AN ASSESSMENT OF THE POSSIBLE QUANTITIES OF MAR INSTALLATIONS IN THE WATER-SCARCE BARIND REGION OF NORTHWEST BANGLADESH

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ABSTRACT

The sustainable management of groundwater in the water-stressed Barind Tract, located in the northwest region of Bangladesh, is crucial and demands quantifying the probable number of management aquifer recharge (MAR) installations. So the study has been conducted aiming at calculating the possible number of MARs in the re-excavated Kharies and Beels of Godagari, Mohanpur, and Niamatpur upazilas under the Barind area. To perform the study, data on groundwater level (GWL), rainfall, borehole lithology, and other pertinent data were obtained from the offices of the Barind Multipurpose Development Authority (BMDA); information on re-excavated Kharies and Beels was collected from the BMDA and land offices; and recently published journal articles and Ph.D. theses conducted for the study area provided details about MAR and their recharge performances. The yields of the catchments of the *Kharies* and *Beels* were determined using rational formulae. The number of MAR units was calculated by dividing the available surplus water by the recharge rate of the MAR unit. For sustainable groundwater management, the total estimated number of MAR installations was found to be 3251 for 376.68 km of *Khari* and 64 for 9 *Beels* in the study area. So the right application of MAR in the right amount is now the demand of time for the survival of the fauna and flora in Bangladesh's Barind region.

Keywords: *Barind Tract, Bangladesh, MAR, Groundwater, Sustainable management.*

1. INTRODUCTION

Water, a major component of the environment, is essential for the lives of those living on the planet (Hossain, et al., 2021a). "Life is written in water," said the catchphrase for the Barind tract, a drought-prone, water-stressed area in northwest Bangladesh, and the primary challenge here is to create available water for irrigation, drinking, household, and other uses (BMDA, 2006; Hossain, et al., 2021a). Because of its flood-free highland area, insufficient rainfall, limited surface water sources, and dense clay on the aquifer that hinders natural groundwater recharge, this grain producing hub has become entirely dependent on groundwater for different uses including irrigation, resulting in the continuous decline of the groundwater water table (IWM, 2012; Rahman and Mahbub, 2012; Ahmed, 2006; BMDA, 2006; Hossain, et al., 2020, 2021b, 2022a, 2022b; Bari, et al., 2021). Sustainable water management has become more challenging due to population growth and ongoing urbanization (Elshall et al., 2020; McDonald et al., 2011). This is crucial for the most groundwater-dependent countries, such as Iran, Saudi Arabia, Mexico, China, Bangladesh, and India, which together account for two-thirds of the world's groundwater-irrigated area (Shah, 2023). According to Sherif et al. (2023), groundwater exploitation in the majority of Middle East and North Africa (MENA) countries considerably exceeds its renewability, ranging from 6% to 100%. It is also important to note that around 73% of Bangladesh's irrigated land is covered by groundwater, and in the Barind region, that percentage raises to nearly 91% (BADC, 2020). The average annual rainfall in the Barind region is 1410 mm, which is significantly less than the national average of 2550 mm (Jahan, et al., 2020) and according to Faisal et al. (2018), 80% of the rainfall occurs between the months of June and October. The area experiences temperature ranges of 8^0C to 44^0C (Ahmeduzzaman, et al., 2012), and yearly rainfall ranges of 1250 mm to 2000 mm (IWM, 2012). According to Rasheed (2008), Alexander (1995), Brammer (1987), and Rahman et al. (2017), the region also suffered moderate to severe hydrological drought and agricultural drought. The continuous depletion of groundwater level due to excessive withdrawals for irrigation, inadequate rainfall, and negligible infiltration (2–3 mm/day) because of thick surface clay (Barind Clay of Pleistocene age) has made some parts of the area unsustainable for its further withdrawal (Jahan et al., 2015; Mojid et al., 2019; Rahman et al., 2017; Hossain et al., 2019a, 2019b; Ali et al., 2023). Therefore, the Barind region needs managed aquifer recharge (MAR), which is the intentional replenishment of aquifers with water for later recovery or environmental benefit (Dillon et al., 2009). This tool can be used to boost the sustainability of groundwater development and recover groundwater levels (Wendt et al., 2021; Page, 2018; Sprenger et al., 2017; Stefan et al., 2017). The Barind Multipurpose Development Authority (BMDA) has re-excavated a significant number of *Khari* (natural canal) to conserve rainwater for supplementary irrigation. There are also some *Beels* (larger water body than pond) in this area. These *Kharies* and *Beels* have potential for MAR application as rainwater is accumulated there. On an experimental basis, two MAR installations have been constructed in this area, one in a *khari* and the other in a *beel*, and found acceptable performance (Hossain et al., 2019c; Hossain, 2023), which demands the computation of the potential of MAR construction. That is why the present study has been undertaken with the aim of calculating the potential number of MARs in the study area.

2. STUDY AREA

The Barind tract is classified mainly as a high Barind tract, a level Barind tract, and a high Ganges river floodplain. The study area includes Godagari and Mohanpur Upazila under the Rajshahi district and Niamatpur Upazila under the Naogaon district, which covers all three classes of the Barind tract (District and Upazila are the second and third tiers of the administrative units from top to bottom in Bangladesh). Most of the part of Godagari upazila falls in the 'high Barind tract class' and a minor part is in the 'high Gange river floodplain class' while the major area of Mohonpur upazila covers the 'level Barind class' and a minor is in the 'high Gange river floodplain class'. On the other hand, the major area of Niamatpur upazila covers the 'high Barind tract class', whereas the minor segment falls in the 'level Barind tract class'. The location map of the study area is shown in Figure 1.

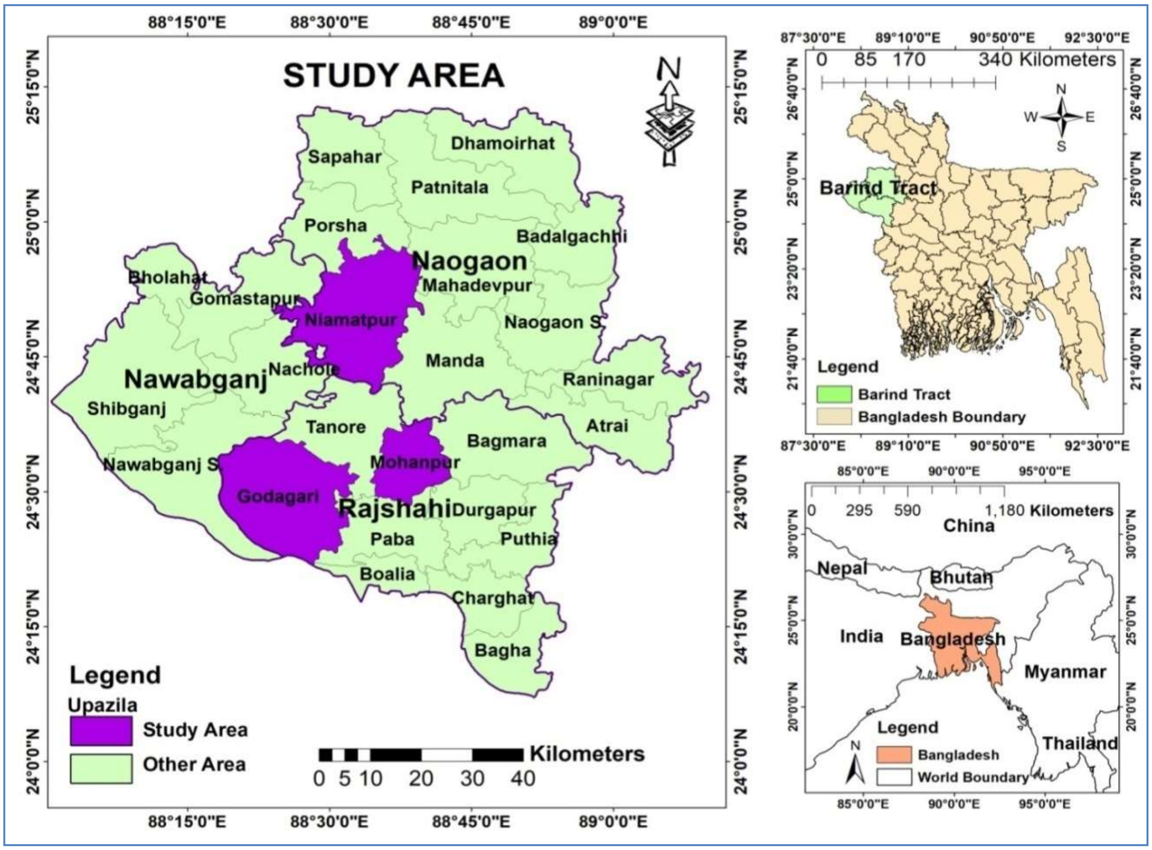

Figure 1: Location map of the study area

3. METHODOLOGY

3.1 Data Collection and Analysis

Bore log lithology, rainfall, and groundwater level (GWL) fluctuation data were acquired from the BMDA, and information on *Beels* and *Kharies* was collected from the Land offices of the study area.

3.1.1 Bore log lithology, rainfall and GWL information

According to lithological data (Figure 2), Amtoli (Godagari) area shows that a 39 m top clay layer overlies an 18 m sand aquifer layer and is underlain by a clay layer; Nimdighi (Niamatpur) area's lithology depicts that a 21 m top clay layer overlies the 24 m sand aquifer layer and is underlain by the clay layer; and Mohanpur (Mohanpur) area's bore log data reveals that the aquifer is stratified (from the bottom) as 12 m gravel, 14 m sand, a 4.5 m clay barrier, and 6 m sand overlain by 21 m thick clay. So, a thick clay layer (Barind clay of Pleistocene age) varying from 21 m to 39 m dominates at the top of the aquifer in the whole study area (Figure 2), imposing a barrier on natural recharging and causing depletion in GWL.

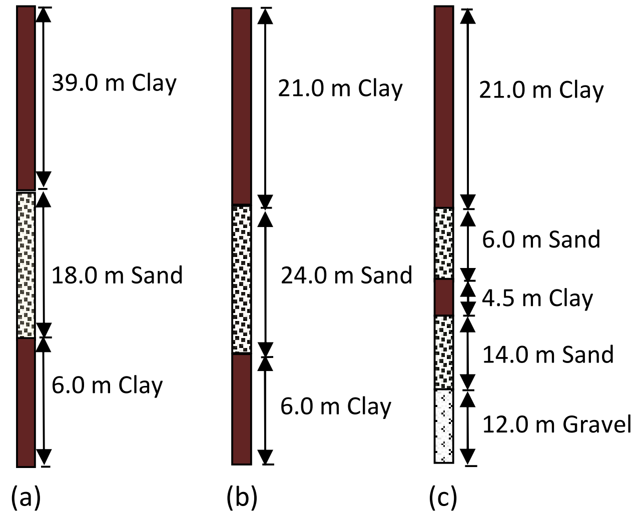

Figure 2: Lithological log (a) Godagari upazila (Amtoli), (b) Niamatpur upazila (Nimdighi) and (c) Mohanpur upazila (Mohanpur)

From the permanent rain gauge station installed at the BMDA Godagari, Niamatpur, and Mohanpur zonal office campuses, 19 years (2002–2020) of rainfall recorded data were collected and analyzed, and found annual average rainfall for these three upazilas is 1231 mm, 1414.27 mm, and 1132.12 mm, respectively. Maximum rainfall, valued at about 90% of the average rainfall, occurs in the months of May to September (Figure 3). During this time, the average rainfall in Godagari is 1112.19 mm, 1276.49 mm in Niamatpur, and 1028.35 mm in Mohanpur upazila. These amounts of rainfall can be used for groundwater recharge by an appropriate MAR system.

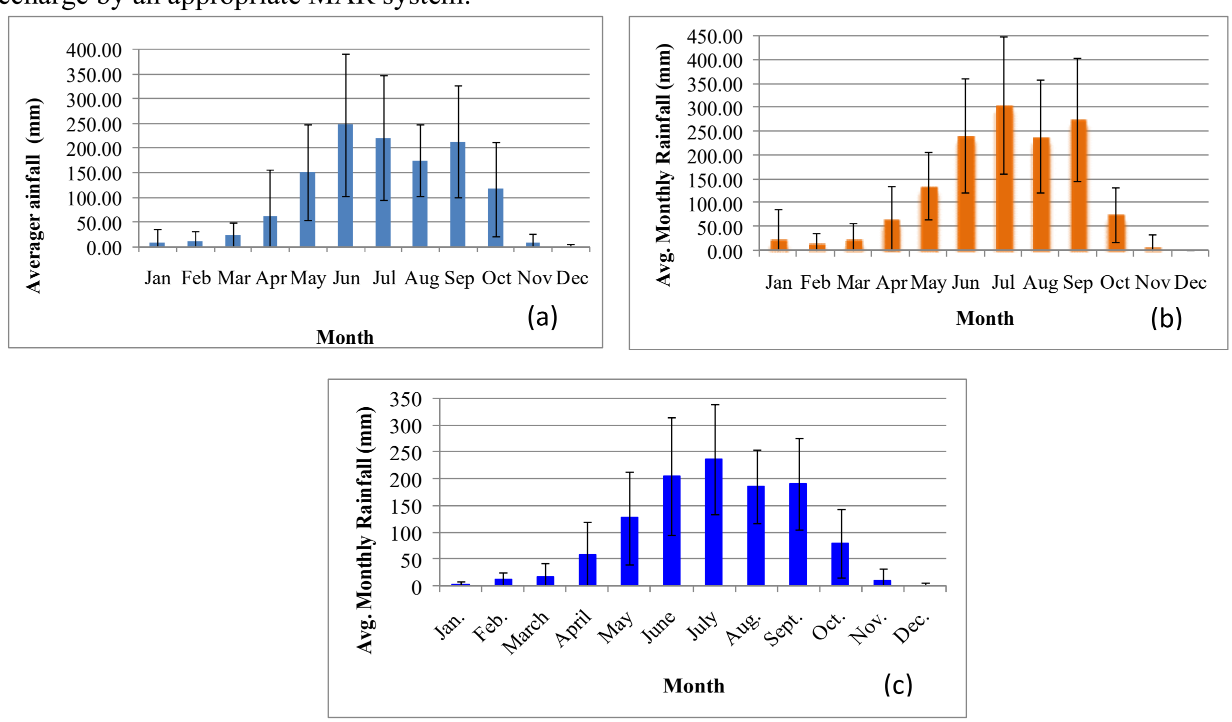

Figure 3: Monthly average rainfall status of (a) Godagari, (b) Niamatpur and (c) Mohanpur

The GWL data for the period 2005–2021 were collected from the monitoring wells' records of BMDA Godagari, Niamatpur, and Mohanpur Upazila offices and plotted in the hydrograph (Figure 4). Continuous declination is observed all over the entire study area, and depletion is about 6.6 m, 5.24 m, and 1.6 m in Godagari, Niamatpur, and Mohanpur Upazila by 17 years, with a declination rate of 0.39 m, 0.31 m, and 0.09 m per year. The declining situation of GWL can be reversed with the application of a suitable MAR construction.

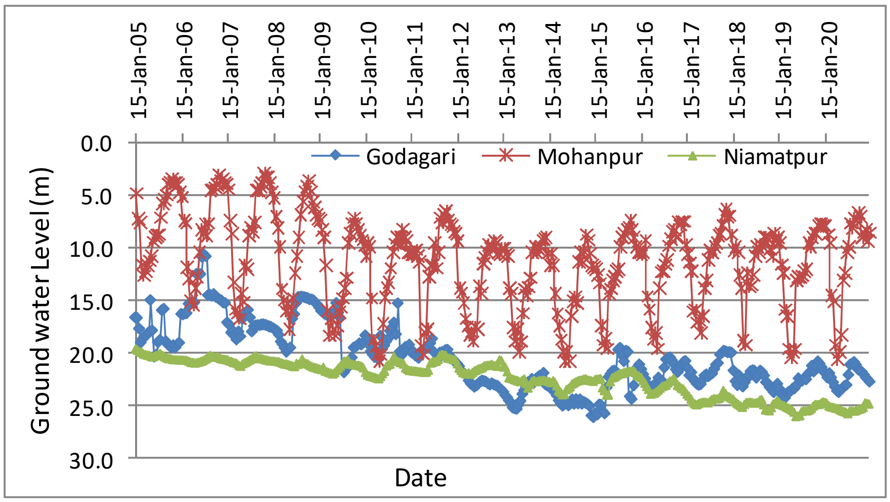

Figure 4: Groundwater level hydrograph for the study area

3.1.2 Information about *Khari* and *Beel*

Information about re-excavated *Kharis* and *Beels* was collected from the Upazila land offices of the study area and found that the length of *Kharies* in Godagari, Niamatpur, and Mohanpur Upazila is 129.49 km, 243.8 km, and 3.42 km, while the number of cross dams is 88, 103, and 1 and the number of *Beels* is 2, 2, and 5, respectively. The length of the *Khari* containing no cross dam has not been considered for groundwater recharge, and thus the effective lengths for groundwater recharge are 124.99 km, 227.63 km, and 1.9 km in Godagari, Niamatpur, and Mohanpur Upazila, respectively. The information on *Kharies* and *Beels* is shown in Table 1 and Table 2.

Table 1: Information about *Kharies* in the study area

Upazila	Information of Khari (Canal)			Information of Cross dam	
	Length (km)	Width (m)	Depth (m)	Quantity (no.)	Height (m)
Godagari	129.49	9.81	3.97	88	1.83
Niamatpur	243.77	42.16	4.81	103	2.13
Mohanpur	3.42	6.5	2.5	1	1.52
Total	376.68			192	

Table 2: Information about *Beels* in the study area

Upazila	Name of Beel	Beel area (acre)	Ave. water depth remains (m)
Godagari	Beel Choroi	9.41	1.22
	Beel Vela	3.0	0.90
Mohanpur	Shutkir Beel	37.87	0.75
	Dhakai Dara Beel	20.6	0.85
	Beel Hilna	107.46	0.75
	Beel Dubi	9.19	0.75
	Batupara Beel	22.26	0.75
Niamatpur	Beel Bahagole	31.89	0.75
	Beel Shidine	15.43	0.75
	Total	257.01	

3.1.3 Information about MAR construction at *Khari* and *Beel* and their recharge performance

Information about MAR constructions in the study area and their recharge performances was collected from articles published in journals and Ph.D. theses. Hossain et al. (2019d) and Hossain (2023) reported that two MAR installations were constructed in the study area, one in the Sharmangla *Khari* under Godagari Upazila and the other in the Bajerpur *Beel* under Mohanpur Upazila, and observed their recharge performance during the dry season (water absent in the Khari and MAR areas) and monsoon season (water available in the *Khari* and *Beel*). Recharge performances were observed for six consecutive years (2016–2021), and the mean recharge rate was found to be 28.97 liters per minute and 162.68 liters per minute for Sharmangla *Khari* and Bajerpur *Beel* MAR constructions in the monsoon season, respectively. Monsoon performances were considered for calculating the number of MAR constructions, as at this time water remains available in the *Khari* and *Beel* and groundwater recharging occurs through MAR construction automatically and continuously.

3.2 Computing the potential number of MAR constructions

The availability of surplus surface water in the *Beels* and *Kharies* was taken into account to estimate the number of MAR constructions. Rainwater accumulates in the *Kharies* and *Beels* from their surrounding catchments as surface runoff. The catchment area was taken from Google Earth Pro contour map. To estimate the number of MARs, the yield of the catchments is calculated using the following rational formulae (Eq. 1) (Raghunath, 1997)

$$Yield = CAP \tag{1}$$

Where, A = area of catchment, C = runoff coefficient and P = Precipitation

The value of runoff coefficient C, which varies from 0.4 to 0.6 with an average of 0.5, was considered for catchments cultivated or covered with vegetation (Raghunath, 1997). The available surface water for recharge was estimated by deducting the required water to maintain the required minimum depth of 1.22 m from the total runoff water accumulated in the *Beels*. On the other hand, surplus water that would overflow the cross dam was considered available water for recharge. The number of MAR units was determined by dividing the available surplus water by the recharge rate of the MAR unit.

4. RESULTS AND DISCUSSIONS

A huge water bodies including ponds, *khals* or *kharies* and *beels* are available within the study area. The prospect of MAR construction based on ponds water is negligible because of small volume of water, fish culture and supplementary irrigation with low lift pump. The analysis shows that the required depth of water for fish culture will not remain in the pond due to the installation of MAR for groundwater recharge with pond water. However, *Khals* or *Kharies* carry huge water and allowed to overflow over the cross dam that finally goes to the river. The overflowing water can be used to recharge aquifer through MAR system.

4.1 Potential Number of MAR for *Khari*

The potential number of MAR was calculated based on overflowing water over the cross dam that enter into the *khari* by surface runoff from the catchment area and recharge rate of 29 leters/min through the MAR for *khari* (Hossain, et al., 2020). The possible number of MAR that might be constructed considering the quantity of overflowing water is presented in Table 3.

Table 3: Possible number of MARs can be constructed in the *kharis* of study area

Upazila	Runoff water (m^3)	Storage Capacity (m^3)	Available water for recharge (m^3)	Cross dam (No.)	Possible MAR (No.)
Godagari	9495952.63	2243857.98	7252094.65	88	966
Mohonpur	85188.514	15017.6	70170.914	1	9
Niamatpur	37529687.8	20441356.1	17088331.7	103	2276
Total	47110828.94	22700231.7	24410597.26	192	3251

It is found that 966 numbers of MAR are possible to construct within 129.49 km *khari* having 88 number of cross dam in Godagari upazila while 2276 numbers of MAR can be constructed in Niamatpur upazila where length of *khari* is 243.77 km with 103 cross dam. However, only nine MAR can be installed in 3.42 km *khari* under Mohonpur upazila. The total 3251 MAR is possible to install within 376.68 km *kharis* in the study area. The numbers of MAR in each kilometer *khari* are 7.5, 2.6 and 9.33, respectively in Godagari upazial, Mohonpur upazila and Niamatpur upazila. This variation in number of MAR is due to the variation of width and depth of *kharis*, height of cross dam and average rainfall in different upazilas. Furthermore, about 24410597 m^3 runoff water can be possible to recharge through the MAR out of 47110829 m^3 annually while about 22700231.7 m^3 would be possible to store for supplementary irrigation by using low lift pump. The available water for possible recharge is about 52% of total runoff water.

4.2. Number of MAR constructions for *Beel* areas

There are nine *Beels* (vast bodies of water) in the study area contain substantial quantities of surface water. The surplus water was considered for replenishment, maintaining the *Beels'* average natural water depth round the year and the possible numbers of MAR under each upazila were computed considering the average recharge rate of 162.7 leters/min (Hossain, et al., 2019d). The possible numbers of MAR under each upazila in the study area is presented in Table 4.

Table 4: Possible number of MARs can be constructed in the *beels* of study area

Upazila	**Name of Beel**	**Beel area (acre)**	**Ave. water depth remains (m)**	**Runoff water (m^3)**	**Minimum required water (m^3)**	**Available water for recharge (m^3)**	Reqd. No. of MAR
Godagari	Beel Choroi	9.41	1.22	153590	46478	107112	3
	Beel Vela	3.0	0.90	48968	10931	38037	1
Mohonpur	Shutkir Beel	37.87	0.75	512426	114990	397436	9
	Dhakai Dara Beel	20.6	0.85	279403	70891	208512	5
	Beel Hilna	107.46	0.75	1342184	326296	1015889	24
	Beel Dubi	9.19	0.75	124360	27905	96455	2
	Batupara Beel	22.26	0.75	300844	67591	233253	6
Niamatpur	Beel Bahagole	31.89	0.75	515015	96832	418183	10
	Beel Shidine	15.43	0.75	225815	46852	178963	4
Total				3502605	808766	2693840	64

The estimation shows that there are 64 MAR can be constructed in the study area among which four MAR in Godagari upazila, 46 MAR in Mohonpur upazila and 14 MAR in Niamatpur upazila. The total possible number of MAR in *beels* is very less than the possible MAR in *kharis* in the study area. This is due to the consideration of usable volume of water in the *beels*. Here it is considered that the quantity of water that remains round the year will not be recharged and only the additional water that coming as surface runoff from the catchment area. However, about 77% water of the *kharis* can be used for groundwater recharge with 64 numbers of MAR in the study area.

It is observed from the study that about 27104437.3 m^3 of water from surface runoff can be possible to use for groundwater recharge with the development of appropriate MAR structures in the study area. About 3315 MAR structures need to be installed to recharge the available runoff water.

4. CONCLUSIONS

Sustainable management of groundwater in the drought-prone, water-stressed Barind region of Bangladesh has now become a great concern, which could be possible to achieve by applying the MAR tool. The available surplus surface water was estimated for the re-excavated *Kharies* and *Beels* in the study area, and the number of MARs was computed by dividing the surplus water of each *Khari* and *Beel* by the recharge rate of the MAR unit established in the study area. The computed number of MAR was found to be 966 for 129.49 km of *Khari* in Godagari Upazila, 2276 for 243.77 km of *Khari* in Niamatpur Upazila, and 9 for 3.42 km of *Khari* in Mohanpur Upazila, amounting to a total of 3251 MAR in 376.68 km of *Kharies*. On the other hand, 64 MAR constructions are possible for 9 *Beels* in the study area, of which 4 are for Godargari, 14 are for Namatpur, and 46 are for Mohanpur Upazila beel areas. For sustainable agricultural production, the environment, and ultimately the survival of flora and fauna, the entire Barind tract is suggested to be brought under MAR application with a judicious number of MARs with their sound design and capacity.

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