GROUNDWATER MANAGEMENT THROUGH ARTIFICIAL RECHARGE: ISSUES AND NEW PERSPECTIVES

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ABSTRACT

Artificial recharge to groundwater is a viable option for augmentation of groundwater resources. This paper deals with the various aspects of artificial recharge of groundwater including Managed Aquifer recharge (MAR) techniques and Remote Sensing (RIS) & Geographical Information Systems (GIS) Techniques suitable for various hydrogeologic regions. Some issues and new perspectives in groundwater management is dealt with in detail hoping this work will be useful to all agencies engaged in planning and management of groundwater resources through artificial recharge techniques.

INTRODUCTION

Earth, as we know it, is a watery planet, with water covering roughly 71% of the total surface area. Total volume of water on earth is estimated to be about 1.386 billion km^3. But not all of this water is potable or suitable for industrial purposes. Of this huge volume of water, about 97.5% is saline (1.351 billion km^3) and the rest 2.5% is fresh water (35 million km^3). But even all the fresh water is not available for use, as most of this fresh water is locked up in the form of ice in glaciers and in the poles. Of all the fresh water, most of it, about 99% is groundwater, and less than even 1% is in the form of lakes, rivers and swaps which are readily available for human use. As evident from this data and the current human consumption of water, this tiny 1% of fresh water is being exploited in all possible ways and would soon become too polluted to be usable. We also depend heavily on the rest 99% that is the groundwater. But accessing this groundwater is cost intensive.

Groundwater, unlike the surface fresh water, is not available readily at one particular depth. We can dig only up to a limited depth to pump out this groundwater; hence, not all of it can be accessed. The accessible part of groundwater is being used by us extensively and this has led to the lowering of groundwater table, making it more and more difficult to access. Lowering of groundwater table is not the only effect of human use, there is also the more worrisome problem of groundwater pollution and the degradation in its quality. Recharging of groundwater takes place naturally via percolation and infiltration of rain water. But the recent climate change effects on rainfall have rendered this natural method unpredictable. Therefore, the need arises for artificial groundwater recharge. Artificial recharge to ground water is defined as the recharge that occurs when the natural pattern of recharge is deliberately modified to increase recharge (ASCE, 2001). In broadest sense one can define artificial recharge as "any procedure, which introduces water in a pervious stratum" (CGWB, 2007). Just the methods of groundwater recharge are not the only concern of research; there are several perquisite conditions and other factors which are to be considered in order to ensure safe recharging and sustainable use of groundwater. Some issues and new perspectives in groundwater management have been dealt with in detail hoping that they may help the agencies or persons engaged in planning and management of groundwater resources through artificial recharge techniques. The relevant literature has compiled and studied to prepare this comprehensive review article to make it as a ready reference for researchers, field engineers and the persons engaged in the works of artificial recharge of groundwater. Some past studies on artificial recharge of groundwater from literature have been highlighted herein for their appropriateness.

METHODS OF ARTIFICIAL GROUNDWATER RECHARGE

Listed below are the modern and conventional techniques of artificial groundwater recharge:

Managed Aquifer Recharge (MAR) Techniques

Managed Aquifer Recharge (MAR) can be used in conjunction with water harvesting techniques to recharge an aquifer by catching water during rainfall, thus impeding the quick runoff out of a catchment area (IGRAC, 2007). The International Groundwater Resources Assessment Centre (IGRAC) is a non-commercial organization facilitating and promoting world-wide exchange of groundwater knowledge related to MAR through their website www.igrac.nl to improve assessment, development and management of groundwater resources. To get an idea of what kind of recharge techniques are being used all over the globe, one may use the MAR techniques that lists out the various groundwater recharge techniques undertaken in 50 different countries. In recent years there has been a rapid increase in the application of MAR around the world. It has detailed information of the projects along with associated journal papers that give a deep insight into the technique being undertaken at that place. Different methods are coded with different colours for easy identification of the type of technique to be adopted as per the hydrogeologic regions. For more details the readers may see the website link as given herein. https://apps.geodan.nl/igrac/ggis-viewer/viewer/globalmar/public/default.

Basin Method

This method is one of the simplest artificial groundwater recharge techniques. Recharge can be done by releasing water into basins formed by excavation or by construction of dikes. Periodic maintenance is required, which includes scarifying, disking or scraping the bottom of the basin when dry. Multiple basins are preferred over a single basin, as they offer continuity of operation when certain basins are under maintenance, and also act as silting basins for systems where streamflow runoff is being spread. Figure 1 shows a typical plan of a multiple basin recharge project diverting water from a stream.

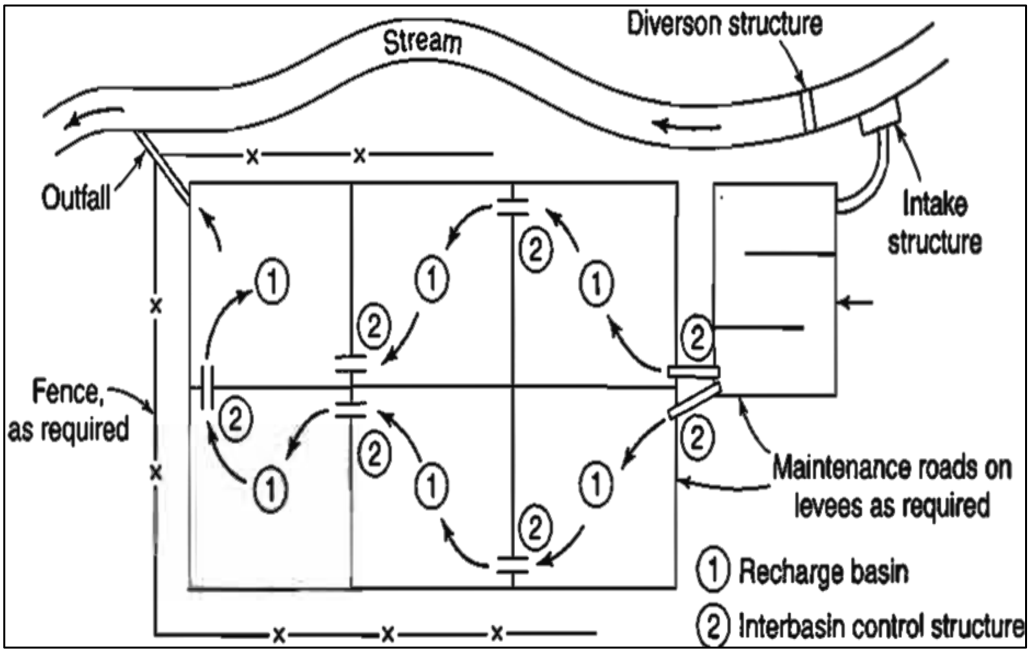


Figure 1: Typical plan of a multiple basin recharge project diverting water from a stream (Source: ASCE, 1972).

Stream-channel Method

A naturally losing channel can provide water for recharge over a greater area and longer period of time. In order to enhance infiltration both upstream management of flow and channel modifications are required. Upstream modifications may include reservoirs which regulate erratic runoff and limit the flow rates within the absorptive capacity of downstream channels.

Channel modifications may include widening, leveling, scarifying or ditching to enhance infiltration. Flow can also be diverted along the channel into basins located alongside the channel to increase recharge by aiding in basin method.

Ditch and Furrow Method

A series of shallow, flat bottomed, closely spaced ditches or furrows constructed alongside a channel are used for improving infiltration. The properties of ditches are suited to obtain maximum water contact area. Three basic layouts are available for this system: (1) Contour, where ditches follow the ground contour; (2) Tree shaped, where the main canal branches into ditches; (3) Lateral, where a series of ditches extend laterally from the canal.

Flooding Method

This method is employed in relatively flat topography. Figure 2 shows the schematic representation of ditch and furrow method. Water is allowed to spread evenly over a large area, forming a thin sheet over the land, moving at a minimum velocity so as not to disturb the soil. In order to control the water, embankments or ditches should surround the whole flooding area. This method costs least of all the methods for land preparation.

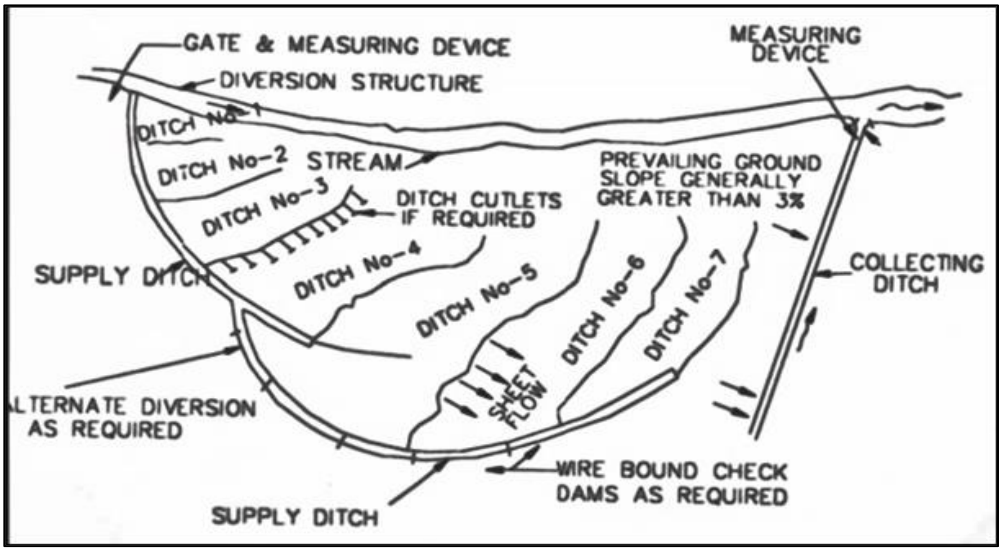


Figure 2. Schematic representation of ditch and furrow method (Source: megphed.gov.in).

Irrigation Method

In croplands, water can be deliberately allowed to spread for recharge. This deliberate action has to be carefully timed, usually during winter months or non-irrigating periods so as to ensure least loss by evaporation. No additional cost for land preparation is needed as the distribution system is already in place. Irrigation canals can be kept full to allow water to seep and increase infiltration. Utmost care has to be taken to prevent water logging and leaching of water contaminated with salts or carrying soil nutrients which would otherwise adversely affect the crop yield.

Recharge by Pit Method

A pit excavated into permeable soil can serve as a groundwater recharge facility. In order to avoid high excavation costs, abandoned pits such as gravel pits should be used. Areas having low permeable clay layers on top can restrict surface infiltration, so pits can be the solution here as they can reach lower permeable strata. Besides being economical, recharge pits can also counter silting. The silt settles at the bottom, leaving the walls unclogged for continued filtration of water. The design should be given proper consideration in order to ensure optimum infiltration rate.

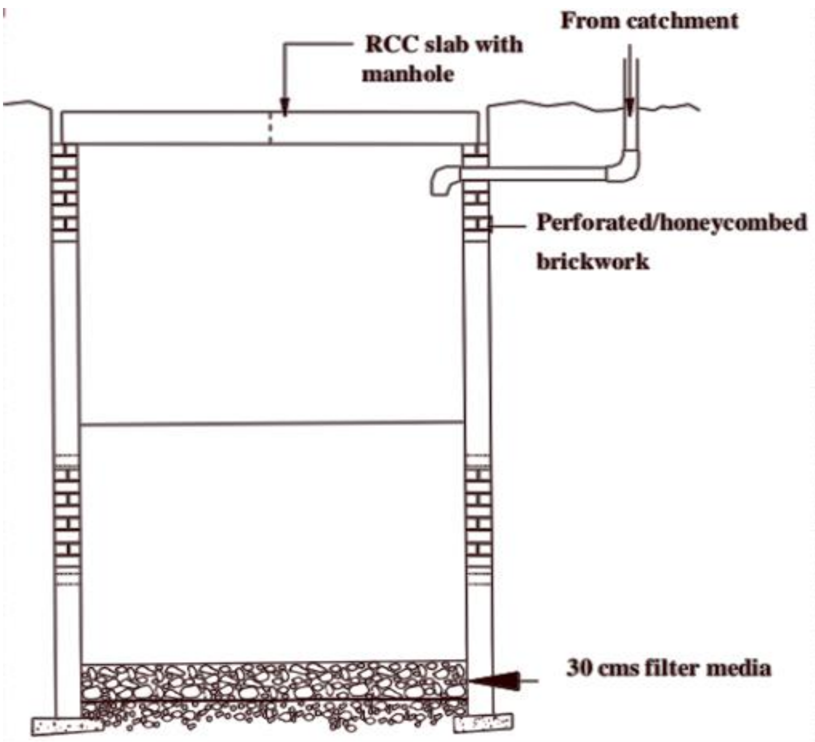


Figure 3. Cross-sectional view of a recharge pit.

Groundwater Dams

A dam is built across a river or stream for collection and storage of surface water. A groundwater dam also serves as a collecting structure purposed to divert groundwater to recharge an adjacent aquifer or to raise the groundwater table of an aquifer. This need of groundwater dam arises due to the erratic rainfall. It is a means to bridge over the seasonal dry periods.

Recharge Well

A recharge well admits water from surface to aquifers. A recharge well's flow is reverse of a pumping well, but its construction may or may not be same. The radial flow from recharge wells penetrating (a) confined and (b) unconfined aquifers are given in Figure 3. When water is admitted into a recharge well, a cone of recharge will be formed that is similar in shape but reverse of a cone of depression surrounding a pumping well.

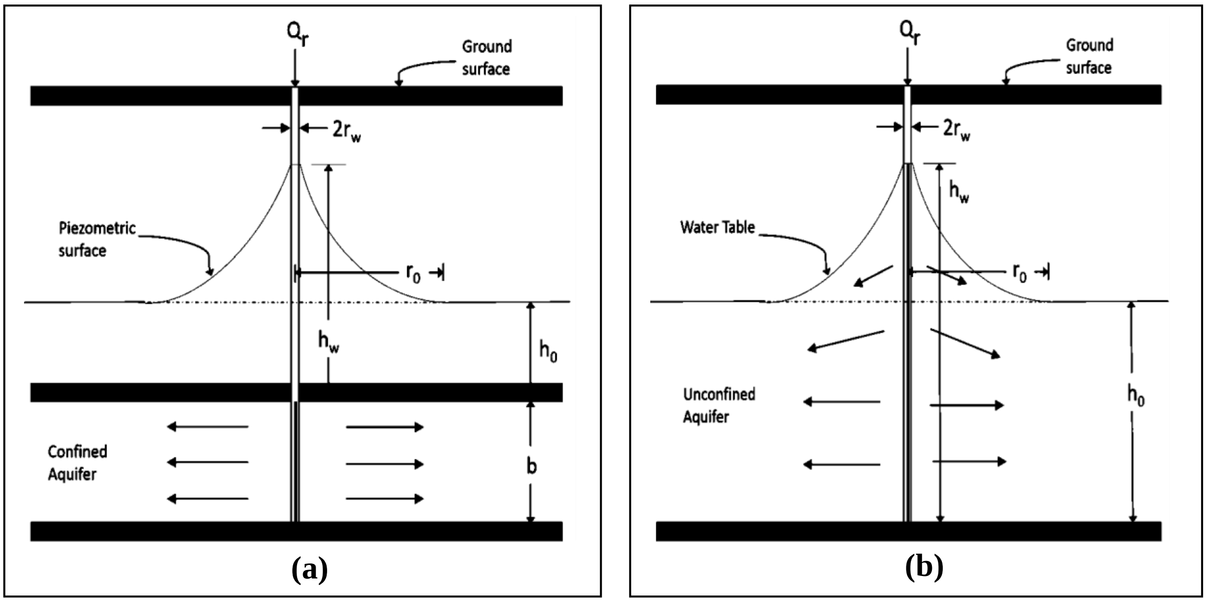


Figure 4. Radial flow from recharge wells penetrating (a) confined and (b) unconfined aquifers (Source: Todd and Mays, (1959))

For a confined aquifer with water being recharged via completely penetrating well at a rate Q_r, the approximate equation can be written similarly as Thiem's equation:

$$Q_r = \frac{2\pi K b(h_w - h_0)}{\ln(r_0/r_w)} \quad \text{...} (1)$$

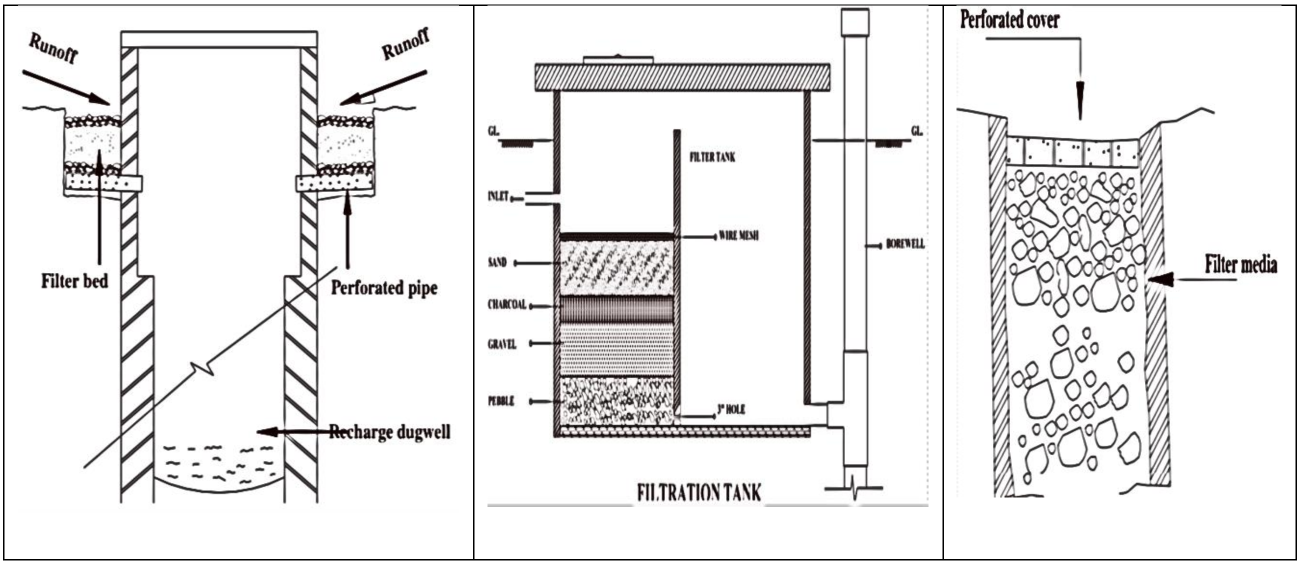
For a recharge well penetrating an unconfined aquifer:

$$Q_r = \frac{\pi K(h_w^2 - h_0^2)}{\ln(r_0/r_w)}$$

………………………………………………….. (2)

(Symbols as identified in Figure 4 (a) and 4(b)

Groundwater aquifers can also be recharged by various kinds of structures to ensure percolation of rainwater in the ground. The widely used groundwater recharge methods are given in Figure 5 (a) to 5 (c)



(a) **(b)** **(c)**

Figure 5. (a) Recharging dug well, (b) Recharging bore well and (c) Recharge Trench

Sprinkling Infiltration

Sprinkling infiltration is a groundwater recharge technique which is done by infiltrating surface water through forest soil. This method has been introduced in Finland. On the basis of studies carried out by Kaarakka et al. (2019), this method is an environment altering soil treatment, which results in long term neutralization of the forest soil and infiltration induced changes in soil dynamics could potentially be long-lasting and soil recovery from such a treatment may take years, if not decades.

Rainwater Harvesting (RWH)

Rainwater harvesting (RWH) is the process of collecting and storing water for future productive use and is an important environment friendly approach with double benefit in both keeping the groundwater table undisturbed and charging the aquifer. Broadly, there are two ways of harvesting rainwater, one is surface water harvesting and the other is rooftop rainwater harvesting. Rainwater harvesting techniques can be coupled with artificial groundwater recharge techniques. In a study by Alataway et al. (2018) of the centralized RWH system to recharge groundwater in Wadi Al-Alb region of Sauid Arabia, it was found that losses due to evaporation could be mitigated by drilling recharge bore wells in the reservoirs. However, periodic cleaning and maintenance of the wells is necessary to prevent clogging by siltation. Treated wastewater can also be a viable source of water for artificial groundwater recharge. Among various challenges of treating wastewater and reusing it, the most prevalent is the psychological barrier of the users. Case study on an aquifer in Cyprus by Kostas (2011) shows that recharging of groundwater using pre-treated wastewater via deep boreholes is a feasible option. Clogging of recharge borehole should be considered while designing and appropriate measures should be taken to avoid such problems. Further, groundwater can also be recharged through wetlands. In a study by Adarsh et al. (2019), it was found that paddy fields effectively act as artificial wetlands which recharge ground water.

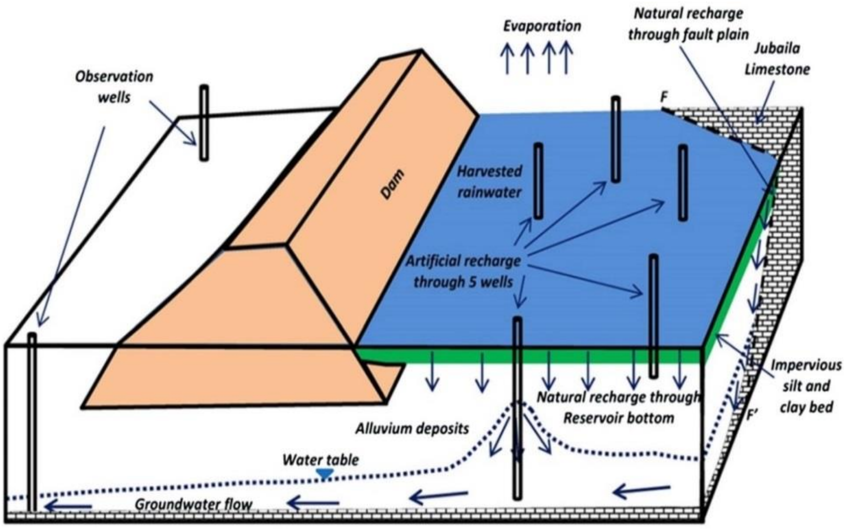


Figure 6. Conceptual model of the shallow aquifer recharge (Source: Alataway et al. 2018).

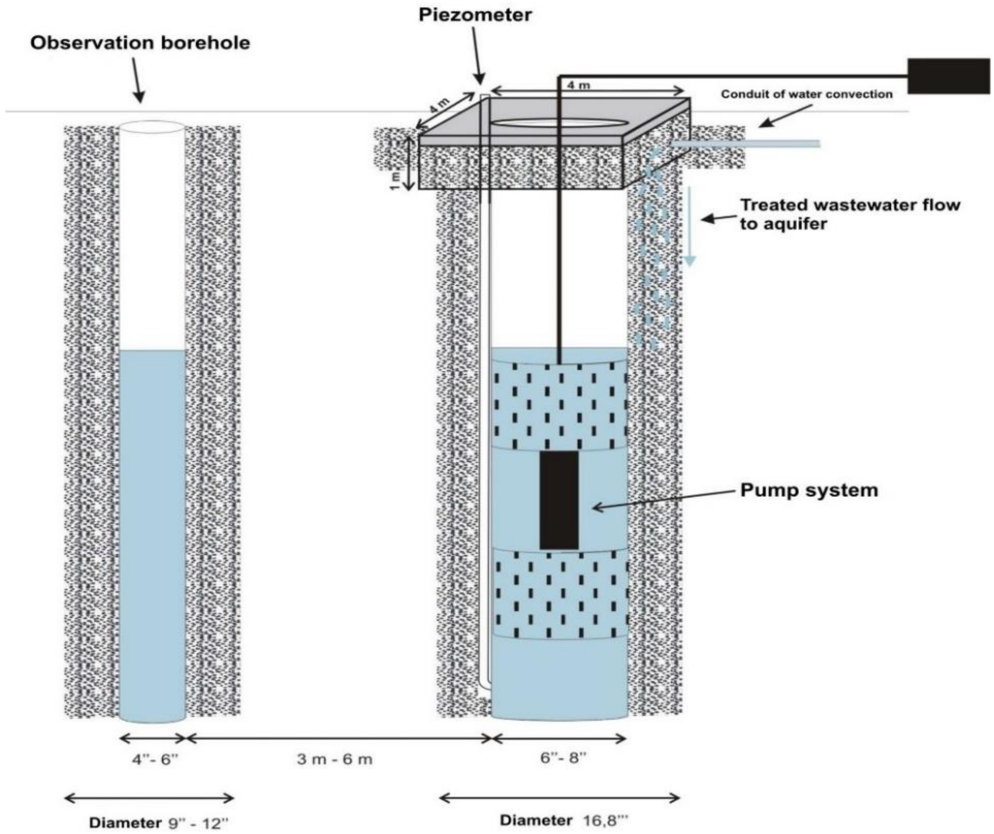


Figure 7. Proposed installation of the recycled water recharge system via deep borehole (Source: Kostas, 2011)

Rooftop Rainwater Harvesting

Rooftop rainwater harvesting is the process of collecting rainwater falling on rooftops in a tank or sump for future productive use. Rooftop rainwater harvesting can be a viable mode of rainwater harvesting for sustainable usage of resources. In a study conducted by Rao, et al., (2013) runoff availability for rooftop harvesting was calculated using widely used rational method and NRCS-CN methods.

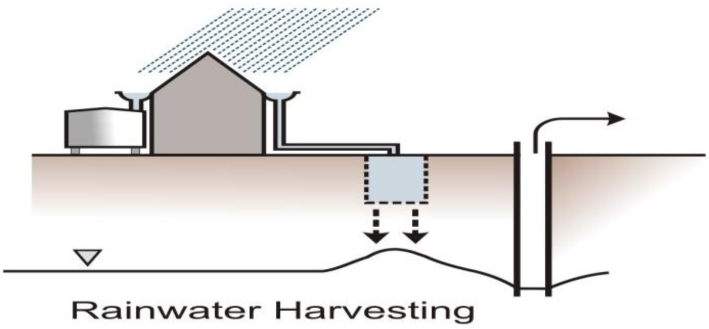


Figure 8. Definition sketch of rooftop runoff (Source: Rao et al. (2013)

Remote Sensing (RIS) & Geographical Information Systems (GIS) Techniques

The use of Remote Sensing (RIS) & Geographical Information Systems (GIS) based analysis in artificial groundwater recharge studies in aquifers of watersheds have been increased. The physiography, geomorphology and land use/land cover of aquifers of watersheds will be analyzed accurately and the quantitative and qualitative assessment of groundwater recharge will be done more easily. A study done by Norouzi, et al (2019) is presented herein. It is a learning method based on ensemble decision trees which integrates various factors such as slope and slope aspect, soil texture, erosion, land use, groundwater quality, permeability and geological lithology with a geographic information science (GIS) in order to determine sites suitable for recharge. The accuracy of the model can be evaluated with receiver-operating characteristic (ROC) curve and the mean squared error (MSE).

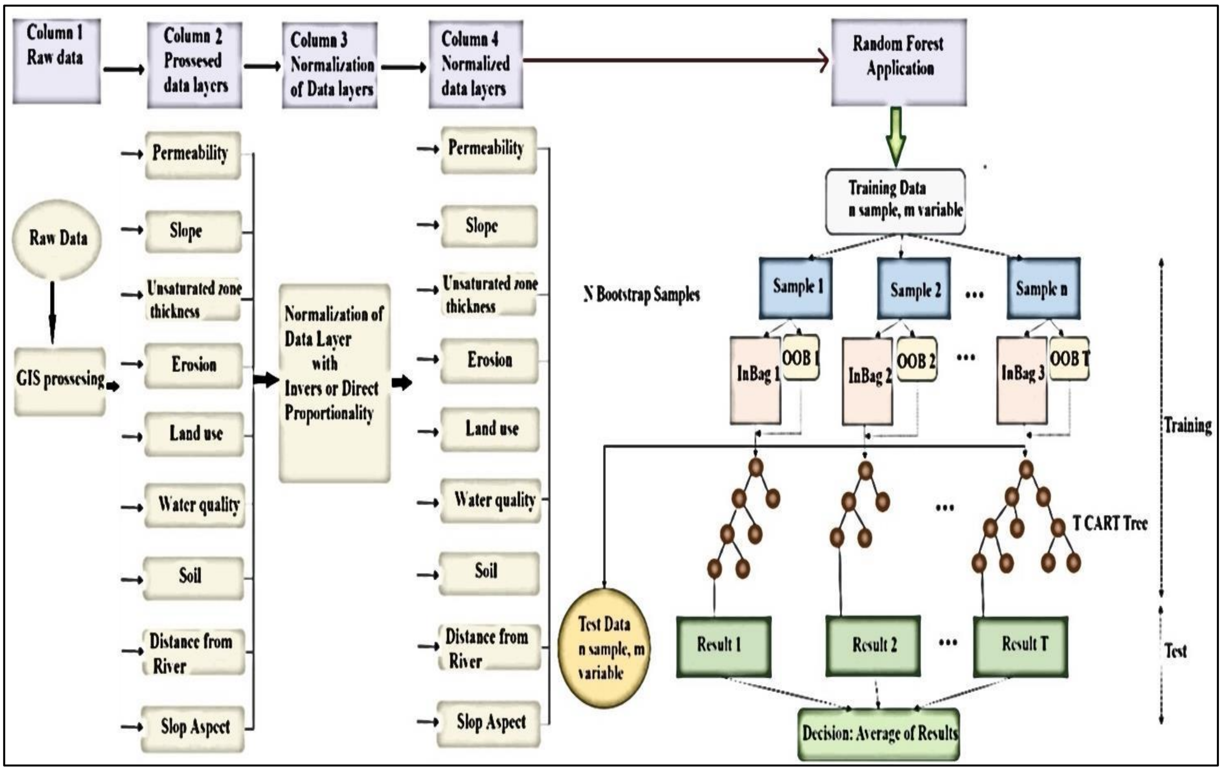


Figure 9. A general methodological flowchart of random forest (Source: Norouzi et al., 2019)

CONCLUSIONS

Groundwater development and management call for urgent steps for augmentation of groundwater resources to ensure their long-term sustainability. The agencies involved in the groundwater development and management must be in the forefront to perform many activities for augmenting groundwater resources through scientifically designed artificial recharge techniques to catch the water where it falls. In this work, some issues and new perspectives of various modern and conventional techniques of artificial groundwater recharge have been dealt with in detail. Applications of new methods like GIS and MAR techniques suitable for various hydrogeologic regions are also discussed herein.

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