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Is Rainwater Harvesting System really contributing effectively to the Ground Water of the locality ?

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Abstract

Water being a miraculous and wonderful material on Earth is vital for the survival and very existence of living beings . Rainwater is the purest form of water available in abundance on earth. Rainwater conservation is of prime importance for human beings on Earth since ancient times.

Due to rapid urbanization and use of Groundwater in large quantities, it is highly required to replenish them through natural means to maintain its quality and quantity.Every care should be taken by local governing authorities to prevent water pollution. Rainwater Harvesting System is widely being used in moder n times as a solution to solve this problem.

A detailed study of Rainwater Harvesting System and comparing them to those water conservation methods adopted in ancient times alongwith a deep study of theory of Groundwater movement and Engineering Principles behind accumulation and storage of Groundwater leads to throw light on whether Rainwater Harvesting System is effective in recharging Groundwater or not . Then , what should be the solution to effectively recharge the Groundwater of the locality of Human Civilisation today ?

Index Terms– *Rainwater , Groundwater , Water Conservation , Rainwater Harvesting System,components of rain water harvesting, elements of rain water harvesting, how is rain water harvesting done, rain water harvesting, rain water harvesting structure*.

1.Introduction

!! Existence !! of Living Beings on earth since time immemorial have been possible only due to !!**W**ater!! present in abundance on this only known planet in our galaxy named Milky Way .

Numerous experiments have been carried out by mankind to discover water on other planets since ancient times but human beings on Earth has been unsuccessful in its mission until today .

Importance of Water

According to H.H Mitchell , Journal of Biological Chemistry 158 , human adult body is composed of 60% water on an average , in which brain and heart is composed of 73% water , lungs have 83% water , skin 64% , muscles and kidneys 79% water and even bones have 31% water .

We are all existing today because of this miraculous and wonderful material named water on Earth .

Can you imagine life without water ? Water is a renewable resource which moves itself from one place to another in the form of Hydrologic Cycle changing its form , from liquid to vapour.

It is practically not possible to manufacture water, hence the only option available before mankind is to conserve water present on Earth and prevent its wastage and loss.

Importance of Rainwater

Rainwater is one of the source of water easily available on Earth . Due to construction of houses, roads , concrete pavements and other impermeable surface by human beings , in the process of developing its civilization in a locality; the rainwater falling on Earth which would have contributed to the Ground Water of the locality ; due to impermeable surface , flows off far away from the existence of their dwellings into the river and finally carried by rivers into the ocean.

Therefore it is practically not possible to tap this most important source of water and utilize them in its present form , available in abundance on Earth in its purest form vital for the survival of mankind.

Hence , Rainwater Harvesting System has come to use on Earth since time immemorial.

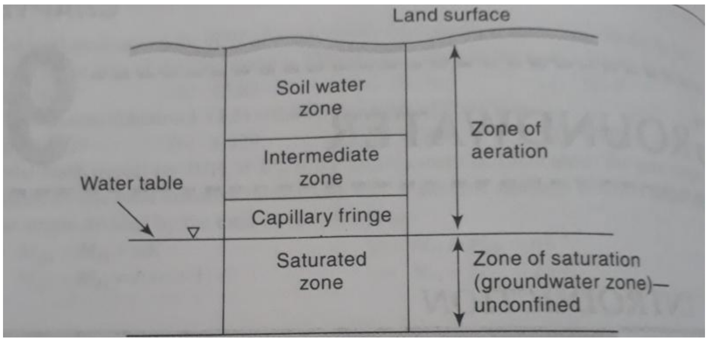
2.Sources of Groundwater

Groundwater is derived not only from precipitation but mainly due to recharge from surface water .

It is that water which has infilterated into the earth directly from rainfall , recharge from streams and other natural water bodies and artificial recharge due to action of man .

Infilteration and downward percolation from sources like rain, melting of snow and ice , rivers and streams , lakes , reservoirs , canals and other watercourses are usually the main sources that contribute to the groundwater of a locality.

3.Classification of Subsurface Water



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BEDROCK

Figure 1.*Classification of Subsurface Water.*

Water available within the soil mantle is classified into two zones.

Zone of Aeration

Here the soil pores are only partially filled with water and further divided into 3 subzones.

a. **Soil Water Zone :** It is close to ground surface containing major root band of vegetation from which water is transported to the atmosphere by evapotranspiration.

b. **Capillary Fringe :** Here water is held by capillary action starting from water table to top of capillary rise.

c. **Intermediate Zone :** It lies between soil water and ` Capillary Fringe` zone and useful for irrigation engineering and agricultural practice.

Zone of Saturation

It is also called groundwater zone where all the pores of the soil are filled with water . Here water table forms the upper top layer with a free surface exposed to atmospheric pressure in unconfined aquifer.

4.Theory of Groundwater Movement

Infilteration and percolation both processes move water within the pores of the soil.The main difference between them is that Infilteration occurs closer to the top surface of the soil. It denotes the entry of rainwater or ponded water into the earth surface .

The top interface is essence of infilteration process. The downward movement of infiltered water through soil and rock is called percolation.

Infilteration delivers water to the plant rooting zone whereas percolation moves water downward under action of gravity to replenish groundwater or become part of subsurface runoff. Percolation is the movement and flow of water from unsaturated to saturated zone.

In soil the pores are so small that the flow of water through them is always laminar;therefore velocity of flow is proportional to the hydraulic gradient.

Soil consist of discrete particles and void spaces between them forming intricate network of irregular micro-tubes.When a potential difference is created in soil mesh due to action of gravity, water is free to move or flow from zone of high potential to zone of low potential. The resistance to flow is greater when pores are smaller in size and vice-versa.

The degree of perviousness of the soil is called its permeability which describes the ease with which water flows through soil. It directly influences the rate of flow of water in the soil.

$$q \propto (\Delta h / L).A$$

where $(\Delta h / L)$ is hydraulic gradient ` i`

A is area of cross-section.

In the form of Darcy`s Law

$$q = K\, i\, A\ ,$$

where k is coefficient of permeability.

5.Groundwater Accumulation and Storage – Engineering Principles

Groundwater is available in aquifer formation within the earth. It is a saturated formation of earth material which not only stores water but also yields it in sufficient quantity. An aquifer transmits water easily due to its high permeability

Unconsolidated deposit of sand and gravel form good aquifers. Ability of aquifer to release water held in its pores and transmit the flow easily depend upon the composition of the aquifer.

The volume of water contained in ground water reservoir in any localised area , i.e water storage capacity of ground water is dependent upon following factors.

i. the porosity and permeability of the rocks are geological factors governing occurrence of ground water.

ii. the rate at which water is added to it by infilteration.

iii. The rate at which water is lost from it by evaporation,transpiration,seepage to surface courses and withdrawn by man.

When grain size increase , particles/interstices surface area reduces thereby reducing specific retention and increasing the yield. Specific retention is the amount of water held between pores due to molecular attraction against pull of gravity.

A water bearing formation of coarse gravel would supply large quantity of water to wells , whereas clay although saturated and of high porosity would be of little value .

For alluvial soils in a slope range of 0.1 to 10 percent , the long time infilteration rate `w` in meter/day is given by

$$w = 0.65 + 0.56\, i^{*}$$

where i^{*} = natural ground slope in percent ,

and w = Infilteration Rates.

Amount of pore space per unit volume of aquifer material is called porosity.(n) and expressed as

$$n = V_V / V_O$$

where V_V = Volume of Voids and

V_o = Volume of porous medium

Porosity greater than 20% is considered large , between 5% and 20% as medium and less than 5% as small.

While porosity gives a measure of water-storage capability of a formation , not all the water held in the pores is available for extraction by pumping or draining by gravity. The pores hold back some water by molecular attraction and surface tension.

Actual volume of water that can be extracted by force of gravity from a unit volume of aquifer material is called specific yield (S_y). The fraction of water held back in aquifer is known as specific retention , Sr . Hence porosity is expressed as

$$n = S_y + S_r$$

Porosity and Specific Yield of some formations are shown in the following table 1.

Formation	Porosity %	Specific Yield %
Clay	45 - 55	01 - 10
Sand	35 - 40	10 - 30
Gravel	30 - 40	15 - 30
Sandstone	10 - 20	05 - 15
Shale	01 - 10	0.5 - 05
Limestone	01 - 10	0.5 - 05

Porosity and Specific Yield of some Formations

Table 1

Although both clay and sand have high porosity the Specific Yield of Clay is very small compared to that of sand .

Specific Retention (S_r) is given by following formulae

$$Sr = V_g / V_t$$

where V_g = Volume of water held against gravity

and V_t = Total Volume of material drained.

6.Water Conservation

Water conservation is the most effective and environmentally sound method to fight global warming. Water conservation is what that can reduce the scarcity of water. It aims to improve the efficiency of use of water, and reduce losses and waste.

Many of us who live in big cities enjoy a carefree lifestyle with 24 hours of running taps, swimming pools, Jacuzzis and decorative fountains. Sheltered by this layer of comfort, we remain unaware of the impact of these water-intensive activities on our environment. Rapid urbanization and water pollution has widened the supply and demand gap, putting enormous pressure on the quality of surface and groundwater bodies. Clean water is destined to become one of the rarest commodities soon, if the general public is not educated about the significance of storing, recycling and reusing water.

7.Water Conservation methods adopted in Ancient times

Since ages, people across different regions of India, have experienced either excess or scarce water due to varied rainfall and land topography. Yet, they have managed to irrigate their agricultural fields using localized water harvesting methods. Their traditional ways, though less popular, are still in use and efficient. They are enriched with knowledge to manage water in communal ways. Let's also learn about some traditional water conservation methods in India used by some illiterate yet successful water managers as well as kings and queens in ancient times.

Katta

Katta is a temporary structure made by binding mud and loose stones available locally. Built across small streams and rivers, this stone bund slows the flow of water, and stores a large amount (depending upon its height) during the dry months. The collected water gradually seeps into ground and increase the water level of nearby wells. In coastal areas, they also minimize the flow of fresh water into the sea.

Kattas can go a long way in sustainable water management.

Bawdi/Jhalara

These step-wells in Rajasthan are grand structures of high archaeological significance constructed since ancient times, mainly in honor of kings and queens. They are typically square shaped step-wells with beautiful arches, motifs and sometimes rooms on sides. Located away from residential areas, the water quality in these Bawdis was considered to be good for consumption.

Traditional Bamboo mat was also used for water conservationin ancient times.

8.Water Conservation methods adopted in different parts of ancient India in Brief.

Kul in Himachal Pradesh and Jammu

Kuls are diversion channels that carry water from a glacier to village. Often spanning long distances, with some over 10 km long, kuls have been around for centuries. They are the lifeline of people of Spiti valley of Himachal Pradesh and in Jammu too.

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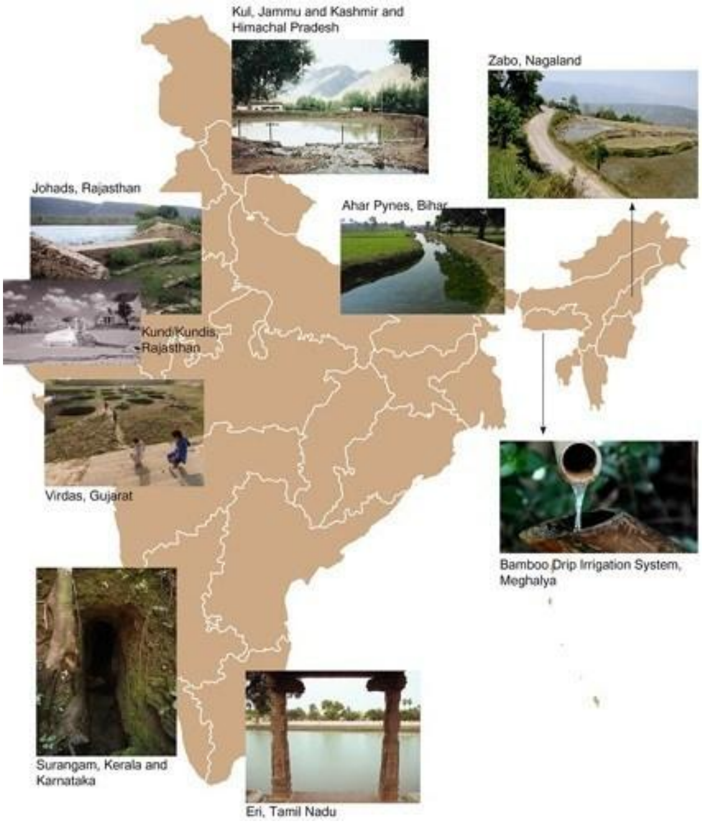

Figure 2.*Water conservation methods in ancient India*

Kul starts at the glacier, which is to be tapped. Keeping the head clear of debris is achieved by lining the sides of Kul with stones which ensure that there is no seepage or clogging. The Kul leads to the village where the water is stored in a circular water tank. The water is drawn from here as per the need of the village.

Bamboo Drip Irrigation System in Meghalaya

This system of water conservation and usage of stream and spring water is done using bamboo pipes. Practised in Meghalaya, its primary purpose is to irrigate plantations. This 200-year-old system involves 18-20 litres of water entering the bamboo pipe system every minute to irrigate the fields downhill. A brilliant drip irrigation system, it uses bamboos of various sizes and reduces the output to to 20-80 drops per minute, which is splendid for betel leaf and black pepper crops.

Johadsat Alwar in Rajasthan

Alwar district of Rajasthan is one of the driest regions in India with water scarcity being a common occurrence. After the drought of the 1980s, the villagers attempted to revive the traditional method. Johad, a crescent shaped small check dam built from earth and rock to intercept and conserve rainwater, was thus reinvented. This helps to improve percolation and increases groundwater recharge.

By recharging the aquifer below the surface, Johads have helped increase agriculture in the area. Usage of Johads has also helped increase the flow of river Arvari, making it a perennial river now. It earlier used to dry off after the monsoon.

Khadin at Jaisalmer and Barmer in Rajasthan

Khadin is a water conservation system designed to store surface runoff water for the purpose of agriculture. It entails an embankment built around a slope, which collects the rainwater in an agricultural field. This helps moisten the soil and helps in preventing the loss of topsoil. Additionally, spillways are provided to ensure that excess water is drained off.

This system of water conservation is common in the areas of Jaisalmer and Barmer in Rajasthan. A dug well is usually made a bit further from Khadin to additionally take advantage of groundwater recharging that happens around the structure.

Virdas at Rann of Kutch in Gujarat

Developed by the nomadic Maldhari tribes of Rann Of Kutch, virdas are shallow wells dug within a natural depression(Jheel). Since the area around is very saline, when rainwater seeps down the soil, it collects over the saline groundwater due to the difference in density (rainwater being less dense). The tribesmen identify areas on basis of flow of the monsoon runoff and build these shallow wells.

This smart method helps them separate freshwater from saltwater and provide water for a variety of purposes. Vegetation is planted along virdas to help protect them.

Kunds/Kundis in Rajasthan and Gujarat

With the look of an upturned cup nestling in a saucer, these water conservation structures are built to harvest rainwater. Usually dotting the areas of Rajasthan and Gujarat, they have a saucer shaped catchment area sloping towards the centre to where the well is situated.

To prevent debris from falling into the well, a wire mesh is used while the sides of the well pit are covered with lime and ash, which act as a disinfectant. Usually, the depth and diameter of these kunds depend upon the purpose of use i.e. drinking or for domestic usage.

There are many other methods too that are practised in various combinations. These methods have been around for hundreds of years, and with a lot of areas suffering from water scarcity, it may be time to revisit some other traditional methods to help innovate new ways of revival.

Zabo in Nagaland

Zabo means impounding water. Known locally as the Ruza system, this system is a unique combination of water conservation with animal care, forests and agriculture. Mostly practised in Nagaland, Zabo is used to deal with a lack of drinking water supply. During monsoon, rainwater that falls on the hilltops is collected into the pond like structures that are carved out on the hillsides. The water is then passed onto cattle yards below from where the water enters the paddy fields rich in manure.

Eri in Tamil Nadu

One of the oldest water conservation systems in India, Eri (tank) of Tamil Nadu is still widely used around the State. With over a third of irrigation in the State being made possible due to Eri, the traditional water harvesting system plays an important part in the agriculture. They also have other advantages such as prevention of soil erosion, recharge of groundwater, and flood control.

Eri can either be fed through channels that divert river water, or rain-fed ones. They are usually interconnected to balance the water in case of excess or lesser supply.

Surangam in Karnataka and Kerala

Surangam is a traditional water conservation system present in areas of Karnataka and Kerala. The terrain of the area makes it impossible for people living around to survive only on surface water. Thus a complex labyrinth of fine tunnels are built which constitutes horizontal wells dug in laterite rocks. The Surangam can be of varying length and can even go up to 300 metres. Water is collected into a storage tank using gravitational force. Vertical shafts are provided for airflow.

The population nearby depends mainly on these horizontal wells for their water requirements. They are also used to irrigate crops such as paddy and coconut. What is also important that the water from Surangam is of good quality.

Ahar Pynes in South Bihar

This is a water conservation technique indigenous to South Bihar. Due to a variety of reasons including sandy soil, temporal river flow, low groundwater levels etc, floodwater harvesting is considered as the most suitable option for the area.

Ahar consists of a catchment basin embanked on three sides, at the end of a rivulet or a canal that leads from a river. Pynes are artificial channels, which were constructed to use river water for agriculture. The process starts from the river, from where the water goes to pynes and eventually lands up in an ahar. Although the system suffered under British rule, it has again been rejuvenated for agricultural purposes, especially in the district of Gaya.

9.Elements of Rainwater Harvesting System being adopted in modern time

A rainwater harvesting system comprises components of various stages – transporting rainwater through pipes or drains, filtration, and storage in tanks for reuse or recharge. The common components of a

Figure 3.*Rainwater Harvesting System adopted today*

harvesting system involved in these stages are illustrated here.

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9.1.Catchment - The catchment of a water harvesting system is the surface which directly receives the rainfall and provides water to the system. It can be a paved area like a terrace or courtyard of a building, or an unpaved area like a lawn or open ground. A roof made of reinforced cement concrete (RCC), galvanised iron or corrugated sheets can also be used for water harvesting.

9.2.Coarse mesh - Coarse mesh at the roof to prevent the passage of debris

9.3Gutters - Gutters are channels all around the edge of a sloping roof to collect and transport rainwater to the storage tank. Gutters can be semi-circular or rectangular .

The size of the gutter should be according to the flow during the highest intensity rain. It is advisable to make them 10 to 15 per cent oversize.

Gutters need to be supported so they do not sag or fall off when loaded with water. The way in which gutters are fixed depends on the construction of the house; it is possible to fix iron or timber brackets into the walls, but for houses having wider eaves, some method of attachment to the rafters is necessary.

9.4.Conduits - Conduits are pipelines or drains that carry rainwater from the catchment or rooftop area to the harvesting system. Conduits can be of any material like polyvinyl chloride (PVC) or galvanized iron (GI), materials that are commonly available.

9.5.First-flushing - A first flush device is a valve that ensures that runoff from the first spell of rain is flushed out and does not enter the system. This needs to be done since the first spell of rain carries a relatively larger amount of pollutants from the air and catchment surface.

9.6.Filter - The filter is used to remove suspended pollutants from rainwater collected over roof. A filter unit is a chamber filled with filtering media such as fibre, coarse sand and gravel layers to remove debris and dirt from water before it enters the storage tank or recharge structure. Charcoal can be added for additional filtration.

9.7.Filter for large rooftops - When rainwater is harvested in a large rooftop area, the filtering system should accommodate the excess flow. A system is designed with three concentric circular chambers in which the outer chamber is filled with sand, the middle one with coarse aggregate and the inner-most layer with pebbles.

a) Filter channel : One square metre in cross-section and eight m in length, laid across the tank embankment, the filter channel consists of three uniform compartments, the first packed with broken bricks, the second with coarse sand, followed by fine sand in the third compartment.

b) Sump: A storage provision to collect filtered water from the tank through the filter channel for storage and collection.

9.8.Storage facility - A storage tank made of galvanised iron sheets.There are various options available for the construction of these tanks with respect to the shape, size and the material of construction.

9.9.Recharge structures - Rainwater may be charged into the groundwater aquifers through any suitable structures like dugwells, borewells, recharge trenches and recharge pits.

Various recharge structures are possible – some which promote the percolation of water through soil strata at shallower depth (e.g., recharge trenches, permeable pavements) whereas others conduct water to greater depths from where it joins the groundwater (e.g. recharge wells). At many locations, existing structures like wells, pits and tanks can be modified as recharge structures, eliminating the need to construct any structures afresh. Here are a few commonly used recharging methods:

9.9.1.Recharging of dugwells and abandoned tubewells.

In alluvial and hard rock areas, there are thousands of wells which have either gone dry or whose water levels have declined considerably. These can be recharged directly with rooftop run-off. Rainwater that is collected on the rooftop of the building is diverted by drainpipes to a settlement or filtration tank, from which it flows into the recharge well (borewell or dugwell).

If a tubewell is used for recharging, then the casing (outer pipe) should preferably be a slotted or perforated pipe so that more surface area is available for the water to percolate. Developing a borewell would increase its recharging capacity (developing is the process where water or air is forced into the well under pressure to loosen the soil strata surrounding the bore to make it more permeable).

If a dugwell is used for recharge, the well lining should have openings (weep-holes) at regular intervals to allow seepage of water through the sides. Dugwells should be covered to prevent mosquito breeding and entry of leaves and debris. The bottom of recharge wells should be desilted annually to maintain the intake capacity.

9.9.2.Settlementtank

Settlement tanks are used to remove silt and other floating impurities from rainwater. A settlement tank is like an ordinary storage container having provisions for inflow (bringing water from the catchment), outflow (carrying water to the recharge well) and overflow. A settlement tank can have an unpaved bottom surface to allow standing water to percolate into the soil.

In case of excess rainfall, the rate of recharge, especially of borewells, may not match the rate of rainfall. In such situations, the desilting chamber holds the excess amount of water till it is soaked up by the recharge structure. Thus, the settlement chamber acts like a buffer in the system.

Any container, (masonry or concrete underground tanks, old unused tanks, pre-fabricated PVC or ferrocement tanks) with adequate capacity of storage can be used as a settlement tank.

9.9.3.Recharging of service tubewells.

In this case the rooftop runoff is not directly led into the service tubewells, to avoid chances of contamination of groundwater. Instead rainwater is collected in a recharge well, which is a temporary storage tank (located near the service tubewell), with a borehole, which is shallower than the water table. This borehole has to be provided with a casing pipe to prevent the caving in of soil, if the strata is loose. A filter chamber comprising of sand, gravel and boulders is provided to arrest the impurities.

9.9.4.Recharge-pits

A recharge pit is 1.5m to 3m wide and 2m to 3m deep. The excavated pit is lined with a brick/stone wall with openings (weep-holes) at regular intervals. The top area of the pit can be covered with a perforated cover. Design procedure is the same as that of a settlement tank.

9.9.5.Soakaways / Percolation pit

Percolation pits, one of the easiest and most effective means of harvesting rainwater, are generally not more than 60 x 60 x 60 cm pits, (designed on the basis of expected runoff as described for settlement tanks), filled with pebbles or brick jelly and river sand, covered with perforated concrete slabs wherever necessary.

9.9.6.Recharge-trenches

A recharge trench is a continuous trench excavated in the ground and refilled with porous media like pebbles, boulders or broken bricks. A recharge trench can be 0.5 m to 1 m wide and 1 m to 1.5 m deep. The length of the recharge trench is decided as per the amount of runoff expected. The recharge trench should be periodically cleaned of accumulated debris to maintain the intake capacity. In terms of recharge rates, recharge trenches are relatively less effective since the soil strata at depth of about 1.5 metres is generally less permeable. For recharging through recharge trenches, fewer precautions have to be taken to maintain the quality of the rainfall runoff. Runoff from both paved and unpaved catchments can be tapped.

9.9.7.Recharge troughs

To collect the runoff from paved or unpaved areas draining out of a compound, recharge troughs are commonly placed at the entrance of a residential/institutional complex.These structures are similar to recharge trenches except for the fact that the excavated portion is not filled with filter materials. In order to facilitate speedy recharge, boreholes are drilled at regular intervals in this trench. In design part, there is no need of incorporating the influence of filter-materials.

This structure is capable of harvesting only a limited amount of runoff because of the limitation with regard to size.

9.9.8.Modified-injection-well

In this method water is not pumped into the aquifer but allowed to percolate through a filter bed, which comprises sand and gravel. A modified injection well is generally a borehole, 500 mm diameter, which is drilled to the desired depth depending upon the geological conditions, preferably 2 to 3 m below the water table in the area. Inside this hole a slotted casing pipe of 200 mm diameter is inserted. The annular space between the borehole and the pipe is filled with gravel and developed with a compressor till it gives clear water. To stop the suspended solids from entering the recharge tubewell, a filter mechanism is provided at the top.

10.Research Hypothesis

After a detailed and deep study of groundwater movement theory and engineering principles pertaining to accumulation and storage of groundwater and applying them to the effectiveness of Rainwater Harvesting System in recharging the Groundwater of the locality , the following observations are made.

I. The resistance offered by air to movement of a raindrop in atmosphere is far less compared to the resistance offered by soil particles to movement of the same raindrop within the pores of the soil where capillary action and surface tension also plays an important role in the groundwater movement depending upon the size of pores and type of soil .

   Therefore , a raindrop travels much faster in atmosphere than in soil.This leads to higher accumulation of rainwater on the surface of the soil than the rate of infilteration.

II. Drawing conclusion from above hypothesis,it can be very easily said that for all rainwater of volume `v` falling within a catchment to enter the pores of the soil , we have two options.

(i) Keep the rainwater of volume `v` and depth `d`standing on the surface of the soil for as long duration `t` as the rate of infilteration capacity of the soil which is high in sandy soil and extremely low in clayey soil.

(ii) Provide a very large surface area of absorption for the same standing rainwater of volume `v`.In this case the depth `d` reduces drastically due to increase in surface area ; volume `v` being kept constant.

(iii) Increase in surface area of soil increases the number of pores (channel of flow of rainwater under gravity) ; also leads to reduction in depth ` d` of rainwater for constant volume `v` which reduces the time duration `t` drastically for a constant rate of infilteration due to increase in the number of channel(soil pores)for flow of rainwater into the soil.

III. The rainwater conservation methods adopted in ancient times provided for large surface area of absorption and the dutation `t` of standing rainwater was infinite . Hence the groundwater of the locality used to be effectively charged.

IV. On the other hand , rainwater harvesting system adopted today provide a very small surface area of absorption and the volume of rainwater accumulating in a village pond cannot be accommodated within the recharging structure of the Rainwater Harvesting System because of drastic reduction in surface area of absorption ; remaining rainwater of the locality cannot wait for its turn of infilteration into the ground but flows away from the locality as surface runoff intothe sewer and drains.

11.Conclusion

Therefore based on above hypothesis the conclusion can be very easily drawn that rainwater harvesting system adopted in modern times today is not as effective in re-charging groundwater as the methods adopted in ancient times.

Also the cost involved in constructing many Rainwater Harvesting Systems to match the surface area of absorption in a locality is much higher than the cost involved in adopting the solutions prevalent in ancient times.

Finally , it is advisable to go for water conservation methods adopted in ancient times alongwith Rainwater Harvesting System adopted in modern times for an effective recharge to groundwater of the locality . For this the governing bodies of the locality should allocate suitable vast area of costly land for adopting those facilities of ancient times in their master plan.

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