Aquifer Modelling for Feasibility and Design of Rainwater Harvesting- A Review

Mohd. Saleem[1], Sajid Ali[2]

[1] University Polytechnics, Faculty of Engineering and Technology, Jamia Millia Islamia, New Delhi-110025, India

[2] Department of Applied Sciences and Humanities, Faculty of Engineering and Technology, Jamia Millia Islamia, New Delhi-110025, India

Abstract: ***Aquifer modelling and rainwater harvesting are better means of groundwater recharging as well as other purposes such irrigation, drinking etc. After careful analysis of study area and application of suitable scientific techniques take part to fulfill the demand of current generation and to retain the sustainability of the future generation. Assessment of ground water potential and rain water potential for the ground water quality and quantity improvement feasibility and design of rainwater harvesting system, that will also be helpful to improve the agriculture production as well to reduces the water crises.***

Keywords: Rainwater harvesting, Groundwater, Aquifer, Modelling, ASR.

1. Introduction

An aquifer is an underground layer of water-bearing permeable rock or unconsolidated materials (gravel, sand, or silt) from which groundwater can be extracted using a water well. Related terms include **aquitard**, which is a bed of low permeability along an aquifer, and **aquiclude** (or aquifuge), which is a solid, impermeable area underlying or overlying an aquifer. If the impermeable area overlies the aquifer pressure could cause it to become a confined aquifer. There are two types of aquifers; unconfined and confined. **Unconfined** aquifers are sometimes also called water table or phreatic aquifers**,** because their upper boundary is the water table or phreatic surface. Typically the shallowest aquifer at a given location is unconfined, meaning it does not have a confining layer (an aquitard or aquiclude) between it and the surface. Confined aquifers have very low storability values (much less than 0.01, and as little as 10^{-5}), which means that the aquifer is storing water using the mechanisms of aquifer matrix expansion and the compressibility of water, which typically are both quite small quantities. Unconfined aquifers have storativities greater than 0.01 (1% of bulk volume); they release water from storage by the mechanism of actually draining the pores of the aquifer, releasing relatively large amounts of water. A confined aquifer is one that is bounded from above and from below by impervious formations. In many places the water collected is just redirected to a deep pit with percolation. The harvested water can be used as drinking water as well as for storage and other purpose like irrigation. The rainwater harvesting is the simple collection or storing of water through scientific techniques from the areas where the rain falls occur (Khandagale & Joshi, 2011). It involves utilization of rain water for the domestic as well as agricultural purpose. The method of rain water harvesting has been into practices since ancient times. It is the far best possible way to conserve water and awaken the society towards the importance of water. This way to conserve the water is simple and cost effective too. It is especially beneficial in the areas which are facing the problem of water scarcity. Most modern technologies for obtaining drinking water are related to the exploitation of surface water from rivers, streams and lakes, and groundwater from wells and boreholes. However, these sources account for only 40% of total precipitation. For improving per capita water availability in the country, replenishment of ground water resources is a necessity which can be done very effectively through rain water harvesting (Kumar, 2006).

2. Discussion Part of the Paper

Dwivedi et. al. (2013) studied on rooftop rain water harvesting for ground water recharge in an educational complex and the rainwater harvesting techniques locally collects and stores rainfall through different technologies, for future use to meet demands of human consumption or human needs. However, rainwater harvesting has much better perspectives, in particular, if it is considered in relation to its role in supporting ecosystems goods and services. An integrated planning rooftop rain water harvesting system for different institutes in the premises of an educational complex is done.

Hatibu et. al. (2006) revealed that the Economics of rainwater harvesting for crop enterprises in semi-arid areas of East Africa. The analysis was done for four categories of rainwater harvesting systems differentiated by the size of catchments from which water is collected and the intensity of concentration and/or storage of the collected rainwater. Those categories are as micro-catchments and macro-catchments. Micro-catchments linked to road drainage and macro-catchments with a storage pond and results show that rainwater harvesting for production of paddy rice paid most with returns to labour of more than 12 US$ per person-day invested.

Oweis et. al. (2006) studied on Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. Their study in the dry areas, water is the most limiting resource for improved agricultural production not land. Supplemental irrigation (SI) is a highly efficient practice with great potential for increasing agricultural production and improving livelihoods in the dry rain-fed areas. In the drier environments, most of the rainwater is lost by evaporation;

therefore the rainwater productivity is extremely low. It was found that over 50% of lost water can be recovered at a very little cost. It shows that substantial and sustainable improvements in water productivity can only be achieved through integrated farm resources management. On-farm water-productive techniques if coupled with improved irrigation management options, better crop selection and appropriate cultural practices, improved genetic make-up, and timely socioeconomic interventions will help to achieve this type of objective.

Xiao et. al. (2007) studied on the integrating rainwater harvesting with supplemental irrigation into rain-fed spring wheat farming. In their study they made a field experiment at the Haiyuan Experimental Station, in a semiarid region of China, from 2000 to 2003 for rain-fed spring wheat (Triticum aestivum) production to maximize the utilization of low rainfall. The study reports that the two field cultivations of rainwater harvesting with a sowing in the furrow. The indices of supplemental irrigation during the whole growth stage of rain-fed spring wheat must reach over 59 and 40 mm in order to realize the 2250 and 2000 kg ha1 yield, respectively.

Xiaolong et. al. (2008) developed a field experiment was conducted to determine effects of a rainwater-harvesting furrow/ridge system on spring corn productivity under simulated rainfalls. The results showed that when rainfall supply ranged between 230 and 440 mm, the rainwater-harvesting furrow/ridge system increased surface temperature by 0.7-1^{0}C at the depth of 10 cm and increased soil water storage by 5%–12% in the soil layer of 0–120 cm compared with the control. Spring corn yield in the rainwater-harvesting furrow/ridge system was 83% higher in the 230 mm rainfall treatment, 43% higher in the 340 mm rainfall treatment, and 11% higher in the 440 mm rainfall treatment compared with the control. In their results from this study indicate that 440 mm rainfall during the spring corn growing season is the upper limit for which the rainwater- harvesting furrow/ridge system should be adopted.

Helmreich & Horn (2009) reported on opportunities in rainwater harvesting that Water scarcity is a major problem in many developing countries. Harvested rainwater can then be used for rainfed agriculture or water supply for households and found that water affected by bacteria and other pollutants. Membrane technology would also be a potential disinfection technique for a safe drinking water supply.

Cheng & Liao (2009) revealed that the regional rainfall level zoning for rainwater harvesting systems in northern Taiwan. The rainwater harvesting systems had been widely accepted as solutions to alleviate the problems of water shortages. A two-step cluster analysis was used to classify the sample areas into several regions in accordance with rainfall level characteristics and spatial continuity.

Yeh et. al. (2009) revealed that the aquifer parameter estimation for a constant-flux test performed in a radial two-zone aquifer. The patchy aquifer or an aquifer with a finite thickness skin can be considered as a radial two-zone aquifer system, which can be characterized by five parameters that is the thickness of the first zone and four aquifer parameters including the transmissivity and storage coefficient for each of the first and second zones. Approach based on an analytical solution of a constant-flux pumping in a confined two-zone aquifer and the simulated annealing algorithm to determine the five parameters simultaneously. The estimated results indicate that the first-zone parameters are much more difficult to accurately identify than the second-zone parameters due to insufficient early-time data and high correlation of the sensitivities among the first-zone parameters.

Dwivedi & Bhadauria (2009) concluded on the domestic rooftop water harvesting-a case study. Due to indiscriminate pumping of ground water, the water table is going down abnormally and if the problem is not given a serious look, then the future generations may have to face severe crisis of water. Rain water is an ideal solution of water problem where there is inadequate groundwater supply quantitatively and qualitatively and surface sources are either lacking or insignificant. Rain water is bacteriologically pure, free from organic matter and soft in nature. The estimation of the appropriate size of the water tanks and their costs required to fulfill the annual drinking water demands through Domestic Rooftop Water Harvesting (DRWH) from rooftop of different areas.

Koen et. al. (2013) revealed on Enabling Successful Aquifer Storage and Recovery of Freshwater Using Horizontal Directional Drilled Wells in Coastal Aquifers. An aquifer storage and recovery (ASR) of freshwater surpluses can reduce freshwater shortages in coastal areas during periods of prolonged droughts. However, ASR is troublesome in saline coastal aquifers as buoyancy effects generally cause a significant loss of injected freshwater. The use of a pair of parallel, superimposed horizontal wells is proposed to combine shallow ASR with deep interception of underlying saltwater. This fresh maker setup was successfully placed in a coastal aquifer in the Netherlands using horizontal directional drilling to install 70-m-long horizontal directional drilled wells (HDDWs). Groundwater transport modeling preceding ASR operation demonstrates that this set up is able to abstract a water volume of 4,200 m3 equal to the injected freshwater volume without exceeding strict salinity limits, which would be unattainable with conventional ASR.

Vandenbohede et. al. (2008) revealed that feasibility of aquifer storage and recovery (ASR) was tested in a deep aquifer near Koksijde, Belgium. To achieve this, toxic drinking water was injected into a deep aquifer (the Tienen Formation) that contains anoxic brackish water. Chemical processes caused by the injection of the water were studied by two push-pull tests. The step-drawdown test was interpreted by means of an inverse numerical model, resulting in a trans-missivity of 3.38 m^2 between the injection and pristine waters, and cation exchange, as the major processes determining the quality of the recovered water.

Wada et.al (2010) studied on the Global depletion of groundwater resources. In the regions with frequent water stress and large aquifer systems groundwater is often used as an additional water source. The analysis to sub-humid to arid areas estimate that the total global groundwater depletion to have increased from 126 (±32) km^3 1 in 2000. The latter equals 39 (±10)% of the global yearly groundwater abstraction, 2 (±0.6)% of the global yearly groundwater recharge, 0.8 (±0.1)% of the global yearly continental runoff and 0.4 (±0.06)% of the global yearly evaporation, contributing a considerable amount of 0.8 (±0.1) mm a-1 to current sea-level rise.−1 in 1960 to 283 (±40) km^3.

Kumar et. al. (2011) revealed on the Rain Water Harvesting and Ground Water Recharging in North Western Himalayan Region for Sustainable Agricultural Productivity. The study of low cost traditional water harvesting structures that helps in improving the socio-economic status of the poor farmers of the hill region. It is estimated that about 40 per cent of the total geographical area of Himachal Pradesh, Uttrakhand and Jammu and Kashmir is highly degraded. Soil loss through erosion is about 3.6 to 80 t ha^{-1}. The most efficient and cheapest way of conserving rainwater at the agricultural farm was found to be in-situ runoff management, which also reduces soil losses and increases the opportunity time for ground water recharging. In addition, good results of harvesting and storage are being achieved in ferrocement water storage structures of different dimensions of 3 to 5 m deep and 1 to 3 m in diameter.

Ward et. al. (2008) studied on the rainwater harvesting: model-based design evaluation. In which they investigated the rate of uptake of rainwater harvesting (RWH) in the UK has been slow to date, but is expected to gain momentum in the near future. It was found that design methods based on simple approaches (such as used in these two cases) generate tank sizes substantially larger than the simulation model. Comparison of the actual tank sizes and those calculated using the simulation model established that the actual tanks installed are oversized for their associated demand level and catchment size. The importance of catchment size was demonstrated, a factor neglected in the simpler methods commonly used in practice. Financial analysis revealed that RWH systems within large commercial buildings may be more financially viable that smaller domestic systems.

Gerolin et. al. (2010) revealed there has been growing interest in the use of rainwater harvesting systems in recent years. The impact of rainwater harvesting practices on drainage systems, mainly during extreme rainfall events, has been a secondary consideration, one reason being that these two functions, namely supplying water and managing storm water runoff, appear to be contradictory. The study uses a time series modelling approach to assess the benefits achieved in runoff reduction at a plot scale during heavy rainfall events, across three locations in England. Considering the assumptions of the model, the results show that substantial reductions can be achieved in areas where the rainfall supply is smaller than the non potable domestic demand in the households.

Singhal & Goyal (2011) revealed that the development of representative conceptual groundwater flow model is an important step before translating it into a numerical model. In his, research a methodology for development of conceptual groundwater flow model has been presented in which spatially distributed values for groundwater recharge has been utilized instead of lump sum average values of recharge normally obtained by water budgeting method and study also extensively uses GIS for preprocessing of hydrological, hydrogelogical and geological data.

Mahadevaswamy et al. (2013) observed the modeling of groundwater flow in watersheds is of great concern in characterizing the hydrogeological environments. The study presents an application of groundwater flow model using the finite difference method, to simulate flow conditions. Results from this computation served as a methodology for analyzing the groundwater behavior at micro level. During the modeling procedures, it has been found that the head changes in the aquifer system of watershed at any specified time is a function of various aquifer characteristics. These changes are obtained by solving the equation of flow through porous media. The output obtained from this model is of practical application to hydro geologists and similar stake holders for applying appropriate aquifer management practices.

Kaviyarasan et. al. (2013) observed that the groundwater flow modeling for an unconfined coastal aquifer surrounded by saline water bodies plays a significant role in providing the information on direction and magnitude of groundwater flow with respect to seasons and location. The modeling package MODFLOW was employed in the Visual MODFLOW Pro 2009.1 was applied to simulate the steady state run for Kalpakkam coastal aquifer. The steady state simulation was in good agreement with respect to groundwater flow field. The model output results show the groundwater flow was found to follow topography. The model outputs are helps to determine the groundwater flow paths, also helps to delineate the recharge and discharge areas in the coastal aquifer.

Helmreich et. al. (2009) suggested that, the depending on precipitation intensity rainwater constitutes a potential source of drinking water. In addition, its proper management could reduce water and food crisis in some of these regions. Rainwater harvesting (RWH) is a technology where surface runoff is effectively collected during yielding rain periods. In order to support such technologies RWH systems should be based on local skills, materials and equipment. Harvested rainwater can then be used for rainfed agriculture or water supply for households. Unfortunately, rainwater might be polluted by bacteria and hazardous chemicals requiring treatment before usage. Slow sand filtration and solar technology are methods to reduce the pollution. Membrane technology would also be a potential disinfection technique for a safe drinking water supply.

Mathur et. al. (2012) concluded that the water crisis continues to become severe, there is a dire need of reform in water management system and revival of traditional systems. Their study attempts to formulate an Environmental Management Plan to conserve and utilize rainwater in the University. It was concluded that in University the Environmental Management Plan for Rain Harvesting System will be very important for campus as that collected water can be used for different purpose in various Departments of University and also the excess of rain water which can be used for ground water recharge it will increase the ground water table in surrounding area of University.

Rahman et. al. (2012) investigated the water savings potential of rainwater tanks fitted in detached houses at 10 different locations in Greater Sydney, Australia. A water balance simulation model on daily time scale is made and water savings, reliability and financial viability are examined for three different tank sizes, 2 kL, 3 kL and 5 kL. It is found that the average annual water savings from rainwater tanks are strongly correlated with average annual rainfall. It is also found that the benefit cost ratios for the rainwater tanks are smaller than 1.00 without government rebated. It is noted that a 5 kL tank is preferable to 2 kL and 3 kL tanks and rainwater tanks should be connected to toilet, laundry and outdoor irrigation to achieve the best financial outcome for the home owners.

Eroksuz et. al. (2010) studied the rainwater harvesting in multi-unit buildings in Australia is less common. They investigated the water savings potential of rainwater tanks fitted in multi-unit residential buildings in three cities of Australia: Sydney, Newcastle and Wollongong. They found that for multi-unit buildings, a larger tank size is more appropriate to maximize water savings. It is also found that rainwater tank of appropriate size in a multi-unit building can provide significant mains water savings even in dry years. A prediction equation is developed which can be used to estimate average annual water savings from having a rainwater tank in a multi-unit building in these three Australian cities.

Singh et. al. (2014) Concluded that the seawater intrusion is a widespread environmental problem of coastal aquifers where more than two third of the world's population lives. Computer-based models are useful tools for achieving the optimal solution of seawater intrusion management problems. Various simulation and optimization modeling approaches have been used to solve the problems. Optimization approaches have been shown to be of great importance when combined with simulation models. It is recommended that the future research should be directed toward improving the long-term hydraulic assessment by collecting and analyzing widespread spatial data, which can be done by increasing the observation and monitoring networks. The coupling of socioeconomic aspects in the seawater intrusion modeling would be another.

3. Conclusion

Through this review study we concluded that the aquifer modeling should be apply for the assessment of ground water potential and rain water potential for the good water quality and quantity improvement feasibility and design of rainwater harvesting system. Review study will be helpful by providing better means of rainwater harvesting and groundwater recharging after careful analysis of study area and application of suitable scientific technique to fulfill the demand of current generation and to retain the sustainability of the future generation. It will also help in the development of the nation.

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