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Rainwater Harvesting (RWH) - A Review

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Abstract*:*
As the world population increases, the demand increases for quality drinking water. Surface and groundwater resources are being utilized faster than they can be recharged. Rainwater harvesting is an old practice that is being adopted by many nations as a viable decentralized water source. This paper reviews the methods, design of rainwater harvesting systems, and its impacts adopted in all parts of the world.

Keywords*: Rainwater harvesting (RWH), Literature review*

1. Introduction

As the world population increases, the demand increases for quality drinking water. Surface and groundwater resources are being utilized faster than they can be recharged. Rainwater harvesting is an old practice that is being adopted by many nations as a viable decentralized water source. Individual rainwater harvesting systems are one of the many tools to meeting the growing water demand. Rainwater harvesting is an environmentally sound solution to address issues brought forth by large projects utilizing centralized water management approaches. Population growth all over the world is causing similar problems and concerns of how to supply quality water to all.

As land pressure rises, cities are growing vertical and in countryside more forest areas are encroached and being used for agriculture. In India the small farmers depend on Monsoon where rainfall is from June to October and much of the precious water is soon lost as surface runoff. While irrigation may be the most obvious response to drought, it has proved costly and can only benefit a fortunate few. There is now increasing interest in the low cost alternative-generally referred to as 'Rain Water Harvesting' (RWH).

Water harvesting is the activity of direct collection of rainwater, which can be stored for direct use or can be recharged into the groundwater. Water harvesting is the collection of runoff for productive purposes.

According to Kim et al. (2005), rainwater harvesting may be one of the best methods available to recovering the natural hydrologic cycle and enabling urban development to become sustainable. The harvesting of rainwater has the potential to assist in alleviating pressures on current water supplies and storm water drainage systems. Rainwater collection has the potential to impact many people in the world.

As water harvesting is an ancient tradition and has been used for millennia in most dry lands of the world, many different techniques have been developed. However, the same techniques sometimes have different names in different regions and others have similar names but, in practice, are completely different (Oweis 2004). Consequently, there are a dozen of different definitions and classifications of water harvesting techniques and the terminology used at the regional and international levels has not yet been standardized (Nasr 1999).

1.1 Benefits of rain water harvesting system:

- Rainwater is a comparatively clean and totally free source of water.
- Rainwater is improved for scenery plants and gardens because it is not chlorinated.

- It can supplement other sources of water supply such as groundwater or municipal water connections.
- It lower the water supply cost.
- It can provide an excellent back-up source of water for emergencies.
- It is socially acceptable and environmentally responsible.
- It uses simple technologies that are inexpensive and easy to maintain.
- Reduced flood flows and topsoil loss.
- It is free; the only cost is for collection and use.
- It reduces the contamination of surface water with sediments, fertilizers and pesticides from rainwater run-off resulting in cleaner lakes, rivers, oceans and other receivers of storm water.
- It is used in those areas which face insufficient water resources.
- It is good for laundry use as rainwater is soft and lowers the need for detergents.
- It can be used to recharge groundwater.
- It minimizes the runoff which blocks the storm water drains.

1.2 Need for Rainwater Harvesting

1. As water is becoming scarce, it is the need of the day to attain self-sufficiency to fulfill the water needs.
2. As urban water supply system is under tremendous pressure for supplying water to ever increasing population.
3. Groundwater is getting depleted and polluted.
4. Soil erosion resulting from the unchecked runoff.
5. Health hazards due to consumption of polluted water.

2. METHODS OF RAINWATER HARVESTING

- Rainwater stored for direct use in above ground or underground sumps / overhead tanks and used directly for flushing, gardening, washing etc. (Rainwater Harvesting)
- Recharged to ground through recharge pits, dug wells, bore wells, soak pits, recharge trenches, etc. (Ground water recharge)

3. Rainwater Harvesting Studies All Over The World

Kahinda *et al.* (2008) defined RWH as the collection, storage and use of rainwater for small-scale productive purposes. Critchley (1991) defined it as the collection of runoff for productive use. Oweis (2004) defined it as the concentration of rainwater through runoff into smaller target areas for beneficial use. Mati *et al*. (2006) defined RWH as the deliberate collection of rainwater from a surface known as catchment and its storage in physical structures or within the soil profile.

Rainwater harvesting is an ancient practice that has been increasingly receiving attention in the world, fueled by water shortages from droughts, pollution and population growth (Nolde 2007; Meera and Ahameed 2006).

Runoff may be harvested from roofs and ground surfaces as well as from intermittent or ephemeral watercourses and thus water harvesting falls into two broad categories: Water harvesting techniques which harvest runoff from roofs or ground surfaces named RWH and all systems which collect discharges from water courses named flood water harvesting (Critchley *et al.* 1991). RWH technologies and systems can be classified in several ways, mostly based on the runoff generation process, size of the catchment and type of storage.

Runoff generation criteria yields two types of systems i.e. runoff based systems (runoff concentrated from a catchment) and *in-situ* water conservation (rainfall conserved where it falls). The runoff storage criteria yield two categories, i.e., storage within the soil profile and storage structures. The size of catchment yields two categories, i.e., macro catchments and micro catchments (within field).

In general, RWH systems for crop production are divided into three different categories basically determined by the distance between catchment area (CA) and cropped basin (CB) (utilization area): *In-situ* RWH, internal (Micro) catchment RWH and External (Macro) catchment RWH (Hatibu and Mahoo 1999). To give the general overview of the three categories, a short summary extracted from Hatibu and Mahoo (1999) for each is presented below.

Gitte and Pendke (2002) conducted a study on the water conservation practices, water table fluctuations and ground water recharge in watershed areas. The study revealed that water conservation measures were found to be effective for rising of water table in observation wells, located in the middle and lower reach of the watershed.

The overall groundwater recharge due to corresponding rainfall was in the tune of 3.76 to 8.85 cm in the influence of area of soil and water conservation structure.

A study by Ngigia (2005) in the Laikipia district, Kenya showed that improved farm ponds provide one of the feasible options of reducing the impacts of water deficit that affect agricultural productivity in semi-arid environments in Sub-Saharan Africa. The field evaluation revealed that on-farm RWH systems are common in the study area with sizes ranging from 30 to 100 m^3 and catchment areas varying from 0.3 to 2 ha. The hydrological evaluation of the farm ponds revealed that one of the challenges was how to reduce the seepage and evaporation water losses. He reported significant water losses through seepage and evaporation, which accounted on average for 30–50% of the stored runoff. The high losses are one of the factors that affect the adoption and up-scaling of on-farm water storage systems. If seepage loss is reduced with lining material and if RWH is combined with drip irrigation on-farm storage systems can be economically viable and farmers are able to recover the full investment costs within 4 years.

United Nations Environment Programme (Mati *et al*. 2006) conducted a study to determine if RWH technologies can be mapped at continental and country scales. The project utilized a number of GIS data sets including rainfall, land use, land slope, and population density to identify four major commonly adaptable RWH technologies: roof top RWH, surface runoff collection from open surfaces into pans/ponds, flood flow storages and sand/sub-surface dams and *in-situ* RWH.

Mondal and Singh (2004) conducted a study of unconfined aquifer response in terms of rise in water level due to precipitation; a rapid and cost-effective procedure is evolved in hard rock terrain. Cross correlation of rise in water level and precipitation is established. The entire area is classified into various zones depending on variability in coefficient of correlation. Thus, most favorable zone for artificial recharge is delineated with the help of correlation coefficients.

Uddameri (2006) used feed-forward neural network models to train the back-percolation algorithm to forecast monthly and quarterly time-series water levels at a well that taps into the deeper Evangeline formation of the Gulf Coast aquifer in Victoria, TX. Causal relationships existed between water levels and hydro-meteorological variables measured near the vicinity of the well. As such, an endogenous forecasting model using dummy variables to capture short-term seasonal fluctuations and longer-term (decadal) trends was constructed. The root mean square error, mean absolute deviation and correlation coefficient (*r*) were noted to be 1.40, 0.33 and 0.77, respectively, for an evaluation dataset of quarterly measurements and 1.17, 0.46 and 0.88 for an evaluative monthly dataset not used to train or test the model. These statistics were better for the Artificial Neuron Network (ANN) model than those developed using statistical regression techniques.

Mansur *et al.* (2007) reported that more than half respondents (56.67%) in his study opined that proposed method of bunding was not useful, while more than one-fifth of the respondents had no idea about its utility.

It has been reported that rainwater harvesting can promote significant water saving in residences in different countries. In Germany, a study performed by Herrmann and Schmida (2008) showed that the potential of potable water saving in a house might vary from 30% to 60%, depending on the demand and roof area. In Australia, Coombes et al.(2011) analyzed 27 houses in Newcastle and concluded that rainwater usage would promote potable water saving of 60%. In Brazil, a study performed by Ghisi et al. (2009) showed the potential water saving by using water harvesting in 62 cities ranges from 34% to 92%, with an average potential for potable saving of 69%.

In the context of agricultural production in African drylands, soil and water conservation (SWC) practices such as rainwater harvesting (RWH) provide an opportunity to stabilize agricultural landscapes in semiarid regions and to make them more productive and more resilient towards climate change (Wallace, 2000; Lal,2001). Stabilization of the agricultural landscape includes the restoration of degraded cultivated and/or natural grazing lands. There are many marginal water sources that could be used more efficiently such as road and land runoffs that are normally lost through erosion processes (Prinz and Malik, 2002).Among the most common soil and water conservation techniques, rainwater harvesting is massively promoted by NGOs, national agricultural extension services and government agencies in African countries (Stroosnijder, 2003), as well as in India (Bachelor et al., 2002) where RWH practices already have along tradition (Pandey et al., 2003). Rainwater harvesting is also one of the practices recommended by UNCCD to combatdesertification.RWH practices are generally considered to be only beneficial in this respect but the main problems are low rates of adoption(e.g. Tabor, 1995; Nji and Fonteh, 2002; Bodnar and de Graaff,2003; Woyessa et al., 2005) or failed adoption processes due to insufficient participation by farmers (Aberra, 2004). Nevertheless, some experts warn about the unreflected and in appropriate use of RWH which might lead to severe side effects as shown for erosive events in Kenya (Ngigi, 2003a), competition between neighbours, or unreliable drinking water supply for parts of the community in India (Batchelor et al., 2002). In these cases, RWH practices do not fulfill all the landscape functions described above. The overall aim of this paper is to present a general overview of different, partly contra dictionary effects of small scale, the so called, in situ rain water harvesting practices. Recognition of the trade-offs between different landscape functions might support the implementation of measures that should increase resilience against climate change impacts.

Ghayoumian .J *et .al* (2006) paid Special attention to artificial groundwater recharge in water resource management in arid and semi-arid regions. Parameters considered in the selection of groundwater artificial recharge locations were diverse and complex. In their study, factors such as: slope, infiltration rate, depth to groundwater, quality of alluvial sediments and land use were considered, to determine the areas most suitable for groundwater recharge in a coastal aquifer in the Gavbandi Drainage Basin in the southern part of Iran. Thematic layers for the above parameters were prepared, classified, weighted and integrated in a GIS environment by the means of Boolean and Fuzzy logic. To determine the relationships between geomorphological units and the appropriate sites for groundwater artificial recharge, land-use and geomorphological maps were developed from satellite images. The results of their study indicate that about 12% of the study area is considered as appropriate and 8% moderately appropriate sites for artificial groundwater recharge. The relationship between geomorphology and appropriate areas for groundwater recharge indicate that the majority of these areas are located on alluvial fans and pediment units. At the reconnaissance stage these geomorphological units can be considered as appropriate sites for artificial recharge in regions with similar characteristics.

Sturm.M *et.al* in their paper entitled Rainwater Harvesting as an Alternative Water Resource in Rural Sites in Central Northern Namibia described the results of the investigations on rainwater harvesting (RWH) in central northern Namibia which are part of the transdisciplinary research project CuveWaters. On the basis of hydrological and technical as well as social and cultural conditions, appropriate solutions for RWH are developed, discussed, and evaluated. Main objective is to analyse their technical and economical feasibility as well as their affordability for future users. In detail, two small-scale RWH systems are examined: roof catchments using corrugated iron roofs as rain collection areas and ground catchments using treated ground surfaces.

Cheng C.L *et.al* in their paper Regional rainfall level zoning for rainwater harvesting systems in northern Taiwan stated that Rainwater harvesting systems had been widely accepted as solutions to alleviate the problems of water shortages. The main objective of this paper is to convert a rainfall station system based on a point concept to one based on a spatial concept in order to cope with the problems of rainfall data. A two-step cluster analysis was used to classify the sample areas into several regions in accordance with rainfall level characteristics and spatial continuity. The acquired rainfall level classification represents the homogeneity of rainfall intensity and duration because of the minimum combined difference within a cluster; the efficiencies of actual potable water savings in an identical rainfall cluster can approximately reflect a specific range with fewer variations because of the similarity of rainfall intensity and duration. This rainfall zoning system would contribute to the standardized regional precipitation database for the rainwater harvesting application.

4. Rain Water Harvesting Studies In India

Deepak Khare et al (2004) have reviewed the impact assessment of RWH on ground water quality at Indore and Dewas, India. The impact assessment of roof top improve the quality and quantity of Ground Water. The roof top rainwater was used to put into the ground using sand filter as pretreatment system. This lead to a reduction in the concentration of pollutants in ground water which indicated the effectiveness of increased recharge of aquifer by roof top rain water. He observes that in certain areas, the amount of total and faecal coliform were observed high in harvested tube well water than normal tube well water. The reason of this increases was poor cleanliness of roof top and poor efficiency of filter for bacterial removal. The author concludes that quality mounting of rainwater harvesting is an essential prerequisite before using it for ground water recharge.

Venkateswara Rao (1996) in his article has reviewed the importance of artificial recharge of rainfall water for Hyderabad city water supply. Rainfall water from the roof tops of the buildings recharged through specially designed recharge pits in order to augment the ground water resource in the city. This Water meets almost 80% of domestic water requirements, storm runoff from the public places like roads, parks play grounds etc., is recharged through naturally existing tank within the city by not allowing municipal sewage and industrial effluents in these tanks. He finally suggests that, wherever natural tanks are not existing, community recharge pits are to be constructed at hydro geologically suitable location.

Ravikumar et al (2003) describe the roof top rainwater harvesting in Chennai Airport using GIS. They explain the estimation of surface runoff using SCS method and design of rainwater harvesting structures in Chennai Airport Terminal buildings. Thematic maps were digitized in map Info GIS software and roof drainage delineation was done in GIS environment. Based on the topography and lithology of airport. the artificial recharge structures like recharge shaft, recharge well and recharge pit were designed and located.

Kadirvelu (2002) describe the impact assessment of RWH in madras University-Marina campus. He designed RWH structures on the basis of the in situ soil conditions. It was constructed on the study area. The frequent monitoring of three open wells was carried out. The water levels during the pumping before and after the implementation of RWH are monitored. The water levels and the water quality are compared with the observation well which is situated near the study area and maintained by TWAD. The benefit cost ratio is also analyzed on the basis of construction cost of RWH and the population to be served by the harvested rain. Finally, he concluded from the results that the quantity and quality are improved. The benefit cost ratio is also arrived to 2.38. The impact of RWH is positive in the study area in view of improved in quantity, quality and benefit cost.

Rainfall analysis for the period of 1901-1990 for Amod, Jambusar and Vagra was carried out (Khandelwal *et al.* 2002) to determine the onset and withdrawal of effective monsoon, rainfall depth-duration relationship, irrigation and surface drainage requirement, as well as to develop design parameters for rainwater harvesting structures on the unit catchment area basis in Gujarat, India. Water requirement and irrigation scheduling for cotton and pigeon pea under rainfed conditions were also determined using the CROPWAT model. Results showed that the earliest and the latest probable date of onset of effective monsoon (OEM) vary from 12-14 June to 15-16 July in the region. Mean date of withdrawal of monsoon was during 19-21 September. Correlation between the 2- to 7-day annual maximum rainfall and 1-day annual maximum rainfall showed that coefficient of determination and correspondingly F ratio decreased with an increase in rainstorm duration from 2 to 7 days. Surface drainage coefficient based on maximum moving rainfall of 7 consecutive days with a 7-day tolerance period varied from 25.1 to 35.8 mm/d. Attributes of water requirement under rainfed and 20% yield reduction condition for two (pigeon pea and cotton) crops under irrigation were similar, which indicates that even under non-irrigated conditions, 80% of the potential yield of both crops can be achieved in an average normal rainfall year.

Singh and Thapaliyal (1991) assessed the impact of watershed programme on rain fed agriculture in Jhansi district of Uttar Pradesh and indicated that the underground water table in the area showed a significant increase, the average annual increase in the water table being 3.7 meters. A shift in the area from pulses to cereals and from cereals to pulses was observed in Rabi and Kharif seasons, respectively.

Hazra (1997) in his overview of crop yield performance in Tejpura watershed reported that, due to soil and water conservation works and water storage structures, the wells which earlier used to fetch water for about 1-2 hours, fetched water for more than 8-10 hours due to the increased ground water table by 10 to 23 feet after the construction of water storage structures.

Bisrat (2000) in his study on economic analysis of watershed treatment through groundwater recharge of Basavapura micro-watershed in Kolar district of Karnataka revealed that average yield of bore well increased from 1150 gallons per hour (GPH) to 1426 GPH that is by 24 per cent due to construction of water harvesting structures.

Naidu (2001) in his study on Vanjuvankal watershed of Andhra Pradesh noticed that, because of water harvesting structures and percolation ponds the ground water level in watershed area showed a rise by 2 to 3 meters.

According to Muralidharan *et al.* (2007) precipitation is the principal source of replenishment of moisture in the soil through the infiltration process and subsequent recharge to the groundwater through deeper percolation. The amount of infiltrated moisture that will eventually reach the water table is accounted as the natural groundwater recharge. In this study an attempt on correlating the rainfall amount and subsequent rise in water level yielded an exponential relation indicating that daily rainfall exceeding 40 mm/day results in significant rise in water level.

Venkatesh and Jose (2007) conducted a rainfall study on the coastal and its adjoining areas in Karnataka State. The statistical analyses conducted included cluster analysis and analysis of variance. The study revealed that there exist three distinct zones of rainfall regimes in the study area, namely, Coastal zone, Transition zone and Malanad zone. It is observed that, the maximum rainfall occurs on the windward side ahead of the geographical peak. Further, mean monthly rainfall distribution over the zones has been depicted to enable agricultural planning in the study area.

Sreekanth *et al.* (2009) used a prediction model to forecast ground water level at

Maheshwaram watershed, Hyderabad, India. The model efficiency and accuracy were measured based on the root mean square error (RMSE) and coefficient of determination (R^2). The model provided the best fit and the predicted trend followed the observed data closely (RMSE = 4.50 and R^2 = 0.93).

Narayanagouda (1992) reported that the adoption level of soil and moisture conservation practices was higher among the participants of Chitravati watershed in Kolar district of Karnataka as compared to non-participants. However, he observed that a higher percentage of farmers had not adopted the practice of stabilization of bunds with vegetative species. Lack of conviction and difficulty to establish were the dominant reasons for their lack of adoption.

Anand (2000) in his study conducted in Bidar district of Karnataka revealed that the major problems/reasons for non-adoption or partial adoption of watershed technology include, lack of capital for contour bund and land levelling, unawareness of technology for compartment bunding and live bunds, lack of knowledge and hard sub-surface soil in opening of ridges and furrows and plantation of horticulture and forest tree species.

Naik (2000) reported the major reasons for non-adoption of water harvesting structures and grade stabilization structures in the Kanakanala and Indawar-Hullalli watersheds in Northern Dry Zone of Karnataka that non availability of credit and high interest rates were severe problems (69% each) followed by long gestation period (68%), high hiring charges of improved implements (65%) and small holdings (61%) etc. in the non-watershed area.

Nirmala (2003) reported that the farmer perception and constraints analysis under impact study of watershed development programme on socio-economic dimensions in Ranga Reddy district of Andhra Pradesh and found that technologies were beneficial in the form of increased income (58.33%), increased moisture (51.66%) and increased productivity (48.33%) along with increased employment generation. Reduced soil erosion integrated ground water recharge *etc.* were other benefits of technology as perceived by the farmers. Further she observed that the major reasons for non-adoption of structures in non-watershed area were lack of capital (51.6%) technical know-how (46.60%), size of holding (45%) followed by problems of irrigation, inadequate input availability non-availability of labour, inadequate extension services and poor quality of land etc.

5. Conclusion

It is no denying that sustaining and recharging the groundwater along with judicious use of the limited fresh water resources is the need of the hour. If sufficient measures are not taken up immediately, we will face a crisis which will be detrimental to the very survival of mankind. Efficient management of water resources and education about judicious utilisation of water resources along with measures of harnessing, recharging and maintaining the quality of water and water bodies has to be taken up on war footing.

6. References

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