# Evaluating Landform Feature Dynamics Through Spatio-Temporal Change Detection Methods for Narmada River Estuary, Gulf of Cambay, Gujarat Using RS-GIS Techniques

Modi D S
*Department of Civil Engineering, BVM Engineering College, Vallabh Vidyanagar,Gujarat, India*

***Abstract*—The Gulf of Cambay (GoC), also known as the Gulf of Khambhat, is a vital extension of the Arabian Sea along Gujarat's coastline. The coastal belt plays a significant role in the state's economic development, particularly through its estuarine systems like those of the Mahi, Dhadhar, Narmada, and Tapi rivers and others too. However, these regions are facing a multitude of environmental challenges due to both natural processes and human activities. For evaluation of Landform Feature Dynamics through Spatio-Temporal Change Detection Methods of Narmada River Estuary at Gulf of Cambay, decadal landform changes for the 1978–2017-time frame and Level I & II Classification System for Coastal Land Use Mapping for the geology and geomorphological features were considered. Satellite data were used in ArcGIS environment to construct the geo-data sets and produce LULC classified thematic maps and geo-statistics. Statistical analysis generated were materialised to reveal the outcomes. Additionally, human interference has too largely played crucial role to alter the land scape. Almost 30 large, 135 medium and 3,000 small dams and related water infrastructure to harness the waters of the Narmada and its tributaries are either planned or constructed or even under construction. With the passage of time, on account of what so ever reason like population growth, industrialization, huge power demand and else factors have changed the river scape along with the landscape of the river basins. Industries, mangroves, settlements, depict a growth from 1978 to 2017. Sandbars have negative and mudflats have positive but fluctuating trend. Further association of classified and predictable features on image were established with Ground Control Points (GCP). The spatial extent of mud flats, salt encrusted land and sand bars have transformed indicating the natural parameters are under pressure over this region. The trend of fluvial water and rejuvenation through sediment flux in gulf in the recent time is declining compare to previous and in contradictory, the spatial extent of mud of marine nature and its deposition and change in its quality is striking and evident.**

***Index Terms*—Gulf of Cambay, Narmada River, River estuaries, Landform features, LULC dynamics, Spatial and Temporal analysis, RS & GIS**

## 1 INTRODUCTION

The coastal zone includes river basins and catchments, estuaries and coastal seas and extends to the continental shelf. It is a broad transitional area in which terrestrial environments influence direct marine environments and vice-versa [2]. The coastal zone comprises a suite of unique ecosystems adapted to high concentrations of energy, sediments and nutrients that stimulate both high biological productivity and a diversity of habitats and species [1]. The Pilot Analysis of Global Ecosystem (PAGE) study defines coastal regions to be the intertidal and sub-tidal area on and above the continental shelf (to a depth of 200 meters) area routinely inundated by saltwater and immediately adjacent lands [3]. In other arguments coastal zones are the area of interaction between land and sea which is located between terrestrial and marine environments [5]. Over the last century, human with their technological capabilities have accelerated the rate of change, increasing their influence on the dynamics of already highly variable ecosystems [4]. Sixty percent of the world's major cities are located in coastal zones, and 40% of the all the people on the planet live within 100 km of a coastal zone [6]. Total coast line of the world is 35, 6000 km and the coastal area covers more than 10% of the earth surface. In India, 500 m distance from the high tide line towards

landward is taken for demarcating the coastal zone [5]. The estuary is a transitional zone where freshwater from the River mixes with saltwater from the sea water, creating unique ecological conditions. The estuary plays a crucial role in the ecosystem of the region, providing habitats for diverse species and supporting local communities. The estuarine area is vulnerable to pollution from industrial effluents, waste disposal, and fishing activities. Because of the economic benefits that accrue from access to ocean navigation, coastal fisheries, tourism, recreation and industrialization, human settlements are often more concentrated in the coastal zone than elsewhere. About 40% of the world's population lives within 100 km of the coast. About 10% of the world's population resides in low elevation coastal zone (<10 m) making their lives highly vulnerable to coastal disasters. About 35% of Indians live within 100 km of the country's coast line measuring 7517 km [7]. Here is the statistics summarised in TABLE: 1 stating the share of Indian cost to the world.

| | Coastal Length (km) | Area of Continental Shelf (up to 200 m depth) | Territorial Sea (Up to 12 nm) | Claimed Exclusive Economic Zone | Exclusive Fishing Zone | Total Potential Maritime Area | Population within 100 km from the coast |
|---|---|---|---|---|---|---|---|
| | a | 000 km2 | 000 km2 | 000 km2 | 000 km2 | 000 km2 | Percent |
| World | 1634701 | 24287.1 | 18816.9 | 102108.4 | 12885.2 | X | 39.0 |
| India | 17181 | 372.4 | 193.8 | 2103.4 | X | 2297 | 26.3 |

Table 1 Share of coastal area of India to the world: (Courtesy: PAGE: WRI, 2000)

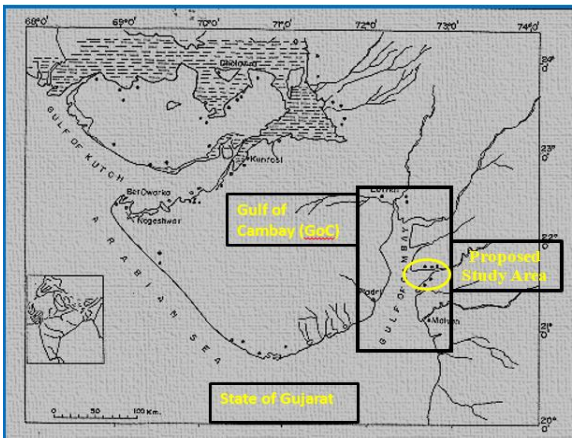
The Pilot Analysis of Global Ecosystems (PAGE) highlights that human activities have significantly altered coastal ecosystems worldwide. Approximately 30% of the land area in these ecosystems has been extensively modified or destroyed due to increasing demands for housing, industry, and recreation. This degradation is further exacerbated by the growing coastal population [3]. Gulf of Cambay part of Gujarat coastal belt, Western coast of India too, facing the environmental challenges like human encroachment, transforming land use land cover pattern, landform dynamics, wet land loss, and shore line erosion. Along the Gujarat coastal belt, the population in coastal taluka of Gujarat Coast has increased by nearly 18.3 percent from 2001 [8]. The urban Population increased by about 34 percent in the six major coastal districts of Gujarat [9]. Over the last century, humans with their improving technological capabilities have accelerated the rate of change, increasing their influence on the dynamics of already highly variable ecosystems [1]. The RS tool provides a valuable source of multi-temporal data at spatial and temporal scale. The GIS is useful for mapping and assessing the associated patterns. These tools provide a unique opportunity to develop information sources and support decision-making activities in a plethora of coastal zone applications [5]. This paper is an effort to study the Narmada River Estuary at Gulf of Cambay.

## 2 OVER VIEW OF THE STUDY AREA:

### 2.1 General

The Gulf of Cambay (GoC) also referred as Gulf of Khambhat, is geographically located between latitude 20° 30' and 22° 20' N and longitude 71° 30' and 73° 10' E. (Fig.1). The Gulf of Cambay (Khambhat) in the state of Gujarat, is an inverted funnel shaped highly indenting, constituting western Continental shelf of India. The trumpet shaped gulf has separated Saurastra peninsular to the Main land Gujarat crafting western flank of Gulf i.e. Saurastra and eastern flank of Gulf i.e. Main land Gujarat. The mouth of this Gulf opening to Arabian Sea is having width of 70-75 kms and attaining length of 130-135 kms [24]. As a part of research work of GoC, it is found that the width drastically reduces to 25 km at Bhavnagar and then approximately 15 km [24] or even less up to ~ 6 km [9] towards the tail of the Gulf while towards the mouth width attains almost 200 km [7]. Geographically the limits of the GoC is covered by Survey of India Toposheet No.46 B/8 and 46C /6, C/9, 10, 11, 12 and 14 at scale of 50,000 of 1968 to 1974 years and the Naval Hydrographic Chart No.208

(Hydrographic Chart of Gulf of Khambhat at scale 1:50,000, Original published in 31.07.2006 by National Hydrographic Office-Dehradun, GOI. [24].



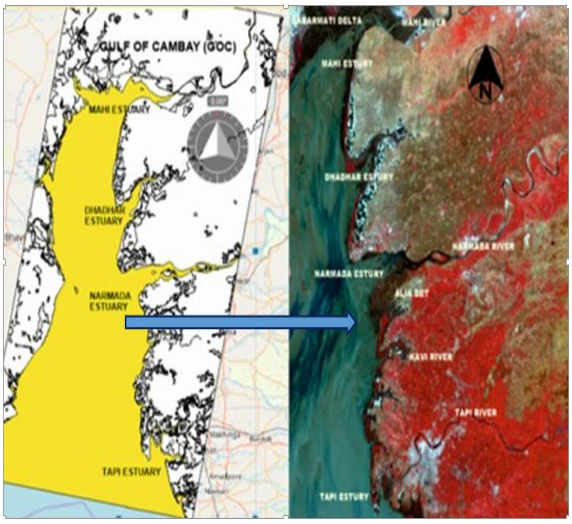




Figure: 1 Study Area

Geologically to quote, the Narmada River is occupied by the rocks belonging to Vindhyan and Satpura towards upper reaches and Deccan basalt towards lower reaches and Alluvium of Quaternary of the coastal area. The river rises in the Amarkantak and flows over the marble rocks and widen into estuary entering the Gulf of Cambay (GOC). The resultant silt deposition of the Narmada River is deposited in to extreme lower of the lower Narmada basin, prior to debouching its water into Gulf of Cambay of Arabian Sea. Several rivers join the gulf, including the Sabarmati, Mahi, Dhadhar, Narmada, Tapti, and Shetrunji, Bhadar, and Kalubhar and hence, the GoC is characterized by a number of estuaries, islands, mudflats, cliffs, and mangroves. Among all these rivers Sabarmati, Mahi, Narmada, Tapi are perennial rivers and the rest are seasonal or drain with negligible water flow. Shetrunji, Kalubhar and Bhadar meets Gulf from the western flank while Sabarmati empty its water from north of GoC and the remaining rivers Mahi, Dhadhar, Narmada, and Tapi debouch their water from eastern flank.

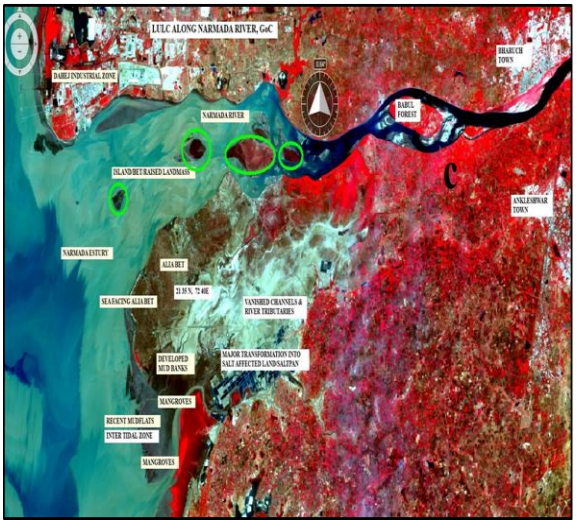



Figure: 2 Satellite Image representing Narmada cell - (The Narmada River opens up into Gulf of Cambay eastwardly, showing estuary, salt encrusted /salt affected land, salt pans, md flats, vegetation, mangroves, sandy beach, waste land or scrub, Industrialisation and Settlement etc.)

## 3 METHODOLOGY

### 3.1 Data Used

hile selecting the data, it was preferred to have a data of same season/period and tidal height at specific interval of temporal resolution to estimate the spatial and temporal variations in the LULC pattern over the past few decades. In order to ensure consistency in comparison studies, it is imperative to select imageries with similar characteristics (season, tidal conditions, etc.). Landsat TM; Landsat ETM, and Landsat OLI_TRS datasets with universal transverse

| Satellite | Date | Sensor | Resolution (mts) | Band (Nos.) | Time Pass | Path | Row | Zone/ projection |
|---|---|---|---|---|---|---|---|---|
| Landsat 3 | 16.10.1978 | MSS | 60 | 04 | 04:38:00 | 159 | 45 | Datum: WGS 84 Map Projection: UTM Zone 43 |
| Landsat 5 | 19.10.1990 | TM | 30 | 07 | 04:38:00. | 148 | 45 | |
| Landsat 7 | 22.10.2000 | ETM+ | 30 | 08 | 05.23.26 | 148 | 45 | |
| Landsat 5 | 14.11.2011 | TM | 60 | 07 | 5.20.41 | 148 | 45 | |
| Landsat 8 | 29.10.2017 | OLI-TIRS | 30 | 11 | 5.33.30 | 148 | 45 | |
| IRS-R2 | 11.03.14 | LISS 4 (NRSC) | 5.8 | 03 | 5.20 | 093 | 057 | |
| Additional support of Google earth Pro (2018); Bhuvan-NRSC, High resolution satellite images (new-2018) and open street map during process and analysis of work. | | | | | | | | |

Mercator (UTM) zone 43 north Projection – WGS ‘84 projection system has been used for this study region. Data used are shown in TABLE: 2

Table: 2 Satellite data used for the study

3.2 Methodology

Satellite Imageries is affected by the solar incidence angle, solar azimuth, earth-sun distance, viewing angle, atmospheric effects, bidirectional reflectance distribution function (BRDF) of the surface sensed, and sensor band spectral response functions, thus these factors in combination produce significant band radiometric differences [29]. To correct this the most essential step is conversion of digital number to reflectance of each dataset, used for interpretation. It is desirable to implement these steps to bring in consistency of the time-series data set. After radiometric correction geocoded Landsat digital data series (1978-2017) were then analysed using onscreen visual interpretation techniques using major key elements along with ancillary information through topo maps, hydrographic charts, published thematic maps to interpret landforms and LULC of North of GoC, Gujarat. LULC maps were prepared on 1:50,000 scale in Geographical Information System (GIS) environment. Geo-data base was created in GIS using ARC GIS10.3. Software package based on Nation Spatial Framework on 1:250000 with LCC projection and WGS 84 datum. An exclusive landform features classification was evolved due to spatio-temporal data set to facilitate an appropriate assessment of all the land use/land cover categories and landform features over the study area. This outcome is the part of research work of whole Gulf of Cambay to understand the natural dynamics and anthropogenic influence. The selected area is based on the uniqueness of geology, geomorphology and physiography of the region with consideration of presence of estuarine delta treated here is a cell. Here the dimensions, size and shape of the cell and district boundaries are not taken into consideration. Attributes of the cell for chosen area is given in TABLE: 3. Adaptation of Level I & II - Classification System for Coastal Land Use Mapping [30], [31] for Narmada Estuary cell could help to recognise some of the Nine landforms while extracting the information from the available satellite data sets which are considered for the Land Use/ Land Cover change as well forming the landform features partly (Landform dynamics). The different landforms features used here are having essence of geomorphology as well as ecology as referred into various papers, not defined here

| S.N. | Cell Name | | latitude | longitude | Area | L (Max) | W (Max) |
|---|---|---|---|---|---|---|---|
| 1 | Narmada | LT | 21 75N | 72 49E | 827.84 | 37 | 23 |
| | | RT | 21 70N | 72 85E | | | |
| | | RB | 21 55N | 72 47E | | | |
| | | LB | 21 51N | 72 84E | | | |
| LT: Left Top LB: Left Bottom | | | NOTE: The dimensions of each cell are non-uniform and having variable Length (L) and Width (W) even for individual cell. | | | | |
| RT: Right Top RB: Right Bottom | | | | | | | |
| Max: Maximum | | | | | | | |

Table: 3 Attributes of the selected area

## 4 RESULTS AND DISCUSSION

### 4.1 Landform cover change: General overview of the region

The Mainland Gujarat coast facing the Gulf is made up of fluvial sediments of considerable thickness; nowhere hard rocks are encountered on the surface along the coast (exceptionally at few location). The Mainland Gujarat coast is alluvial dissected by rivers Narmada, Mahi, Dhadhar, Tapi and others, and with cliffy river mouth banks. The rivers carry a lot of water and also bring vast quantities of sediments every year. The waters of Gulf heavily loaded with the fluvial sediments brought from the mainland side as well as the Gulf sediments, constantly churned up by the tidal currents of the Gulf. The extreme muddiness of the Gulf waters and the complex interplay between the tides and river water flow has resulted into an interesting assemblage of depositional land forms in and around the Gulf. Mudflats represent the most dominant landform stretching One study is based on suspended sediment concentration, flow structure, geomorphic features and hydrodynamics reveals that the fine-grained sediments are transported to the inner Gulf and sandy sediments are transported south words as the tides here are largest in the Indian coast [34]. At many places the flats are seen supporting growth of mangroves. Here is the geo-statistical analysis TABLE: 4 carried out for the years of 1978, 1990, 2000, 2011, 2017

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| Land use Land cover in % | | | | | |
|---|---|---|---|---|---|
| Narmada River Cell | | | | | |
| Category | 1978 | 1990 | 2000 | 2011 | 2017 |
| Agriculture Land | 28 | 28 | 28 | 26 | 25 |
| Industrialisation | 0 | 0 | 2 | 7 | 7 |
| Mangrove | 0 | 4 | 4 | 4 | 3 |
| Mud Flats | 15 | 14 | 4 | 5 | 3 |
| Salt encrusted land/ salt pan | 22 | 22 | 21 | 19 | 18 |
| Sandbar | 0 | 0 | 0 | 0 | 0 |
| Scrubland | 3 | 1 | 1 | 3 | 3 |
| Settlement | 0 | 0 | 0 | 1 | 2 |
| Water body | 31 | 31 | 40 | 35 | 40 |
| Grand Total | 100 | 100 | 100 | 100 | 100 |

Table4:geostatistical analysis of different land features identified (Area covered by feature of total in %)

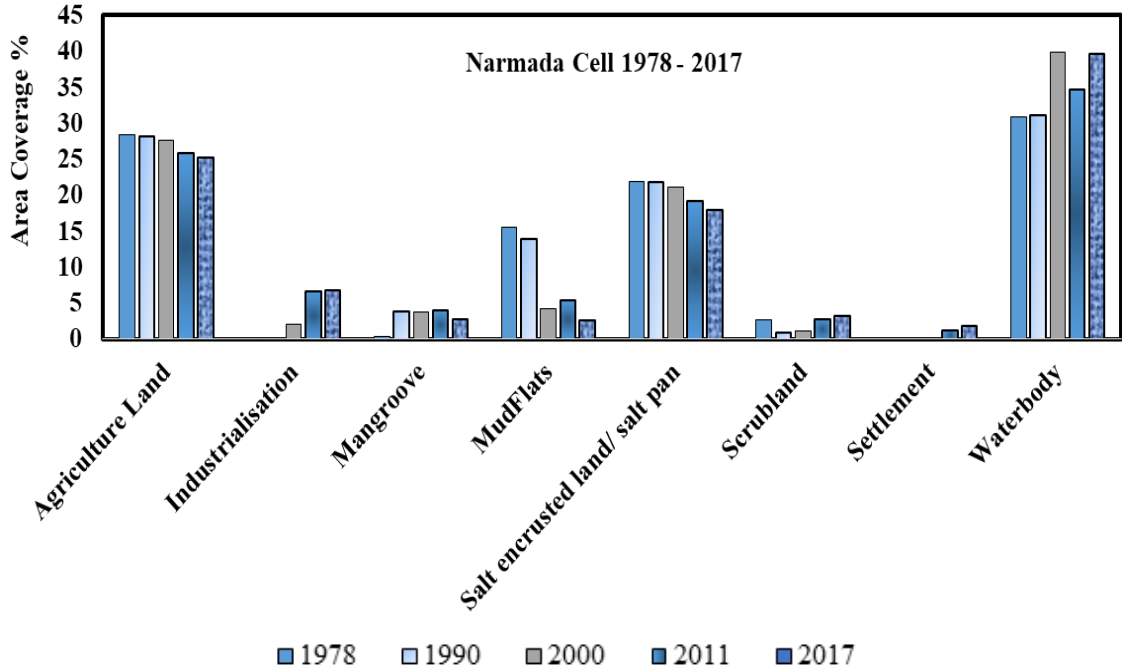


Fig: 3 Geo-statistical graphs: Features calculated in % of the total area of the cell in Narmada.

Geo-statistical graphs are presented for the area in figure: 3 for the timeframe 1978-2017 and spatio-temporal mapping of the same timeframe for selected area has been presented in Fig.4 for understanding the change in landforms.

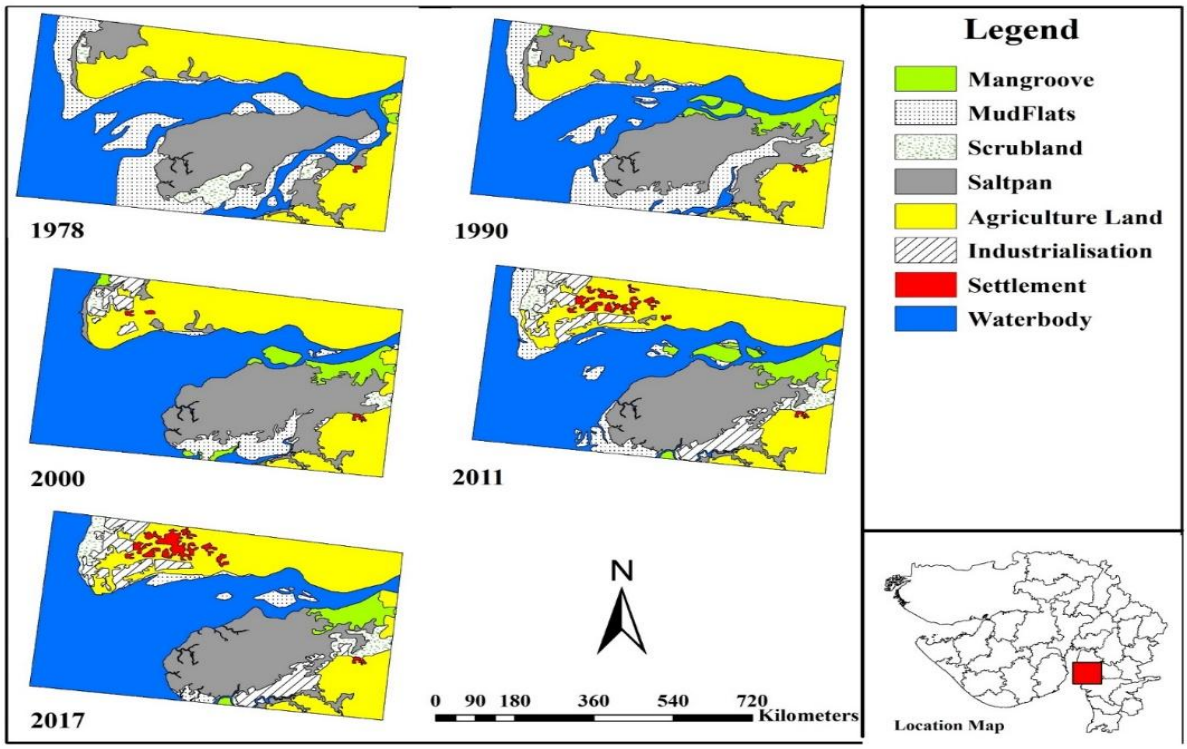


Fig: 4 Spatio-temporal landform feature change for the Narmada River (1978-2017)-Digital processed Landsat Images

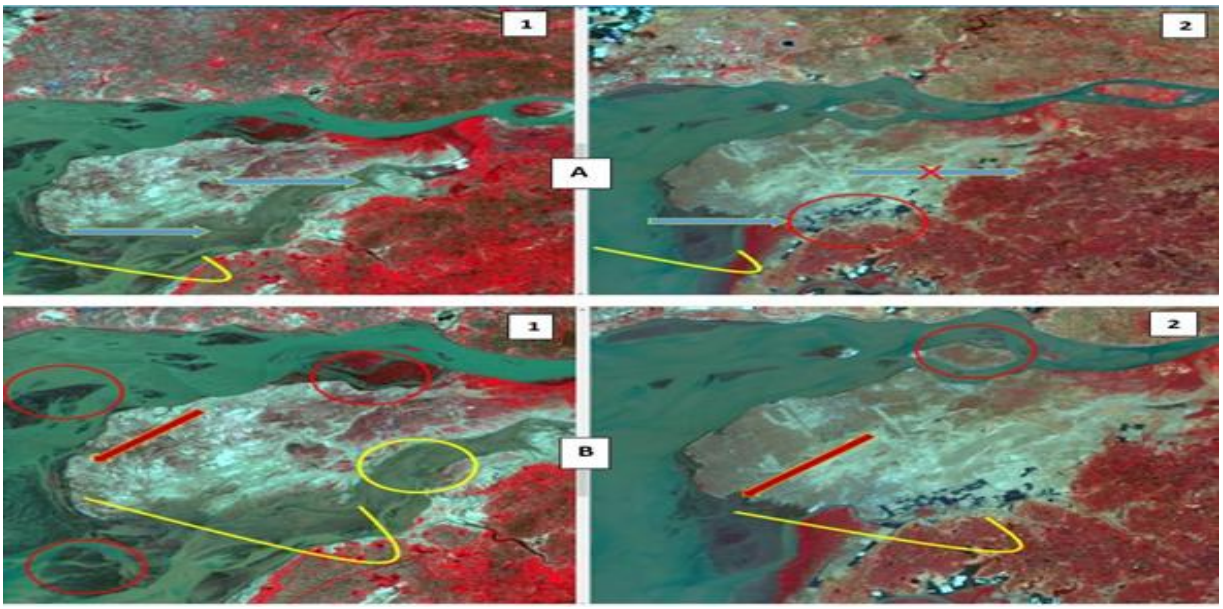


Fig: 5: Satellite Images Processing and Analysis for land form dynamics

5.Observations:

Well-developed Agricultural /vegetation cover shows declining trend for the Narmada region. Industrialization and human settlement categories show increasing trend in this region. The industrialization is up to 10% rise. This can be matched with the considerable upsurge and spatial expansion of the region Dahej and Hazira (ports) and the urban built-up class. The influence of this category is noticeable for the salt pan and mudflat features. Mangrove illustrates an increasing trend (from 0 to 4% of the total cell area), but in the end, it is also slightly declining for all these cells. A reducing trend in the area of Narmada and the Hazira can be seen along with a decrease in the extent of mudflats (10 -15%), scrubs (2-3%), sandbars (1-2%), and salt-encrusted land. That can be matched with the increment of aquaculture and salt pans activity in these regions. The salt pan farming has increased at the cost of reduction of salt-encrusted land and mudflats (13-15%). The growth of human settlements, industrialization, and the expansion of saltpans along the Narmada River have transformed the surrounding landscape. These developments have increased connectivity between towns and led to the disappearance of channels and tributaries, significantly altering the river's landform features.

6. Validation: Photograph description in favour of ground truth as given below


Fig .6 field photographs ground truth validation

## 5 CONCLUSION:

The present study is an effort towards continuous observing the changes along coastal belt of Cambay. Periodic studies and monitoring can provide information about the previous to current situations. The amplified industrialization and urbanization in the last few decades have stressed on coastal area of Gujarat state. Different spatial classes are represented here in image for temporal resolution of 1978, 1990,

2000, 2011, 2017 along with the statistics and graphical bar charts on decadal scale. Mangroves are taken care of by the nature. The contribution of water and sediments flux from river side is comparatively (based on referred research work) compare to mud flat expansion through tides within the gulf and along estuaries, encouraging more marine deposition and saline in nature. The quality degradation and quantity of mud flats in this region of estuary is eye catching. It could be inferred that the incremental rise can transform the scenario of the region. For the refined outcome, using satellite data of higher resolution at specific smaller interval and at micro level is essential.

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