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**Review Article**

# Analysis of impact of Canal Irrigation on Waterlogged Areas and Environment Using Geo-informatics Technology in Gujarat State, INDIA

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## Abstract

The present study was carried out in Mahi Canal Command area in Vadodara district for monitoring the environmental impact of water logging and salinity on agriculture using Multi-temporal Remote Sensing data of past 15-years. The Indian Remote Sensing Satellite (Resourcesat-1) LISS-III, LISS-IV and Landsat TM data of 2000, 2006, 2010 and 2016 covering study area was analyzed for mapping waterlogged and salt-affected areas. The data from open-well observations was also collected to monitor the impact of canal irrigation on water-table and in turn on water-logging in the study area. The point measurements of open-well data were used to generate spatial distribution maps using Inverse Distance Weighting (IDW) Interpolation technique and these were superimposed on Satellite data. The waterlogged and salt-affected areas delineated using Remote sensing data was validated by carrying out detailed field survey as well as spatial IDW layers of water-table in the study area.

The results of analysis of agricultural area indicate that agricultural area has substantially increased due to introduction of canal irrigation which has helped to improve socio-economic condition of the farmers in the Vaghodia taluka. Agricultural area of medium and dense categories has increased during 2000 to 2016 accounting an increase from 12% to 26% in case of medium and 6.9% to 20% in dense agriculture, respectively. The water table in some of the villages in the study area has slightly come up during the period of last 15-years and at most predominantly after introduction of canal irrigation but it is much below to cause any water logging problem. However, it was also observed that waterlogged and salt-affected areas have decreased over the period of one decade due to augmentation of drainage system in the study area.

**Keywords:** Water logging, Salinity, Canal Irrigation, Geo-informatics, NDVI, Indian Remote Sensing Satellite, Static Water Level (SWL), Inverse Distance Weighting (IDW) Interpolation

## Introduction

Water-logging in general is caused due to excessive irrigation, seepage from canals and lack of drainage. Waterlogged condition is a quasi-natural sign of lowlands and these are important in the study of man and environment. Waterlogged areas, a natural issue (Bowonder et al., 1986), are watched all through the world over China, Pakistan, Bangladesh, India, etc. and hence this issue of water-logging is viewed as a worldwide issue (Bastawesy & Ali, 2012). The waterlogged condition is an aftereffect of blockage of water on the area surface, particularly in a low-lying range. This obstructing of water is controlled by local geology, topography, drainage, and the amount of water supplied to the site (Holden et al., 2009). It is additionally the consequence of changing land use within the human environment. Water-logging like flooding causes harm to agrarian lands affecting the crops, and thus the livelihood and the economy of the nation (Kumar & Kunte, 2012. It is the consequence of all round intra- and interrelationship of climatic, geomorphic, hydrologic, vegetative, and anthropogenic factors in planetary environment (Yücel et al., 2002; Röder et al., 2010; Minar et al, 2013; Jesse, et al., 2019). Thus, there are natural, quasi-natural, and man-made factors behind the onset of water-logging hazards.

## Remote Sensing and GIS Applications

Remote sensing offers several advantages over conventional ground methods used to map and monitor water-logging and soil salinity/alkalinity. By virtue of synoptic viewing capability, repetitiveness and spectral sensitivity to water and salt, it is a valuable tool for obtaining dynamic information on water-logging and soil salinity/alkalinity commonly associated with irrigated commands. The project entitled "Assessment of water-logging and salt and/or alkaline affected soils in the commands of all major and medium irrigation projects in the country using satellite remote sensing" has been carried out by RRSSC, ISRO, Department of Space, Jodhpur (Sharma et al., 2009; Gazioğlu, et al., 2010). This study was focused on existing status of the irrigation commands in terms of i) surface water-logging and salinity/alkalinity and ii) spatial correlation between ground water fluctuation and surface water-logging was carried out by The seasonal waterlogged areas are those which exhibits water-logging only in one season i.e. April or November and perennial water-logging, indicates where it persists in both the seasons. Likewise the salt affected areas include those, visible on satellite images, confirmed after soil analysis, and further characterized for its types and severity based upon pH, Electrical Conductivity (EC) and Exchangeable Sodium Percentage (ESP) values. Remote Sensing based observations have demonstrated their unique capability in monitoring canal command areas. Sahai et al. 1985, using multi-date, multi-spectral Landsat imagery of pre and post monsoon period for 1972-81 studied the impact of canal irrigation on the ecosystem of the Ukai-Kakrapar command area in Gujarat due water-logging and salinity. Kalubarme et al. (1983, 1985), Mohitkumar & Bhagwat (1989) have also studied extent of water-logging and salinity in Gujarat State. The temporal changes in land-use/land cover have been studied using multi-temporal Indian Remote Sensing Satellite (IRS) data for Mahi Right Bank Canal (MRBC) command area in Kheda district of Gujarat state (Brahmabhatt et al. 2000; Gorji, et al., 2019). Land use change analysis of Vaghodia taluka using multi-temporal RS and GIS data was carried out by Paria and Bhatt, 2012.

**Objectives**

This study was carried out in the Mahi Canal Command area in Vadodara district for studying the environmental impact of water-logging on agriculture using Multi-temporal Remote Sensing data of past 15-years. The waterlogged and salt-affected areas delineated using Remote sensing data was validated by carrying out detailed field survey as well as by monitoring the changes in water-table data in GIS environment. The major objectives of this study are as follows:

- ✓ Monitoring of waterlogged and salt affected areas in Vaghodiya Taluka using multi-temporal remote sensing data of past one decade.
- ✓ Relating ground water table depth data (open well observations) with surface waterlogged areas delineated using Remote Sensing Satellite data in GIS environment
- ✓ Monitoring impact of canal irrigation on agriculture over the period of 15-years.

## 1. MATERIAL AND METHODOLOGY

**Study area**

Vaghodia taluka is located in Vadodara district and geographically area lies between 73°17’ to 73°33’E longitude and 22°12’to 22°21’N latitude covering 96 village (Census 2001) and it lies on very gentle slope and fertile alluvial plains. Taluka is a subdivision of a district which consists of a group of several villages organized for revenue purposes. The area is bounded by River Mahi in the north and Dhadhar in the south. This area is naturally drained by River Dhadhar and its tributaries like Surya, Vishwamitri, and Jambua. The total geographical area of the taluka is 585.12km² with a population 1,49,914 (Census of India 2011). The major irrigation sources in the study area are tube wells, Narmada branch canal, and natural drains of river Mahi and Dhadhar. The location map of the study area is given in Fig. 1.

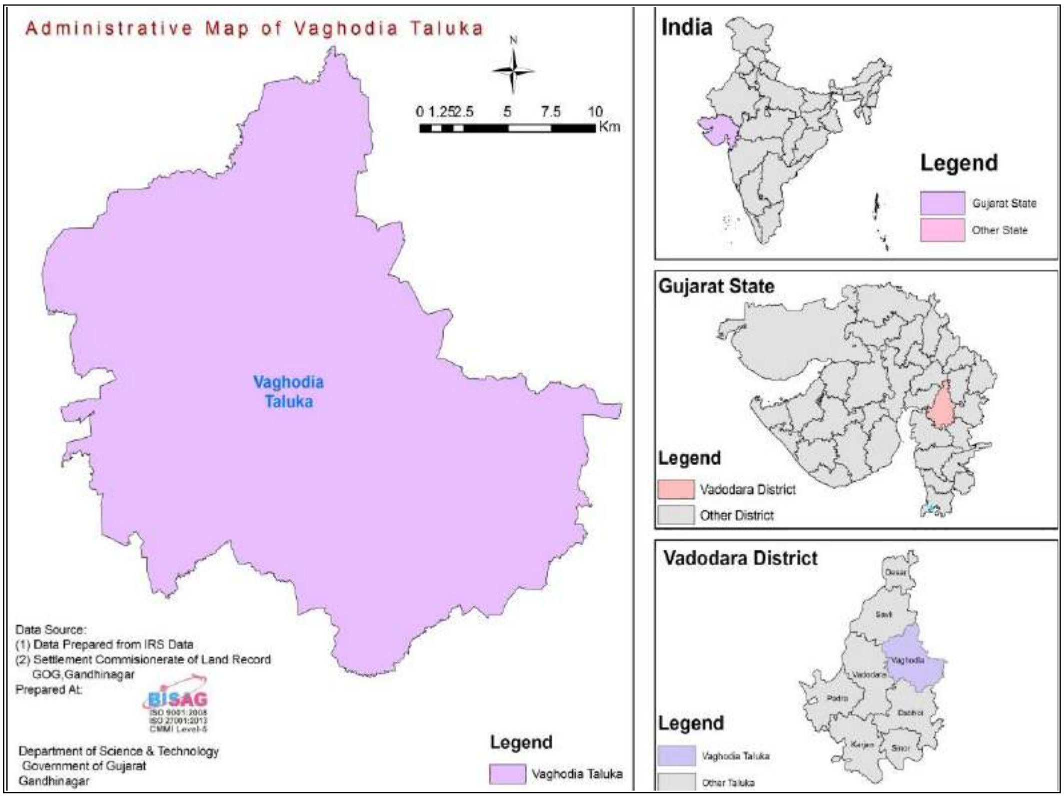


Figure 1: Location of the study area in Gujarat state

**Data Used**
In this study, Indian Remote Sensing Satellite (IRS) LISS-III and LISS-IV data, Landsat TM and GIS data was used. Remote Sensing and GIS techniques were used for the analysis and interpretation of the satellite data.

**Remote Sensing (RS) satellite data**
Multi-temporal satellite images of Indian Remote Sensing Satellite (Resourcesat-1) LISS-IV, LISS-III and Landsat-8 TM data of different dates were used for mapping and monitoring waterlogged and salt-affected lands (Table-1). The Landsat TM data was downloaded from URL 1.

The taluka boundary was superimposed on the satellite data and area of interest covering Vaghodia taluka was extracted from the multi-date satellite data. The Multi-temporal satellite data covering Vaghodia taluka used in this study is given in Fig 2.

**IRS LISSIII JAN 2012**

Table-1: Details of Remote Sensing Satellite data used

| Sr. No. | Satellite | Sensor | Path/Row | Resolution | Date of Pass |
|---|---|---|---|---|---|
| 1. | Landsat-7 | TM | 148/045 | 30m | Feb-2000 |
| 2. | Resourcesat-1 | LISS-III | 093/056 | 24 m | Nov-2006 |
| 3. | Resourcesat-1 | LISS-IV | 094/056 | 5.8 m | April-2015 |
| 4. | Resourcesat-1 | LISS-III | 093/056 | 24 m | October-2015 |
| 5. | Landsat-8 | TM | 148/045 | 30 m | Feb-2016 |

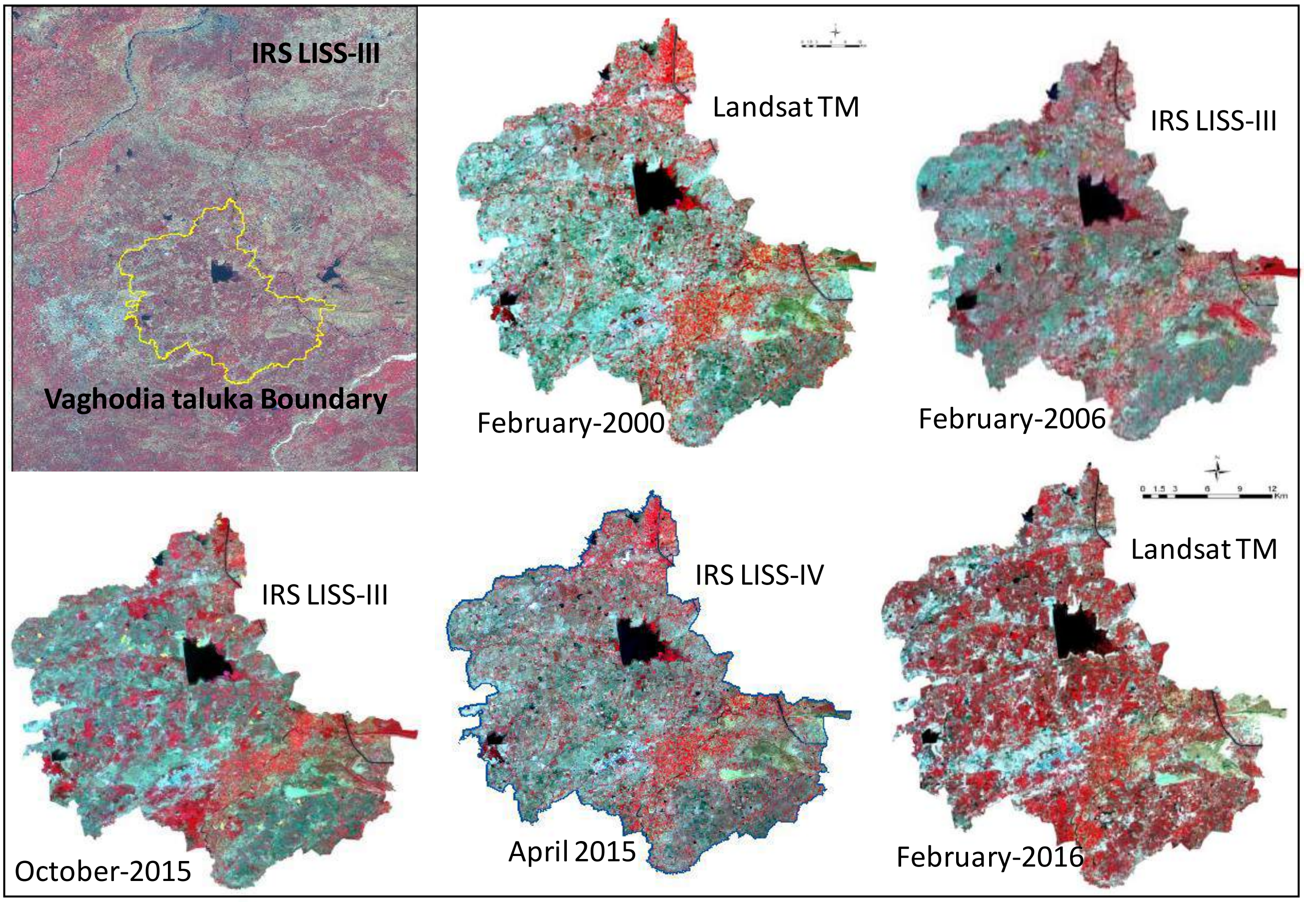


Figure-2: Multi-temporal satellite data covering Vaghodia taluka.

**Geographic Information System (GIS) data**
The GIS data available with BISAG like: a) district/ taluka/ village boundaries, b) transport network, c) water bodies and drainage network, d) canal network, etc. was used for preparation various base maps of the study area. The base maps of drainage network and canal network in Vaghidia taluka are given in Fig. 3.

**Field Data collection**
Field data collection is an important component in this study for precise identification of waterlogged and salt affected areas using RS data. Geographic coordinates for the visited fields were also recorded using GPS, which were transferred on the satellite image for accurate area identification. The field details like crops grown, cropping pattern, irrigation facilities, soil type etc. were also recorded. Field photographs of water-logged and salt-affected areas in different villages were also taken and the concept of geo-tagging was used for actual visualization of the field details and areas as seen on the RS data. Geo-tagging of photographs helps to associate the photograph with the geographical location in the field. The locations of field observations and geo-tagged photographs superimposed on the Satellite data covering Vaghodia taluka is given in Fig. 4.

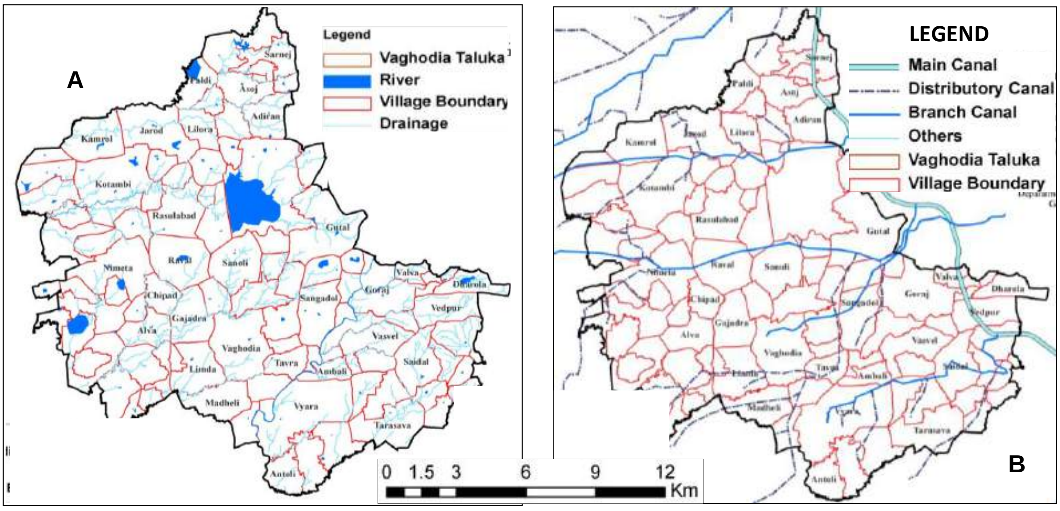


Figure-3: Base maps: A) Village boundary & drainage network, B) canal network in Vaghodia

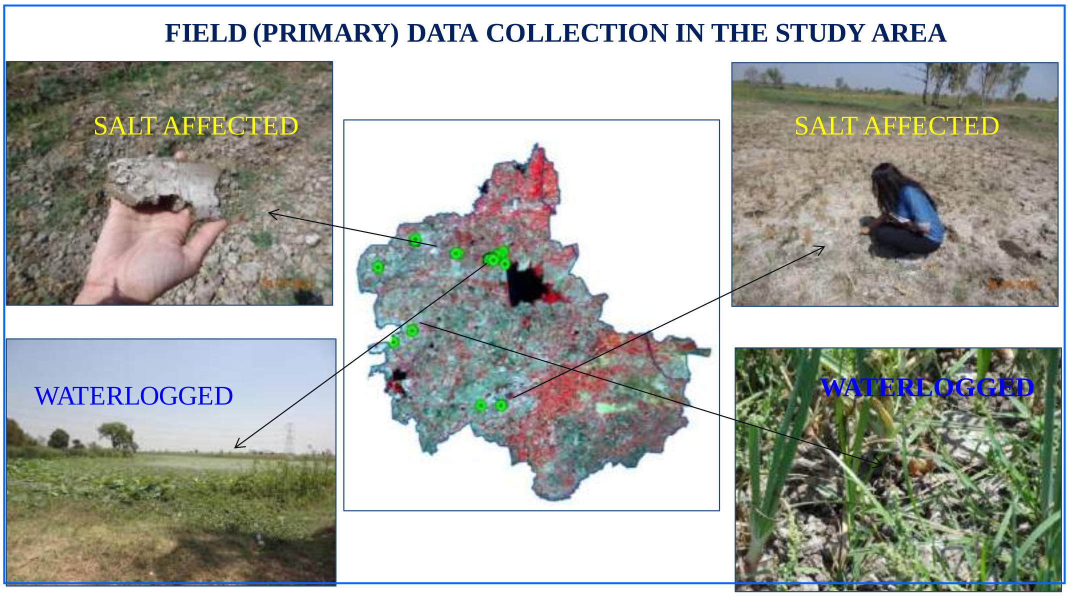


Figure 4: Field data collection on waterlogged and salt-affected areas in Vaghodia.

**Water Table Data**

The Static Water Level (SWL) data from open wells in different villages of Vaghodia taluka for 2000 and 2012 along with its geographic coordinates were collected from Sardar Sarovar Narmada Nigam Limited (SSNNL) department, Vadodara. The geographic coordinates of open wells in different villages were used to super-impose on the RS data. The village boundaries of some of the villages along with well locations were also superimposed on satellite data (Fig. 5). From this data, the changes in SWL data in some the villages were monitored over the period of 12 years (from year 2000 to 2012).

**Soil Health Card Data**

Soil health card programme of the government plans to help farmers get good harvest by studying the quality of soil. The soil health card provides health of soil based on a complete evaluation of the quality of soil, water and nutrients content and other biological properties. It will also contain corrective measures that a farmer should adopt to obtain a better yield. Government of Gujarat has issued Soil health cards to various farmers indicating the status of soil pH, Electrical conductivity (EC), fertility status in terms of Organic Carbon (OC), phosphorus and potash. The part of soil health cards of two farmers in two different villages in Vaghodia taluka indicating soil pH, EC and fertility status is given in Fig. 6.

**Rainfall data**

The study area experiences tropical climate with three main seasons: summer, monsoon and winter. The climate is dry except for the monsoon season. The southwest monsoon brings a humid climate from mid-June to mid-September. The annual average rainfall in the study area is 800 mm. The total rainfall data from year 2007 to 2015 was collected from India Meteorology Department (IMD) and BISAG. The rainfall pattern over 9-year period in Vaghodia taluka is given in Fig. 7. The rainfall in the study area has decreased over the period of 9-years. The changes in rainfall pattern was analysed with respect to changes in SWL and introduction of canal irrigation in study area.

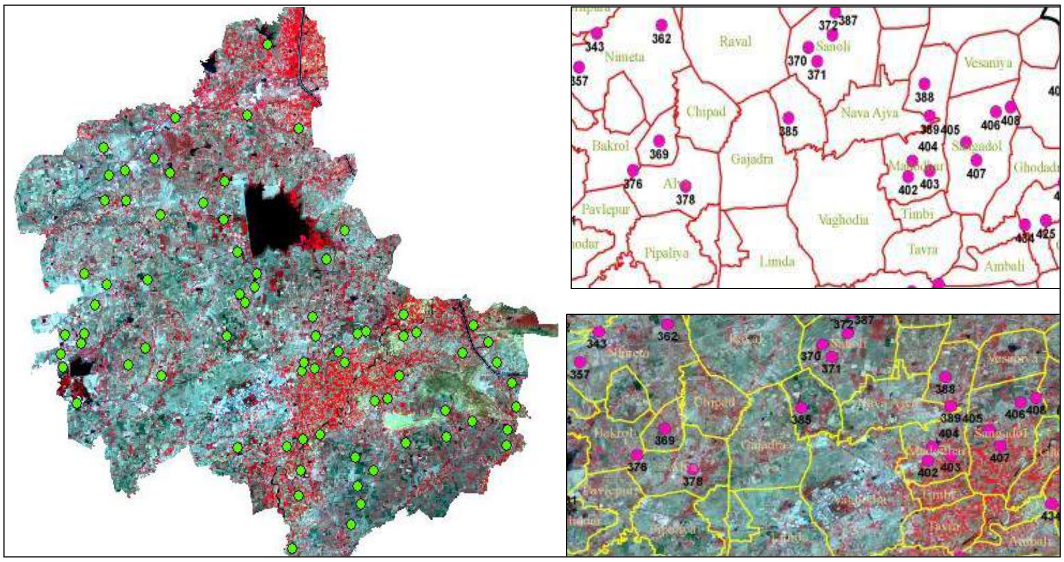


Figure 5: Open well locations for SWL observations in Vaghodia taluka along with some village boundaries superimposed on satellite data.

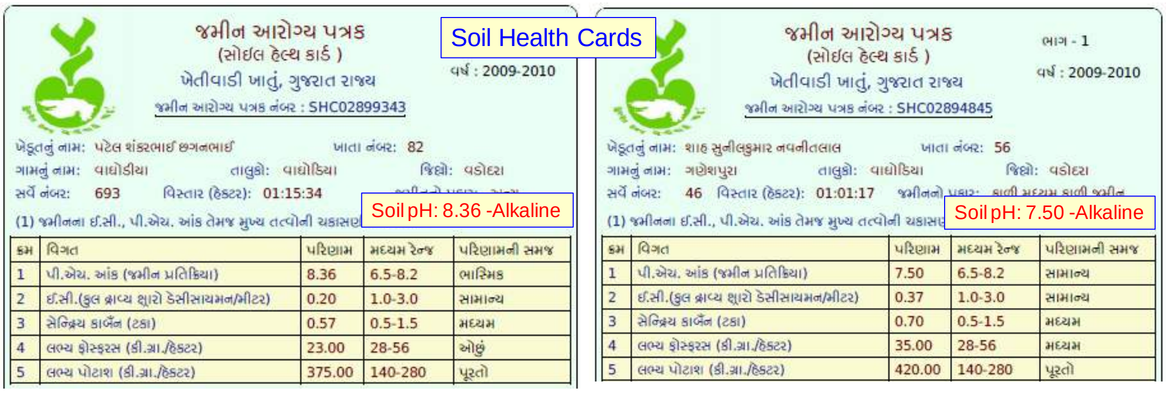


Figure 6: Part of Soil Health Cards in two villages indicating soil pH and fertility status in Vaghodia taluka (URL 2).

| Year | Rainfall (mm) |
|---|---|
| 2007 | 1644 |
| 2008 | 1160 |
| 2009 | 850 |
| 2010 | 526 |
| 2011 | 950 |
| 2012 | 866 |
| 2013 | 625 |
| 2014 | 725 |
| 2015 | 178 |

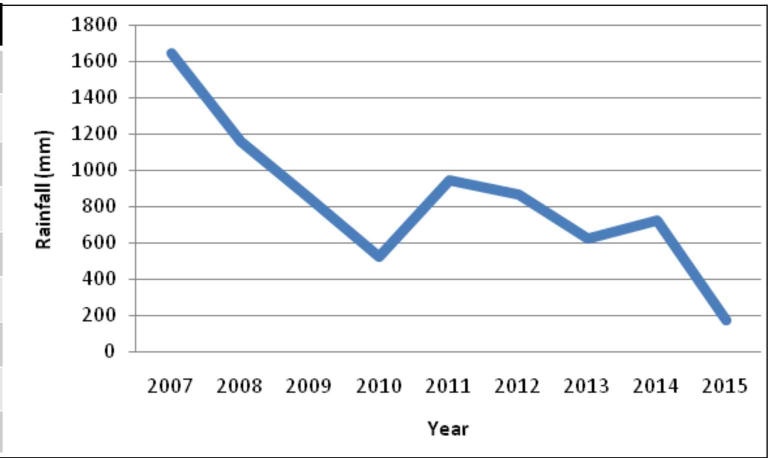


Figure 7: Rainfall pattern during 2007 to 2015 in Vaghodia taluka (Source: India Meteorology Department)

**Data Analysis**

**Water Table Data Analysis**

The Static Water Level (SWL) data of 2000 and 2012 from different villages collected from SSNNL department, Vadodara was analyzed and histograms for 2000 & 2012 were generated (Fig. 8). These histograms indicate that SWL during 2012 has increased as compared to SWL of 2000 in many villages.

**Inverse Distance Weighted (IDW) Interpolation**

According to ArcGIS, "Inverse distance weighted (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance. The surface being interpolated should be that of a locational dependent variable. Using the geographical locations of open wells in different villages and their SWL the IDW of static water level was generated for the year 2000 and 2012 for Vaghodia Taluka (Fig. 9).

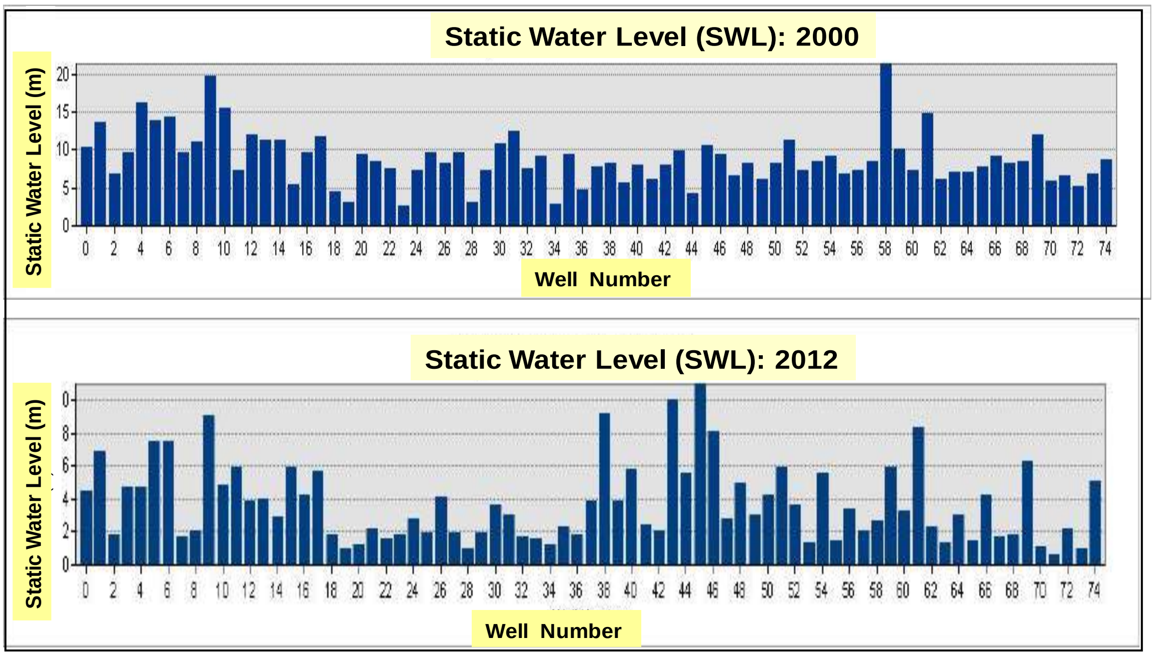


Figure 8: Histograms of Static Water Level (SWL) in different wells in Vaghidia

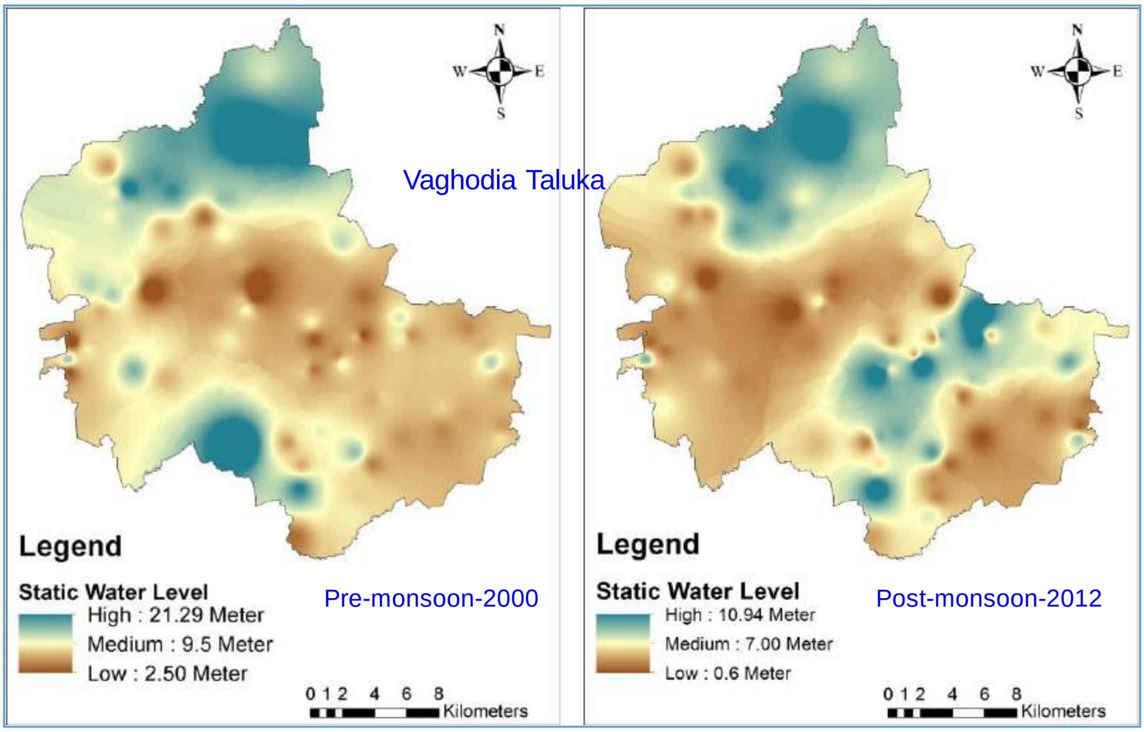


Figure 9: IDW of static water level generated for 2000 and 2012 in Vaghodia Taluka

**Remote Satellite Data Analysis**

Resourcesat-1 LISS-III data of Year 2006 and 2015 was analyzed for mapping salt-affected and waterlogged areas. From this analysis changes in the salt-affected and waterlogged areas were calculated and changes in waterlogged and salt-affected areas over the period of one decade in Vaghodia taluka were monitored. The Landsat TM data of year 2000 and 2016 was downloaded and used for monitoring changes in agricultural area due to impact of canal irrigation in the Vaghodia taluka. Normalized Difference Vegetation Index (NDVI), Rouse et al. (1974) images were generated and NDVI thresholding was adopted for generating vegetation density classes.

**Results and Discussion**

**Mapping of salt affected areas using Satellite Data**

Salt-affected areas are one of the most important degraded areas where soil productivity is reduced due to either salinization (EC > 4 dS/m) or sodicity (ESP > 15) or both. The soils with EC more than 2 dS/m in black soils and >4 dS/m in non-black soils was considered as saline in the present project. Soils with soil pH more than 8.5 results in increase of exchangeable sodium percentage (ESP) in soils (> 15) and are termed as sodic. Based on the type of problem, it has been divided into saline, sodic and saline-sodic (Salt-affected and waterlogged areas of India, 2014). The salt-affected areas in Vaghodia taluka were mapped based on visual interpretation of IRS LISS-III data of 2006 and 2015. The IRS LISS-III images were displayed and on-screen digitization of salt affected areas was carried out based on the field information of these areas in various villages. The salt affected areas mapped using IRS LISS-III data are given in Fig. 10.

**Independent Analysis based on soil health cards and Department data**

The soil pH and salinity data of Vaghodia Taluka was collected from SSNNL department as well from the Soil Health Card data (Table-2). The results of pH and salinity of Vaghodia taluka indicate that the salinity and pH are in the normal range.

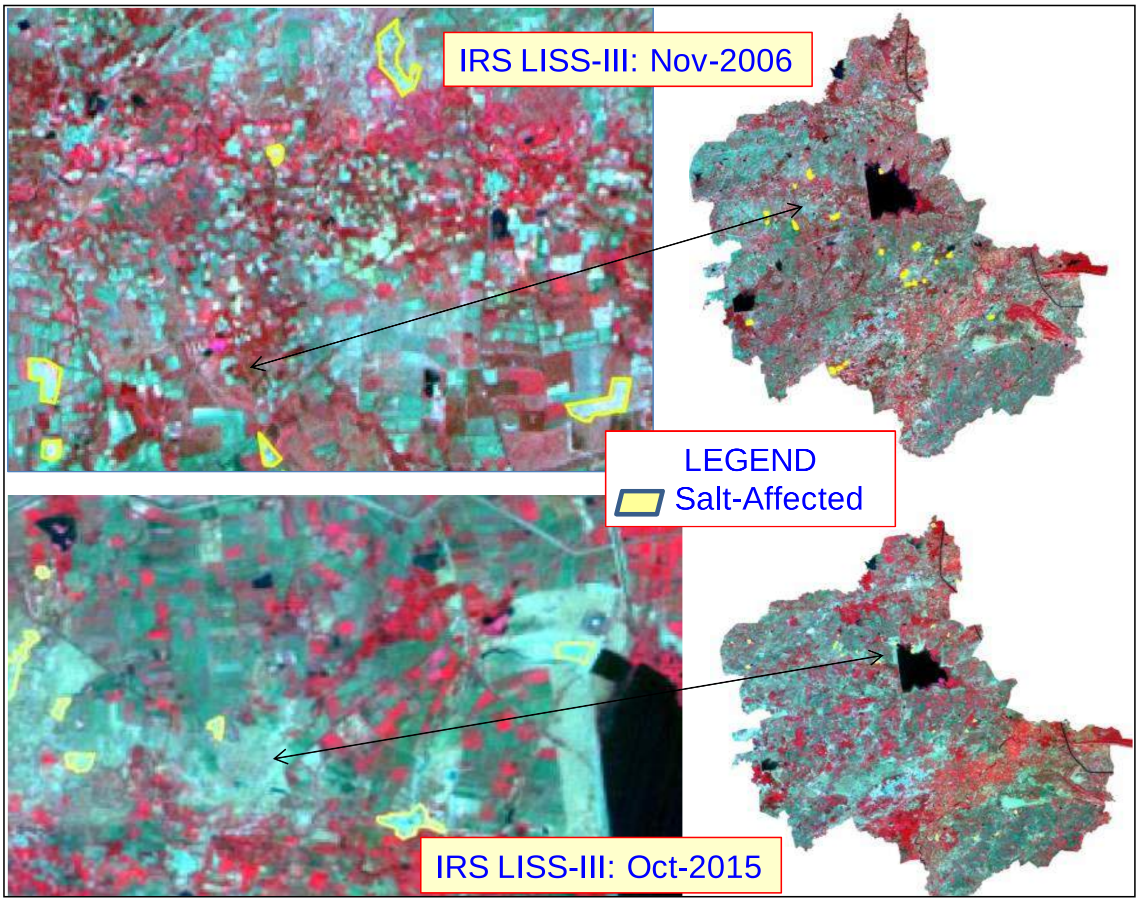


Figure 10: Salt-affected areas mapped on IRS LISS-III data of 2006 and 2015.

Table-2: Salinity and pH of soil in different villages of Vaghodia Taluka

| Site ID | Village | Salinity (EC in dS/m) | pH |
|---|---|---|---|
| 415 | Ganeshpura | 0.260 | 8.30 |
| 368 | Kamrol | 0.610 | 8.40 |
| 398 | Rahakui | 0.780 | 8.30 |
| 110 | Rasulabad | 1.010 | 8.26 |
| 36 | Limda | 1.150 | 8.30 |
| 53 | Limda | 0.990 | 8.40 |
| 449 | Vyankatpura | 0.320 | 8.40 |
| 9 | Vaghidia | 1.510 | 8.50 |

**Generation of IDW of pH and Soil Salinity data**

The soil pH and salinity data collected from SSNNL and Soil Health Cards from various villages in Vaghodia taluka was used to generate spatial layers using IDW technique. The spatial distribution of soil salinity and pH are given in Fig. 11 and 12, respectively. The spatial distribution of soil salinity and soil pH at the soil depth of 0 to 90 cm in Vaghodia taluka indicates that both are in the normal range. The salinity in terms of EC (**dS/m)** is in the range of 0 to 1 **dS/m** in almost 96 per cent area of the Vaghodia taluka. The pH values are in the range of 8 to 9 in almost 93 per cent area of the Vaghodia taluka and in some pockets the pH ranges from 9 to 10.

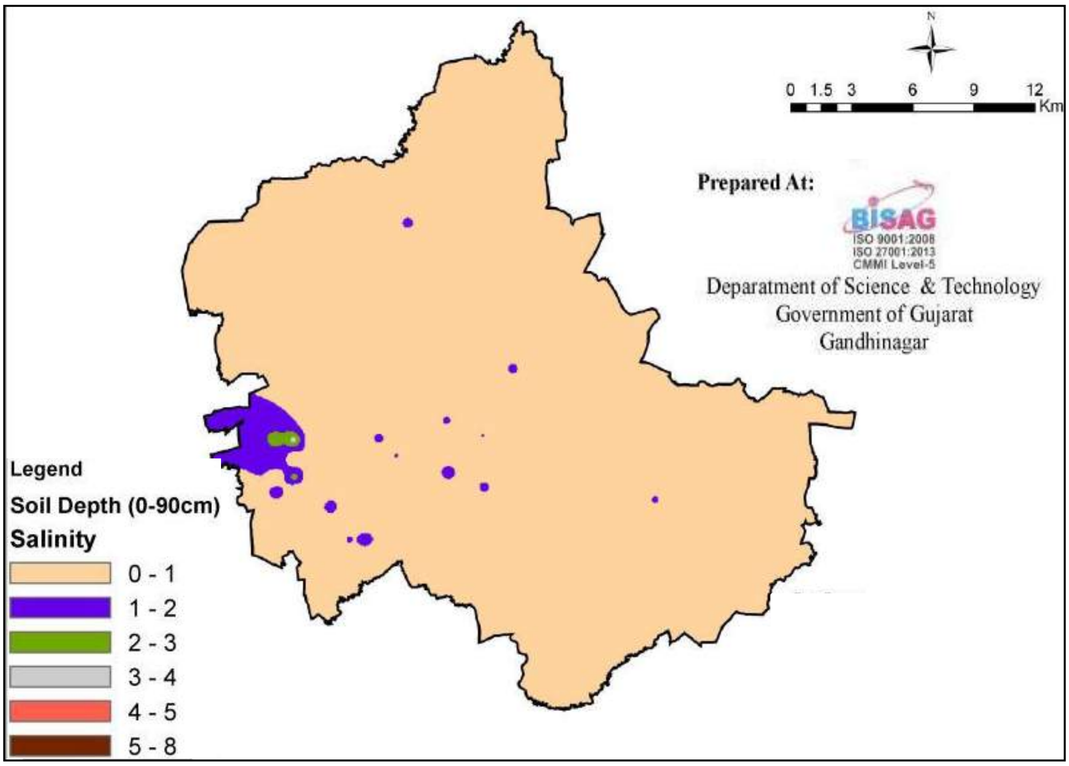


Figure 11: Spatial Distribution of Soil Salinity levels in Vaghodia Taluka

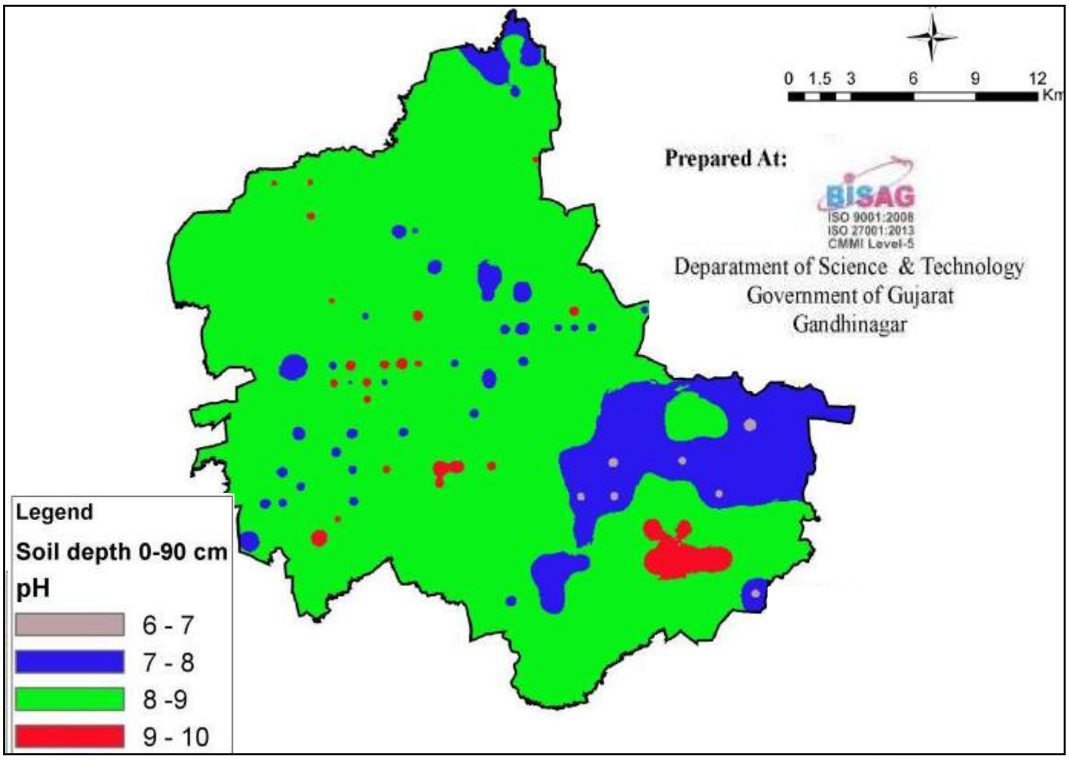


Figure 12: Spatial Distribution of Soil pH levels in Vaghodia Taluka

**Mapping of Waterlogged areas using Satellite Data**

The waterlogged areas were also mapped based on visual interpretation of IRS LISS-III data of 2006 and 2015 covering Vaghodia taluka. The IRS LISS-III images were displayed and on-screen digitization of waterlogged was carried out based on the field observations of these areas. The waterlogged areas mapped using IRS LISS-III data are given in Fig. 13. The results of salt affected and waterlogged areas mapped using satellite were compiled and statistics were generated for both the categories. The results of area under waterlogged and salt affected soils are given in Fig. 14. The results compiled for salt affected and waterlogged areas indicate that the areas under both the categories have decreased over the period of one decade. The major reason for this decrease is that proper drainage was provided with construction of canals in this area.

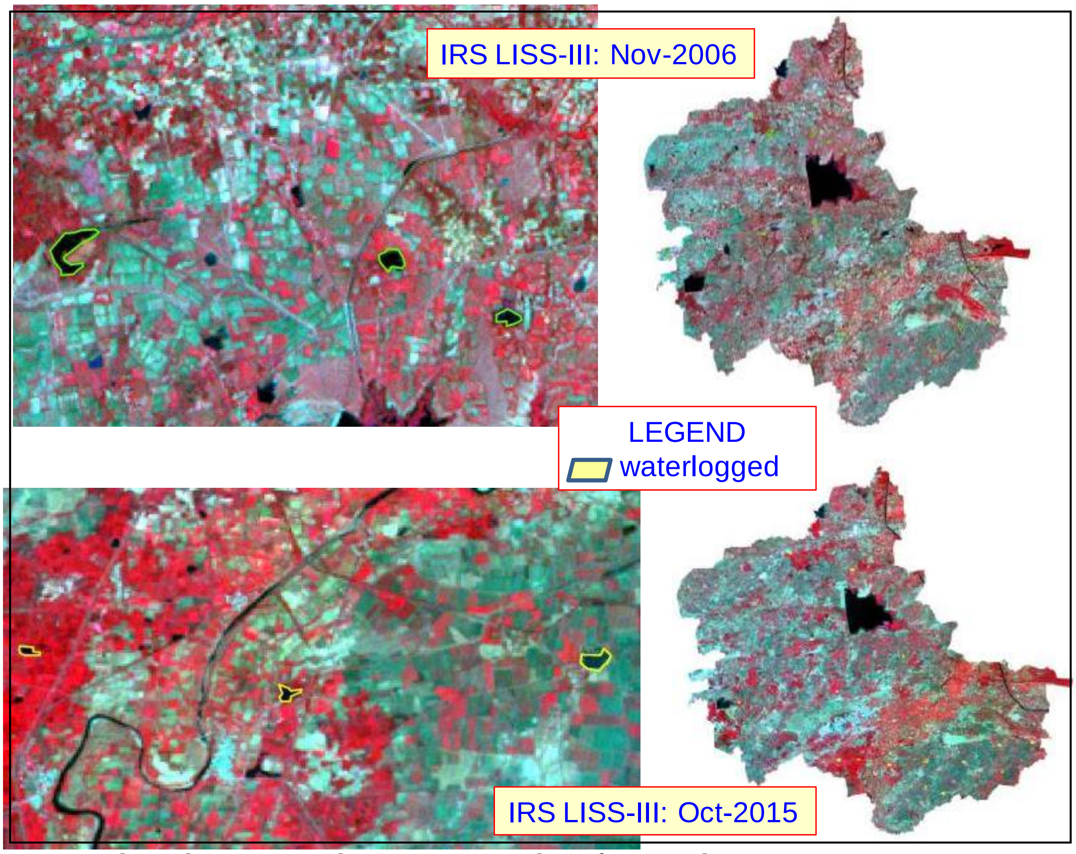


Figure 13: Waterlogged areas mapped on IRS LISS-III data of 2006 and 2015

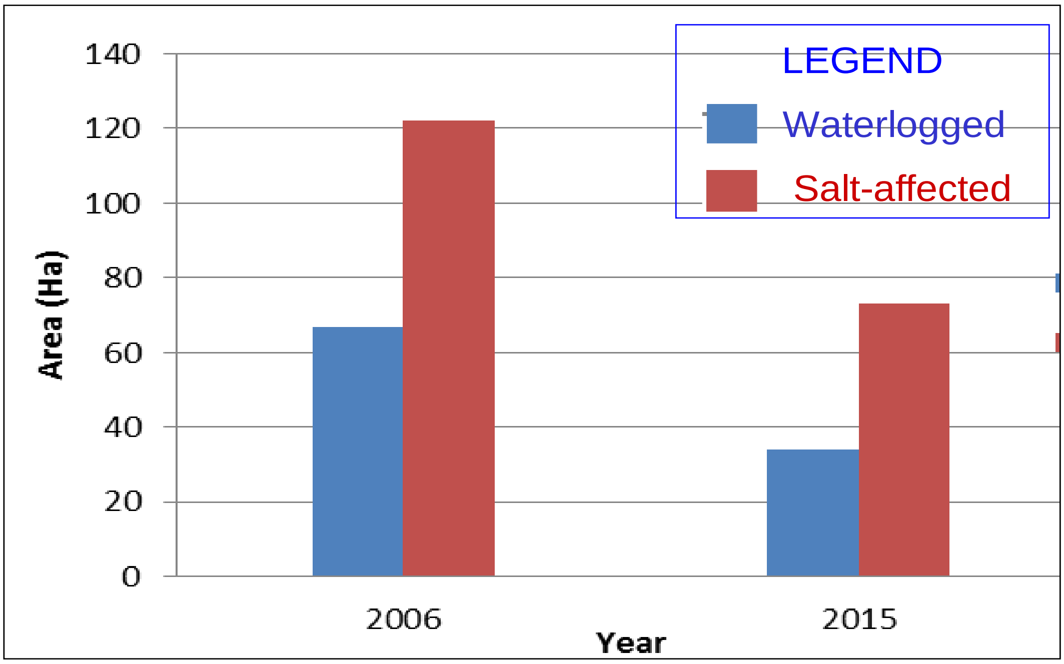


Figure 14: Changes in Waterlogged and salt affected areas mapped using IRS LISS-III data of 2006 and 2015.

**Monitoring changes in waterlogged areas based SWL data**

The Static Water Level (SWL) data of 2000 and 2012 from different villages and histograms for 2000 & 2012 were generated for monitoring the changes in different villages. These histograms along with village boundary were superimposed on Vaghodia taluka map for spatial visualization (Fig. 15). These histograms indicate that SWL during 2012 has increased as compared to SWL of 2000 in certain villages. However, it was also observed that waterlogged and salt-affected areas have decreased over the period of one decade due to augmentation of drainage system in the study area.

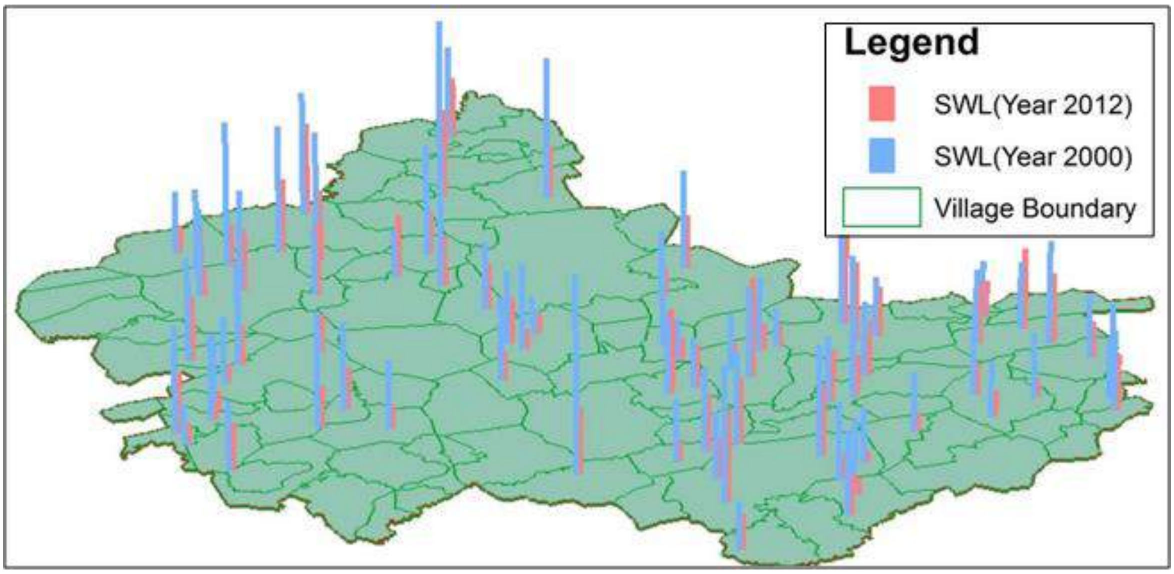


Figure-15: Spatial Visualization of Changes in Static Water Level (SWL) during 2000 and 2012.

**Monitoring Impact of canal Irrigation on Agriculture**

Landsat TM data of February month during 2000 and 2016 covering Vaghodia was downloaded from earthexplorer.usgs.gov/ website and used for analysing impact of canal irrigation on agriculture over the period of 16 years. The Normalized Difference Vegetation Index (NDVI) images of Feb 2000 and Feb 2016 data covering Vaghodia taluka were generated. Vegetation indices derived from satellite imagery provide an estimate of the health and vigor of agricultural crops. One of the most widely used vegetation indices is the Normalized Difference Vegetation Index (NDVI) defined in 1974 (Rouse et al., 1974; Gazioğlu et al., 2014). This index is based on the difference between the maximum absorption of radiation in the red due to the chlorophyll pigments and the maximum reflection of radiation in the NIR due to the leaf cellular structure and the fact that the soil spectra, lacking these mechanisms, typically do not show such a dramatic spectral difference. NDVI provides a measure of vegetation health and vigour. The NDVI images were generated using the following formula:

$$NDVI = (NIR - R) / (NIR + R) \quad \text{(Eq.1)}$$

The NDVI images generated for Feb. 2000 and Feb. 2016 are given in Fig. 16.

**NDVI Image Thresholding**

The histograms of NDVI images were generated and non-agricultural areas as well as fallow lands were identified on the Landsat TM data as well as NDVI images based on field data. The agricultural vegetation was divided in to two density classes and the range of NDVI values for each class were decided for 2000 and 2016 images separately. NDVI threshold values will be different for different image dates because each pixel's value changes temporally due to changes in soil condition, soil moisture, vegetation health, leaf area, and atmospheric effects (Qi et al., 2002). The false colour composites images from NDVI threshold values were generated separately for 2000 and 2016 images. The NDVI threshold images along with false colour campsites of 2000 and 2016 covering Vaghodia taluka are given in Fig. 17 and 18, respectively.

**Monitoring Impact of Canal Irrigation on Agriculture**

The canal water from the main canal was released in to the branch and distributaries covering Vaghodia taluka was released during 2007. After introduction of canal irrigation in this region there is tremendous improvement in the crop cultivation and area under various crops. The area under agricultural crops and the vegetation density of agricultural crops were monitored using the NDVI threshold images of 2000 and 2016 covering Vaghodia taluka. Area under various land use classes like non-agricultural land, fallow land, medium agriculture and dense agriculture were calculated. The estimated area under each class was converted in percentages using the geographical area of the taluka which are presented as bar chart in Fig. 19.

The results indicate that area under medium agriculture vegetation cover has doubled and under dense agriculture vegetation cover has increased by almost three times over the period of 16-years in Vaghodia taluka. The data on irrigated area in Vaghodia taluka was collected from department of agriculture; Vadodara from 2007 to 2013 to analyze changes irrigated areas. Results indicate that the agricultural area along with the irrigated area has increased after release of canal water in Vaghodia taluka over the period of one decade (Fig. 20). The rainfall data analysis from 2007 to 2015 indicates that, there is continuous decline in total rainfall from 1600 mm to 200 mm in Vaghodia taluka. Therefore, the increase in agricultural area as well as increase in dense and medium vegetation cover is mainly due to availability of canal irrigation to farmers.

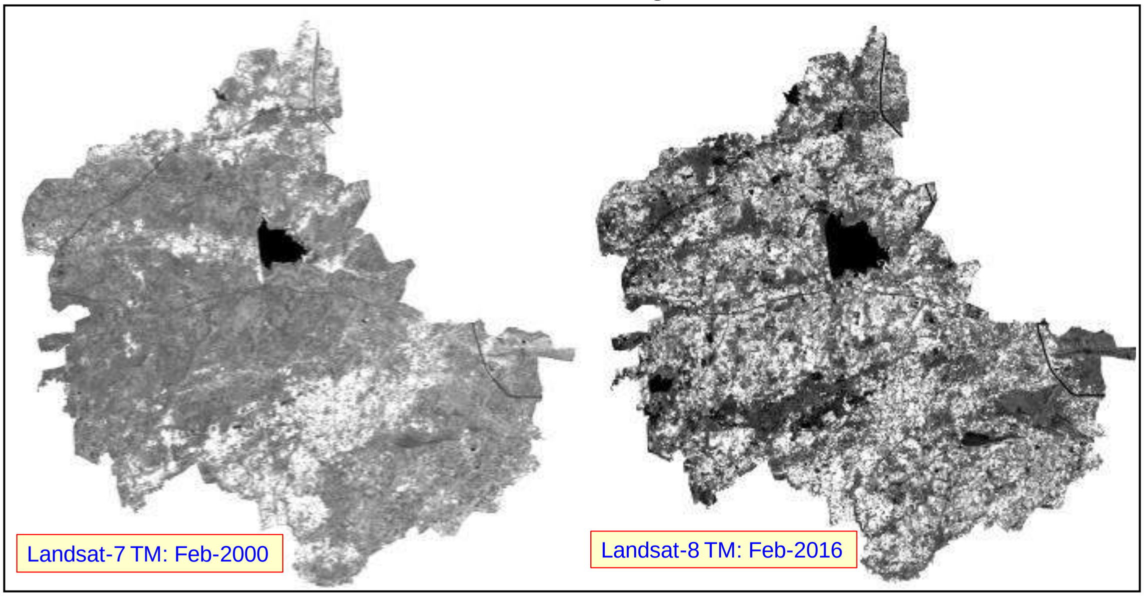


Figure-16: NDVI images Feb 2000 and Feb 2016 covering Vaghodia Taluka

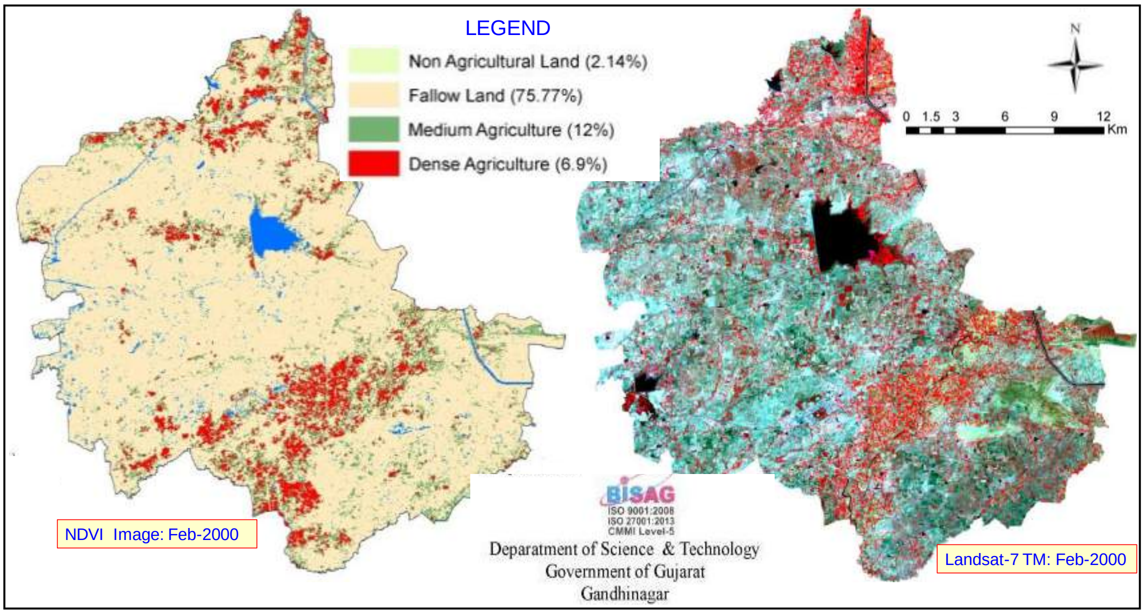


Figure-17: NDVI threshold image along with false colour composite (Feb 2000) covering Vaghodia Taluka

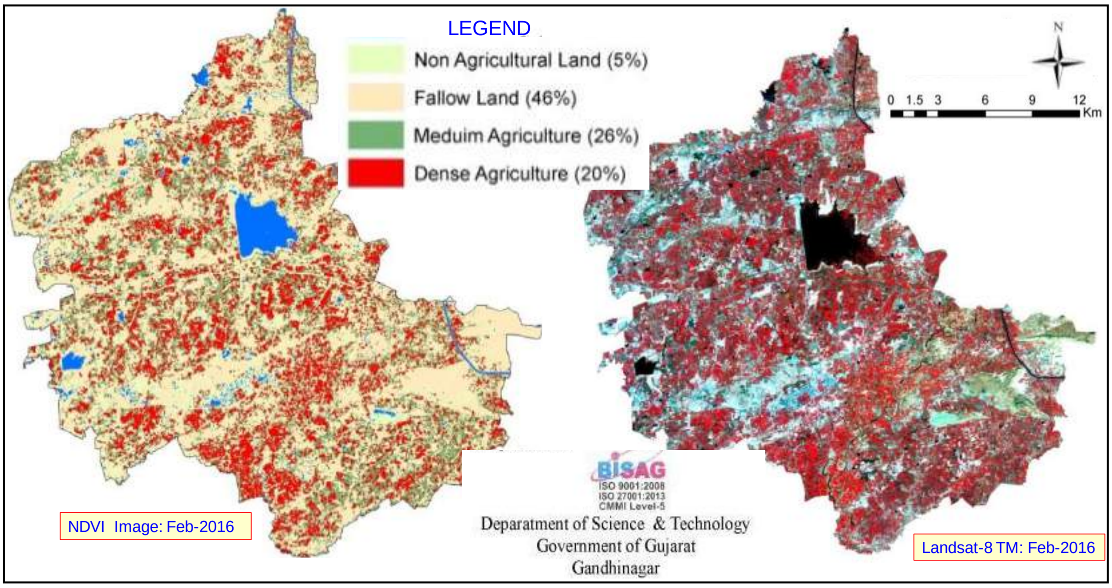


Figure 18: NDVI threshold image along with false colour composite (Feb 2016) covering Vaghodia Taluka

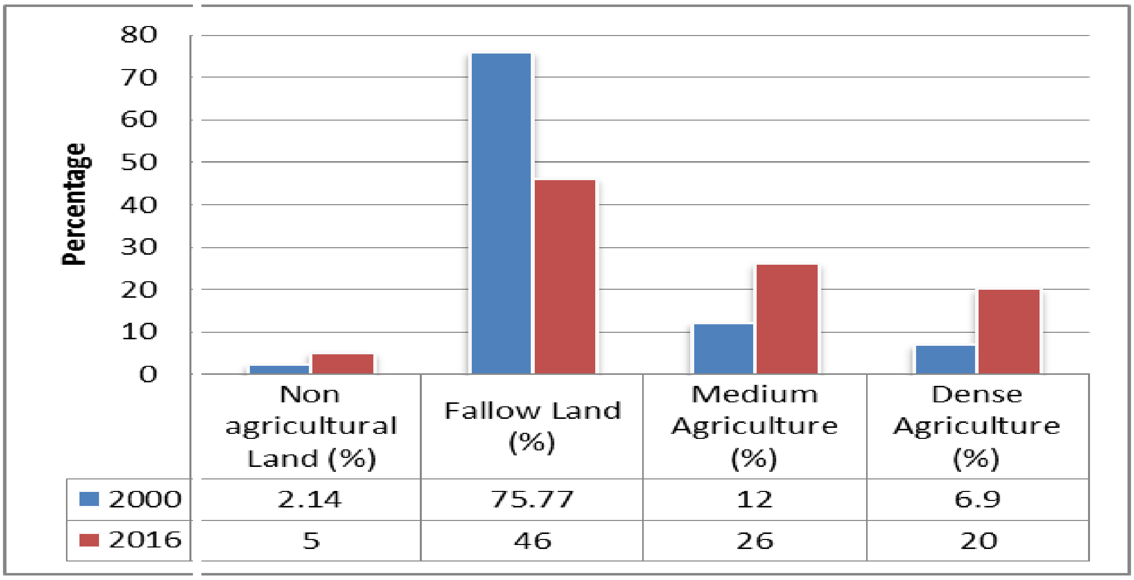


Figure 19: Changes in Area under Agriculture crops and density for year 2000 and 2016

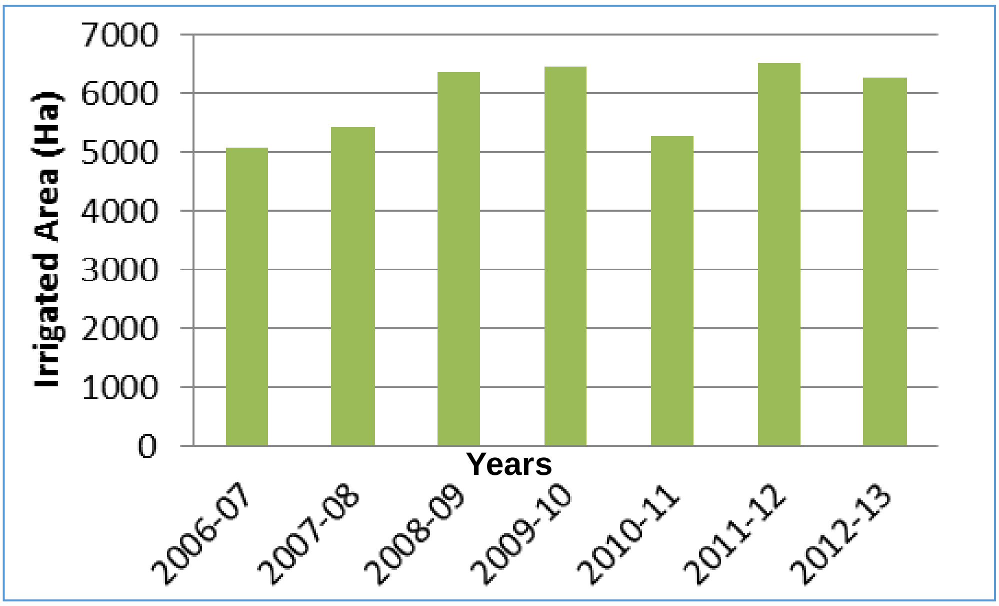


Figure 20: Changes in irrigated area during one decade in Vaghodia taluka.

**Conclusion**

The present study on Environment impact analysis of canal irrigation on waterlogging and soil salinity in Vaghodia taluka, Gujarat State using Geospatial technology was carried using multi-temporal Remote Sensing Satellite data of last 16-years. Indian Remote Sensing Satellite (IRS) data of LISS-III and LISS-IV as well as Landsat TM data from 2000 to 2016 was analysed in this study. Ground water-table data from open wells in various villages, rainfall data, Soil Health Card data and detailed field data was also collected. The major objective of this study was to assess and monitor the changes in waterlogged and salt-affected areas along with introduction of canal irrigation during 2007.

The waterlogged and salt-affected areas were delineated on the Satellite data based on detailed field survey and study of changes in water-table data in various villages. The soil pH and EC data from Soil Health Card was also used to map and monitor the changes in salt-affected areas. The waterlogged salt-affected areas mapped using satellite data were verified in the field through ground truth data collection at selected sites in different villages.

**The major conclusions of this study are as follows:**

- ✓ The water table in some of the villages in the study area has slightly come up during the period of last 15-years and at most predominantly after introduction of canal irrigation but it is much below to cause any water logging problem. However, it was also observed that waterlogged and salt-affected areas have decreased over the period of one decade due to augmentation of drainage system in the study area.
- ✓ The waterlogged areas in Vaghodia taluka have decreased from 67 ha to 34 ha during 2006 to 2015 mainly because of provision of proper drainage before introduction canal irrigation.
- ✓ Salt-affected areas decreased from 122 ha in 2007 to 73 ha in 2015. The introduction of canal irrigation has helped to bring these areas under cultivation. Soil pH and salinity also found to be normal in study area mainly because of canal irrigation.
- ✓ Rainfall data analysis indicated that the region received a decline in rainfall from the year 2007 to 2013, but still the area under agriculture showed increase during 2007 to 2103 which clearly indicates that area under irrigated agriculture and density of agricultural vegetation has increased mainly because of availability of canal irrigation.
- ✓ The agricultural vegetation cover of medium and dense categories shows an increment from year 2000 to 2016 accounting an increase from 12% to 26% in medium and 6.9% to 20% in dense vegetation.
- ✓ Increase in the irrigated and agricultural areas has significantly given rise to increase in the economic conditions of the farmers in the Vaghodia taluka.

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