CHASING A MIRAGE: WATER HARVESTING AND ARTIFICIAL RECHARGE TO SOLVE WATER PROBLEMS IN NATURALLY WATER-SCARCE REGIONS[1]

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Abstract

Often as a frantic response to problems of water scarcity and consequent hardships faced by communities in urban areas as well as country-side, India had invested many billions in rainwater harvesting. The analysis presented in this paper shows that in water-scarce regions of India, runoff harvesting does not offer any potential for groundwater recharge or improving water supplies at the basin level. The issues can be summarized as follows. 1. Water harvesting in "closed" basins have negative hydrological impacts on the downstream areas. 2. Due to high inter-annual variability in rainfall and subsequent runoff WHSs become highly unreliable during drought years, whereas attempt to capture runoff would remarkably increase the unit cost of harvesting water. 3. In closed basins, intensive water harvesting will lead to negative welfare outcomes due to high negative externalities at higher degrees of basin development. 4. Even at the local level, physical efficiency of WH is likely to be poor, mainly due to groundwater-surface water interactions; and poor storage capacity of hard rock aquifers underlying most of the water-scarce regions. Artificial recharge systems in natural water-scarce areas in India are economically unviable.

1. INTRODUCTION

India has a long tradition of water harvesting (Agarwal and Narain, 1997). But, the past two decades in the country's water sector history are characterized by a boom in water harvesting. They are markedly different from the traditional ones in 2 ways; first from the context; and second from the purpose. As regards the context, they are able to use recent advancements in soil, geosciences and hydro-sciences; and modern day techniques and technologies in survey and investigation, earth moving and construction; and management tools such as hydrological and hydraulic modeling (Kumar et al., 2006). While the traditional ones represented the best engineering feat of those times, in terms of water technology used for water harnessing and distribution (Agarwal and Narain, 1997); and the volume of water handled, the modern water harvesting systems are at best miniatures of the large water resource systems that use advances in civil engineering and hydrology. As regards purpose, they are employed as resource management solution, and not as resource development solutions (Kumar et al., 2006).

The limited Indian research on runoff harvesting (RWH)/artificial recharge so far had focused on engineering performance of individual structures (see Muralidharan and Athawale, 1998; Patel, 2002). While a lot of anecdotal evidences on the social and economic gains exist, there is little understanding based on empirical work to study: 1] the impacts of water harvesting activities on local hydrological regime in terms of net water gain; 2] basin level impacts on the water balance of the overall basin; and 3] economic imperatives from a long term perspective (Kumar et al., 2006). Analysis of performance of runoff harvesting systems also misses the influence of "scale factor", with the exception of the work by Ray and Bijarnia (2006). Of late, researchers have raised questions about the reliability of water supplies from these systems in water-scarce regions, its

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[1] This paper draws partly on the ideas and data presented in Kumar *et al*. (2006) in addition to fresh analyses and insights.

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possible unintended impacts (see Bachelor et al., 2002; Kumar et al., 2006; Ray and Bijarnia, 2006), its economics (see Kumar, 2004; Kumar et al., 2006), and its role in improving the overall basin water economy (Kumar et al., 2006).

2. PURPOSE AND SCOPE OF THE PAPER

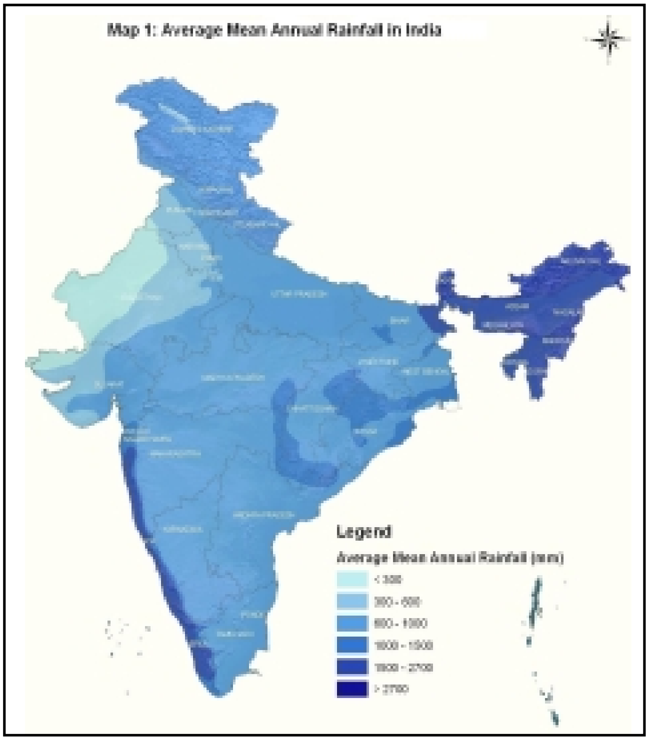
The purpose of this paper is to: 1] assess the effectiveness of runoff harvesting in improving both local hydrological regimes, and basin water balance in water-scarce regions of India; 2] discuss the various considerations needed to analyze economics of runoff harvesting; 3] discuss the imperatives of runoff harvesting for determining the optimum level of water harvesting in water-scarce basins. In order to do this, we analyze and synthesize macro level hydrological and geo-hydrological data for the country, including data on annual rainfalls, rainfall variability, no. of rainy days, soil infiltration, potential evaporation (PE); data on rainfall, runoff and reference evapo-transpiration (ET_0) for selected basins viz., Narmada, Cauvery, Pennar, Krishna and Sabarmati; and data on effects of water harvesting on stream flows and groundwater levels for Ghelo river basin in Saurashtra, Gujarat.

3. RUNOFF HARVESTING IN WATER SCARCE REGIONS: PETER TAKING PAUL'S WATER?

In order to understand the issue of negative downstream impacts of intensive water harvesting, we must first define "natural water-scarce regions", and "closed and open basins".

3.1 Which are the naturally water-scarce regions in India?

From an anthropogenic perspective, water-scarce regions are those where the demand for water for various human uses far exceeds the total water available from the natural system, or the technology to access it is economically unviable. This includes the surface water, water stored in the aquifers, and that held in the soil profile. Water scarcity can also be felt when the resources are available in plenty in the natural system in a particular region, but adequate financial resources to access it are not available with the populations living there. The former is called physical scarcity, and the latter economic scarcity. north Gujarat in India and Israel are ideal examples of physical scarcity, whereas Ethiopia in eastern Africa and Bihar in eastern India are ideal examples of economic scarcity of water. In this article we are concerned with regions facing physical scarcity of water.


Map 1: Average Mean Annual Rainfall in India

Physical scarcity of water occurs in regions which experiences low to medium rainfalls and high evaporation rates. Most parts of western, north-western, central and peninsular India fall under this category. They have low to medium rainfalls (see Map 1[3]), and high potential evaporation rates (see Map 2). The mean annual rainfall ranges from less than 300mm to 1000mm, where as the PE ranges from less than 1500 in some pockets in the north east to more than 3500 in some pockets in Gujarat and Maharashtra.

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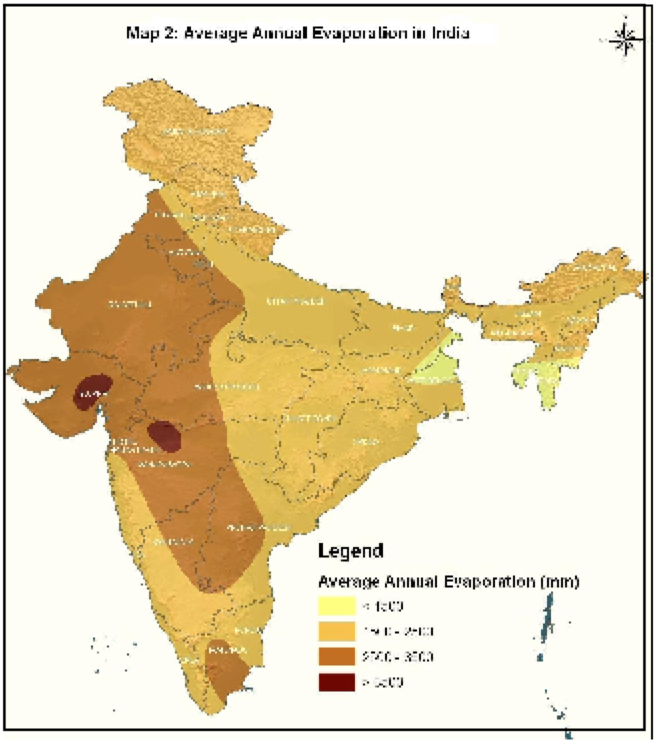
[3] Data used for generation of GIS Maps 1, 3, 4 and 5 were derived from Pisharoty (1990).


Map 2: Average Annual Evaporation in India

In the subsequent section, we will explain the processes that determine supply and demand for water, which in turn induces water scarcity in those regions. The natural water supply and runoff[4] available from precipitation and groundwater recharge per unit area of land is low. This is because of high evaporation rates, which depletes the soil moisture which infiltrates rain water. This leaves little chance for water to runoff (see Kumar et al., 2006 for detailed discussion).

Crop evapo-transpiration mainly determines the demand of water for agriculture. Agriculture is the largest source of water demand for human uses in all major river basins in India.

Table 1 gives the reference evapo-transpiration against the effective renewable water resources from surface runoff and replenishable groundwater[5]. It shows that for all the 5 basins, annual reference evapo-transpiration is many times more than effective renewable water resources. But, what is available for crop production includes the soil moisture storage as well. But since the soil moisture storage is a small fraction of the rainfall even in very high rainfall regimes, the potential evapo-transpiration (PET) for the entire year would be much higher than the sum of soil moisture storage, (which is a fraction of the rainfall) and effective renewable water resources.

The imbalance between effective water availability and water demand for agricultural uses is very high for all the five basins. In addition to agricultural water, there are demands for water from domestic and industrial sectors as well. However, for the time being, we can ignore the other sectors. This gap between demand and renewable supplies can be reduced if we have very little arable land, and very large amount of land serving as natural catchments for supplying runoff water. Unfortunately, the remaining virgin catchment in water-scarce regions of India is very small. It varies from 58.6% in case of the Pennar basin to 28% in case of the Sabarmati basin.

The increasing intensity of crop production in the rich upper catchments of river basins and watersheds has two major negative impacts on available renewable water resources. First: it captures a share of the runoff generated from the area, and therefore reduces the available surface water supplies. Second: increase in cultivated land increases the water requirement for irrigation. This way, large regions in India are facing shortage of water to meet the existing demands. The recent report on groundwater resource assessment and irrigation potential in India shows that the regions facing problems of groundwater over-exploitation are mostly in Gujarat, Rajasthan, Maharashtra, Madhya Pradesh, Andhra Pradesh, Tamil Nadu and parts of Karnataka, which are the naturally water-scarce regions (GoI, 2005).

3.2 "Closed" vs "Open Basins"

"Closed" basins are those where no extra renewable water resources are available for diversions to meet consumptive water demands, or "closed" basins are those where new diversions would reduce the availability of water for uses at some other points within the basin. This means in such basins, it is not possible to increase the beneficial evapo-transpiration, as wastage of water through non-beneficial evaporation or flows into the natural sink such as saline aquifers or seawater do not take place. "Open basins" are those where wastage of

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[4] Runoff is the amount in excess of the soil moisture storage and storage.

[5] For a basin, if only a small fraction of the drainage area is under cultivation, then effective renewable water availability per unit of cultivated land would be more, and vice versa.

Table 1: Average Reference Evapo-transpiration Against Mean Annual Rainfall in Selected River Basins in Water-Scarce Regions

Sr. No	Name of the basin	Mean annual rainfall (mm)		Average annual water resources[1] (mm)	Effective annual water resource[2] (mm)	Reference Evapo-transpiration[3] (mm)	
		Upper	Lower			Upper	Lower
1	Narmada basin	1352.00	792.00	444.70	937.60	1639.00	2127.00
2	Sabarmati basin	643.00	821.00	222.84	309.61	1263.00	1788.80
3	Cauvery basin	3283.00	1337.00	316.15	682.80	1586.90	1852.90
4	Pennar basin	900.00	567.00	193.90	467.80	1783.00	1888.00
5	Krishna basin	2100.00	1029.00	249.16	489.15	1637.00	1785.90

Sources: [1] The average annual water resources was estimated by taking the sum of annual utilizable runoff (GoI, 1999: Table 3.6) and the dynamic groundwater resources from natural recharge in these basins (GoI, 1999: Table 3.9) and dividing by the geographical area of the basin.

[2] The effective renewable water resources were estimated by dividing the average renewable water resources for the basin by the fraction of total cultivated land to the total basin drainage area. The basin-wise total cultivated land considered was for the year 1993-94 (GoI, 1999).

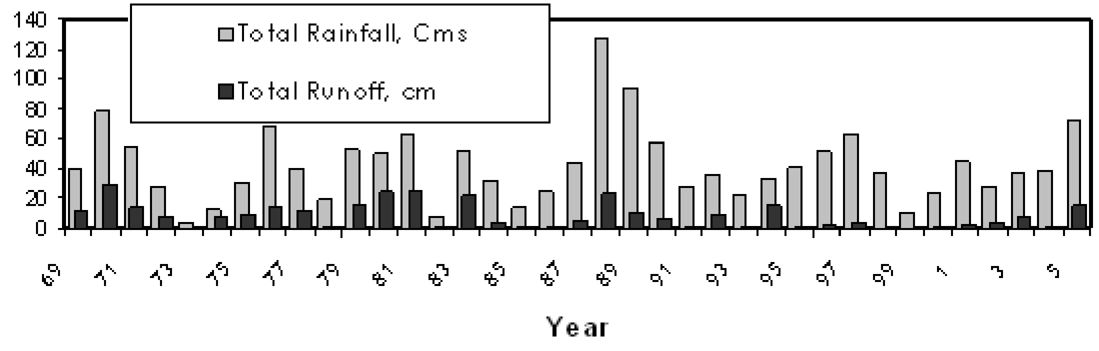
[3] Reference evapo-transpiration values were estimated using meteorological data from FAO CROPWAT model, except for Pennar basin and upper Krishna. For Pennar and upper Krishna, the data were obtained from IWMI climate atlas.

water through non-beneficial evaporation or flow into natural sinks take place, and where it is possible to increase utilizable water resources and increase beneficial evapo-transpiration. In the subsequent section, we will show which basins in India are considered “closed”.

3.3 Downstream Impacts of Upstream Water Harvesting

The states of Gujarat, Rajasthan, Madhya Pradesh and Maharashtra took up intensive water harvesting during the past 20 years. The first decentralized modern water harvesting intervention in India was dug well recharging, and started in Saurashtra region after 3 years of consecutive droughts during 1985-87. This involved diverting field runoff and runoff in the local streams and nallas into open wells, which have the characteristics

Figure 1: Ghelo-Somanath Rainfall and Reservior Inflows



of hard rock region (Kumar, 2000). Grass root level NGOs, spiritual and religious institutions, private agencies and social activists participated in this programme, which later on came to be known as Saurashtra dug-well recharge movement (Kumar, 2000).

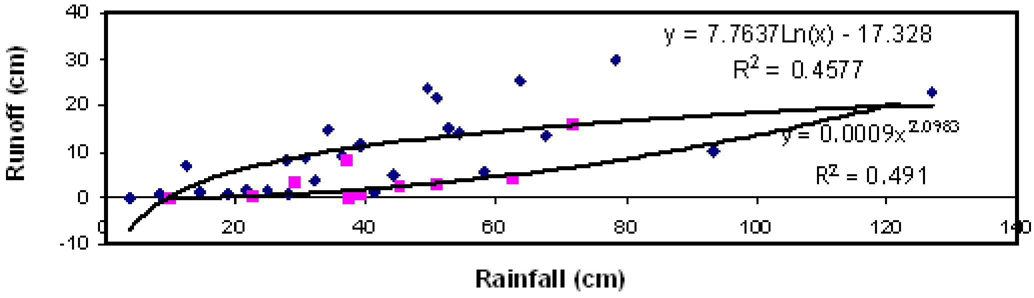
The argument was that the 7 lac open wells in the region could be recharged using monsoon runoff, which was flowing waste into the sea. The people behind this movement, did not consider that approximately 110 medium and a few large reservoirs located downstream were not getting sufficient flows for irrigation and drinking even in normal rainfall years. The dependable runoff of the entire Saurashtra peninsula, generated from 91 small river basins, is 3613 MCM. Whereas all the major and medium reservoirs in the region have sufficient storage capacity to capture up to 5458 MCM water annually. This clearly shows that dug well recharging if carried out in the upper catchments of these basins, would only help reduce inflows into these reservoirs (Kumar, 2000).

The government of Gujarat launched the Sardar Patel Participatory Water Conservation programme in Saurashtra and north Gujarat in 1999 and built nearly 54,000 check dams in local streams, and nallas with the involvement of local communities (GoI, 2007). As Prof. Saul Arlosoroff, an Israeli water expert opined, this indiscriminate water harvesting activity has the potential to spell doom for the ecology of Saurashtra region.

But, the general belief is that because these structures are too small they are benign (Batchelor et al., 2002) though present in large numbers in most cases. The primary reason for such an outlook is that the agencies concerned with small water harvesting (in the upper catchment) and those concerned with major head- works are different and they do not act in coordination at the basin level. Building small water harvesting systems such as tanks and check dams is often the responsibility of the minor irrigation department or district arms of the rural development departments of the states concerned. This ad hoc approach to planning often leads to over-appropriation of the basin water, with negative consequences for large reservoir schemes downstream (Kumar et al., 2000). The quality of implementation of the programme came under severe attack from Public Accounts Committee, which found that the quality of construction was poor and funds were mis-appropriated. While the Panchayats were supposed to carry out the work, all construction work was awarded to a few big contractors.

Data collected from Ghelo river basin shows that the inflows into Ghelo-Somnath reservoir reduced significantly after intensive water harvesting work was undertaken in the upper catchment. The total number of structures in the upper catchment area of 59.57 km^2 is around 100. Figure 1 shows the catchment rainfall and runoff in Ghelo-Somnath. After 1995, the year which saw intensive water harvesting work, the reservoir overflowed only in 2005 when the rainfall recorded was 789 mm. Regressions of rainfall and runoff, carried out for 2 time periods i.e., 1969-95 and 1995-05, clearly show that the relationship between rainfall and runoff had changed after water harvesting interventions (see Figure 2). The amount of rainfall required for filling the reservoir had now increased from 320 mm to 800 mm. Though the curves intersect at higher rainfall magnitudes, this does not occur frequently as such high rainfall does not occur in the basin.

Figure 2: Impact of Water Harvesting on Inflows in Reservior: Ghelo-Somnath



Many large and important river basins in India, which are also facing water scarcity, are now “closed” or do not have uncommitted flows that are utilizable through conventional engineering interventions. Some of them are Pennar, Cauvery and Vaigai in the South (based on GoI, 1999), and Sabarmati, Banas in the west. In addition to these, all the west-flowing rivers in Saurashtra and Kachchh in Gujarat are also “closed” (Kumar, 2002). While Krishna basin is on the verge of closure, one basin which is still “open” is Godhavari in the east (based on GoI, 1999).

In nutshell, water harvesting interventions in the “closed basins” located in the naturally water-scarce regions would have adverse impacts on stream-flow availability for downstream uses. One could always argue that in wet years, the runoff would be sufficient to completely fill up downstream reservoirs, it would mean huge investments for the structures. The aquifers in hard rock areas lack the storage capacity to absorb the runoff diverted into the system. This is dealt with separately in Section 3.2. On the other hand, in low rainfall years, the downstream impact of intensive water harvesting systems in the upper catchments would be severe. This is also evident from Figure 2 where the difference in runoffs between pre and post water harvesting scenarios is quite high for low rainfall regimes.

4. WHERE DOES RECHARGING OF GROUNDWATER REALLY WORK?

The effectiveness of groundwater recharging in any area depends on three factors: i] technical efficiency of recharging; ii] storage potential of aquifers, which are being recharged; and, iii] dynamics of interaction between groundwater and surface water. We also discuss hydrological variability and its implications for reliability of supplies and cost of water harvesting.

4.1 Poor Technical Efficiency in Artificial Recharge Activities

From a technical perspective, there are 3 major problems facing artificial recharge efforts in water-scarce regions of India. First: most water-scarce regions are underlain by hard rock formations (see Map 3). These hard rock formations consist of Deccan basalt, crystalline rocks and sedimentary sandstone and limestone aquifers.

Most of South Indian peninsula has crystalline rocks and basalts, whereas Central India has basalt formations, crystalline rocks and sedimentary aquifers. The soils in the hard rock regions, mostly loamy clay, have very poor infiltration capacity (Muralidharan and Athavale, 1998**)**. After the first few minutes, the rate of infiltration comes down to zero. The performance of water harvesting structures such as tanks, ponds and check dams, which depend on infiltration, is poor. Second: in water-scarce regions, the evaporation rates are very high. Tanks and ponds are the common water harvesting systems found in south Indian peninsula. These structures have very high surface area in relation to the total amount of water they impound. Therefore, evaporation losses from these structures are bound to be high. Third: hard rock geology induces significant constraints in recharge efforts through percolation tanks. The high depth to water table below and around the recharge structure due to occurrence of recharge mount and shallow bed rocks and low infiltration capacity of the thin soils overlaying the hard rock formations prevent percolation of water (Muralidharan, 1990 as cited in Muralidharan and Athawale, 1998).

Over the past couple of decades, “dug well recharging” had attracted a lot of attention from government agencies in other states facing water shortages. This is also known as Aquifer Storage and Recovery (ASR) method of recharging. This was considered as a simple method for conservation of rain water, involving a meager expense of Rs.150 (US $ 4 approximately). According to the proponents, 300,000 wells were recharged in Saurashtra alone using this method. The proponents argued that a single well could recharge as much as 4,000m^3 of water, based on the assumption that each well will have a storage capacity of 800m^3 on an average, and could receive 5 fillings.

These success stories from Saurashtra motivated the government planning new artificial recharge schemes in hard rock district of south India. But, planning such a project did not consider the availability of uncommitted flows in the particular river basins/regions, for which such schemes are proposed. The government of India report on groundwater management and ownership (GoI, 2007) cited a figure of 214 BCM as the uncommitted runoff in India for recharging, and 35 BCM as the total annual recharge technically feasible. However, the calculation does not consider that in regions where ground water is over-exploited, there are no uncommitted flows. Instead, it only looks at the aggregate figures at the country level and the storage space in the aquifers. Further, from the point of view of technical efficiency, no thought has gone into working out the amount of catchment needed to harvest runoff as high as 4000m^3 per well, nor the storage efficiency of the dug wells in hard rock areas.

The catchment area required in four different basins in South India, estimated on the basis of the average runoff in these basins, are given in Table 2 below. In all these basins, the hilly and forested upper catchments are rich in terms of runoff generation potential. The runoff generation potential of the moderately plain agricultural lands in the basin would be much lower due to the lower rainfall, higher aridity (as Table 1 indicates), milder slopes, and presence of field bunds and standing crops. Hence, the actual catchment required would be much higher. Again, we have ignored flows that are committed for downstream tanks, ponds and reservoirs.

Even if we assume that such a large volume of water can be recharged effectively into the aquifers through dug wells at the farmer level, the availability of sufficient amount of private land to be used as catchments is open to question. In the most optimistic situation, only some of the large farmers would be able to manage such a large amount of field runoff.

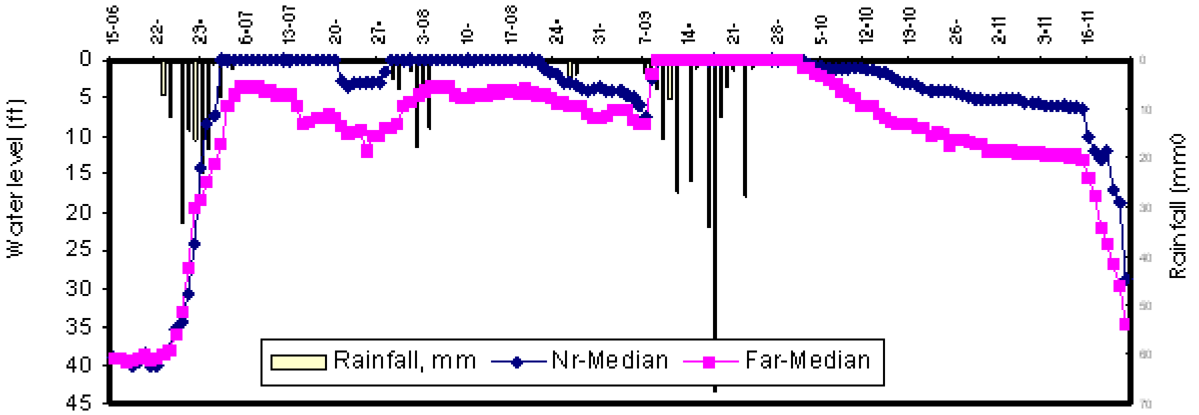
Table 2: Catchment Area Required to Harness Field Runoff for Well Recharging

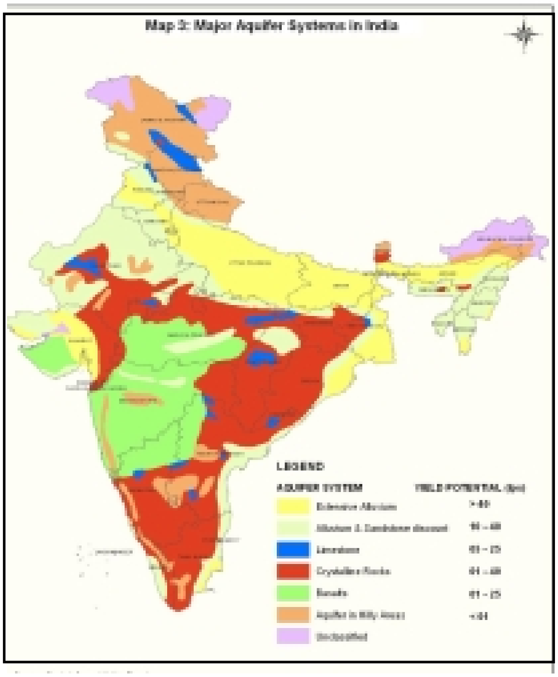
Sr. No	Name of the Basin	Average Utilizable Annual Runoff (m)*	Catchment area (acre) required for a runoff of 5000 m^3
1	Cauvery River Basin	0.216	5.76
2	Pennar River Basin	0.120	10.24
3	Krishna River Basin	0.220	5.58
4	East Flowing Rivers in the South**	0.168	7.45

* Estimated on the basis of the utilizable runoff in the basin and the total drainage area provided in GoI (1999).

** Between Pennar & Cauvery, and East Flowing Rivers South of Cauvery

Figure 3: Water Level Fluctuation in Wells in Fulzar, Ghelo River Basin



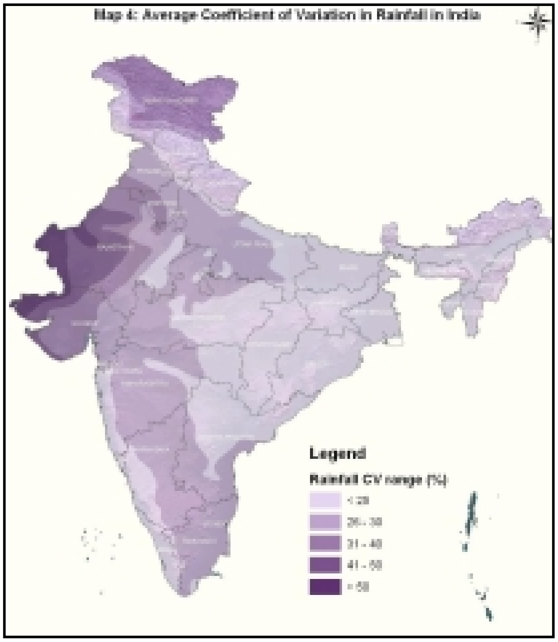


As regards the storage efficiency, for each well to harness 4000-5000 m^3 of water, the well would have to receive 15-20 fillings during the monsoon. The hydraulic diffusivity is very poor in hard rock areas. Hence, the recharge mount created from a filling is unlikely to disappear before the wells starts getting the next inflow. An empirical study carried out back in 1997 in Saurashtra region of Gujarat showed very limited impact of this method of recharging groundwater with a total recharge to the tune of 320 m^3.

4.2 Poor Aquifer Storage in Hard Rock Areas

With two third of the country's geographical area underlain by hard rock formations, storage capacity of aquifers poses a major challenge for artificial recharge from local runoff. Most parts of water-scarce states like Gujarat, Madhya Pradesh, Maharashtra, Karnataka, Andhra Pradesh, Orissa, Chhattisgarh and Tamil Nadu are underlain by hard rocks ranging from basalt, crystalline granite, hill aquifers and sandstone. A small areas in of the Narmada valley ad Cambay Basin in Gujarat has extensive alluvium (see Map 3). Hard rock aquifers have no primary porosity and have only secondary porosity. Due to low specific yield (0.01-0.03), sharp rise in water levels is observed in aquifers during monsoon, leaving little space for infiltration from structures. Harnessing water for recharge is extremely important during normal and wet years when the natural recharge in hard rock formation is high (based on regression equations shown in Figure 7 in Athawale, 2003), further reducing the scope for artificial recharge.

Significant recharge efforts were made in Saurashtra. But, the biggest constraint in storing water underground during high rainfall years is the poor storage capacity or specific yield of the basalt formations. During good rainfall years, the aquifers get saturated with natural recharge immediately after the rains, leaving no space for entry of water from the recharge systems (Kumar, 2000).



The groundwater level fluctuation data obtained from Ghelo river basin in Saurashtra illustrate this. The basin had experienced intensive water-harvesting since 1995. The data were collected periodically from open wells located inside the basin during and after the monsoon rains. The wells located close to the water harvesting structures and those away from the structures were demarcated. The water level fluctuation in the wells in relation to the rainfall events were analyzed and are presented in Figure 3. The time series data shows that the wells close to water harvesting structures get replenished faster than those located away from the structures. But, these wells start overflowing after the first major wet spell, while the second category of wells showed similar trends after the second wet spell. There is a steep rise in water levels in the order of 35 – 40 ft in wells located both close to and away from the water harvesting structures soon after the first wet spell. The steep rise in water levels shows the poor specific yield of the aquifer in the area, as the magnitude of cumulative rainfall that had caused this fluctuation is only 200 mm.

This leads to the conclusion that in hard rock areas, the aquifers get fully replenished during good rainfall years even without water harvesting systems. Therefore, the only way to store the runoff would be through surface storage. This would have serious negative implications for the cost of the system. This issue is dealt with in detail in section 3.4.

4.3 Hydro-schizophrenia: Ignoring Groundwater-surface Water Interactions

In many river basins, the surface water systems and groundwater systems are often inter-connected. Any alterations made in one of them could change the availability of water in the other (Sohiquilo, 1985; Llamas, 2000). In many river basins, which do not get snow melt but have perennial flows, part of the monsoon recharge in the upper catchment areas outflows into the surface streams as base flow. This is the water which is available as non-monsoon flows in these river basins. Examples are basins in central India such as Narmada, Mahi and Tapi, and those in Peninsular India such as Krishna, Pennar and Cauvery. Such outflows occur due to negative hydraulic gradients between groundwater levels and stream water levels. A recent analysis showed that increased groundwater withdrawals in the upper catchments led to a reduction in stream-flows in the Narmada basin (Kumar et al., 2006).

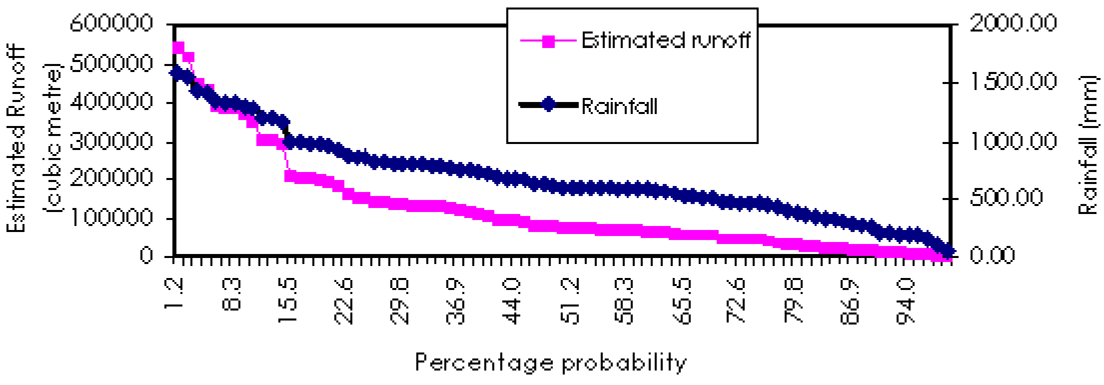
In such cases, water harvesting interventions to store water underground may not make much sense as it would get rejected and appear as surface flows (Mayya, 2005). On the other hand, in regions with deep water table conditions like in north Gujarat, the runoff directly moves into the groundwater systems of the plains through the sandy river bed as dewatering of the upper aquifers increases the rate and cumulative percolation (Kumar, 2002b).

4.4 High Inter-annual Variability in Rainfall and its Implications for Reliability of Water Supplies and Economic Viability

Regions with semi arid and arid climate experience extreme hydrological events (Hurd et al., 1999). As seen from Map 1, 2 and 4, regions with high variability in rainfall in India coincide with low magnitudes of rainfall and high PE, which also has high dryness ratio. In such areas, a slight variation in precipitation or PE can substantially magnify the water stress on biological systems as compared to humid regions (Hurd *et al*., 1999). Rainfall variability induces higher degree of variability in runoff. We take the example of the catchments of Banas basin in North Gujarat to illustrate this.

In Palanpur area of Banaskantha district in north Gujarat, which has semi arid to arid climatic conditions, the rainfall records show a variation from a lowest of 56mm in 1987 to 1584mm in 1907. The runoff estimated on the basis of regression equation developed for a sub-basin, named, Hathmati of Sabarmati basin in north

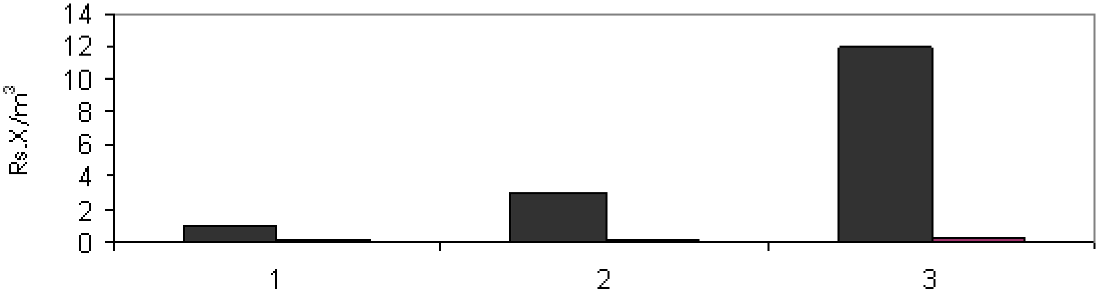
Figure 4: Probability of Occurance of Ranilfall and Runoff in Banas Basin



Gujarat, which is physiographically quite similar to Palanpur area of Banaskantha, shows that the runoff can vary from a lowest of 0.6mm to 541mm (Figure 4). The lowest runoff is close to 1/1000th of the highest runoff. This means, in drought years, when the actual water demand for irrigation increases, the amount of runoff that can be captured is almost negligible. Hence, the water harvesting systems become unreliable. What can occurs at the sub-basin level may not be representative of that in small upper catchments, the difference will not be drastic.

When there is a high inter-annual variability in the runoff a catchment generates, a major planning question which arises is "for what capacity the water harvesting system should be designed". When scarcity is acute, highest consideration is given to capturing all the water that is available. If all the runoff which occurs in a high rainfall year is to be captured, then the cost of building the storage system would be many hundred times more than what is required to capture the one which occurs during the lowest rainfall. But, the system would receive water to fill only a small fraction of its storage capacity in the rest of the years. This will make it cost-ineffective. The issue of variability is applicable to the design of large head works as well. But, in large systems, the water in excess of the storage capacity could be diverted for irrigation and other uses to areas which face water shortages during the same season, thereby increasing effective storage.

Figure 5: Cost of Rainwater Harvesting with Increasing Collection Efficiently



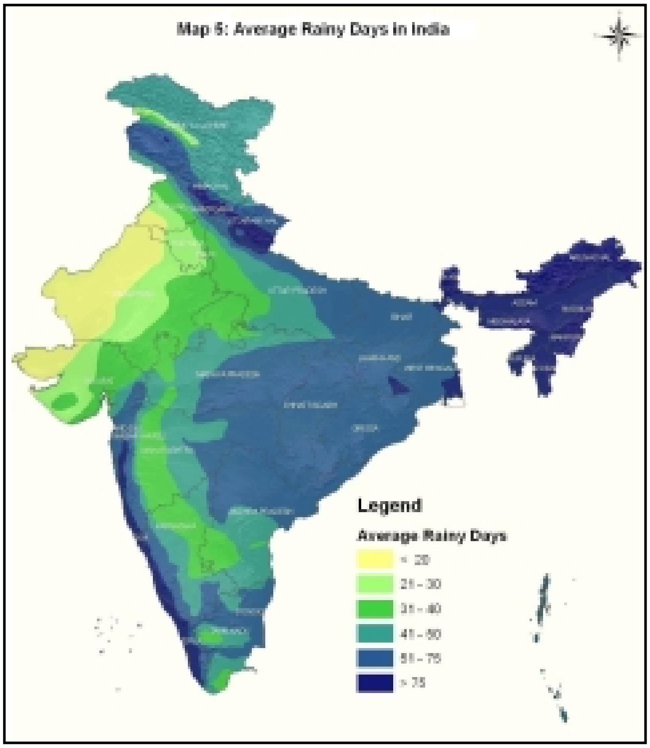
In order to illustrate this point, we use data generated from Ghelo river basin in Saurashtra. The basin has a total catchment area of 59. 20 km^2. It had a medium irrigation reservoir with a storage capacity of 5.68 MCM, which has been functional since 1966. Inflow data of the reservoir for the period 1969-95 showed that the total runoff generated in the basin varied from zero in the year corresponding to a rainfall of 39 mm to a maximum of 17.78 MCM in the year corresponding to a rainfall of 1270 mm. Today, the total capacity of water harvesting systems built in the upstream of Ghelo reservoir is 0.15 MCM. During the period from 1969 to 2005, the reservoir showed overflow for 13 years with a total quantum of 60.936 MCM. If one million cubic metres of runoff had to be captured in addition to the 5.89 MCM that would be captured by the medium irrigation reservoir, it would cost around 0.09 X/m^3 of water, while capturing 3 MCM would cost 0.11 X/m^3 of water. If the maximum runoff observed in the basin, i.e., 17.785 MCM has to be captured, the total volume of water captured would be only 60.91 MCM, in which case the unit cost of water harvesting would be around 0.21 X/m^3 of water (Figure 5). Here, "X" is the cost of storage structures for creating an effective storage space of one MCM. Here, again, we are not considering the incremental financial cost of the special structures for capturing high magnitudes of runoff, which cause flash flood.

6. IN WATER HARVESTING, SHOULDN'T WE WORRY ABOUT THE ECONOMICS?

6.1 Economics of Water Harvesting for Groundwater Recharge

In the planning of large water resource systems, cost and economics are important considerations in evaluating different options. But unfortunately, the same does not seem to be applicable in the case of small systems, though concerns about economics of recharge systems in certain situations were raised by authors such as Phadtare (1988) and Kumar (2004).

Part of the reason for lack of emphasis on "cost" is the lack of scientific understanding of the hydrological aspects of small scale interventions, such as the amount of stream flows that are available at the point of impoundment, its pattern, the amount that could be impounded or recharged and the influence area of the recharge system. Even though simulation models are available for analyzing catchment hydrology, there are great difficulties in generating micro lavel data on daily rainfall, soil infiltration rates, catchment slopes, land cover and PET which determine the potential inflows; and evaporation rates that determine potential outflows. Further for small water harvesting projects, implemented by local agencies and NGOs with small budgets, cost of hydrological investigations and planning is hard to justify. Often, provision for such items is not made in small water harvesting projects.



The amount of runoff a water harvesting structure can capture depends on not only the total quantum of runoff, but also how it occurs. A total annual runoff of 20 cm occurring over a catchment of one sq. km. can generate a surface flow of 0.20 MCM. The amount that can be captured depends on the pattern. The low rainfall, semi arid and arid regions of India, which experience extreme hydrological events, have annual rains occurring in a fewer number of days as compared to sub-humid and humid regions with high rainfalls regions (Map 5). As a result, as Garg (1987) points out, in these regions, high intensity rainfalls of short duration are quite common (source: Garg, 1987 as cited in Athawale, 2003: Figure 24). This runoff generates flash floods[1]. If the entire runoff occurs in a major rainfall event, the effective runoff collection would reduce with reducing capacity of the structures built. If large structures are built to capture high intensity runoff thereby increasing the runoff collection efficiency, that would mean inflating cost per unit volume of water captured. In fact, authors such as Oweis, Hachum and Kijne (1999) have argued that runoff harvesting should be encouraged in arid area only if the harvested water is directly diverted for crop use.

Given the data on inflows and runoff collection efficiencies, predicting the impacts on local hydrological regime is also extremely complex, requiring accurate data on geological and geo-hydrological profiles, and variables. In lieu of the above described difficulties in assessing the effective storage, unit costs are worked out on the basis of the design storage capacity of the structures and thumb rules on number of fillings (see for instance Raju, 1995). The recent book by Dr. R. N. Athawale on rainwater harvesting in India had covered a gamut of technical aspects of water harvesting in different regions of India, does not deal with economics issues (see for instance Athawale, 2003). However, proponents project them as low cost technology and under-estimate the costs and inflate the recharge benefits. The best example is the government of India report on groundwater management and ownership (GoI, 2007), and recently-sanctioned government of India scheme for recharging aquifers in hard rock districts of south India, with an investment of 1,800 crore rupees.

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[6] Many parts of Kachchh, which records one of the lowest mean annual rainfalls (350 mm) experienced floods during 1992 and 2003 with many WH structures overflowing. Flash flood occurs even in some of the semi arid and water scarce basins such as Sabarmati and Banas (Kumar, 2002b).

Table 3: Estimated Unit Cost of Artificial Recharge Structures Built under Pilot Scheme of CGWB

Sr. No	Type of Recharge Structure (Life in years)	Expected Active Life of the System	Estimated Recharge Benefit (TCM)	Capital Cost of the Structure (in Lac Rs.)	Cost of the Structure per m^3 of water (Rs/m^3)	Annualized Cost* (Rs/m^3)
1.	Percolation Tank	10	2.0-225.0	1.55-71.00	20.0-193.0	2.00-19.30
2.	Check Dam	5	1.0-2100.0	1.50-1050.0	73.0-290.0	14.60-58.0
3.	Recharge Trench/Shaft	3	1.0-1550.0	1.00-15.00	2.50-80.0	0.83-26.33
4.	Sub-surface Dyke	5	2.0-11.5	7.30-17.70	158-455.0	31.60-91.00

Source: GoI, 2007, Table 7: pp14

*Estimated by dividing the capital cost by the life of the system

The government of India report (GoI, 2007) bases its arguments for rainwater harvesting on the pilot experiments conducted by CGWB in different parts of India using five different types of structures (see GoI, 2007:). While the estimated costs per cubic metre of water were one-time costs (see Column 6 of Table 3), the report assumes that the structures would have a uniform life of 25 years. Two things in these figures are very striking. First: the costs widely vary from location to location and from system to system, and the range is wide, which the report duly acknowledges. Second: even for a life of 25 years, the upper values would be extremely high, touching Rs.7.7/m^3 of water for percolation tank and Rs. 18.2/m^3 for sub-surface dyke. But, such a long life for recharge system is highly unrealistic[7]. Considering an active life of 10 years for a percolation tank, 5 years for check dam and sub-surface dyke, and 3 years for recharge shaft, we have worked out the unit cost of recharging using these systems.

The results are provided in Column 7 of Table 3. It shows that the costs are prohibitively high for sub-surface dyke and check dam, and very high for percolation tanks. Added to the cost of recharging, would be the cost of pumping out the water from wells. The size of returns from crop production should justify such high investments. A recent study in nine agro-climatic locations in Narmada river basin showed that the gross return ranged from Rs. 2.94/m^3 to Rs.13.49/m^3 for various crops in Hoshangabad; Rs. 1.9/m^3 to Rs. 10.93/m^3 for various crops in Jabalpur; Rs. 2.59/m^3 to Rs. 12.58/m^3 for crops in Narsingpur; Rs. 1.33/m^3 to Rs. 17/m^3 for crops in Dhar; and Rs. 3.01/m^3 to Rs. 17.91/m^3 for crops in Raisen (Kumar and Singh, 2006). The lower values of gross return per cubic metre of water were found for cereals, and high values were for low water consuming pulses, and cotton. This means that the net returns would be negative if recharged water is used for irrigating such crops. Contrary to this, the report argues that the costs are comparable with that of surface irrigation schemes (GoI, 2007: pp 13). Such an inference has essentially come from over-estimation of productive life of the structures.

A close look at the dug well recharging method reveals that this method of in situ water conservation suffers from many problems. First: the open wells used for irrigation are always located at the highest elevation in the farms, which makes it easy for farmers to take the pumped water to the fields by gravity. This means that farmers have to cut deep channels to convey the runoff water from the farthest points in the field to the wells for recharging, which may run into hundreds of metres. This can cost significant amount of money. The filter box alone could cost around Rs. 5000 per farmer. As seen in Section 3.1, the benefits, which are likely to accrue against these investments, are quite low.

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[7] The life of the system depends on the type, and also a variety of complex hydrological and hydraulic parameters. In regions receiving flash floods, and where the silt load in flood water is high, the technical efficiency of recharge structures drastically reduces after every major rainfall event. Percolation tanks would require de-silting continuously year after year, cost of which is quite significant when compared to the capital cost of the system. Filters attached to recharge shaft become dysfunctional very fast, after one or two years of rains. So is the case with the recharge tube wells fitted with sub-surface dykes.

Scale considerations are extremely important in evaluating the cost and economics of water harvesting/ groundwater recharge structures because of the hydrological integration of catchments at the watershed and river basin level. The economics of water harvesting systems for individual systems in isolation do not make sense when the amount of surplus water available in a basin is limited (Kumar, 2000a) and interventions in the upper catchments reduce the potential hydrological benefits from systems in the lower catchment (Kumar *et al.*, 2006; Ray and Bijarnia, 2006). In case of the Arwari basin, while the irrigated area in the upper catchment villages increased (where structures were built), it reduces significantly in the lower catchment villages (Ray and Bijarnia, 2006). It is therefore important to look at the incremental hydrological benefit due to the introduction of a new structure.

In any basin, the marginal benefit from a new water harvesting structure would be smaller for basins with higher degrees of development, while the marginal cost would be higher (see Figure 6). The reason being: 1] higher the degree of basin development, lower would be the chances for getting socially and economically viable sites for building water impounding structures, increasing the economic and financial cost of harvesting every unit of water; and 2] with higher degree of development, the social and environmental costs of harvesting every unit of water increases (Frederick, 1993), reducing the net economic value of benefits. Therefore, the cost and economic evaluation should move from watershed to basin level. As Figure 6 indicates, the level at which basin development can be carried out depends on whether we consider the flows in a wet year or dry year or a normal year. There is a stage of development (marked by O in the chart) beyond which, the social, economic and environmental benefits start becoming negative. Here, O is the optimum level of water resource development.

But, it is important to keep in mind that the negative social and environmental effects of over-appropriation of basin's water resources may be borne by a community living in one part of the basin, while the benefits are accrued to a community living in another part. Ideally, water development projects in a basin should meet the needs and interests of all stakeholders. Therefore, optimum level of water development should not aim at maximizing the net basin level benefits, but rather optimizing the net hydrological and socio-economic benefits for different stakeholders and communities across the basin.

The potential impacts of the artificial recharge projects of the government have to be seen from this perspective. Even if recharging of millions of wells and tanks and ponds in the region is achieved successfully, it is unlikely to create equivalent additional economic benefits from agriculture production. As per official

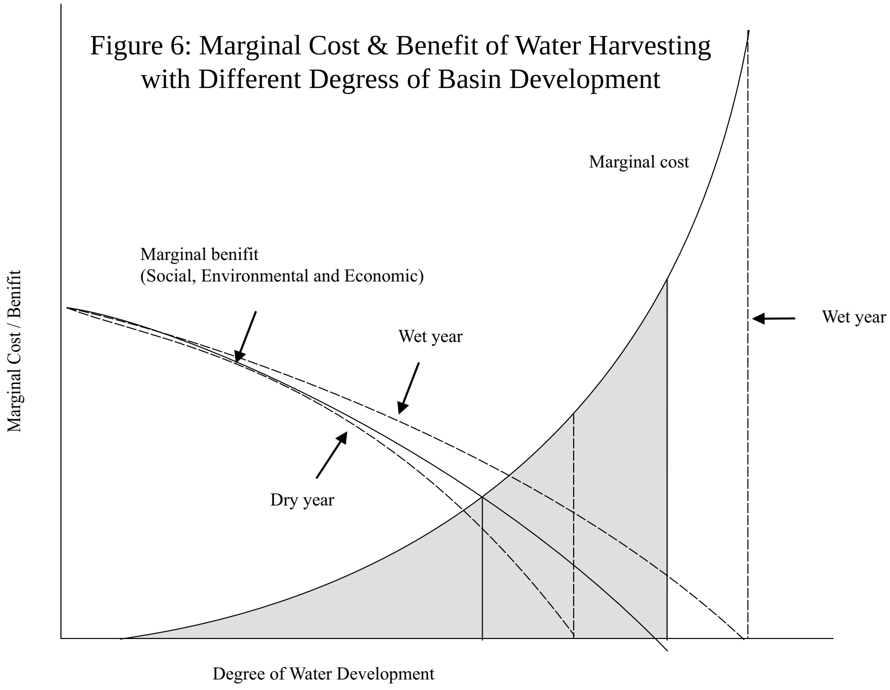

Figure 6: Marginal Cost & Benefit of Water Harvesting with Different Degress of Basin Development

estimates, the total storage capacity created in the river basins of South and Central India, viz., Cauvery, Pennar, Krishna, Narmada, east flowing rivers between Pennar and Cauvery, and east flowing rivers south of Cauvery is 57.11 BCM, against utilizable water resources of 100.32 BCM (GoI, 1999, Table 3.5 and 3.6). Now, the actual volume of water being effectively diverted by the reservoirs/diversion systems in these basins would be much higher due to diversion during the monsoon, and additional water stored in the dead storage. This apart, the traditional minor irrigation schemes such as tanks are also likely to receive inflows during monsoon. It is estimated that the south Indian Peninsula had nearly 135000 tanks, which cater to various human needs including irrigation. Thus, the existing storage and diversion capacities in the region would be close to the utilizable flows. Hence, the livelihoods of farmers, who do not have access to groundwater, will be at stake at least in normal rainfall years and drought year.

To improve the economics of RWH, it is critical to divert the new water to high-valued uses. Phadtare (1988) pointed out that recharge projects would be economically viable in alluvial north Gujarat if the water is diverted for irrigation, as structures are expensive. Yield losses due to moisture stress are extremely high in arid and semi-arid regions and providing a few protective irrigations could enhance yield and water productivity of rain-fed crops remarkably, especially during drought years (Rockström et al., 2003). The available extra water harvested from monsoon rains should therefore be diverted to supplement irrigation in drought years. There are regions where drinking water for human and cattle become high priority demands. North western Rajasthan, which is arid and dominated by pastoral communities, named Gujjars, is one such example. The social and economic value realized from the use of water for human drinking and livestock use, respectively, would be much more than the economic value realized from its use in irrigating crops.

6. SUMMARY AND CONCLUSIONS

In most instances, the regions facing problems of water shortage in India do so due to natural water scarcity. In these regions, demands for water exceeds the utilizable water resources. This is one reason why these regions are facing over-draft of groundwater. These regions are characterized by low and erratic annual rainfalls, high inter-annual variability in rainfall, high aridity due to excessively high evaporation rates including that during monsoon and low and highly variable runoffs. These regions are mostly underlain by hard rock formations, which have poor water holding capacity. These regions have also experienced high degree of water resources development in the past many decades. The basins here are either “closed” or on the verge of “closure”. Modern water harvesting initiatives are concentrated in these regions.

Analysis of data available from pilot projects of CGWB shows that artificial recharging using methods such as percolation tank, check dam, sub-surface dyke and recharge shaft is prohibitively expensive. Also, the cost of using a cubic metre of recharge water for irrigation is much higher than the expected gross returns per cubic metre of the water, making irrigated crop production with it unviable.

As evidences suggest, in these regions, it is impossible to carry out local water harvesting and groundwater recharge activities in an economically efficient way and without causing negative downstream impacts. The reasons are many: highly variability in runoff means high unit cost of capturing water; low infiltration rates for soils overlaying hard rock areas reduce technical efficiency of recharging through percolation tanks and check dams; hard rock aquifers offer very little storage space to absorb the high runoff in good rainfall years; due to high aridity, evaporation from surface storage is very high during monsoon; and the degree of water development is already very high in most water-scarce basins with small traditional water harvesting systems and large reservoirs/diversion systems. This is leading to colossal waste of scarce resources, apart from causing several negative social and environmental consequences. In spite of all this, the recent government of India plans to undertake artificial recharge of groundwater in over-exploited areas of India. This raises fundamental questions about the method used for analyzing the hydrological and economic impacts of these interventions.

Further intensive runoff harvesting in basins with high degree of water development can lead to several negative externalities on the ecosystem health, and the socio-economic production functions, and an overall negative welfare impacts, and therefore has to be discouraged even at private costs.

In sum, there are no “quick fix solutions” to the complex water problems facing India. There has to be a better application of natural and social sciences, the socio-economic and institutional and policy context while designing water management programmes and policies. In this particular case, it is important to generate better understanding of the catchment and basin hydrology, the groundwater storage potential, the stage of water development in the basin, and climatic and socio-economic factors that determine water demands. The experiences from different parts of India show that piecemeal solutions, which do not take cognizance of these, would do more harm than mitigating the problems.

REFERENCE

Agarwal, A. and Sunita Narain (Eds.) (1997), Dying Wisdom: Rise, Fall and Potential of Traditional Water Harvesting Systems in India, 4th Citizen’s Report. New Delhi: Centre for Science and Environment.

ADB (1993), Water Utilities Data Book Asian and Pacific Region. Philippines: Asian Development Bank, November.

Athawale, R. N. (2003), Water Harvesting and Sustainable Supply in India, published for Environment and Development Series, Centre for Environment Education, Rawat Publications, Jaipur and New Delhi.

Batchelor, Charles, Ashok Singh, MS Rama Mohan Rao and Johan Butterworth (2002), Mitigating the Potential Unintended Impacts of Water Harvesting, paper presented at the IWRA International Regional Symposium ‘Water for Human Survival’, 26-29 November, 2002, Hotel Taj Palace, New Delhi.

Boughton, J. C. and J. J. Stone (1985), Variation of Runoff with Watershed Area in a semi arid Location, Journal of Arid Environment, Vol. 9, pp13-25.

Frederick, K. D. (1993), Balancing Water Demand with Supplies: The Role of Management in a World of Increasing Scarcity, Technical Paper 189, Washington D. C: World Bank.

Garg, S. K. (1987), Hydrology and Water Resources Engineering, Khanna publishers, Delhi, pp.110-181.

GOI (1999), Integrated Water Resource Development: A Plan for Development, Report of the National Commission for Integrated Water Resources Development Vol. I, Ministry of Water Resources, Government of India, New Delhi.

GOI (2005), Dynamic Ground Water Resources of India, Central Ground Water Board, Ministry of Water Resources, Government of India, August.

GOI (2007), Report of the Expert Group on Groundwater Management and Ownership, Planning Commission, Yojana Bhawan, New Delhi.

Gujarat Agriculture University (1997), Agro-climatic Atlas of Gujarat, Department of Agricultural Meteorology, B. A. College of Agriculture, Gujarat Agricultural University, Anand Campus.

Hurd, Brian, N. Leary, R. Jones and J. Smith (1999), Relative Regional Vulnerability of Water Resources to Climate Change, Journal of the American Water Resources Association, 35 (6): 1399-1419.

Institute of Rural Management Anand/UNICEF (2001), White Paper on Water in Gujarat, government of Gujarat, Gandhinagar.

__________ (2000), Dug-well Recharging in Saurashtra: Are the Impacts and Benefits Over-stretched? Journal of Indian Water Resources Society, July.

Kumar, M. Dinesh (2001), Drinking Water: A Scarce Resource, Hindu Survey of the Environment-2001, Kasturi and Sons.

___________(2002), Reconciling Water Use and Environment: Water Resource Management in Gujarat, Resource, Problems, Issues, Strategies and Framework for Action, report submitted to Gujarat Ecology Commission for the Hydrological Regime Subcomponent of the State Environmental Action Programme supported by the World Bank.

Kumar, M. Dinesh; V. Ballabh and T. Jayesh (2000), Augmenting or Dividing: Surface water Management in the Water Scarce River Basin of Sabarmati, IRMA Working Paper 147, Institute of Rural Management, Anand.

Kumar, M. Dinesh (2004), Roof Water Harvesting for Domestic Water Security: Who Gains and Who Loses, Water International, 39 (1): 43-53.

Kumar, M. Dinesh and O. P. Singh (2006), Green and Blue Water Use and Productivity in Agriculture: A Study of Narmada River Basin in Madhya Pradesh, India, paper presented at the 3rd Asia Pacific Conference of Hydrology and Water Resources-APHW-2006, Bangkok, Thailand, October.

Kumar, M. Dinesh, Shantanu Ghosh, Ankit Patel, O. P. Singh and R. Ravindranath (2006) Rainwater Harvesting in India: Some Critical Issues for Basin Planning and Research, Land Use and Water Resources Research, 6 (1): 1-17.

Llamas, M. Ramon (2000), La Inserción De Las Aguas Subterráneas En Los Sistemas De Gestión Integrada, Paper presented at II Congresso Ibérico Sobre Planeamento E Gestão De Água, 9-12 November 2000, Oporto.

Mayya, G. S. (2005), Water harvesting and groundwater recharge in the west cost of India-The Myth and the Truth, 4th IWMI-Tata Annual partners’ meet, Institute of Rural Management Anand, 24-26 February, 2005.

Mehta, Lyla (1998), Social Differences in Water Resources Management, ILEIA Newsletter for Low External Input and Sustainable Agriculture.

Muralidharan, D. and R. N. Athawale (1998), Artificial Recharge in India, base paper prepared for Rajiv Gandhi National Drinking Water Mission, Ministry of Rural Areas and Development, National Geophysical Research Institute.

Oweis, T. A. Hachum and J. Kijne (1999), Water Harvesting and Supplementary Irrigation for Improved Water Use Efficiency in Dry Areas. SWIM Paper, Colombo, Sri Lanka.

Patel, A. S. (2002), Impact of Groundwater Recharge Activities in Saurashtra, paper presented at the annual partners’ meet of the IWMI-Tata Water Policy Research Programme, Anand, February 19-20.

Phadtare, P.N. (1988), Artificial recharge of groundwater, paper submitted in the meeting of the working group on Water Harvesting, NCL, Pune, August 5, 1988.

Pisharoty, P. R. (1990), Characteristics of Indian Rainfall, Monograph, Physical Research Laboratories, Ahmedabad.

Prinz, D. (2002), The Role of Water Harvesting in Alleviating Water Scarcity in Arid Areas, Keynote Lecture, Proceedings, International Conference on Water Resources Management in Arid Regions. 23-27 March, 2002, Kuwait Institute for Scientific Research, Kuwait (Vol. III. 107-122).

Raju, K. C. B. (1995), Rainwater Harvesting for Groundwater Recharging: The Experience of SVRTI in Moti Rayan Village, Kachchh in Moench, M. (Ed.) Groundwater Management: Supply Dominated Focus of Government and NGO Efforts, Monograph, VIKSAT, Nehru Foundation for Development, Ahmedabad.

Ray, Sunil and Mahesh Bijarnia (2006), Upstream vs Downstream: Groundwater Management and Rainwater Harvesting, Economic and Political Weekly, July 10, 2006.

Rockström, J., Jennie Barron and Patrick Fox (2002), Water productivity in rain-fed agriculture: Challenges and opportunities for smallholder farmers in drought-prone tropical ecosystems. In Jacob Kijne and others (Eds.) Water Productivity in Agriculture: Limits and Opportunities for Improvement, Comprehensive Assessment of Water Management in Agriculture. UK: CABI Publishing in Association with International Water Management Institute.

Sahuquillo, Andres (1985), Groundwater in Water Resource Planning: Conjunctive Use, Water International, 10 (1985) 57-63.

Scott, C. A and Silva-Ochoa (2001), Collective action for water harvesting irrigation in Lerma-Chapala basin, Mexico, Water Policy, 3: 55-572.