Journal of Geomatics Vol 10 No. 2 October 2016

Assessing impact of water resources development: A case study of Bhukhi watershed (5H2B5), Kachchh district, Gujarat, India

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(Received: Feb 28, 2016 , in final form: Oct 23, 2016)

Abstract: Impact analysis of water resources development over a period of 20 years has been carried out to understand the trend of salinity variation for 750 sq km area of Bhukhi watershed (5H2B5) covering about 70 villages located in semi-arid coastal region of Kachchh district, Gujarat. The study is based on watershed approach, with the use of Remote Sensing (RS) and Geographic Information System (GIS) techniques. The thematic maps like watershed, drainage, land use /land cover, geomorphology, ground water level and ground water quality were prepared at 1:50,000 scale using Landsat and IRS LISS III (1994-2013 period) and ancillary data. The watershed was characterized based on observed changes in groundwater levels and salinity by using linear trends fit to well-monitoring data of 1994 to 2013 period for 7 observation wells. When compared with the TDS and ground water level value of 1994 to 2013, 6 out of 7 villages showed increase in water level. It is observed that till 2006, the Kachchh Irrigation Circle (KIC) constructed 7 large Bandharas and 105 smaller Check-dam structures. Based on geospatial analysis our estimates indicate that the number. of water harvesting structures have increased, simultaneously percent agriculture area has increased and Number of heads of population affected is reduced, ground water level has risen and salinity has decreased.

Keywords: Geomatics, Watershed development, Remote sensing, GIS, Kachchh, Rain water harvesting

1. Introduction

Water is an essence of life. It is a very vital resource on earth gifted by nature and a very essential resource for any type of development worldwide (Mariappan et al., 2005). Water is available in the form of surface water and groundwater resources. Groundwater is most sustainable and reliable resource than surface water. Availability of groundwater depends on local hydro-geological condition (Jameel, 2002) However, groundwater is, sometimes, over exploited. Any type of economic development depends on land and water resource potential of the area (Rajmohan et al., 2002). Bhukhi watershed, the western most part of Gujarat is an arid region characterized by water crisis and repetitive drought cycles. It has a very low potential of surface and groundwater resources. The geological formations are deposited in marine environment and are hence having inherent salinity. Therefore, availability of potable groundwater is highly restricted. During the last three decades the study area had a major share of industrial investment and development as compared with other regions of Kachchh. This development can be attributed to location of Mandvi port town within the coastal part of study area and Mudra port town in adjacent watershed located in the east. Along with industrialization, population and basic infrastructure have also grown. Resultantly, manifold increase in industrial and domestic water demands have put groundwater resource of the study area under tremendous stress and also adversely affected long practiced agricultural industries of the region. Area being coastal region, over exploitation of groundwater has invited the threat of seawater intrusion in the aquifers having considerable environmental implications. Realizing the fact, Kachchh Irrigation Circle (KIC) developed several multipurpose water resources structures in Bhukhi watershed. Meaningful and effective solutions exist in the Bhukhi watershed and that will set the right course for growth and development of agriculture and fulfil the requirements of people of villages as well as towns in the watershed. This paper deals with the evaluation of impact of water resources development and changes in Bhukhi Watershed over a period of two decades (1994-2013) by using Geomatics techniques.

2. Study area

The Bhukhi watershed is the study area. It is identified as 5H2B5 in AISLUS Atlas (Anon, 1990), comprises of 82 micro-watershed and covers 750 km^2 area and is located in coastal arid agricultural region of Kutch district, Gujarat. Geographically the watershed area extends from 22^{0}42'00" to 23^{0}12'00" north latitudes and 69^{0}26'46" to 69^{0}57'00" east longitude (Fig. 1). Administratively it covers 70 villages and is bounded by Bhuj taluka in the north, Anjar taluka in the northeast, Mandvi taluka in the west and Gulf of Kutch in the south.

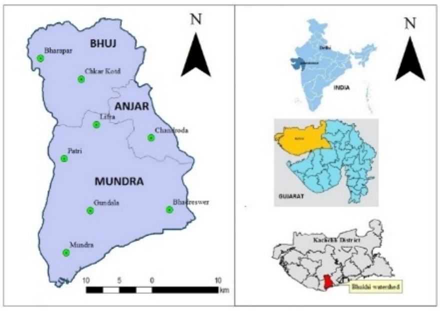

Figure 1: Location of Bhukhi watershed

3. Objectives and scope of work

The main objective is to carry out an in-depth study on the impact of water resources development in Bhukhi Watershed, Kachchh district, Gujarat by using temporal remote sensing and observation well data.

Detailed tasks are as under:

- Preparation/ collection and compilation of various theme layers such as, Geomorphological map, Lithological map, Land use / Land cover map and map of drainage and surface water bodies.
- Watershed characterisation through analysis of theme layers.
- To study dynamics of rainfall and ground water quality variation in the spatial and temporal context using remote sensing and GIS techniques.
- Decadal analysis of development of water harvesting structures and assessment of their impact on water quality.
- Study of impact of water resources development on livelihood and socio-economic profile.

4. Data used

In this study the multi-date satellite data corresponding to the Kharif, Rabi and Summer seasons has been used. The collateral data collected in the form of published maps, reports, charts, etc., from Central and state Government line Departments are also used for the study.

4.1 Satellite data

Indian Remote Sensing Satellite (IRS) Resourcesat-1 and LANDSAT satellite data for Rabi, Kharif and Summer season for the period 1995 to 2015 have been used. IRS data was procured from National Remote Sensing Centre, Hyderabad and freely available LANDSAT data was downloaded from USGS Website (http://www.landsat.usgs.gov).

The data comprises of Geo-coded products of IRS LISS III & LISS IV, AWiFS, Landsat TM and MSS. Table or list of data with path and row.

4.2 Collateral data

- Village boundary maps, Taluka / Block maps and Settlement locations from the District Administration.
- Daily and weekly Rainfall data from IMD and State irrigation dept.
- Hydrological data mainly observation well information on ground water level, quality as total dissolved solids (TDS) fluctuation from GWS&SB, GWRDC, SWDTC, Gandhinagar
- Watershed boundary map at 1:50,000 scale (based on AISLUS Atlas) from SAC.
- Published Geological and geological structures maps from Geological Survey of India and Oil and Natural Gas Commission.
- Maps of Drainage, Surface water body, Ground water prospects from SAC.
- Data of surface water bodies form KIC- Bhuj.

5. Methodology

The methodology comprised preparation, collection and compilation of various theme maps. Time variable remote sensing data along with other collateral data was used in onscreen interpretation to prepare theme maps like drainage, watershed, geomorphology and lithology. The temporal hydrogeological information from observation wells for period 1993 to 2013 was compiled and used to prepare Isobath (Hydro-isobath and TDS-isobath) maps in GIS environment. Village boundary and settlement location were geo-referenced with the watershed boundary and the attribute information on the number and type of water harvesting structures constructed by government agencies were attached. Comparative analysis of above data to assess the temporal variations and possible impact on water resources in terms of ground water quantity and quality variation was carried out in GIS environment. The details of theme maps prepared are given below.

5.1 Drainage and watershed map preparation

The shape of watershed and its area extent are significant indicator for understanding the behaviour of rainfall runoff and also the nature of geological control in the region. The boundaries from Watershed Atlas of India (Anon, 1990) have been superimposed on satellite data and drainage map is prepared. The watershed and micro-watershed boundaries are then updated using this drainage map. The information on slope / elevation obtained from SRTM DEM is also used to prepare the final watershed map showing the micro-watersheds (Fig. 2).

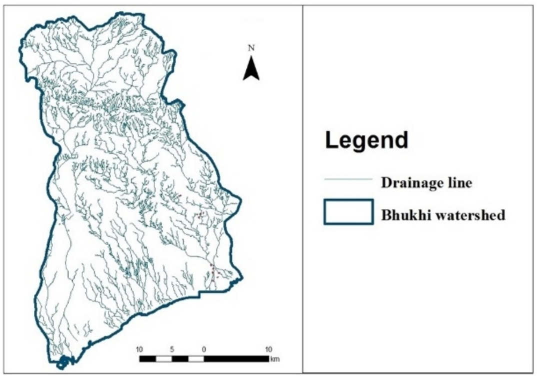

Figure 2: Drainage map of Bhukhi watershed

5.2 Lithology map preparation

The lithological map (Fig. 3) is prepared using satellite data and available maps from Geological Survey of India (GSI) and Oil and Natural Gas Commission (ONGC). The various litho units have been stratigraphically identified using the available published maps and accordingly classified into litho-stratigraphic units. The available litho-stratigraphic boundaries obtained from published maps have been modified as per image signature at the micro level. Vesicular basalt is a dominant litho-stratigraphic unit occupying 40.16 percent of the study area followed by sand stones which occupy 39.79 percent of the study area. Other litho-stratigraphic unit occurring in the study area are Madh, Recent clay, Sandy clay together occupying 20.05 percent of the study area.

5.3 Geomorphological map preparation

Information on landforms is an important input for land management, soil mapping and identification of potential zones of groundwater occurrence. The geo-morphological map is prepared using multi-date satellite data of three season (pre, post monsoon, summer season) data (Fig. 4). This shows the spatial extent and distribution of various landforms in the study area. It is observed that coastal type landform is dominating in the study area. The Pediplain with 35.11percent area is dominant class. The alluvial plain the plateau are second dominant class with 18.97 percent and 31.78 percent area respectively. Other geomorphic units occurring in the study area are coastal plain, deltaic plain, structural hill, flood plain and river-body mask having 14.14 percent area.

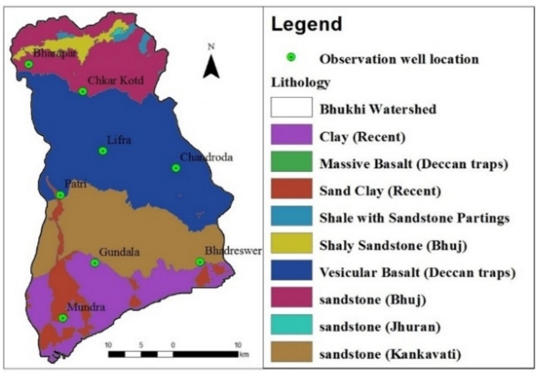

Figure 3: Lithology map of Bhukhi watershed

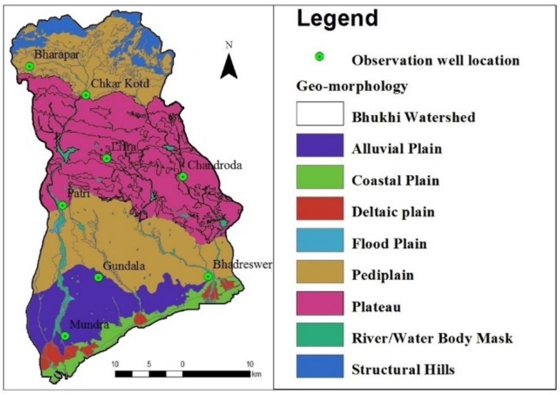

Figure 4: Geomorphology map of Bhukhi watershed

Due to data gaps in observation well at Mudra, hydrological data of 7 observation wells was considered for analysis. Sample Hydro-isobath map of 2013 is given in Figure 5.

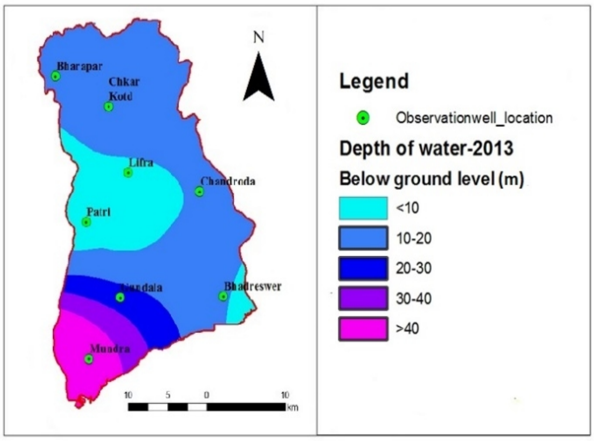

Figure 5: Hydro-isobath map (2013)

6. Results and discussions

6.1 Ground water level fluctuation analysis

Study on hydro-geological aspects of any area play a pivotal role in understanding the various geological controls on ground water regime. The hydro-geological attributes viz; distribution, chemical content of ground water and relative potential in time and space serve as a basis to formulate strategies for development and management of resources (Sazian, 2012). Water levels in the Bhukhi watershed generally follow a cyclic pattern that mimics seasonal variations in recharge and discharge. High water levels occur in the rainy season when recharge from precipitation exceeds discharge; low water levels occur during the dry summer when discharge by pumping, evapotranspiration, and leakage to streams exceeds recharge.

Hydrogeological survey of Mundra Taluk was carried out by Arid Communities and Technologies (Anon., 2006) has divulged that the huge number of abandoned sources / Wells are identified and it clearly point out the depletion in water levels and deterioration in ground water quality. As per GWRDC, the Mundra Taluka has remained as

Dark Zone until 2002 and later re-graded as Semi-critical Zone as a part of ground water potential assessment during year 2007 indicating improvement in ground water conditions.

Realizing this fact, Groundwater fluctuation has been analysed based on historic data collected from GWRDC over a 20 years' period from 1994-2013. Secular change in water level fluctuation has been analysed through isobaths map, hydrographs for all 7 locations of observation wells. Average Groundwater levels in the area ranges from 9.9 m to 60.5 m below ground level. Following graph (Fig. 6) shows the average water level of the observation wells.

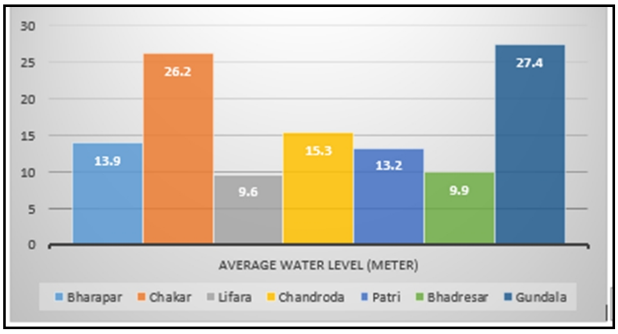

Figure 6: Average ground water level of observation wells (1994-2013)

The average rate of decline of ground water level in Bhukhi watershed is -2.5 m/year. When compared, the water level of 1994 with 2013, 6 out of 7 villages show increase in water level (Fig. 7).

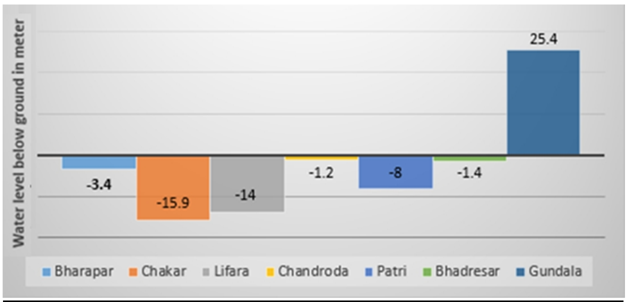

Figure 7: Difference of water level between 1994 and 2013 of observation wells

Spatial distribution pattern of seasonal behaviour of water levels on an annual basis gives an insight in demarcating the areas inflicted from the problems of over exploitation and the balanced utilization of groundwater resources.

Hydro-isobath maps between 1994 to 2006 period prior to industrial development is representing water demand in irrigation and domestic sectors. However, this represented 12 years' scenario display quite an alarming situation of lowering of water table in the study area. Although approximately 50 percent of the study area has witnessed rise in water table, remaining 50 percent study area has suffered from the problem of water table decline. Hydro-isobaths map representing phase 2006-2013 demonstrate rise of groundwater storage. There has been a perceptible rise in all the categories pointing to lowering of groundwater levels. Even the area showing fall in water table for the period (1994-2005) has increased significantly. This sharp increase during 8 years i.e. (2006-2013) may be possibly ascribed to development of water resources on Bhukhi watershed.

Maximum water level of 1994 is considered as baseline for the analysis which is 40 meter below ground level. During the period of 1994 to 2002, the water level decrease below the baseline and area below the baseline is increase from 3.1percent to 39.7 percent in the study area. After 2002, the water level rises in the study area and the area below 40 meter is reduced to 12.5 percent at the end of 2013. In 2013, only western part of the study area around Mundra region shows ground water level greater than 40m, which may be possible due to industrial growth in that area. Based on the analysis of hydrographs and isohyets, the area under water level above 40 m and No. of villages are calculated as shown in Table1.

Table 1: Percent area and number of villages benefited due to rise in ground water level above the baseline water level of 40m B.G.L

Sr. No.	Year	Percent area		No. of village benefited
		SWL >40 m B.G.L	SWL <40 m B.G.L	
1	1994	3.1	96.9	3
2	1998	2.5	97.5	2
3	2002	39.7	60.3	29
4	2006	18.9	77.4	15
5	2010	16.7	77.3	12
6	2013	12.5	76.8	9

6.2 Ground water salinity analysis

Groundwater quality is as important as the quantity. Groundwater salinity can be defined simply as high concentration of dissolved salts in water more than permissible limit for drinking and irrigation water use. Salinity is a very critical problem of groundwater quality worldwide as it makes adverse impact on human health, plant growth, livelihoods and ecosystem. Once groundwater becomes brackish or saline, it is very difficult to remediate. Sea water encroachment in deeper aquifer takes place due to over exploitation of groundwater. Sea water salinity in groundwater is very critical issue in coastal area where sea water is a major source of salinity. In natural groundwater, the reported salt content ranges from < 25 mg/l in quartzite spring to more than 3,00,000 mg/l in brines (Houlihan and Lucia, 1999). Salinity trend in ground water has been analysed based on historic data collected from GWRDC over a period of 1994-2013. Secular change in TDS has been analysed through isobaths map, hydrographs for all 7 locations of observation wells with reference to Lithology and Geomorphology. Ground water salinity in the area ranges from 740 ppm to 2740 ppm (Fig. 8). The average TDS in Bhukhi watershed is decreasing at a rate of -194 ppm/year.

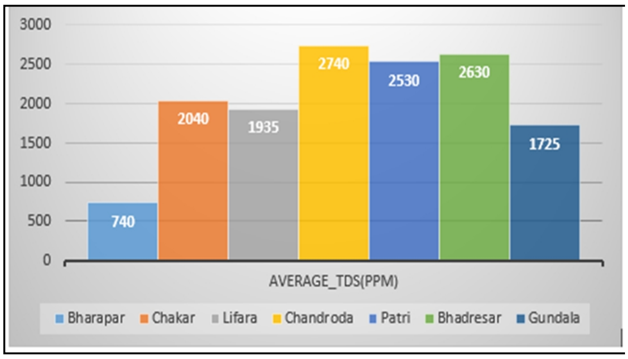

Figure 8: Average TDS values of observation wells (1994-2013)

On comparing the TDS value of 1994 with2013, 6 out of 7 villages show reduction in TDS values. Difference in TDS values for observation wells is shown below in Fig. 9.

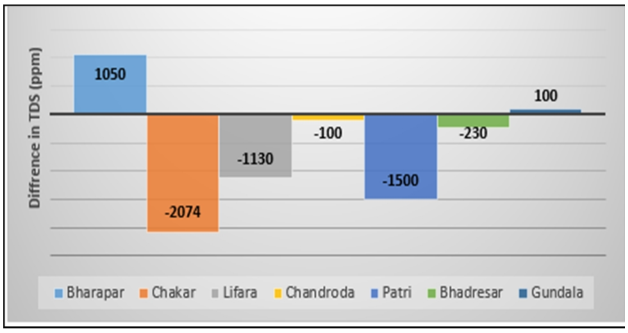

Figure 9: Difference in TDS values between 1994 and 2013 of observation wells

Isobaths map is considered to be the most illustrative way to represent spatial changes over a large area. TDS Isobaths maps for the study area have been prepared for pre monsoon seasons at interval of four years viz. for the year 1994, 1998, 2002, 2006, 2010, and 2013. Ground water aquifer region having TDS values higher than 2500 ppm is identified as not utilizable for drinking, domestic, industrial and agriculture use. Iso-TDS contours are drawn to identify and extent of these regions to study the temporal and spatial variations (Fig. 10). The temporal variation in the total area above and below cut off TDS of 2500 ppm within the study area is estimated using GIS.

During the period of 1994 to 2010, the salinity increased above the baseline and area above the baseline increased from 13.97 percent to 30.4 percent in the study area. After 2010, the salinity reduced in the study area and the area above 2500 ppm is reduced to 5.65Percent at the end of 2013.

Table 2: Percent area and number of villages affected due to salinity above the baseline TDS of 2500

Sr. No	Year	Percent Area >2500 ppm	Village affected
1	1994	13.97	10
2	1998	25.2	18
3	2002	17.93	13
4	2006	18.99	14
5	2010	30.4	22
6	2013	5.65	4

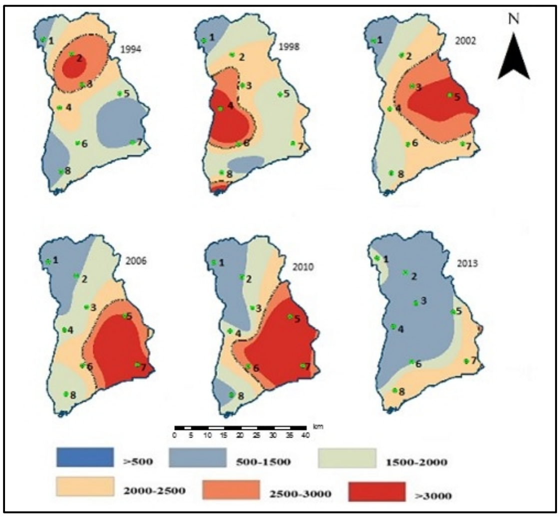

Figure 10: TDS variation for period 1994-2013. Colour represents TDS class in ppm. Observation well locations 1-Bharpara, 2-Chakar Kotda, 3-Lifra, 4-Patri, 5-Chandroda, 6-Gundala, 7- Bhadreshwar and 8-Mudra

6.3 Development of water resources structure

In the study area, availability of water in both quantity and quality is severely affected due to increased demand as a result of population growth and other demographic changes (urbanization, agricultural and industrial expansion). The water resources development is needed to meet the demand of agriculture, domestic and drinking as well as industrial requirement. As per GWRDC the study area remained as DARK ZONE until 2002 and later re-graded as SEMI-CRITICAL as a part of ground water potential assessment during the year 2007. Realizing this fact, Kachchh Irrigation Circle (KIC) developed several multipurpose water resources structures in Bhukhi watershed. The water harvesting structures constructed comprise of village tank for drinking and domestic use as well as for cattles, Percolation tank, Government Irrigation Dam, Bandhara, Check dams and Other irrigation structure. A list of various water harvesting structures in the region is given below in Table. 3 (Source: Kachchh Irrigation Circle-2013, Anon., 2009).

Based on analysis of available data and observations the development of water resources on Bhukhi watershed can be divided into two phases:

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Table 3: Details of Rain Water Harvesting (RWH) structures

Sr. No	Type of structure	Total Nos.
1	Government Irrigation Dam	7
2	Bandhara	7
3	Other irrigation structure	7
4	Check dams	210
	Total structures	**231**

Phase: 1 (Before 2006)
Many water resources activities took place till 2006 under which Kachchh Irrigation Circle (KIC) constructed 7 Dams and 105 check dams. But they were not enough to meet the requirements.

Phase: 2 (After 2006)
After 2006, Kachchh Irrigation Circle (KIC) introduced a new scheme of water resources development called as 'Bandhara Yojana'. Under this scheme they constructed Bandhara (Dams) in coastal villages and then further they construct check dams towards the land. Main purpose of construction of Bandhara is to restrict the sea-water intrusion on the coastal area by back washing of the fresh water flow of the rivers. In Bhukhi watershed KIC constructed 7 no. of Bandhara between the periods of 2006 to 2010. Bandhara constructed in Bhukhi watershed are shown in Table 4.

Table 4: Details of Bandhara scheme after 2006 (Source: Kachchh Irrigation Circle-2013)

Village	River	Year of Completion of work
Dhrub	Phot	2007
Wandh	Local stream	2008
Samaghogha	Phot	2009
Bhadreshwar	Mitti	2009
Gundala	Luni	2010
Luni	Local stream	2011
Bhadreshwar	Sarka	2011

Under the 'Bandhara Yojana', the frequency of construction of check dams increased as shown in graph (fig. 11). From the analysis of observation well data, the water quality has improved considerably after 2010. The total area having TDS value more than 2500 ppm is monitored to estimate the per cent area extent changes over a period of time in GIS environment. The trend of area extent variation as observed from 1994 to 2013 shows positive developments. Area above 2500 ppm in 1994 was 13.97 percent and it increase till 2010 and in 2010 it was 30.40 percent, but it is decrease to 5.65 percent in 2013. So the improvement in water quality can be attributed to the development of water resources harvesting structures after 2006.

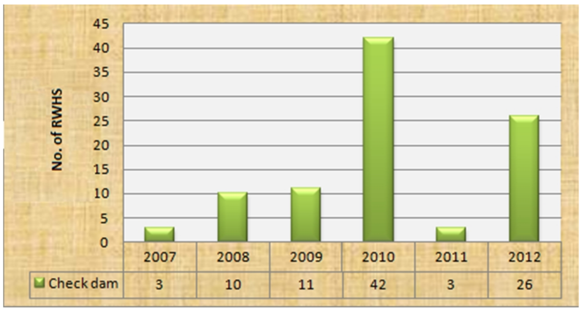

Figure 11: No. of rain water harvesting structures (Check dams) constructed between the periods of 2006 to 2013

6.4 Assessing the impact of water resources development
Agriculture land cover of the entire region has been derived from high resolution data of the IRS and Landsat satellite image of year 1994 and 2013 for the Rabi season (November to March) and comparative analysis is made (Fig. 12). Accordingly, percent of agriculture area is calculated for 1994 and 2013. While Rabi agriculture is 6.25 percent of total area in 1994 it has increased to 10.98 percent by the year 2013.

Rain fed agriculture is dominant with mix cropping pattern that includes sesame, green gram, black gram, guar, etc. Irrigated field crops include cotton, wheat, groundnut, bajara, fodder, etc. while date palm and mangoes are main fruits in horticulture.

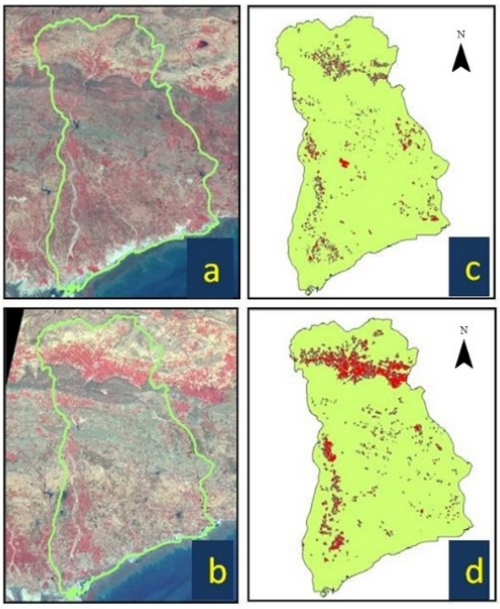

Figure 12: Agriculture mapping
a) Landsat (TM) Satellite Image of Nov. 1994
b) IRS P6 (LISS III) Satellite Image of March 2013
c) Double cropped area (Kharif+Rabi) in Red 1994
d) Double cropped area (Kharif+Rabi) in Red 2013

7. Conclusion

In Bhukhi watershed, the steady decline of ground water table during period 1994-2005 has been checked with the systematic construction of water harvesting structures after 2006.There has been a sharp rise in ground water table and water storage. The recharge by harvesting structures has also improved the ground water quality in the region. Although the overall population has increased, the There is an increasing trend (4.73 percent) in total area under agriculture after 2006. Thus there is a positive impact in the Bhukhi watershed due to the construction of rain water harvesting structures. Remote sensing and GIS techniques are useful in analysis of multi-temporal spatial and aspatial data for assessing impact of water resources development at watershed level.

Acknowledgements

The study was part of Dissertation Work for M. E. Water Resources Engineering, L.D.C.E, Ahmedabad. Work was carried out at Space Applications Centre (ISRO), Ahmedabad. The support received from L.D.C.E and Space Applications Centre (ISRO), Ahmedabad is acknowledged.

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