MLR, ANN	ANN	Scientific Reports	2003-2019	Population, Rainfall, Temperature, Irrigation, Elevation, Groundwater Level
16	(Uz Zzaman, 2021)	NW of Bangladesh, Bangladesh	MLR, ANN	ANN	Scientific Reports	2003-2019	Population, Rainfall, Temperature, Irrigation, Elevation, Groundwater Level
17	(Karim et al., 2021)	Bogura, Dinajpur, Pabna, Rajshahi, Rangpur	AHP, MIF	MIF	MSc Thesis (BUET)	2000-2019	Rainfall, Lithology, Slope, Soil, Geomophology, LULC, Lineament Density, Drainage Density
18	(Sarkar et al., 2022)	NW of Bangladesh	NAM, MIKE 11	NAM, MIKE 11	Australia's National Science Agency	1985-2014	Rainfall, Flow Data, Groundwater, Crop Coefficient, Potential Evapotranspiration (PET), Pumping Rate, Irrigation Demand, Catchment Area
19	(Sresto et al., 2021)	Bangladesh	AHP	AHP	Water Supply	2018	LULC, Rainfall, Topographic Position Index (TPI), Temperature, Slope, Humidity, Geology, Roughness, Curvature, Topographic Wetness Index (TWI), Drainage Density
20	(Salem et al., 2017)	Rajshahi	MLR, SVM	MLR, SVM	Hydrological Research Letters	1991-2009	Groundwater Level Data, Rainfall, Temperature
21	(Hasan et al., 2022)	Barind Tract	MCDM, GIS	MCDM, GIS	Sustainable Water Resources Management	2016	Landsat 8
22	(Ferozur et al., 2019)	Barind Tract	AHP, WLC	AHP, WLC	Groundwater for Sustainable Development	2014	Lithology, Lineament Density, LULC, Rainfall, Slope, Geomorphology, Drainage Density
23	(Rahaman et al., 2018)	Chapai Nawabganj	MAR	MAR	3rd International Geosciences Congress	1980-2009	Relative Humidity, Groundwater Level Data, Wind Speed, Evaporation, Rainfall, Temperature, Sunshine Hour

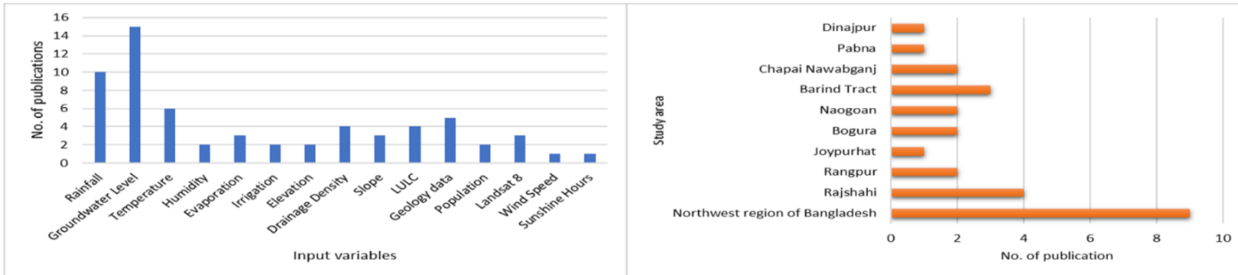

Figure 1. Inputs in different publications (left) and study locations in the publications (right)

Among the 23 papers, the following models were used: LWLR-GPR, MIKE SHE, FAHP, MAKESENS, WLC, ARIMA, WBM, Wavelet-ARIMA, Random Forest, NARX, Non-parametric STL, WTF, ANN, MIF, NAM, MIKE 11, MCDM-GIS, MAR, SVM, and AHP. Among the 23 publications where ARIMA and MIKE SHE models were more accurate, the MIKE SHE, ARIMA, SVM, AHP, and MLR models were utilized in 10 papers (2 papers each). In figure 2, the publication year and the used techniques are illustrated.

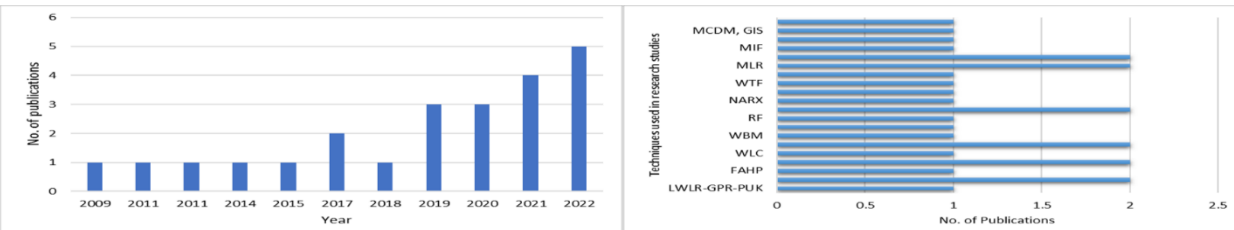

Figure 2. Publication year (left) and Techniques used in the publications (right)

6 Conclusions and Recommendations

In general, machine learning models were more accurate at modeling and making predictions. Artificial intelligence models prove invaluable in situations where the development of a knowledge-driven simulation model becomes arduous due to the inherent challenge of constructing a mathematical or physical model that accurately represents the intricate underlying processes. It is expected that the performance of these models will be deemed good, provided precise attention is given to all phases during their construction. It should be noted, nevertheless, that there was no set technique for these stages; instead, different researchers carried out each step empirically or by using a trial-and-error method while taking into account the data that was available and the situation at the time. In order to choose appropriate input variables, more consideration should be given at the input consideration stage. Compared to the single-approach strategy, hybrid models offer more accurate results. Therefore, combining the models will improve the prediction.

References

Elbeltagi, A., Salam, R., Pal, S. C., Zerouali, B., Shahid, S., Mallick, J., Islam, M. S., & Islam, A. R. M. T. (2022). Groundwater level estimation in northern region of Bangladesh using hybrid locally weighted linear regression and Gaussian process regression modeling. *Theoretical and Applied Climatology*, *149*(1–2), 131–151. https://doi.org/10.1007/s00704-022-04037-0

Ferozur, R. M., Jahan, C. S., Arefin, R., & Mazumder, Q. H. (2019). Groundwater potentiality study in drought prone barind tract, NW Bangladesh using remote sensing and GIS. *Groundwater for Sustainable Development*, *8*, 205–215. https://doi.org/https://doi.org/10.1016/j.gsd.2018.11.006

Hasan, M. T., Jahan, C. S., Rahaman, M. F., & Mazumder, Q. H. (2022). Delineation of zones and sites for artificial recharge of groundwater in dry land Barind Tract, Bangladesh using MCDM technique in GIS environment. *Sustainable Water Resources Management*, *8*(5), 147. https://doi.org/10.1007/s40899-022-00713-1

Hasanuzzaman, M., Song, X., Han, D., Zhang, Y., & Hussain, S. (2017). Prediction of Groundwater Dynamics for Sustainable Water Resource Management in Bogra District, Northwest Bangladesh. In *Water* (Vol. 9, Issue 4).

https://doi.org/10.3390/w9040238

Hasda, R., Rahaman, M. F., Jahan, C. S., Molla, K. I., & Mazumder, Q. H. (2020). Climatic data analysis for groundwater level simulation in drought prone Barind Tract, Bangladesh: Modelling approach using artificial neural network. *Groundwater for Sustainable Development*, *10*, 100361. https://doi.org/https://doi.org/10.1016/j.gsd.2020.100361

Hodgson, G., Mojid, M., Peña-Arancibia, J., Islam, M., & Mainuddin, M. (2018). *Groundwater trends in the northwest region of Bangladesh*. *September*, 2–3.

Iquebal Hossain, M., Bari, N., & Matin, I. (2020). Groundwater Zoning for the North-West Region of Bangladesh. *Hydrology*, *8*(3), 52. https://doi.org/10.11648/j.hyd.20200803.13

Islam, M. T., Masud, M. S., & Hossain, D. A. A. (2014). Scope for Groundwater Development in North West Region of Bangladesh. *IOSR Journal of Mechanical and Civil Engineering*, *11*(3), 38–44. https://doi.org/10.9790/1684-11383844

Kamal, A. S. M., Fahim, A., & Shahid, S. (2022). *Spatial Modeling of Groundwater Level in Bangladesh Using Physio-Climatic Variables: Machine Learning and Statistical Approaches*. https://doi.org/10.21203/rs.3.rs-2261689/v1

Karim, F., Islam, T., Mainuddin, M., Janardhanan, S., Islam, M. M., Rahman, M. R., Masud, M. S., & Kirby, M. (2021). *Surface water modelling and water balance in the northwest region of Bangladesh*. https://research.csiro.au/sdip/wp-content/uploads/sites/98/2022/09/SW-Modelling_FINAL_HQP.pdf

Khalek, A., & Ali, A. (2016). *Comparative Study of Wavelet-SARIMA and Wavelet- NNAR Models for Groundwater Level in Rajshahi District* (Vol. 10, Issue 7, pp. 1–15).

Mojid, M. A., Parvez, M. F., Mainuddin, M., & Hodgson, G. (2019). Water Table Trend—A Sustainability Status of Groundwater Development in North-West Bangladesh. In *Water* (Vol. 11, Issue 6). https://doi.org/10.3390/w11061182

Nowreen, S., Newton, I. H., Zzaman, R. U., Islam, A. K. M. S., Islam, G. M. T., & Alam, M. S. (2021). Development of potential map for groundwater abstraction in the northwest region of Bangladesh using RS-GIS-based weighted overlay analysis and water-table-fluctuation technique. *Environmental Monitoring and Assessment*, *193*(1), 24. https://doi.org/10.1007/s10661-020-08790-5

Rahaman, M., Jahan, C., & Mazumder, Q. (2018). *Stress on Groundwater Resource and Application of MAR Technique as Adaptation Measure in Drought-Prone Barind Tract, Rural Bangladesh.*

Reza, A. H. M. S., Mazumder, Q. H., & Ahmed, M. (2013). Groundwater Balance Study in the High Barind, Bangladesh. *Rajshahi University Journal of Science*, *39*(0 SE-Life and Earth Sciences), 11–26. https://doi.org/10.3329/rujs.v39i0.16539

Salam, R., Towfiqul Islam, A. R. M., & Islam, S. (2020). Spatiotemporal distribution and prediction of groundwater level linked to ENSO teleconnection indices in the northwestern region of Bangladesh. *Environment, Development and Sustainability*, *22*(5), 4509–4535. https://doi.org/10.1007/s10668-019-00395-4

Salem, G. S. A., Kazama, S., Shahid, S., & Dey, N. C. (2017). Impact of temperature changes on groundwater levels and irrigation costs in a groundwater-dependent agricultural region in Northwest Bangladesh. *Hydrological Research Letters*, *11*(1), 85–91. https://doi.org/10.3178/hrl.11.85

Sarkar, S. K., Esraz-Ul-Zannat, M., Das, P. C., & Ekram, K. M. M. (2022). Delineating the groundwater potential zones in Bangladesh. *Water Supply*, *22*(4), 4500–4516. https://doi.org/10.2166/ws.2022.113

Shahid, S., Wang, X.-J., Moshiur Rahman, M., Hasan, R., Harun, S. Bin, & Shamsudin, S. (2015). Spatial assessment of groundwater over-exploitation in northwestern districts of Bangladesh. *Journal of the Geological Society of India*, *85*(4), 463–470. https://doi.org/10.1007/s12594-015-0238-z

Shamsudduha, M., Chandler, R. E., Taylor, R. G., & Ahmed, K. M. (2009). Recent trends in groundwater levels in a highly seasonal hydrological system: the Ganges-Brahmaputra-Meghna Delta. *Hydrology and Earth System Sciences*, *13*(12), 2373–2385. https://doi.org/10.5194/hess-13-2373-2009

Sresto, M. A., Siddika, S., Haque, M. N., & Saroar, M. (2021). Application of fuzzy analytic hierarchy process and geospatial technology to identify groundwater potential zones in north-west region of Bangladesh. *Environmental Challenges*, *5*, 100214. https://doi.org/https://doi.org/10.1016/j.envc.2021.100214

Uz Zzaman, M. R. (2021). Application of Different Remote Sensing and GIS Based Multi-Criteria Approaches in Mapping Potential Recharge Zones of Groundwater in The North West of Bangladesh. *MSc Thesis*. http://lib.buet.ac.bd:8080/xmlui/bitstream/handle/123456789/6156/Full Thesis.pdf?sequence=1&isAllowed=y

Zzaman, R. U., Nowreen, S., Khan, I. M., Islam, M. R., Ibtehaz, N., Rahman, M. S., Zahid, A., Farzana, D., Sharmin, A., & Rahman, M. S. (2022). A Machine Learning-based Approach for Groundwater Mapping. *Natural Resources Research*, *31*(1), 281–299. https://doi.org/10.1007/s11053-021-09977-4