

Shoreline Analysis Report: Integrated River Basin
and Shoreline Management Plan for Goa

Submitted to



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Executive Summary

Water Resources Department (WRD), Government of Goa under the financial assistance of Ministry of Jal Shakti Department of Water Resources, River Development and Ganga Rejuvenation, Government of India under National Hydrology Project of World Bank has planned to formulate an integrated river basin and shoreline management plan for Goa state. Subsequently, preparation of the integrated river basin and shoreline management plan has been entrusted to National Institute of Ocean Technology (NIOT), a Research and Development organisation under the Ministry of Earth Sciences, Government of India by WRD.

To prepare the shoreline management plan, NIOT aims to study the shoreline dynamics by integrating upstream characteristics of major river catchments which serves as a source of sediments with coastal sediment transport process. The integration of upstream catchment characteristics with coastal dynamics is one of its kind and may set a precedent for formulation of future shoreline management plans in India.

To achieve the objectives of formulation of an integrated shoreline management plan the entire study has been divided in to 7 tasks which encompass activities from inception stage to detailed engineering design stage. This report details the outcome of the second task "Shoreline and Catchment Characterization".

As part of the task, Shoreline change studies carried out by Space Application Centre-Ahmedabad, Indian Space Research Organisation (ISRO) and National Centre for Coastal Research (NCCR), Ministry of Earth Sciences, Government of India were reviewed. Later NIOT has carried out an analysis of satellite imageries from 1972-2020 to determine catchment and shoreline characteristics.

Shoreline change analysis using satellite imageries was carried out from 1972-2020 by NIOT, it is observed that 12.5% of the coast is eroding, 20.1% is accreting and 67.4% is stable. These statistics are comparable with the findings of NCCR. Tiracol, Chapora, Vagator, Anjuna, Calangute, Candolim, Miramar, Cavelossim, Betul, Agonda, Palolem, Talpona and Polem are the eroding stretches of the Goa coast. Similarly, river catchment is characterised by analysing the satellite images using the supervised classification method. The land use/ land cover changes for the years 1990, 2001, 2012, 2020 has been analyzed. From the catchment characterization, it is observed that, the urban and mangrove area have been increased since



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1990. Based on this report three priority hot spot locations shall be finalized by WRD, Goa in coordination with stakeholders and NIOT to carry out further studies.



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1 INTRODUCTION

Goa is located in the western region of India and it shares its borders with the Arabian Sea to the west, Maharashtra to the north and Karnataka to the south and east. Its economic growth is driven by the strong performance of mining, tourism and pharmaceuticals sectors. It is traditionally known as a tourist paradise for its natural scenery, unique beaches and cultural diversity. Tourism is generally focused on the coastal areas of Goa, with decreased tourist activity inland.

The world-famous beaches of Goa are facing a threat from nature as well as from humans. Tourism and traditional habitats in coastal belt are facing threat to their life and property due to the diminishing coastline. Many hotels and bars, hundreds of houses and fishing infrastructural equipment are situated near the beaches. It is feared that continuous sea erosion would displace them all.

Analysis of long and short-term shoreline change along Goa coast from 1990-2016 using Remote Sensing and GIS techniques done by National Centre for Coastal Research (NCCR), Ministry of Earth Sciences, Government of India revealed that 68% of the coast is stable in condition, 20% is accreting and 12% is eroding.

The shoreline dynamics has influence of sediments transported from the upstream of the rivers into the sea. The Goa state has two major rivers namely Mandovi and Zuari in terms of catchment and discharge when compared with others. There is need for a well-defined plan that seeks to treat the shoreline and the issue of erosion in a more integrated, sustainable and strategic manner. This can be achieved by Shoreline Management Plan (SMP) integrated with river basins, which considers the issues at a reasonable scale. So, The Water Resources Department (WRD), Goa has taken a grant from Ministry of Jal Shakti Department of Water Resources, River Development and Ganga Rejuvenation under National Hydrology Project funded by World Bank in order to draft a shoreline management plan considering the river catchments and to provide suitable erosion mitigation solutions at 3 identified hotspot areas along the Goa coast.



WRD, Goa has made a contract agreement (Contract No. 01/WWIII/WRW/ACCTS/NHP/2020-21/dt:08.07.2020) with National Institute of Ocean Technology (NIOT) on 08 July 2020 to complete the above scientific study. As per the SCC clause 13.1 of signed contract, commencement of services i.e., start date is considered four weeks from signing of contract i.e., 05th August 2020. The study has the following tasks:

Task 1: Inception phase

Task 2: Shoreline Analysis

Task 3: Data collection

Task 4: Conceptual design and Feasibility studies

Task 5: Environmental and social Impact assessment

Task 6: Integrated River Basin and Shoreline Management Plan

Task 7: Detailed design

Task 1, "Inception Report" was prepared and submitted on 21 Sep 2020 and approved by WRD, Goa on 21 Oct 2020. As part of Task – II Activity "Shoreline and catchment characterization" the shoreline analysis by the various institutes has been reviewed. Considering the short falls in these studies a long-term analysis of shoreline and catchment area were carried out by analyzing satellite Images from 1972 to 2020. Based on this analysis, critical hotspot locations were identified and trend analysis for these hotspot erosion sites were carried out.

2 STUDY AREA

The area of interest in this study is the entire Goa state. Goa, is located along the Central West Coast of India between 15°44'30" and 14°53'30" N latitude, and 73°45' and 74°26'E longitude. It has a shoreline about 150 km long with 53 coastal villages that are located along the coast. Goa covers an area of 3702 square kilometers and comprises two revenue districts, viz. North Goa and South Goa. Boundaries of Goa extend from Tiracol river in the North which separates it from Maharashtra, in the East and South by Karnataka State and West by Arabian Sea.



3 OBJECTIVES:

The broad objective of this study is to understand periodic changes in shoreline and catchment characteristics and identify critical erosion hotspot sites. This will be achieved through:

- Review the long-term shoreline analysis carried out by National Centre for Coastal Research (NCCR).
- Analysis of satellite Images, other data products and field measurements of hydrology as mentioned below:
 - Long term shoreline analysis using satellite and aerial images to identify hotspots for erosion.
 - Analysis of changes in upstream river catchment area.

4 LITERATURE REVIEW

The studies carried out by various institutes and agencies on shoreline analysis and catchment characterization were reviewed. The details are provided in the subsequent sub-sections.

4.1 SHORELINE ANALYSIS

In India, NCSCM has prepared shoreline change maps for few coastal states. The shoreline changes maps were prepared on a scale of 1:50000 scale. These maps were prepared only for Odisha, Kerala and Gujarat. Further, Space Application Centre (SAC) has prepared shoreline change maps Atlas on a scale of 1:25000 scale using two shorelines. Recently, National Centre for Coastal Research (NCCR) has prepared maps on a scale of 1:25000 scale using satellite data from 1990 to 2016.

4.1.1 SPACE APPLICATION CENTER (SAC)

Space Application Centre (SAC) has prepared shoreline change maps with Central Water Commission in the form of Atlas (1: 25000 scale). The objective of the work was to prepare a digital shoreline change atlas in GIS environment on 1:25,000 scale using satellite data (1989-91 and 2004-06). This report gives an overview of by

plotting 2 high water lines obtained from land use /land cover mapping study carried out at SAC using datasets i.e., 1989-91 and 2004-06.

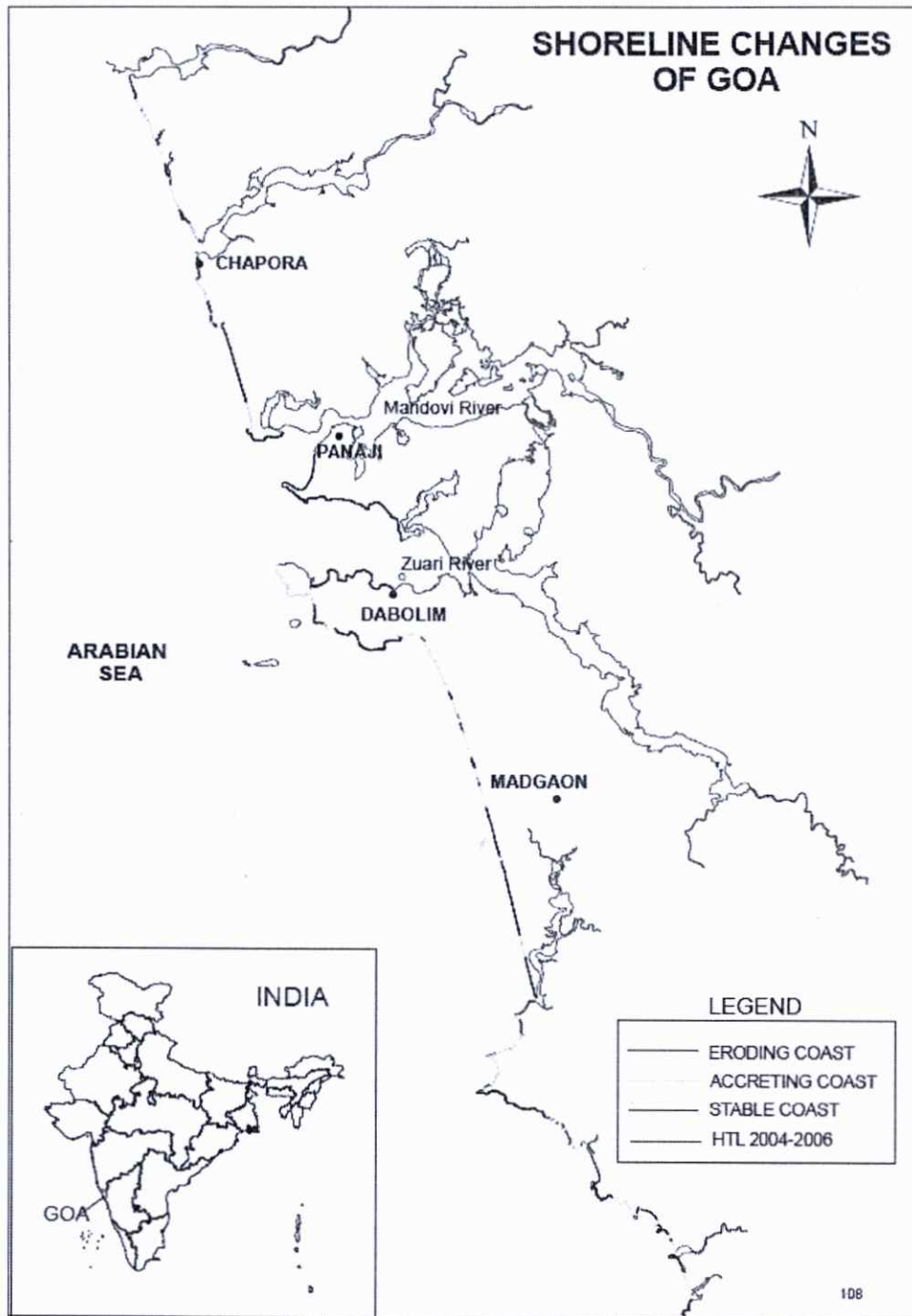


Figure 4-1: Shoreline Change Map for Goa coast (Source: SAC-ISRO report, 2014)



About 155.39km of Goa shoreline was analyzed and it was observed that 27.03km (17.4%) length had eroded, 46.98 km (30.2%) had accreted and 81.38 km (52.4%) was stable during the time frame of 1989-91 and 2004-06. The total area eroded is estimated at 0.77 sq km and accreted is 1.53 sq km.

The summary of the study is as follows:

- Shoreline along Northern Goa shows segments of erosion, accretion as well as stable nature. Severe erosion is seen at Keri and Tetrapods have been used here along with sea wall to check erosion. The coastal stretch extending from Harmal, Mandrem, up to Morjim shows accretion to stable trend. Chapora, Vagator in the north show eroding to stable nature. Other regions showing stable nature of coast are south of Anjuna, Candolim, Sinquerim between Calangute and Nerul and Shinken. Few pockets of erosion are observed north of the Chapora River, around Arpora, south of Calangute.
- The Central coastal segment of Goa comprises of regions around the Aguada and Mormugao Bay. The Mandovi and Zuari rivers discharge into these respectively. This region is between south of Shinken up to Vasco. This coastal stretch is majorly stable in nature, except few small segments of erosion. Coco beach, south of Shinken is a pocket beach showing local erosion. Eroding segment is also observed near Dona Paola.
- In South Goa sector, long linear beaches, rocky cliffs, headlands are observed. Pocket beaches are formed between rocky headlands. Segments of erosion, accretion as well as stable nature occur in the South Goa sector. The coastal stretch along Bobdan, south of Vasco, Kimsavlin, Arossim, Sernabatim, near Kavleshi and south of Talpona up to Mahi shows accretion. Erosion is observed around Betalbatim, between Colva and Majorda. Uprooting of Casuarina plantation due to coastal erosion and protection measures taken near Betalbatim. Erosion is also observed along South of Betul, up to Kanagini and between Parven to Agonda. Small segments of stable coast occur along Dabolim, Arossim, south of Sernabatim, Bogmalo, Chicolna. A long stretch of stable beaches is observed from Fatrade almost up

to Betul. Stable coast at Karmona, north of Kavleshi is observed and beautiful sandy beaches (Benaullim, Varca, Betul) occur along this segment. The rocky cliffs in the southern region, from Cape Rama to Loliem near Karnataka border constitute the stable coastal stretch.

The maps were useful for initial assessment of erosion hotspot sites. However, only two years data is used and these maps don't depict the temporal behavior and non-linear changes of shoreline, which is very essential for coastal management. Also, this data is only applicable for understanding status till 2004 and cannot be further extrapolated.

4.1.2 NATIONAL CENTRE FOR COASTAL RESEARCH (NCCR)

National Centre for Coastal Research (NCCR) has prepared shoreline change maps in the form of Atlas (1: 25000 scale). The major objective of this activity is to prepare a web based coastal service on annual shoreline changes along the Indian coast in GIS environment on 1:25,000 scale using satellite data (1990 to 2016). Satellite data sets Landsat TM, ETM+, IRS- P5 (Cartosat-1), IRS-P6 (LISS-III) and (LISS-IV) was used as the primary data source. Long-term rates of change are calculated using 9 different years of shorelines positions i.e., for the year 1990, 2000, 2006, 2008, 2012, 2013, 2014, 2015 and 2016.

About 140km of Goa coast is analyzed from 1990 - 2016 and results shows that around 68% of the coast is in stable condition, 20% is accreting and 12% is eroding. The coast of North Goa district is stable with a few pockets of erosion and accretion regions. It's observed that 29% of North Goa district is eroding. South Goa is also dominated by stable coast with about 20% of the coast showing accretion. Major portion of the Goa coast which comes under stable category constitutes rocky cliff, headlands and promontories of basaltic origin which are resistant to wave action. Headlands and promontories occurring in the stretch play an important role in controlling the morphology of the beach adjacent to them. Sediments along the pocket beaches get circulated within the headland, bounding their ends depending on season.

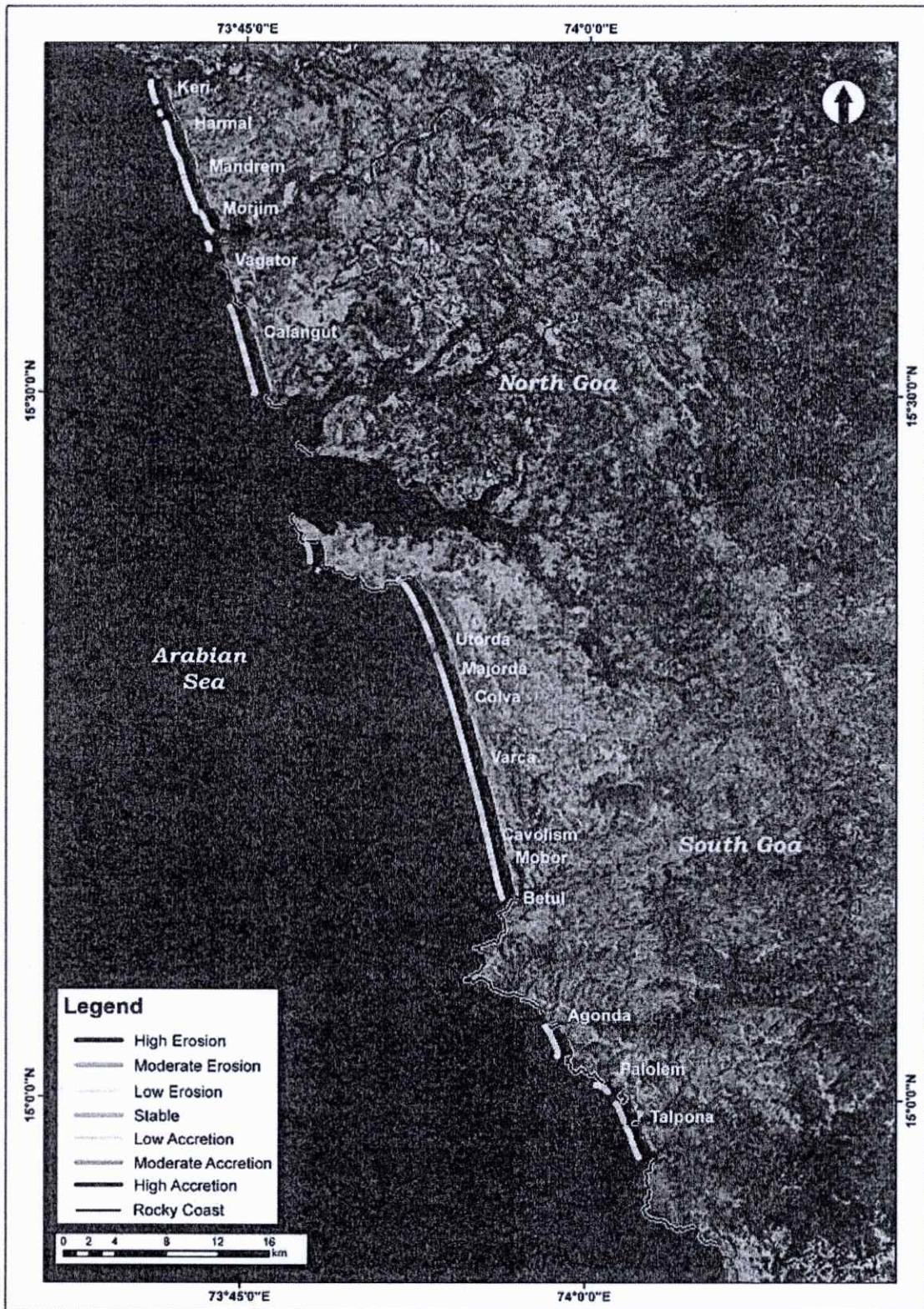


Figure 4-2: Shoreline Change Map for Goa coast (Source: NCCR report, 2018)



Study results indicate Accretion in Majorda, Velsao, Arossim, Utorda, Colva, Mobor, Betul regions of South Goa and northern part of Calangute beach, northern bank of Chapora river and along coastal stretch from Harmal to Mandrem of North Goa. Erosion is seen in the coast of Keri, Vagator, southern part of Calangute, Mandrem to Morjim, Candolim in North Goa and Palolem, Talpona, north of Galgibaga and region from Varca to Cavelossim in South Goa.

These maps are very useful in assessment of erosion hotspot sites and understand temporal behavior and non-linear changes of shoreline, which is very essential for coastal management. However, as these maps are made on national scale only 9 shorelines were used and only covers 1990 to 2016. The recent changes from were also not covered in this study.

The summary of both the studies are given in Table 4-1. The review of shore line from SAC and NCCR indicate need for preparation shore shoreline trends on long scale (about 50 years) and also considering more samples of data for reliable understanding of spatial and temporal coastal changes.



Table 4-1: Shoreline change assessment by various institutions

Item	SAC-ISRO (2014)	NCCR (2018)
Duration of Study	1989 - 2006	1990 - 2016
Number of shorelines Considered	2	9
Years Considered	HWL of 1989-91 and 2004-2006	1990, 2000, 2006, 2008, 2012, 2013, 2014, 2015 and 2016.
Type of Satellite Images Considered.	IRS-P6, LISSIV, SPOT-1 & 2 Multispectral and IRS-1A & IRS-1B, LISS-II	Landsat TM, ETM+, IRS P5 PAN, IRS P6 LISS III, Resourcesat LISS IV
Field Validation	Field checks were carried out and based on field observations.	Field checks were carried out and based on field observations.
Method used for study	End Point Method	Weighted Linear Regression Analysis
Classification	3 Categories Erosion Stable Accretion	7 Categories High erosion Moderate Erosion Low Erosion Stable coast Low Accretion Moderate Accretion High Accretion

4.2 CHATCHMENT CHARECTORIZATION

4.2.1 RAINFALL PATTERNS AND RIVER DISCHARGES

Over 90 percent of the annual rainfall in Goa occurs during monsoon period of June to September. The balance of 10 percent occurs during the pre-monsoon period from March to May and post-monsoon period from October to December. The data at eight stations, three in Mandovi catchment (Mapusa, Panjim and Valpoi) and five in Zuari catchment (Ponda, Margao, Mormugao, Quepem and Sanguem) were analyzed from 1979 to 2019. This indicates an average annual rainfall of 3275 with a

peak annual rain fall of 5114 at Valpoi during 2011 in Mandovi basin and 3276 with a peak annual rain fall of 4969 at Sanguem during 2019 in Zuari basin. Along the Zuari basin the stations Mormugao, Margao, Ponda, Quepem and Sanguem are along the river from sea side, the annual average rainfall is 2070, 2510, 3320, 3445 and 3672 mm respectively. Similarly, along the Mandovi basin Panjim, Mapusa and Valpoi are along the river from sea side, the annual average rainfall is 2887, 2956 and 4059 respectively. It can be observed in both the cases that rainfall intensity is less along the coast and increase towards the landside. It is also observed that monsoon rainfall is in the order of 90 % during June to September, 7 % during post-monsoon period of October to December and 3 during pre-monsoon from January to May months.

The variation in annual rainfall over the last 40 years for 8 stations is shown in Figure 4-4. It can be observed that there is an increasing trend in annual rainfall for Panjim and Valpoi and neutral trend for Mapusa for Mandovi basin. In case of Zuari river an increasing trend is observed in four stations Mormugao, Margao, Ponda and Sanguem and decreasing trend at Quepem. A maximum decreasing trend of 10mm/year is observed at Quepem and maximum increasing trend of 7.2 is observe at Panjim station. Overall, it can be concluded that there is increasing trend in rainfall in both the river basins.

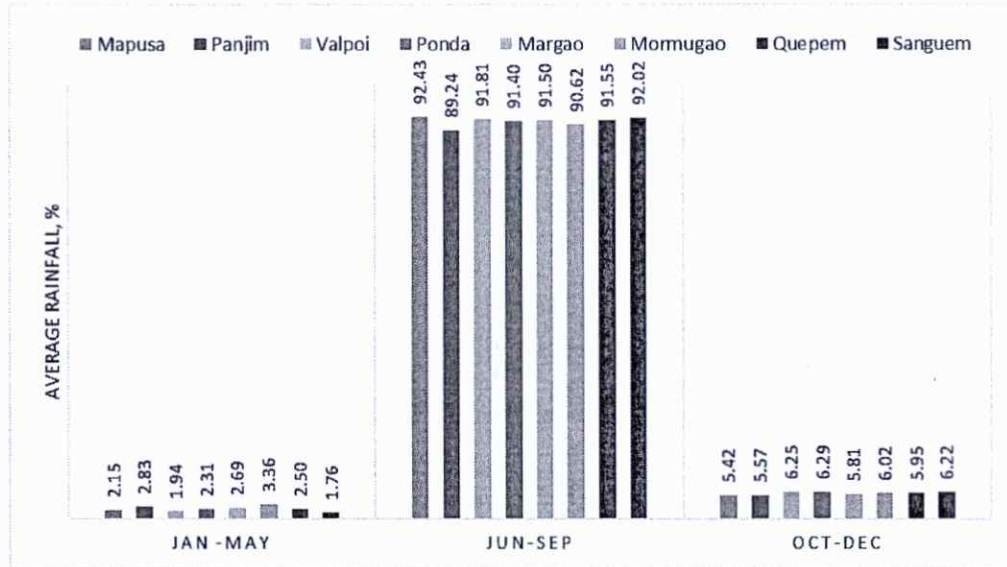


Figure 4-3: Average rainfall (%) along Mandovi and Zuari catchment, 1970-2019

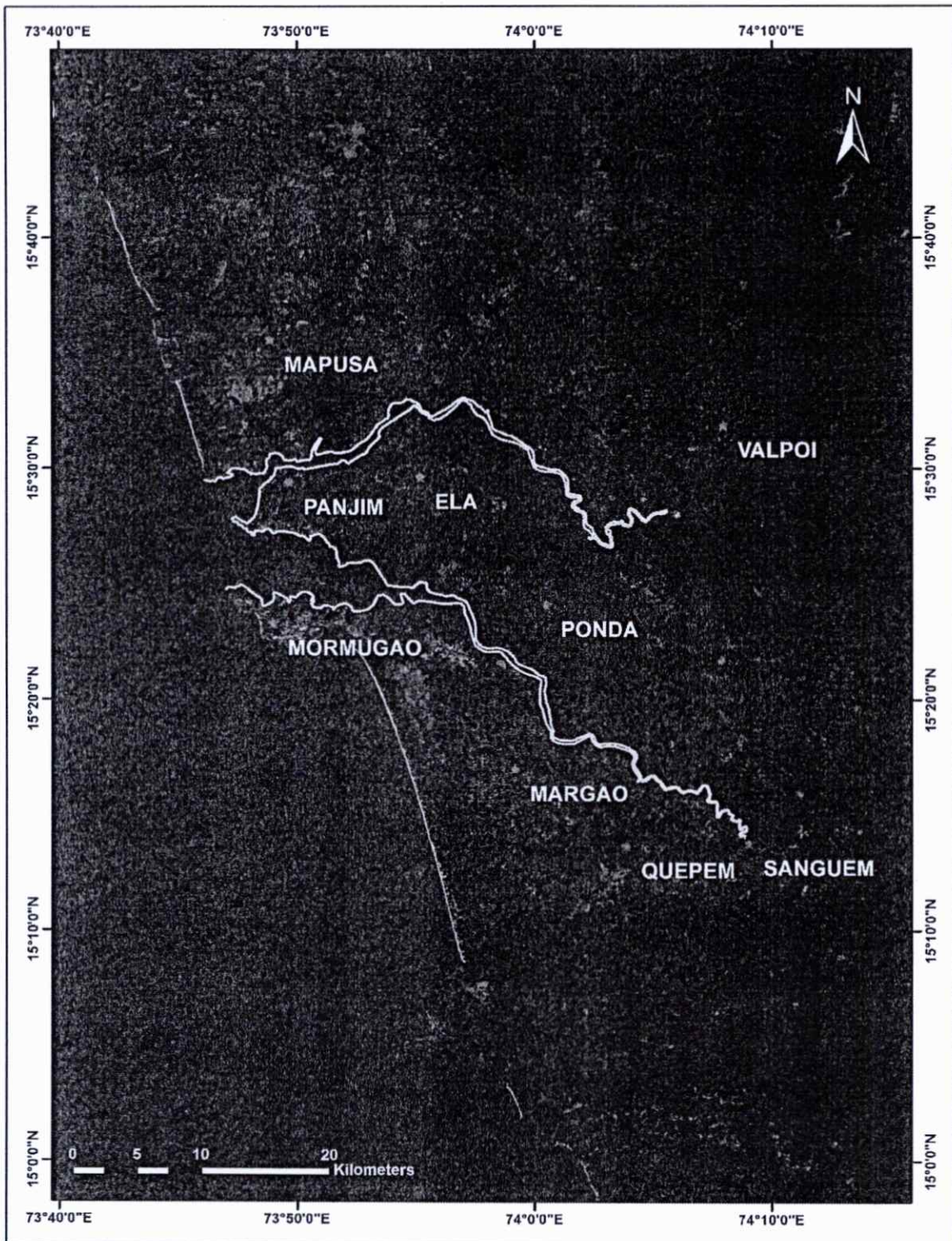


Figure 4-4: Locations of rain Gauge Data

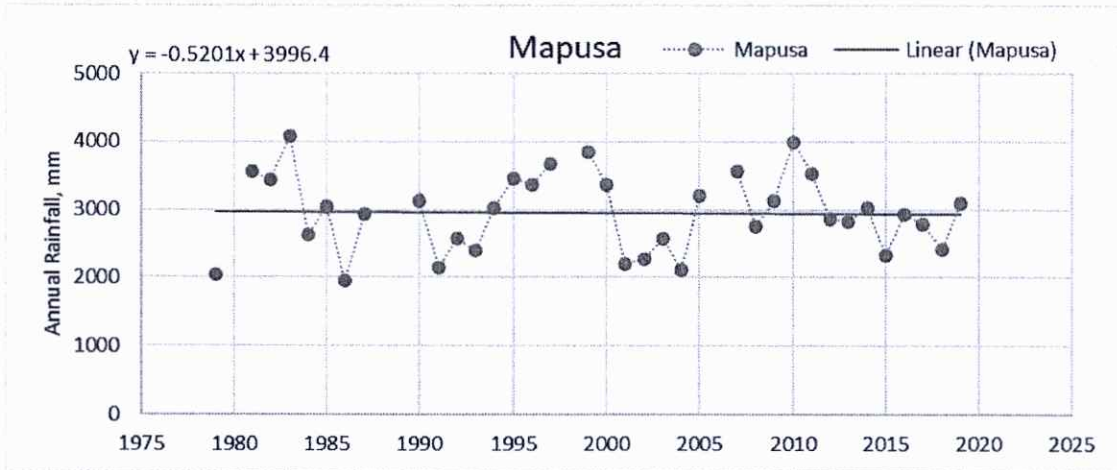


Figure 4-5: Annual rainfall variation at Mapusa, Mandovi catchment

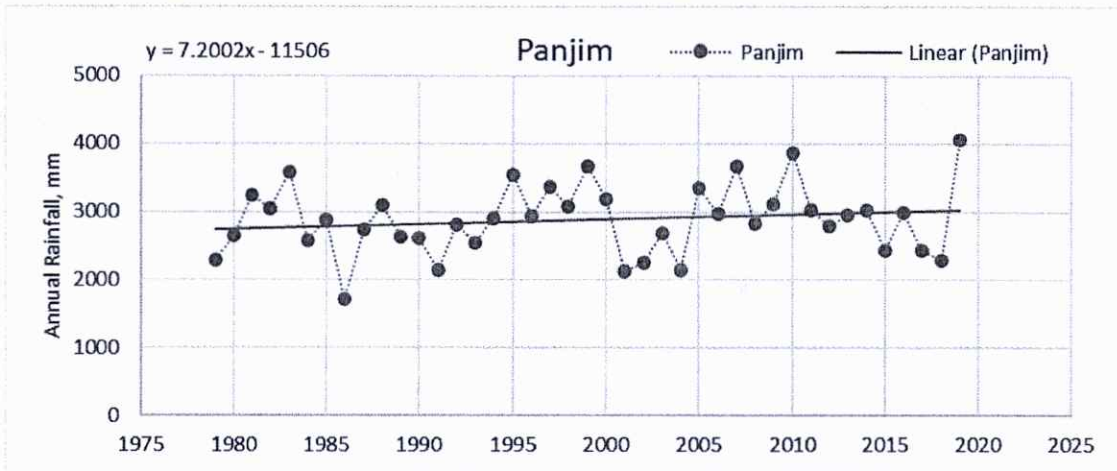


Figure 4-6: Annual rainfall variation at Panjim, Mandovi from 1970-2019

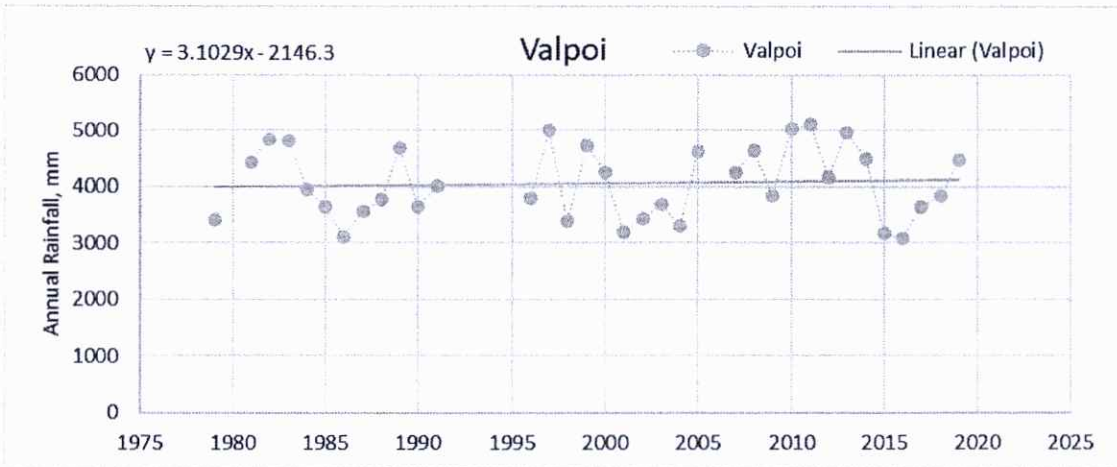


Figure 4-7: Annual rainfall variation at Valpoi, Mandovi from 1970-2019

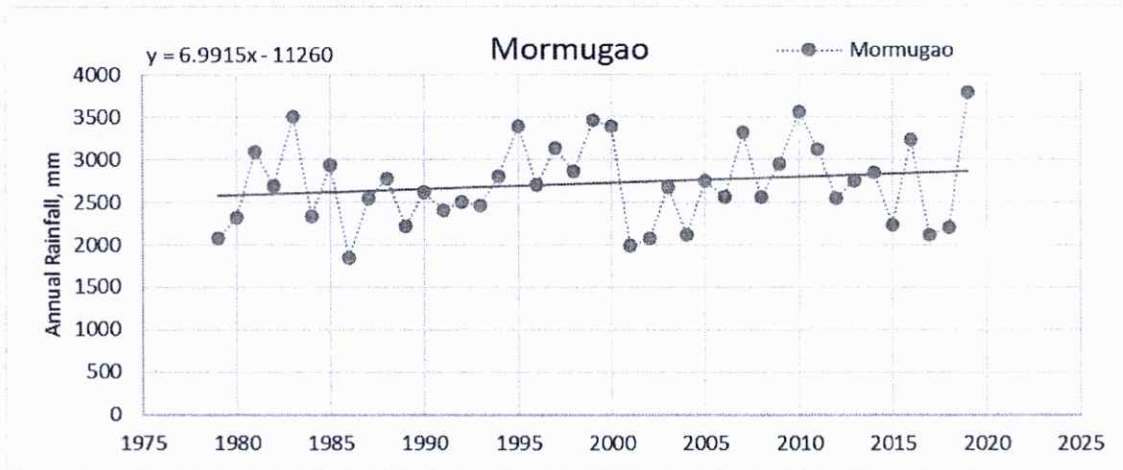


Figure 4-8: Annual rainfall variation at Mormugao, Zuari catchment

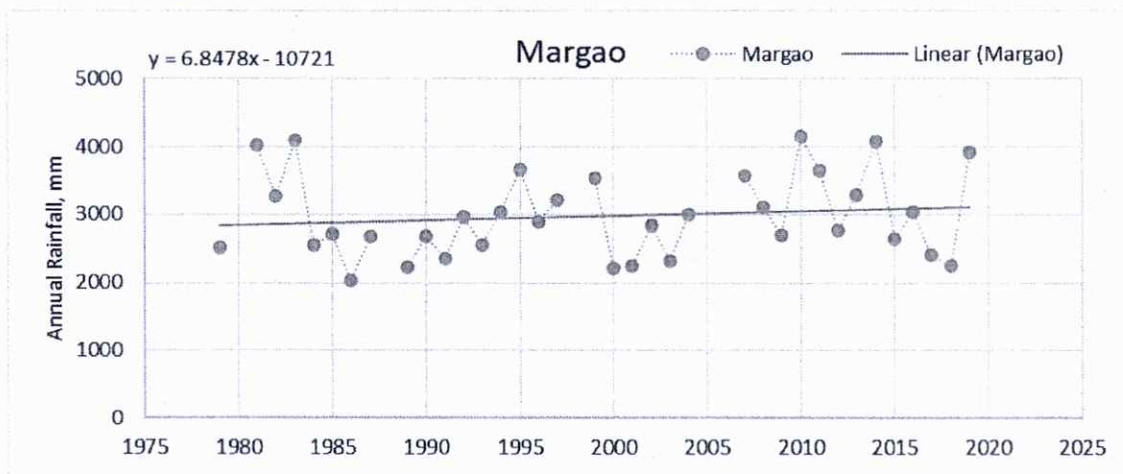


Figure 4-9: Annual rainfall variation at Margao, Zuari catchment

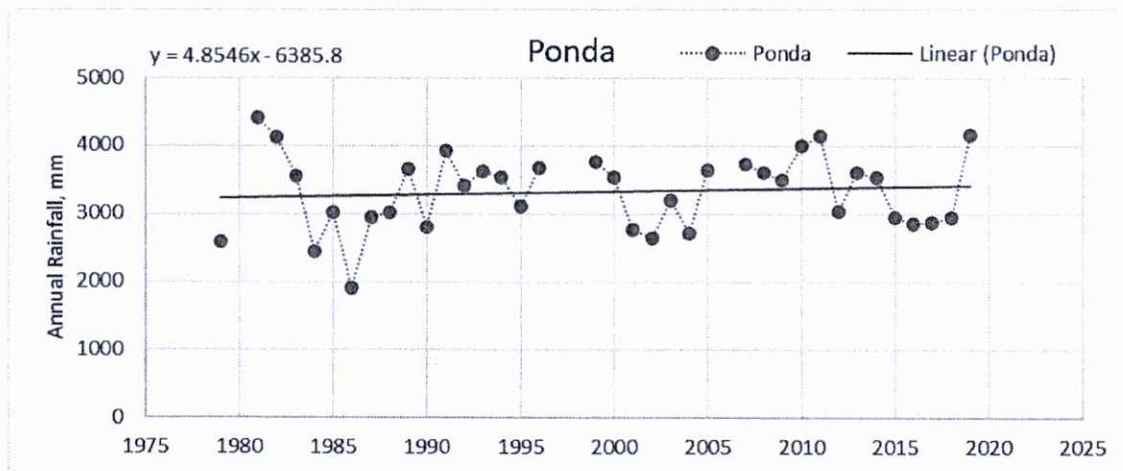


Figure 4-10: Annual rainfall variation at Ponda, Zuari catchment

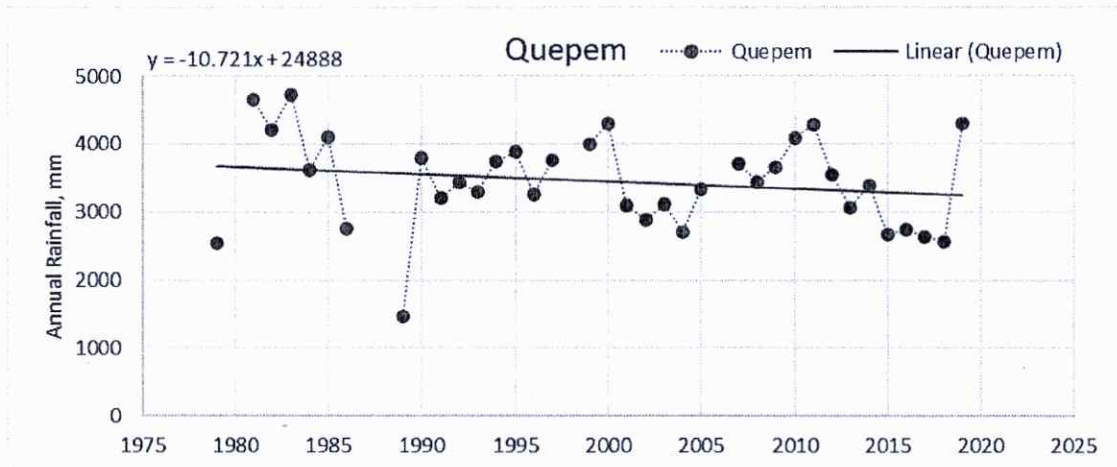


Figure 4-11: Annual rainfall variation at Quepem, Zuari catchment

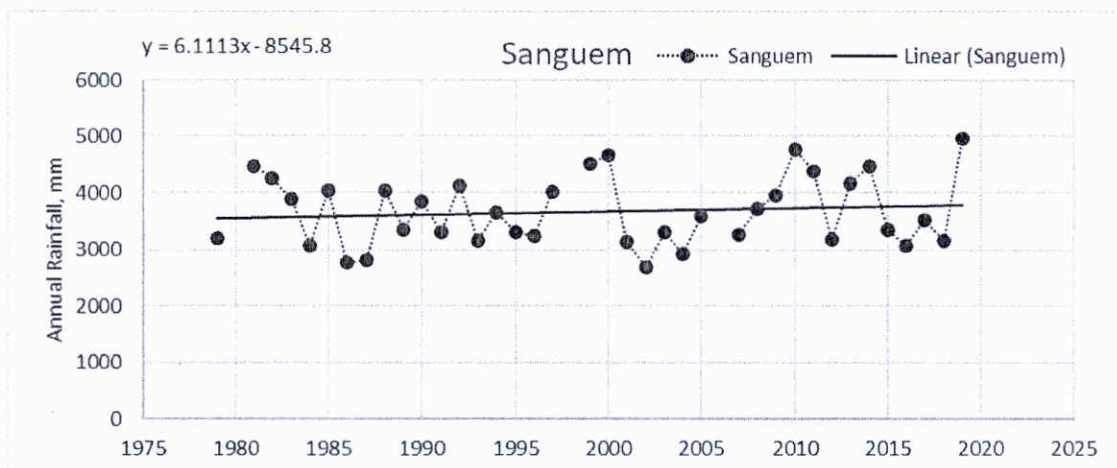


Figure 4-12: Annual rainfall variation at Sanguem, Zuari catchment

The Mandovi river, including its upstream part, the Mandovi River, has a length of 87 km and a catchment area of $1896 \times 10^6 \text{m}^2$. The Mandovi River, the major supplier of runoff to the Mandovi estuary during the monsoon, and a small river Ragda joins the Mandovi estuary near Ganjem about 50 km from the mouth of the estuary. River runoff is gauged regularly at two locations in the Mandovi basin. One of them, Ganjem, is located on the Mandovi River about 50 km from the mouth of the Mandovi; the other gauging station is at Kulem, which is located on the Khandepar, the biggest of the Mandovi tributaries. The average annual runoff at Ganjem and Kulem are $3400(\pm 648) \times 10^6 \text{m}^3$ and $502(\pm 91) \times 10^6 \text{m}^3$ respectively during the period of 1981-1998. (K. Suprit et al., 2008).

The major suppliers of freshwater to the Zuari estuary are Uguem, Guloli and Kushavati rivers. The Uguem and Guloli rivers join the main channel of the estuary at Sanguem, 50 km upstream from the mouth of the Zuari. The Kushavati river joins the Zuari about 14 km downstream of Sanguem. There is a dearth of information on river runoff in the Zuari estuary. The only available measurement of runoff was made in 1978 in Sanguem and Kushavati rivers. The annual runoff during 1978 in Sanguem and Kushavati were $1152 \times 10^6 \text{ m}^3$ and $493 \times 10^6 \text{ m}^3$, respectively (Vijith et al., 2014).

The estuaries of both rivers are classified as "monsoonal estuaries" which receive abundant river discharge only during the monsoon (June– September) and negligible discharge in the remaining period. Both Mandovi and Zuari rivers are fed by monsoon precipitation and from discharges from a catchment area of about 1150 and 550 km^2 respectively. Mandovi basin covers an area 1530 km^2 and constitutes 42% of the land area of the territory whereas; Zuari basin covers an area of 973 km^2 and constitutes 27% for the total land area of the territory.

4.2.2 MAJOR INFRASTRUCTURE IN CATHCMENT AREA

Zuari river catchment region

The Salauilm dam is the major irrigation project that is constructed across Salauilm/Sanguem River, which is a major tributary of Zuari River in the year 2000. The length of dam is about 1000m and it is an integral component of the Salauilm Irrigation Project which envisages benefits of irrigation and drinking water supply. The dam is a composite earth-cum-masonry dam of 42.7 meters height with a water spread area of 24 km^2 . The river drains a catchment area of 227 km^2 with a gross storage capacity of 234.36M cu.m. This project has led to submergence of 2964 Ha land, which includes cultivated area of 1240 Ha, forest of 706 Ha and uncultivated Govt. land of 1018 Ha.

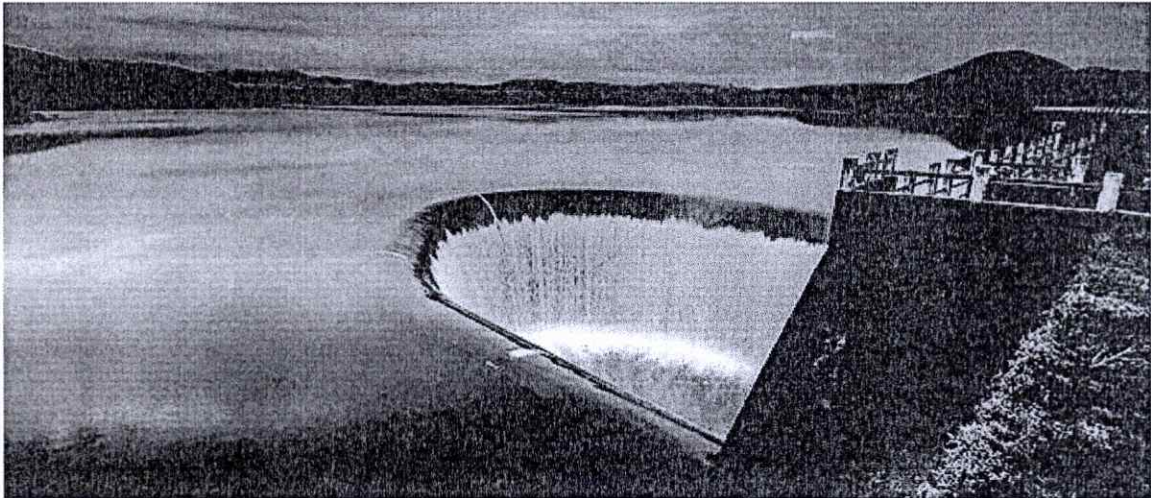


Figure 4-13: Salaulm Dam on Sanguem River (Zuari Tributary)

The Moisal dam is part of Panchawadi minor irrigation project that drains water into Zuari River. The length of dam is about 230m and it is constructed in 1986 which envisages benefits of irrigation and drinking water supply. The dam is an earth dam of 20 meters height with a submergence area of 53 ha and gross storage capacity of 44709 h.m.

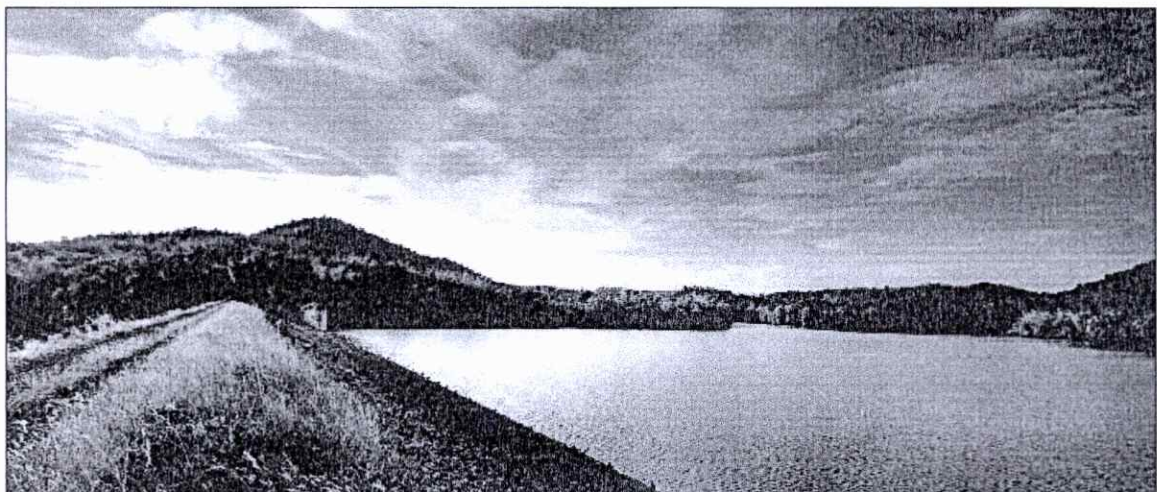


Figure 4-14: Moisal Dam on Panchawadi Minor Irrigation Project

Many bridges were constructed across Zuari river, which includes a parallel bridge constructed across Zuari River by connecting Sanvordem and Curchorem area in 2004. Currently another four-lane bridge is constructing across Sanguem River

connecting Dando and Bend regions at Sanguem. A new eight lane road bridge is being constructing across Zuari river near to the old Cortalim Bridge and the construction of this bridge started during 2017. Another bridge was constructed in 2009 by connecting St Jacinto Island with Chicalim region across Zuari river. At Undir a small bridge was constructed over Zuari river during 2017-2019. Another major bridge is constructed during the year 2012 to 2014 over Kushavati River which is a tributary of Zuari river. Along Uguem river almost 4 numbers of weirs have been constructed during the year span of 2006-2008.

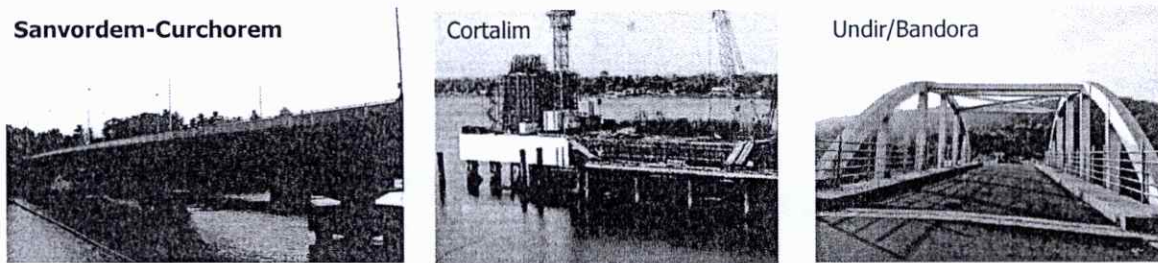


Figure 4-15: Bridges on Zuari River

Mandovi river catchment region:

The Anjunem irrigation project is located on Costi river at Anjunem village in Sattari Taluka of North Goa District, a tributary of Valvanti River under Mandovi Basin (tributary of Mandovi River). The project envisages construction of Gravity Masonry Dam of 176m long and 42.6 m height in 1989. This Project is a medium irrigation project completed in 1989 and the full ultimate potential of 4600 Ha (2100 Ha CCA) has already been created of which 1415 Ha (CCA) is underutilization.

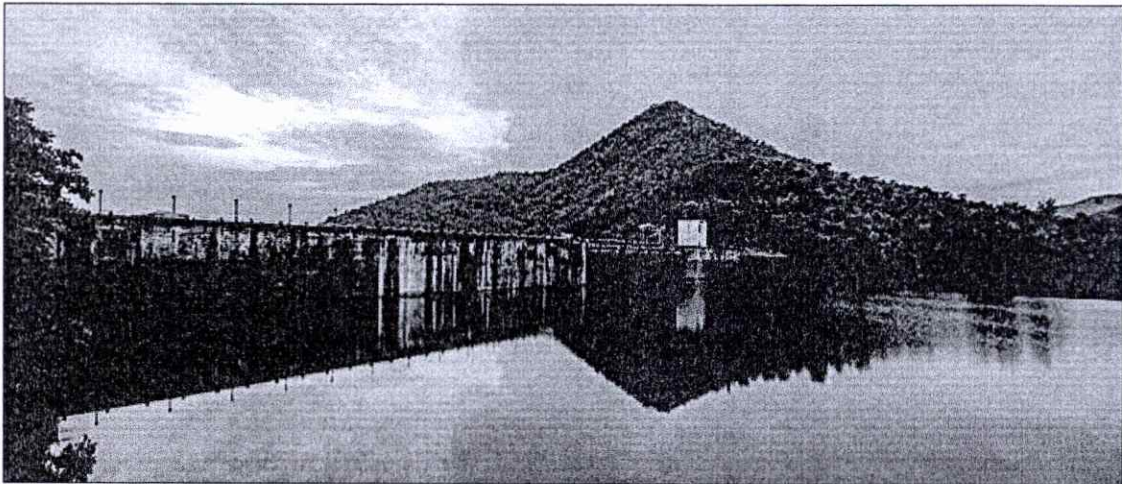


Figure 4-16: Anjunem Irrigation Project

The Amthane dam is part of Amthane minor irrigation project that drains water in to Mandovi River. It is an earth-fill dam constructed in 1988 with a length of 450m and height of 29.4m. This project has a total capacity of 597 ha.m.

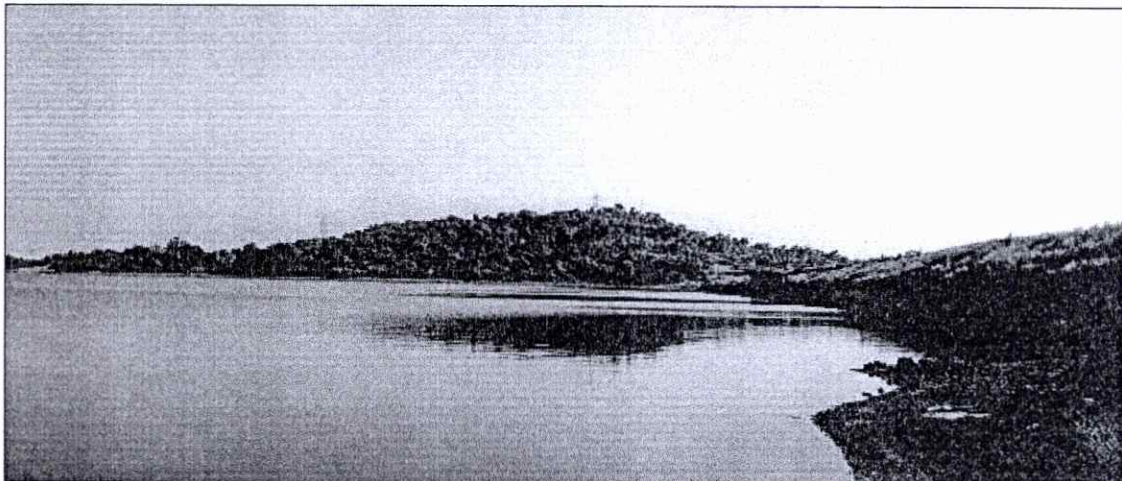


Figure 4-17: Amthane Minor Irrigation Project

Atal Setu Bridge is one of the famous bridges that constructed across Mandovi River. It is a cable stayed parallel bridge constructed during the year 2017-2019. Another bridge was constructed across Mandovi River at Candola connecting Amona in the year 2002 and completed by 2004. Usgao Bridge was constructed in the year of 2007 across Mandovi River, which is four lane road bridges parallel to the existing bridge at Usgao. At Ganjem, a bridge was constructed in the year 2007 across

Mandovi River and a barrage was also constructed further north of the Mandovi River in the same year. Further north of Ganjem, several numbers of weirs and barrages were built across Ragada River and Mandovi river branches during the year span of 2006 -2014. A new bridge is constructed at Khandepar over Mandovi River which is close to Khandepar Bridge and completed its work by 2019.

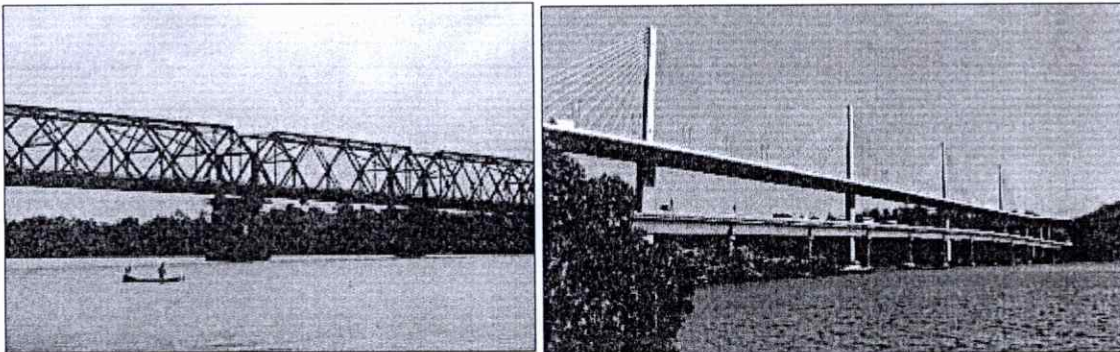


Figure 4-18: Amona bridge and Atal Setu bridge

4.2.3 LAND USAGE CHANGES

The georeferenced Landsat-MSS data for 1985, IRS-1A LISS-I data for 1994 and IRS-P6 LISS-III data of 2006 have been used to generate the land use / landcover maps by Sampath Kumar et al,2014. Al-usmani, 2018 has studied, the changes in land usage and land cover using satellite from 1997 to 2011. Misra et al., 2015 assessed land use/ land cover changes for the period from 1973 to 2011 for the classes viz. Water, Mudflats, Mangroves, Plantation, Agriculture, Vegetation cover, Urban, Barren and beach/shoreline features by analyzing spatial and temporal changes in the LU/LC classes using satellite datasets from Landsat MSS, TM and IRS-LISS III for the years 1973, 1989, 2001 and 2011 using principal component analysis method.

The results of this study are shown in Figure 4-19 and Table 4-2. Mangrove growth has increased by 254.4 ha from 1973 to 1989 along Mandovi catchment and 31.9 ha along Zuari catchment. There is a considerable increment during the period 1989-2001, and the overall growth of 793.3 ha is estimated along both Mandovi and Zuari rivers (including Cumbarjua Canal). The rate of growth of mangrove extent

decreased from 2001 to 2011 as evident from the statistics, being only 209.7 ha in case of Mandovi and 154.8 ha in case of Zuari. In the span of 38 years, there is an overall increase in the mangrove coverage of 910.3 ha along Mandovi and 533.2 ha along Zuari (Cumbarjua canal included).

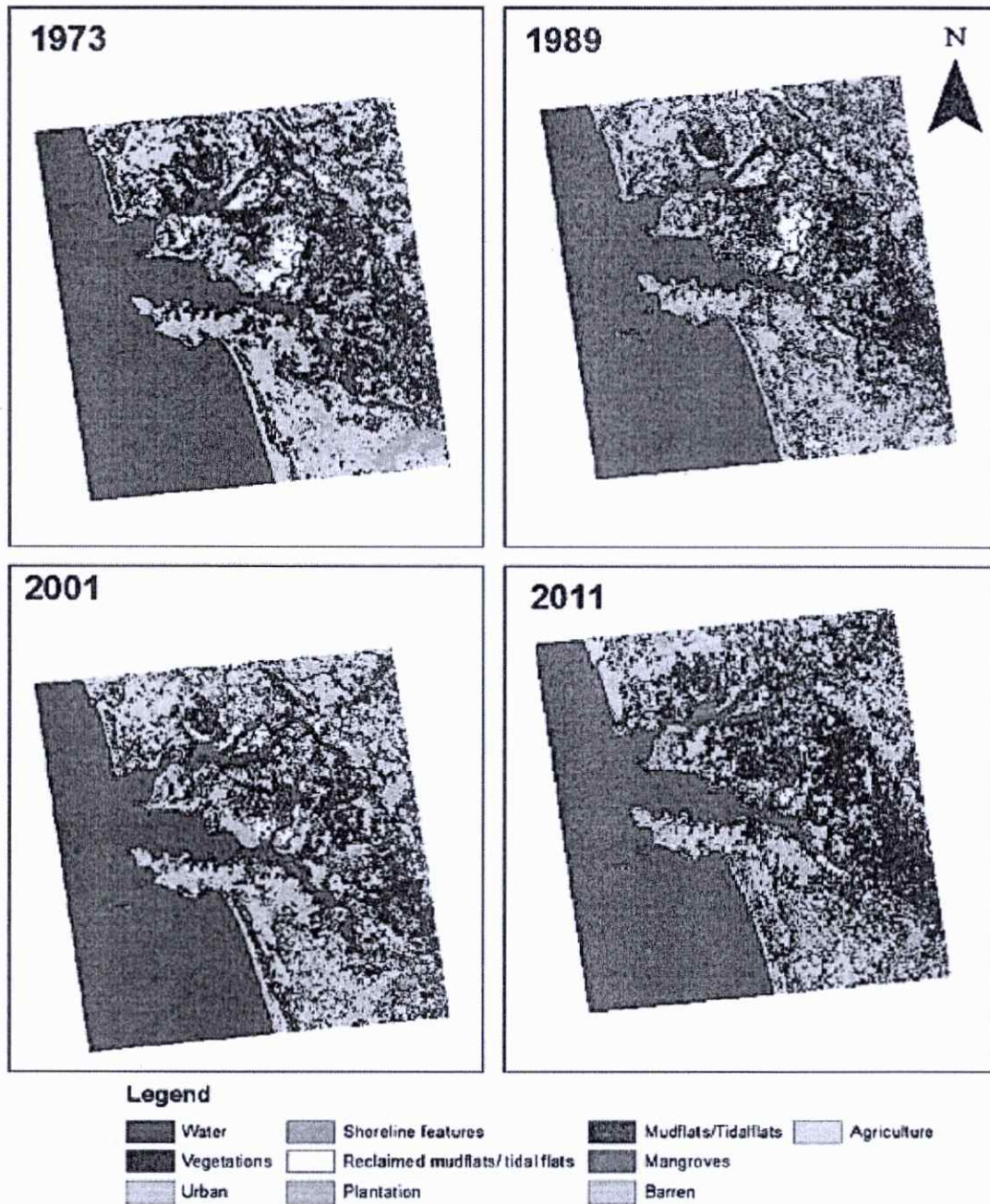


Figure 4-19: Land Use/Land Cover map of Goa state

Table 4-2: Land cover usage along Mandovi and Zuari river catchment

Class Names	Percentage change (%)			
	1973–1989	1989–2001	2001–2011	1973–2011
Water	-0.90	-0.40	-0.20	-1.50
Mudflats/tidal flats	-44.0	287.80	5.30	128.50
Reclaimed mudflat/tidal flats	-9.50	-46.60	14.80	-44.50
Mangroves	73.20	127.90	35.70	435.40
Shoreline	-16.30	27.70	-45.10	-41.30
Agriculture	-11.90	-2.70	-16.20	-28.20
Plantation	7.30	4.70	107.50	133.20
Vegetation	6.00	-8.20	13.70	10.70
Urban	80.40	23.30	28.00	184.80
Barren	5.20	29.50	-33.80	-9.80

Table 4-3: Physical Characteristics of Zuari and Mandovi River (Vijith et al., 2009)

Parameter	Mandovi	Zuari
Length	50km	50km
Width at the mouth	3.7 km	4.8km
Width at the head	0.1 km	0.10 km
Depth at the mouth	7m	10m
Depth at the head	1m	1m
Volume w.r.t MSL	160x10 ⁶ m ³	309x10 ⁶ m ³
Catchment area	1896x10 ⁶ m ²	917x10 ⁶ m ²
Runoff at head during June-October	258m ³ /s	147m ³ /s
Runoff at head during November- May	6.0m ³ /s	0.8 m ³ /s
Low runoff	2 m ³ /s	2 m ³ /s
High runoff	3900 m ³ /s	1156 m ³ /s
Tidal range at the mouth(spring)	2.3 m	2.3 m
Tidal range at the mouth (neap)	1.5 m	1.5 m



5 PRESENT STATUS OF COAST

5.1 ZONE 1 NORTH GOA

The North Goa sector is a linear coastal segment comprising of wide beaches, rocky cliffs, and mangroves. It has more tourist attraction with famous beaches and resorts. In North Goa, the shoreline shows segments of erosion, accretion as well as stable nature. This coast is facing relatively more erosion compared to central and southern Goa coasts. The Tiracol and the Chapora are major rivers of this coastal sector. As the coast is experiencing severe erosion at few stretches, several coastal protection measures were implemented at Tiracol, Arambol, Anjuna, Uddo, Cocoa and Dona Paula to protect the coast. At certain stretches like Morjim, beaches are very flat and experiences flooding of coastal areas during the high tides and extreme climate conditions.

Tiracol beach experiences seasonal erosion and accretion. A seawall was constructed using the Tetrapods to protect the shoreline. It is observed that the Tetrapods were dislocated and settled down at few locations. The sea wall has been partially destroyed due to the wave action. Steep cut beach berm and uprooting of Casuarina plantation is observed here. Cliff erosion is observed at Anjuna. The coastal stretch extending from Harmal, Mandrem, up to Morjim shows accretion to stable trend. Chapora, Vagator in the north show eroding to stable nature. Other regions showing stable nature of coast are south of Anjuna, Candolim, Sinkerim between Calangute and Nerul and Shinken. Few pockets of erosion are observed north of the Chapora River around Arpora, south of Calangute.



Figure 5-1: Shore protection measures at Keri/Tiracol

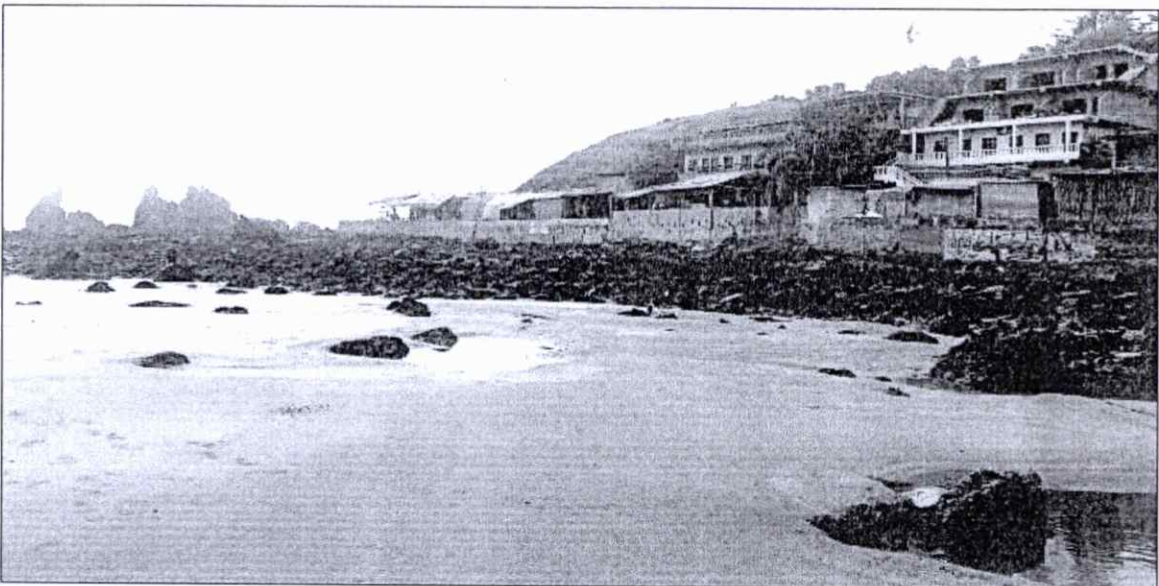


Figure 5-2: Shore protection measures at Arambol

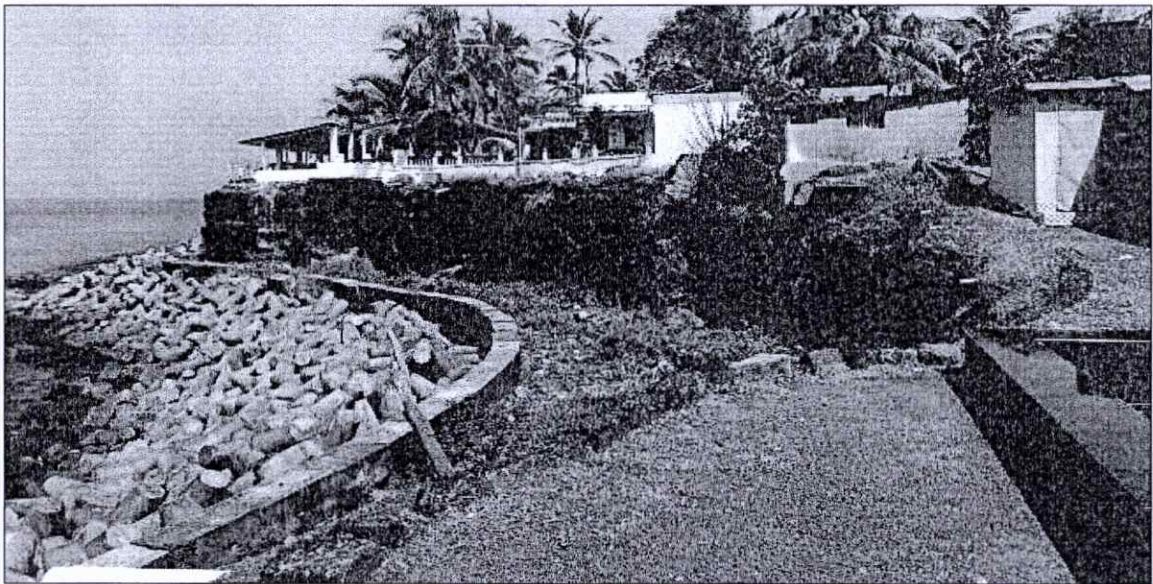


Figure 5-3: Shore protection measures at Anjuna

5.1 ZONE 2 CENTRAL GOA

The Central coastal segment of Goa comprises of regions around the Aguada and Mormugao Bay. The Mandovi and Zuari rivers discharge into these respectively. This coastal stretch is majorly stable in nature, except few small segments of erosion. Coco beach, north of Nerul river mouth a pocket beach showing local erosion. Eroding segment is also observed near Dona Paula and Vaddem beach. The famous Miramar beach is located in this segment near Caranzalem. Sea walls have been constructed at several locations around Miramar, Dona Paula, Cabo Hill, Campal to protect the coast and remedial measures have been taken for stabilizing unstable slopes of Cabo Hill.

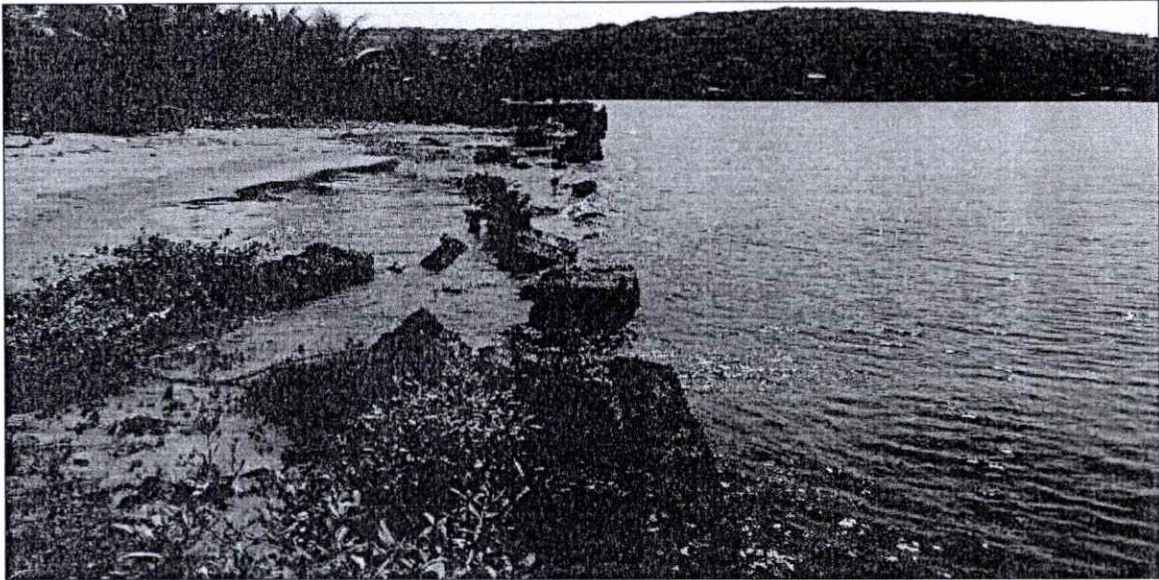


Figure 5-4: Shore protection measures at Uddo beach



Figure 5-5: Shore protection measures at Coco beach

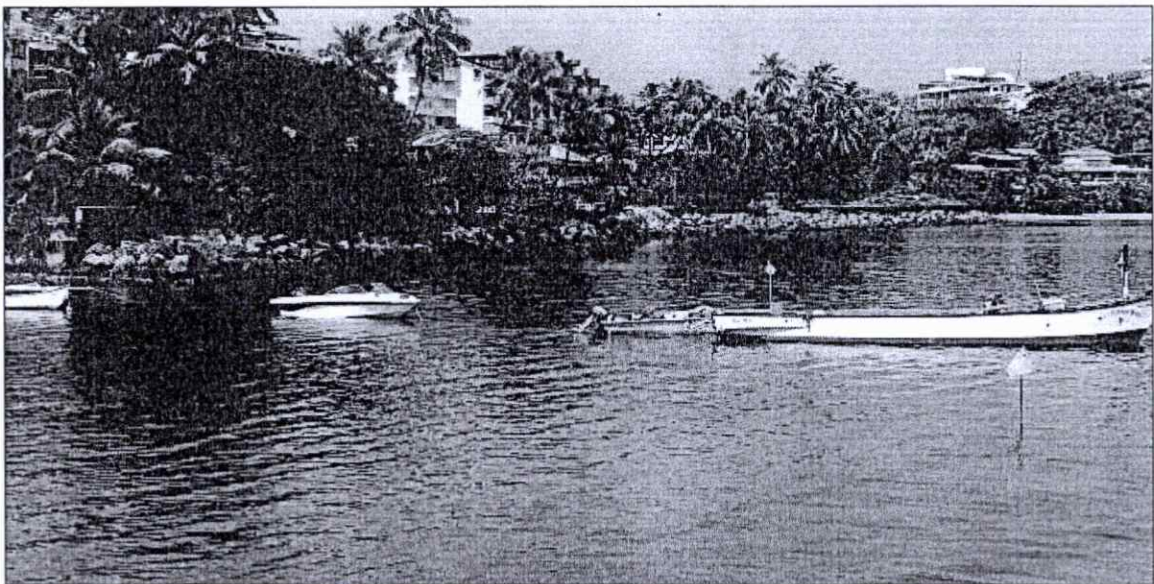


Figure 5-6: Shore protection measures at Dona Paula

5.2 ZONE 3 SOUTH GOA

In South Goa sector, long linear beaches, rocky cliffs, sand dunes, headlands are observed. Pocket beaches are formed between rocky headlands. Segments of erosion, accretion as well as stable nature occur in the South Goa sector. The coastal stretch along Bogmalo, south of Vasco, Kimsavlin, Arossim, Sernabatim near Kavleshi and south of Talpona up to Mahi shows accretion. Erosion is observed around Betalbatim, between Colva and Majorda. Erosion is also observed along South of Betul, up to Kanagini and between Parven to Agonda. Small segments of stable coast occur along Dabolim, Arossim, south of Sernabatim, Bogmalo, and Chicolna. A long stretch of stable beaches is observed from Fatrade almost up to Betul. Beautiful sandy beaches (Benaulim, Varca, and Betul) occur along this segment.



Figure 5-7: Shore protection measures at Hollant beach



Figure 5-8: Shore protection measures at Sunset beach



Figure 5-9: Shore protection measures at Canaguinim

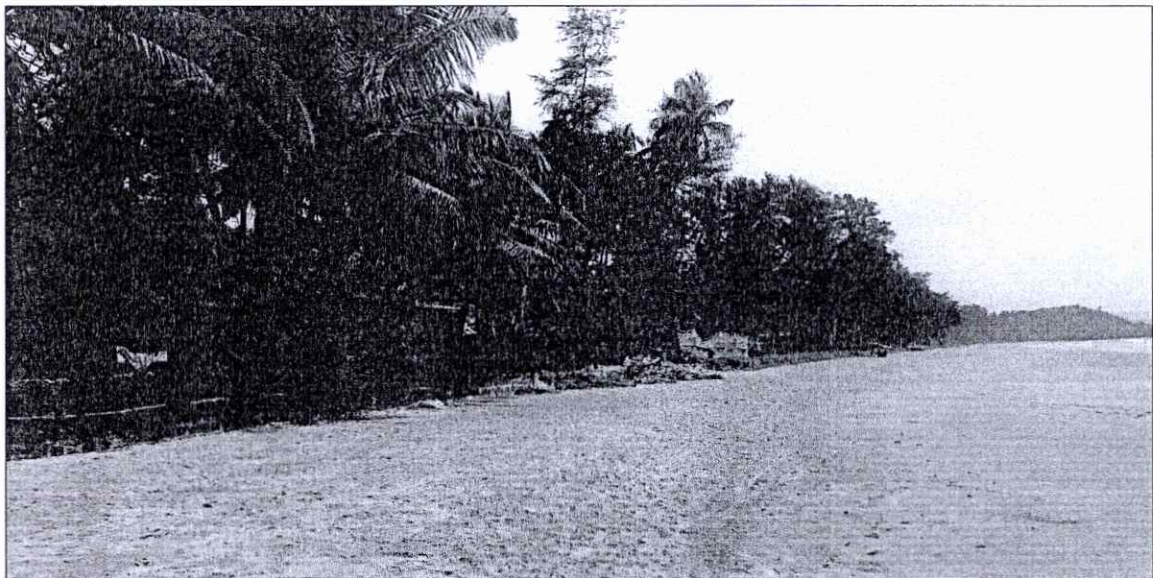


Figure 5-10: Shore protection measures at Talpona

6 SHORELINE ANALYSIS:

6.1 METHODOLOGY

The shoreline change analysis has been carried out using open-source data as well as National Remote Sensing Agency (NRSA) to estimate the rate of change in terms of distance eroded or accreted. The shoreline change rate from 1972 to 2020 has been analyzed using Digital shoreline change analysis system (DSAS) that works within the Geographic Information System (ArcGIS) software. DSAS computes rate-of-change statistics for a time series of shoreline vector data. The approach of shoreline change analysis using satellite imageries is shown in Figure 6-1.

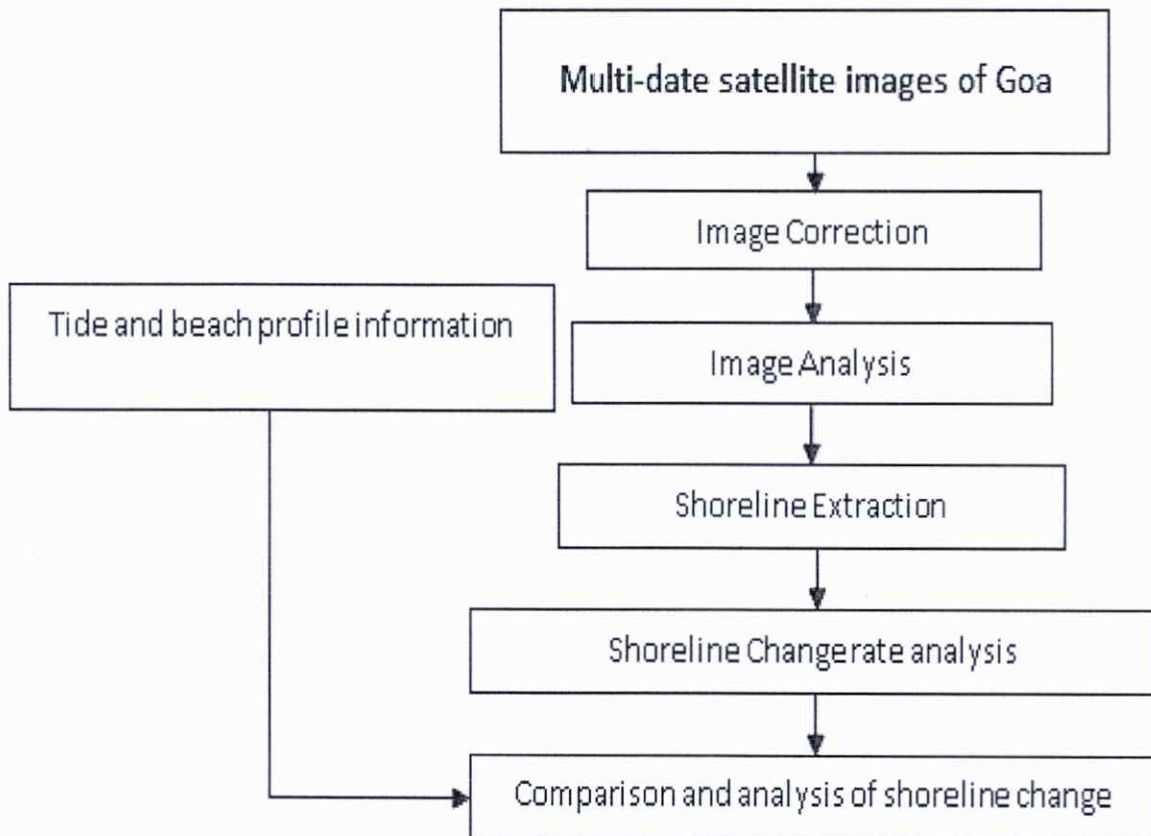


Figure 6-1: Flow chart of Shoreline Analysis



6.1.1 SATELLITE DATA AND IMAGE RECTIFICATION

The high-resolution satellite imageries available from various sources such as NRSC for LISS IV, United States of Geological Survey (USGS) for Landsat and European Space Agency (ESA) were reviewed and suitable images were collected/procured. About 32 images from 1972 to 2020 were used in analysis and the details of time stamp and resolution are provided in Table 6-1. The acquired images were analyzed and rectified using Ground Control Points (GCP's).

Table 6-1: Available satellite image data used for shoreline change analysis

Satellite	Date	Sensor	Resolution (m)
LANDSAT 1-3	02 Dec 1972	MSI	60
	02 Mar 1973		
	19 Mar 1975		
	26 Dec 1976		
	08 Mar 1977		
	26 Dec 1978		
	06 Apr 1980		
LANDSAT 4-5	12 Apr 1996	TM/ETM	30
	04 Mar 1990		
	01 Feb 1991		
	04 Feb 1992		
	10 Mar 1993		
	04 Mar 1994		
	16 Mar 1995		
	25 Jan 1997		
	17 Mar 1998		
	20 Mar 1999		
	29 Mar 2000		
09 Mar 2001			
06 Jan 2002			
EO I	25 Nov 2003	ALI	30
RESOURCESAT	18 Oct 2008	LISS3	24

LANDSAT 8	11 Apr 2013	OLI	15
	29 Mar 2014		
	11 Apr 2015		
SENTINEL	21 Mar 2017	2A/2B	10
	21 Mar 2018		
	21 Mar 2019		
	15 Mar 2020		
RESOURCESAT	05 Jan 2010	LISS4	5
	02 Sep 2011		
	12 Feb 2012		
	02 Mar 2013		
	01 Feb 2014		
	20 Feb 2015		
	10 Mar 2016		
	09 Feb 2017		
	28 Feb 2018		
	24 Mar 2019		
	23 Feb 2020		

6.1.2 SHORELINE EXTRACTION

Shoreline from individual images were extracted using semi-automated method (automatic and manual digitization). This method also reduces the pixel mismatch which is common in automated methods. The shoreline proxy used in the analysis also varies from place to place. Therefore, semi-automated method is the best suited for shoreline extraction. The following criteria was adopted for Identifying shoreline for different types of coast.

- In **sandy shore**, "wet/dry line" which is clearly identifiable from all images was considered as shoreline proxy. This wet/dry line is equivalent to high water line (HWL) mark from all satellite images. The identification of the feature "wet/dry line" from the images is as follows: on a rising tide, it is



equal to maximum run up line, and on falling tide, it is equal to part of beach which is still wet, but it may be beyond the instantaneous run up limit.

- **Vegetative line** is considered as shoreline proxy, where there is no sandy beach. The waves directly interact with the vegetations along the coast. Seashore facing direction of vegetative limits is demarcated as shoreline proxy and it can be clearly interpreted with the satellite images.
- In case of **artificial structures** (seawalls), the sea shore facing direction of seawall is considered as shoreline position.
- In **rocky coast**, cliff base or sea shore edge is considered as shoreline position.

6.1.3 SHORELINE CHANGE ANALYSIS

There are many statistical methods used for shoreline change analysis by DSAS to calculate the shoreline change rate. These methods are End Point Rate (EPR), Linear Regression Rate (LRR) and Weighted Linear Regression (WLR). In Regression methods the variation in temporal changes of shoreline can be capture. So, these methods are superior to end point method.

A linear regression rate-of-change (LRR) statistic is determined by fitting a least-squares regression line to all shoreline points for a particular transect. The regression line is placed so that the sum of the squared residuals (determined by squaring the offset distance of each data point from the regression line and adding the squared residuals together) is minimized. The linear regression rate is the slope of the line. However, the linear regression method is susceptible to outlier effects and also tends to underestimate the rate of change relative to other statistics.

In Weighted linear regression method (Figure 6-2), more reliable data are given greater emphasis, or weight towards determining a best-fit line. In the computation of rate-of-change statistics for shorelines, greater emphasis is placed on data points for which the position uncertainty is smaller. The weight (W) is defined as a function of the variance in the uncertainty of the measurement (E).

$$W = 1 / (E^2) \text{ where } E = \text{shoreline uncertainty value}$$

The uncertainty field of the shoreline feature class is used to calculate a weight. In conjunction with the weighted linear regression rate, the standard error of the estimate, the standard error of the slope with user-selected confidence interval, and the R-squared value are reported.

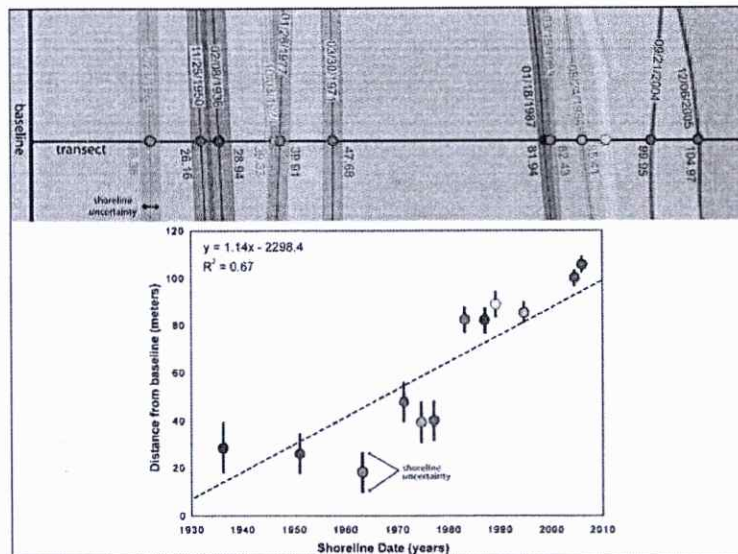


Figure 6-2: Calculation of Long Term (WLR method) Shoreline change analysis

In order to apply WLR, it is necessary to accurately estimate the errors (i.e.) uncertainties associated with each shoreline. Several sources of error impact the accuracy of historical shoreline positions and final shoreline change rates. There are different sources of errors are summed in quadrature (the square root of the sum of the squares) to get a total positional uncertainty (U_s).

- Positional uncertainty (E_p)** is related to all features and phenomena that reduce the precision and accuracy of defining a representative shoreline position in a given year. These uncertainties mostly centre on the nature of the shoreline position at the time of satellite image is collected. Influences on position include stage of tide and the conversion from HWL to LWM in T-sheets. Uncertainty value equal to Tide range from the nearest station is considered.



- **Seasonal error (Es)** is quantified by using summer and winter beach profiles (or seasonal shoreline positions from satellite image). Many beaches have seasonal cycles where they accrete in summer and erode in winter (or vice versa). Uncertainty value is considered based on the slope (5 - 10 m based on the regions).
- **Digitizing error (Ed)** Digitizing the shoreline is a difficult task. Digitizing the shoreline position by the same analyst may change when he does it again. After considering all the factors, the error is fixed. Uncertainty value equal to Half of the pixel size is considered.
- **Rectification error (Er)** is calculated from the ortho rectification process. satellite images are corrected, or rectified, to reduce displacements caused by lens distortions, Earth curvature, refraction, camera tilt, and terrain relief using remote sensing software. For this correction Root Mean Square error values are performed by ERDAS software by Auto Sync which uses an automatic point matching algorithm to generate thousands of tie points, and produces a mathematical model to tie the images together. The RMSE error thus obtained during rectification is considered as error value.

These errors are random and uncorrelated and may be represented by a single measure calculated by summing in quadrature (the square root of the sum of the squares).

$$E = \sqrt{E_p^2 + E_s^2 + E_d^2 + E_r^2}$$

6.1.4 VALIDATION OF SHORELINE CHANGES

Shorelines are tracked at select locations mainly during the satellite pass time. Shoreline extracted from the satellite imagery analysis are cross validated with the observed shore tracks from the field.



6.2 SHORELINE CHANGE MAPS

In the present study, the shoreline rate of change statistics has been calculated from time series of multiple shoreline positions of Goa coast. The transect interval of 50m and transect length of 350m has been used for the analysis. The result from the shoreline change analysis carried out from 1972 to 2020 based on Weighted Linear Regression principle for single transect method is presented in this report. Based on the rate of change over the period, shoreline change rate has been categorized as High erosion (<-5.0m), Moderate Erosion (-5.0m to -3.0m), Low Erosion (-3.0 to -0.5m), Stable (-0.5m to 0.5m), Low Accretion (0.5m to 3.0m), Moderate Accretion (3.0m to 5.0m), and High Accretion (>5.0m).

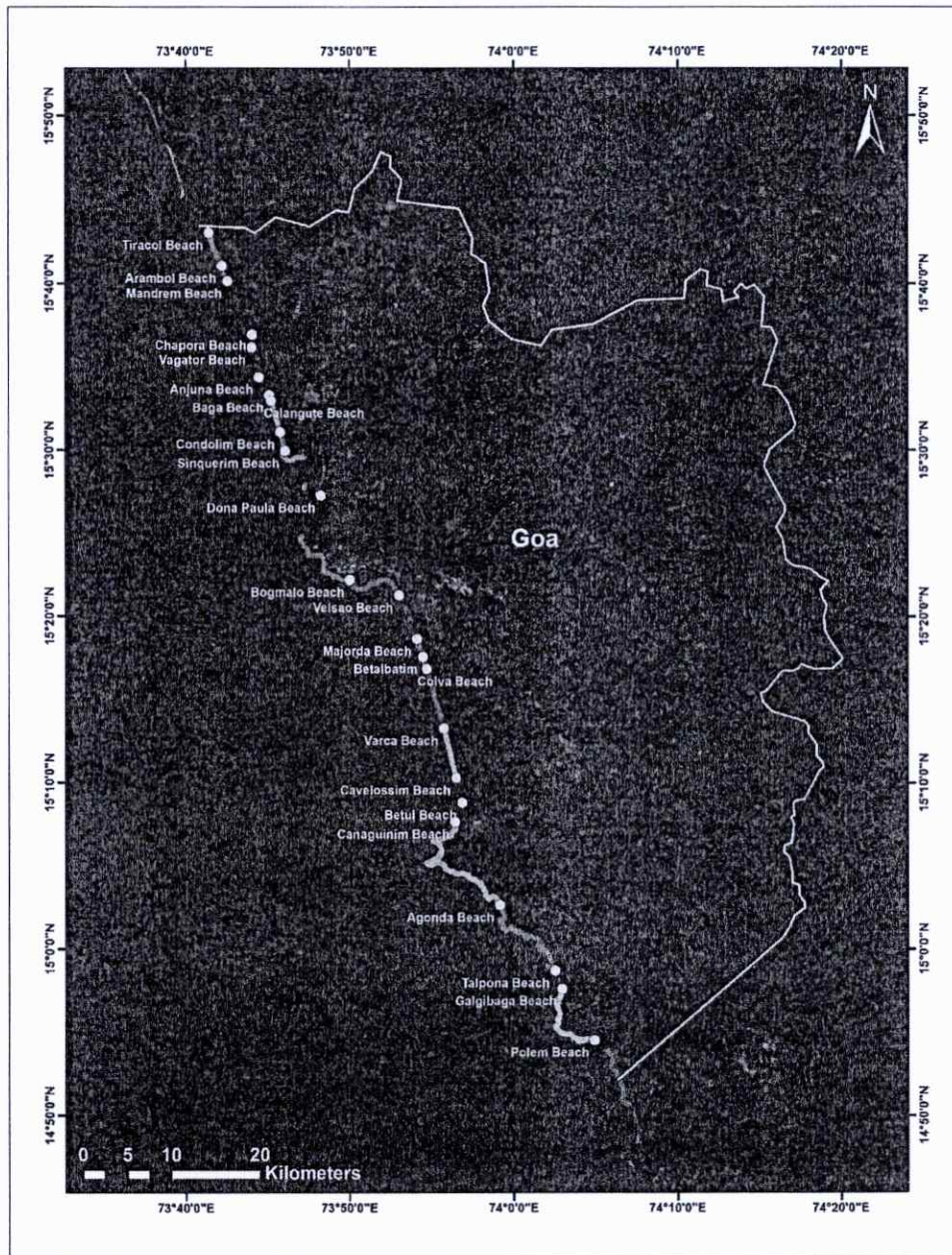


Figure 6-3: Coastal stretches along the Goa

The coastal stretch of Goa starts from south of the Tiracol river and extends to Polem in the south for the length of 150km. Goa is divided into North Goa and South Goa districts. The North Goa sector is a linear coastal segment comprising of wide beaches, rocky cliffs, and mangroves. The Tiracol and the Chapora are major rivers of this coastal sector. The Central coastal segment of Goa comprises of regions around the Aguada and Mormugao Bay. The Mandovi and Zuari rivers discharge into

these respectively. In South Goa sector, long linear beaches, rocky cliffs, headlands are observed. Pocket beaches are formed between rocky headlands. The Goa coastline is divided 22 small segments to detail the behavior of the shoreline and is shown in figure Figure 6-3. The shoreline change analysis has been carried out for the period 1972 to 1980, 1980 to 1990, 1990 to 2000, 2000 to 2010, 2010 to 2020 and overall 1972-2020 is shown in Figure 6-5 to Figure 6-40. The shoreline changes from North Goa to the South Goa near Polem are discussed in detail in the subsequent sub-sections.

6.2.1 TIRACOL TO ARAMBOL BEACH

The coast is characterized by sandy beaches. Seawalls with tetrapod as armour units have been constructed along the berm for shore protection. Intra decadal changes indicate that the overall coast is moderately eroding with high erosional patches at few locations along the stretch.

6.2.2 ARAMBOL BEACH TO MANDREM BEACH

The coastal stretch from Arambol Beach to Mandrem beach is characterized by sandy beaches. Decadal shoreline changes indicate the coastal stretch is moderately accreting. The entire coastal stretch is protected by high sand dunes with dune vegetation. Some of the sand dunes are shifting in nature as can be observed in Mandrem where new dunes, presently low in height, are being formed which makes the area a prograding coast.

6.2.3 MANDREM BEACH TO CHAPORA BEACH

In general, sandy beach between Mandrem to Chapora exhibit moderately accreting trend. A small stretch near Morjim beach where rocky outcrops are present shows moderate erosion in the decadal shoreline change variations.

6.2.4 CHAPORA BEACH TO VAGATOR BEACH

This stretch is highly dynamic as it is located to the south of the Chapora river, which acts as a source or sink of sediments. The coast is characterized by rocky



coast with few pocket beaches. Decadal shoreline changes (1972-1990) indicate the stable accreting nature of this shoreline. From 1990, the coast starts eroding and undergoes high erosion from 2010 to 2020 which is observed in intra decadal analysis.

6.2.5 VAGATOR BEACH TO ANJUNA BEACH

The stretch extends from south of Vagator beach to the rocky headland located south of Anjuna beach. From 1972 to 1990, shoreline changes indicate erosion at few pockets along the stretch. These eroding pockets increase progressively from 1990 to 2000. The shoreline analysis for the year 2000 to 2010 indicates erosion pattern along the entire stretch with high erosion pockets. Recent intra decadal analysis from 2010 to 2020 shows moderate erosion with accretion patches north of the Anjuna.

6.2.6 ANJUNA TO BAGA BEACH

South of the Anjuna beach forms a headland and the Baga creek opens to the Arabian sea south of the headland. The 1972 to 1990 shoreline analysis indicate high erosion along the creek mouth with stable coast further south. From 1990 to 2000, the stretch remains to be stable and progressively erodes from 2000 to 2010. The analysis of 2010 to 2020 shows the overall coast is moderately accreting in nature with high erosion at few pockets.

6.2.7 BAGA TO CALANGUTE BEACH

The Baga - Calangute stretch consists of sand dunes, with diverse dune vegetation. From 1972 to 2000 the coastal stretch has remained stable and moderately accreting in different pockets within the same stretch. However, with haphazard increase in anthropogenic activities a large number of dunes have decimated resulting in moderate erosion. High erosional patches have been observed since 2000.

6.2.8 CALANGUTE TO CANDOLIM BEACH

The analysis of satellite imageries from 1972 to 1990 indicates the coastal stretch has undergone moderate erosion and later the coast is found prograding since 1990.

6.2.9 CANDOLIM TO SINQUERIM

The Candolim - Sinkerim stretch extends up to the Aguada headland. The Aguada coast is rocky and barren up to mouth of the Mandovi estuary. From the analysis of images during the period 1972 to 1990, the coastline is stable and moderate to high erosion is observed at some patches from 2000 to 2020. This erosion may be attributed to the beaching of oil tanker MV River Princess at Candolim which obstructed the natural littoral transport process.

6.2.10 DONA PAULA TO BOGMALO BEACH

This stretch extends from the headland south of Zuari river which is characterized by rocky coast with small pockets of sandy beach. The shoreline changes from 1972 to 1990 indicating moderate erosion, whereas the analysis from 2000 to 2010 indicates accretion to the north of this stretch and recent analysis from 2010 to 2020 indicated moderate erosion. This stretch is highly dynamics as it is located between opening of two major rivers Zuari and Mandovi.

6.2.11 BOGMALO TO VELSAO

Bogmalo to Velsao stretch is characterized by small pocket beaches between headlands. The satellite image analysis from 1972 to 2010 indicate that the stretch retards from stable to moderately eroding coast. On the contrary from 2010 to 2020 analysis shows an accreting pattern.

6.2.12 VELSAO TO MAJORDA

Significant stretch of this shoreline is observed to undergo erosion during the period 1972 to 2010. This coastal stretch is observed to vary from stable nature to



moderately eroding from 2000 to 2010. However, the shoreline changes from 2010 to 2020 show sand deposition to the north of Majorda indicating accretion.

6.2.13 MAJORDA TO BETALBATIM

The coastal stretch from Majorda to Betalbatim has been stable from 1972 to 2000. Moderate erosional patches are observed along this stretch from 2000 to 2020. Several resorts / hotels and dwellings have come up in sandy areas of this stretch resulting in erosion.

6.2.14 BETALBATIM TO COLVA BEACH

The river mouth along the south of Betalbatim stretch makes the coast highly dynamic. The coast has experienced moderate erosion from 1972 to 2020 at some patches and various steps have been taken for coastal protection.

6.2.15 COLVA BEACH TO VARCA BEACH

The stretch was most prolific packed by protective sand dunes and remained stable from 1972 to 1990. With several dunes being flattened and even removed due to anthropogenic activities, some areas have undergone erosion since 1990.

6.2.16 VARCA BEACH TO CAVELOSSIM

The short term shoreline changes analysis between 1990 to 2000, 2000 to 2010 shows the coast is moderately eroding. Shoreline changes for 2010 to 2020 exhibit accretion for significant part of the stretch and high erosion for the remaining portion.

6.2.17 CAVELOSSIM TO BETUL

Sal river runs parallel to the coastal stretch and drains to the Arabian sea at the southern end of this stretch. The short term shoreline analysis between 1972 to 1990 shows that this coast is a stable coast whereas the Northern portion experienced moderate erosion. The 1990 to 2000 shoreline analysis shows that this coasts experienced accretion on the north. Similarly, during the 2000 to 2010, this

coast experienced moderate erosion on the north. The 2010 to 2020 shoreline analysis shows that this coast is eroding cost. As the Sal river mouth drains in the southern end of this stretch, it experiences erosion throughout the analysis.

6.2.18 BETUL TO CANAGUINIM

South of the Betul is characterized by rocky beaches / outcrops projecting into Arabian sea. Small pocket beach at Canaguinim is followed by rocky outcrops in the south till Agonda. The shoreline analysis between 1972 to 1990 indicates the coast is undergone moderate to high erosion. However, during the periods 1990 to 2000, 2000 to 2010, 2010 to 2020 shows the coast is moderately accreting.

6.2.19 CANAGUINIM TO AGONDA

This stretch comprises of rocky coast followed by wide beach at Agonda. Saleri river drains into the Arabian sea north of the Agonda beach. The short term shoreline changes analysis between 1972 to 1990 shows the coast is high in erosion at various places. The 1990 to 2000 image analysis experienced moderate erosion with few places showing high erosion. The north part of Agonda beach appears to be a geologically dynamic shoreline which is prone to monsoon inundation and has been subjected to severe erosion. In recent years, beach at Agonda is threatened with severe erosion which is evident from the short term shoreline analysis between 2010 to 2020.

6.2.20 AGONDA TO TALPONA

The stretch from Agonda to Talpona exhibits both rocky and sandy beaches. Palolem is another popular protected beach between two rocky headlands. South of the Palolem beach, Talpona river drains into Arabian sea and the river mouth is highly dynamic. The short term shoreline analysis between 1972 to 2020 shows that this shoreline is eroding and retreating at a fast rate.



6.2.21 TALPONA TO GALGIBAGA

The satellite image analysis reveals the coastal stretch is stable from 1972 to 1990. Erosion has been observed during the period 1990 to 2000. The stretch is accreted during 2000 to 2010. However, analysis from 2010 to 2020 shows coast is undergoing erosion.

6.2.22 GALGIBAGA TO POLEM

The stretch from Galgibaga to Polem is rocky headland in the southernmost part of Goa and is susceptible to high wave attack. Presence of Galgibaga river in the north of the stretch makes the coast more dynamic by spit formation. Shoreline changes indicate the stretch is highly eroding from 1972 to 1990 and moderate erosion from 1990 to 2020.

Goa coast is divided into 5 segments: G1, G2, G3, G4, and G5 and generated the intra decadal shorelines change maps in 1:25000 scale to understand the shoreline behaviour during the period 1972 to 2020. Index map of the Goa coast with the five coastal segments is shown in Figure 6-4.

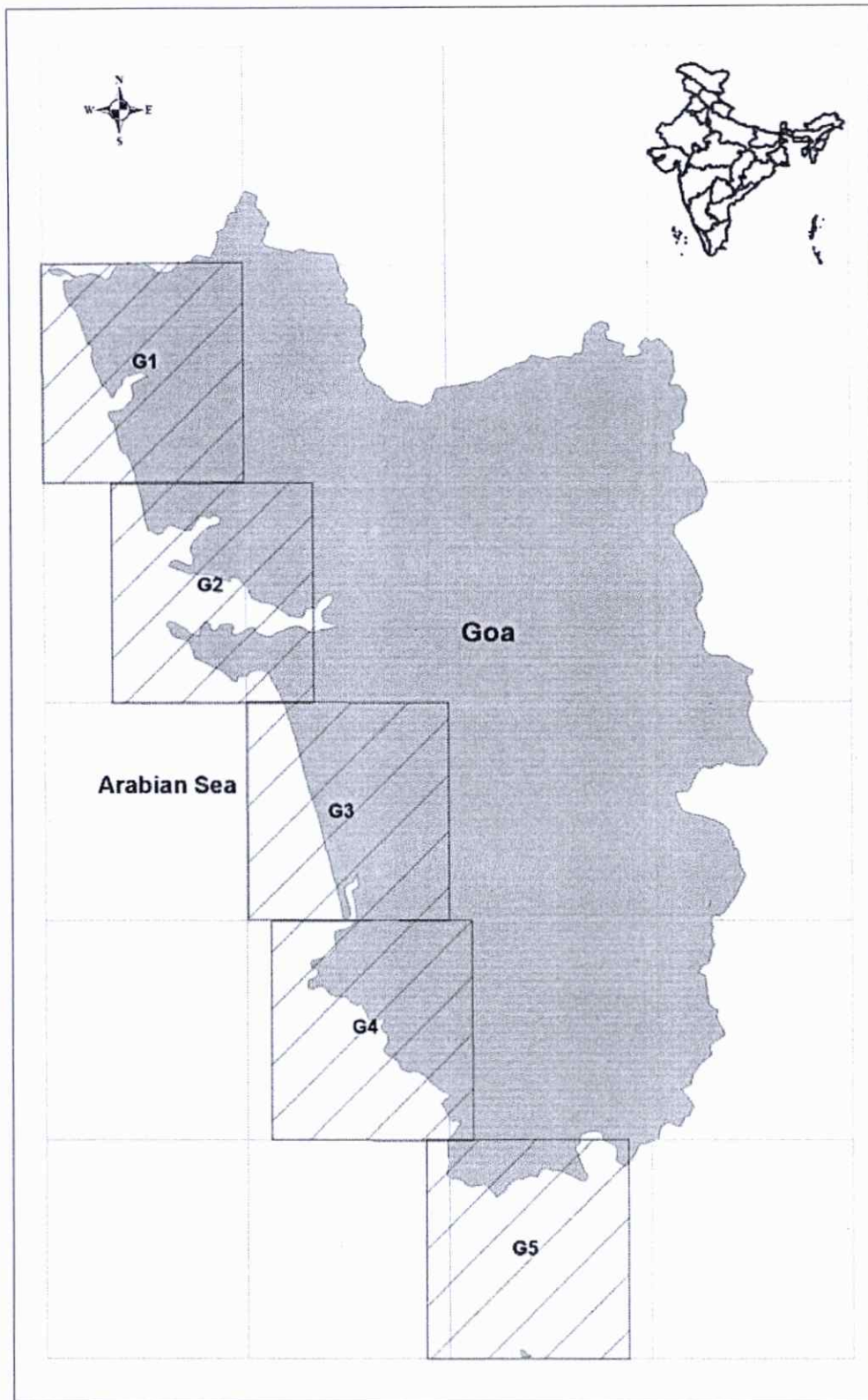


Figure 6-4: Index map of the Goa for shoreline change analysis

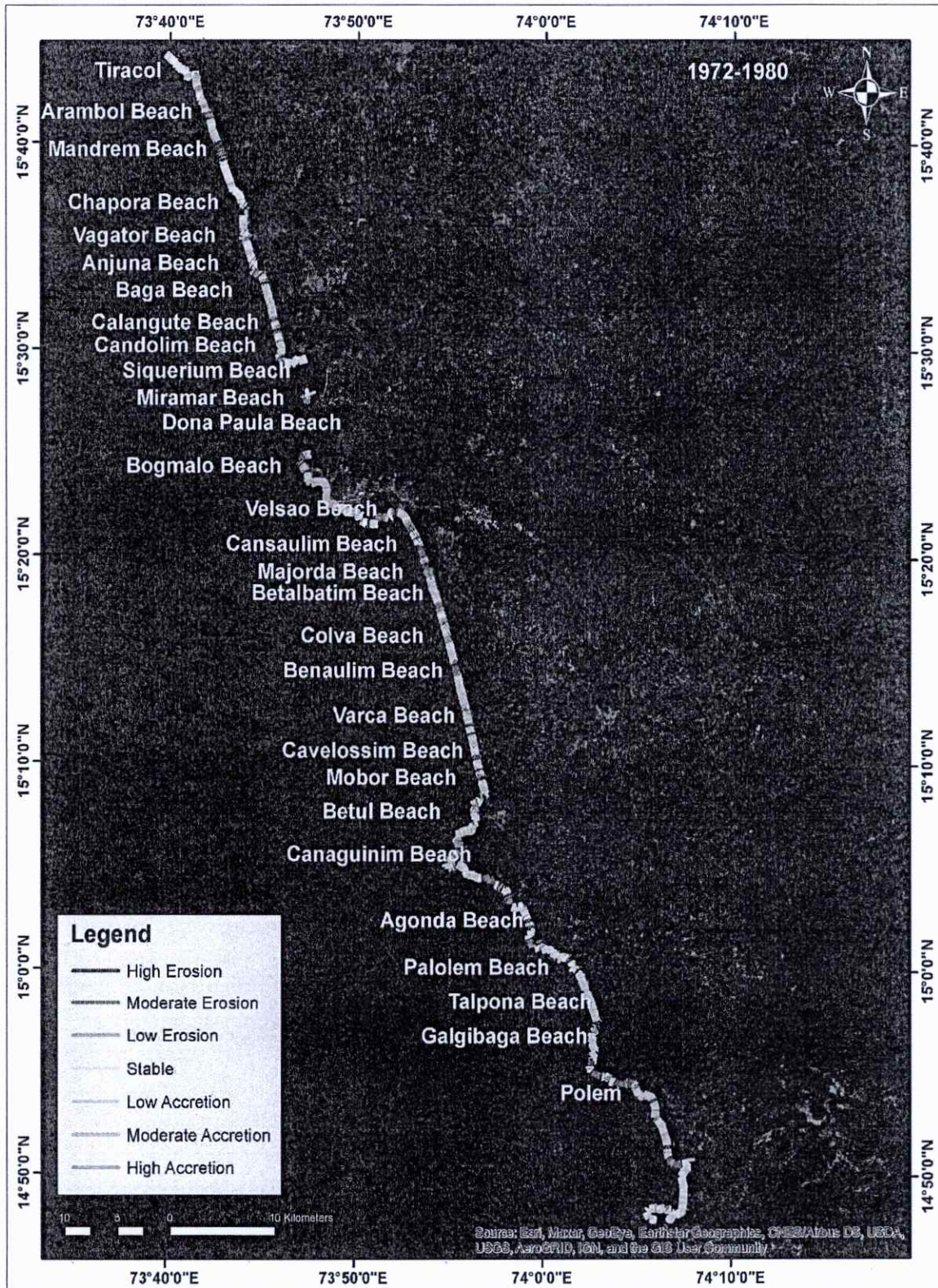


Figure 6-5: Shoreline Change Map of Goa coast 1972-1980

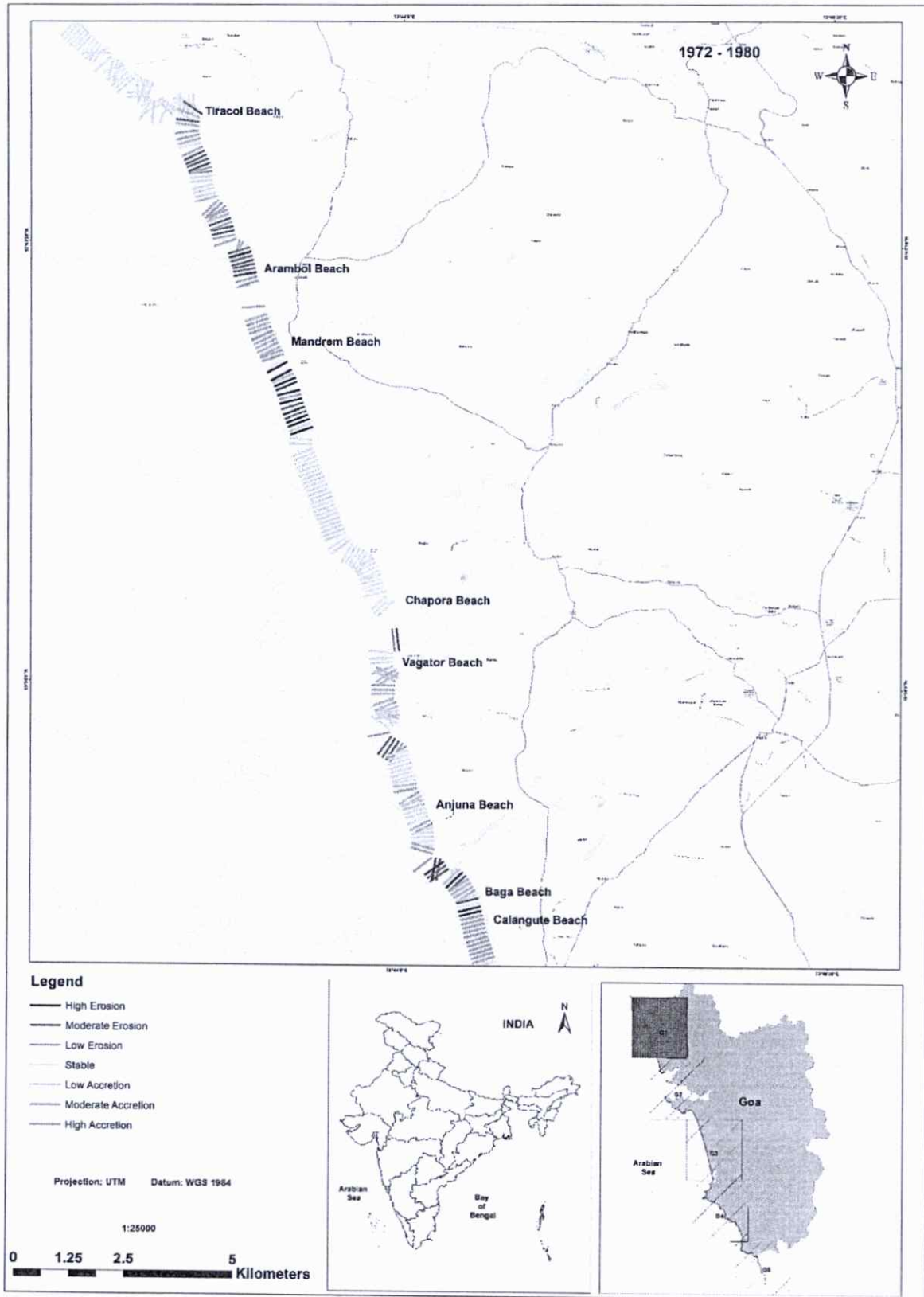


Figure 6-6: Shoreline change map of Segment G1 from 1972-1980

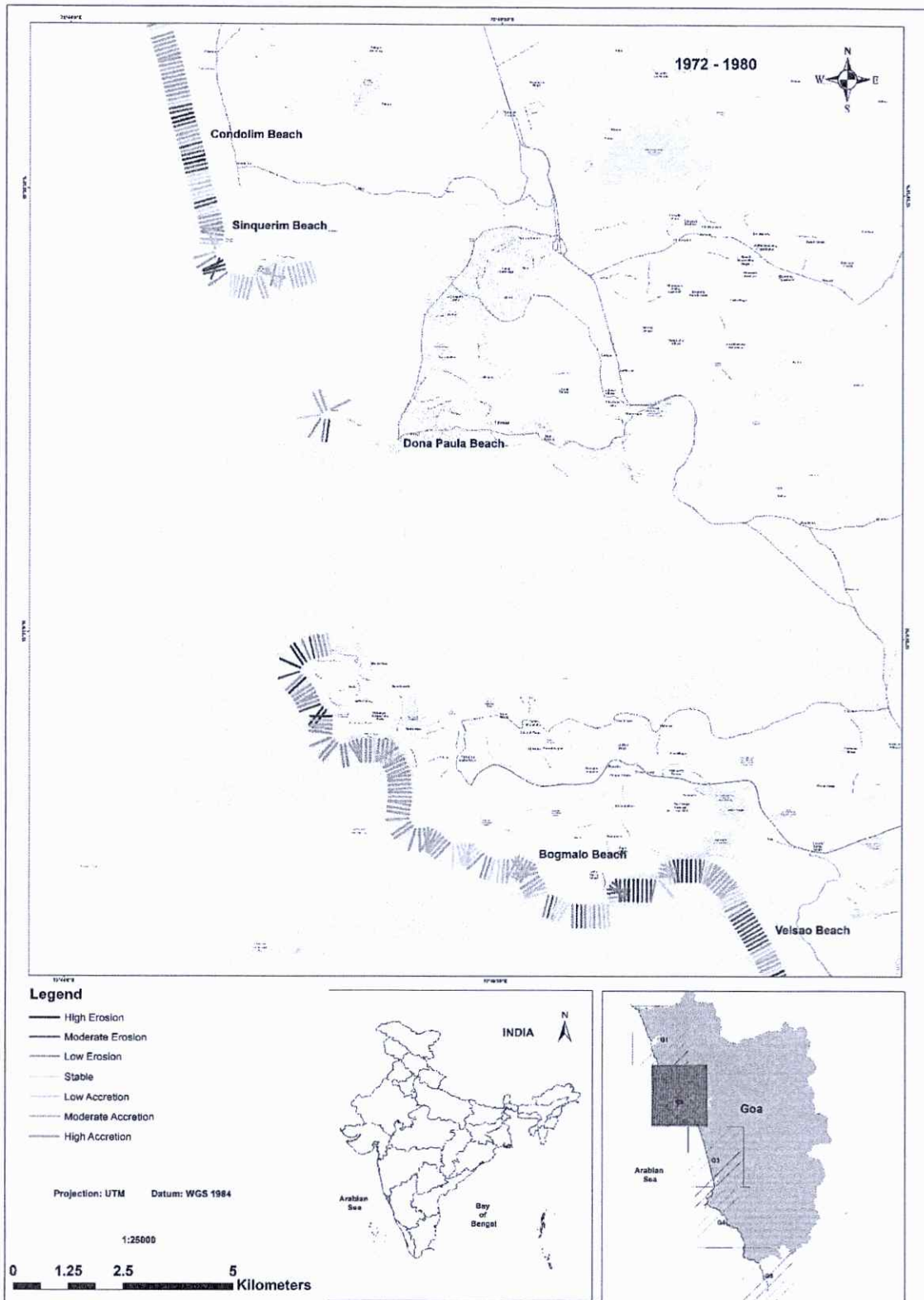


Figure 6-7: Shoreline change map of Segment G2 & G3 from 1972-1980

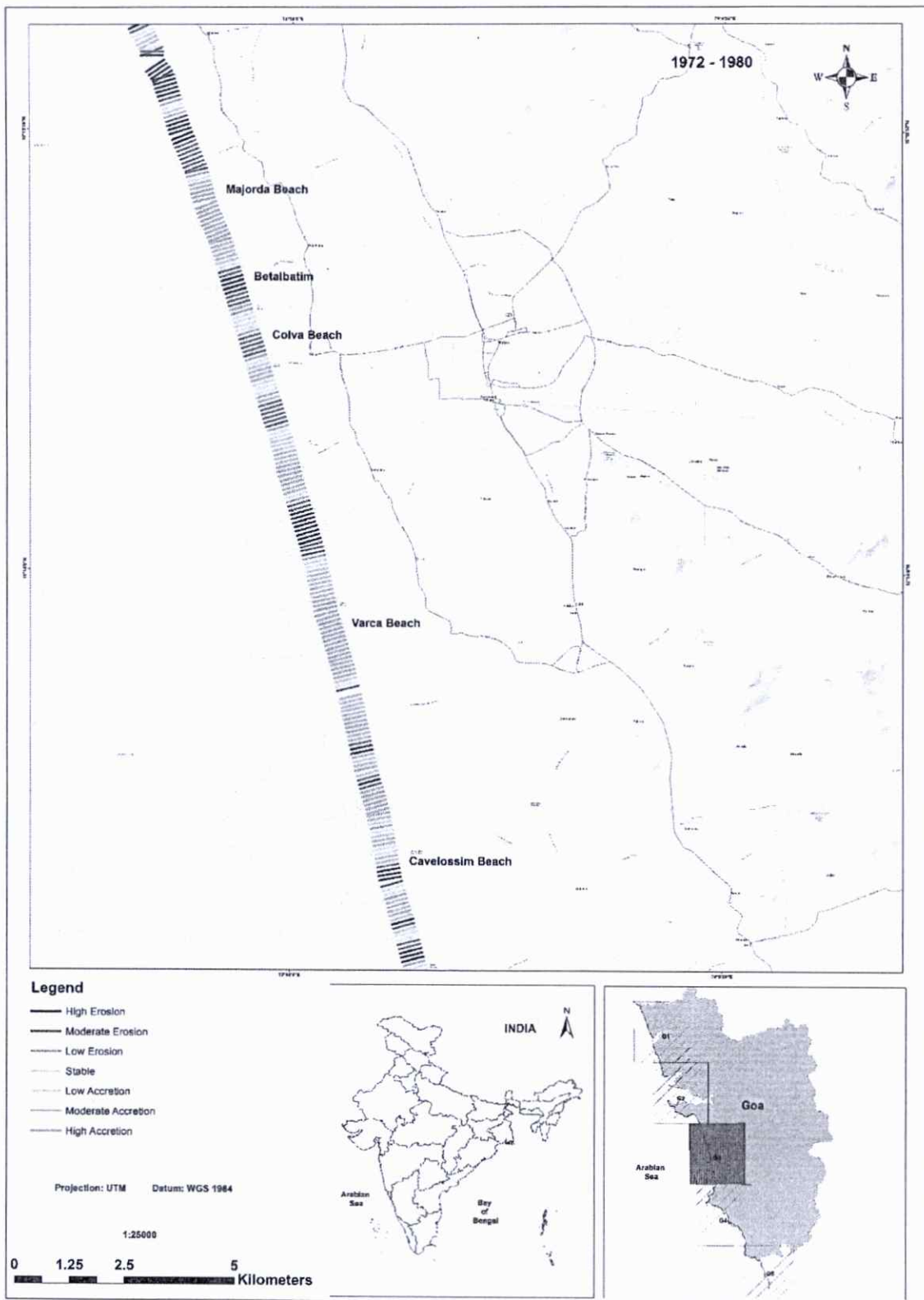


Figure 6-8: Shoreline change map of Segment G4 from 1972-1980

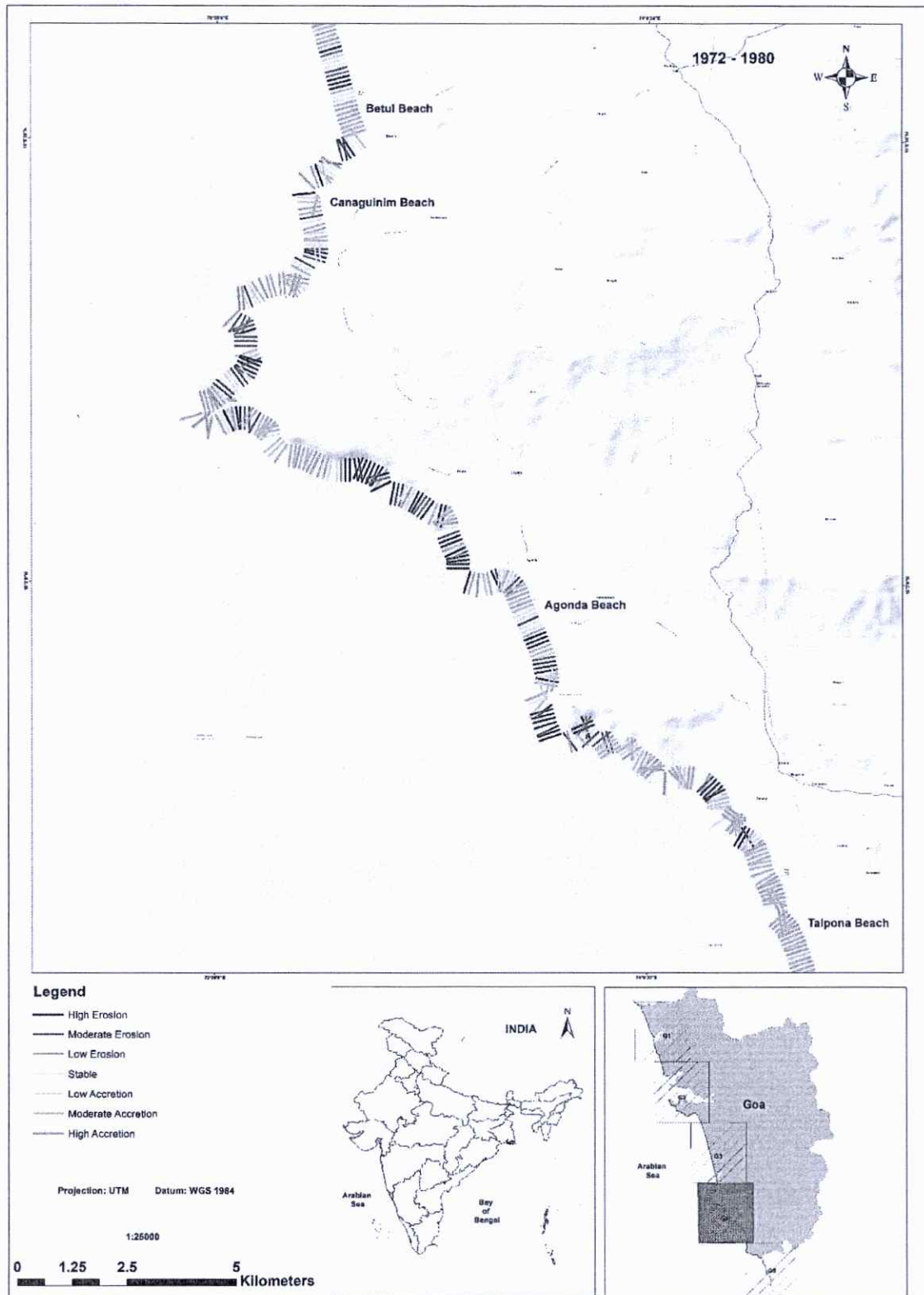


Figure 6-9: Shoreline change map of Segment G5 & G6 from 1972-1980

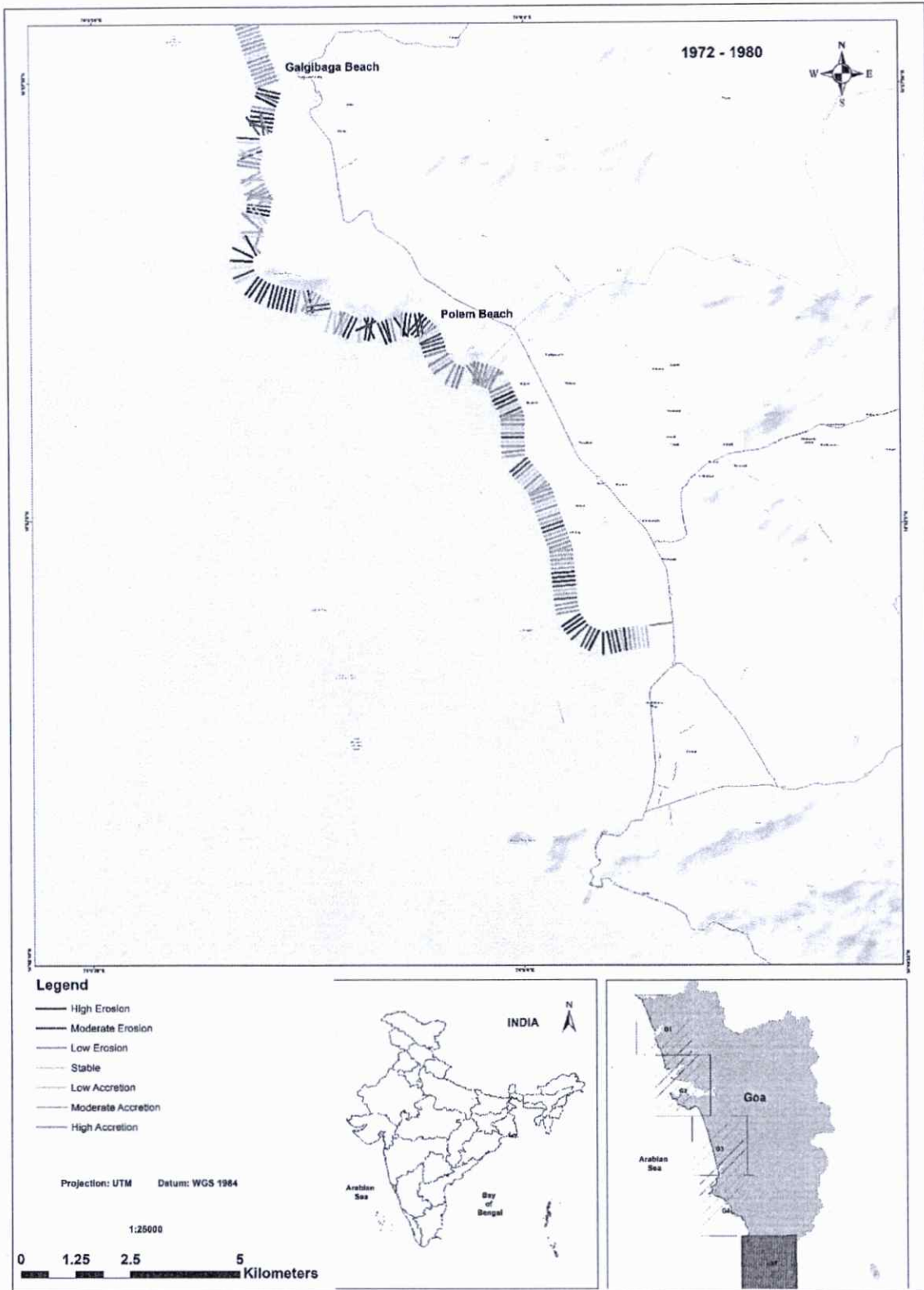


Figure 6-10: Shoreline change map of Segment G7 from 1972-1980

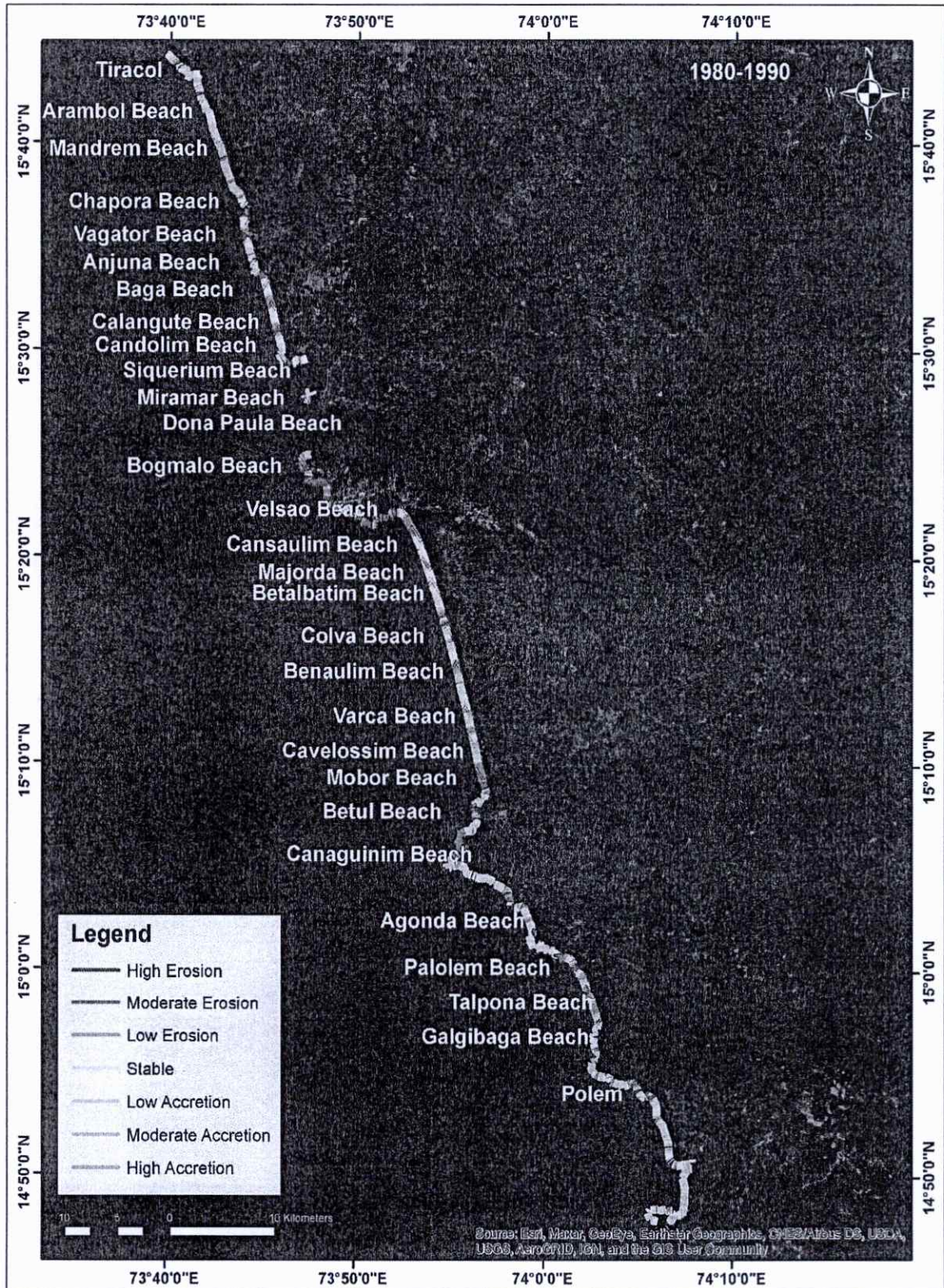


Figure 6-11: Shoreline Change Map of Goa coast 1980-1990

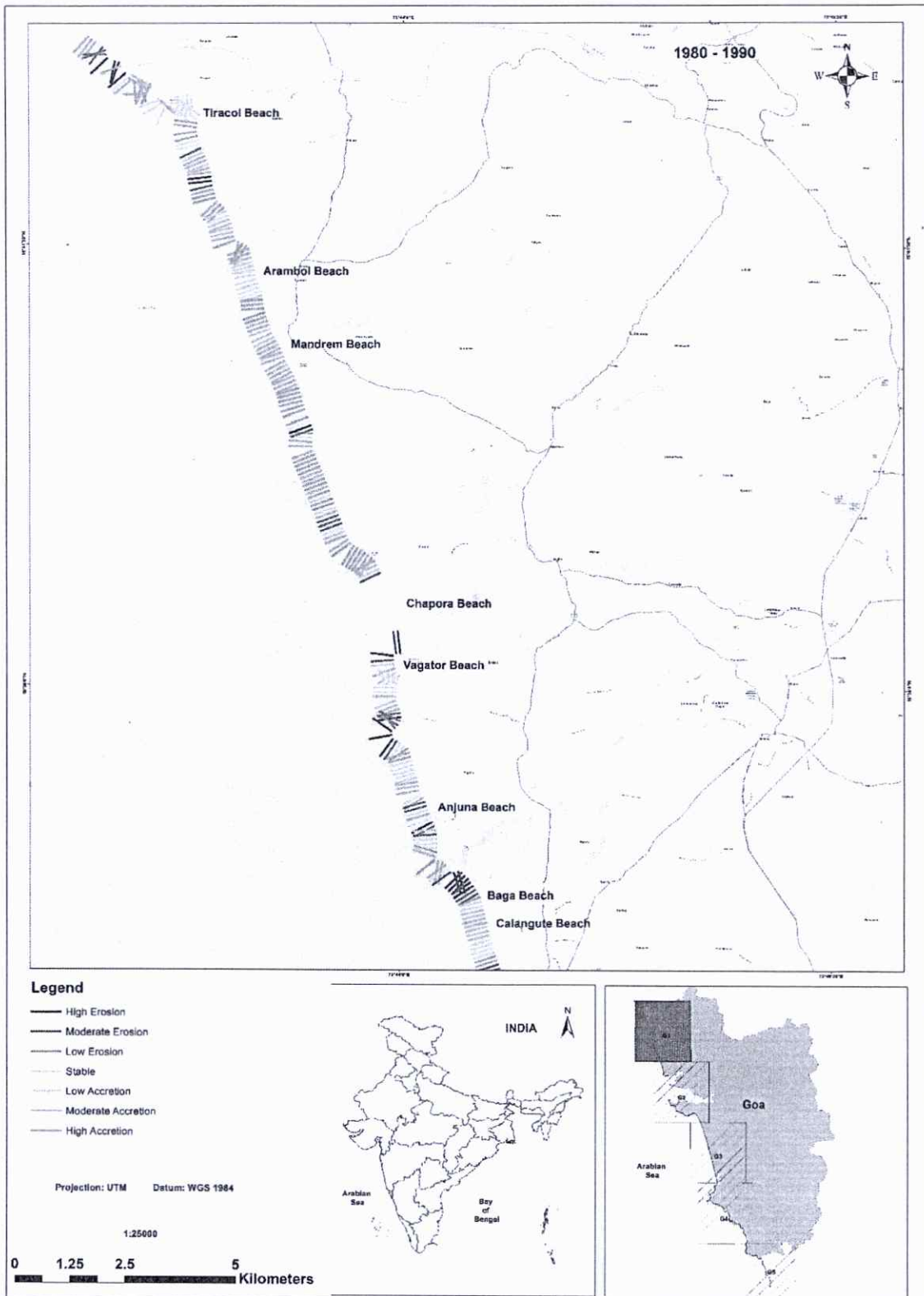
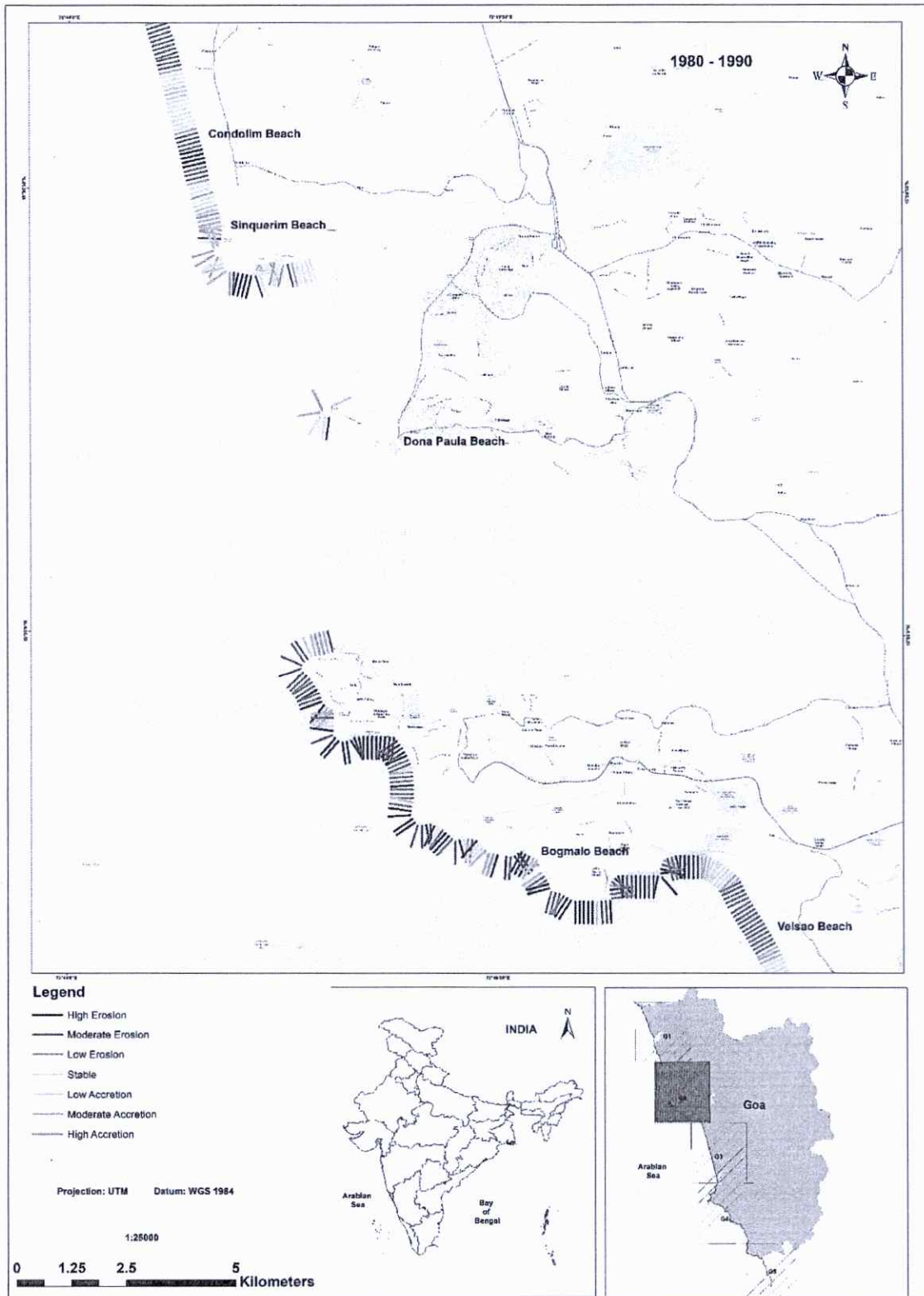


Figure 6-12: Shoreline change map of Segment G1 from 1980-1990



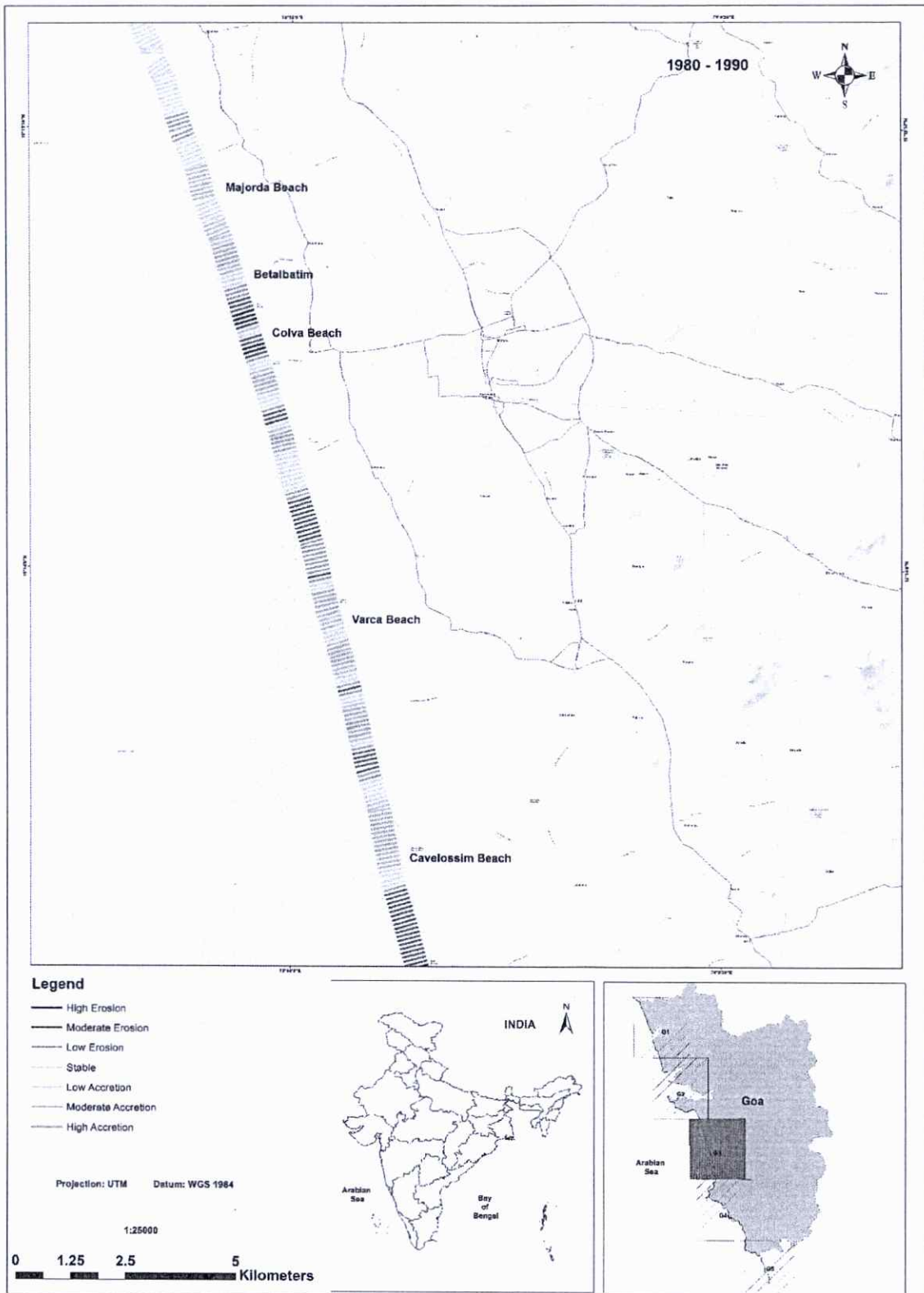


Figure 6-14: Shoreline change map of Segment G4 from 1980-1990

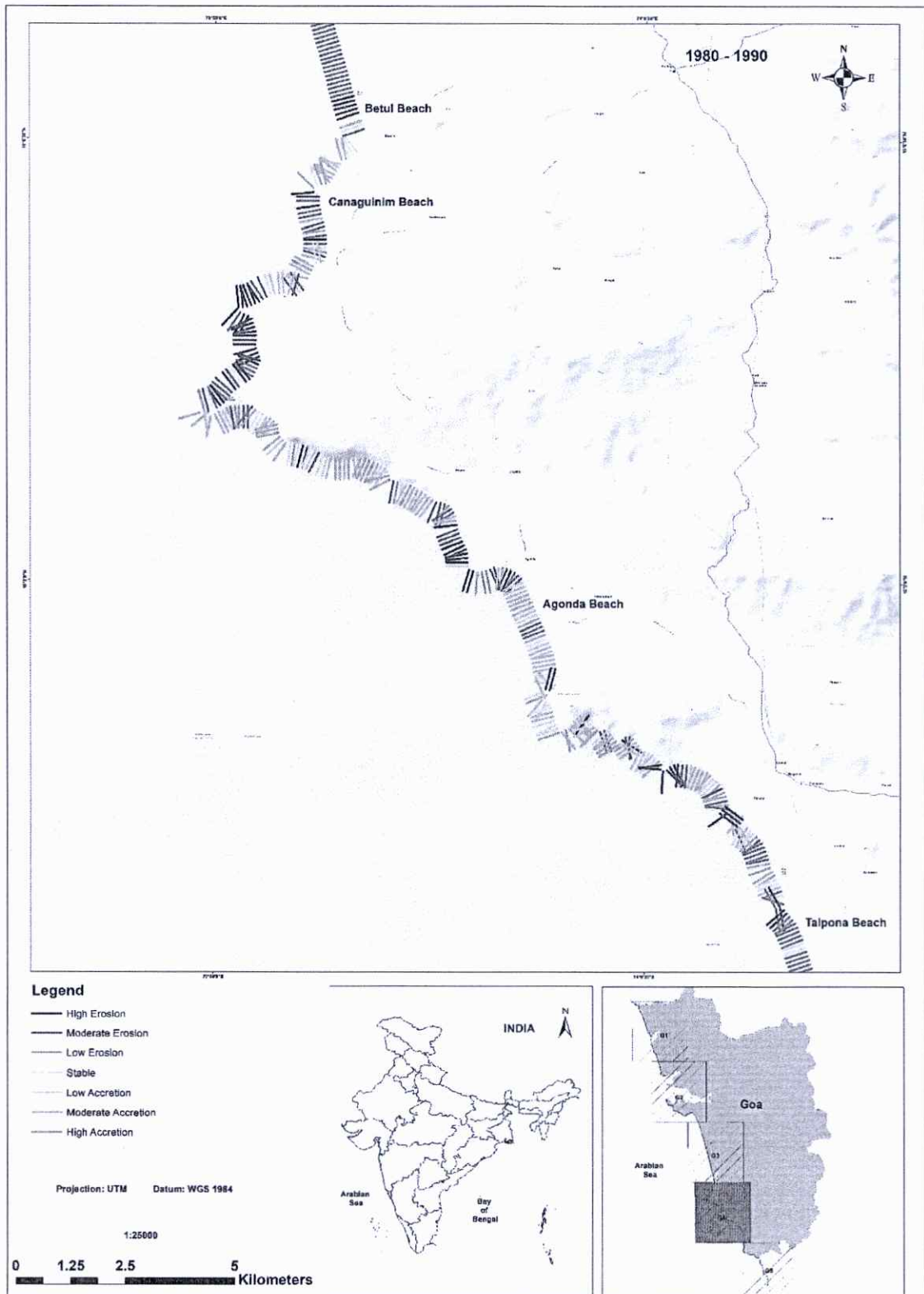


Figure 6-15: Shoreline change map of Segment G5 & G6 from 1980-1990

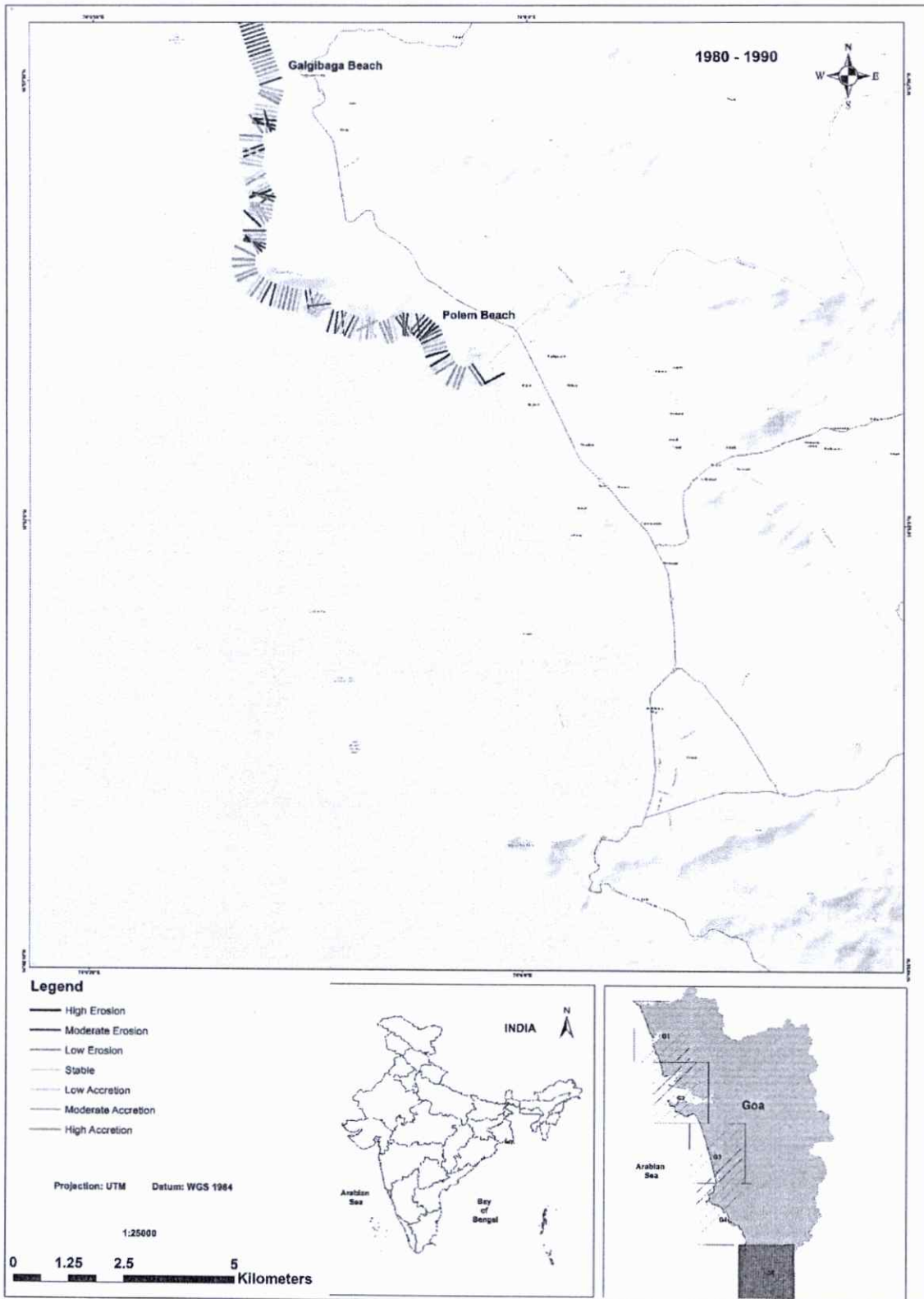


Figure 6-16: Shoreline change map of Segment G7 from 1980-1990

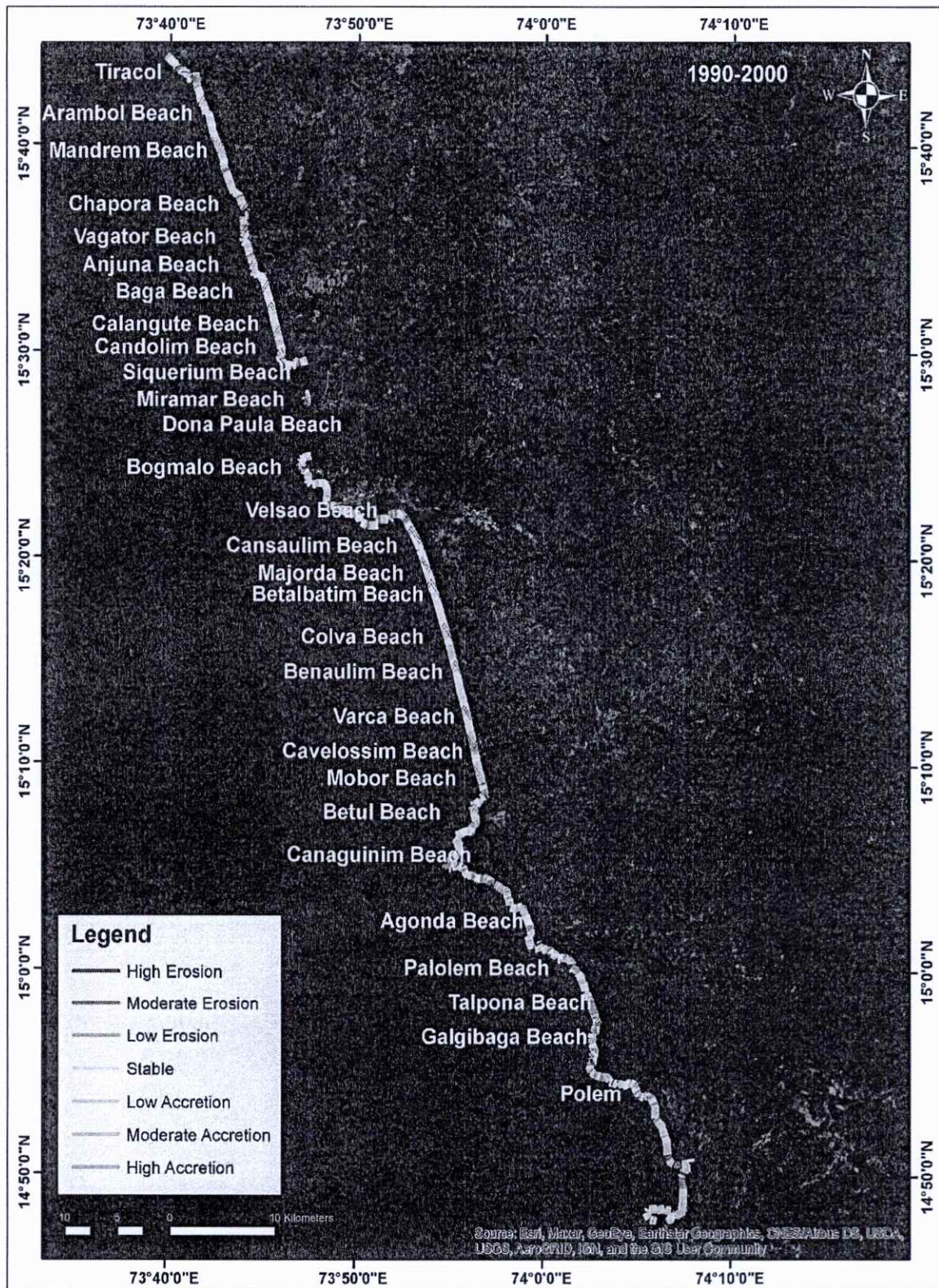


Figure 6-17: Shoreline Change Map of Goa coast 1990-2000

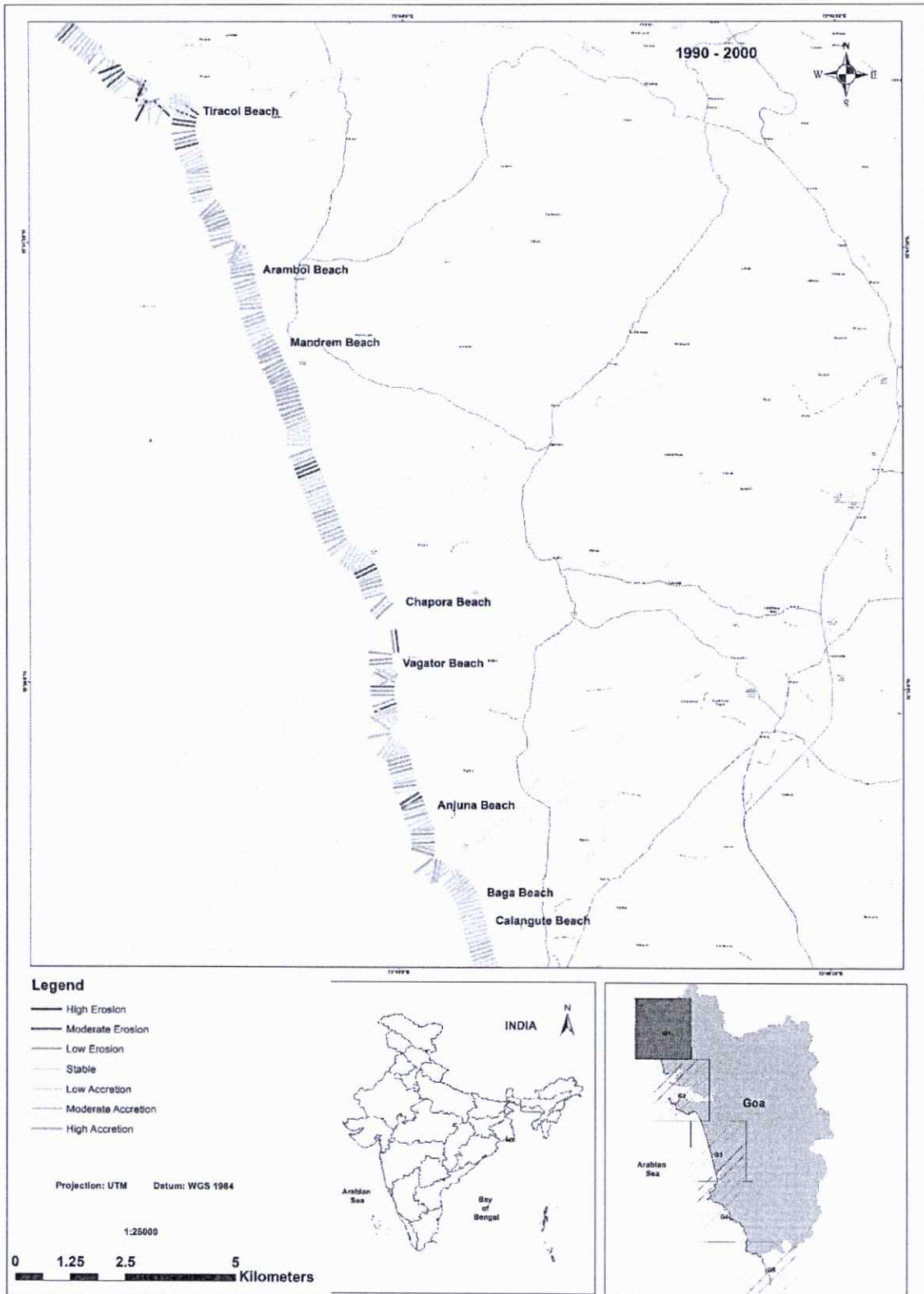


Figure 6-18: Shoreline change map of Segment G1 from 1990-2000

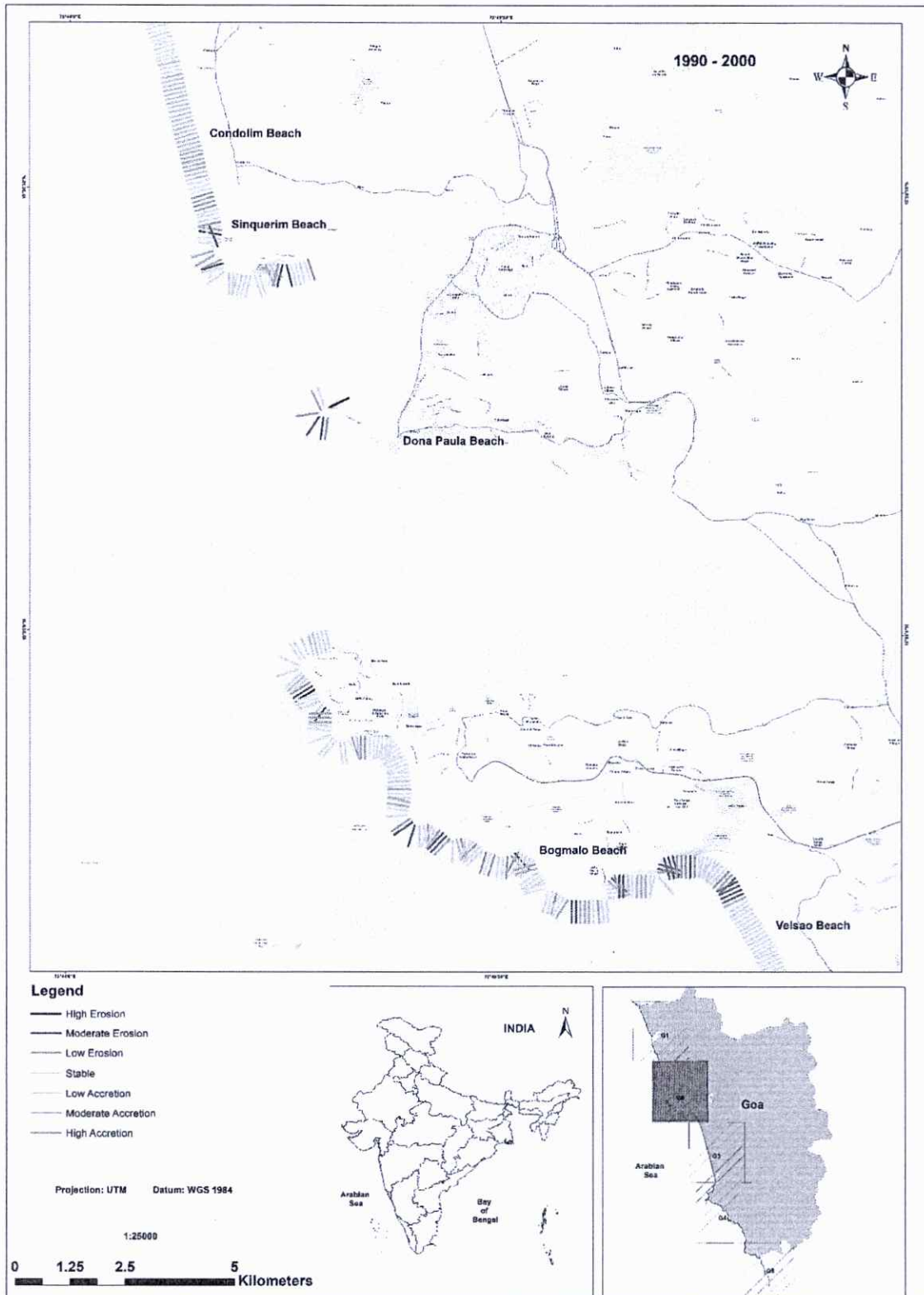


Figure 6-19: Shoreline change map of Segment G2 & G3 from 1990-2000

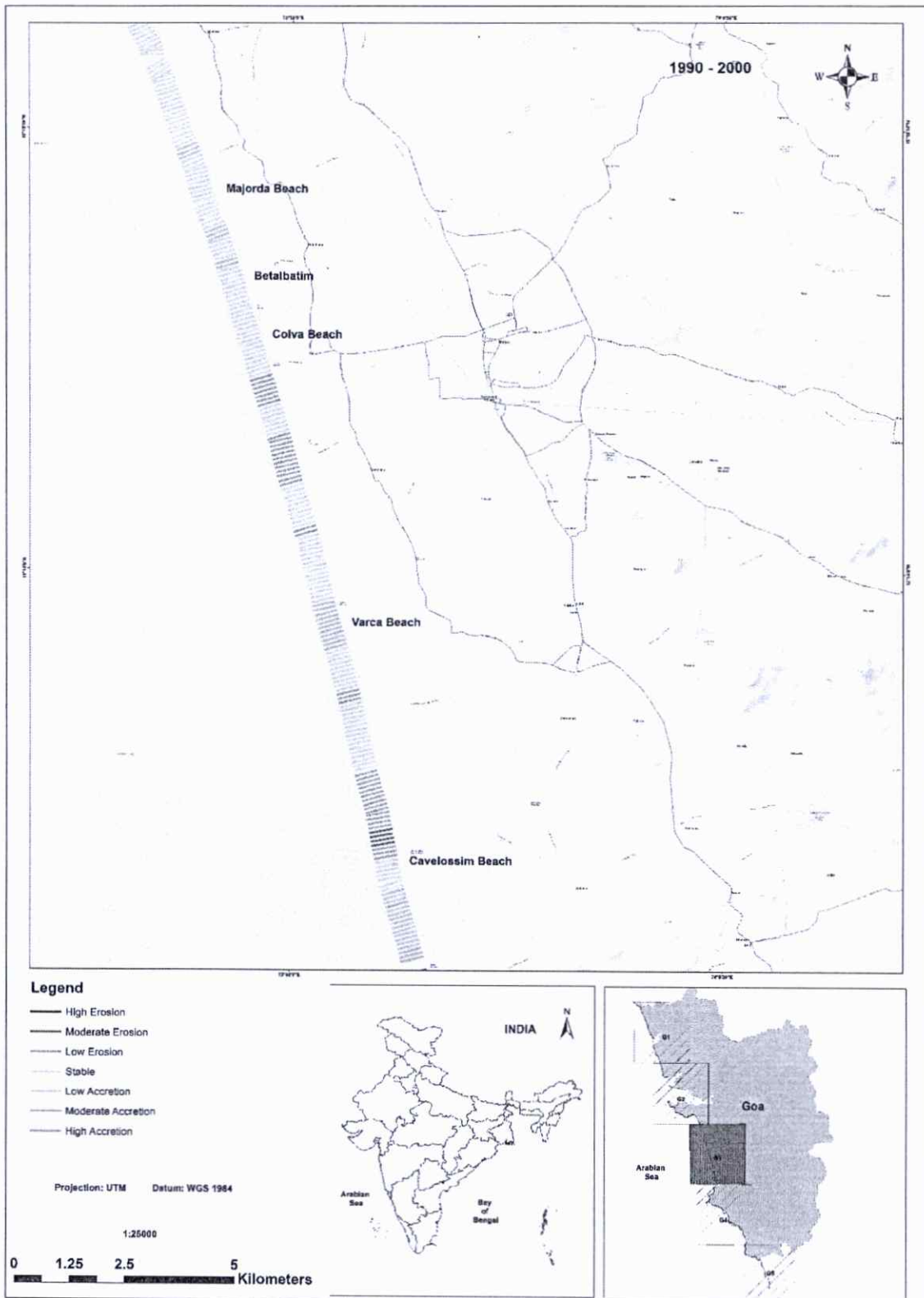


Figure 6-20: Shoreline change map of Segment G4 from 1990-2000

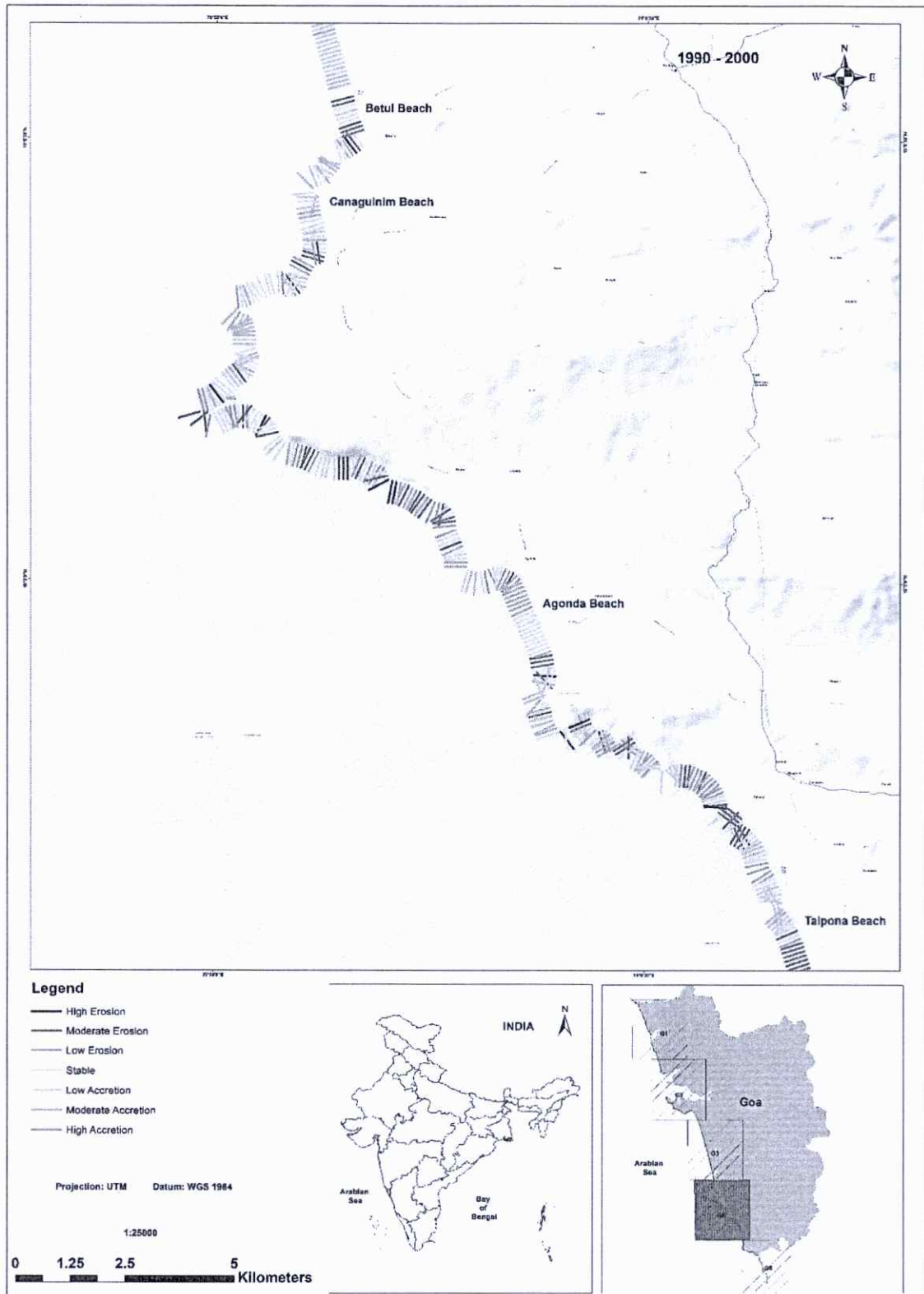


Figure 6-21: Shoreline change map of Segment G5 & G6 from 1972-1980

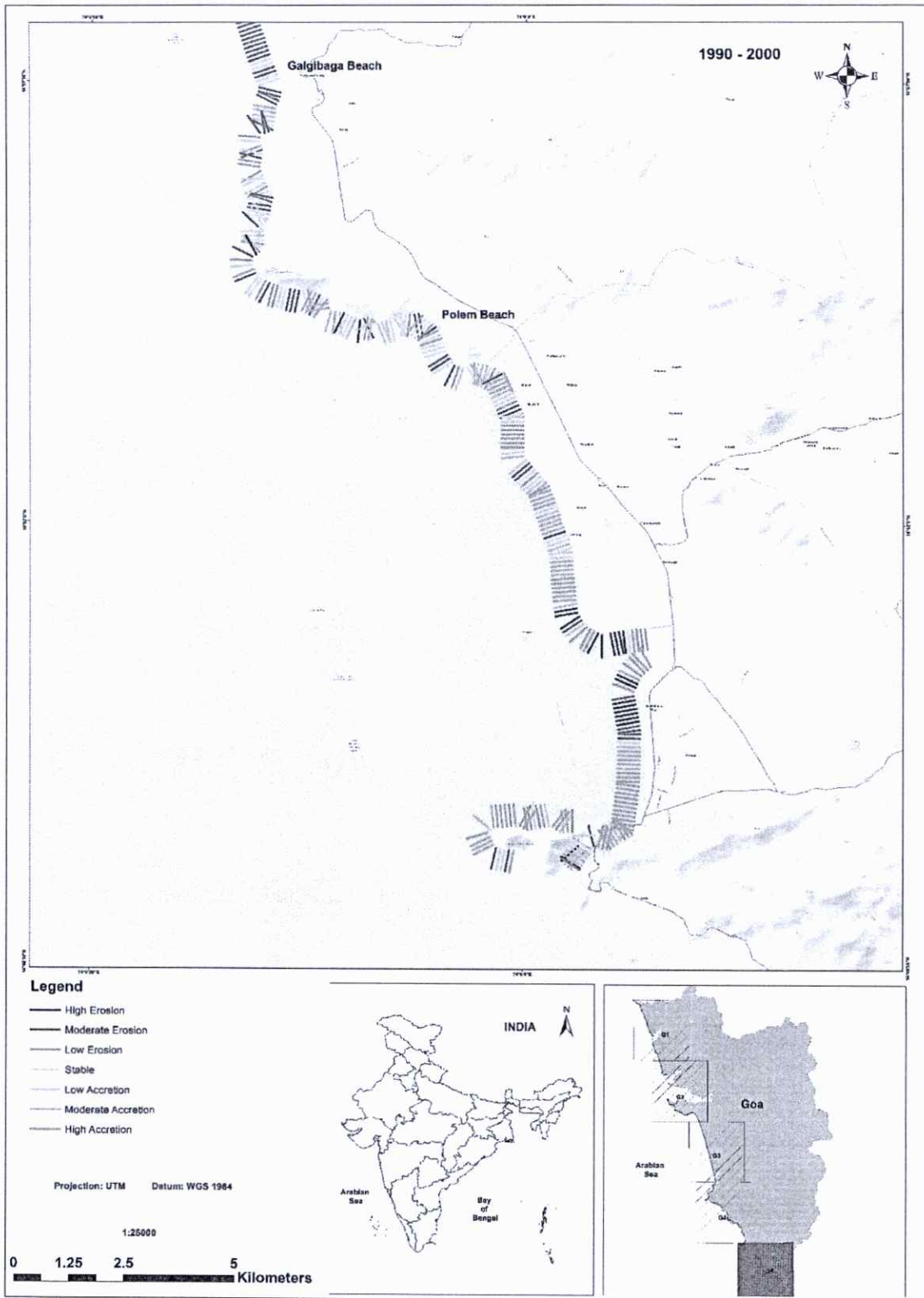


Figure 6-22: Shoreline change map of Segment G7 from 1990-2000

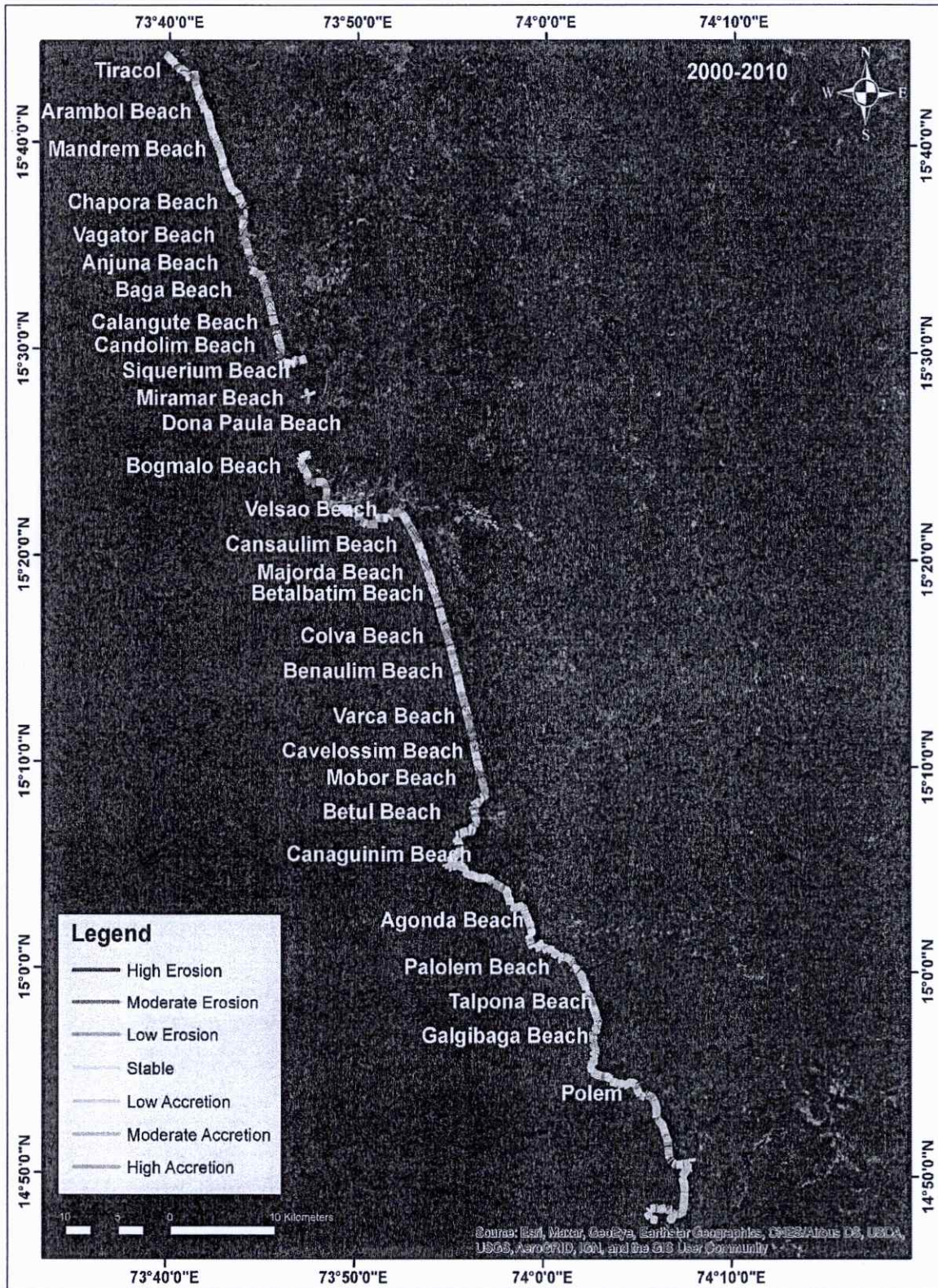


Figure 6-23: Shoreline Change Map of Goa coast 2000-2010

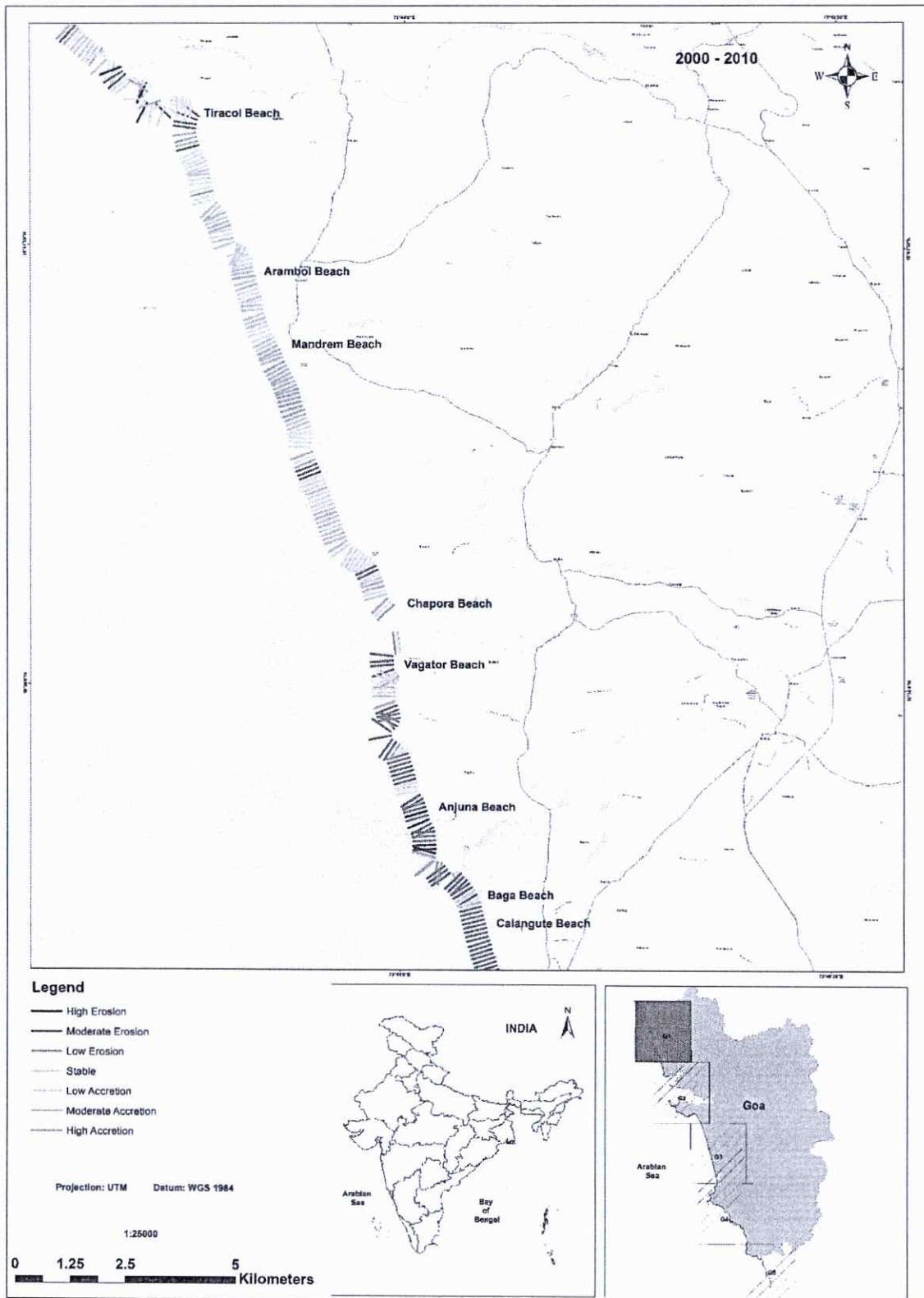


Figure 6-24: Shoreline change map of Segment G1 from 2000-2010

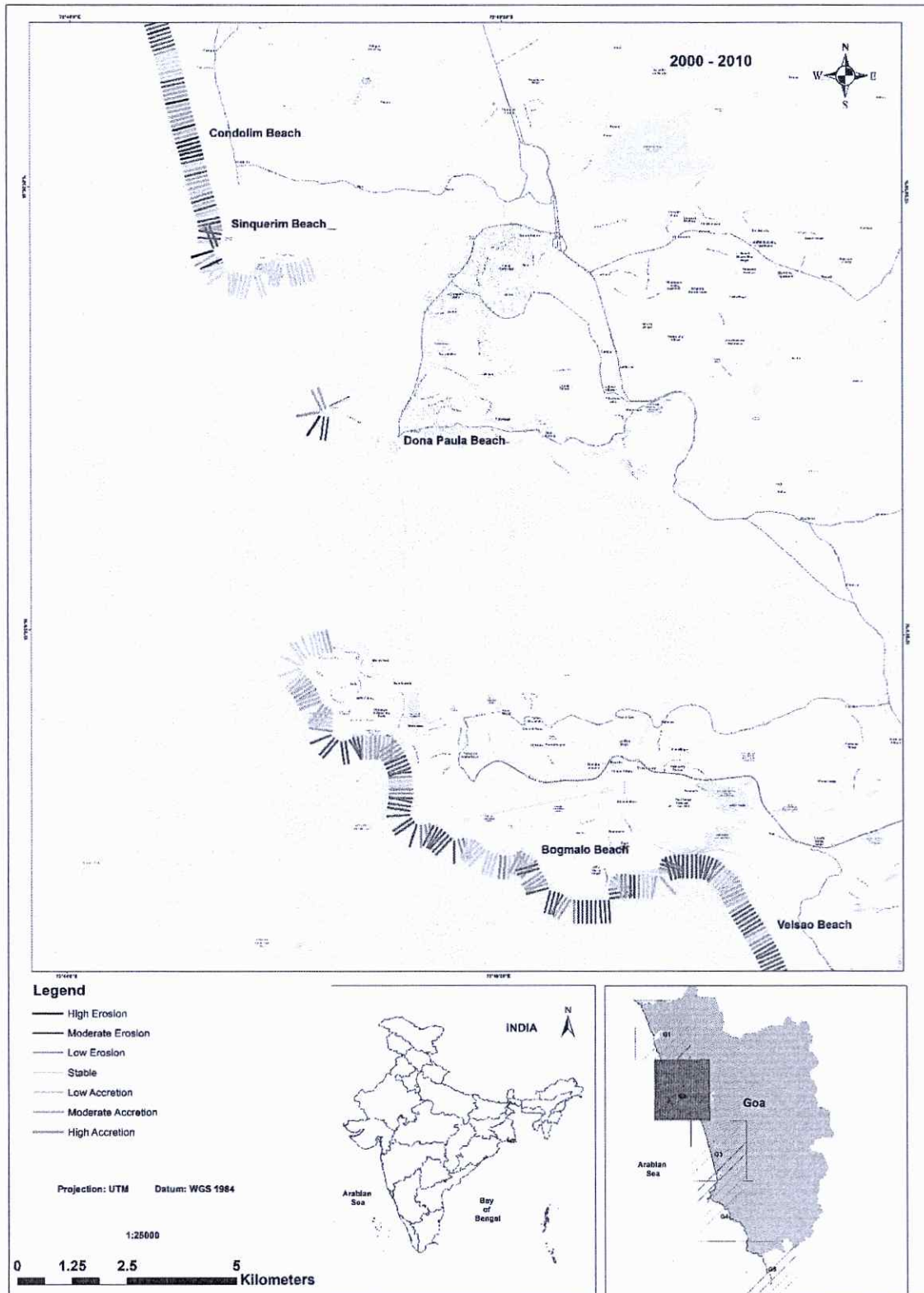


Figure 6-25: Shoreline change map of Segment G2 & G3 from 2000-2010

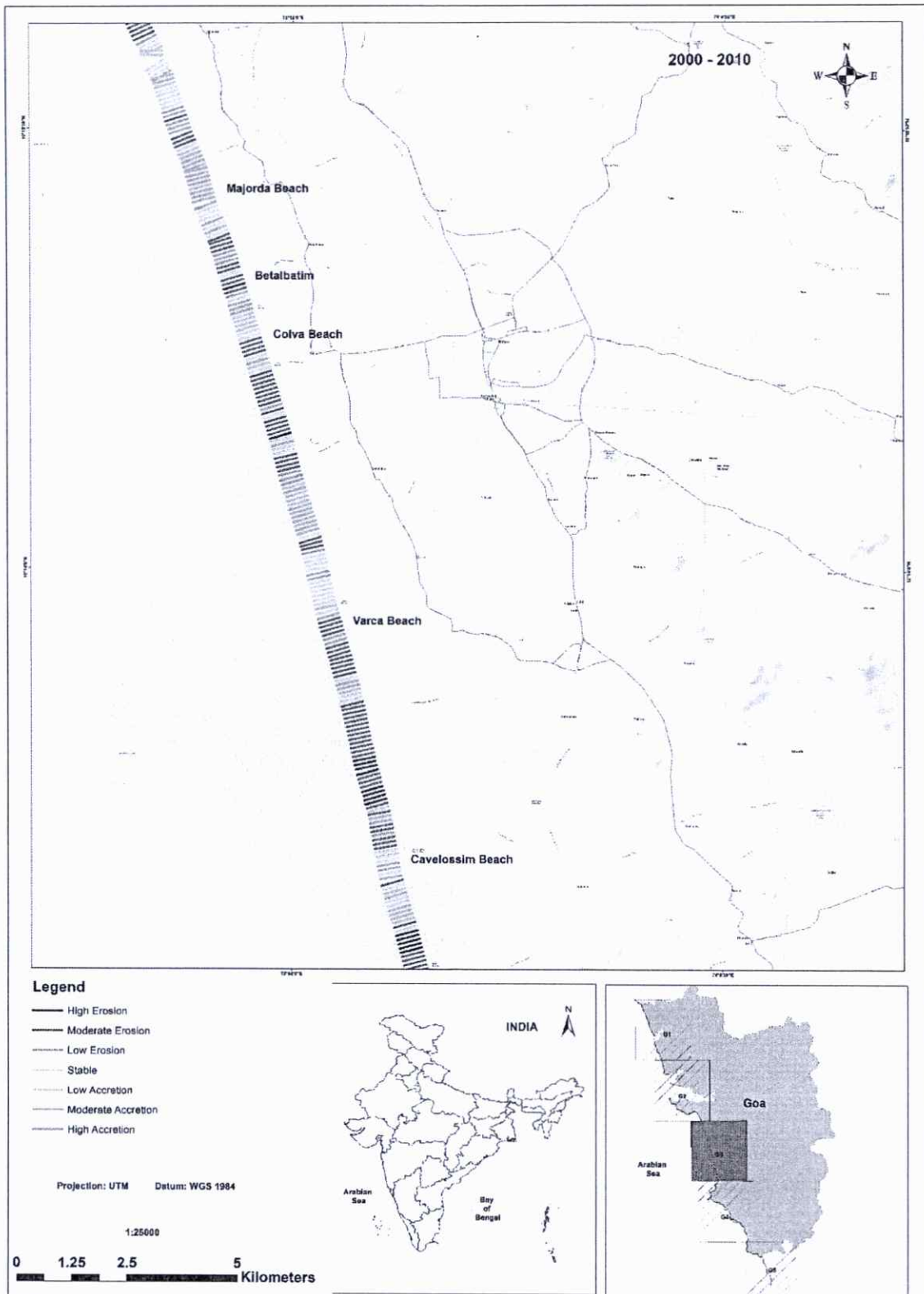


Figure 6-26: Shoreline change map of Segment G4 from 2000-2010

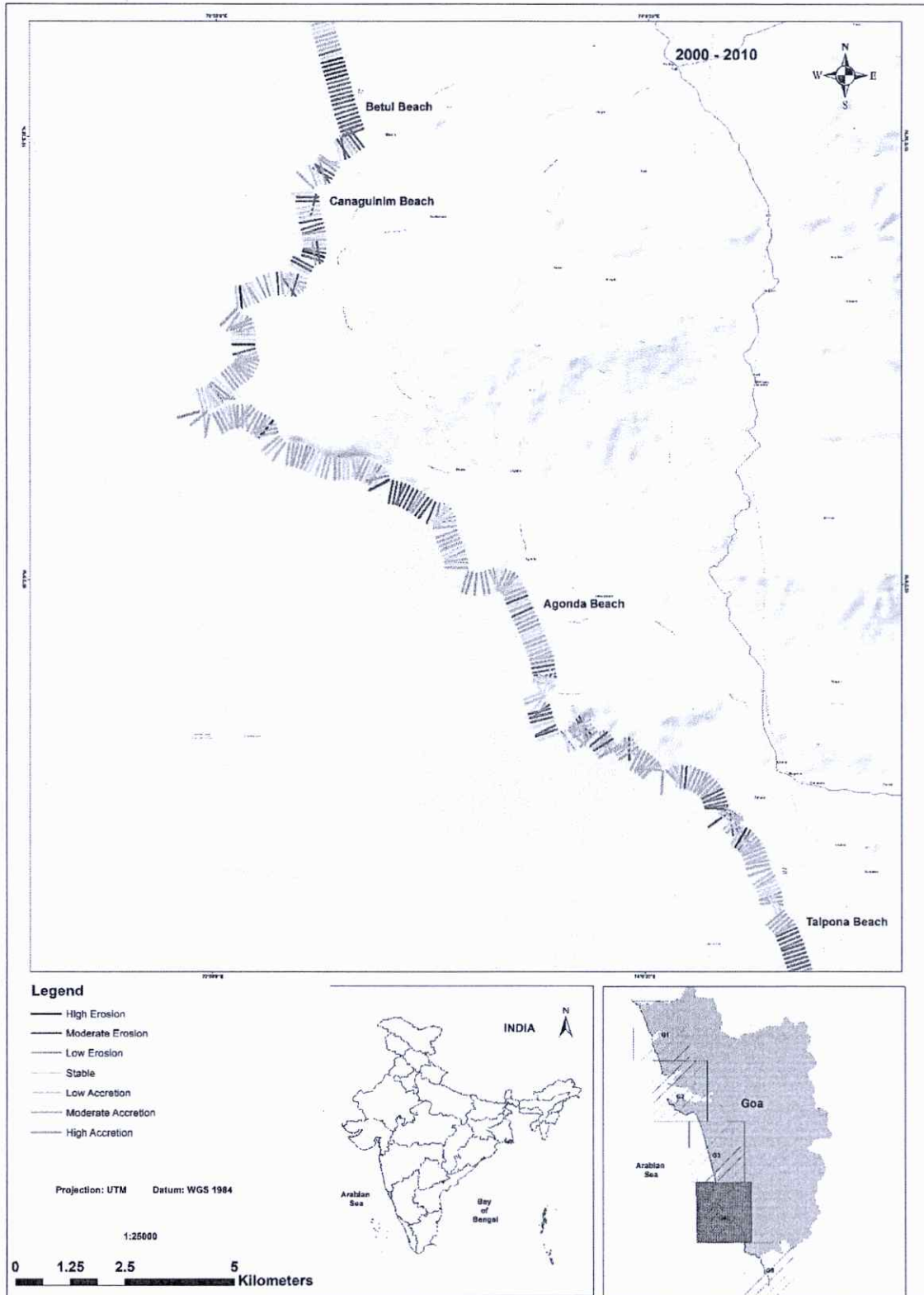


Figure 6-27: Shoreline change map of Segment G5 & G6 from 2000-2010

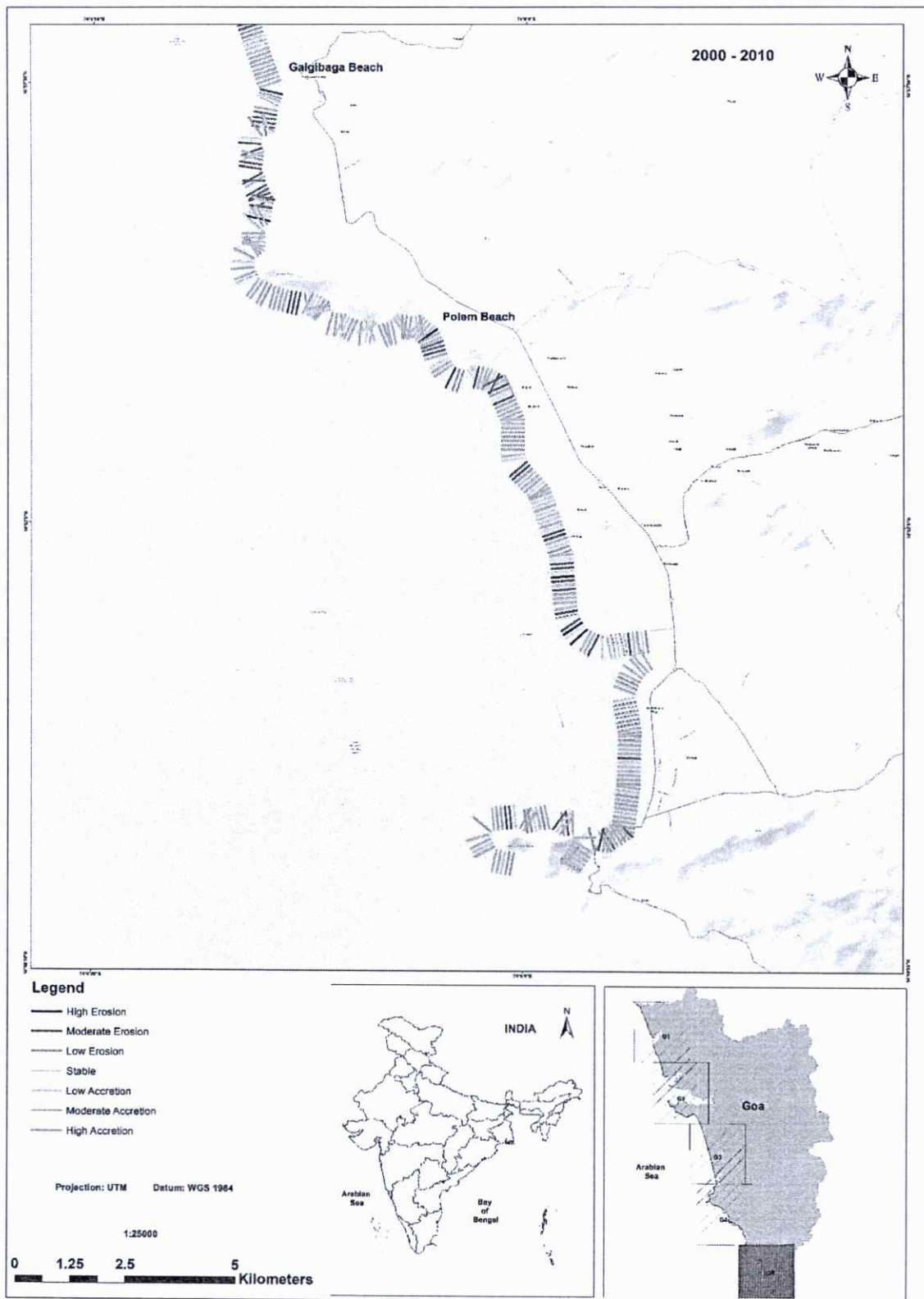


Figure 6-28: Shoreline change map of Segment G7 from 2000-2010

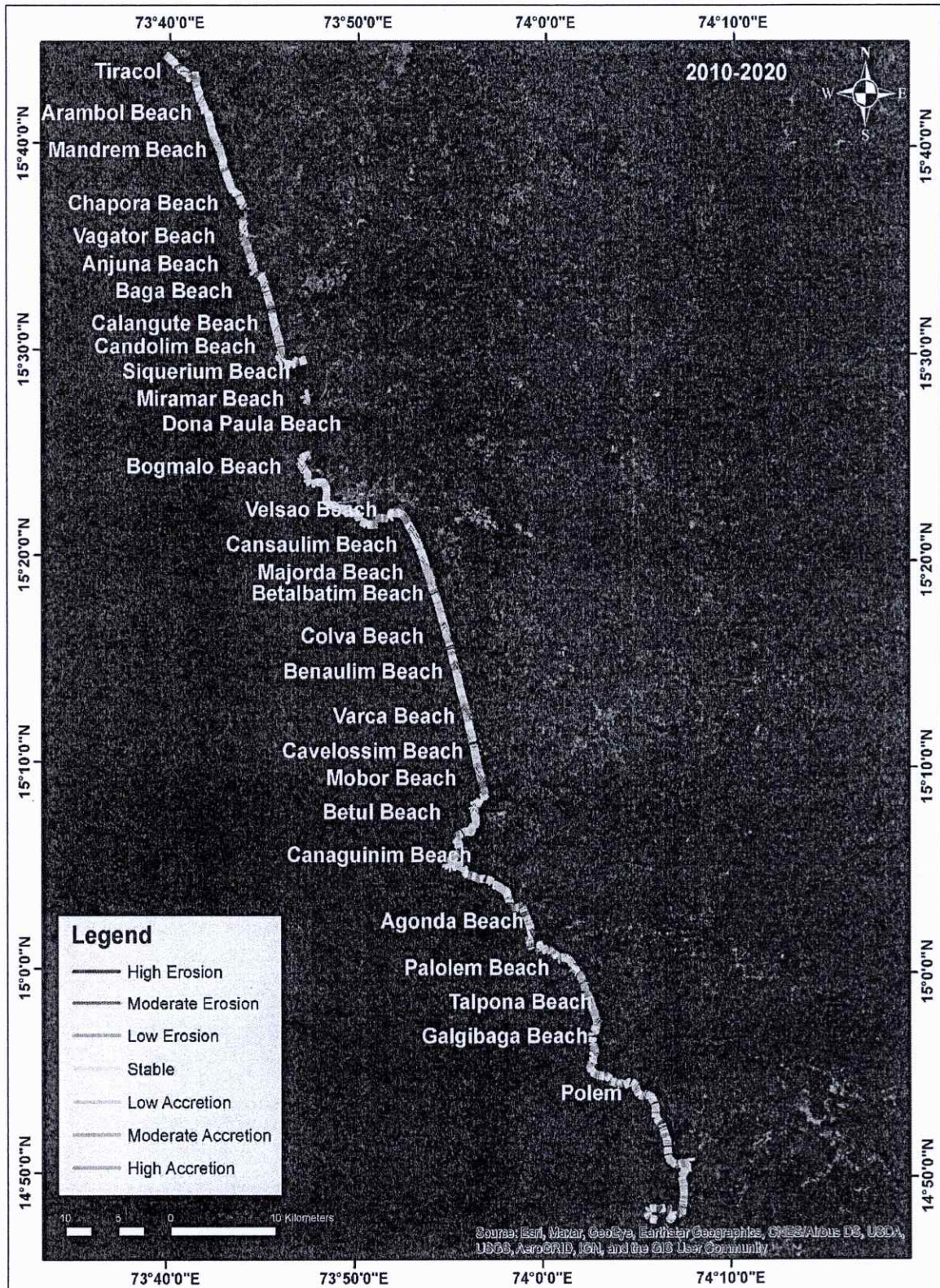


Figure 6-29: Shoreline Change Map of Goa coast 2010-2020

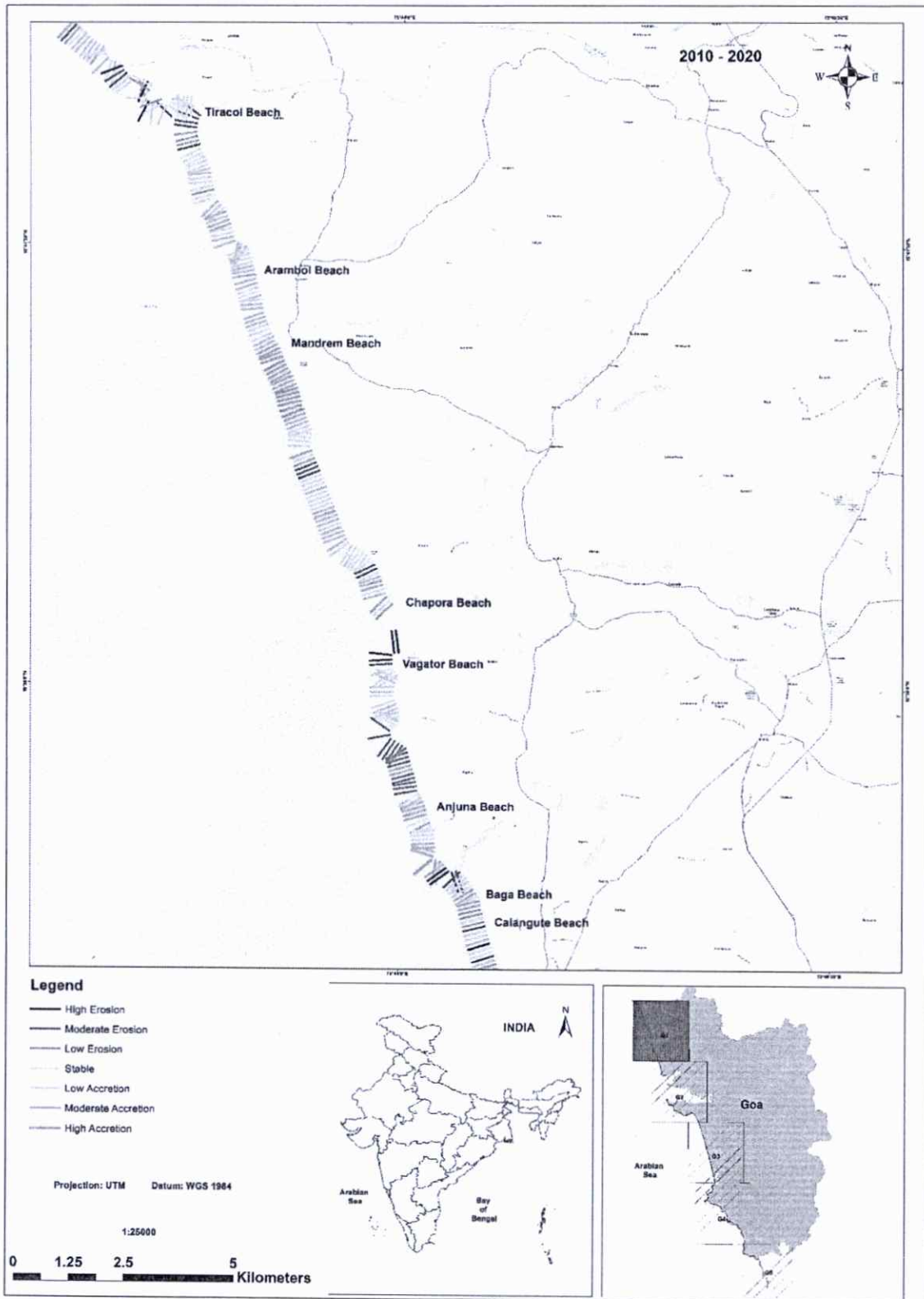


Figure 6-30: Shoreline change map of Segment G1 from 2010-2020

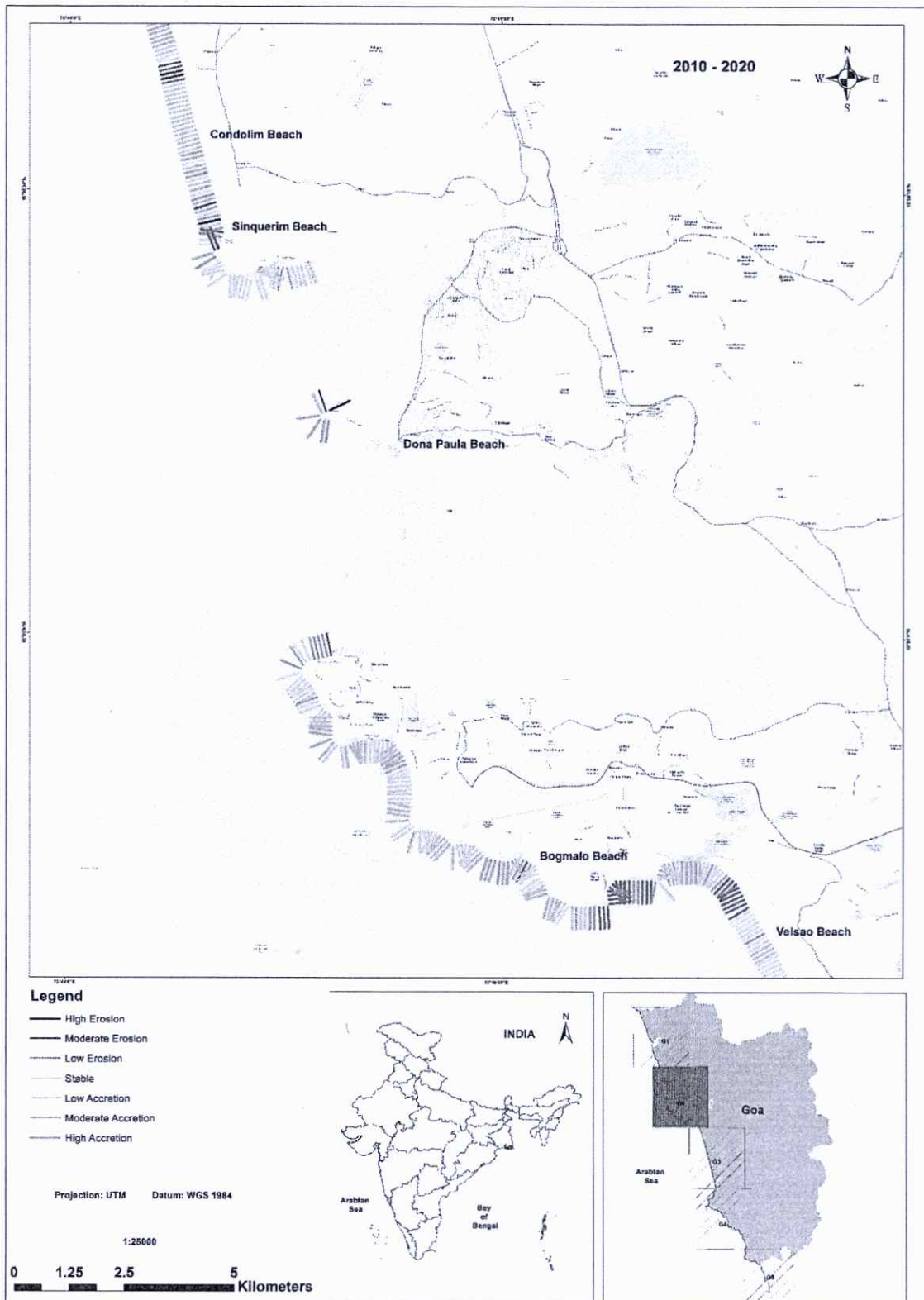


Figure 6-31: Shoreline change map of Segment G2 & G3 from 2010-2020

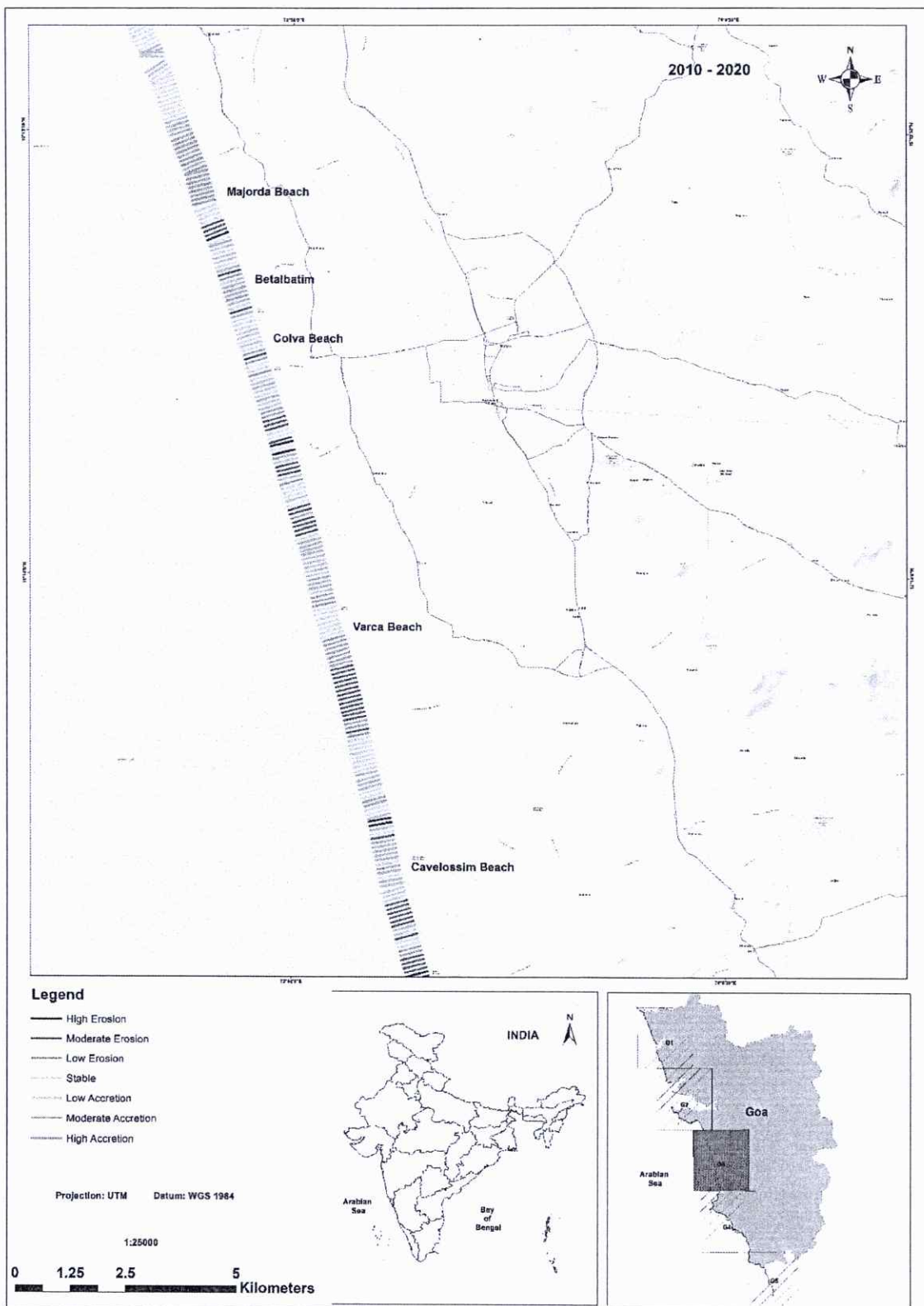


Figure 6-32: Shoreline change map of Segment G4 from 2010-2020

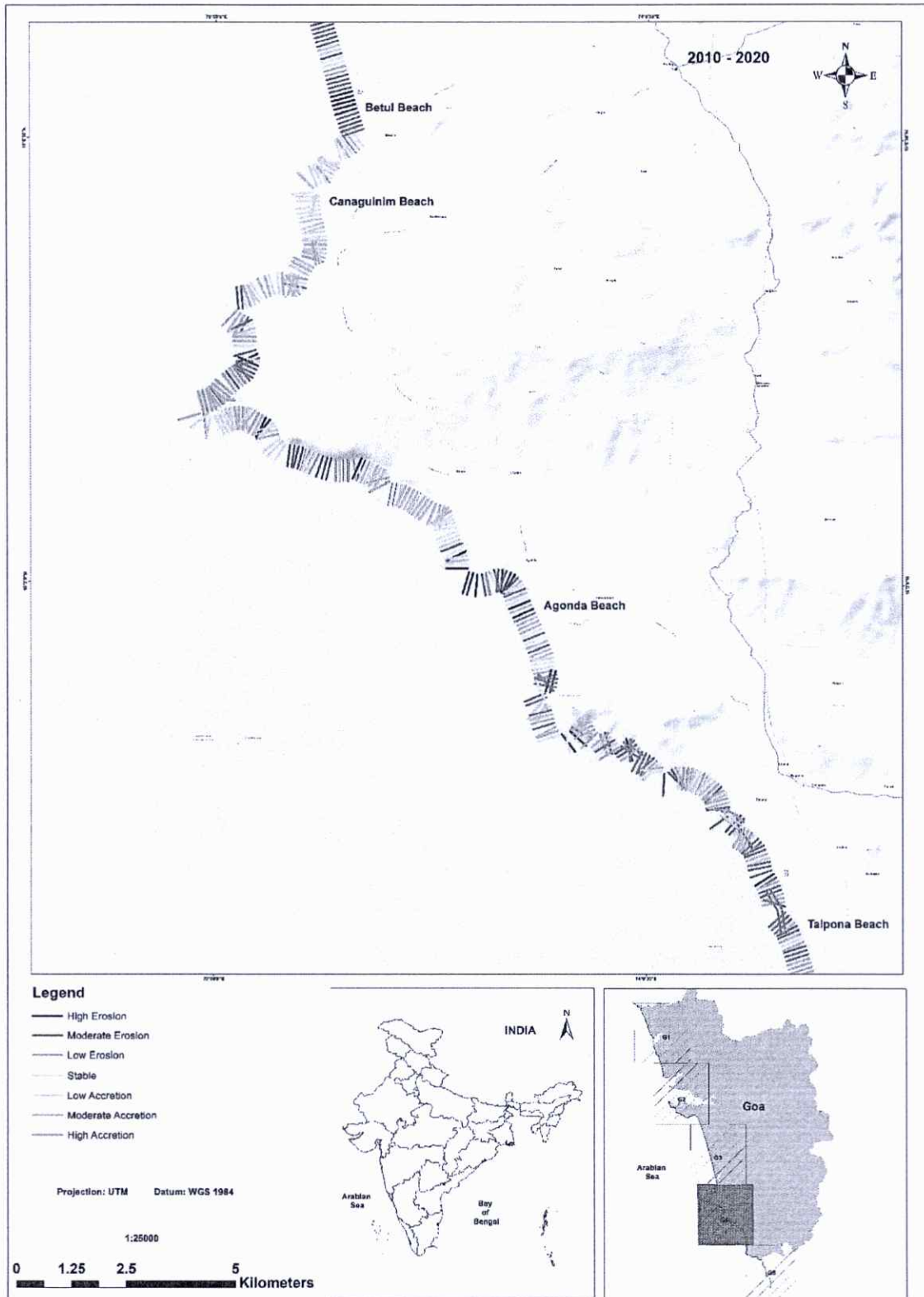


Figure 6-33: Shoreline change map of Segment G5 & G6 from 2010-2020

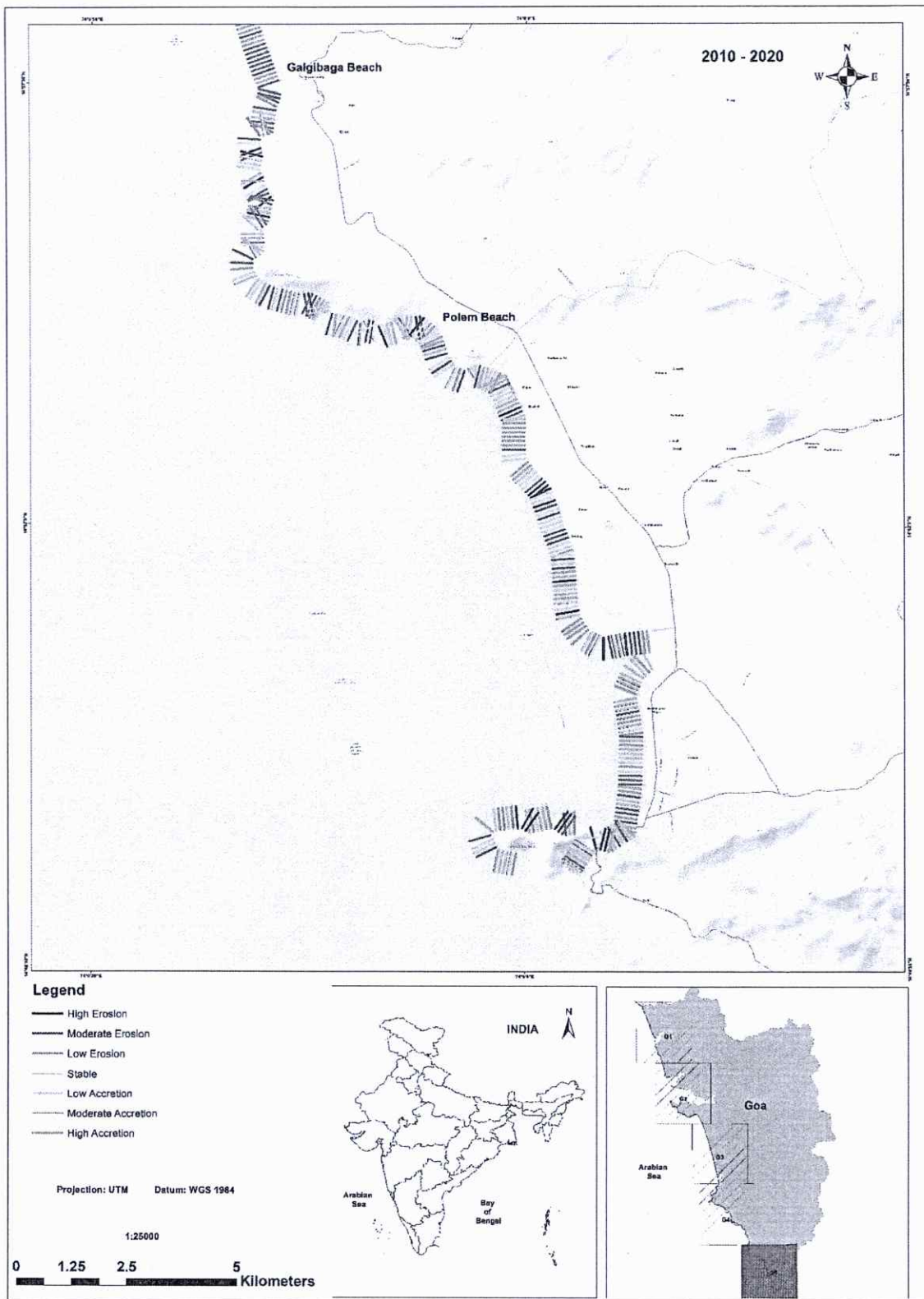


Figure 6-34: Shoreline change map of Segment G7 coast from 2010-2020

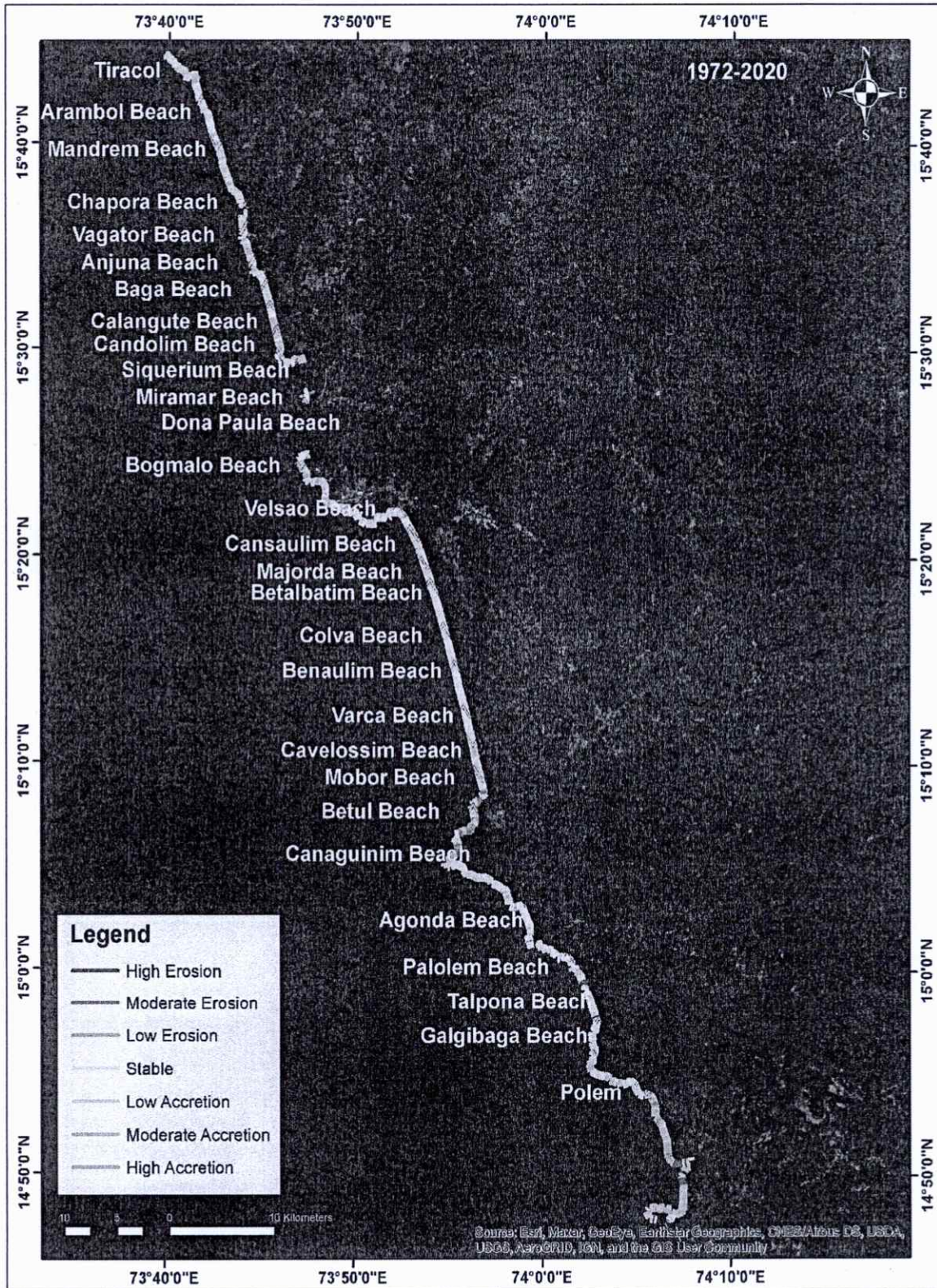


Figure 6-35: Shoreline Change Map of Goa coast 1972-2020

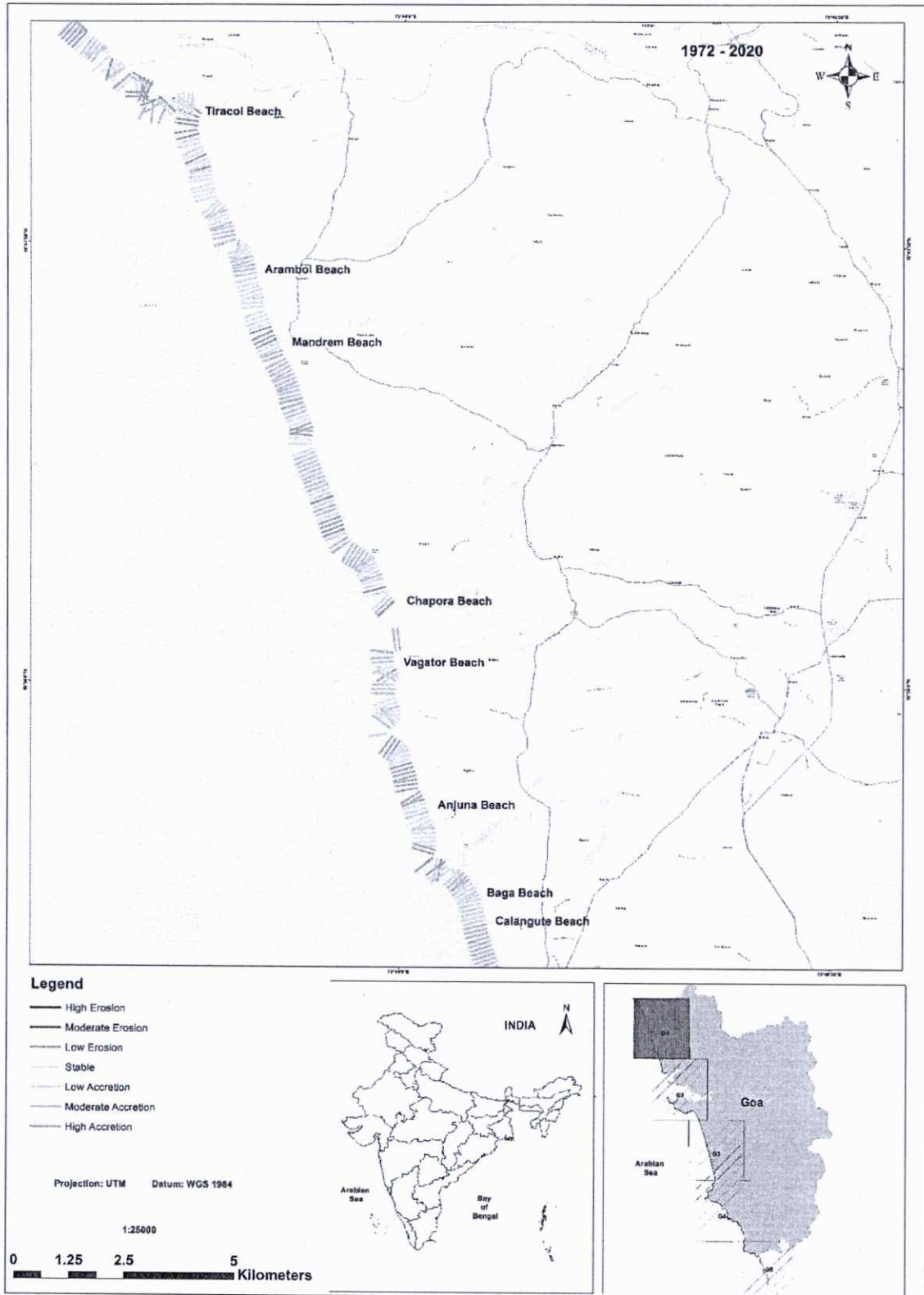
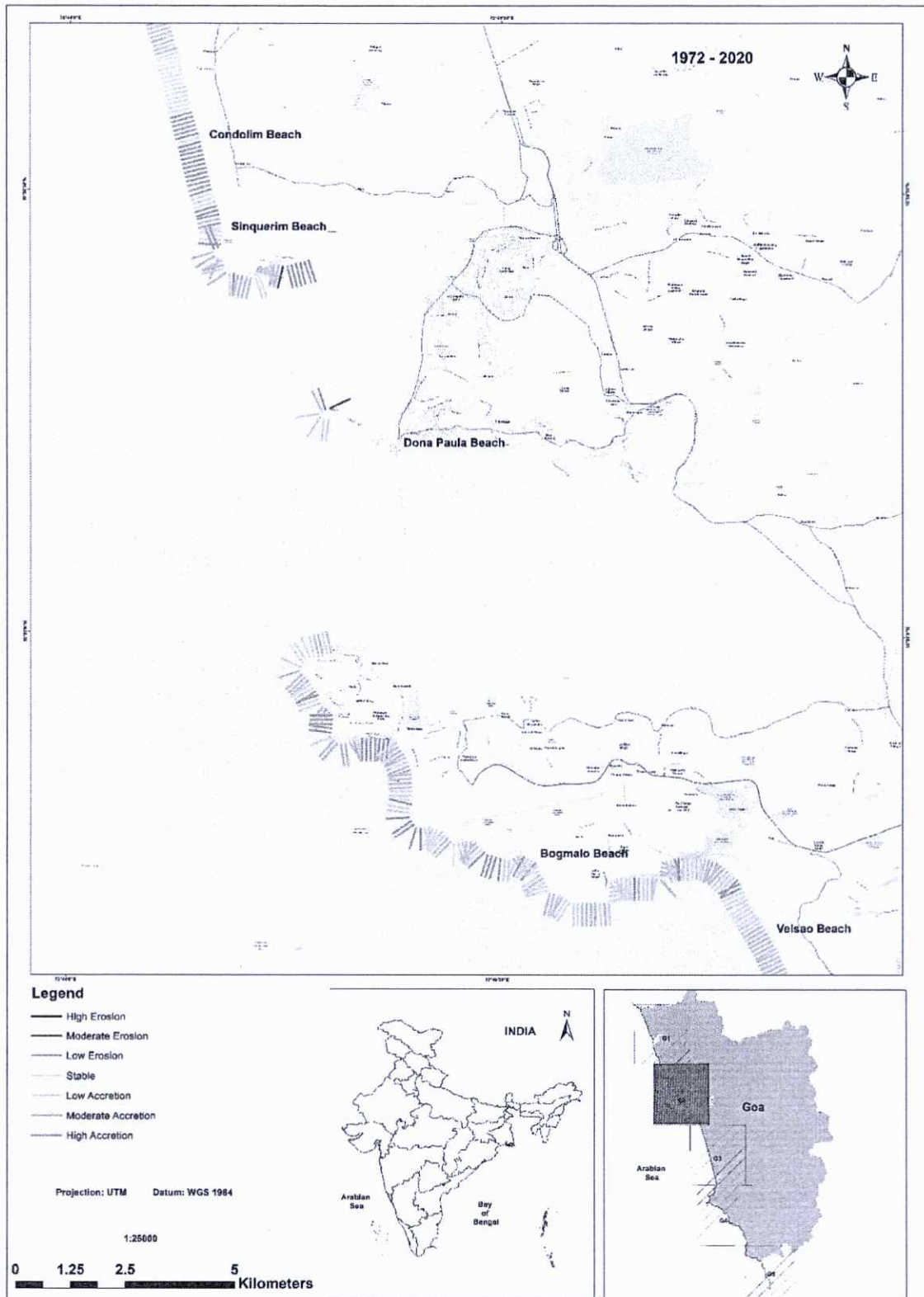


Figure 6-36: Shoreline change map of Segment G1 from 1972-2020



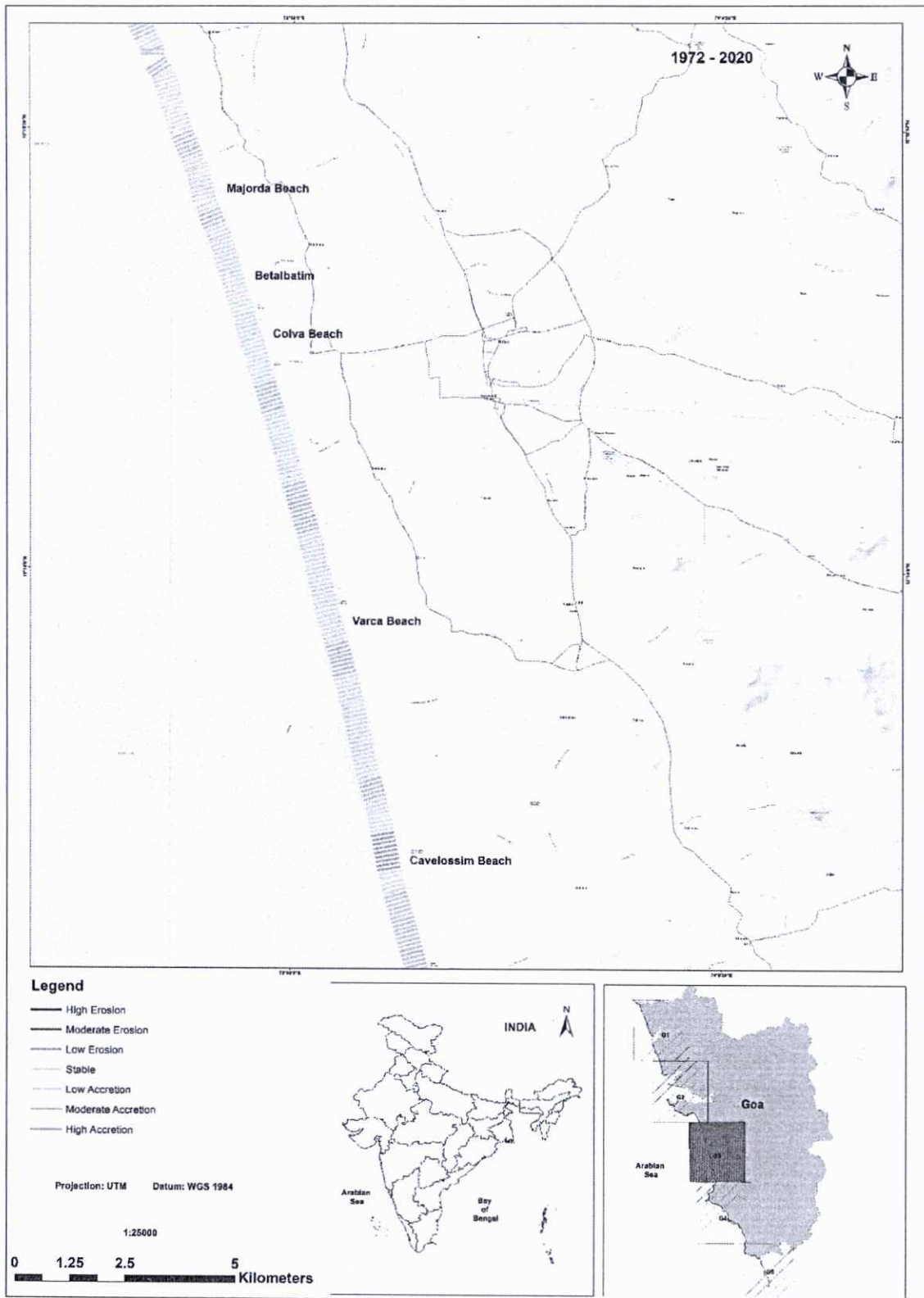


Figure 6-38: Shoreline change map of Segment G4 from 1972-2020

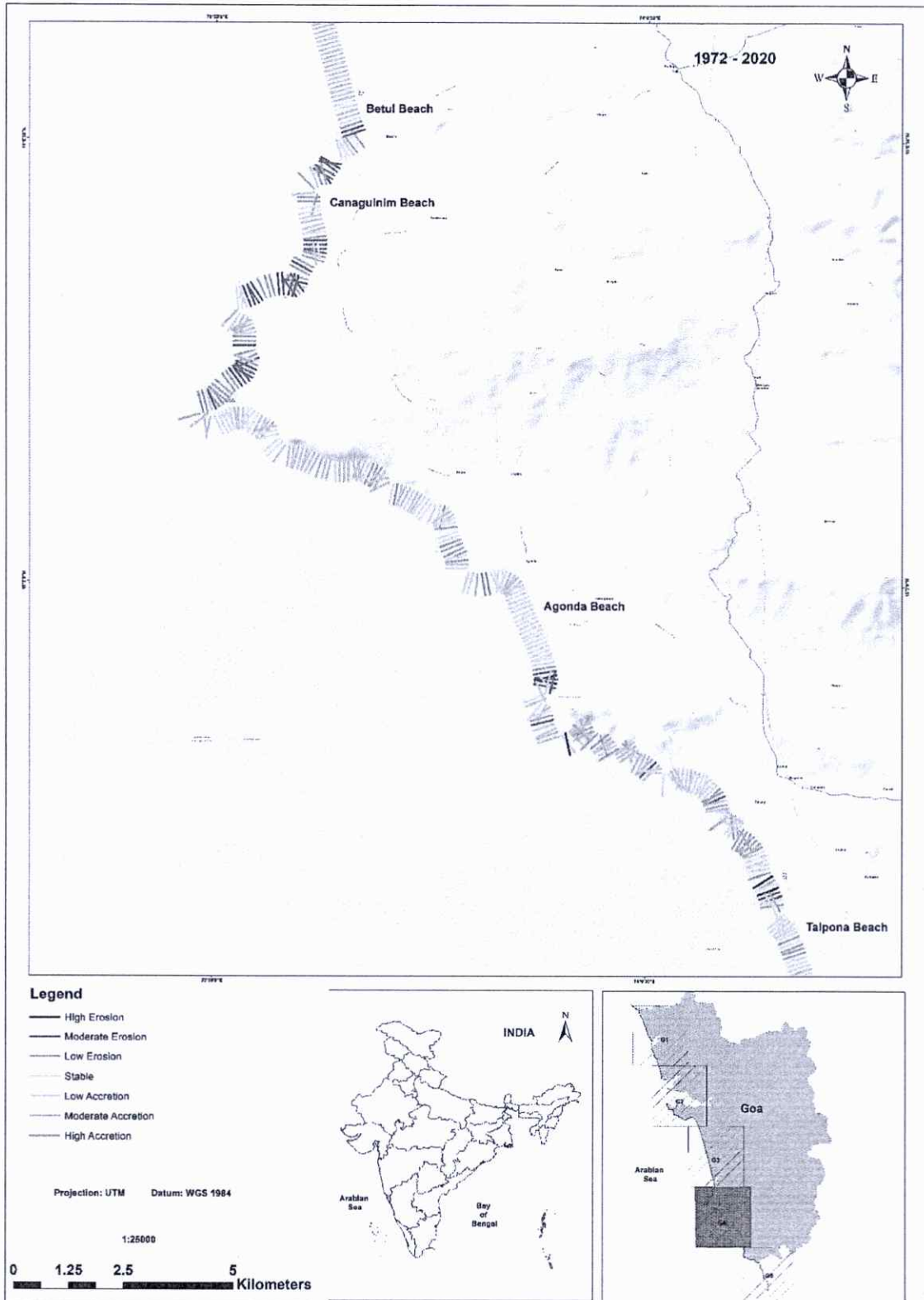


Figure 6-39: Shoreline change map of Segment G5 & G6 from 1972-2020

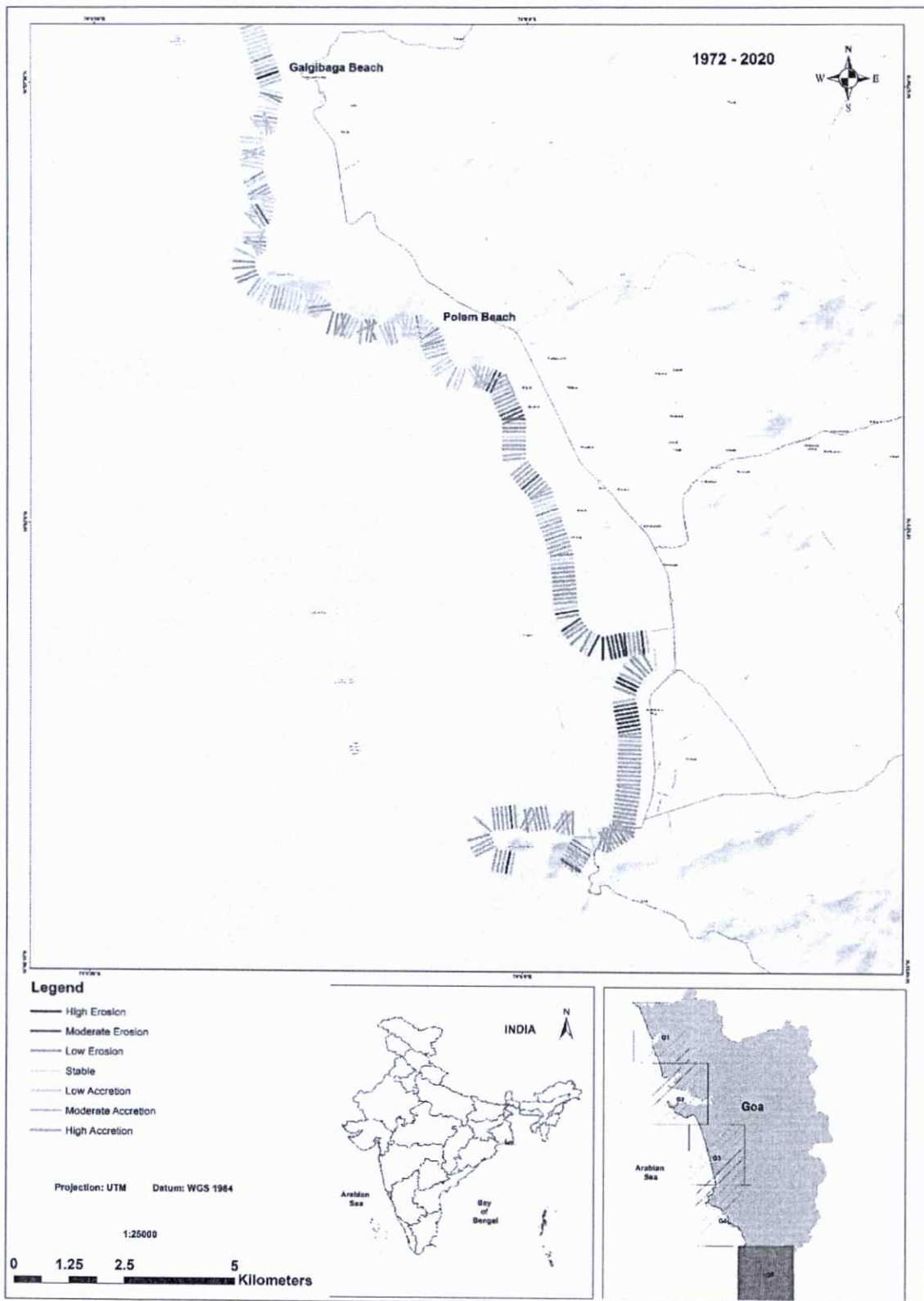


Figure 6-40: Shoreline change map of Segment G7 from 1972-2020



Table 6-2: Erosion and accretion spots since 1972 to 2020 along Goa coast

	1972-1980	1980-1990	1990-2000	2000-2010	2010-2020	1972-2020
Erosion Spots	Tiracol, Arambol, Calangute, Candolim, Velaso to Cansoulim, Colva to Benaulim, Cavelossim, Mobor to Agonda, Talpona to Polem	Tiracol, Vagator, Bogmalo to Cansoulim, Mobor, Betul, Agonda to Talpona	Tiracol, Miramar, Canaguini to Galgibaga	Tiracol, Vagator, Anjuna to Calangute, Condolim, Dona Paula, Bogmalo to Cansoulim, Betalbatim to Mobor	Tiracol, Vagator, Anjuna, Miramar, Benaulim to Varca, Mobor, Agonda to Polem	Tiracol, Vagator, Anjuna, Miramar, Mobor, Betul, Agonda, Palolem, Polem

The percentage of the coast facing erosion, accretion and stable derived from the present study has been compared with the results from the reports of SAC-ISRO 2014 and NCCR 2018 and presented in Table 6-3 and Table 6-4.

Table 6-3: Comparison of percent of erosion, accretion and stable coast of Goa

S.No.	Reports	Years of the data used	Erosion (%)	Accretion (%)	Stable Coast (%)
1.	SAC-ISRO (2014)	HWL 1989-91 and HWL 2004-06	17.40	30.20	52.40
2.	NCCR (2018)	Landsat, Liss 4 data (1990-2016)	12.00	20.00	68.00
3.	NIOT (Present study)	Landsat, Sentinel, Liss 4 data	12.50	20.10	67.40

From the Figure 6-5 to Figure 6-40 and Table 6-2, the erosion hotspots along Goa coast have been identified as Tiracol, Chapora, Vagator, Anjuna, Calangute, Candolim, Miramar, Cavelossim, Betul, Agonda, Palolem, Talpona and Polem. It can be noted that few stretches along the Goa coast have undergone changes in

erosion/accretion characteristics by implementation of various shore protection measures resulting in moderate erosion or stable shorelines.

Table 6-4: Comparison of erosion spots of Goa from various reports

S.No.	Institutes/ Organization	Erosion spots
1.	SAC-ISRO (2014)	Keri, north of the Chapora River, Coco beach, south of Shinken, Dona Paola, Betalbatim, between Kolva and Majorda, South of Betul, up to Kanagini and between Parven to Agonda
2.	NCCR (2018)	Keri, Vagator, southern part of Calangute, Mandrem to Mornjim, Candolim, Palolem, Talpona, Galgibaga and Varca to Cavelossim
3.	NIOT (2020-0-21)	Tiracol/Keri, Chapora, Vagator, Anjuna, Calangute, Candolim, Miramar, Cavelossium, Betul, Agonda, Palolem, Talpona and Polem

The erosion and accretion rates at selected locations for the period 1972 to 2020 has been listed in Figure 6-5.



Table 6-5: Rate of accretion and erosion (m/year) at various locations along Goa from 1972 to 2020

	Tiracol	Chapora	Vagator	Anjuna	Calangute	Candolim	Miramar	Cavlossim	Betul	Agonda	Palolem	Talpona	Polem
1972-73	-16.6	-23.5	-29.3	-16.5	38.0	-19.5	-57.4	63.6	-79.2	59.5	-3.6	8.4	-24.3
1973-75	32.7	15.7	38.7	17.7	12.2	-101.7	-5.6	29.4	-3.5	45.6	-32.2	-103.1	4.1
1975-76	31.2	-20.6	-45.8	-66.8	-56.9	142.7	-17.3	-19.2	-15.1	-92.3	14.1	145.6	34.5
1976-77	14.5	33.6	36.6	54.6	-15.6	-55.9	43.2	50.1	79.4	-0.9	14.7	-126.3	-63.8
1977-78	-26.1	70.5	6.6	21.7	79.0	13.8	30.1	-84.0	0.5	-39.6	0.0	95.5	9.3
1978-80	-7.8	-35.1	-12.6	-29.0	-48.4	-32.3	-23.1	10.3	-45.9	24.4	-12.8	-19.3	2.5
1980-90	-9.1	-31.1	-3.8	-19.7	6.9	-20.4	-6.3	-2.5	-54.6	13.7	-9.5	-42.7	5.1
1990-91	95.8	-22.3	0.3	9.4	1.4	35.6	2.5	-5.3	5.3	-14.6	-6.5	17.7	8.6
1991-92	-21.5	1.5	-1.3	-6.2	-6.5	23.9	-8.8	-4.4	17.8	-11.8	5.7	-21.6	9.6
1992-93	14.0	16.6	4.2	-8.2	-10.2	10.5	6.1	-5.5	2.7	26.0	-7.5	-46.5	-18.3
1993-94	-72.2	12.6	34.1	27.0	19.2	-44.7	4.3	-1.2	3.5	-6.5	15.6	43.6	-2.1
1994-95	63.0	-31.8	-28.6	-11.0	-16.6	18.2	-9.8	-4.1	-19.3	18.3	-1.7	6.4	3.8
1995-96	-21.6	-11.9	-25.4	-15.0	-4.5	-65.1	11.1	25.1	21.4	-33.0	-8.4	-87.2	19.4
1996-97	2.2	62.0	32.7	18.0	26.3	21.0	-8.6	-21.6	-27.0	10.6	-0.8	38.1	-17.5
1997-98	-33.0	-13.4	-13.0	11.8	-11.1	34.1	6.4	4.6	4.4	-7.8	-3.5	38.8	-30.0
1998-99	-4.5	-28.4	-4.1	3.2	-18.5	6.5	7.4	-26.2	4.7	2.1	16.2	66.8	32.2
1999-00	-11.1	-12.2	-1.5	6.2	20.6	-40.0	-22.8	25.5	22.0	1.9	10.3	-120.5	3.7
2000-01	64.2	7.5	8.6	-14.4	1.3	76.2	15.0	28.1	0.8	19.5	-28.2	50.9	-28.3
2001-02	-72.3	6.9	26.5	-3.8	13.6	-24.7	-8.2	-40.2	-3.9	-23.4	12.9	7.0	9.0
2002-03	4.4	6.6	-74.0	-4.8	-46.9	-33.6	1.7	3.4	-5.7	10.4	4.2	16.3	8.9
2003-08	-10.9	-10.3	6.6	-17.8	23.0	31.0	-8.7	10.9	-6.2	-12.3	-7.7	-13.0	-4.9
2008-10	-4.7	-3.1	8.9	22.5	4.6	0.7	6.9	-5.3	-4.0	13.1	3.1	18.9	-6.8
2010-11	-27.5	-8.1	21.2	-13.8	18.3	6.1	3.7	11.2	17.9	11.9	15.7	27.5	3.5
2011-12	-19.6	-22.3	14.8	-3.8	10.7	18.5	10.4	-9.4	-3.9	-13.6	-7.1	-4.4	5.4
2012-13	-56.8	43.6	-0.6	-6.8	-37.7	0.8	9.0	-12.2	-3.1	0.7	14.9	-64.0	3.4
2013-14	138.3	2.2	-11.7	10.7	20.9	18.3	-25.8	5.3	14.2	4.6	-16.3	-9.1	3.7
2014-15	-104.5	-25.1	-7.9	-12.7	20.2	6.3	7.2	-4.8	-8.8	-22.6	-1.3	130.1	15.8
2015-17	94.3	-11.0	24.9	2.9	-29.9	-44.5	5.2	25.2	6.4	10.0	22.2	-80.3	-34.8
2017-18	-31.7	-4.7	-15.5	-9.6	0.6	1.4	-18.3	-15.9	-25.9	12.8	-30.6	10.1	5.6
2018-19	-91.4	4.4	-10.8	-5.9	-19.2	-52.1	-15.3	-10.0	27.0	8.8	-13.1	-30.0	23.2
2019-20	48.4	-4.9	19.9	22.5	31.7	58.6		13.1	-16.3	-34.0	20.5	12.6	-62.1

+ve Accretion-ve Erosion

6.1 TREND ANALYSIS AT CRITICAL LOCATIONS

The shoreline trend analysis for the erosion locations along the Goa coast; Tiracol, Chapora, Vagator, Anjuna, Calangute, Candolim, Miramar, Cavelossim, Betul, Agonda, Palolem, Talpona and Polem are shown in Figure 6-42 to Figure 6-46. The trend analysis of the shoreline position from the baseline has been indicated for the period from 1972 to 2020 along with decadal trends for the period 1972-1980, 1981-1990, 1991-2000, 2001-2010 and 2011-2020.

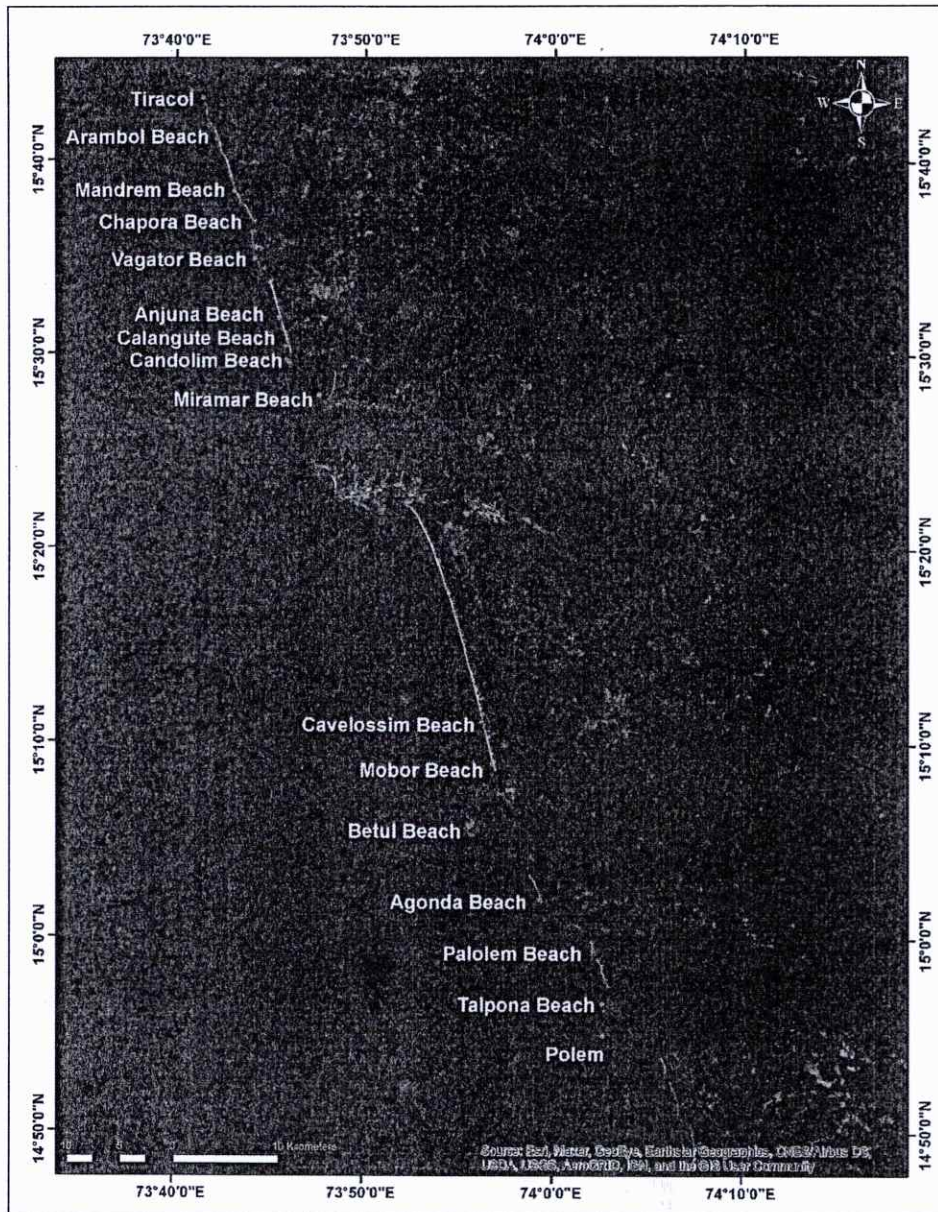


Figure 6-41: Location of Erosion hot spots where trend analysis is carried out

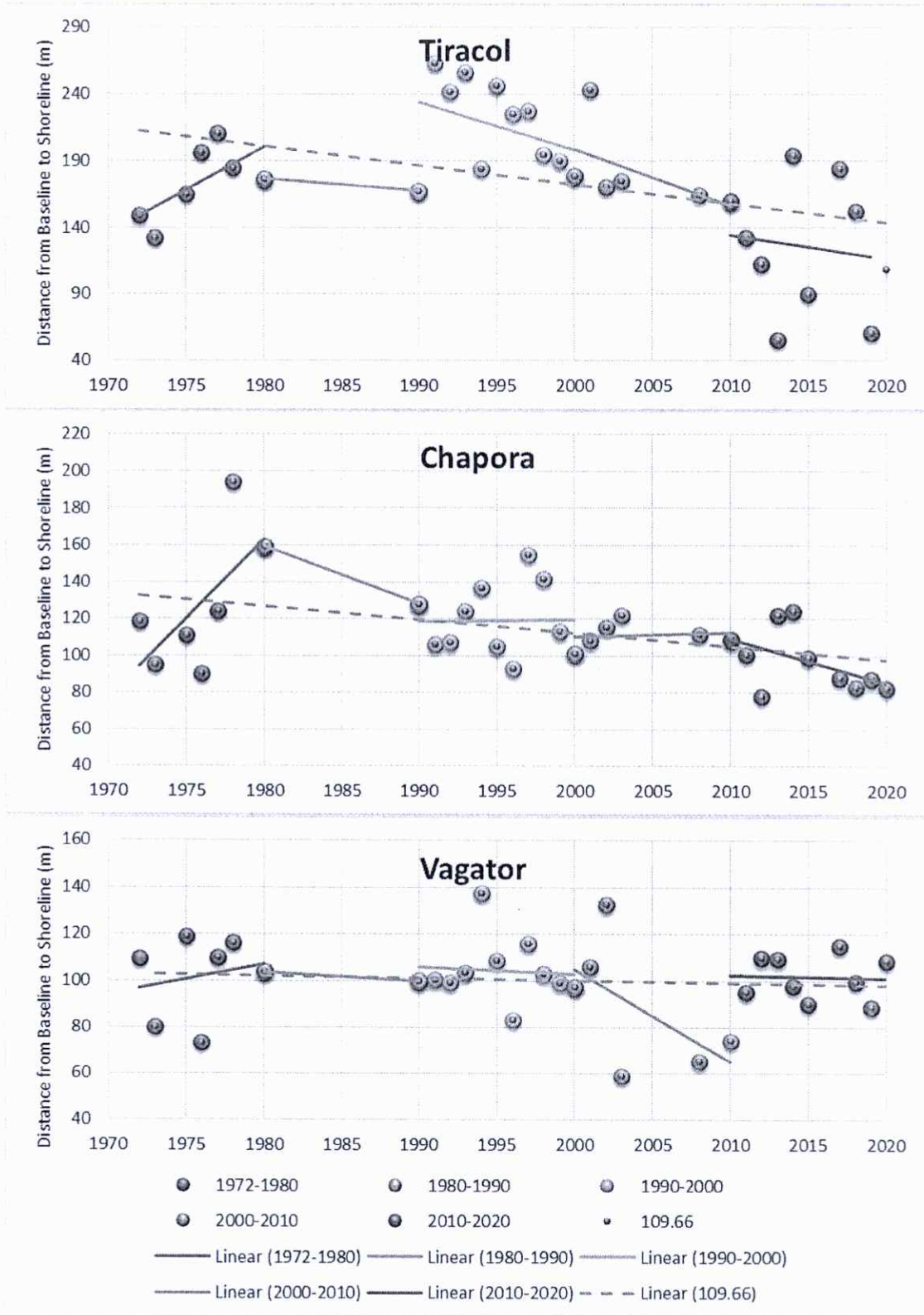


Figure 6-42: Shoreline change at Tiracol, Chapora, and Vagator from 1972-2020

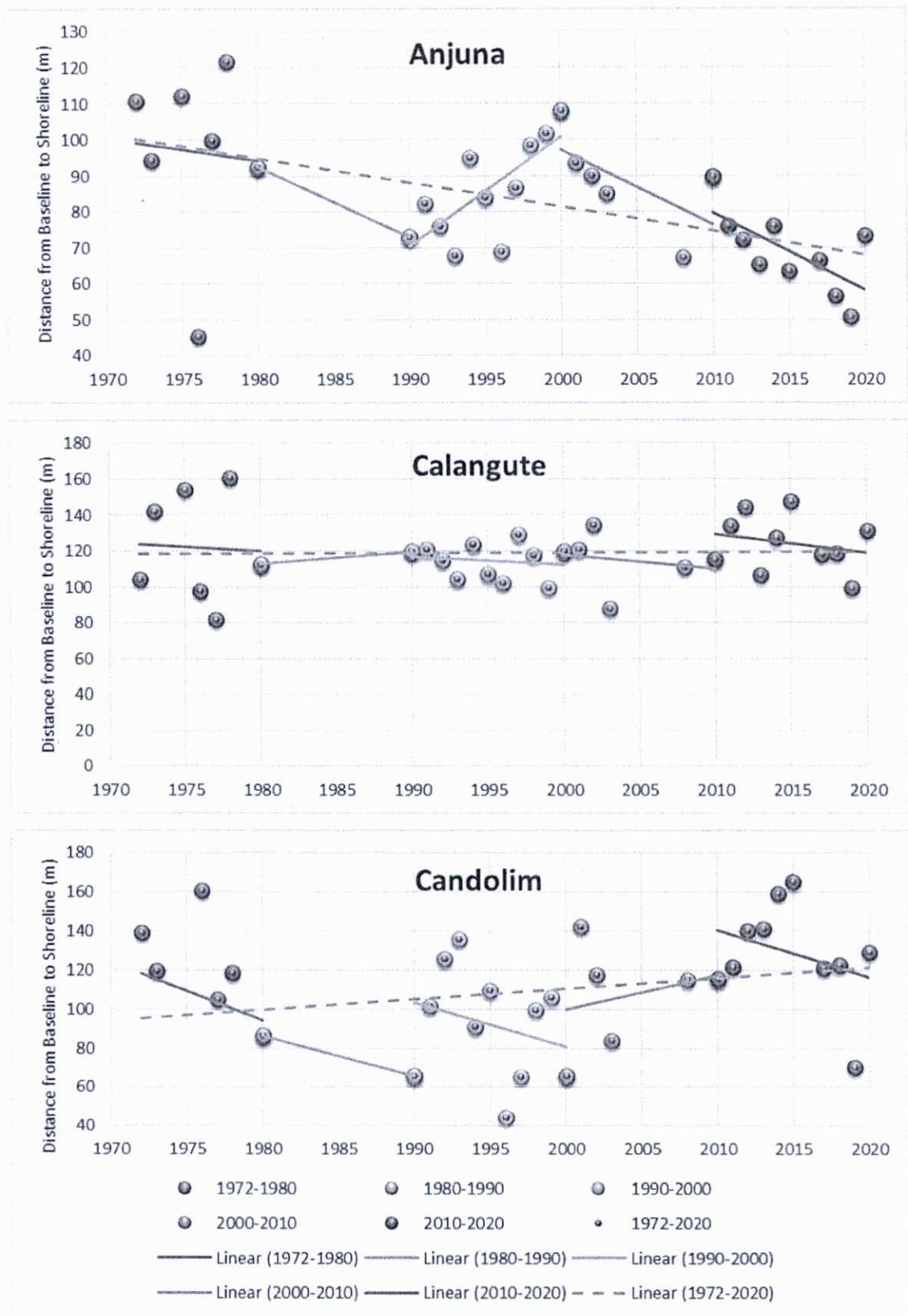


Figure 6-43: Shoreline change at Anjuna, Calangute, and Candolim from 1972-2020

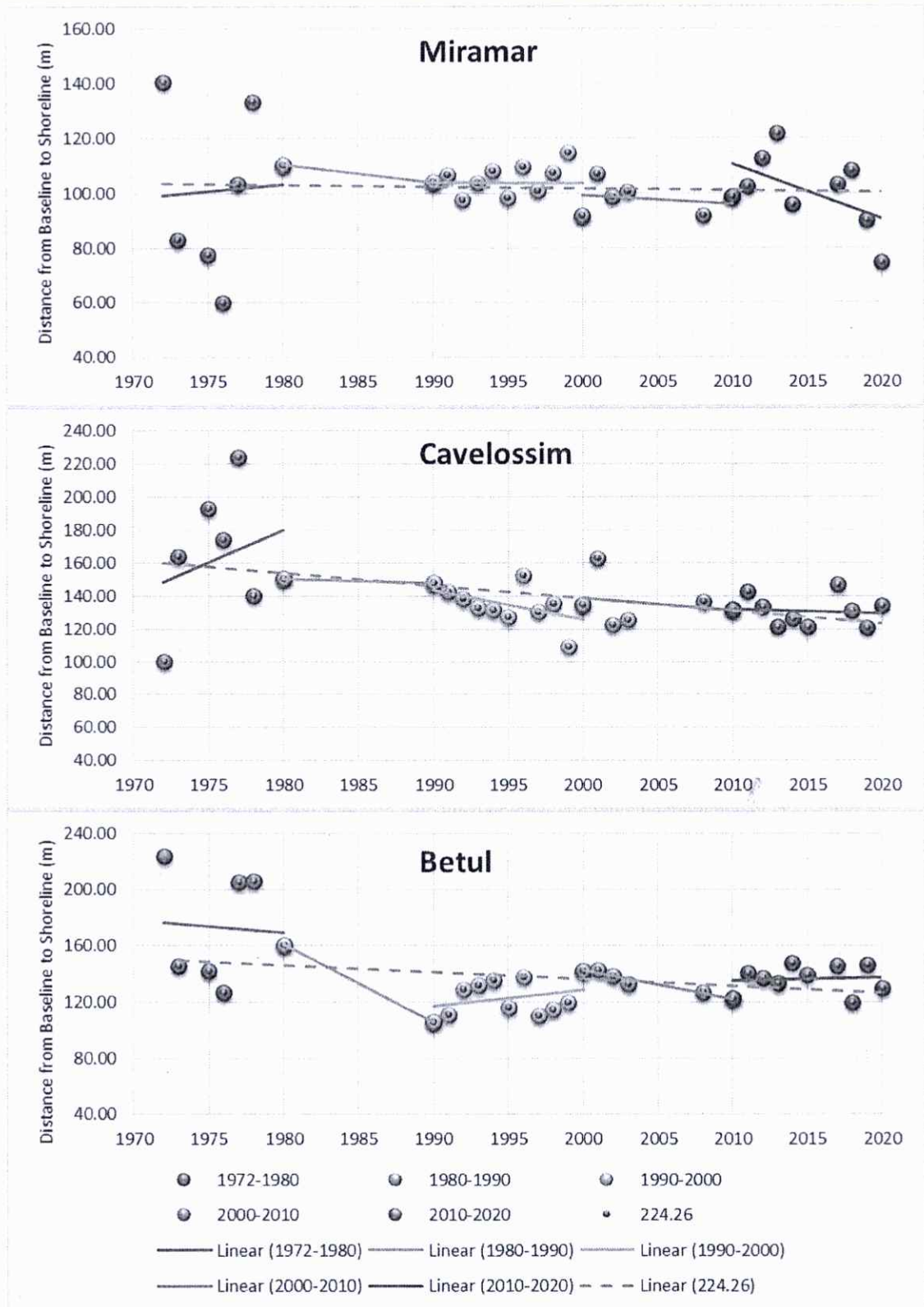


Figure 6-44: Shoreline change at Miramar, Cavelossim, and Betul from 1972-2020

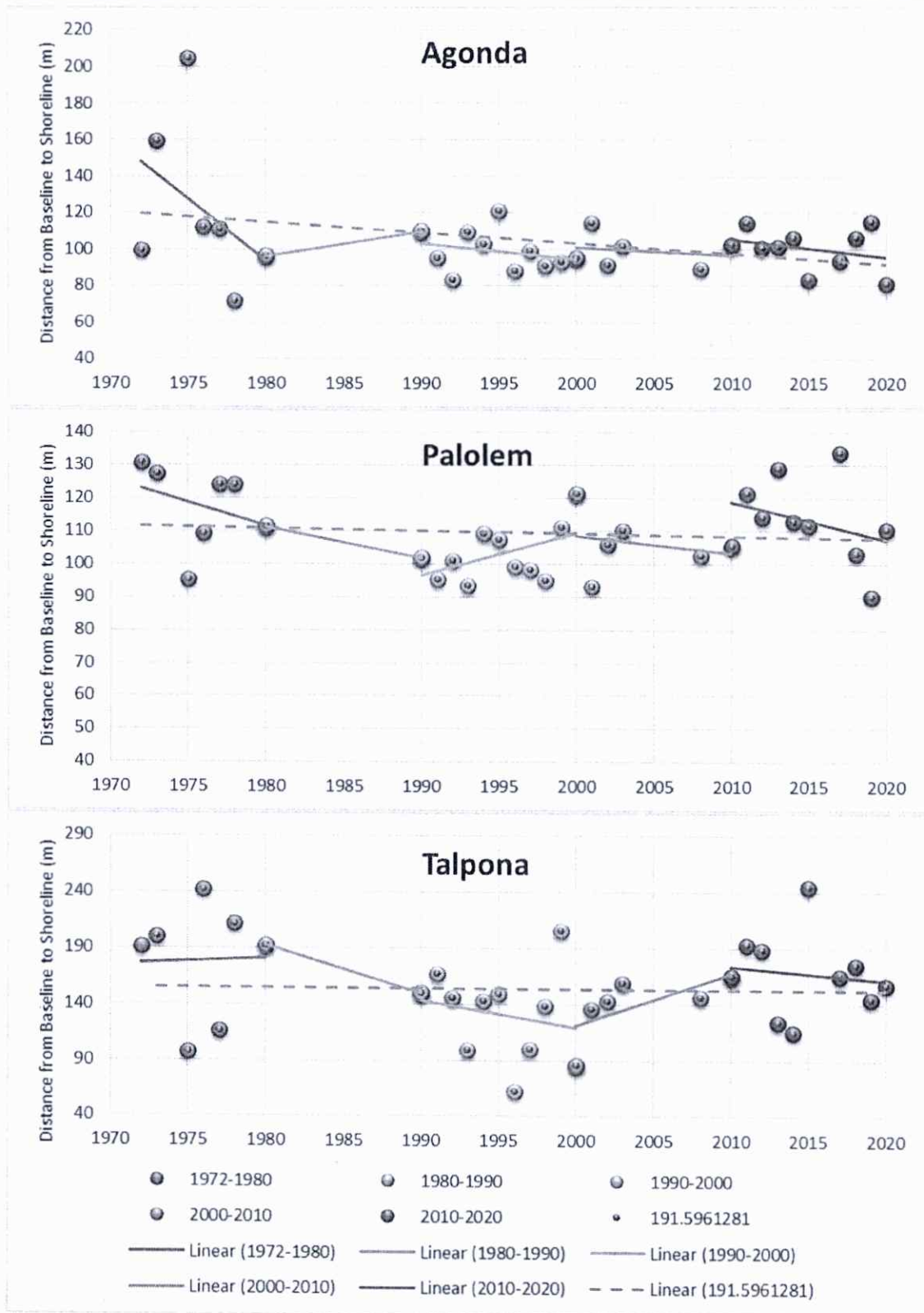


Figure 6-45: Shoreline change at Agonda, Palolem and Talpona from 1972-2020

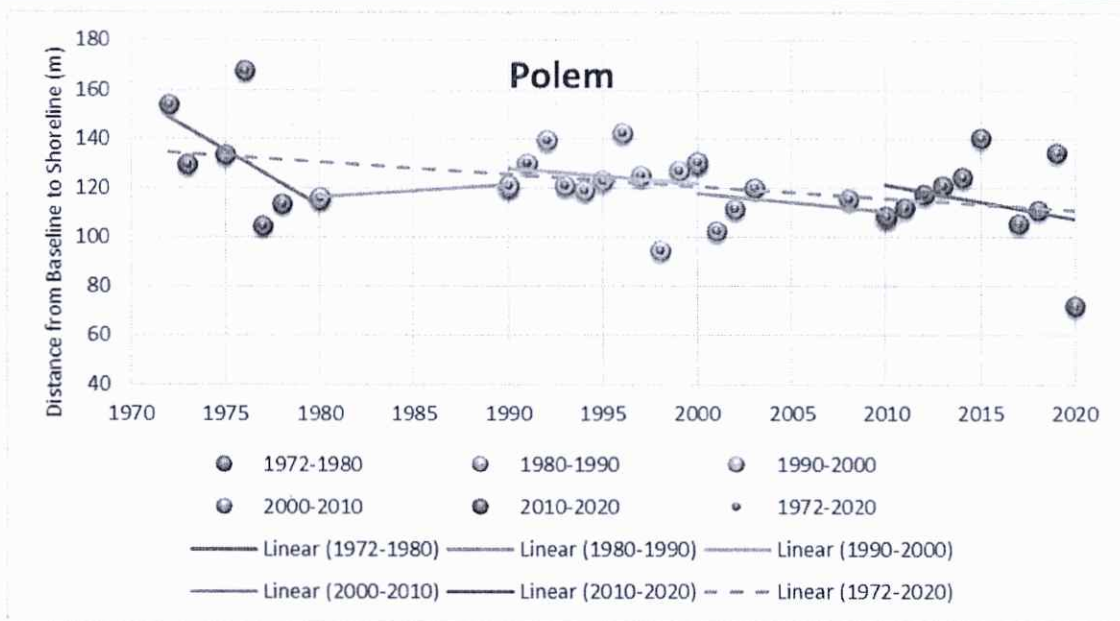


Figure 6-46: Shoreline change at Polem from 1972-2020

The shoreline position to the baseline is high when compared to previous year indicates accretion while the shoreline position to the baseline is low indicates the erosion. From the trend analysis of the erosion and accretion hotspots, it can be noted that the period from 1990-2001 has been showing the accreting trend in both erosion and accretion hotspots. With the high resolution satellite images of 5m from 2010 to 2020, the shoreline position has been precisely digitized and the erosion spots indicates eroding trend and the accretion spots indicate accreting trend except Arambol.

7 CATCHMENT AREA ANALYSIS:

7.1 METHODOLOGY

The catchment area of River Mandovi and River Zuari for the years 2000, 2010, 2015 and 2020 shown in Figure 7-1.

NIOT has followed the supervised classification method which includes the following categories viz, Water body, Vegetation, Plantation/ Agriculture, Mangroves, Mudflats, Barren and Urban for the years 1990, 2001, 2012 and 2020 using Landsat images of

30m and LISS IV images of 5m spatial resolution as per the level 1 classes in LU/LC by NRSC, ISRO. The land use/ land cover map from 1990 to 2020 has been shown in Figure 7-2 and Table 7-1 represents the area estimates of the land use/land cover classes in hectares for various categories viz, 1990-2001, 2001-2012, 2012-2020, 2012-2020 and 1973-2020.

From the results, it is observed that the urban and mangrove area have been increased and a bar chart representing the land use/land cover area is shown in Figure 7-3 and Figure 7-4.

7.2 CATCHMENT CHANGE MAPS

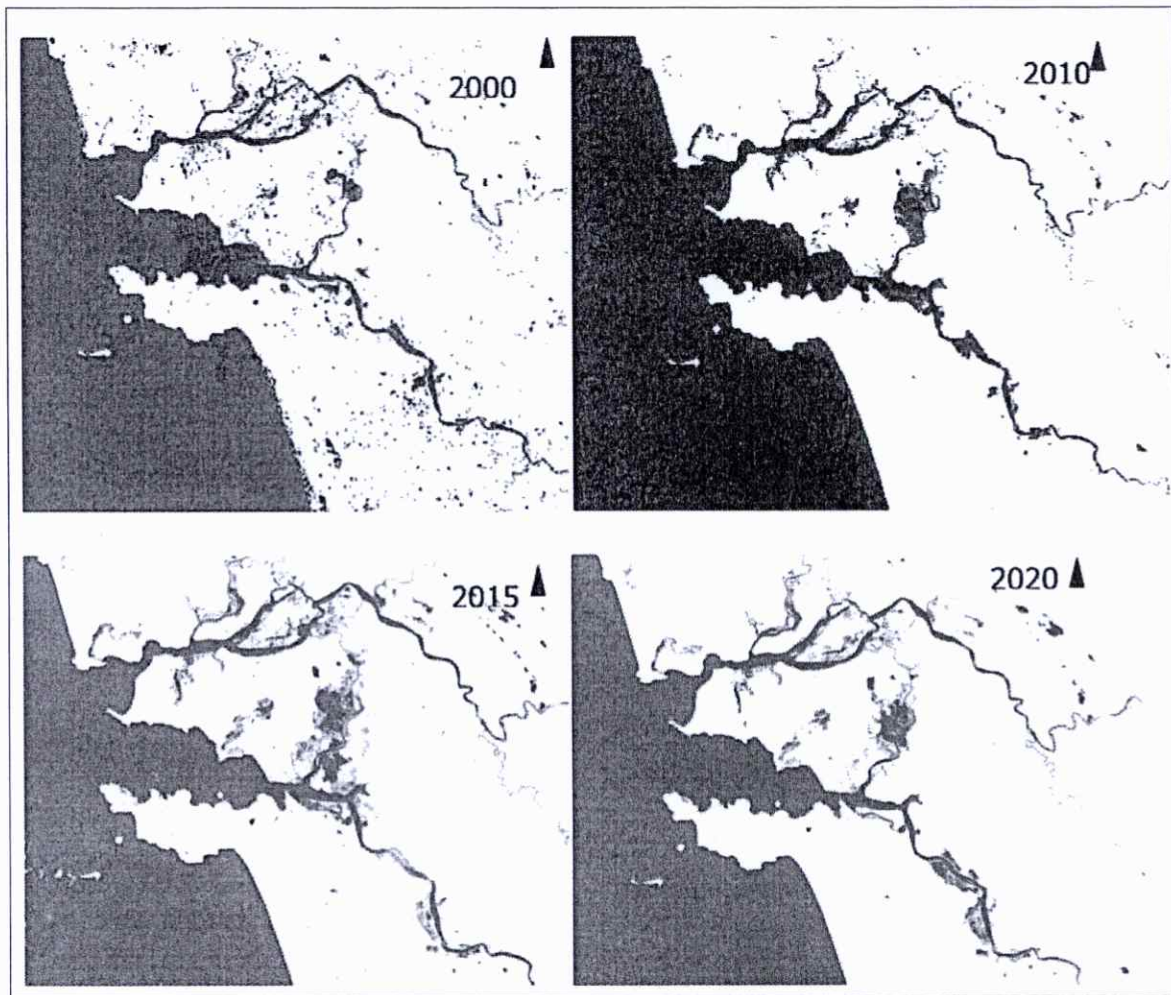


Figure 7-1: Catchment area of River Mandovi and River Zuari

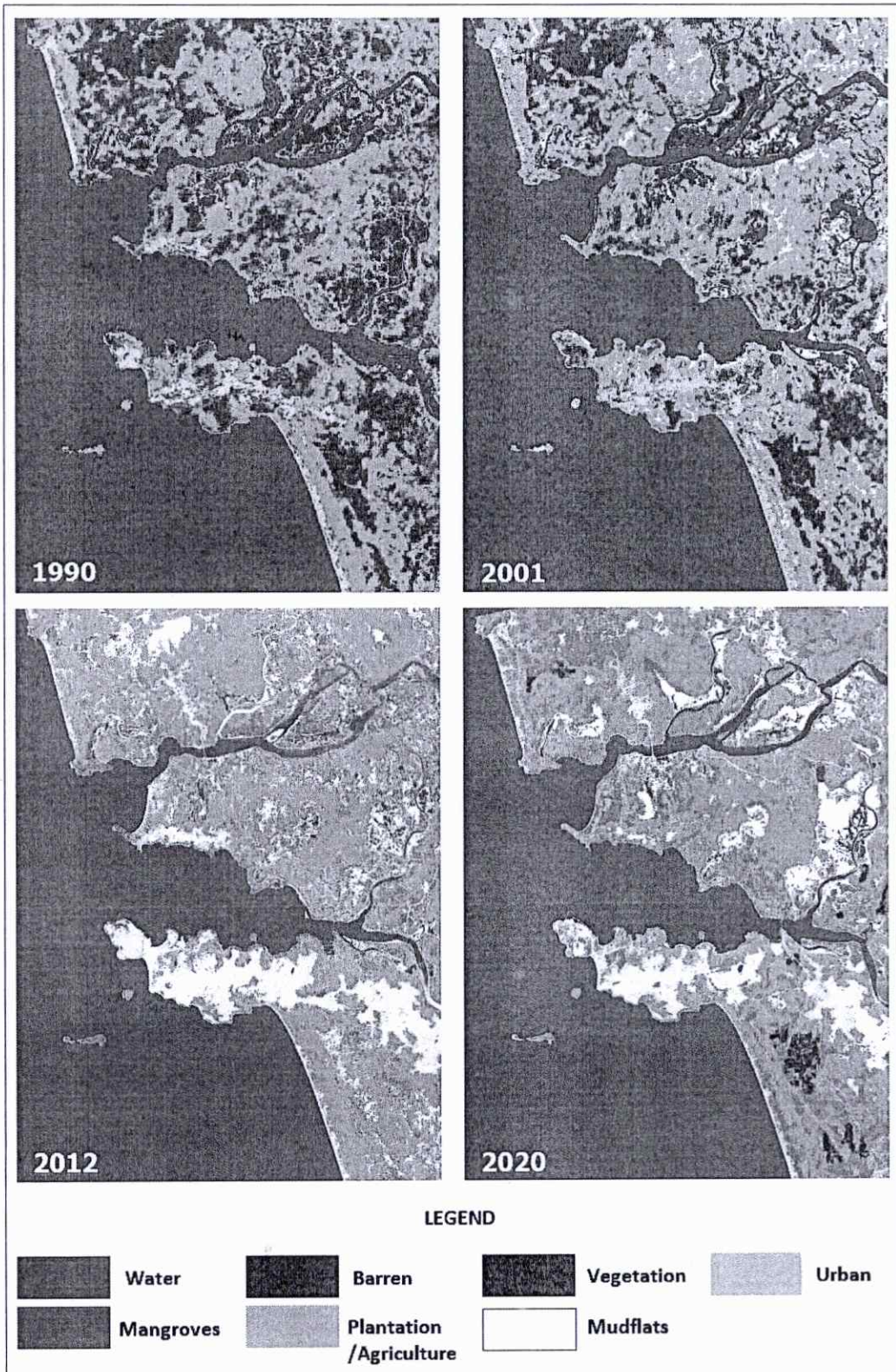


Figure 7-2: Land Use/ Land cover map from 1990 to 2020

Table 7-1: Area estimates for LU/LC classes in hectare and percentage change from 1990 to 2020

Class	1990	2001	2012	2020
Water	35276	35028	35288	35652
Mud/Tidal Flats	5932	5575	5275	4630
Mangroves	331	559	2269	2630
Barren	4554	3689	3236	3465
Urban	6689	7566	7869	8526
Plantation/Agriculture	11784	11964	11094	10150
Vegetation	14598	14783	14134	14111

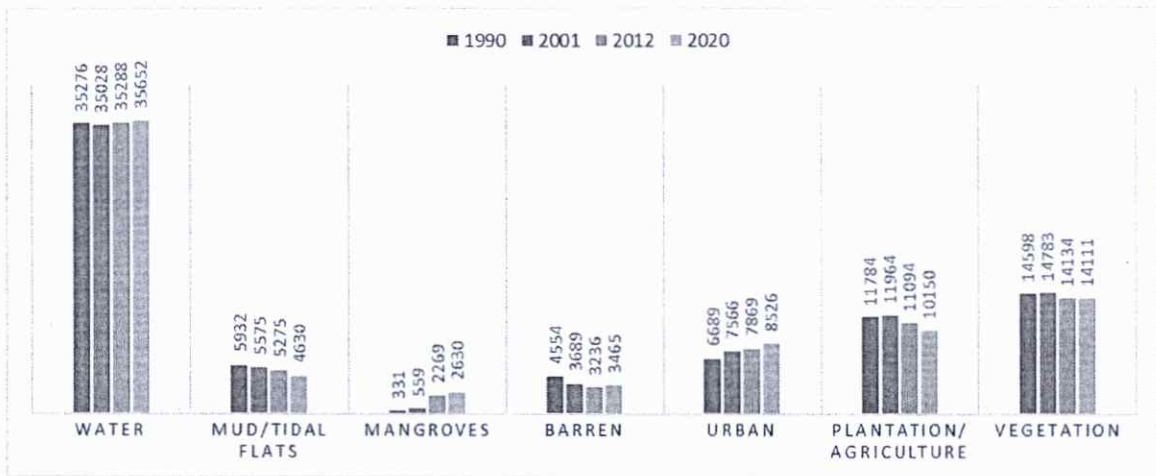


Figure 7-3: Area of LU/LC classes in hectare 1990 to 2020

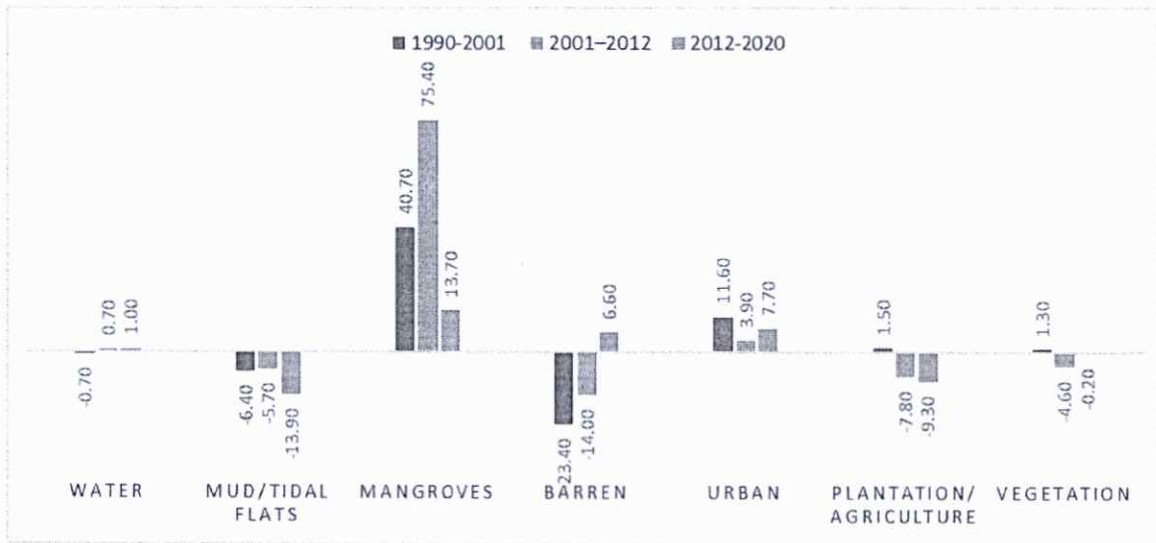


Figure 7-4: Land use land cover variation (%) from 1990 to 2020



The mangrove cover reported in India state of forest reports (FSI) since 1989 has been compiled in Table 7-2. The present analysis shows a similar trend of mangrove cover from the LU/LC classification using latest satellite images for Goa.

Table 7-2: Area estimates for Mangrove cover in hectares

1987	1989	1991	1993	1995	1997	1999	2001	2005	2009	2011	2013	2015	2017	2019
0	300	300	300	300	500	500	500	1600	1700	2200	2200	2600	2600	2600

Source: India State of Forest Reports

8 CONCLUSIONS

The results of shoreline change analysis using available data sources from 1972 to 2020. The shoreline change analysis carried out by NIOT indicates 12.5% of the Goa coast is eroding, 20.1% of the coast is accreting and 67.4% is stable. According to Space Application Centre (SAC) 2016 report by comparing the High Water Line (HWL) 1989-91 and HWL 2004-06, 17.40% of the coast faced erosion 30.20% of the coast faced accretion and 52.40% has been stable. As per National Centre for Coastal Research (NCCR), 2018 report, 12% of the coast is facing erosion, 20% of the coast is facing accretion and 68% of the coast remains stable along Goa coast.

The erosion spots along Goa coast have been identified as Tiracol, Chapora, Vagator, Anjuna, Calangute, Candolim, Miramar, Cavelossim, Betul, Agonda, Palolem, Talpona and Polem from the shoreline change analysis for the period from 1972 to 2020. The results have also been compared with the available reports on shoreline change analysis for Goa coast prepared by SAC-ISRO 2014 and NCCR 2018. The 3 hotspot areas will be identified based on the Government of Goa priorities considering the livelihood of the local communities, existing infrastructure and tourism etc.

The land use/ land cover changes for the years 1990, 2001, 2012 and 2020 has been analyzed. From the catchment characterization, it is observed that, the urban and mangrove area have been increased since 1990.

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