ROOF TOP RAIN WATER HARVESTING, CONSERVATION AND MANAGEMENT STRATEGIES FOR URBAN AND RURAL SECTORS

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ABSTRACT

Water has been harvested in India since antiquity. Roof top water harvesting techniques are not new for Indians. Water scarcity is a serious problem throughout the world for both urban and rural community. Urban centers in India are facing an ironical situation of water scarcity today.

The paper presents State of Art, Professional Practice, Codal guidance & their limitations. To overcome them Geotechnical aspect based, field tested technology evolved is illustrated for wide applications. It includes evolving required parameters in execution to confirm a design discharge for planning rooftop harvesting which is environmental friendly and tested on prototype. The economics is briefly outlined for cost benefit ratio.

This paper includes a Theoretical, Experimental and Computational approaches to predict capacity of installed recharge well and water mound below the G.W.T. This criterion is essential for the proper management of suitable artificial ground-water recharge systems to maintain water balance and stop salt water intrusion. Evaluated recharge rate Q_r using computational approach in all selected field case studies from various zonal sites, difference in percentage error is minimum (less than 10 %) as compare to theoretical approach.

Authors have designed prototype test model at SVNIT campus and verified all design governing parameters influence ground water recharge by establishing relationship between hydraulic conductivity, radius of recharge well and head causing flow. This required for predicting the ground water mound depending on the intensity of recharging rate of well.

Authors made comparison between recorded infiltration rate of water in well and water meter reading showed good agreement and hence justifies the proper working of installed recharge well at NIT – Surat. Theoretical and actual runoff with % Error indicated good reliability for irregular intensity of rain i.e. theoretical (assumed) data validates the actual field data.

Key words: Terrace roof top harvesting, precast octagonal recharge well, rainfall – runoff coefficient, unconfined aquifer, water quality standards, Infiltration rate of water

1. INTRODUCTION

Scarcity of water resources, pollution and climate change will be the major emerging issues in the next century. Due to depletion of water table, scanty and uneven pattern of rainfall is faced by arid and semi-arid district of Gujarat State. The runoff for roof top is computed based on average rainfall intensity. In addition to irregularity of rainfall, the change in life style, population explosion, rapid industrialization, rapid urbanization, irrigated agriculture and inefficient water management plan are the main factor which has lead to present water shortage problem. Adequate space for surface storage is not available in urban areas; water levels are deep enough to accommodate additional rainwater to recharge the aquifers, rooftop and runoff. Adopting the concept of sustainability and conservation of water resources using artificial recharge technique can help to cope with the global water shortage in decade or two.

The climate change of last decade shows plenty of floods and vast areas having scarcity of water. Looking to international studies by WHO, Prime Minister gave priority to harvesting every drop of rainwater in urban and industrial sectors in his water resources day speeches (2006-07). The rooftop harvesting to succeed must make it public participation programme. This cannot be possible unless a simplified technology which can be adopted by public at large is provided by engineers. The paper presents State of Art, Professional Practice, Codal guidance and their limitations. To overcome them Geotechnical aspect based, field tested technology evolved is illustrated for wide applications. It includes evolving required parameters in execution to confirm a design discharge for planning rooftop harvesting which is environmental friendly and tested on prototype. The economics is briefly outlined for cost benefit ratio.

The present contribution is attempt to provide quick, economical, simple technology for roof top harvesting to recharge fast depleting ground water table in urban India.

2. POPULATION AND WATER SCARCITY

The earth's population is projected to double from the present 5.6 billion to about 10 billion by the year 2050. By the year 2050, the per capita availability of water will drastically reduce and majority of countries in the world including India shall be water stressed in many river basins. Water resources are limited and water is becoming a scarce due to ever-increasing demand in proportion to the rapidly increasing population. In 1947 population of India is about 343 million, the population has cross the 1,000 million mark in 2000.

In year 2050, India's projected population is 1.64 billion. For feeding a population of 1.64 billion [4], nearly 450 million tones (i.e. 750 grams per capita per day) of food grains would be required in 2050, production of which would be a gigantic task considering the constraints being faced in the irrigation sector.
Only 2.14% of the total water available is fresh water and 97.20% is saline water. Groundwater does not recycle as fast as the surface water, with rates of groundwater turnover varying from years to millennia, depending on aquifer location, type, depth, properties, and connectivity. The average time for the renewal of groundwater is 1400 years.

3. WATER NEED AND WATER AVAILABILITY

Water needed 135 liters per person per day, when projected India's population was 1.64 billion in year 2050, and then water requirement will be 80811 x 10^9 liters per year.

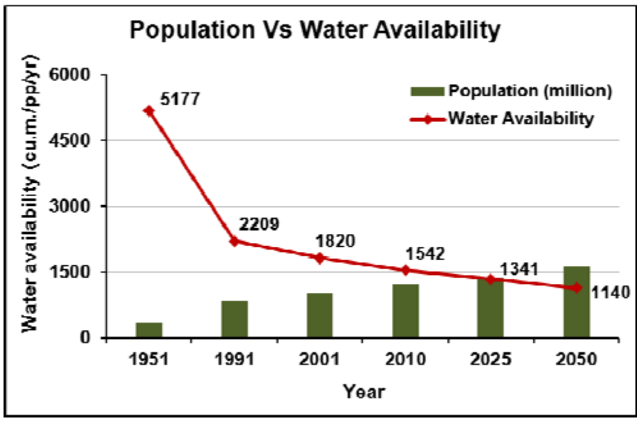

Figure 1 indicated that the volume of water available per person in India is decreasing steadily from 5177 m^3/pp/yr in 1951; it fell to 1542 m^3/pp/yr in 2010. According to the Ministry of Water Resources it is expected to decrease further by 1140 m^3/pp/yr in 2050 [9].

Figure 1 Water Availability of India

Minimum requirement will be 1700 m^3/pp/yr and availability will be 1140 m^3/pp/yr which is imbalance. There fore India is under water stress area and face acute crisis of water. It is priority base to add other source of water to fulfill this requirement.

Annual water resources in our river basins are estimated as natural runoff 1869 bcm. Owing to hydrological, topographical and geological limitations; only 690 bcm of surface water can be utilized by conventional storages and diversion structures. There is a vast difference between potential (1869 bcm) and the conditional availability (690 bcm if it can be stored). On an average annual replenish able ground water has been assessed as about 432 bcm. Thus the total utilizable water resources, both from surface as well as ground water is about 1122 (690 + 432) bcm out of 1869 bcm [9].
India's total water requirement by the year 2010 and 2050 will become 733 bcm and 1422 bcm respectively. At the national level, it would be a very difficult task to increase the availability of water for use from 733 bcm to the desired level of 1422 bcm by the year 2050 [4].

Rainfall is termed as primary source of water and its contribution to the world's water supply. The main source of recharge to ground water body is rainfall. As such rainfall characteristics have to be analyzed like rainfall pattern, estimation of mean precipitation, probability of its recurrence and coefficient of variation. In spite of higher average annual rainfall in India (1170 mm) as compared to the global average (800 mm), it does not have sufficient water. Most of the rain falling on the surface tends to flow away rapidly, leaving very little for the recharge of groundwater**.**

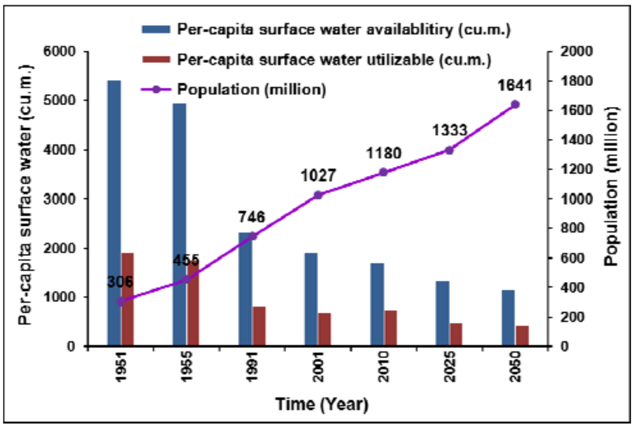

Figure 2 Statistics of surface water available and surface water utilizable in India

In year 2025 - 2050 increase in (projected) population 1.64 billion with decrease in water availability as mentioned in **Figure 2** [9]. Due to increasing gap between Per-capita surface water availability and Per-capita surface water utilizable in India, the water scare regions are facing problems. An optimum development can be achieved by the conjunctive use of surface and ground water.

In India, fast developing state of Gujarat and diamond city Surat is under water stress area and face acute water crisis as water availability is less than 1700 (m^3/pp/yr). Scenario of Water Resources of Gujarat State and Surat city are alarming and seek urgent attention.

State of Gujarat

The rainfall pattern intensity has been now changing with change in Geographical condition which is high lighted in **Figure 3**.

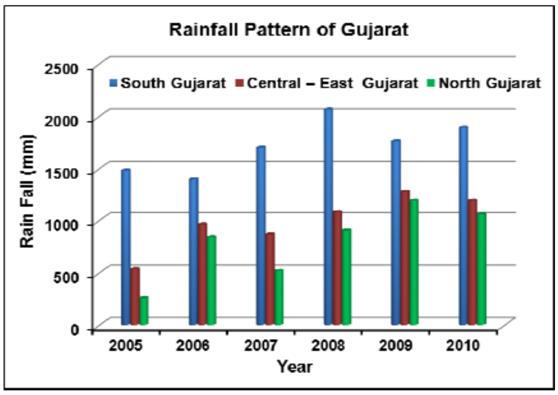

Figure 3 Rainfall pattern of Gujarat.

Rainfall intensity of North, Center-East and South Gujarat is uneven and unpredictable due to climatic change as shown in **Figure 3** [4]. Rainfall occurs in about 4 months in a year but the spatial and temporal distribution of rainfall is so uneven that the annual averages have very little significance for all practical purposes.

Surat City

City area increases doubled and due to industrial expansion, after 2007 use of water is drastically increasing. Available source of water is only 1050 m^3/year/head, so great dependency only on ground water source in 2015.

Table 1 Hypothesis of water availability and lowering of water level in Surat

Year	Availability in market	Average depth of water from G.L.
1970	Freely available	10 m
1980	50 paisa/glass	30 m - 40 m
2000	Rs.12/liter	50 m - 60 m
2050 (Projected)	Rs.100/liter	80 m - 100 m ***If not recharged now***

Table 1 shows scenario of the costing of water available at present and in future [11]. With the growing demand of water, ground water level dropped drastically, therefore artificial ground water recharge is an immediate need to conserve every source of usable water for the future generation. *Planning and management of 10 years could postpone water crisis by few more years.*

Based on above information, the coping with this challenges artificial recharge to ground water is truly a matter of great national priority and policy. Artificial recharge thus becomes relevant in a situation witnessed by India, where the following facts are considered for water crisis after 2015.

- Unequal and Uncertainty of Rainfall due to climate change, Unequal land and water resources, Due to vast difference between Per-capita surface water availability and Per-capita surface water utilizable. Unequal Population Density. Unequal Geographical conditions, Non availability of land in urban area, Non availability of standardized, reliable, economical and user friendly technique for recharging, Non availability of proper guidelines and design methodology for artificial recharging of ground water.

To overcome such difficulties conservation of ground water by artificial means are necessary and therefore this study work is conducted. Prototype test model is installed at NIT-Surat project site and analyzed calculated results.

Literature and research paper review is carried out for searching of proper and perfect guidelines, methodology for artificial recharging of ground water so that whatever lacking in these previous work can be supplement by this research work. The literature review, I.S. code and manual do not give any guide lines to evolve design of recharge well system for roof top runoff and geotechnical aspects of aquifer are not considered in NGOs / Present design practice. Thus depth and diameter of well, length of perforated strainer or detention tank are chosen by the driller or plumber and is cause of major failures of projects implemented in past 5 years.

4. DESIGN APPROACHES FOR EVALUATION OF RECHARGING CAPACITY OF RECHARGE WELL (Q_r)

4.1 Theoretical Approach using Geotechnical Parameters for Evaluation of Recharging Capacity of Recharge well (Q_r).

Determination recharge rate using Darcy's of seepage through soil mass [1]

$$\mathbf{Q_r = k \times A \times i \times t} \quad \mathbf{(1)}$$

k = Co-efficient of permeability (cm/sec)
Permeability of aquifer can be determined by Allen Hazen equation = C x $(D_{10})^2$
(Valid for 0.1mm to 4mm fraction size)
C = Allen Hazen constant = 100
D_{10} = diameter of soil particle 10% finer (cm)
A = Area of Recharge well = $2\pi rl$
r = Radius of recharge well
l = length of strainer (0.7 to 0.8 times H). In field practice strainer is not fully penetrate to impervious strata. Generally adopted as 0.7 to 0.8 H or (2/3 of H) or (l = H) [6]

H = Average thickness of saturated aquifer below ground water table restricted to length of fully draining strainer installed. It is presumed that bottom and sides are fully allowing flow of water (k of strainer > k of aquifer soil)
i = Hydraulic gradient = h/L
h = Depth of head causing flow above the ground water table
L = Radius of influence (Influence range)
t = Time for required water seeps through soil mass (hr)

4.1 (a) Evaluation of recharging capacity of well (Q_r) with radius of well (r) and head causing flow above the ground water table (h).

$$\mathbf{Q_r = 15 \times r \times h} \qquad \mathbf{(2)}$$

Equation 2 is the derived generalized theoretical equation for any required value of radius of the well and depth of head causing flow above the ground water table in unconfined aquifer [10]. It is highlighted in **Figure 4**.

4.1 (b) Evaluation of recharging capacity of well Q_r with diameter of well (d) and permeability (k) of the aquifer soil strata.

$$\mathbf{Q_r = 55 \times d \times k} \qquad \mathbf{(3)}$$

Equation 3 is the derived generalized theoretical equation for any required value of diameter of the well and permeability of soil of unconfined aquifer soil [10]. It is highlighted in **Figure 5**.

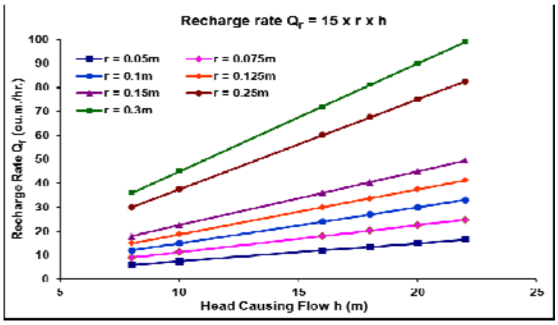

Figure 4 Recharging capacity of borehole Q_r with depth of head causing flow above the ground water table (h) verses radius of recharge well (r)..

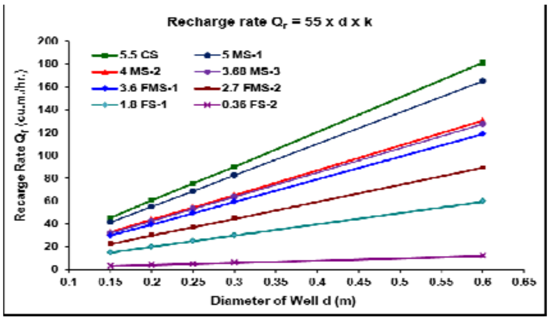

Figure 5 Recharge capacity of recharge well Q_r verses diameter of recharge well (d) with variable permeability of aquifer (k).

4.2 Experimental Approach (Prototype Test at NIT-Surat Project site)

Field test is carried out at NIT-Surat project site for determination of actual value of recharging capacity of well after erection of recharging system at site and also for the verifications and confirmation of derived generalized theoretical equations 2 and 3. Only roof top rain water is fed to system to eliminate contaminant and pollutant of surface water.

Observations:

Referring soil investigation report of NIT-Surat project site following observations is summarized:

- Over all sand strata of NIT-Surat project site and its surrounding sites exist at 20-30 m depth below ground water table, type of soil is SW-SM-SC-GM [2] which is suitable for recharging. Below this depth, highly impervious soil strata CH-CI exist. Recharge system can be designed and analyzed under **UNCONFINED AQUIFER** category.

- Slope of sand strata is not towards sea or river. It implies also if artificial recharge well is constructed at this region, water can be retaining in the recharge well. Water does not drain away either towards sea (to west) nor towards river. This soil topography and stratification of aquifer fulfills the criteria for recharging.

4.2.1 Erection of Precast Octagonal Recharge well at project site

All the connection of pipes from terrace roof of NIT-Surat project site and connected with detention tank, water meter chamber, sand filtration module, two layered precast recharging system and recharge well shown in **Figure 6**.

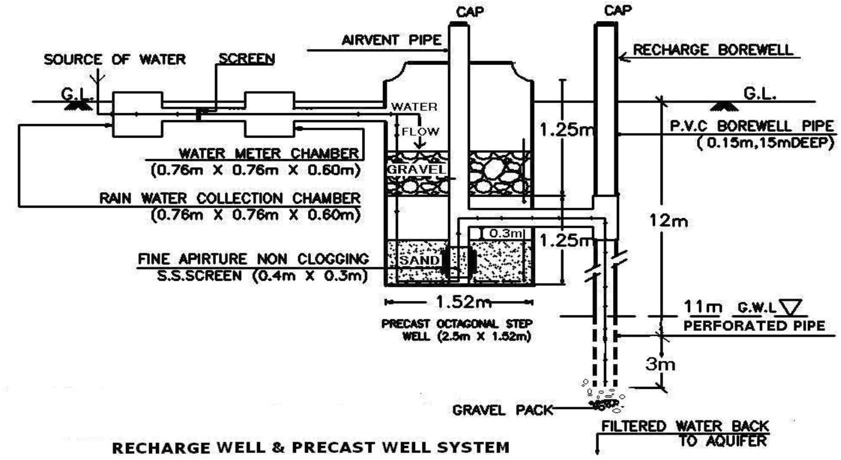

Figure 6 Connection details for collection of rain water from terrace roof

Figure 7 Network of Roof terrace rainwater collection pipes with recharge system

Figure 8 Recharge system with Water meter chamber, Detention tank and Recharge well

Figure 7 and 8 shows actual photographs of NIT-Surat project site where roof top recharging system is installed. Details of connected pipes with terrace roof 300 m^2 area, detention chamber, water meter chamber, pre cast recharge system, recharge well etc.

4.2.2 In-situ Constant Head Test

Insitu constant head test was conducted for evaluation of recharging capacity of installed recharge well at NIT-Surat project site.

♦ *Experimental (field test) data:* [5]	♦ *Justification through actual rainfall data:*
Capacity of 8000 liter (8m^3) water tanker was used to fill water in PVC casing above ground level by 1 m height. Time to empty tanker water into recharge well is 15 minute. Q_r actual is **32 m^3/hr.**	Maximum intensity of rainfall in Surat is 100 mm/hr (0.1 m/hr) Terrace roof top area of project site is = (22.2 m x 13.5 m) = 300 m^2

The overall recharging capacity of installed recharge well at project site is 32 m^3/ hr. It shows that in one hour 32,000 liter water store in recharge well without spill off.	Rain water from roof top (recharge rate) = Catchment area x rainfall x coefficient of runoff = 300 x rainfall x coefficient of runoff = 300 m^2 x 0.1 x 0.8 m/hr = **24 m^3/hr**

Summary:

- Recharging capacity of designed well system by field flow test is **32 m^3/hr**, which is checked with theoretical approach mentioned in figure 5 **is 29.7 m^3/hr**. Also adopting roof top runoff calculation of project site recharge rate is **24 m^3/hr**. All values are fairly confirmatory. Derived theoretical approach is justified. It must be noted that procedure for estimation of recharge rate is not available in present codes or design practices. The expression derived is based on many assumptions.

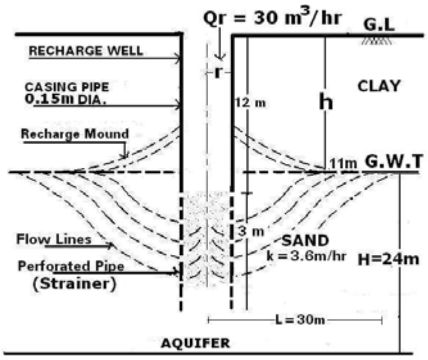

Figure 9 Installed recharge well having Q_r = 30 m^3 /hr (NIT-Surat Project site)

Figure 9 shows flow lines moves in upward direction and merge with altered ground water level i.e. it forms hump (recharge mound) above the ground water level and thus raises water table. Due to the gravel packing at the base of casing pipe, silt particles will not directly enter in recharge well and minimize or prevent against choking of the strainers [3].

4.3 Computational Approach using Geo-Hydro meteorological parameters

Geotechnical parameters (permeability, particle size D_{10}, porosity, water head, depth of G.W.T. etc.) and Hydro-meteorological parameters (rain fall intensity and its time duration, surface runoff, designed catchment area – its coefficient etc.) [8] are used to determine recharging rate of installed recharge well.

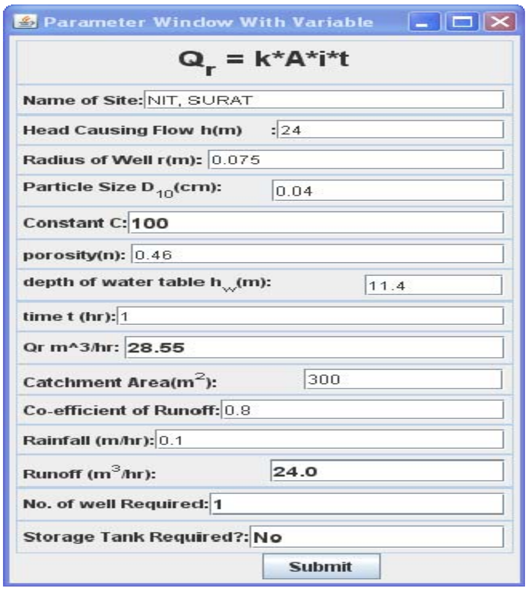

Figure 10 Calculation and results of NIT-Surat Project Site

Figure 10 shows calculated recharge rate of well Q_r is 28.55 m^3/hr and runoff is 24 m^3/hr. Installation of one well is required for recharging; storage tank is not required at NIT-Surat Project site [10]. It also gives the guideline for requirement of storage tank and rise in water level after installing recharge well. This approach also gives the confirmation of the results obtained from theoretical equations 2 and 3 as well as experimental – field prototype constant head test approach [7].

5. ANALYSIS OF EVALUATED RESULTS FROM ALL DESIGN APPROACHES

Comparison and Percentage Error Difference of Evaluated Results of different zonal site is represented as below [11]

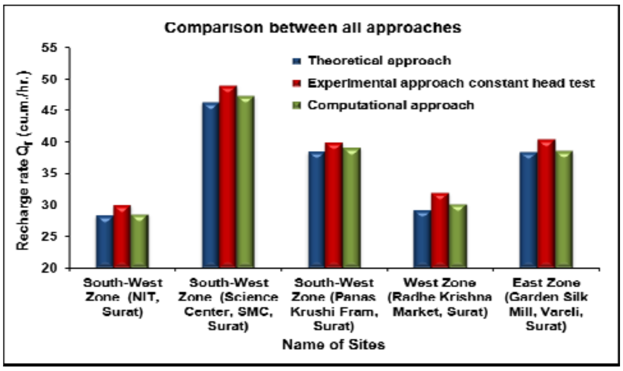

Figure 11 Comparison of evaluated recharge rate Q_r from all approaches

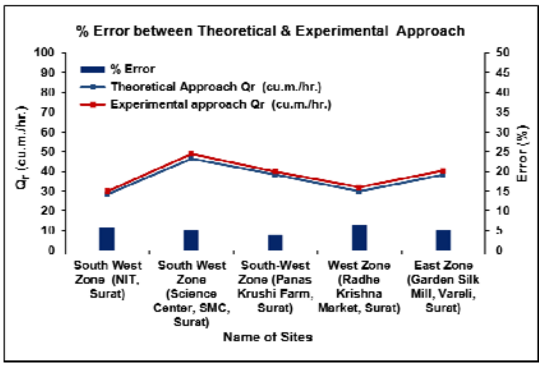

Figure 12 Comparison of % Error between Theoretical and Experimental approach

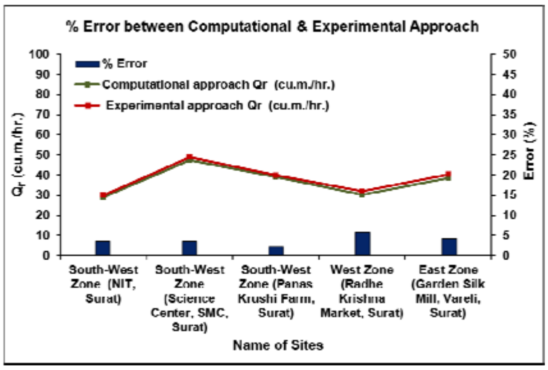

Figure 13 Comparison of % Error between computational and experimental approach.

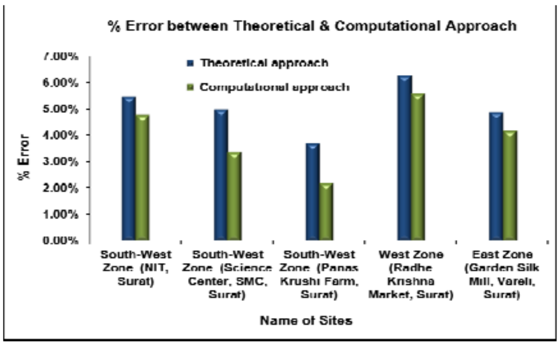

Figure 14 Comparison of % Error between Theoretical and computational approach

Figure 14 shows evaluated value Q_r of all case studies from computational approach having less difference than theoretical approach. Difference of this value is represented in % Error. Graphs of experimental and computational approach are almost parallel (fig.13). It indicates that both Geotechnical and Hydro-meteorological parameters impact on recharge rate rather than only Geotechnical parameters used in theoretical approach. Therefore computational approach is preferred than theoretical approach.

6. QUALITY ANALYSIS OF WATER AND RISE IN G.W.T. AFTER INSTALLATION OF THE SYSTEM

Quality values of water and rise in water level are tested and recorded at regular time interval in pre recharging and post recharging installed well. Quality of water and location of water level trends are shown in **Figure15** [12].

Figure 15 shows within two years considerably reduction in chloride, total hardness, alkalinity, pH, Turbidity, T.D.S. and increase in water level, it implies that installed recharge system works satisfactorily in adding usable ground water for future. Constituents obtained after recharging are within permissible limit which is confirmed with standard quality values of water given in I.S.10500 – 1991. If periodical maintenance of recharge well is carried out and process of recharging is continuous than in future (year 2015) impurities in all constituents may be reduced in large scale.

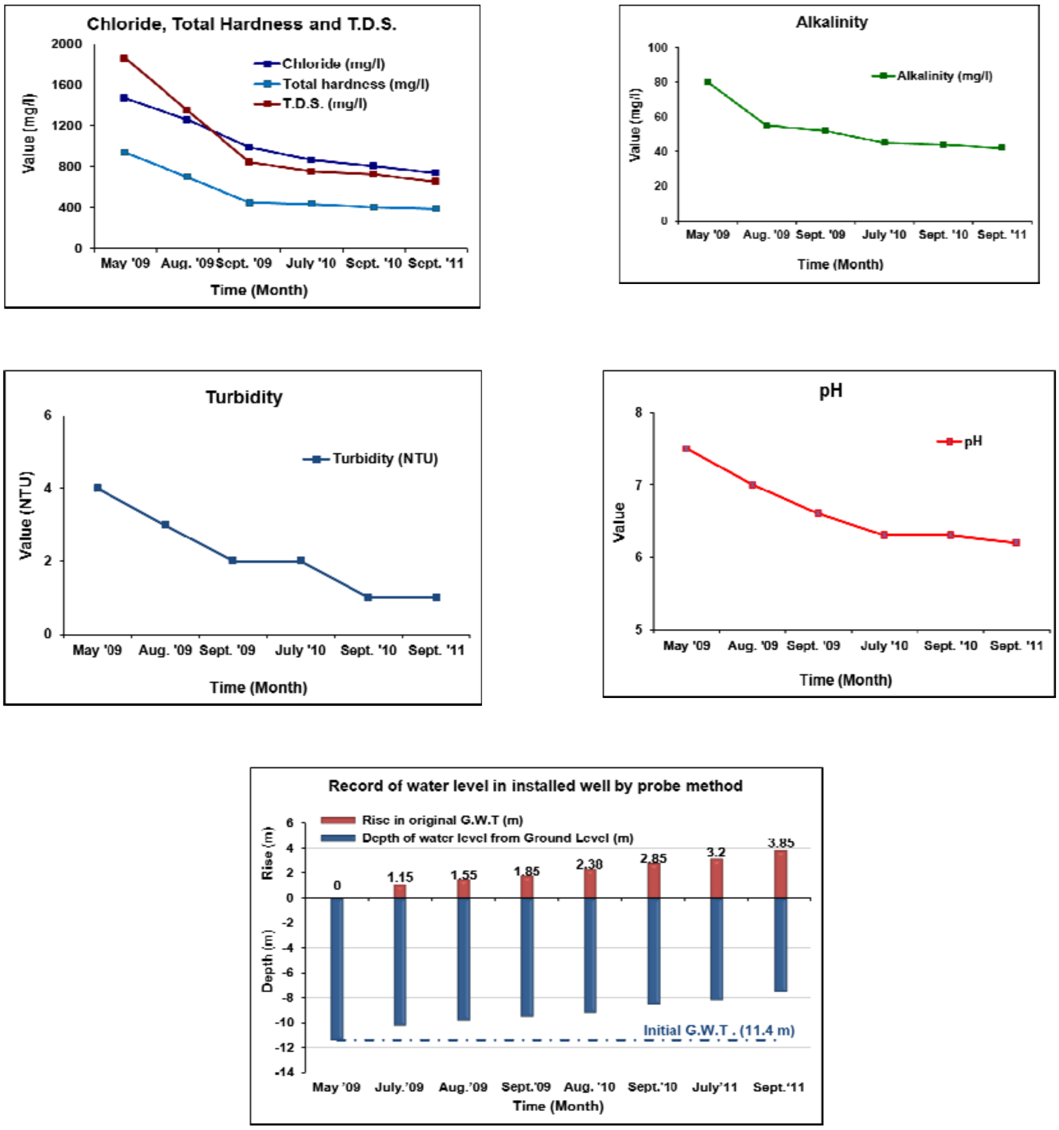

Figure 15 Water quality constituents and rise in water level after recharging

7. JUSTIFICATION AND FUNCTIONALITY OF THE SYSTEM

Justification

Daily observed runoff data of south west zone were collected as per water meter and rainfall average for city during July 2010 and September 2011 are reported by local press represented [12].

Figure 16 shows very good reliability between Theoretical and Actual runoff for irregular intensity of rain. Behavior of the both graphs is almost same. It means theoretical (assumed) data match with the actual data. Behavior of this graphs justify the assumed design parameters are valid.

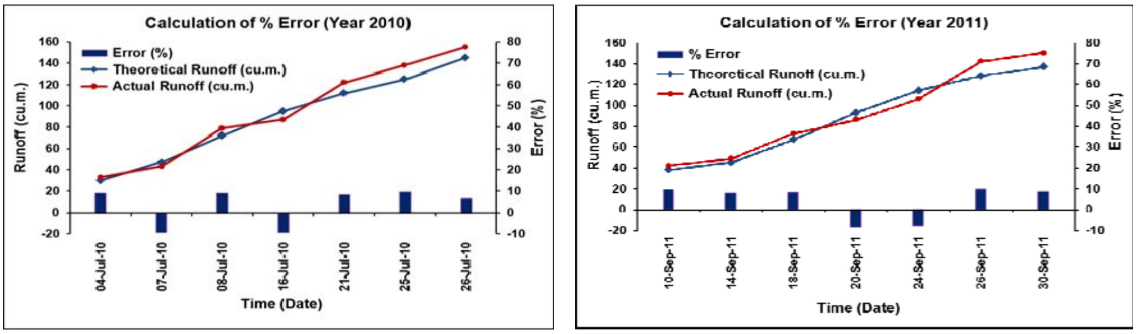

Figure 16 Representation of Theoretical and Actual runoff with % Error (year 2010-11)

Functionality of the System

(a) Infiltration rate of water in installed well and water meter reading

Water meter reading (cu.m.) is confirm with Infiltration rate of water in well (cu.m./day) for checking of proper working of installed recharge well at NIT-Surat project site.

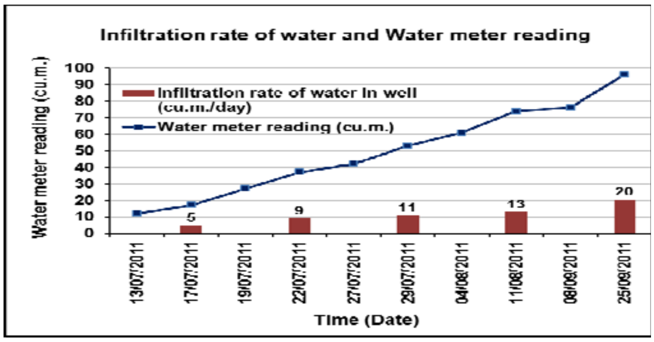

Figure 17 Water meter reading correlated with Infiltration rate of water in well

Figure 17 gives on an average value of infiltration rate of water per day. Amount of infiltration rate of water per day shows clogging of silt particles not formed below bottom of the casing pipe, there fore it not affect the recharging capacity of well.

(b) Daily rainfall data and water meter reading

Recorded data of daily rainfall from local press and water meter reading installed at site for check the functionality of the installed system with all connections [5].

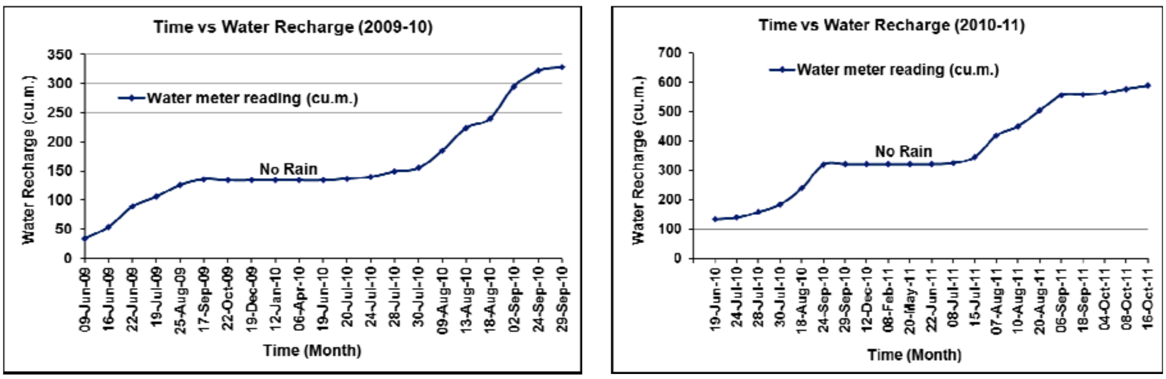

Figure 18 Data collection of rain water harvesting from roof top with time at NIT-Surat Project site.

Figure 18 gives total water recharge was **590 m^3** at the end of monsoon from roof top of NIT-Surat Project site. During 2009-2010-2011 rainy season amount of water recharged recorded from water meter. Straight line portion in both the graphs indicates *No Rain Fall* during that period as water meter reading shows constant reading. Enough amount of water recharged through well in 2 years of span after installation. Also verify that the connections of network between each chamber to recharge well are proper done. No fault in a junction of each pipe.

8. COST ASPECTS

Table 2 Actual cost of installed recharge system at NIT-Surat.

Item No.	Description	Amount in Rs.
1.	Drilling of Well, Gravel pack, compressor cleaning, PVC pipes (depth up to 15 m)	16,000=00
2.	Precast Octagonal Recharging System	45,000=00
3.	PVC pipe down take from Roof Top	5,000=00
4.	Labor Charges	3,500=00
5.	PVC chamber	1,200=00
6.	Dumping of materials (Sand, Gravel, pipes, cement etc.	5,000=00
	Excluding recurring maintenance ….Total Rs…	75,700=00

Total cost including recurring maintenance at site will be Rs.1,00,000/-. Considering annual interest of 10% on capital (Rs. 10,000/-), recovery of water for above project shows 300 cu.m. of water conserved. This water when recovered after five years can have market value of Rs. 3,00,000/- at national rate of Rs. 1 per liter. Individual investment can give benefits of water at 1/5 market rate (Rs. 10/- per liter per purified water from recharged Rs. 2 per liter.)

CONCLUSIONS

- Recharging capacity of well reduces with decrease in permeability of soil. Medium to coarse sand is most suitable for recharging of aquifer as maximum advantage of recharge rate. If required recharge rate is more then provide larger diameter bore can instead of providing (installing) two smaller diameter of bore.
- Recharge rate of installed system is totally site specific, it totally depend on geotechnical parameters of the site. Geotechnical parameters (d, n, D_{10}, k, Q_r, h) used for designing a recharge system at various zonal sites as located in Surat city. Successive parameters as rise in water level and improvement in water quality after one year of the installation of the recharge system recorded. It indicated that all assumed design parameters at each sites justify the performance of the installed system.
- With the help of computational approach using Geo-Hydro-meteorological parameters design value of recharge rate of well, requirement of no. of wells and storage tank at project site can be easily determine.
- With reference to field test Error getting from both approaches are comparatively acceptable and confirms that the computer algorithm can substitute theoretical approach. Evaluated recharge rate Q_r using computational approach in all case studies error difference in minimum and within acceptable limit than theoretical approach. Value of % error is not exceeding 10% which is permissible under consideration of actual field condition. This error difference is totally depend on variation exists in site condition.
- This study approach and formulation will supplements the present practice of architect, engineers and make it more scientific successful in achieving objective of rain water recharging through recharge well system in urban and industrial areas.

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