IJART- Vol-1, Issue-2, December, 2016 Available online at http://www.ijart.info/
IMPACT FACTOR- 1.625

INTERNATIONAL JOURNAL OF APPLIED RESEARCH AND TECHNOLOGY
ISSN 2519-5115
RESEARCH ARTICLE

SMALL WATER HARVESTING AND ARTIFICIAL RECHARGE INTERVENTIONS IN SINGODA RIVER BASIN COASTAL SAURASHTRA: HYDROLOGICAL AND SOCIO ECONOMIC IMPACTS

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Received: November 14, 2016
Revised: December 02, 2016
Published: December 31, 2016

ABSTRACT

Coastal Saurashtra in Gujarat, India is characterized by highly erratic rainfall, aridity, and seawater intrusion resulting from excessive withdrawal of groundwater from coastal aquifers for irrigation. Under such conditions, water resources needs to be judiciously managed to ensure crop production and domestic water-security. Ambuja Cement Foundation (ACF), a philanthropic organization, is engaged in basin-level water harvesting interventions in this region. This research study highlights the hydrological and socio-economic impacts of these interventions in the three river basins of coastal Saurashtra. The interventions considered for the study include check dams; and reservoirs in mined out areas. In order to estimate the impacts of these interventions, simple hydrological models and statistical tools were used.

Analysis shows that there was a significant impact on groundwater regime, as indicated by higher pre-post monsoon average rise in water levels in the wells) near the check dams (9.63 m) as compared to those wells located away from the check dam (7.64 m). Further, the well yields have improved significantly, 3 to 7.35 litre per second higher for wells located in the influence area. It was estimated that as a result of these water impounding systems, water spread area in the basins increased by 3,024 hectares during monsoon of 2010. Further, a larger proportion of the cropped area was allocated to water intensive sugarcane after the interventions. As a result, there was a substantial increase (by Rs. 22,248) in farm income per ha of land. Apart from contributing to agricultural economy, harvested water was also being used by women and children for domestic and recreational purposes. The major environmental benefit of these water harvesting structures is the creation of many small lakes in streams of different orders. Thus, there has been significant positive impact of these water harvesting structures, both on the local hydrology and rural livelihoods. The rates given in this paper are as per the research done during the year 2011.

Keywords- Artificial recharge, hydrological interventions, socio economic impacts

INTRODUCTION

Systematic studies dealing with physical and socio-economic impacts of water management interventions at the basin scale are very few in India. In the case of small and un-gauged river basins, while many studies of hydrological and socio-economic impacts of water harvesting and watershed development interventions are available, there is hardly any study available on the comprehensive impact of water harvesting and recharge interventions. There are several reasons for this. First: it is often very hard to obtain data on stream-flows, silt load and other hydrological parameters like groundwater levels at various control points in the drainage system. The interventions are confined to a small river or sub-tributary in the basin, which is not gauged by the official agencies concerned (Kumar et al., 2006). Second: the interventions are not basin-wide, and are concentrated in a few watersheds in the upper catchments, making it even more difficult to capture the impacts at the basin level. Third: even when there is large concentration of structures across the basin, as noted by Kumar and others (2006), the cost of monitoring and analysis is often prohibitive, making it difficult for the myriad of s mall agencies, which undertake the interventions at the scale of villages and watersheds (Kumar et al., 2006).

The available research in the past highlights the downstream hydrological, socio-economic impacts (Bachelor et al., 2002; Kumar et al., 2006; Kumar et al., 2008), (Kumar and Amarasinghe, 2009; Ray and Bijarnia, 2006) and social & ecological (Kumar et al., 2008) impacts when intensive water harvesting is carried out in naturally water scarce regions. The empirical studies mentioned here were also from naturally water-scarce regions. In this context, the work done by Ambuja Cement Foundation is an exception. The foundations water resource development and water harvesting activities are spread over three river basins in coastal Saurashtra.

COASTAL SAURASHTRA: A Bird's Eye View :Hydrology and Geo-hydrology

Saurashtra has a geographical area of 64,339 sq. km, with 32 percent of the total geographical area of the State. Rainfall in the region is highly erratic. Detailed analyses carried out by the Gujarat Agricultural University using district-wise rainfall figures showed that the mean annual rainy days vary from a minimum of 22 for Rajkot district to a maximum of 29 in Amreli. The mean annual rainfall over the period, 1901-1990, varied from a minimum of about 493 mm in Surendranagar to a maximum of about 701 mm in Junagadh. There are also significant variations in the annual rainfall and the inter-annual variability across the region. The highest variance (46%) was found in Amreli and Junagadh, and lowest (3 9%) in Rajkot district.

Analysis of point rainfall for a large number of rain gauge stations in the region was carried out using long-duration data of 68 to 78 years for the study. It showed that there are significant variations in the rainfall even within districts. In Junagadh, the difference in mean value of rainfall is 299 mm. Further, it was found that while it rains for 37 days in Junagadh (AM), it rains only for 24 days in Porbandar. Rainfall is lowest in the area, which receive highest rainfall (here Junagadh AM) and highest in one of the low rainfall. Figure 1 shows the rainfall of two Locations in Junagadh, viz., Junagadh and Porbandar for the period from 1901 to 1990.

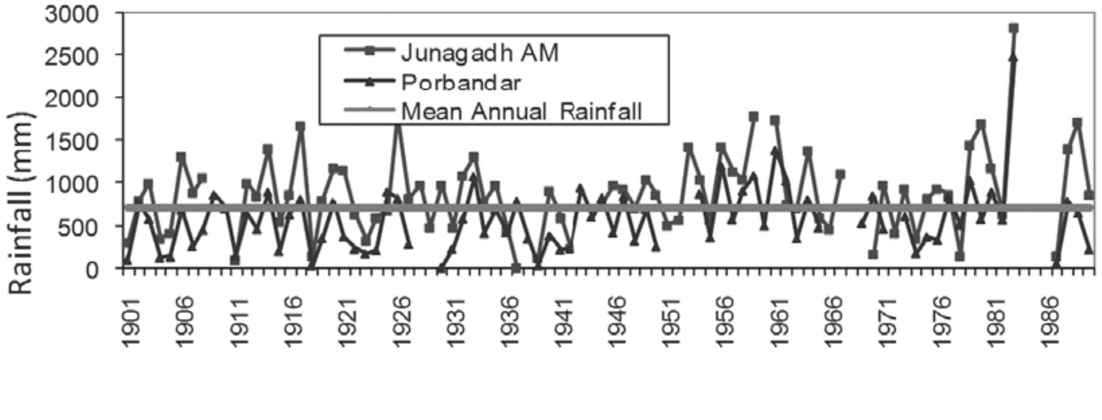
Given the high year-to-year variations in the rainfall and number of rainy days, no meaningful inference can be drawn in terms of water resource potential and water management implications examining the mean values. On the other hand, due to the vast spatial variation in the magnitude of rainfall and number of rainy days, district-level average of rainfall and rainy days does not uniform anything. What matters more is the probability of occurrence of specific quantum of rainfall in a particular area, and also the pattern of variation of rainfall magnitudes and rainy days across a region or a district, which can, in turn, be used for crop planning.

Two issues surface from the analysis of rainfall of different locations within a district. First: the probability of occurrence of a given rainfall differs vastly between two locations. Second: the magnitude of rainfall, which has a high probability of occurrence, is much lower than that which has a slightly lower probability of occurrence. For instance, in Porbandar, the rainfall, which has a probability of occurrence of 75% is 254.1 mm, while that can occur once in two years is 527 mm.

Saurashtra has several small and large seasonal rivers comprising of 84 small river basins. The region has radial drainage with discharges. The major rivers are Shetrunji, Machchu and Bhadar. Kachchh has a large number of rivulets carrying meager of annual flows. They all start from the central point due to the hilly ranges that form watersheds. Some rivers flow towards the sea in the south, some others flow towards the Rann of Kachchh in the north, some others flow towards the Little Rann of Kachchh in the southeast. Rivers in Kachchh have steep gradients. Frequent high intensity rainfalls of short duration cause flash floods are the common features.The total surface water potential of Saurashtra with 60 per cent dependability is only 3613 MCM. The reliability of surface runoff is very low.

The issue of high inter-annual variability in runoff can be understood from the analysis of data on estimated runoff.

Figure 1: Year to Year Variations in Rainfall in Junagadh

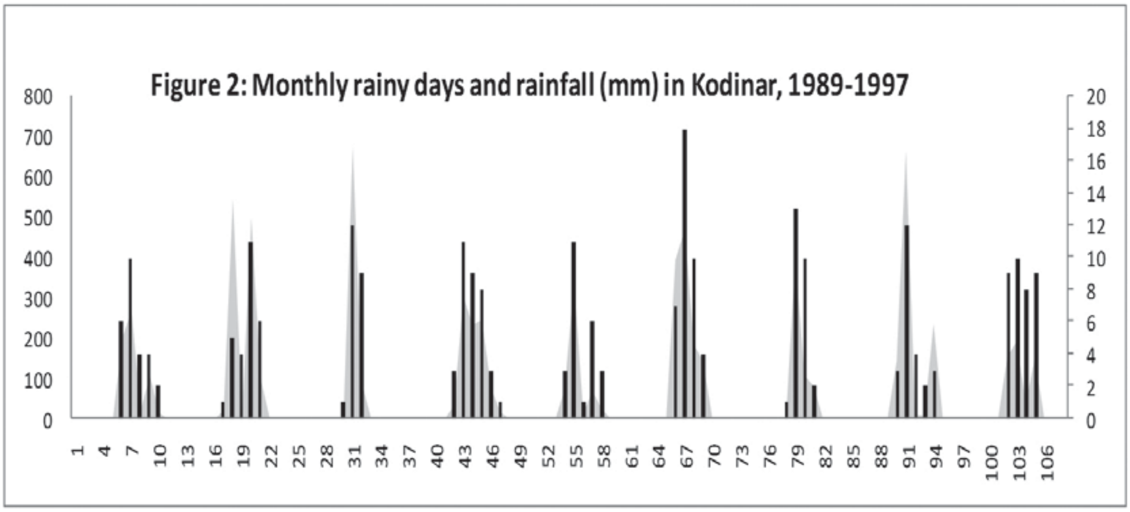


According to the estimates made by Tahal Consultants for the report on Water Resource Planning for the State of Gujaratthe runoff, which will be generated from a 100 sq. km catchment in Saurashtra with 50 percent dependability can be anywhere in the range of 2 MCM and 20 MCM. Similarly, for a 1000 sq. km catchment, it can be anywhere in the range of 20 MCM and 65 MCM.

The basins where Ambuja Cement Foundation (ACF) is carrying out water management activities are Singoda, Somat and Sagavadi located in Amreli and Junagadh districts of Saurashtra (Figure 2). Singoda is one of the small river basins in the region, which was chosen by the ACF for intensive water harvesting activities. The drainage areas of the basins are given in Table 1.

Regional models developed by the National Institute of Hydrology, Roorkee for estimating runoff from rainfall for un-gauged basins of Saurashtra shows that the best fit model to represent the rainfall-runoff relationship of the region is a bi-variate non-linear model with the parameter value of 0.757. But, these regression values do not seem to be quite robust in the sense that higher rainfall in Saurashtra produces disproportionately higher runoff, meaning that the value of the coefficient should be more than one, whereas, it is less than one as per the estimates provided by National Institute of Hydrology.

The analysis of rainfall data for Kodinar available from IMD (only for 9 years from 1989 to 1997) shows that the number of rainy days varies from 22 days in 1991 to 39 days in 1994. The total amount of annual rainfall varied from as low as 524mm in 1993 to 1190mm in 1994.



Source: Indian Meteorological Department (IMD) Data

The mean annual rainfall was only 817.3mm. In the case of Talala, a rain-gauge station upstream of Kodinar, the mean annual rainy days for the period from 1989 to 1998 is 40.5 and the mean annual rainfall was 937.8mm. In 1994, it rained for 60 days with a total rainfall of 1680mm, the highest rainfall during the reporting period. Based on the data for the two locations, it can be inferred that the upper catchment of basins in the area receive higher rainfall, distributed over larger number of wet days.

The entire peninsular region of Saurashtra (except the coastal strip and parts of Surendranagar district), are underlain by hard rock basalt of the Deccan Trap formation. It has no primary porosity but fractures, weathered zones and fissures present in it provide secondary porosity. The coastal tract has recent alluvium, and gaj formations. Part of Surendranagar district has sandstone aquifers. Brackish water is often found in the coastal alluvial tract, while the gaj limestone and clay have inherent salinity due to the marine environment. The aquifers in the entire Saurashtra region (except the coastal region and most parts of Surendranagar district) are shallow and unconfined. Groundwater occurs in fractures and weathered zones. The hydraulic conductivity and specific yield are very low in the basalt. The cavernous limestone in coastal Saurashtra has very high hydraulic conductivity.

Soils and Climate

The coastal region of Junagadh has different soil types. The coastal strip has deep alluvial sand. These soils have a high infiltration capacity.

Water saline partly because of ingress of seawater (from high tides and entry of seawater through coastal creeks), and partly because of using groundwater containing excessive salts for irrigation. The other parts of the coastal area have heavy and medium black soils. These sticky clay soils have high initial infiltration which reduces highly with increasing moisture content. These soils shrink and develop cracks on losing the moisture, and therefore pose a big challenge in irrigation water management. The area is semi-arid, with high relative humidity.

The nearest location in which data on climate related parameters are available is Meghal. The data on min and max temperatures in different months, the no. of hours of sunshine, wind speed & wind direction and humidity (%) are provided in Table 1. The highest temperature is generally observed during March (40.5^{o}C) and May (40^{o}C), and lowest is observed during January and February. The relative humidity is highest during the months of July and August, when the monsoon peaks. The potential evaporation values are highest during the month of May, followed by April with average daily values of 8.22mm and 7.84, respectively. What is important to note is that even during the monsoon months, the potential evaporation rates are quite high, owing to relatively higher wind speed, in spite of lowering of daily temperature and increasing of atmospheric humidity (June, July and September).

Table 1: Climate Parameters from Meghal Weather Station, Junagadh

Sr. No	Month	Evaporation (mm)		Temperature (oC)		Sunshine Hours		Wind Direction	Wind Speed		Humidity (%)
		Total	Average	Max	Min	Total	Avg		8:30am	5:30pm	
1	January	180.1	5.809	33.0	7.0	279.4	9.01	NNW	8.54	8.55	44.45
2	February	192.5	6.875	36.5	7.0	259.5	9.26	WNW	9.83	9.89	40.79
3	March	233.5	7.530	40.5	14.0	290.8	9.38	WNW	10.19	10.23	52.75
4	April	235.3	7.843	38.5	18.5	308.7	10.29	WNW	11.85	11.82	62.93
5	May	254.8	8.219	40.0	22.5	309.7	9.99	WSW	13.78	13.81	69.62
6	June	225.4	7.513	37.0	24.8	205.7	6.86	WSW	15.01	15.00	73.47
7	July	214.9	6.932	33.0	24.1	101.2	3.26	WSW	18.60	18.57	77.18
8	August	190.4	6.141	31.0	23.8	59.1	1.91	WSW	14.12	14.21	81.36
9	September	222.3	7.410	33.5	22.5	265.3	8.84	WNW	10.42	10.43	74.17
10	October	247.3	7.977	41.0	18.8	280.6	9.05	WSW	7.19	7.10	56.57
11	November	238.1	7.936	37.0	15.1	255.4	8.51	WSW	6.68	6.73	45.77
12	December	212.2	6.845	36.0	11.5	262.4	8.46	WNW	7.20	7.27	49.37

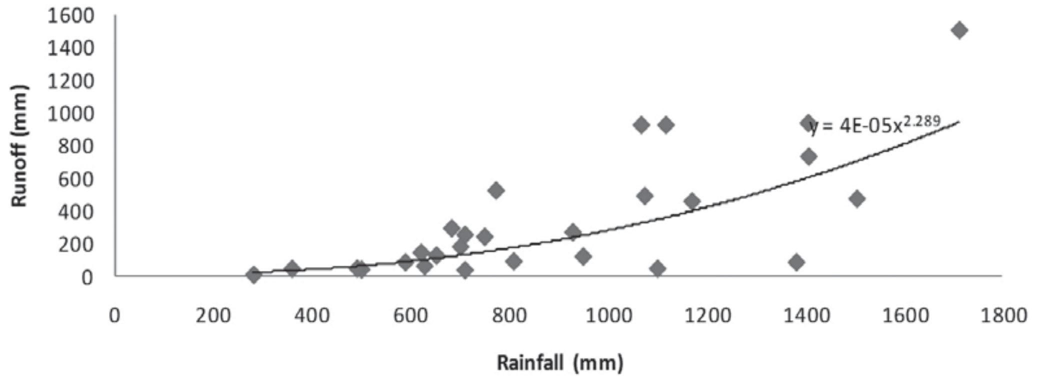
Source: Data from Meghal Weather Station, Meghal

Stream-flows in Kodinar Basins

The success of water harvesting interventions in any area depends on the uncommitted stream-flows available from rivers and streams in the area, the flow characteristics and the inter-annual variability. Singoda is one of the most important river basins where ACF had undertaken intensive water harvesting and recharge activities. Stream-flow data available for a medium reservoir located upstream shows that out of the 27 years, in 15 years, there were excess flows. In one of the years (1994-95), the excess flow was in the order of 380.97MCM. What is interesting to note is that for four consecutive years starting from 2003-04, runoff from the catchment was excessively high, causing huge reservoir overflows. This excess flow, added to the runoff generated in the residual catchment of the basin in the lower reaches, would determine the hydrological opportunity for water harvesting and recharge interventions.

A rainfall runoff relationship for the upper catchment of the basin was estimated on the basis of the rainfall observed in the reservoir catchment, and the estimated values of inflows. The inflow was estimated by summing up the gross storage in the reservoir, the outflows from the reservoir and the lake losses. It shows that the relationship is exponential (Figure 3), whichmeans that with increase in rainfall, the runoff rate also would increase. The rainfall-runoff relationship is defined by the mathematical equation, Y=0.0004*(X) 2.289

Figure 3: Rainfall-Runoff Relationship for Singoda basin (upper catchment)



Socioeconomic Characteristics of the Coastal Junagadh

Junagadh district lies between 21° 10' and 21° 40' north latitude and 70° 18' and 71° 15' west longitude region, in the state of Gujarat India. This district is bounded by the Rajkot district in North, Amreli district in East, Arabian Sea in South and by the Arabian Sea and Porbandar district in the West. Total geographical area of Junagadh district is 6,996,011.21 ha.

Coastal Saurashtra has unique socio-economic characteristics, which are distinctly different from Saurashtra mainland by virtue of the coastal climate, the soils and the exposure of the communities living in this area to several outside cultures. The region's farming systems, characterize this. The area is known for rich mango orchards. The Kesar mangoes of Talala in Junagadh are famous all over the country. The area in and around Kodinar is also known for cultivation of sugarcane. The crop gives very high yield in the area. The other major crops grown in the region are groundnut in kharif and wheat in winter. Dairying is also quite extensive in the region. The Kankreji cows and Jafrabadi buffaloes are well known breeds. Besides this, goat, sheep and bullocks are also reared. The region is also known for coconut plantations in the coastal strip.

The relatively higher rainfall and shallow groundwater triggered agricultural revolution in this region in the late 50s and 60s. The open wells, which were energized using diesel engines and electric pump sets, gave very good yields, and the industrious farmers in this region took 2- 3 crops, apart from the annual and perennial crops. But, this prosperity did not last long. Excessive withdrawal of groundwater for irrigation resulted in intrusion of seawater into the coastal aquifers. Increased salinity in groundwater even made water for drinking and cooking scarce. Estimates made by GWRDC as far back as 1997 showed Kodinar taluka as "over-exploited", with the total groundwater draft (131 .5MCM per annum) far exceeding the utilizable recharge of 82.6MCM per annum (as Cited in CSPC, 2008)

Today, the ability of farmers to use water from these wells depends mostly on the monsoon. If the rainfall is good, the salinity of ground water reduces and the farmers would be able to provide supplementary irrigation for the kharif crops, and sometimes irrigate winter crops. The level of salinity in groundwater is high towards the coastal strip, which reduces gradually towards inland. In the inland aquifers, which are basalt formations, are not extensions of the coastal aquifers, which consist of coastal alluvium followed by cavernous limestone. The wells in basalt formation still provide water of good quality. High degree of salinity is encountered in the wells tapping the coastal alluvium, cavernous limestone and the marine gaj formations1 which are inherently saline. The total number of salinity affected villages in Junagadh and in Kodinar taluka are given in Table 2.

Table 2: Details of Salinity-affected Villages in Coastal Areas of Junagadh District, and Kodinar Taluka

Sr. No	Types of Villages	No. of Villages in	
		Junagadh	Kodinar
1	Fully Saline Villages	92	14
2	Partially Saline Villages	53	10
3	Villages prone to salinity	158	22
4	Total	303	46

OBJECTIVES & METHODOLOGY

The objective of the study was to assess the hydrological and socio-economic impacts of three different types of water harvesting and groundwater recharge structures built in three different basins of Kodinar, viz., Singoda, Somat and Sagavadi.

- The Hydrological Impact of Groundwater Recharge Interventions are analyzed by comparing the pre & post monsoon fluctuation in water levels in wells which are likely to be influenced by the recharge structures with those which are not likely to be under the influence of recharge structures, which are under the same geological setting. This is to nullify the effect of rainfall on groundwater recharge, and to capture the actual effect of recharge structures. Comparison was also be made for the average water level fluctuation in the sample watershed with that of a control watershed or small river basin.

The water level fluctuation of individual well during monsoon, including that due to naturalrecharge =

$$WLF_{Well,\ i} = DWL_{i,\ pre-monsoon,} - DWL_{i,\ post-monsoon}$$

$$DWL_i$$

$$\sum_{i=1}^{m} WLF_{well,\ i}/_{m} * S_y - \sum_{j=1}^{n} WLF_{well,\ j}/_{n} * S_y$$

Where, is the number of observation wells in the treated watershed, and is that for the untreated watershed; is the specific yield of the aquifer.

- At the next level, the impact was analyzed by comparing the yield of wells--in terms of total number of hours for which well located in the influence area of recharge structures could be run before drying up and the discharge (m^3/hour) --before and after the recharge interventions and comparing it with that of wells outside the influence area.
- The Socio-economic Impact of the recharge interventions on the farm households was assessed by analyzing: 1] difference in input use, yield and net income from crops which are benefitted by supplementary irrigation from the recharged wells (Saurashtra) and soil moisture improvements due to traditional water harvesting system (Pali); 2] difference in area under crops which require irrigation; 3] changes in livestock holding & composition of the adopters; and 4] difference in total farm income of families per unit of cultivated land between pre and post intervention situations. In each case, the difference was compared against the figures for who are least likely to be benefitted by the recharge schemes during the same time period. This was to nullify the effect of larger socio-economic changes happening in the region, thereby segregating the impact of the recharge intervention. Here, care was taken to ensure that those farmers who have adopted MI systems are not covered in the sample.
- The Socio-economic Impact of Recharge Interventions at the village level was assessed by analyzing: 1] the changes in cropping pattern; irrigated cropped area; and cropping intensity after the implementation of recharge schemes; 2] the changes in livestock composition, and milk yield of animals in a similar way; 3] the changes in aggregate farm outputs at the village level, comprising crops and dairying; 4] changes in wage labour employment in the village over a control village, expressed in terms of number of days of wage labour in agriculture for the whole year per village; and 5] changes in market value of agricultural land. The changes in the above attributes were compared against similar changes in the control village during the same time horizon.
- The Environmental Impact of the intervention was assessed by analyzing the changes in the composition of stream-flows in the river systems which are treated using artificial recharge interventions, vis-a-vis the percentage contribution of the "total estimated virgin flows" from monsoon and non-monsoon flows. The time series data for this was obtained for pre and post water harvesting/recharge interventions. The other indicator for ecological impact was changes in primary productivity of soils, and soil biota owing to increased use of organic manure for crops (vermi compost etc). This was captured through field observations and discussion with farmers.

DEGREE OF WATER RESOURCES DEVELOPMENT IN SINGODA RIVER BASIN

All the water harvesting and recharge interventions of Ambuja Cement Foundation are concentrated in three river basins of Junagadh, viz., Singoda, Somat and Sagavadi. The drainage areas of these three small river basins are shown in Map 1. The major water harvesting andrecharge interventions include: check dams across the streams of different orders; construction of link canals for connecting two rivers when flow regimes are different; feeding mined out areas with runoff from distant streams for creating large reservoirs; building of roof water collection tanks; promotion of drip irrigation systems amongst orchard and sugarcane growers; rejuvenation of drinking water wells, which have become saline due to seawater intrusion and ingress, through well sealing; and dug well recharging. Table 4 gives the scale of water harvesting and groundwater recharge and drinking water supply interventions carried out by ACF in the two project areas.

Table 4: Details of Various Water Harvesting Structures

Sr. No	Structure	Number of Structures/ Size of the Structure
	Location: Kodinar	
1	Construction/ Renovation of Check Dam	153
2	Dug Well Recharge	902
3	Percolation Tank	96
4	Percolation Well	100
5	Construction of Farm Ponds	717
6	Construction of Link Channels (km)	56.75
7	Roof rainwater harvesting structures constructed	2103
8	Rejuvenation of saline wells (well sealing)	40

Source: Water Resource Management in Junagadh, Ambuja Cement Foundation, 2009

While many such water harvesting and groundwater recharge techniques were attempted by NGOs and government agencies alike in Gujarat and many other water stressed regions of India, the uniqueness of the strategy of Ambuja Cement Foundation is that many of the interventions are designed with due consideration to the peculiar hydrological and geohydrological environment of the region.

For instance, river linking work was undertaken in view of the fact that there is substantial spatial variation in the rainfall and runoff in small basins of the coastal area which are adjacent. At the same time, topography and geo-hydrology induce severe constraints on storing all the water through engineering interventions within the same basin. On the other hand, because of high rainfall occurrence, the demand for water within the basin during the times of inflow will also be high. They together reduce the utilization potential of the flood water within the basin. Diverting this water to the adjoining basins, which experience rainfall deficit, would increase the effective water storage and diversion capacity, and also utilization potential for this water. While it is understood that water harvesting & recharge structures are quite expensive (in terms of cost per cubic metre of water stored or recharged) in regions of low to medium rainfall with high inter-annual variability, and which is erratic in nature (Kumar et al., 2008), one way to increase the cost effectiveness of these structures is to keep the effective utilization far above the storage capacity.

HYDROLOGICAL IMPACT OF WATER HARVESTING STRUCTURES IN KODINAR AREA

A. Impact of Check Dams

Over the past few years, it has almost become common belief in western India that construction of check dams in small streams and rivers would increase water availability in a locality through groundwater recharge, irrespective of the hydrological regime, topography and the geological setting and that such structures can be built with lowest investment. The State of Gujarat had witnessed unscrupulous building of check dams without any consideration to the rainfall, the catchment area availability, the topography and the underlying geology, with the result that the number of such structures sometimes exceeds even 100 within just one village. It goes without saying that scientific prudence needs to be exercised in building such structures, though they are very small in size. While the issues of upstream Vs downstream and overall impact of these structures on the basin water balance are quite crucial (Kumar et al., 2006; Raj and Bijarnia, 2006; Kumar et al., 2008), serious concerns are being raised about the local impacts of these structures on hydrological regime, the life of the system and their costs.

Whether a check dam can produce the intended benefits of augmenting surface water, augment recharge to groundwater depend and how cost effective it is depends on many factors. Some of them are: pattern of occurrence of rainfall and runoff; catchment area; terrain conditions; underlying geology, and geo-hydrology; potential evaporation; and the pattern of use of water. We would discuss the influence of each on the potential impacts of check dams. Occurrence of high intensity rainfalls of short duration in the local catchment can reduce the effective storage of water in a reservoir created by a check dam as the opportunity time available for water to infiltrate would be less. More importantly, during times of inflow, as the local groundwater table would be high due to natural recharge from rainfall (Saurashtra), the percolation will be negligible. Also, the damage such high intensity rainfalls can cause on the structure through high intensity runoff and flash flood, through bank erosion is quite high. Whereas, when rainfall is evenly distributed over long time periods can increase the effective storage of water for the same reservoir capacity. Further, when there are continuous inflows from the upper catchment even after the withdrawal of monsoon (due to base-flows), the check dams down below are likely to be quite effective, as the time for infiltration would be high, and there would be more space in the underlying geological formation for storage of water.

As regards, terrain conditions, hilly (slopping) terrains the check dams are least likely to augment groundwater recharge effectively. This is because of steep groundwater gradients which cause the percolating water to flow out of the formations (Mayya, 2005).

In the context of catchments, it is important to make sure that there is sufficient residual catchment upstream of the proposed check dam site. Intensive water harvesting within a basin means that there is very little residual catchment left in the basin for harnessing. Potential evaporation is a major hydrological variable which determines the effectiveness of small water harvesting structures, including check dams and small dams.

If the evaporation rates are high during the monsoon, this can become a major factor which can negatively influence the performance of the reservoirs created by check dams and small dams. In the case of Junagadh, the potential evaporation rates during the monsoon are high. This

means that the water spread area should be reduced and the structures should be cited at places where the recharge rates would be high due to the presence of geological structures such as lineaments. Finally, in open basins (see Seckler, 1996 for discussions), the benefits of building check dams would be high. It is important to note here that the small river basins of Junagadh district, which are originating from the Gir forest, are open basins, with the reservoirs built upstream still overflowing. The Gir forest area not only receives high rainfall (above 900mm), but also has the terrain that is rocky which provides high runoff rates. Lean season flows, which are contributed by the base-flow in the upper catchment, are also significant in these basins. When basins are closed, the building of new water impounding structures only result in redistribution of water within the basin, rather than augmenting the utilizable runoff.

Hydrological impacts of water harvesting included monitoring fluctuation in water levels of wells around the check dams and which are likely to be influenced by them between pre and post monsoon, and comparison with wells outside the influence area of check dams. Earlier it was planned to compare the water level fluctuations before and after the interventions. But, due to lack of data, this was not done. In the current comparison, it is assumed that the two areas have similar geological setting (top soil and specific yield) so that the same quantum of rainfall would cause the same degree of impact vis-à-vis recharge and water level fluctuations. Hence, the difference in pre & post monsoon water level fluctuations between the two areas would show the effect of the water harvesting structures. By doing this, the effect of natural recharge on water level fluctuations can be nullified.

Water levels in wells in Harmadiya village (influence area of check dam) and Bhiyal and Bhodidar were monitored for analyzing the impact of check dam. Graphical representation of water level fluctuation (pre and post monsoon) in well (39 nos.) in Harmadiya is given in Figure 1. In 38 out of the 39 wells, water level rose in the range of 15-58 feet, while only one well showed a drop in water level of 4feet. The average rise in water level was estimated to be 31 .59feet. Against this, water level fluctuation (rise) in wells in Bhiyal ranged from 15 to 43feet in the case of Bhiyal, and 15 to 46feet in the case of Bhodidar village. The average fluctuation in water was 23.38feet in the case of Bhiyal, and 26.75feet in the case of Bhodidar (Table 5).

The impact of the check dam in terms of inducing additional recharge to groundwater can be seen from the fact that the average fluctuation in water level was 31 .6feet for Harmadiya against an average of 25.06feet for Bhiyal and Bhodidar. The differential rise in water level during monsoon, owing to the presence of check dam in Harmadiya is 6.06 feet. If we consider a specific yield of 0.02 for basalt formations of the area, this means an additional recharge of 3.60cm (specific yield X water level fluctuation).This is nearly 4.5 per cent of the total rainfall of the area.

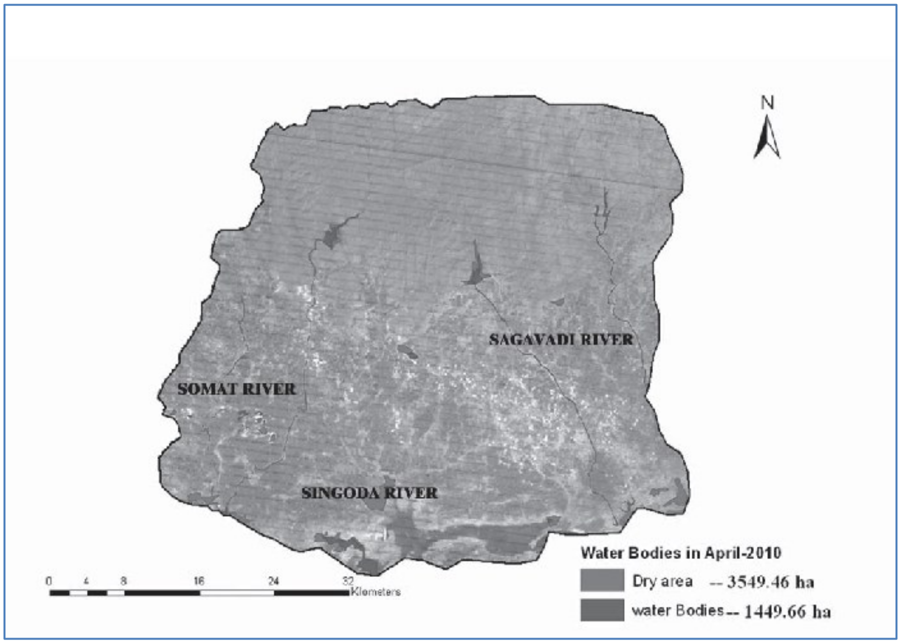
Table 5: Water level fluctuation in wells in the influence area of check dam and outside the influence area

Sr. No.	Name of the Village	Water level fluctuation			Differential Rise in Water Level (feet)
		Mean	Minimum	Maximum	
1	Harmadiya	31.59	-04.00	58.00	6.06
2	Bhiyal	23.38	15.00	43.00	
3	Bhodidar	26.75	15.00	46.00	

B. Impacts of Reservoirs in the Mined-Out Areas

Ambuja Cements use open cast mines to obtain limestone and mar that are essential for cement production. Owing to the mining, large pits measuring between 12 to 15 m in depth are created. Generally these pits are reclaimed by filling, afforestation and pasture land development.

Map 1: Remote Sensing Imagery developed for Kodinar Watersheds: Pre Monsoon

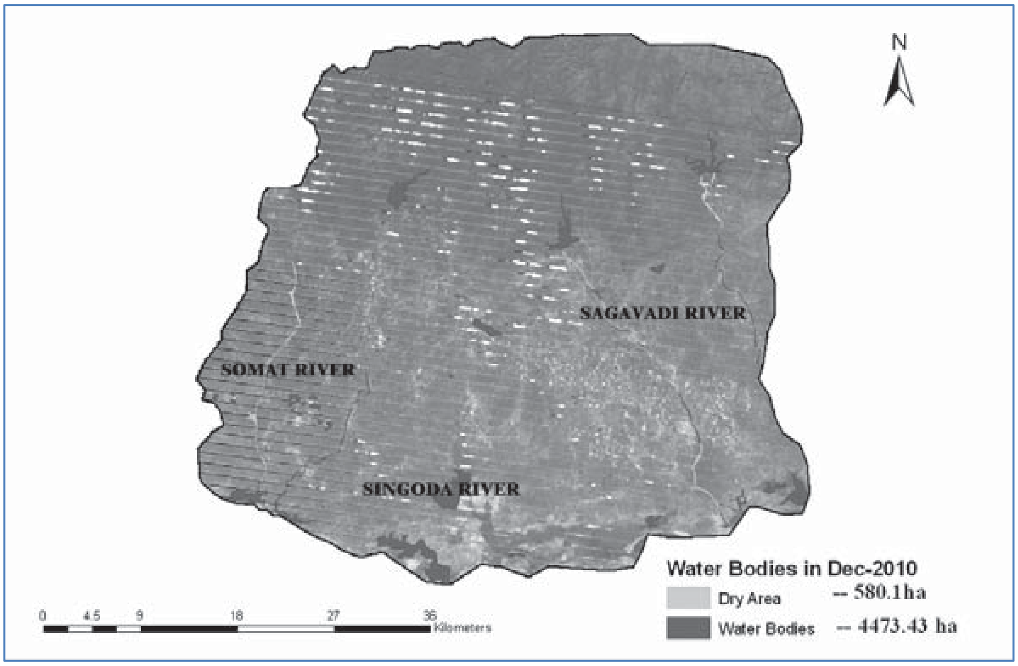


The company, however, chose to use these pits for an entirely different purpose- collection and storage of water. These artificially created reservoirs provide a huge reservoir for the water which comes through the channels constructed to divert the surface run off from all adjoining areas. In 1995 the mined out pits situated in close proximity of the two ACL plants were converted into water harvesting structures by diverting the plant surface run off. To enable the flow of water from the plants, a 1 000m long and 4 m deep trench was excavated and connected to the pit. One of the nearby nallas and the village run-off drain was also connected to the pit to increase the quantity of water coming into the pits.

Over time it was found that each year the pit collects 80-90% of its capacity. Local aquifers too were recharged at no additional cost. The pit has benefited the nearby farmers who have found that the water level in their wells has increased. In 2005, a survey of the area and surface topography and village wisdom, brought to us the possibility of diverting water from a seasonal nalla flowing 3.25km north of the mined-out pits. A scheme was worked out and in consultation with the local residents, the project was taken up. With the onset of the monsoon the Surface

flow of water pits saw a continuous flow of surface run off from the nalla and the pits were soon brimming with water. About 4 million cubic metres of water was prevented from flowing into the sea and thus water was harvested. The surrounding wells consequently got recharged. The success of this experiment propelled us to further inter-linking pits so as to transfer the excess water in the case of heavy rains from one pit to another. Over all 5.5 million cubic meters of water got collected through the diversion canal in 2006.

Map 2: Remote Sensing Imagery developed for Kodinar watersheds: Post Monsoon



SOCIO-ECONOMIC IMPACTS OF WATER HARVESTING & RECHARGE STRUCTURES IN KODINAR AREA

Increased recharge to groundwater would mean raised water levels in wells, and increased well yields. This will increase the irrigation potential of the wells. With this, farmers can expand the area under irrigated crops during winter and summer months. Also, in certain situations, the farmers can also provide supplementary irrigation to kharif crops, thereby raising crop yields. But, this normally does not happen because of the fact that the years of good groundwater recharge from check dam would coincide with the years of good monsoon, wherein the kharif crops would not require supplementary irrigation.

In order to analyze the changes in agricultural production resulting from improved recharge of wells, primary data were collected from farmers in the influence area of the check dam ontheir farming enterprise. The data included those prior to the construction of check dam as well as those after the construction of the check dams. The various attributes considered for analyzing the farm level impact are: area under different crops; the yield and net return from crops; and water productivity of crops both in physical and economic terms. In addition, data on livestock holding were also analyzed. The various structures considered for the analysis included: check dams; link canals and mined out areas.

A. Impact of Check Dams

Comparative analysis of data on the farms benefited by the check dams in terms of improved recharge to groundwater, pre and post check dam construction showed the following. First: the percentage area under high valued crops such as sugarcane, summer bajra and cotton, which are also far more water intensive as compared to kharif groundnut and bajra, increased. Among these, sugarcane is a highly water intensive perennial crop, which requires 30-50 watering over the entire crop cycle. Therefore, such a shift in cropping pattern could be possible only because the farmers were assured of sufficient water in their wells. Second: the proportion of the area under kharif crops, such as kharif bajra and kharif groundnut, got substantially reduced. Overall, the total area under irrigated crops (sugarcane, cotton, til, summer groundnut, winter, fodder crops and summer bajra and wheat) reduced only marginally through the aggregate area under crops reduced significantly during the period from 403 to 352bigha.

The impact of check dams on the farmers choice of crops is explicit from the fact that in the control farms of the area, which were not influenced by the check dams of Harmadiya, had totally different cropping pattern (Column 3 and 6 of Table 6). The percentage area under sugarcane was less than eight, whereas kharif groundnut occupied nearly 13 per cent of the gross cropped area. Moreover, only 72.6 per cent of the gross cropped area was irrigated while 80 per cent of the area cropped by farmers in the influence area of check dams was irrigated.

Table 6: Change in Cropping Pattern Post Check Dam Construction

Sr. No	Name of Crop	Before Check dam		After Check dam		Control	Farm
		Area (bigha)	% Area	Area (bigha)	% Area	Area (bigha)	% Area
1	Kharif Groundnut	52.00	12.9	24.00	6.5	41.5	12.8
2	Summer Groundnut	22.00	5.5	9.00	2.4	0.0	0.0
3	Sugarcane	33.50	8.3	73.00	19.8	25.5	7.9
4	Kharif Bajra	19.50	4.8	13.50	3.7	22.0	6.8
5	Winter Bajra	18.00	4.5	15.00	4.1	0.0	0.0
6	Summer Bajra	39.00	9 . 7	34.00	9.2	17.5	5.4
7	Cotton	68.00	16.9	77.00	20.9	88.5	27.4
8	Wheat	84.00	3.6	57.00	3.1	0.0	0.0
9	Black Gram	23.50	5.8	16.00	4.3	14.0	4.3
10	Fodder	12.50	20.8	9.50	15.4	103.0	31.9
11	Til	27.00	6.7	34.00	9.2	0.0	0.0
12	Chick pea	4.00	1.0	5.00	1.4	0.0	0.0
13	Kharif Jowar	0.00	0.0	0.00	0.0	11.0	3.4
14	Total Area	403.00	100.00	352.00	100.00	323.00	100.00

Source: authors' own analysis using primary data

Further analysis using data on irrigation dosage, yield and net return from crops are as follows. Irrigation dosage for all the crops, estimated as the depth of irrigation, increased post check dam construction for all the winter and summer crops, except for sugarcane. The crop yield did not record any increase, except for wheat. One reason could be that most of these crops are grown during rainy season, and their yield will have effect of rainfall pattern. But, the net returns for all the crops increased significantly post check dam construction. Also, as we have seen earlier, the proportion of area under sugarcane which gives the highest return per unit area of land, is highest after check dam construction, resulting in overall increase in farm returns. Water productivity in physical terms reduced for all crops except sugarcane owing to increased water application. In the case of sugarcane, though the yield hasn't increased post check dam construction, the water dosage reduced substantially. This can be attributed to the effect of rainfall occurrence. Reduction in physical productivity of water means that the yield had not increased in proportion to the increase in irrigation water dosage. As regards water productivity in economic terms, it has increased for all the crops, either because of disproportionately higher increase in net income in relation to the increase in water application rate. It is important to note that sugarcane, which is replacing crops such as kharif bajra and groundnut and winter wheat, has much lower water productivity in economic terms as compared to these crops (only Rs.3.6/m^3against Rs.7.6/m^3 and Rs.5. 1/m^3 for cotton and wheat respectively even under the improved water application scenario). This is a matter of great concern, as investments for constructing the water harvesting structures are quite large.

Table 7: Crop Economics, Pre Check Dam Construction

Sr. No	Name of Crop	Depth of	Yield (kg/bigha)	Net Return	Water productivity (Kg/m^3)	Water productivity (Rs/m^3)
1	Kharif Groundnut		315.15	945.0		
2	Summer Groundnut		233.33	602.0	0.34	0.35
3	Cotton	0.98	547.67	5535.5	3.3	33.4
4	Sugarcane	3.65	22250.0	9954.0	4.20	1.80
5	Kharif Bajra	0.02	591.67	1845.8	6.25	17.85
6	Winter Bajra	0.68	1000.00	3500.0	1.02	3.46
7	Summer Bajra	0.81	816.67	2698.0	0.83	2.64
8	Wheat	0.75	858.33	4399.1	0.96	4.75

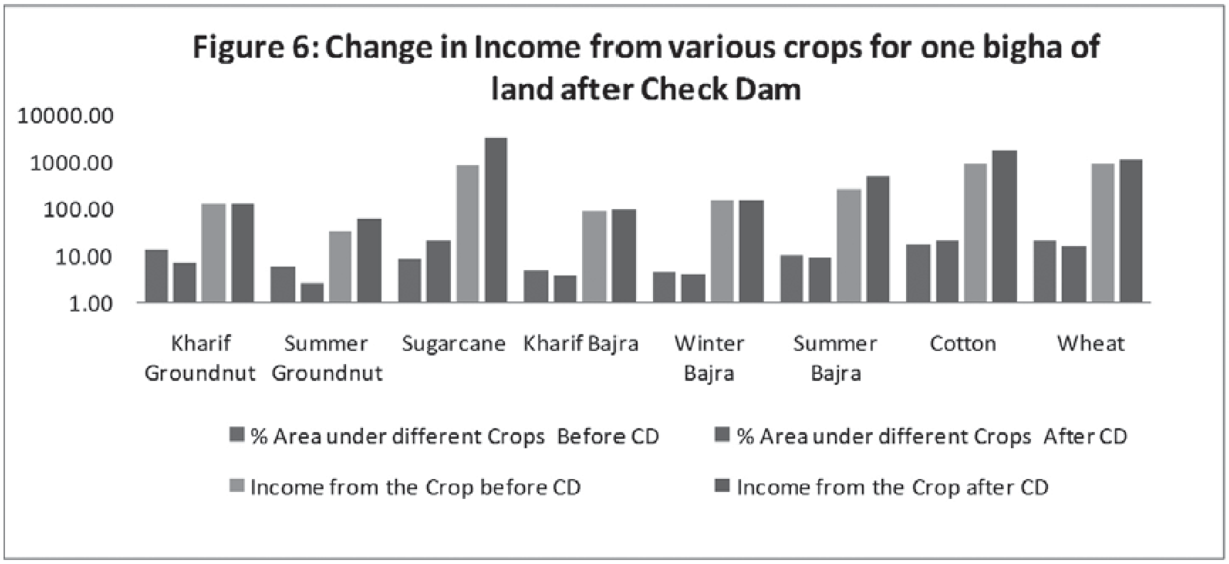
Source: Author's own analysis using primary data

Table 8: Crop Economics, Post Check Dam Construction

Sr. No	Name of Crop	Depth of Irrigatio	Yield (kg/bigha	Net Return	Applied Water Productivity (Kg/m^3)	Applied Water Productivity (Rs/m^3)
1 2	Kharif Groundnut Summer Groundnut		200.00 240.00	1937.5 2525.0	0.14	1.36
3	Cotton	1.09	464.54	8189.3	0.41	7.29
4	Sugarcane	3.28	21702.4	16315.9	4.96	3.63
5	Kharif Bajra	0.14	646.67	2601.0	0.89	N.A.
6	Winter Bajra	1.31	850.00	3825.0	0.60	2.27
7	Summer Bajra	1.58	932.14	5537.5	0.99	5.50
8	Wheat	1.10	900.00	7529.6	0.64	5.12

Source: Author's own analysis using primary data

Due to the shift in cropping pattern towards high valued crops, the overall farm income increased by nearly Rs.3700 per bigha of land, when we considered only seven of the crops, with the current cropping pattern (Figure 6).



B. Impact of Mined Out Areas on Crops and Income

Analysis similar to what has been done in the case of check dam was carried out for farms, which were likely to be benefited by the mined out areas. The results are presented in Table 9. Comparison of net income from crops viz., groundnut, bajra, sugarcane and wheat shows that during the post water impoundment period, the sample farmers secured much higher income as compared to pre intervention period. But, the yield was higher only for sugarcane, whereas in the case of kharif groundnut and summer groundnut, the yield was actually lower after water was introduced in the reservoir. But, not less important is the fact significant differences in cropping pattern exist between pre and post reservoir scenarios. The cropping pattern during thepost reservoir period is dominated water intensive sugarcane with 34 per cent of the gross cropped area under this crop. In contrast to this, the cropping pattern during the pre reservoir period was dominated by wheat and kharif groundnut. This essentially means that for the crops for which farmers are allocating more land, there are able to secure much higher yields.

Table 9: Irrigation Depth, Yield, Net Return and Water Productivity of Crops in the Mined Out Area during Pre and Post Reservoir Periods

Sr. No	Crop Name	Before Reservoir		After Reservoir	
		Yield (kg/bigha)	Net Return (Rs/bigha)	Yield (Kg/bigha)	Net Return (Rs/bigha)
1	Kharif Groundnut	603.8	5141	495	5562.5
2	Summer Groundnut	900	9375	600	9250
5	Sugarcane	30357	16438	31224	27207

Source: Author’s own analysis using primary data

Table 10: Cropping Pattern in the Mined Out Area during Pre and Post Reservoir Periods

Sr. No	Crop	Pre Mined Out		Post Mined Out	
		Area (Bigha)	% Area	Area (bigha)	% Area
1	Kharif Groundnut	25	27.55	18	24.16
2	Summer groundnut	16	17.63	8	10.74
3	Kharif Bajra	4	4.41	2	2.68
4	Winter Bajra	4	4.41	4	5.37
5	Summer Bajra	0	0.00	2	2.68
6	Sugarcane	13.5	14.88	25.5	34.23
7	Wheat	27.25	30.03	15	20.13
8	Jowar	1	1.10	0	0.00
	Total Area	90.75		74.5	

Source: Author’s own analysis using primary data

C. Impact of Link Canal in the Coastal Area

Interlinking of small rivers and rivulets of Junagadh draining into the ocean was an innovative measure by Ambuja Cement Foundation in Kodinar area. When one area or basin receives good rainfall, another area or basin next to it experiences rainfall deficit. Excessive runoff in the high rainfall areas often causes flash floods, and at the same time, there are significant constraints induced by the topography on harvesting this flood runoff using impoundments and utilizing it within the same basin including recharging of aquifers. Therefore, link canals were dug to connect these rivers. There are three such link canals in Kodinar area. These canals have three hydraulic functions. First: the water stored in these canals creates a hydraulic barrier for the saline water from intruding into the freshwater aquifers by exerting hydrostatic pressure. Second: the water stored in these link canals provide opportunity for the farmers located on their banks to lift the water and use for crop production. Third: they also recharge the aquifers in those areas where the rainfall hasn’t been adequate.

A survey of farmers whose farms are located on the banks of the link canal was carried out to understand the impact of this intervention on the farming enterprise. Data on area cropped, area irrigated, inputs, including irrigation dosages, crop yields, and prices were collected from these farmers for one (crop) year during both pre and post intervention periods. They were analyzed and the results are presented in Table 11 and Table 12 respectively for pre and post intervention periods. Comparing the results for pre and post interventions, it appears that the average net income from all the four irrigated crops, viz. kharif bajra, summer bajra and wheat went up after the introduction of the link canal. But, the yield was higher only for wheat. Here, again, a shift in cropping pattern towards sugarcane was seen, though reliable data on the yield and net income from this crop was not available.

Table 11: Irrigation Depth, Yield, Net Return and Water Productivity of Crops in the Link Canal Area during Pre Construction

Sr. No	Crop Name	Depth of Irrigation (m)	Yield (Kg/Bigha)	Net Return (Rs/Bigha)	Water Productivity	
					Physical (Kg/m^3)	Economic (Rs/m^3)
1	Kharif Bajra		614.8	1686		
2	Summer Bajra	0.92	800	2450	0.53	1.63
3	Wheat	0.9	580	2260	0.398	1.14

Source: authors' own analysis using primary data

Table 12: Irrigation Depth, Yield, Net Return and Water Productivity of Crops in the Link Canal Area during Post Link Canal Construction

Sr. No.	Crop Name	Depth of Irrigation (m) (Mean)	Yield (Kg/Bigha)	Net Return (Rs/Bigha)	Water Productivity	
					Physical (Kg/m^3) Mean	Economic (Rs/m^3) Mean
1	Kharif Bajra		900	4550		
2	Summer Bajra	0.48	700	2728	0.587	2.29
3	Wheat	0.81	752	6100	0.58	4.6

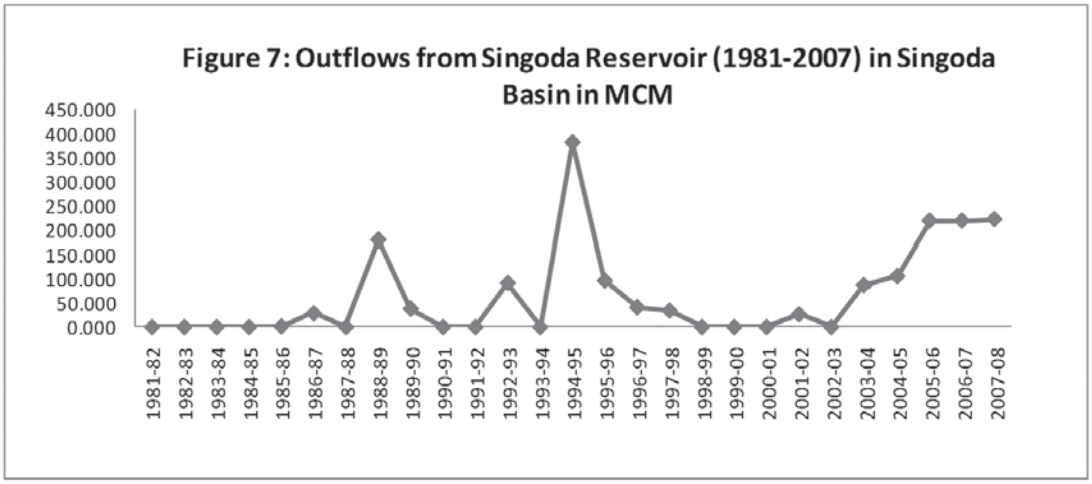
Source: authors' own analysis using primary data

7. ENVIRONMENTAL IMPERATIVES

Intensive water harvesting in watersheds located in the upper catchments of basins located in semi-arid and arid regions of India can cause ecological damages in the downstream areas (Kumar et al., 2006; 2008a). One of the reasons is that the basin could experience years of lowrainfall, which produce very low volumes of runoff. In fact, in such regions, in years of lowrainfall, the runoff would be disproportionately lower than that in high rainfall years, as evident from the rainfall-runoff relationship estimated for the basin. These are years which require a lot of attention in basin-wide water resource, from ecological health point of view. Care should be taken to see that water harvesting systems that are being built do not capture the committed flows.

In the case of check dams built in Harmadiya and other villages in Singoda basin, the runoff water which is being tapped, is actually the outflows from a medium reservoir, built upstream for Singoda irrigation scheme of the government of Gujarat, and the runoff generated in the residual catchment of the basin. Hence, the issue of downstream impact is not major in this case. Nevertheless, stretch of the rivers in the coastal belt could still suffer from environmental water stress in years of low rainfall, owing to the water impoundment happening upstream due to the water harvesting structures such as the check dams. The Chart below (Figure 7) shows that in a little less than 50 per cent of the years, there is no excess flow from the reservoir upstream. Therefore, future building of water harvesting systems should take this aspect into consideration. The total water impounding capacity of the structures in the basin should not exceed the outflows which occur at 60 per cent dependability and the runoff from the residual catchment.

Because of the heavy overflow from the upper catchment, in years of good rainfall, the water harvesting structures, which are built in a series, create large lakes in the coastal areas, which remain till the end of winter and sometimes even during summer. The water from these reservoirs is being used by villagers for a variety of purposes.



MAJOR FINDINGS

- The basins in Kodinar are characterized by flows with high variability. The runoff increases exponentially with the rainfall, as suggested by the rainfall-runoff relationship estimated for Singoda basin. The mean annual rainfall in the area is around 830mm. In nearly 50 per cent of the years, the river has huge outflows. Therefore, the strategy to transfer water from the rivers and streams through link canals to adjacent basins and store in mined out areas, in addition to building water harvesting and recharge structures such as check dams, is sound. It helps improve the cost effectiveness of water harvesting as the utilization potential of the runoff is increased without much increase in the storage capacity of the reservoirs.
- Analysis of hydrological impact of check dams in Harmadiya shows huge impact on groundwater regime, as indicated by higher average pre-post monsoon rise in water levels in the influence area of check dams, as compared to those outside the influence area. While the average increase in water level rise in the wells (due to monsoon rains) surrounding the check dam post intervention was 31.60, it was only 25.06 feet for the wells located outside the influence area of the check dam. This is quite different from the conventional approach of looking at the rise in water level between pre and post monsoon of the wells located in the vicinity of the water harvesting structure, and nullify the effect of during monsoon rainfall and likelihood of occurrence of greater rainfall in the locality during the year of observation and its effect on recharge of groundwater.

- The average recharge induced by the check dams in Harmadiya village was estimated to be 3.6cm, which is about 4.5 per cent of the rainfall. For a region with such hydrological, topographical and geo-hydrological features, the artificial recharge contribution, over and above the natural recharge from monsoon rainfall, is quite significant.

- The extent of water harvesting interventions undertaken by the Foundation and the local hydrological benefits they generate is evident from the fact that the increase in water spread area created by these impounding systems was around 3024ha, during the monsoon of 2010.

- High water table also meant high well yields, in view of the fact that the thickness of the aquifer increases. Higher depth to water table also means the farmers have to use less amount of energy available from electric motors for pumping groundwater. Higher well yields reduced the time spent in irrigating unit area of the crops. Greater well output also meant larger area of the farm under irrigation, increasing the overall farm outputs.
- Though no increase in area under irrigation was observed, a larger proportion of the cropped area was allocated to water intensive irrigated crops after the intervention, particularly sugarcane that give the highest returns per unit area of land amongst all the crops grown in that area. The same trend was found in the influence area of link canals and the farms surrounding the reservoir created by the mined out area.

- The overall increase in farm income per bigha of land, for the existing cropping pattern was estimated to be Rs. 3708, when only the area under seven important crops within that unit area was considered. Similar trend in cropping pattern shift was seen in the case of The farmers allocated greater proportion of their land to irrigated sugarcane after the interventions. But, a worrisome trend is the tendency among the farmers to shift to highly water intensive sugarcane, which earns them high returns per every unit of land, but gives very low water productivity in economic terms (Rs.3 .6/m^3) as compared to wheat (Rs.5.1/ m^3) and cotton (Rs.7.3/m3).

- The environmental impact of the water harvesting structures built in a series in Singoda basin is positive, as they create many lakes in streams of different orders. They change the micro climate through evaporation. The water is also being used by women and children for bathing, washing clothes, animal drinking and recreational purpose. However, care should be exercised while building more structures in future in this basin, and should be limited by the excess flows from the medium reservoir upstream and the total residual catchments.

BEYOND WATER HARVESTING: HOW BEST TO IMPROVE THE ECONOMIC RETURNS FROM WATER HARVESTING?

- The check dams and other water harvesting /recharge structures built by ACF create impact on the farm economy of the area in several ways. First: the continuous recharge from the reservoir created by the structure keeps the water level in the influence area high. But, it is important to note that the effectiveness of the intervention lies in making water available in the reservoirs when water levels in the aquifer starts drawing down. As noted by Kumar et al. (2006) and (2008), in the content of hard rock areas of Saurashtra, during years of good rainfall, the aquifers overflow leaving no space for the incoming flows from the reservoirs.
- In the case of Singoda River, in good rainfall years, continuous stream-flow is available from

the hilly, forested upper catchment, providing continuous inflow into the reservoirs created by the check dams, while water is drawn from the underlying aquifers, creating storage space for the impounded water. The contribution of check dam in providing additional recharge is evident from the higher, post-pre monsoon rise in water levels in the wells near the check dams as compared to those located away from the check dams.

But, there are limits to water harvesting in these basins, imposed by the hydrology and stream-flows. The next generation of interventions in the area should focus on improving the productivity of use of water. As the study shows, with improved recharge from the water harvesting/recharge structures, the farmers are increasingly using the water from their wells to highly water intensive sugarcane, merely because it gives high return per unit of land cultivated. Water productivity of this crop in relation to the irrigation water applied is very low under the traditional method of irrigation. Hence the attempt should be to promote water efficient irrigation among sugarcane growers or introduce new crops which yield high returns, but consume less amount of water.

ACKNOWLEDGEMENT

This paper is based on a study "Study of natural resources management for strengthening Agro - based rural livelihoods in ecologically fragile regions of Gujarat and Rajastan", supported by Ambuja Cement Foundation (ACF), Mumbai. We are thankful to officials of ACF Mr. Chandrakant Kumbhani and Dalsukh Vaghasiya for their cooperation and suggestions. We are thankful to Dr. M. Dinesh Kumar, Executive Director, Institute for Resource Analysis and Policy, who supervised and guided us in all our pursuits. We are also thankful to Dr. MVK Sivamohan, Principal Consultant, Institute for Resource Analysis and Policy, who provided suggestions and guidance in bringing out this paper.

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