



Integrated Rainwater Resource Management (iRaM) Model for Coastal South Gujarat

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Authors' contributions

This work was carried out in collaboration among all authors. Authors PKS and DN designed the experiment and wrote the first draft of the manuscript and author DN implemented and managed the literature survey. Author DPP performed analysis of soil samples. Author SVV analyzed the water and environmental parameters and author HST recorded relevant observations and analyzed data. All authors read and approved the final manuscript.

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ABSTRACT

The South Gujarat region has ample water availability, but, water shortage is being experienced during summer and water logging during monsoon. Also, due to large scale industrialization of south Gujarat, problems of air and water pollution have arisen which have become more complex because of over exploitation of natural resources 'ground water'. In many areas, due to continuous pumping of sweet water, sea water ingress has taken place and bores have become defunct as the water quality deteriorated drastically, due to which many cultivable farm lands have become uncultivable and are lying as wasteland. The water quality had deteriorated to such an extent that neither it could be used for drinking purposes nor for irrigation of crops. High intensity rains occur during the monsoon allowing very little opportune time for the water to infiltrate into the aquifers. All the rainwater during monsoon directly goes as runoff ultimately reaching the sea. Also, where ponds exist, catchment areas are disappearing due to construction work and ponds no longer receive rain water. So, an attempt was made to conserve the "rain water" natural resource while evaluating the potential of raising fish in small pond through harvested rain water. The water balance study was

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carried out in which meteorological and hydrological parameters like rainfall, evaporation, infiltration and runoff were measured and then using the water balance equation, the recharge amount was calculated and it was compared with the estimated recharge. It was concluded from the study that the rain water harvesting in small or big ponds not only replenishes aquifers but also checks deteriorating water quality in addition to providing sweet water fish harvest for economic gain.

Keywords: Rainwater; runoff; rainwater resource management.

1. INTRODUCTION

Navsari located at 20°55'24" N latitude and 72°54'30"E – Longitude receives more than 1500 mm torrential rains during monsoon. Just two decades back, the region had ample water available throughout the year and the landscapes were covered with lush green vegetation round the year. Unfortunately, since last few years water shortages are being experienced during the summer, whereas, water stagnation during monsoon. Rapid strides of development in the form of large scale industrialization have started showing up in the form of air and water pollution, the situation is more complex because of over exploitation of natural resources 'ground water'. The number of dug wells increased from 3.86 million to 9.49 millions and the number of shallow wells has increased from 3000 to 4.75 million over the last 50 years and the trend is still increasing resulting in over exploitation of ground water [1]. The increased use of ground water and limited recharge have lowered the water table to such an extent that yield of many dug wells and tube wells have decreased substantially especially during summer [2]. Most of the farms, suffer from deteriorating soil health, receding water tables, polluted ground water, soil erosion, water scarcity during rabi and summer months and water logging during monsoon.

In many areas, due to continuous pumping of sweet water, sea water ingress is taking place and bores have become defunct as the water quality deteriorated drastically, due to which many cultivable farm land became uncultivable and are lying as wasteland [3]. The water quality had deteriorated to such an extent that neither it could be used for drinking purposes nor for irrigating the crops. High intensity rains occur during the monsoon allowing very little opportune time for the water to infiltrate into the aquifers [4]. All the rainwater during monsoon directly goes as runoff ultimately reaching the sea. Earlier, there were several ponds in the coastal areas, which used to store rain water, but with the increase in population, building complexes have replaced

ponds. In the monsoon, this approach of conserving rainwater by recharge using pond is important because, as in India, the bulk of the year's rainfall is received in some 100 hours of heavy downpour, providing little time for recharging the groundwater [5]. Also, where ponds exist, catchment areas are disappearing due to construction work or obstruction in the flow of natural drains, resulting in missing catchment areas of ponds. Even ponds in cities and towns that used to receive water from surrounding catchments are surrounded by concrete jungle and roads forcing governments to fill such water bodies by canals so as to meet city water supplies. The soil and water management technologies being implemented in India include safe diversion of water to ponds [6]. Farm ponds in gullies or private fields for supplement irrigation and water conservation is recommended for several states of India [7]. The rainfall runoff water in a farm pond is an optimum solution for meeting the water needs of the crops during dry spells [8]. Ponds add value to activities of farming as water from ponds can serve domestic and livestock water supplies as well as irrigation for high-value crops and vegetables [9].

Fish farming of both brackish water and sweet water fish has picked up in most of the coastal areas. In many areas, raising brackish water fish in mainland is resulting in further aggravating the already fragile water quality situation in the coastal villages. In this study, an attempt was made to conserve the "rain water" natural resource while evaluating the potential of raising fish in a small pond through harvested rain water. In this model, ground water table fluctuations, pond water level fluctuation, infiltration, peak discharge, ground water recharge, pond water quality and fish production were studied.

2. MATERIALS AND METHODS

The study was carried out at two locations (Location 1 – Farm pond of Regional Horticultural Research Station and Location 2 – Pond near

College of Forestry) of Navsari Agricultural University campus, Navsari, Gujarat, India over a period of four years. (i.e. 2014-15, 2015-16, 2016-17, 2017-18). The water harvesting structures were different based on their catchment area of the campus. Four different freshwater fish varieties viz. Grass, Catla, Rohu and Mrigal carp were released in rainwater filled pond to assess the growth and yield. Different periodical observations on water quality of pond water and fish were recorded. The parameters of the pond at location-1 and location-2 are given in Table 1.

The Integrated Rainwater Resource Management (iRaM) model is the model which incorporates utilization and management of rainwater with aim of augmenting ground water recharge, water conservation and economic benefits through fish rearing.

The Integrated Rainwater Resource Management (iRaM) model is shown in Fig. 2.

$$\text{Recharge} = \text{Rain} - \text{Storage} - \text{Evaporation} - \text{Runoff}$$

2.1 Peak Discharge Estimation Model

Empirical equation (1) developed for micro watersheds of South Gujarat was used to calculate peak discharge [10].

$$Q = 0.15557 \times A + 0.0161 \quad (1)$$

Where, Q = peak discharge in cubic meter per second and A = Area in hectares

2.2 Estimation of Ground Water Recharge

The amount of rainfall recharge depends on various hydro meteorological and topographic factors, soil characteristics and depth to water table.

Recharge from rainfall was computed using the empirical equation (2) suggested by [11].

$$R_r = 3.984 (P - 40.64)^{0.5} \quad (2)$$

Where,

R_r = Recharge to the groundwater (cms),
 P = Monthly precipitation (cms).

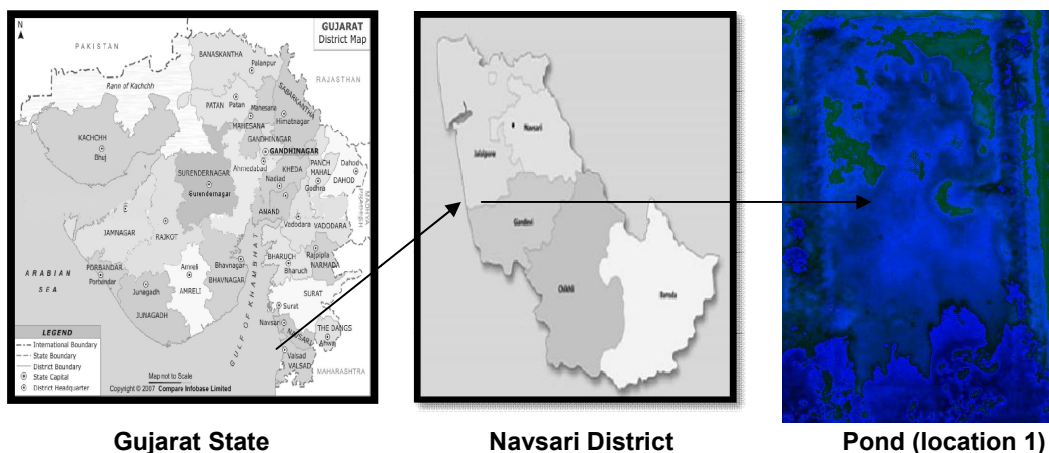


Fig. 1. Location of the study area

Table 1. Pond dimensions

| Sr. no. | Parameter | Location-1 | Location-2 |
|---------|---|------------------------------|-------------|
| 1. | Size | 54 m x 100 m | 27 m x 10 m |
| 2. | Depth (BGL) | 3 m to 5 m | 1 m |
| 3. | Outlet (BGL) | 1 m | 0.4 m |
| 4. | Maximum water storage depth | 3m | 0.6 m |
| 5. | Volume (cubic meter) | 16200 | 162 |
| 6. | Catchment area (ha) | 6 ha | 1 ha |
| 7. | Time period to fill up the pond at the time of peak discharge | 4 hrs 50 minutes or 290 min. | 16.2 min. |

(BGL: Below ground level)

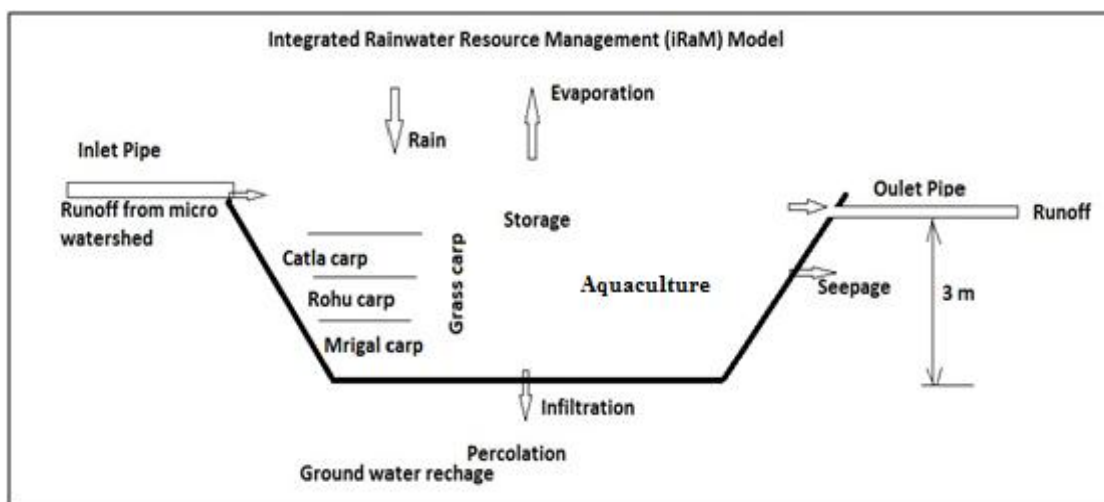


Fig. 2. Integrated Rainwater Resource Management (iRaM) model

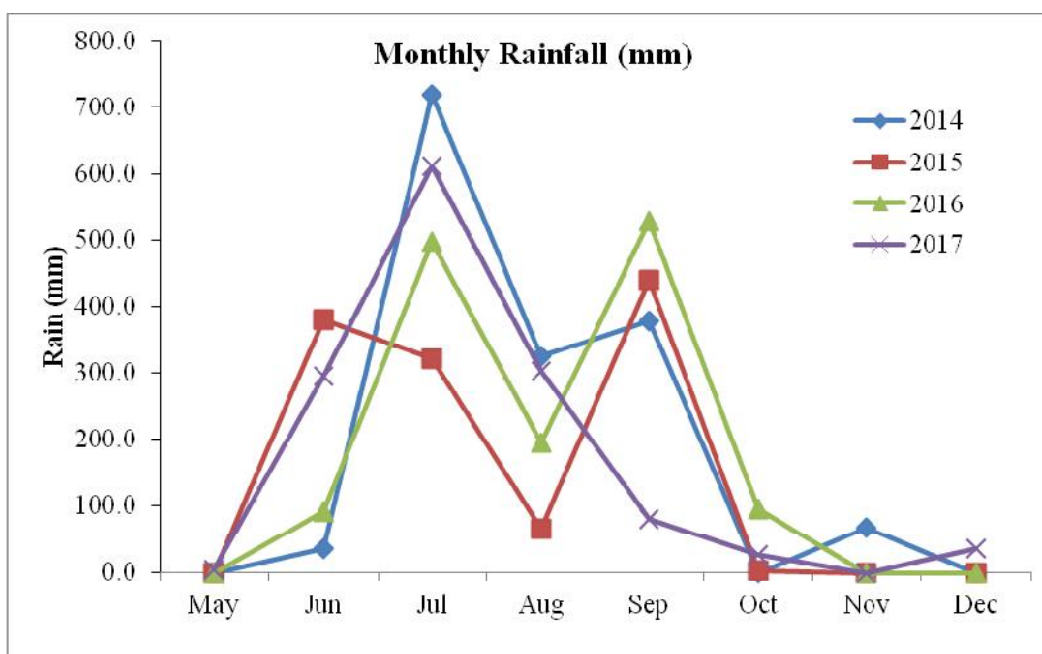


Fig. 3. Monthly rainfall (mm) from 2014-2017 of NAU campus

$$R = 1.35 (P-14)^{0.5} [12]$$

Where,

R = net recharge due to precipitation in inches,

P = Precipitation in inches.

The meteorological data (rainfall and evaporation) during the research period were obtained from the Department of agro-meteorology of Navsari Agricultural University.

3. RESULTS AND DISCUSSION

3.1 Rainfall

Rainfall data for the period of the study indicated that the initiation of monsoon was from June end, maximum rainfall in the months of July followed by September, moderate rains in August and finally monsoon started withdrawing from middle of October (Fig. 3). It showed that good quality rain water was available from mid of July till

October end and if this water was conserved in the pond then it could be used to rear sweet water fish.

3.2 Storage

The storage of ponds was determined based on the pond water level fluctuations on location-1 and location-2. The fluctuations of pond water were recorded daily during the study period.

3.2.1 Pond water level fluctuations

Daily water table fluctuations were observed after monsoon, for a month in both the fish ponds (Fig. 4 and Fig. 5). It is evident from the graph, that rise in line is only when water is added to the pond to maintain the water level in the pond,

which is essentially required for survival of fish. The receding trend line also indicates ground water recharge, which continues at a very fast pace mainly due to ground water pumping by surrounding bore wells for irrigating rabi crops. However, stored rain water helps in maintaining the ground water quality of bore wells. Depleting water levels also indicated that there was less than normal and erratic rainfall during last three years, high intensity rainfalls in short durations resulted in lesser recharge and more runoff. In a fish pond near college (Location-2), during 2015 and 2016, to maintain the water level for survival of fishes, water was added almost daily by connecting excess water disposed while irrigating nursery, lawns and other green house grown crops.

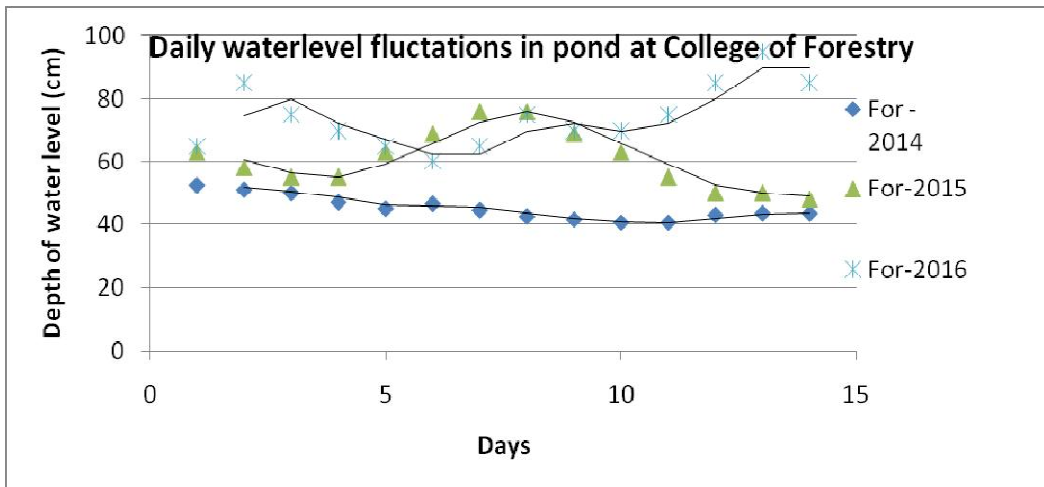


Fig. 4. Daily water level fluctuation in pond at location-2

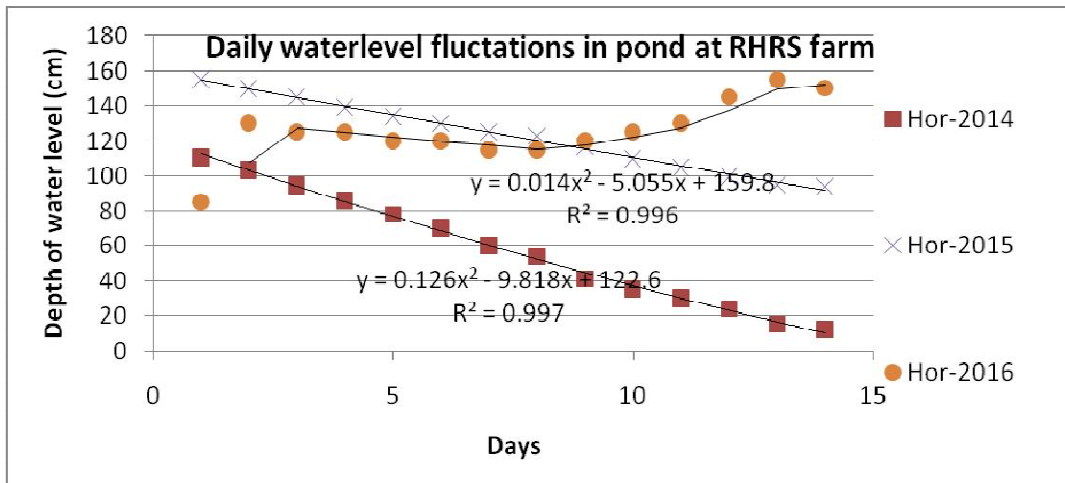


Fig. 5. Daily water level fluctuation in pond at location -1

Depth of water table fluctuations in Location-1 during 2014 and 2015 shows receding trend after cessation of the monsoon, whereas in 2016, the pond was filled by canal or well water which is evident from the rising graph.

3.2.2 Ground water table fluctuations

Water table fluctuations were observed in an open well near the pond of location 2, the average water table depth remains at around 5 to 6 m from July to Dec., the well dries after January; the observations show the water table was closest to surface in 2016 followed by 2017, 2015 and deepest in 2014. Although there was highest rainfall in 2014, but, most of it was in the form of high intensity downpours in the month of July, resulting in runoff and lesser ground water recharge. Trend lines of each year were plotted in Fig. 6 which show the falling trend of water level after cessation of the monsoon, eventually the water level falls below 7 m BGL after January. It may be inferred from these observations that there is a need of more water harvesting water bodies to recharge groundwater. The water table fluctuations in open well are given in Table 2.

Therefore, it shows that these ponds get filled up in a day or in a very short time, after onset of the monsoon, subsequent to initial abstraction.

3.2.3 Infiltration in the micro-watershed

The infiltration rate of micro watershed was obtained through a series of observations using double ring infiltrometer. Infiltration rate representing actual field conditions with the best fit line $y = -6.42\ln(x) + 47.70$ with R^2 of 0.99, whereas cumulative infiltration equation is

$$y = 1.145 x^{0.676}$$

with r^2 of 0.98 is shown in Fig. 7. It is observed that in four months period total infiltration from the above equation is around 300 mm.

3.3 Evaporation

The evaporation was maximum in 2014 and minimum in 2017, however, the evaporation during the period of fish rearing, i.e. in months of July to December remained almost similar (Fig. 8). In July 2014, there were events of high intensity rainfall on the dates 16, 29, 30 and 31 amounting to 121, 181, 110 and 44 mm respectively and again in the same year on Sep. 10 there was 225 mm rainfall. Whereas, in Sep 2015 on the dates 19, 20, 21, 22 there were continuous rains amounting to 175, 67, 60 and 26 mm respectively. In 2016, high rainfall events of 12, 125 and 64 mm were there on Sep 8, 19 and 20 respectively.

Table 2. Water table fluctuations in open well, below ground level (m)

| Year | Best fit trend line | R ² |
|------|---------------------------------|----------------|
| 2014 | $y = 0.738x + 3.416$ | 0.96 |
| 2015 | $y = 1.125x^2 - 5.05x + 10.23$ | 1.00 |
| 2016 | $y = 0.409x^2 - 2.649x + 7.942$ | 0.75 |
| 2017 | $y = 0.193x^2 - 1.000x + 5.925$ | 0.87 |

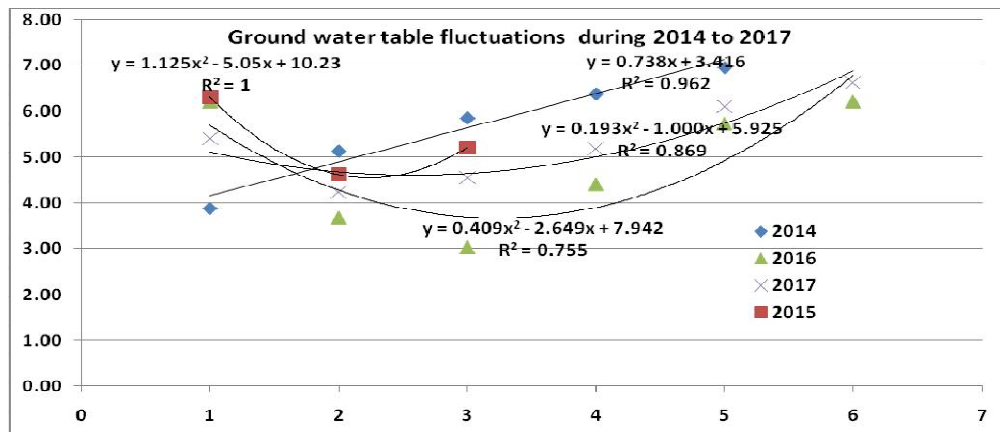


Fig. 6. Ground water table fluctuations during 2014 - 2017

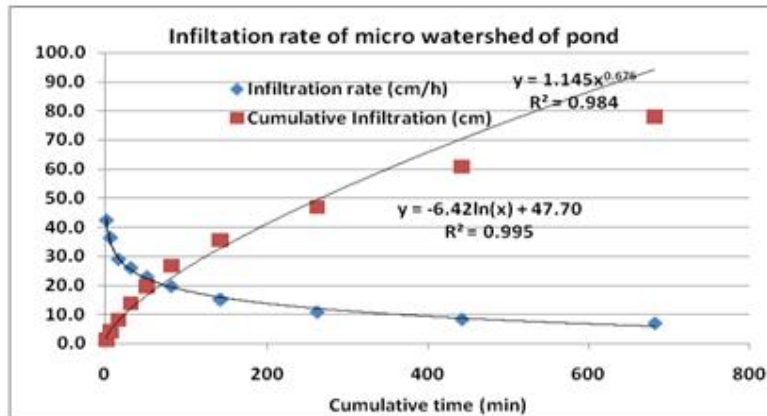


Fig. 7. Infiltration rate of micro watershed of pond

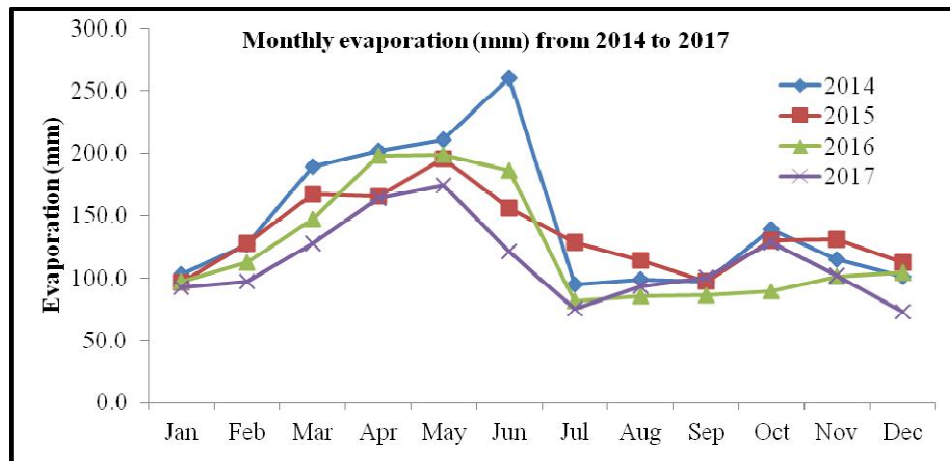


Fig. 8. Monthly evaporation (mm) from 2014-2017 of NAU campus

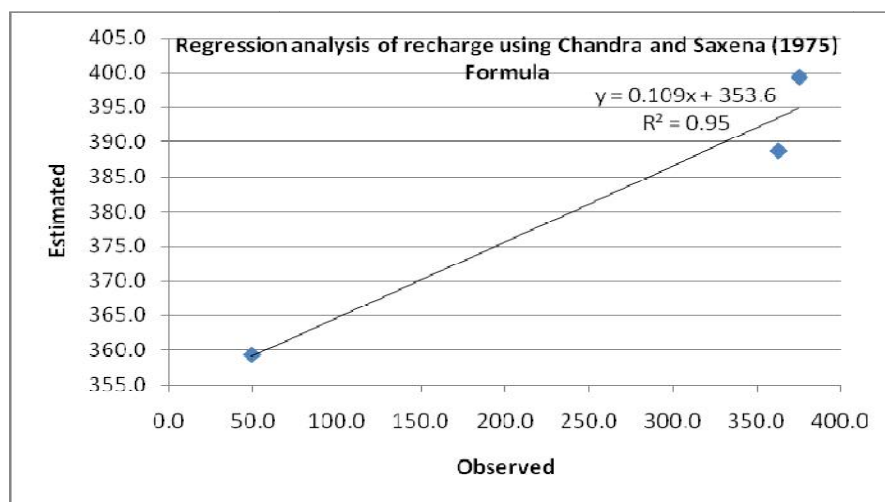


Fig. 9. Regression analysis of recharge using Chandra and Saxena [11] formula

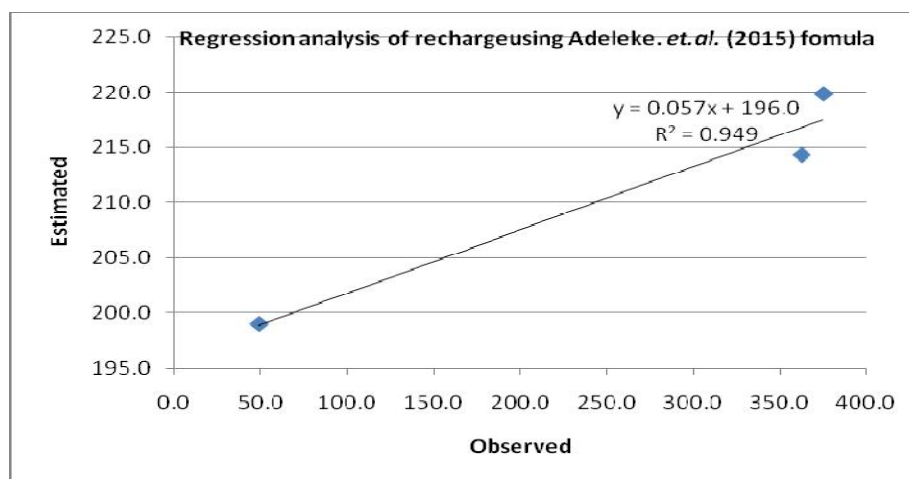


Fig. 10. Regression analysis of recharge using Adeleke et al. [12] formula

3.4 Ground Water Recharge

The trend lines of both the estimation formulas Chandra and Saxena [11] and Adeleke et al. [12] showed a positive relation in regression analysis, with r^2 value of around 0.95 thus showing these estimation formulas could be used for estimating ground water recharge (Figs. 9 and 10).

During 2014, there were erratic events of very high intensity rains in July, in which most of rainfall went as runoff without effective recharge, so for estimation purpose data of 2014 was not considered. The hypothesis is also supported by the ground water table fluctuation of 2014, despite sufficient rainfall; most of it went as runoff.

3.5 Ground Water Quality

Temporal variations in ground water quality were observed from Jan 2014 to Dec. 2017, it shows the ground water quality of well at Location-1 was better than average water quality of different wells of the University. It shows that it varies around 1.5 dS/m during the last four years; the pond constructed in 2009 has effectively maintained irrigation water quality which should be below 2 deci-seimens/metre. The water quality improved in 2016 and 2017, as the excess water from the canal is allowed entry in ponds. However, during brief periods from Nov. 2016 to Mar. 2017, it got deteriorated due to continuous irrigation in the surrounding fields and absence of canal water supply at that time. Whereas, ground water quality of bore well near Location-2 was not of acceptable quality from

2014 till 2015, as there are many wells nearby, catering to the domestic needs of neighboring settlements outside the college boundary, which is hardly 50 m, whereas optimum distance between two wells should be at least 300 m in clay soils. The small pond is not only used for rain water recharging, but also for harvesting diverted excess water from poly houses / nurseries in the vicinity. The temporal variation in ground water quality is shown in Fig. 11 and Fig. 12. The graph indicates the water quality is worse in the well near Location-2; even the average water quality of the wells of the University is superior. The observations underline the need of such water harvesting ponds to sustain ground water quality. Ground water quality showed improvement in 2016 and 2017 despite less rainfall due to diversion of excess water in pond, which eventually percolates to ground water aquifer.

3.6 Pond Water Quality

The main water quality parameter which is very important for fish production is Dissolved oxygen. Successful fish production depends on good oxygen management. Oxygen is essential to the survival (respiration) of fish, to sustain healthy fish and bacteria which decompose the waste produced by the fish, and to meet the biological oxygen demand (BOD) within culture system. Dissolved oxygen levels can affect fish respiration, as well as ammonia and nitrite toxicity. The recommended minimum dissolved oxygen requirements for tropical freshwater fish is 5 mg/L [13]. In the study, the dissolved oxygen was found within the limit. However, in some

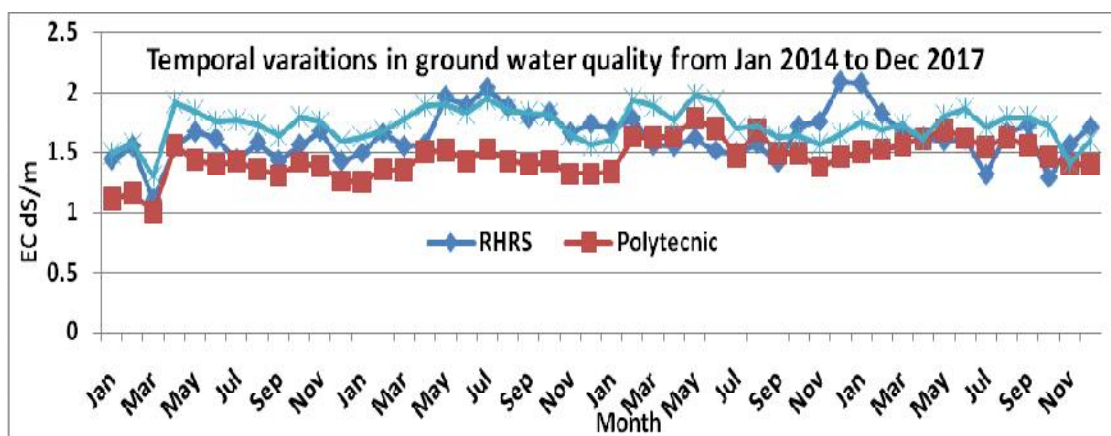


Fig. 11. Temporal variation in ground water quality from Jan 2014 to Dec 2017

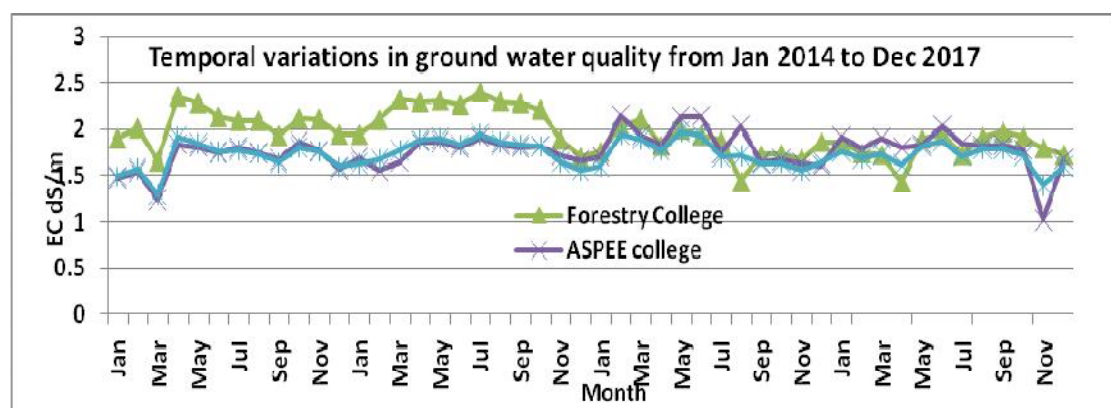


Fig. 12. Temporal variation in ground water quality from Jan 2014 to Dec 2017

Table 3. Water quality of pond water

| | | Mean | SD (±) |
|-------------------|------------------|-------|--------|
| Horticulture pond | Temperature (°C) | 20.21 | 0.57 |
| | pH | 7.90 | 0.44 |
| | EC (mS) | 1.21 | 0.58 |
| | DO (mg/l) | 6.56 | 1.91 |
| | BOD (mg/l) | 2.19 | 2.62 |
| | COD (mg/l) | 251 | 100 |
| Forestry pond | Temperature (°C) | 20.57 | 0.79 |
| | pH | 8.23 | 0.53 |
| | EC (mS) | 1.33 | 0.74 |
| | DO (mg/l) | 5.98 | 2.45 |
| | BOD (mg/l) | 3.22 | 2.76 |
| | COD (mg/l) | 166 | 59 |

instance after monsoon, DO was observed less than 5 mg/L. This is due to the less input of freshwater and accumulation of waste.

Organic waste from agricultural and urban runoff, acts as a food source for water-borne bacteria.

Bacteria utilize these waste using dissolved oxygen, thus reducing the DO present for fish. Biochemical oxygen demand (BOD) is a measure of the amount of oxygen that bacteria will use in decomposing organic waste aerobic conditions. While, Chemical oxygen demand

(COD) is a measure of the amount of oxygen of strong chemicals decomposing organic waste aerobic conditions in the laboratory. In this study, BOD and COD values are found well below the value in polluted water. General standards for discharge of environmental pollutants given by CPCB for BOD are 30 mg/L and COD is 250 mg/L (for inland surface water). However, as in DO, The BOD and COD values are observed higher in some cases may be due to the less input of freshwater and accumulation of waste from runoff. The water quality of pond water is given in Table 3.

3.7 Status of Pond Bottom Soil

Available nutrient, EC and SOC of soil at the bottom of pond after taking up final harvest of fish was analyzed. The mean pH of soils of the pond bottom, in both the ponds, indicates that soils are alkaline in reaction. As, the soil pH is most important factors for maintaining pond productivity - controls most of the chemical reaction in the pond environment. Near neutral or slightly alkaline pH is ideal for fish production. Whereas, when the pH is too low - strongly acidic - reduce the availability of key nutrients in the water and reduces pond productivity. The electrical conductivity of the soil samples for the

Location-2 is normal, but at Location-1 it was high. Soil Organic Carbon, which acts as the source of energy for bacteria and other microbes that release nutrients through various biochemical processes, is found to be medium and low in Location-1 and Location-2 respectively. Nitrogen, phosphorous and potassium are the major nutrients required by phytoplankton, the available N is low in both the ponds, the available P₂O₅ is medium in Location-1 and is low in Location-2, whereas, available K₂O is at a higher level in both pond samples. The best method to sustain quality of soil in aquaculture ponds is to select a site with good soil and an adequate supply of good quality water. If this is done, liming, fertilization and aeration can prevent more soil and water quality imbalances. Proper pond management viz. liming, fertilization, aeration, water exchange and bottom soils drying and oxidation are the keys to improving soil and water quality in ponds. To optimize the land use the pond bottom could be used for raising rabi and summer crops, that may help in maintaining the biosphere of pond bottom which could have a positive impact on fish production. The nutrients, EC and organic carbon on the pond bottom after final harvest is given in Table 4.

Table 4. Nutrients, EC and organic carbon of pond bottom after final harvest

| Sr. no. | Location | Depth (cm) | pH (1:2.5) | EC(1:2.5) dS/m | SOC | Available nutrients | | |
|---------|------------|------------|------------|----------------|------|---------------------|---------------------------------------|--------------------------|
| | | | | | | N (kg/ha) | P ₂ O ₅ (kg/ha) | K ₂ O (kg/ha) |
| 1. | Location 1 | 0-15 | 7.41 | 3.15 | 0.50 | 191.14 | 118.39 | 1262.37 |
| | | 15-30 | 7.92 | 1.46 | 0.66 | 230.81 | 95.24 | 1144.47 |
| | | Mean | 7.67 | 2.30 | 0.58 | 211 | 107 | 1203 |
| 2. | Location 2 | 0-15 | 8.44 | 0.80 | 0.43 | 164.09 | 87.85 | 645.08 |
| | | 15-30 | 8.67 | 0.50 | 0.21 | 90.16 | 30.34 | 803.63 |
| | | Mean | 8.56 | 0.65 | 0.32 | 127 | 59 | 724 |

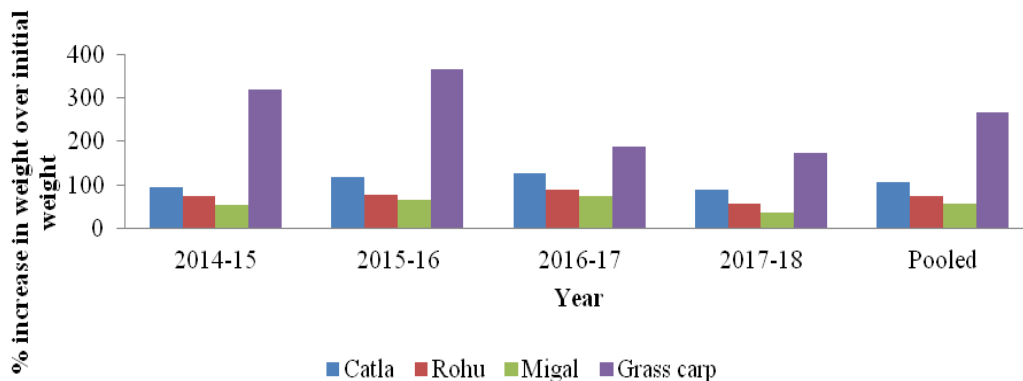


Fig. 13. Percentage increase in fish weight over initial weight at location-1

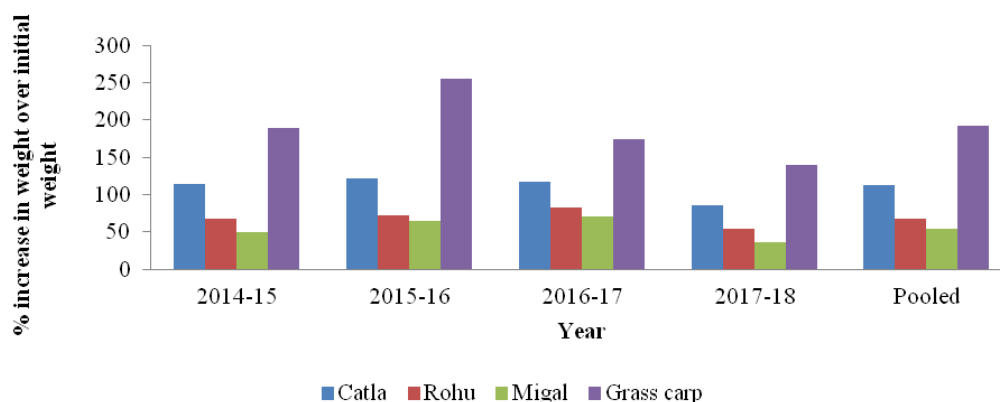


Fig. 14. Percentage increase in fish weight over initial weight at location-2

3.8 Fish Production

The seeds of different varieties of fish used during the experimental period were purchased from local markets. The measurement of initial weight was carried out at the time of release, while final weight was noted at the harvest. The percentage increase in fish weight after the initial weight shown in Fig. 13 and Fig. 14 for four years and pooled analysis, the results depicted that grass carp fish reported maximum increase in percentage of weight over initial weight, in both studied ponds (268 and 193%) which is followed by Catla and Rohu fish.

4. CONCLUSIONS

It was concluded that rain water harvesting in small or big ponds not only replenishes aquifers but also checks deteriorating water quality in addition to providing sweet water fish harvest for economic gain. For coastal south Gujarat, it is suggested that approximately 10% area of the farmland may be allocated for a pond so as to store 2.5 m deep water, to harvest rain water / excess canal water. As per the agro climatic situation of the region fish should be kept ready to be transferred in the pond in the first week of July. Farmers who do not have a facility to refill water into the pond should take the harvest in the first week of November, *i.e.* in four months time. Whereas, farmers who get excess water from the canal or have the facility to maintain the water level for a longer period, may harvest fish for more economic return. To prevent fish from flowing away from the pond along with overflowing water, protection of steel wire mesh firmly tied to iron girders is required on the outlet of the pond, as few events of high intensity

continuous rains lasting two to four days could occur during the monsoon.

The results of soil properties show that the soil of the Location -1 pond has an optimum reaction to the fish growth, whereas, it was inferior, at the forestry college. Both the ponds were deficient in SOC (%) and available N (ppm), is low in both the ponds, the available P_2O_5 is medium in Location -1 pond and low in the Location -2 pond; while, available K_2O is high in both pond samples. Therefore, pond bottom should be used for taking short duration *rabi* or summer crops with recommended application of fertilizers, it will not only supplement the income per unit area, but also help to sustain the biosphere of the pond bottom. Grass carp showed the highest increase in fish weight followed by Catla, Rohu and Mrigal.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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