Int. j. adv. multidisc. res. stud. 2024; 4(1):759-765

Received: 10-12-2023
Accepted: 20-01-2024

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Assessment of the Managed Aquifer Recharges (MAR) Constructed from 2009 to 2018 in the Pleistocene Geological Formation Areas of Bangladesh

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Abstract
After independence in 1971, Bangladesh started to extract extensive groundwater for drinking sources driven by the need for bacteriologically safe sources for public health protection, as a result currently about 98% of the population relies on groundwater for drinking purposes. About 77% of the current irrigation coverage is provided through groundwater sources. 1500 billion litres of groundwater have been extracted annually for the textile industry backyard of the Ready-Made Garment sector. Consequently, significant groundwater depletions are taking place in the Pleistocene geological formation areas along with its surrounding floodplain areas because of the thick top clay layer that limits the natural recharge of groundwater.

To address the groundwater recharge by rainwater both from rooftop and surface runoff, Managed Aquifer Recharge (MAR) is one of the options. In this regard, in 2021 the Bangladesh Water Development Board along with Water Resources Group has drafted the MAR Strategy, yet to be finalized.

For learning and introducing the MAR in Bangladesh some organizations have constructed a few numbers of this technology, some of them are still functioning and some are abandoned. The study team assessed MAR technologies located in Dhaka and Rajshahi Divisions mainly in the Pleistocene geological formation areas constructed by government agencies and non-government organizations. In addition, the study team reviewed the country's policy, strategy, guidelines and journals and conducted interviews with professionals and academicians at home who are associated with MAR technology to get the facts that are associated with the functionality and non-functionality of MAR.

From this study's findings, two significant points have been picked up for MAR's sustainability and better functioning, one is turbidity control of the collected rainwater and another is lithology for having the information of saturated, moderately saturated and unsaturated aquifer zones because of choosing the layer where rainwater is to be penetrated for storage or replenish. Routine maintenance is compulsory for turbidity control as well. In addition, as the rain pattern has already changed, torrential rainfall within a very short time has been happening due to climate change which creates water logging in urban areas that could be partially resolved if MAR scales up significantly, the study team assessed it as well.

Keywords: Managed Aquifer Recharge (MAR), Holocene and Pleistocene Areas, Groundwater Depletion, Climate Change, Urban Waterlogging

1. Background of the study

This study is an initiative to evaluate the current status of MAR constructed by government and non-government organizations in the Pleistocene geological formation areas in Bangladesh where natural groundwater recharge is limited. If the findings of the study align to promote the MAR, then aim to share the findings with government and non-government organizations to take steps for scaling up MAR as a tool of Integrated Water Resources Management (IWRM).

2. Methodology

The study team assessed MAR technologies by physical observation and then analysed them, located in Pleistocene geological formation areas in Bangladesh to identify the facts of why it is functioning and non-functioning. In addition, the study team

reviewed the country's policy, strategy guidelines and interviewed professionals and academicians at home who are associated with MAR technology to get the statistics and facts associated with MAR's functionality and non-functionality.

3. Study Area

The study areas are located in Dhaka city, Rajshahi, Chapainawabgonj, Bogra, and Noagaon, Districts where MARs were constructed from 2009 to 2018 by government and non-government organizations.

4. Review the policy, strategy, guidelines and literature

Managed Aquifer Recharge (MAR) is explicitly mentioned in the country's Drafted Final MAR Strategy, National Building Code, National Environment Policy, Draft Industrial Water Policy, 8th Five-Year Plan and National Conservation Strategy. These mentions create opportunities for applications of MAR for Environment Management, Industrial Water Management and Urban Areas in Bangladesh. BDP2100 included the MARAS project to implement MAR in different hotspot areas of the country.

4.1 Drafted Final MAR Strategy:

Drafted MAR Strategy, 2021 states that MAR is a toolkit for solving problems of water scarcity by groundwater replenishing and will be applied first in (i) the Dhaka – Gazipur metropolis where tables are being drawn down by municipal and industrial pumping; (ii) the low-rainfall Barind tract in Rajshahi Division where levels are falling due to irrigation abstraction; (iii) the saline coastal areas of Khulna Division where drinking water is desperately short in the dry season; and (iv) in the Chittagong Hill Tracts where spring flows are increasingly unreliable.

4.2 National Building Code:

Chapter 7 of the Bangladesh National Building Code specifies the general requirements for rainwater harvesting for different categories of buildings according to their occupancy classification together with all ancillary works of groundwater recharging such as perforated piping, pits and inspection chambers. In this regard, the typical design of the Managed Aquifer Recharge has been stated in Chapter 7 under the National Building Code.

The volume of the recharge pit shall be on the basis of maximum intensity of rainfall in a shorter period of at least 15 minutes. It is about one-fourth of the peak hourly rainfall.

4.3 Convention on Rainwater Harvesting 2012 held in Dhaka:

Was the first convention in Bangladesh to promote rainwater harvesting across the country organized by WaterAid Bangladesh, the Institute of Water Modelling, Bangladesh University of Engineering and Technology (BUET) and the Centre for Science and Environment (CSE) together. The convention had five business sessions where 19 papers were presented and debated. After the convention, the Dhaka Declaration was announced based on the 19 paper's deliberations including the inaugural session. The main point of this declaration is that rainwater should be considered as a solution to water crisis management. The potentiality of rainwater harvesting to address household-level water scarcity as well as to enhance groundwater recharge has already been tested in the context of Bangladesh.

4.4 The country's 8th Five-Year Plan (FYP):

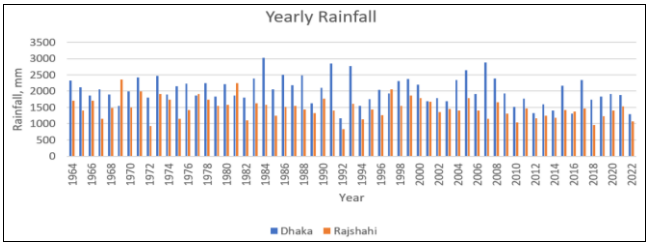
The activities to be undertaken to address climate change in the 8th FYP state developing a strategy for managed aquifer recharge and introducing natural and artificial aquifer recharge systems using rainwater harvesting for groundwater recharge.

5. Discussion and Result

Discussion and result have been carried out in two folders, the first one analysed the rainfall and hydrogeology of the study area and the second one analysed the design and performance of MAR constructed by different organizations in Dhaka and Rajshahi Districts through physical observation and Key Informant Interviews.

5.1 Rainfall analysis:

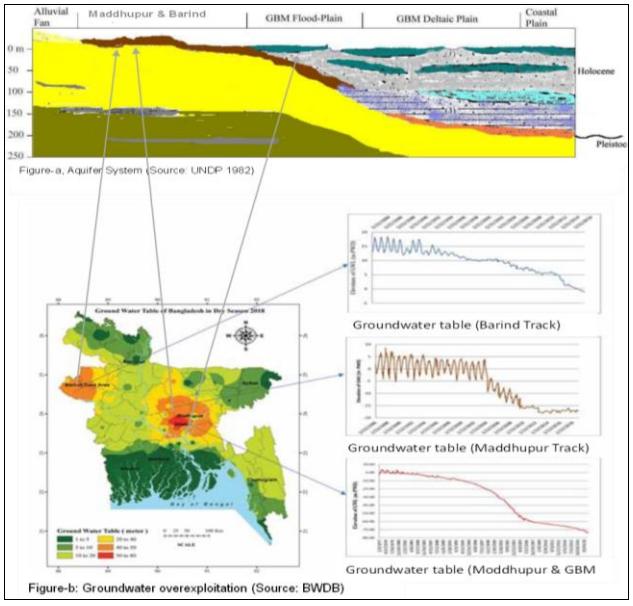
From the Bangladesh Agriculture Research Council, the study team has collected the rainfall data from 1953 to 2022 for the Dhaka district and Rajshahi district both areas are in the Pleistocene geological formation. After analysing the rainfall data following table has been generated which shows the yearly average rainfall at Rajshahi is 1100 to 1200 mm whereas it has increased at Dhaka, where the yearly average rainfall is 1700 to 1800 mm. Monthly rainfall shows that rainfall mainly happens from April to November.



It is very tough to predict the rainfall pattern and yearly rainfall in Bangladesh as it did not follow the annual rainfall for consecutive 3 years.

5.2 Hydrogeology of the study area:

The hydrogeology of the Moddhupur Track, Barind Track and their surrounding areas has been seen in the following figure which is formed by Pleistocene formation soil.



The above figure shows the groundwater depletion rate in Pleistocene areas -Dhaka and Rajshahi districts are very critical because of over-extracting groundwater and natural recharging is limited.

5.3 Physical observation of the MAR, interaction and analysis:

i) MAR, constructed by Dhaka Water Supply and Sewerage Authority (DWASA)

Considering the threat of groundwater mining, Dhaka WASA decided to carry out a pilot study on artificial recharge to aquifers through rainwater harvesting and assigned the Institute of Water Modelling (IWM) in December 2009 to conduct this study. The main objective of this pilot study was to investigate the feasibility of artificial recharge to the upper Dupitila aquifer within the city to protect the aquifer environment and to augment the present supply of water in Dhaka city. IWM selected Segunbagicha and Lalmatia DWASA compounds considering prevailing hydrogeological conditions and the scope of rainwater harvesting from rooftops. For this purpose, $15m^2$ and $14m^2$ recharge pits along with a 1.3m thick three-layer filter bed and 104m & 121m deep injection wells were constructed at the two sites respectively. For the collection and delivery of harvested rainwater into the recharge pit necessary pipe network has also been constructed. After constructing the MAR, IWM monitored both water quality and penetration rate. Through these experiments, some important and interesting output has evolved. These are; The Saturated and pumping part of the Upper Dupitila aquifer is the best depth location for making artificial recharge through gravity inflow in the Upper Dupitila aquifer system. Rainwater in Dhaka city has good quality standards for use in artificial recharge to aquifer layers. In the Segunbagicha area for outflowing recharge water through injection well by gravity, a minimum 560 kPa hydrostatic pressure is to be maintained inside the injection well, while the target aquifer layer has 57m depth to groundwater level, 0.127 specific yield and 21m /day permeability. If 60 % of the total rainfall from concrete rooftops of the city area can be harvested, then annually about 89,496 million litres of rainwater will be available for artificial recharge to aquifer. This recharge volume can make available about 245 mld of water for city water supply (Annual Report-April 2011, IWM) [5]. Later, DWASA constructed another MAR at the staff Quarter Building at Mirpur, Dhaka.

MAR, Segunbagicha MAR, Lalmatia MAR, Mirpur

Rainwater flows in pit through the perforated pipe, designed by DWASA

Result: When the study team visited the MAR at Segunbagicha, Lalmatia and Mirpur in 2023 October, all were well functioning. During physical observation, we found all pipes are connected from the rooftop properly, and maintenance and operation are good. During interaction with the person concerned, we came to know all are operating well. Once, in 2019, they had cleaned the upper sand of the filter bed.

ii) MAR, constructed by WaterAid Bangladesh

WaterAid Bangladesh, an international NGO constructed MAR at Bangladesh University of Engineering and Technology (BUET), Independent University of Bangladesh (IUB)-Bashundhara, Village Education Resource Centre (VERC)-Svar, and University of Information and Technology Science (UITS)-Baridara extension area under the Dhaka District in 2011 to 2012.

MAR, VERC

After the construction of MAR, WaterAid Bangladesh engaged ITN-BUET in 2012 to carry out a research study about the functionality of MAR in 4 places for 3 years. The research finding was good as all of the MARs were functioning during that time, the result was shared at the 2nd Bangladesh RWH Convention held in 2014. In 2023 interaction with the research team of ITN BUET and concerned organizations, the study team came to know that MARs were functioning from 2012 to 2015 and 2016. From June 2023 to October 2023, the study team also physically observed the MARs of those 4 places and interviewed the persons concerned. Among the 4 MARs, only one MAR which has been operating by VERC is now in good condition. MAR's filtering bed at BUET is now clogged because of poor maintenance, waste was dumped by students as it is located at the cafeteria, and no fencing was there. BUET said to us it was functioning up to 2016. UITS's MAR was well-functioning, but it was demolished due to the high-rise building that was constructed in that place in 2015. IUB's MAR was built at the backside of the building and was functioning up to 2017 but it was demolished due to the construction of a road by City Corporation, said the School of Environmental and Life Science of UIB. In addition, two research works were conducted on MARs at UIB and UITS by their student and teachers and they showed both MARs were functioning well (Ahmed, Dakua and Hossain, ResearchGate June 2014); (Islam and Nomaan, ResearchGate December 2013).

Another MAR, WaterAid constructed at Next Accessories Ltd (NAL), an apparel situated at Vulta, Rupgonj in Narayangonj district. In the beginning, it was functioning,

but after a few months, it was clogged due to high turbidity coming from surface and drain runoff.

iii) MAR, constructed by the National Housing Authority (NHA)

The National Housing Authority (NHA) has developed Shopnonagar Residential Area-1, Mirpur-9 in Dhaka with ten buildings where 1040 flats are constructed. In addition, there is a big playground with a community building. Rainwater harvesting facilities with MARs were constructed. During physical observation and interaction with persons concerned the study team came to know that 5 MARs among 16 MARs are now functioning. Interestingly, 2 MARs among 4 MARs surrounding the playground are still functioning. However, most of the rooftop-based MARs are now non-functioning. During the critical analysis of the design and feasibility, the study team understood that there was a design limitation and did not maintain quality control during construction MAR.

iv) MAR, constructed by the Rural Development Academy (RDA, Bogura)

RDA constructed a MAR in the Indoor Sports Complex Building of its campus in 2016. The total catchment area is 697 m2 and the harvesting potential is 1071 m3/year. It shows a successful practice for mitigation of the water logging problem and this approach can be replicated in the urban area as the country has been experiencing torrential rainfall within a very short time (Bangladesh Rural Development Studies Vol. XXII; No.1-2018). During our interaction with RDA and the research team, we came to know this MAR is still operating.

v) MAR, constructed by the Barind Multiple Development Authority (BMDA)

BMDA constructed two types of MAR, one collects rainwater from building rooftops and injects it by borehole, and another type is well-constructed for small irrigation (less water consuming crops), in general located at cropland.

Picture of MAR, BMDA's office, Mohonpur, Rajshahi

MAR was constructed through rooftop rainwater harvesting in the Mohanpur office campus of BMDA, Rajshahi under the Barind track in 2016 June. A water filtration unit was designed considering the average maximum daily rainfall. Rooftop rain waters were collected from the office building and a training shed near the uPVC pipeline, filtered through the sand-gravel filtration media of the filtration unit, and finally recharged to the groundwater through RW. GWL fluctuation of the observation well (OW) installed near the RW was monitored using an Auto Water Level Recorder (AWLR). Performances were evaluated based on groundwater recharge, GWL fluctuation with the rainfall, and quality of water. The study found that groundwater recharging occurred significantly, groundwater level rose when rainwater was infiltrated into the groundwater, and water quality parameters remained within the acceptable limit for drinking as meet the Bangladesh Drinking Water Standard. For the last 3 years (2017 – 2019), annual recharge varies from 255996 to 269100 litres. (I. Hossain, N. Bari, S. Miah and A.Kafi: Application of modified managed aquifer recharge model for groundwater management in drought-prone water-stressed Barind Tract, Bangladesh Published by Elsevier B.V. 2021. ScienceDirect).

Picture of dug type MAR

During the interaction with the Engineers of the BMDA office in Mohonpur Upazila under Rajshahi district, the study team came to know that this MAR technology is still operating and well-functioning.

Since 2013 the BMDA has constructed 240 numbers of Modified Dug wells with a view to irrigating low-water-consuming crops like cauliflower, potato, chills and other vegetables. A rainwater receiving structure with solar panels has been constructed over the dug well, and an overhead water tank has also been set on an elevated tower. Rainwater is received by the solar panel cum rainwater receiving structure during rainfall and stored in the Dug well. The conserved water is then lifted to the overhead tank by a solar energy-driven pump and used for irrigation. Moreover, there is a scope to use the surplus water for groundwater recharge in the water-stressed Barind tract.

The study team reviewed the two journals (N. Basak and N. Basak: Modified dug well in Barind area, a popular irrigation adaptation in the North-western region of Bangladesh: @International Research Journal of Modernization in Engineering, Technology and Science) and (I.Hossain, N.Bari and S. Miah: Opportunities and challenges for implementing managed aquifer recharge models in drought-prone Barind tract, Bangladesh @ Applied Water Science (2021) 11:181) [2]. From these published journals and interactions with BMDA's officers at different levels, the study team came to know that this type of MAR is very effectively functioning and providing irrigation for vegetable-based gardening.

vi) MAR, constructed by the DASCOH Foundation

Picture of MAR at HH by DASCOH

DASCOH Foundation, a National NGO in collaboration with the Swiss Red Cross jointly constructed MAR in Barind track from 2015 to 2018. 2nd phase still continuing. This type of MAR is very simple to construct. During interaction with the person concerned of DASCOH, the study team was informed that since 2015 they constructed 209 MARs and among them, 42 are constructed at Union Parishad and the rest are constructed at households. The study gathered the success information from the Daily Sun (a National daily English newspaper) on 30 September 2023 that Korneleus.

Tudu, 54, and Paulus Tudu, 48, of Barsapara village in Dewpara Union under Godagari Upazila in Rajshahi district, have been harvesting rainwater and inserting those to the underground for the last around four to five years. In interaction with DASCHO Foundation and their consultant, Professor, Department of Geology and Mining of Rajshahi University the study team came to know this type of MAR at household is still operating. Each household has been maintaining its operation. At Union Parishad, MAR is operating as the project staff looking after the maintenance of MAR.

vii) MAR, constructed by the NGO Forum Public Health

In 2012, NGO Forum for Public Health, a National NGO constructed the MAR in Nachole, Chapainawabganj district taking technical support from the professor, Department of Geology & Mining, Rajshahi University. The recharge wells have been constructed in three different locations in Nichole Upazila.

Picture of MAR at HH by NGO Forum

The adjacent Sheds have been used as the catchment of rainwater which is connected to the recharge chamber by using uPVC gutter and pipe network. The groundwater level is monitored by observation wells. After 4 years of close monitoring, NGO Forum has collected the findings and learning and consulted a panel of eminent water experts. Through the engagement of sector and technical experts, NGO Forum finds the possibility of scaling up the MAR technology as a context-specific option for the drought zone. (Source: NGO Forum for Public Health). During interaction with the Programme Head of NGO Forum, the study team came to know that MAR was functioning when they visited in 2016.

viii) Bangladesh Water Development Board (BWDB)

Under the Ministry of Water Resources, Bangladesh Water Development Board (BWDB) has been implementing agency for water resources, flood controlling activities including monitoring and providing hydrological data. They have set up one MAR at their Head Quarter office premise, just one and half years ago (2022) under the guidance of Hydrogeological Unit. The catchment area of this MAR, they used the roof top of *Pani Biggan Bhabon*. During physical observation of the MAR, the study team interacted with the Director of Hydrogeologist, BWDB. They said one monsoon they observed, result is very satisfactory. Total rainwater of the roof top of *Pani Biggan Bhabon* went to aquifer through this MAR. Study team found there is another borehole to monitoring the water quality.

Picture: MAR, BWADB

Picture: Monitoring Borehole, BWADB

5.4 Analysis of the design of MAR constructed at different places:

Rainwater-Storage-Supply and Recharge (RWSSR) concept for places where rooftop rainwater harvesting is possible. A planned schematic diagram, performed in this study, of the RWSSR concept is shown in the following figure. In the RWSSR concept, rainwater is stored in underground storage tanks. Therefore, the roof should be prepared for water harvesting beforehand. A portion of the harvested water is used for non-potable use immediately after low-cost pre-treatment, such as filtration. When the storage tank is full, excess water is passed through the injection well to recharge the upper Dupitila aquifer. A control valve will regulate the water pathway. The recharge of excess water will increase groundwater resources.

Besides the above concept, the storage rainwater in the pit is to be used only for recharge into the upper aquifer. This type of design the study team found in the Bangladesh National Building Code and WaterAid followed this design while constructing the MAR in BUET, IUB, UITS and VERC.

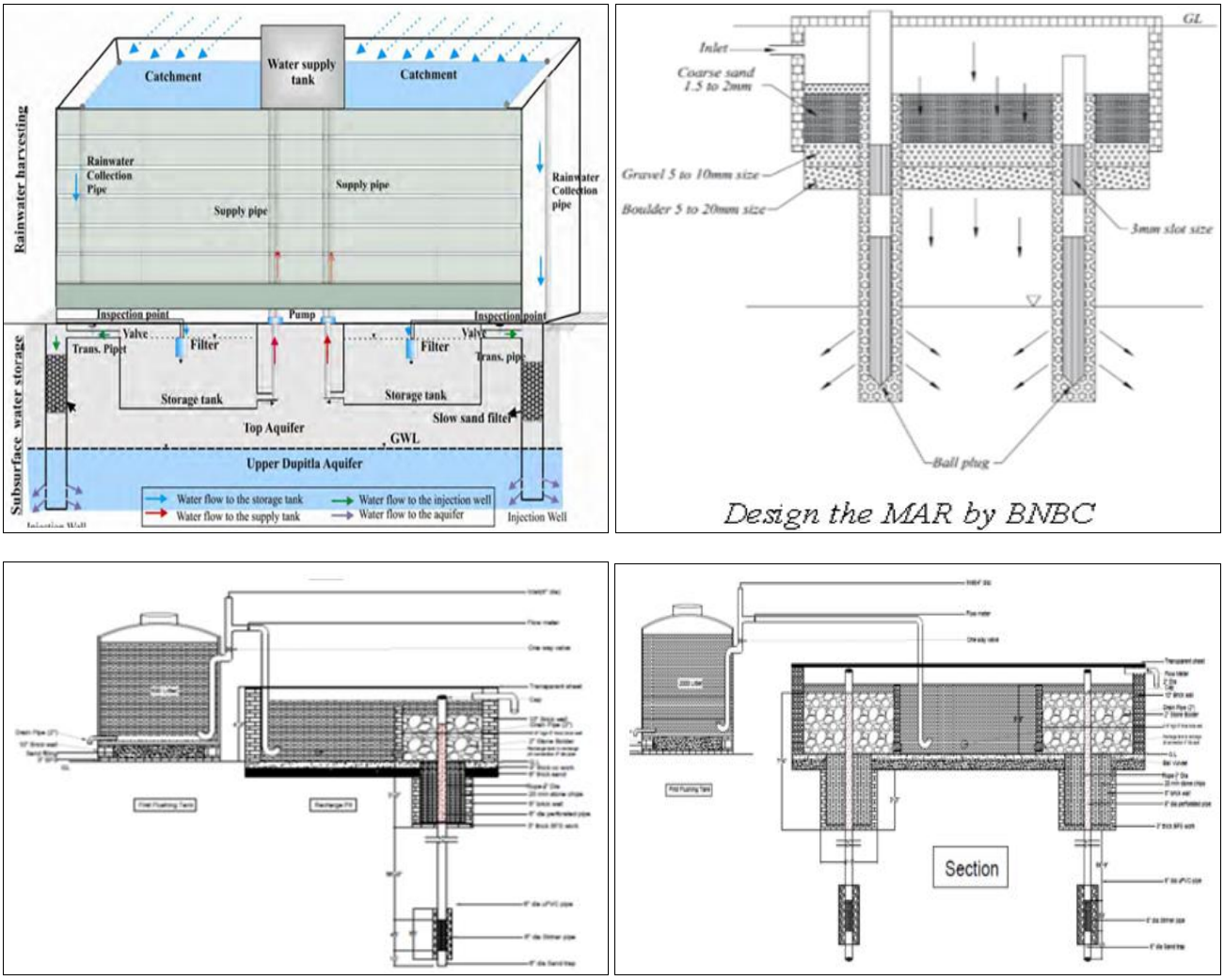


Figure MAR, designed by WaterAid

The following design concept was added to the perforated pipe before dropping the rainwater on the filter bed just to reduce turbidity for easy injection of rainwater to the ground, which one adopted by Dhaka WASA in the figure.

WaterAid currently has been following the design, which are shown above.

6. Conclusion

Analysed the MARs which are still functioning and abandoned under this study, the study team found if anyone follows the design and constructs it accordingly then MAR is operatable. For the sustainability of MAR, cleaning the filtering bed and catchment before the rainy season is essential.

This study has found out the points that are most important for MAR's sustainability and its better functioning, and these are during design it is essential to consider how to get less turbidity after collecting the rain. In this regard, both the catchment area and filtering media need to be designed in a way which reduces turbidity. The second one is to find out the best ground zone where rainwater to be easily penetrated, meaning a coarse or medium-fine sand layer which is comparatively unsaturated. The third one is very important which is regular maintenance of the catchment and filtering chamber so that any clog does not happen.

How much MAR has been contributing to overcoming the water logging caused by torrential rainfall within a short time has yet not been found under this study. If MAR is scaling up in an area, then it would be analysed. So, scaling up for MAR, the final drafted MAR strategy needs to be finalized and promoting government, nongovernment organizations and households to construct MAR by the MAR strategy. In this regard, the design guideline of MAR concerned authority of the government may develop.

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