EROSION MAPPING OF THE COASTLINE OF BALOUCHISTAN AND WESTERN SINDH

FINAL YEAR PROJECT UG 2012

By

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CERTIFICATE

Certified that the contents and form of Final Year Project entitled **“Erosion mapping of the coastline of Balouchistan and western Sindh”** submitted by Ammar Jan and Kamil Khan have been found satisfactory for the requirement of the degree.

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Designation: _________________________

ABSTRACT

Erosion of the coastline is a common phenomenon, the battle between the sea and land is known to humans since ancient times. Unfortunately, with rising human population along the major coastlines of the world due to socio-economic reasons, an increase in the rate of erosion has been observed. And now as much as 70% of the world's coastline are reported to be going through erosion. This high trend can also be attributed to climate change leading to an unusual rate of erosion that is now threatening to vanish coastlines and important ecosystems. With Balouchistan, previously ignored by the government set to go through rapid change with the upcoming China Pakistan economic corridor (CPEC) project, a need for a detailed scientific assessment of the rate of erosion was direly needed. Physical on ground surveys for estimation of erosion is a laborious, capital intensive and a time consuming work, hence modern GIS techniques come into play. This study "erosion mapping of the coastline of Balouchistan and western Sindh" employs the Digital shoreline analysis system (DSAS), a toolbox developed by the United States Geological Survey (USGS). It has already proved its worth and accuracy in worldwide coastal erosion studies, with a number of research articles published to prove it. The approach to this study is fair and simple, starting with Landsat imagery for a duration of 2000-2010-2015, atmospherically corrected using S6 algorithm to the actual digitization and analysis by DSAS means the results can be duplicated easily by any interested researcher as it will be discussed in detail in this study.

The geology of the western coastline has a direct relationship withe trends of erosion, such as the case of Jiwani and Gwadar and Ormara. The hammer head formations at Gwadar and Ormara and the cliff of Jiwani are rock and rough areas which are in nature more prone to erosion due to the lashing waves. The least amount of change in the Hub and Karachi area is suggestive of the flow of Hub River dividing Balochistan and Sindh. The regular flow of sediments keeps the rapid erosion in check in the Hub region.

ACKNOWLEDGEMENTS

We would like to show gratitude to Almighty Allah for giving us knowledge, power and strength to accomplish this task. We learnt a lot while doing this project and this will certainly help us in our forth coming life.

We thank our supervisor Dr. Salman Atif, who went beyond the call of our duty in providing us the numerous detailed comments on technical and pedagogical matters. His supervision helped us a lot during the times of difficulties.

Kamil Marwat

Ammar Jan

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LIST OF ABBREVIATIONS

1	DSAS	Digital Shoreline Analysis System
2	USGS	United States Geological Survey
3	GPS	Global Positioning System
4	OLI	Operational Land Imager
5	TM	Thematic Mapper
6	RS	Remote Sensing
7	NSM	Net Shoreline Movement
8	EPR	End Point Rate
9	SCE	Shoreline Change Envelop
10	LRR	Linear Regression
11	WLR	Weighted Linear Regression
12	LMS	Least Median of Squares

CHAPTER 1

INTRODUCTION

1.1 Background

Coastal erosion refers to the weathering away of geological features along the coastline due to wind and water. It results in the gradual development of new landforms and alters the shape of the coastline over the course of time. There are several factors that determines the rate of the coastal erosion among which the waves breaking along the coastline has the most significant impact. The wind speed and fetch defines the strength of the wave. Waves with longer fetch and stronger winds has more erosive capability. Other factors that determine the nature of the erosion is the land structure, beaches reduces the impact a wave has before reaching the cliff of coastline. The weathering is another factor that adds to the process of erosion, weakening the rock which makes it more vulnerable. Like always, human activity too has an impact on the erosion along the coastline. In the wake of the climate change to assess the impact of ever rising sea temperature on the shoreline the historical study of the area can prove to be of significant importance.

1.2 Study Area

The Pakistani coastline is approximately 1046km in length, divided between the provinces of Balouchistan and Sindh. Sindh has long been of interest to researchers due to the Indus river delta and its changing morphology since the damming of river Indus up north, reducing the rate of sedimentation and threatening the biodiversity of many species and their ecosystem in the process.

This study intends to map the rate and extent of erosion taking place in all the major coastal towns of Balochistan. All these towns are located on the Makran belt of Balochistan, where a semi desert climate prevails. Summers are hot but balanced out by incoming winds from the sea, making human habitation possible as compared further inland.

The mapping of erosion along the coastline were carried out using ArcMap, with statistical analysis done using the DSAS tool. DSAS can be used to compute rate of change of any boundary over a period of time. Our data encompassing three timelines was well suited to this analysis.

1.2 Literature Review

A comprehensive study of the morphodymics of the Indus river delta incorporating multiple data sets ranging from pre-GIS 20th century maps to latest Landsat imagery. Also taking into account the sediment movement in the flow of the Indus river. (Liviu Giosan, Stefan Constantinescu, Peter D. Clift, Ali R. Tabrez 2006)

This paper uses the DSAS for quantifying the shoreline changes for the Kutubdia Island in Bangladesh. A total 65 km stretch of shoreline was studied in depth with WLR, LMS, EPR and LRR. (Md. Ashraful Islam, Md. Shakhawat Hossain1, Tanzeer Hasan and Sanzida Murshed 2014)

This paper discusses in depth the quantifying shoreline change at the Mediterranean coast in Turkey. The methods used in this paper were used by our study, excluding the higher level Landsat data which had to be purchased. (Tuncay Kuleli 2009)

CHAPTER 2

DATA AND METHODS

2.1 Data

NASA's Landsat program is the only complete global imagery dataset for more than 30 years. Making it perfect for many earth related studies. The images were hence downloaded freely by the USGS earthexplorer online service. Being a level 1 product, these images are already radiometrically and geometrically rectified. Geo rectification was done according to UTM 41 N. Data products were derived from the Landsat 5 TM and Landsat 8 OLI platforms. Further information is shown according to path/rows and time period in the next page.

Name	**Path/Row**	**Year/Month**
Landsat TM	(152-156)/(42-43)	2000-2010/March
Landsat OLI	(152-156)/(42-43)	2015/March

Table 1: Landsat timeline and paths/rows

The formats downloaded were in the GeoTiff format, essentially being ready to use ahead. No need further corrections are needed except atmospheric correction for removal of aerosol. This is described later in detail.

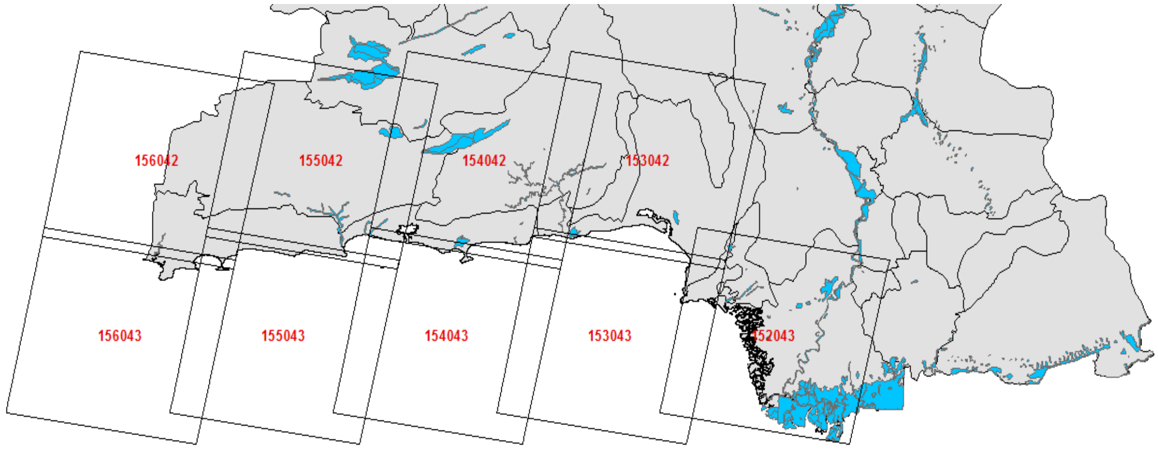


Figure 1: Landsat path/rows

2.2 Data processing

The satellite imagery was corrected atmospherically using a command line tool i.e. the Atmospheric and Radiometric Correction of Satellite Imagery (ARCSI). ARCSI provides automatic method of retrieving the atmospheric correction parameters and using them to parameterize 6S.

The following command line was used for batch processing of the Landsat TM satellite imagery.

```
arcsibuildcmdslist.py -s ls5tm -f KEA --stats -p RAD DOSAOTSGL SREF \

     --outpath ./LS5/Outputs --aeropro Maritime --atmospro Tropical \
     --dem /home/ubuntu/Documents/pk_mosaic.tif \
     --tmpath ./LS5/tmp --minaot 0.05 --maxaot 0.6 --simpledos \
 -i ./LS5/Inputs -e MTL.txt -o LS5ARCSICmds.sh
```

This single line of script (pg. 15) makes the tedious task of processing one single image at a time in a dedicated RS software such as ERDAS very simple and easy. A few single lines already scripted were the foundation of the overall image processing in this study.

Once the satellite imagery was atmospherically corrected, then the short-wave infrared band was extracted for all the scenes using the following script.

```
for i in *_srefdem.kea; do  gdal_translate -b 6 $i $(echo $i | cut
-d _ -f1,2,3,4)_b6.tif; done
```

The above script converts the .kea format obtained after atmospheric correction to the .tif format for ease of analysis in ArcMap. As .kea contains all the bands together in a single raster format, the band 6 (**b 6**) had to be specified for extraction and conversion to .tif format. This script is loop function, meaning all the datasets were extracted and converted in one simple go

The band for the two Landsat sensors that best differentiate between land and water bodies lies in the short-wave infrared range.

Landsat sensor	**Band**	**Wavelength (micrometers)**	**Resolution (meters)**
Thematic Mapper	Band 6	2.08-2.35	30
Operational land imager	Band 7	2.11-2.39	30

Table 2: Landsat bands

The following figure is the mosaicked image after extraction of bands and conversion to .tiff. This was done for the process of complete manual digitization by polyline of the coastline which will then be the basis of the DSAS analysis.

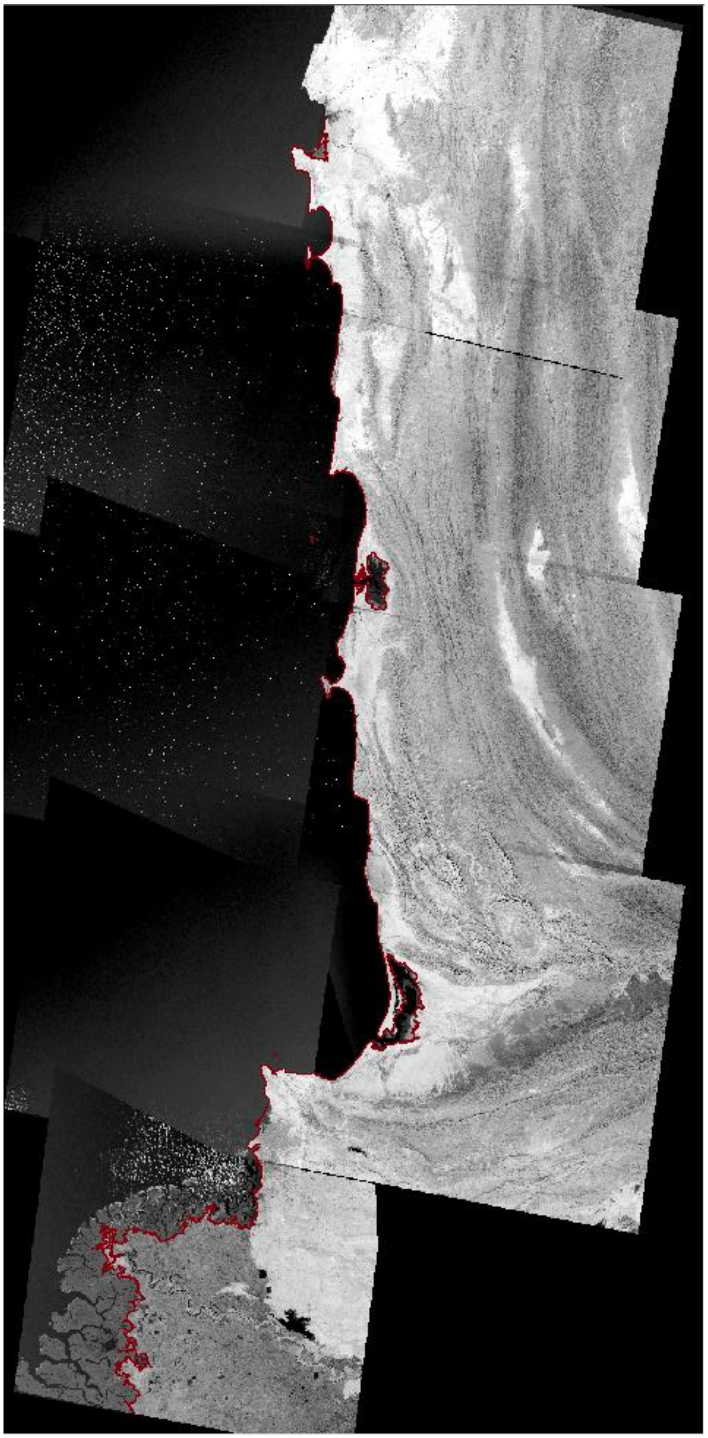


Figure2: Mosaic 2000 imagery with shoreline 2000 shapefile overlay

2.2 Post Processing

By using these mosaicked images, a simple polyline was then manually created. A tedious task, as the manual digitization required a keen eye for recent large scale manmade structures on the coast lines such as the Gwadar port or the Jinnah Naval Base at Ormara. These sites have to be excluded from the study due to them not accounting as a part of the natural coastline. An example of this exclusion is shown in the figures below. Also the resultant digitized coastlines show in an orderly way.

There is some noticeable breaks in the coastline polyline which are not entirely related to any man made feature but because they lie out of the scope of this study. Such features include backwater, lagoons and minor river tributary discharge areas (Hub river, Hingol river) and even some ever changing marshes (Buzi Makola).

Figure 3: 2000 coastline digitized

Figure 4: 2010 coastline digitized

Figure 5: 2015 coastline digitized

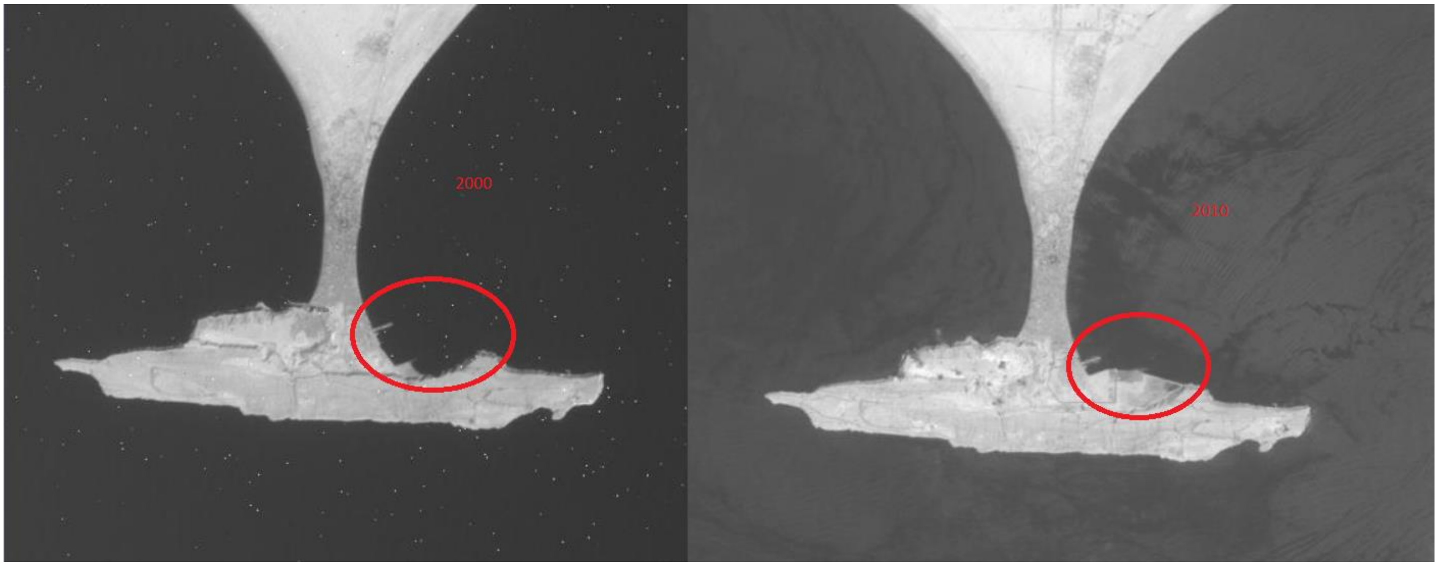


Figure 6: Gwadar port extension, exclusion of manmade coastal infrastructure in studies due to rapid development in the area

2.3 Analysis and DSAS methodology

This section provide detail procedure that we followed to collect the shoreline data and the necessary attribute fields in the shoreline feature class. The coastline data for 2000, 2010 and 2015 were appended to a single file and then imported to personal geodatabase within ArcCatalog. As per the requirement of DSAS the feature class was set to be in meter units in a projected coordinate system.

Each coastline polyline feature represent a specific position in time therefore it was assigned a date in the coastline feature class in attribute table (*Figure 7*).

Shoreline_Gadani

	FID	Shape *	Id	Date_
▶	0	Polyline	0	03/15/2000
	1	Polyline	0	03/15/2010
	2	Polyline	0	03/15/2015

Figure 7: Coastline polyline attribute

The month of March is also assigned as above to the coastlines, with respect to the images collected in this month. This ensures tidal changes are not interfering with the coastline change.

Transects generated by DSAS from baseline intersect coastline polyline feature. The points at which the transects intersect provide time and location information that is used to generate the rates of change. The distance from baseline to each point at which the transect and shoreline feature intersect are used to generate statistics.

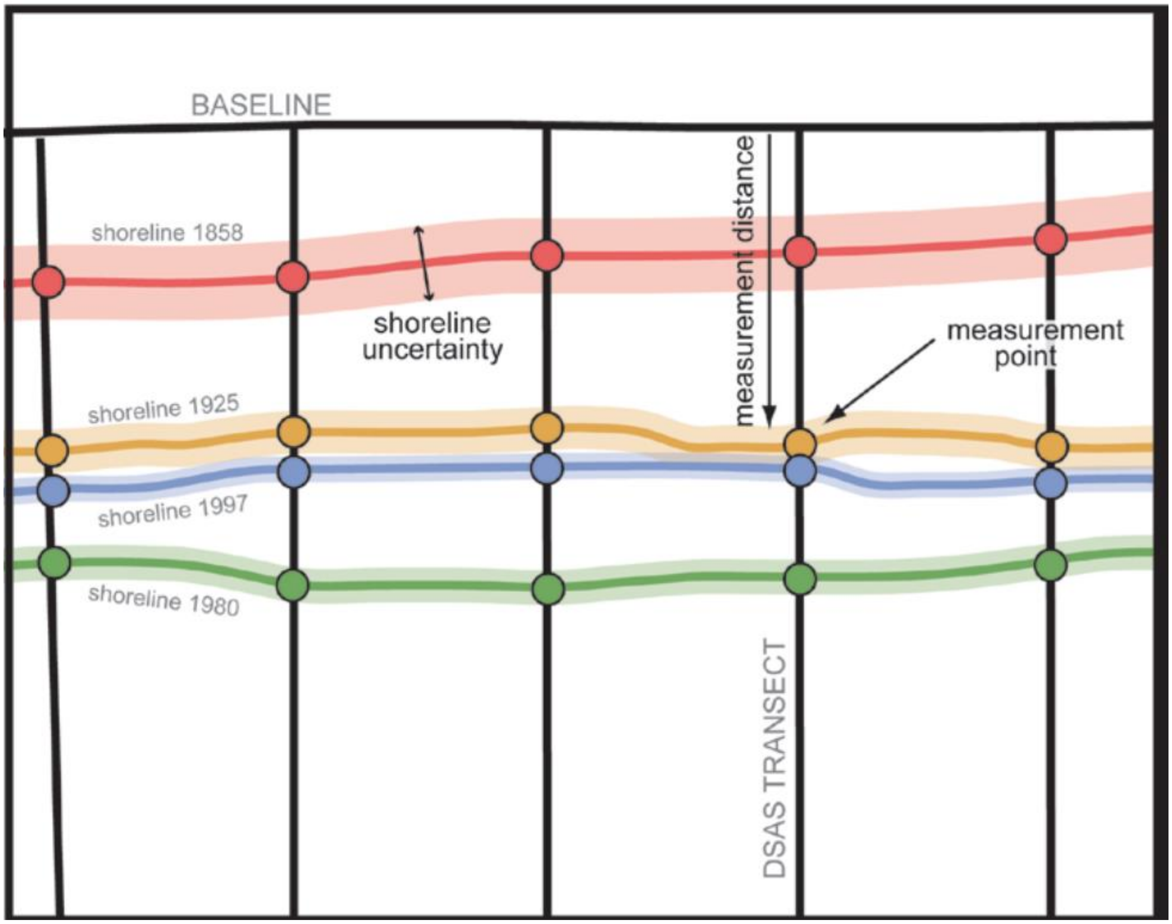


Figure 8: Baseline & transect relationship (Source: DSAS 4.3 tutorial)

The accuracy of the statistics generated by DSAS is limited to the accuracy of coastline data. Therefore to generate better results, we accounted for errors when creating each shoreline position by using the measurement tool in ArcMap to find the offset of digitization between different timelines with respect to the coastline.

The attribute table of shoreline followed for all the coastline polyline feature is as follows

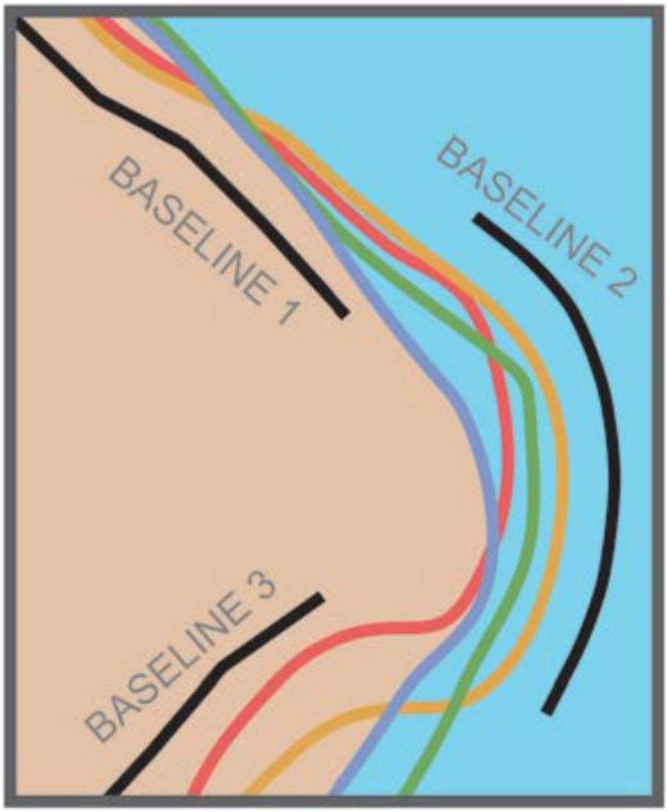
Field name	Data type	
FID	Object ID	Auto-generated
Shape	Geometry	Auto-generated
ID	Long integer	User-created
Date	Text	User-created (Length = 10)

Table 3: Coastline DSAS requirement

The fields described above were entered into our attribute table for the coastline. The empty fields are later filled in by the DSAS statistics.

Moving on, in this section the detailed procedure followed for creating baseline and the attribute field for baseline feature class is discussed. DSAS uses baseline to generate change statistics for time line of shorelines. The baseline is a reference line that is manually created by users.

A new line feature was created adjacent to the coastline polylines. Based on this baseline the DSAS automatically generate transects that is perpendicular to the baseline, at user defined spacing which is 50 meter for this study, and intersect shoreline at different points. The direction of the transect depends on the position of baseline. It's recommended to have the position for transects perpendicular to the trend of shoreline.



The baseline are of two types, it may be created seaward or landward of the coastlines, but each segment of the baseline should be placed with every shoreline to one side. The location of the baseline, offshore or onshore, is set by the user with respect to shoreline. The DSAS tool require the attributes be set correctly to generate rate of change in terms of erosion i.e. negative values and accretion i.e. positive values.

Figure 9: Offshore/onshore baselines (Source: DSAS 4.3 tutorial)

The attribute table for all the baseline created for this study are as follow:

Field name	**Data type**	
FID	Object ID	Auto-generated
Shape	Geometry	Auto-generated
ID	Long Integer	User-created
CastDir	Short Integer	User-created
OFFshore	Short Integer	User-created

Table 4: Coastline baseline DSAS requirement.

The OFFshore field is added to the attribute table of the baseline when it's required to specify if the baseline is landward or seaward. If the baseline is landward it's given a value of 0 and if the baseline is seaward it's given a value of 1.

In case the OFFshore field is added, another field called CastDir too is included. The CasDir determines the direction of transects generated to the baseline as reference. The value of 0 specifies transects are created to the left and value of 1 specifies transects are created to the right of the baseline.

Since we divided the study area, the same steps were followed for all and therefore for each segment of the Baluchistan coastline a separate personal geodatabase was created, in which the shoreline and baseline were imported as the parameters required by the DSAS tool to generate result.

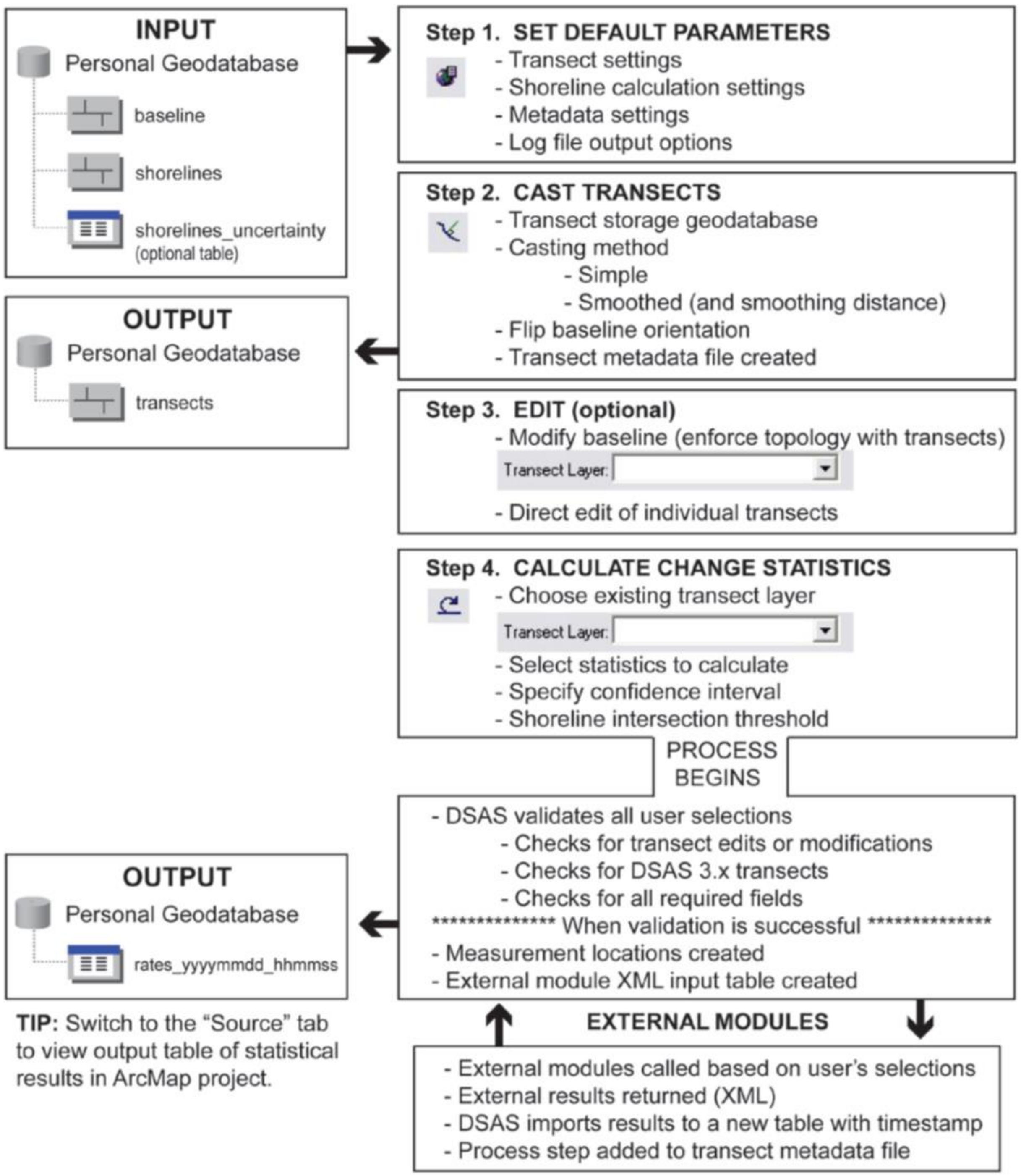


Figure 10: DSAS methodology workflow (Source: DSAS 4.3 tutorial)

With all this in mind, the DSAS toolbar was initialized to project transects on the baselines created earlier. The parameters for transect are discussed below:

- Transect Spacing: The desired space between transects is set in meters, for this study the transect spacing was set to 50m.
- Transect Length: The length of transects is subjective and can be determined by measuring the distance from baseline till the shoreline that lies farthest. For this study we set it to be 500m and 300m for different areas.
- Cast Direction: The cast direction was set to auto-detect.

Shoreline parameters:

- Shoreline Layer: The shoreline layer, in which all the shorelines are appended, that is to be used is selected within geodatabase.
- Date Field: The date field that contains the date of the shoreline is specified.
- Default Data Uncertainty: For this study the default data uncertainty was set to 6 meters.

Intersection Parameters:

- For this study we selected the Farthest Intersection which orders the DSAS tool to account the farthest transect and shoreline intersection point to calculate the change statistics.
- Once the default parameters were set the DSAS tool require storage parameters for transects.
- For storage, the geodatabase where the baseline and shoreline were stored was selected. The name was set to ‘transects’.
- For this study we used Smoothed Baseline Cast which orient transects along curved path of the baseline. The following figure illustrate the difference between simple cast and smoothed transect cast.

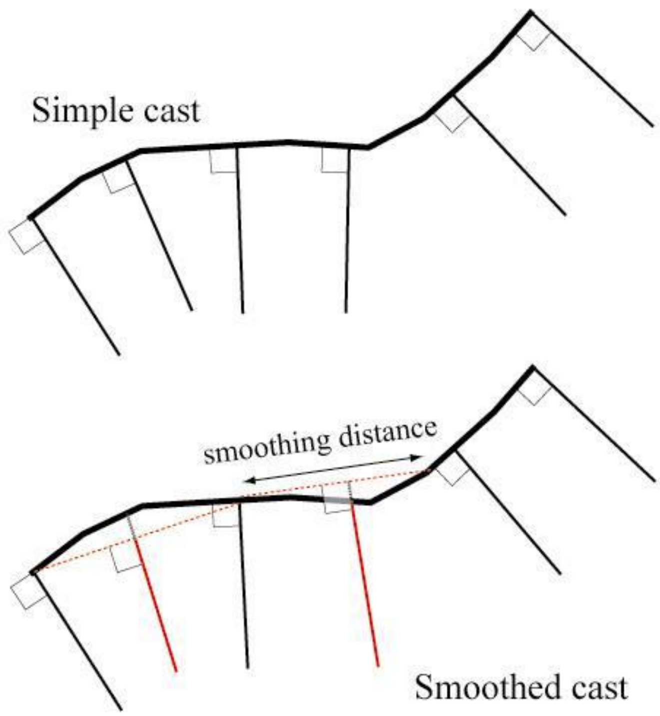


Figure 11: Simple vs Smoothed cast (Source: DSAS 4.3 tutorial)

Once the transects were generated, they were used to produce rates of change at shoreline based on measured differences between shoreline positions at different times, expressed as meters of change per year along the transects.

The DSAS compile the results in a table format. In this study, we calculated the following statistics.

- NSM Net Shoreline Movement
- SCE Shoreline Change Envelope
- EPR End Point Rate

Net shoreline movement (NSM)

As the name suggests net shoreline movement is the total distance between the oldest and the youngest shoreline that is decided upon the date field in the attribute table of the shoreline. Therefore its value is just the representation of distance and not a rate.

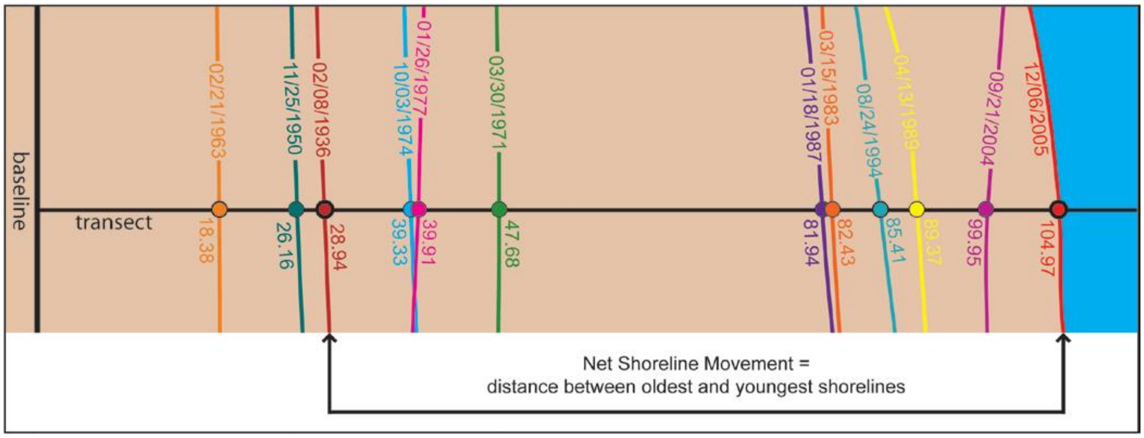


Figure 12: Net shoreline movement (Source: DSAS 4.3 tutorial)

Shoreline change envelope (SCE)

The shoreline change envelope is the value that represents the distance between the shoreline that lies at maximum distance and minimum distance to the baseline regardless of the date of the shoreline. Hence, SCE too is a value that represents a distance and not rate.

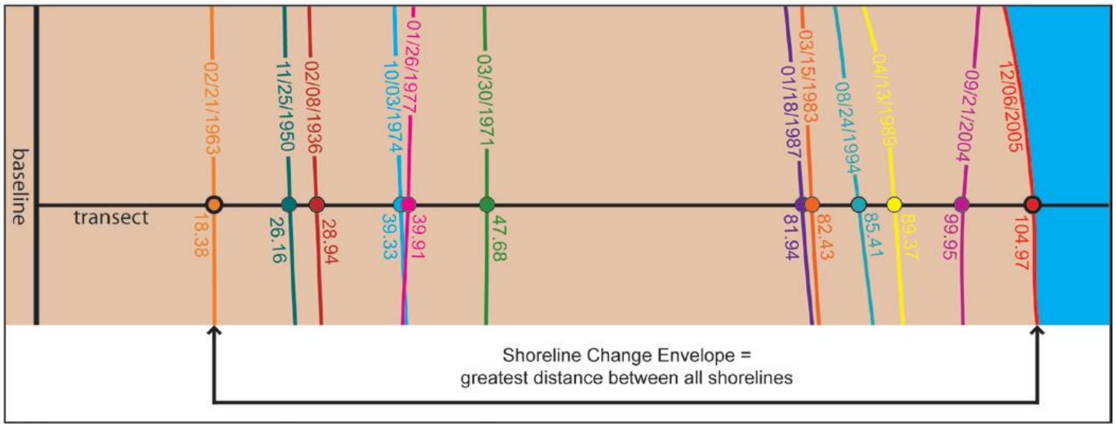


Figure 13: Shoreline change envelope (Source: DSAS 4.3 tutorial)

End point rate (EPR)

End point rate is the only rate that will be important for us for this study. It is the value that is obtained by dividing the distance between the oldest shoreline and the youngest shoreline based upon their dates, divided by the time elapsed between the oldest and the youngest shoreline.

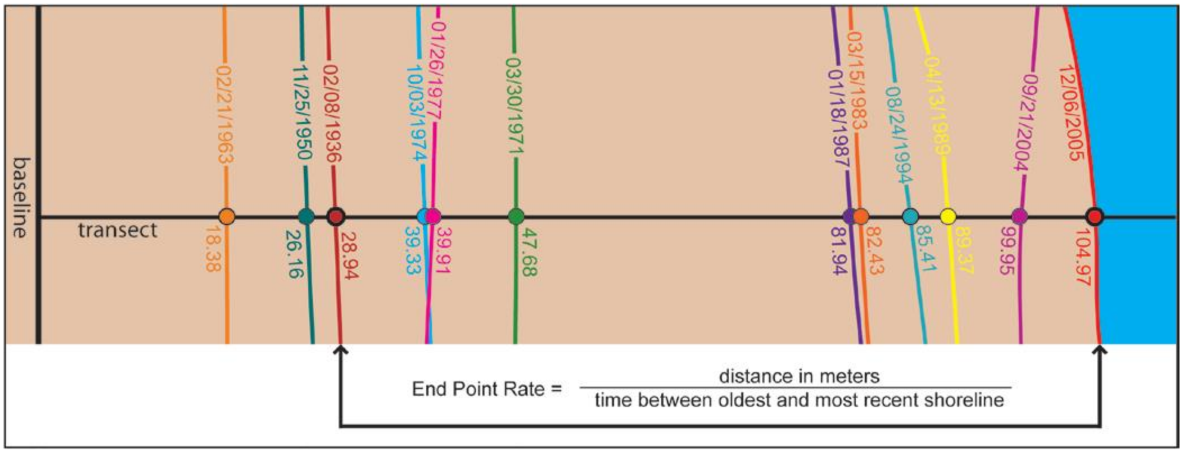


Figure 14: End point rate. (Source: DSAS 4.3 tutorial)

DSAS automatically process all the given parameters and generate results in form of values that is mentioned above. The results and statistics derived are discussed in the next chapter.

Chapter 3

RESULTS

3.1 Maps and statistics

As the DSAS methodology was applied to the coastline shapefile, the change in the coastline was derived in the form of EPR, SCE and NSM.

These terminologies have been discussed in the previous chapter and thereof in this section maps with relation to the derived data have been plotted. The graphs in the following show the length of the transect per transect clipped to the extent of Shoreline Change Envelope (SCE). The longer the length of transect signifies the greater movement of the shoreline position along that transect.

The followings are the mosaicked images of 2010 and 2015.

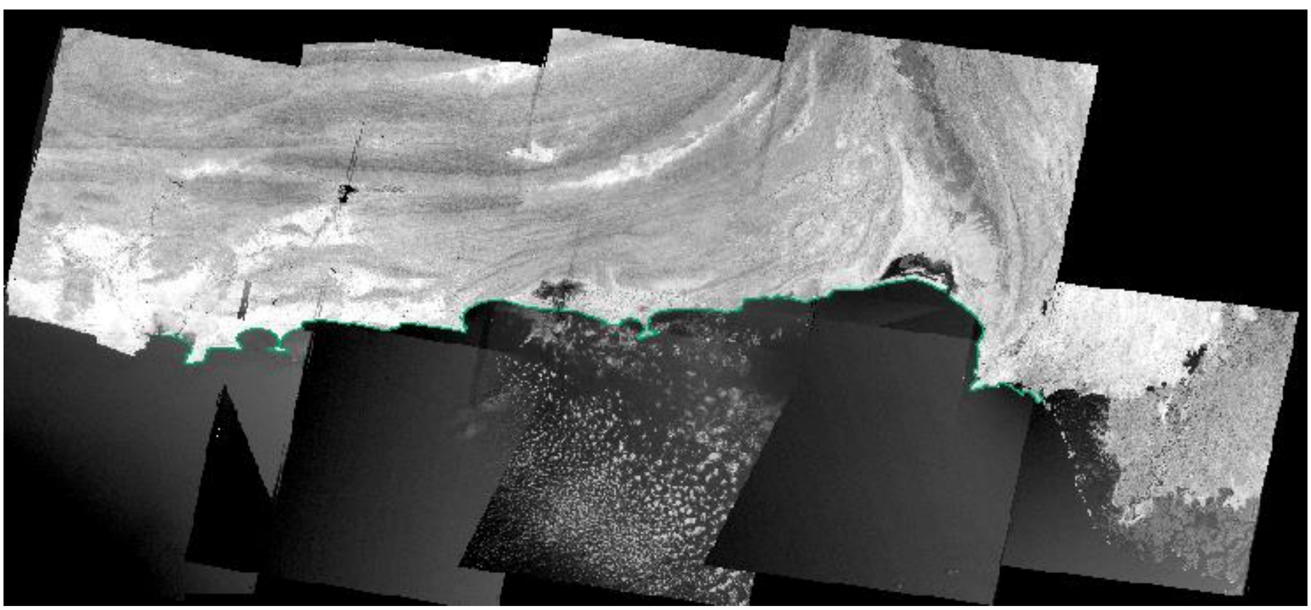


Figure 15: Mosaic 2010 imagery with shoreline 2010 shapefile overlay

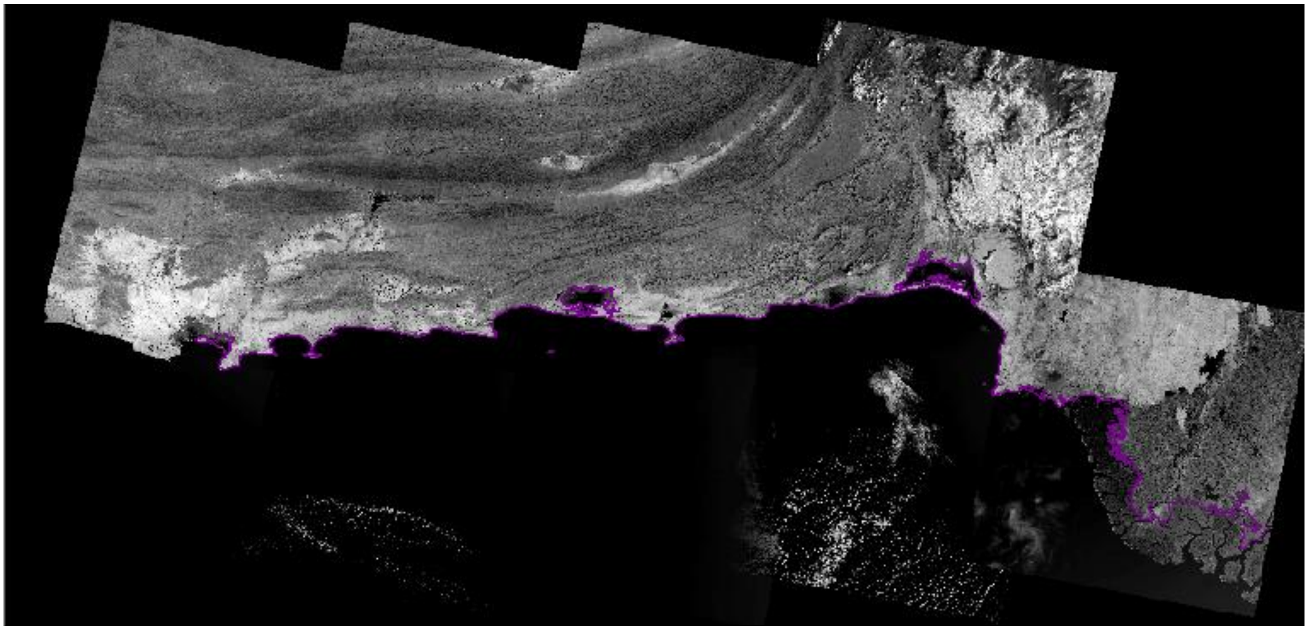


Figure 16: Mosaic 2010 imagery with shoreline 2010 shapefile overlay

The following maps and figure have been arranged in order based on their location from westward to eastward.

On the far west of the Balouchistan coastline is Jiwani, a town and commercial port. Jiwani is followed by Gwadar, a port city that has attracted a lot of investment and development in recent years, in the eastward direction. Further in the east of Gwadar is Ormara another port city in Balouchistan. Then is located Gadani, a coastal village. To the east of Gadani is Hub, an industrial city. In the far east is western Sindh.

1. Jiwani

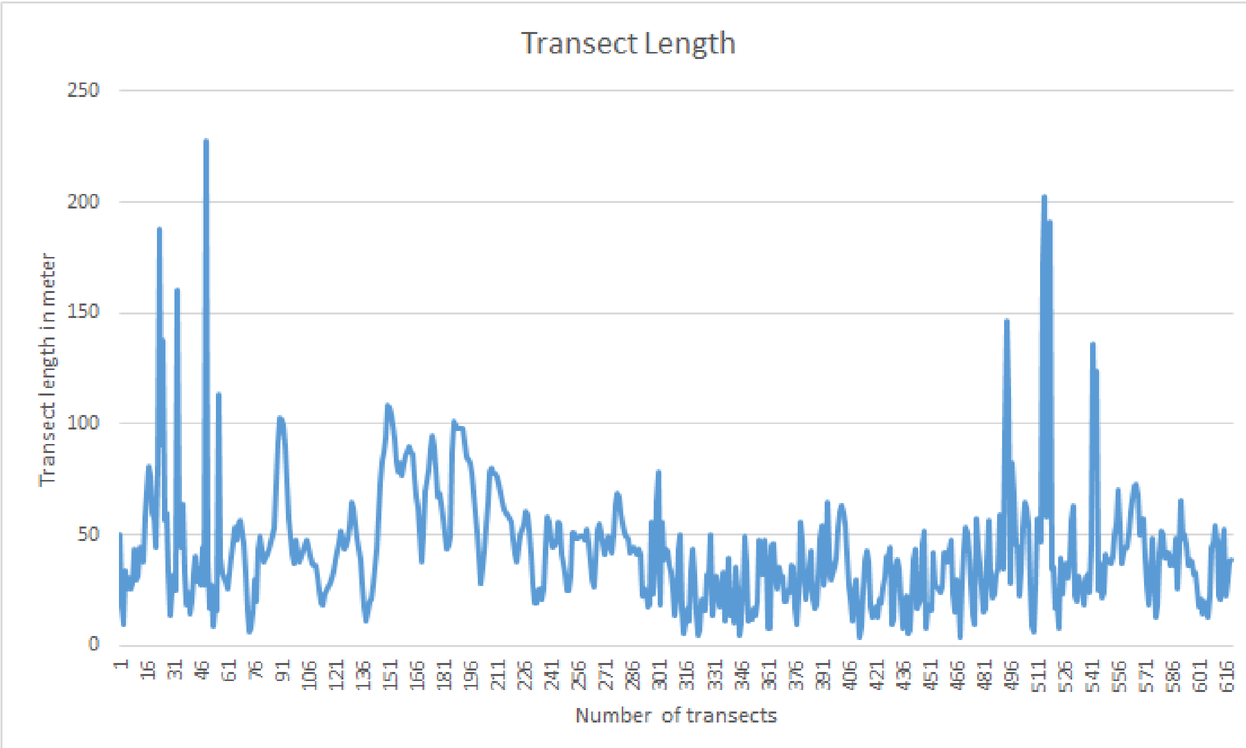


Figure 17: SCE vs Transect number Jiwani

The abrupt change is maximum at approx. 227.5 meter. But the SCE conveys here that only a few small areas have undergone change here. Jiwani map on next page.

Segment	Statistcs	EPR	SCE	NSM
Jiwani	Max	12.5	227.5	187.9
	Min	-10.9	4.01	-163.6
	Median	-0.26	39.6	-3.9
	SD	1.89	27.3	28.4
	Transect Count	618	618	618

Table 5: DSAS stat Jiwani

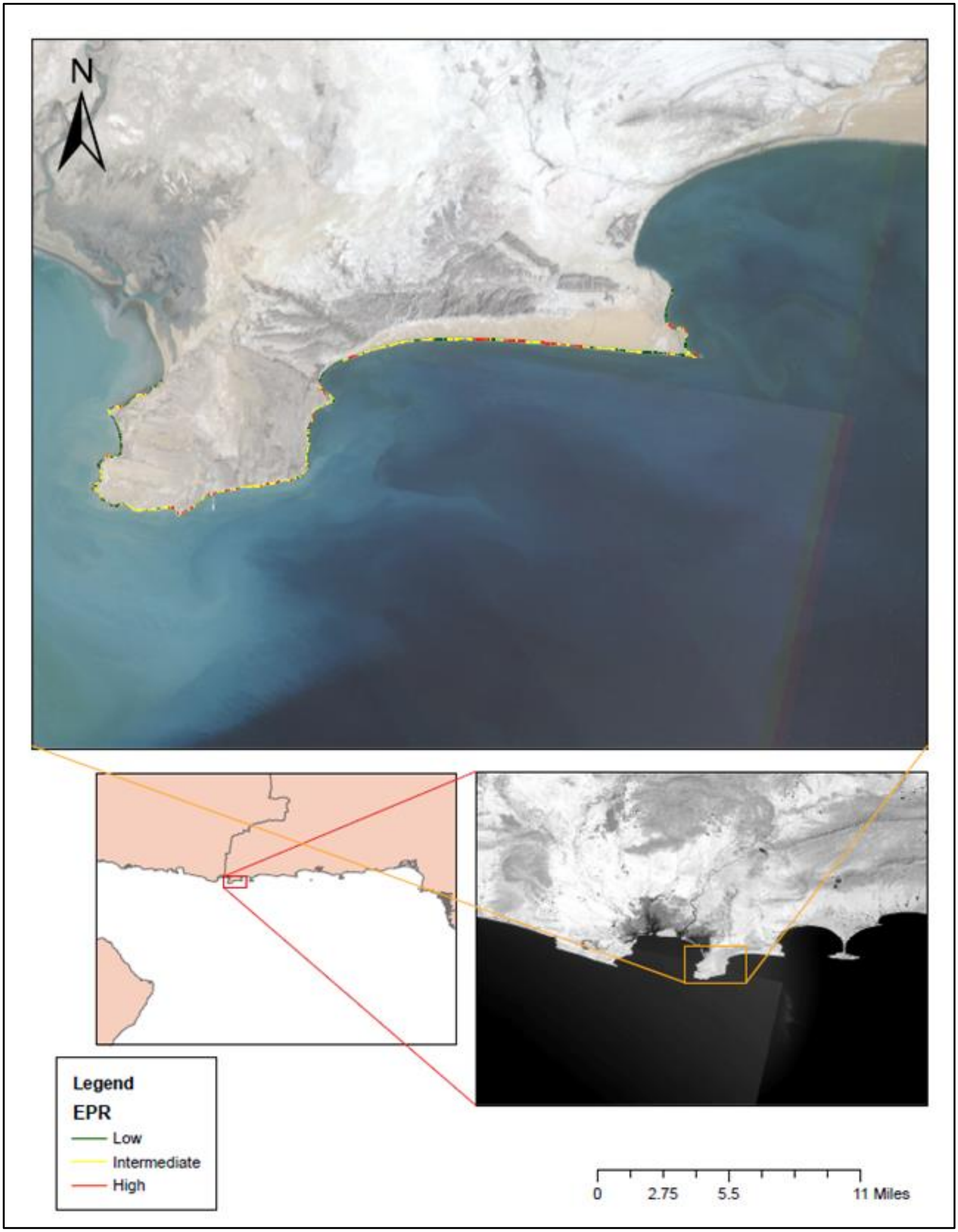


Figure 18: Erosion map of Jiwani

2. Gwadar

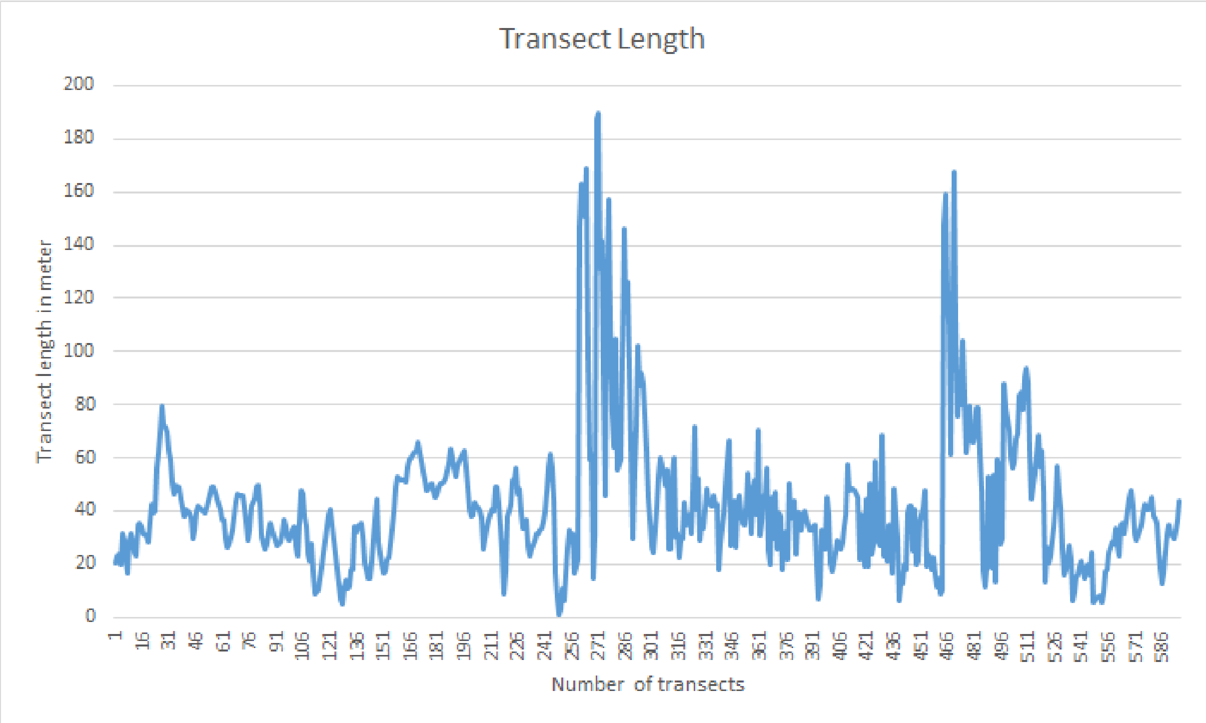


Figure 19: SCE vs Transect number Gwadar

At transect 256-301, the spike is noticeable with 189.5 m SCE. Followed by 466-481. Trend is fluctuating only in a few places. But with rapid increasing change considered in a short timeframe.

Segment	Statistcs	EPR	SCE	NSM
Gawadar	Max	11.1	189.5	166.7
	Min	-3.5	1.06	-52.7
	Median	0.82	37.8	12.32
	SD	2.18	27.1	32.7
	Transect Count	596	596	596

Table 6: DSAS stat Gwadar

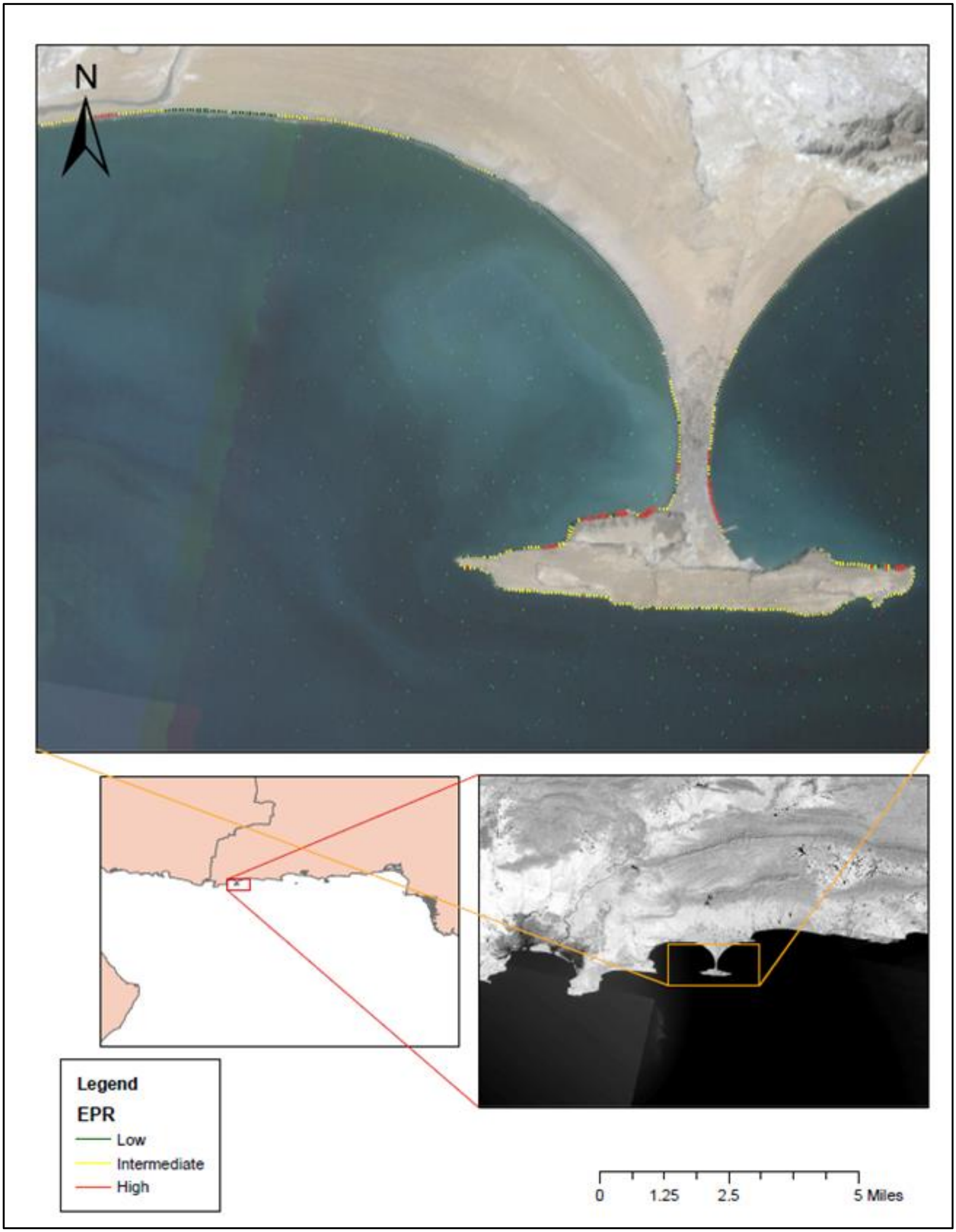


Figure 20: Erosion map of Gwadar

3. Ormara

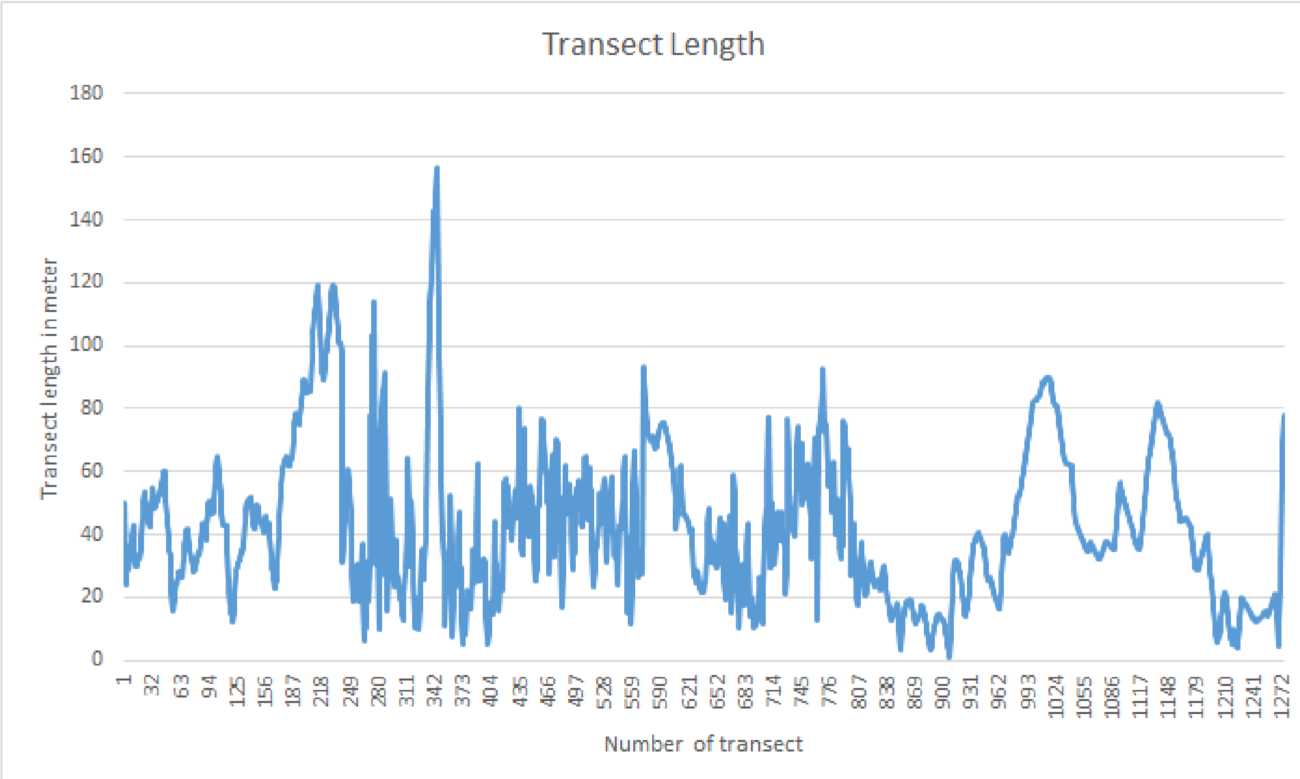


Figure 21: SCE vs Transect number Ormara

Coastline movement here has Max SCE at 156.3 m. A trend close to Gwadar, perhaps due to the similar geological formation of a hammer-head cliff.

Segment	Statistcs	EPR	SCE	NSM
Ormara	Max	7.96	156.3	119.4
	Min	-2.66	1.25	-39.8
	Median	2.08	38.8	31.7
	SD	1.81	24.4	27.2
	Transect Count	1274	1274	1274

Table 7: DSAS stat Ormara

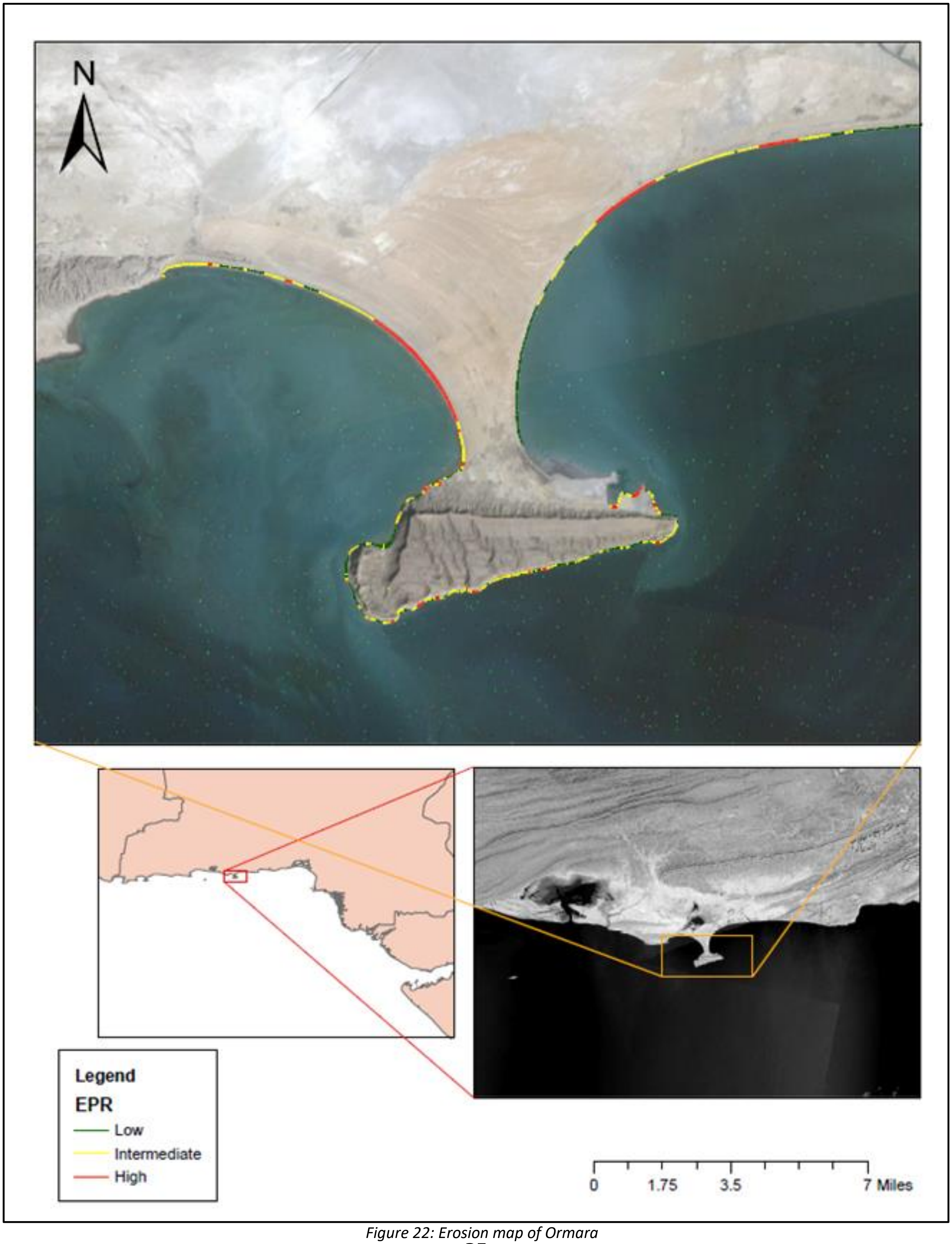


Figure 22: Erosion map of Ormara

4. Gadani

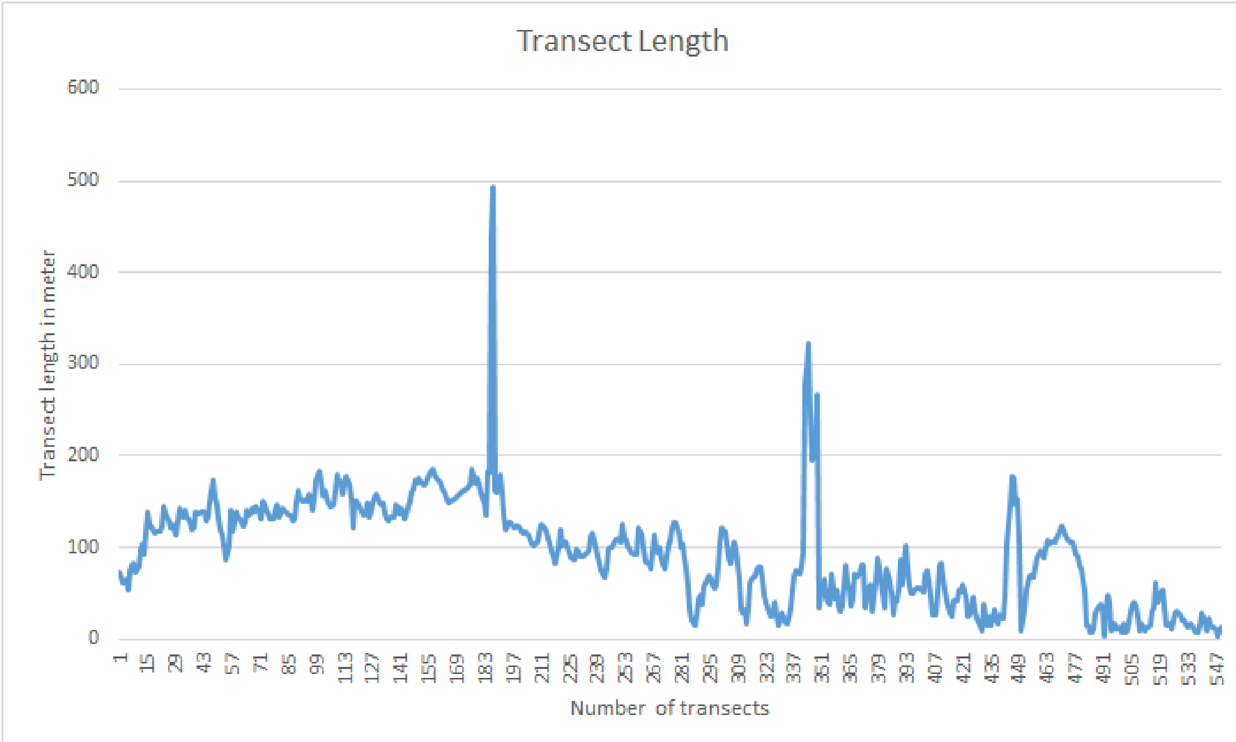


Figure 23: SCE vs Transect number Gadani

The highest jump in SCE at 492 m is seen at Gadani with 492.5 m, this was the highest in our study.

Segment	Statistcs	EPR	SCE	NSM
Gadani	Max	32.8	492	492.5
	Min	-11.8	2.61	-177.9
	Median	5.54	98	83.1
	SD	5.71	57.9	85.7
	Transect Count	549	549	549

Table 8: DSAS stat Gadani

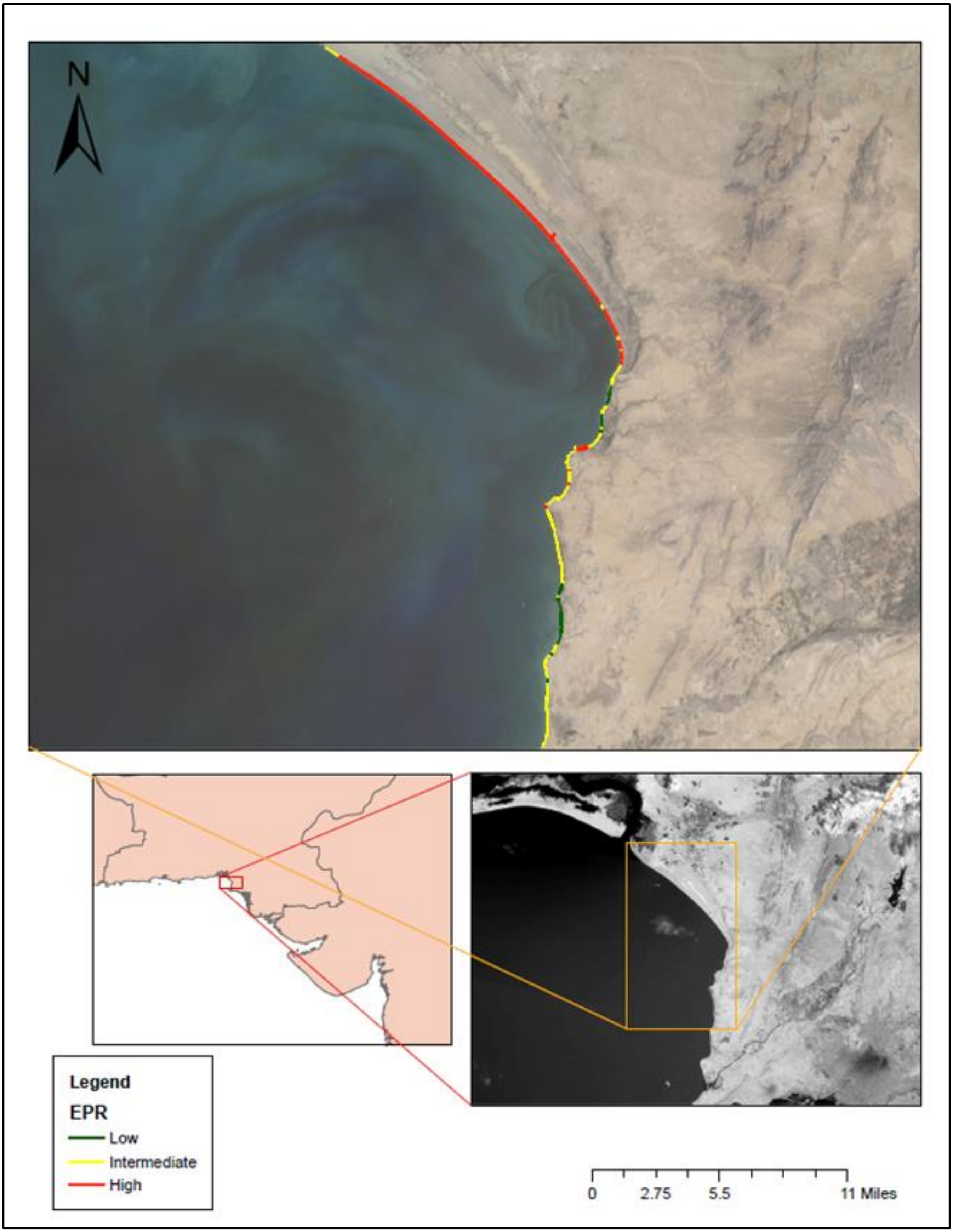


Figure 24: Erosion map of Gadani

5. Hub

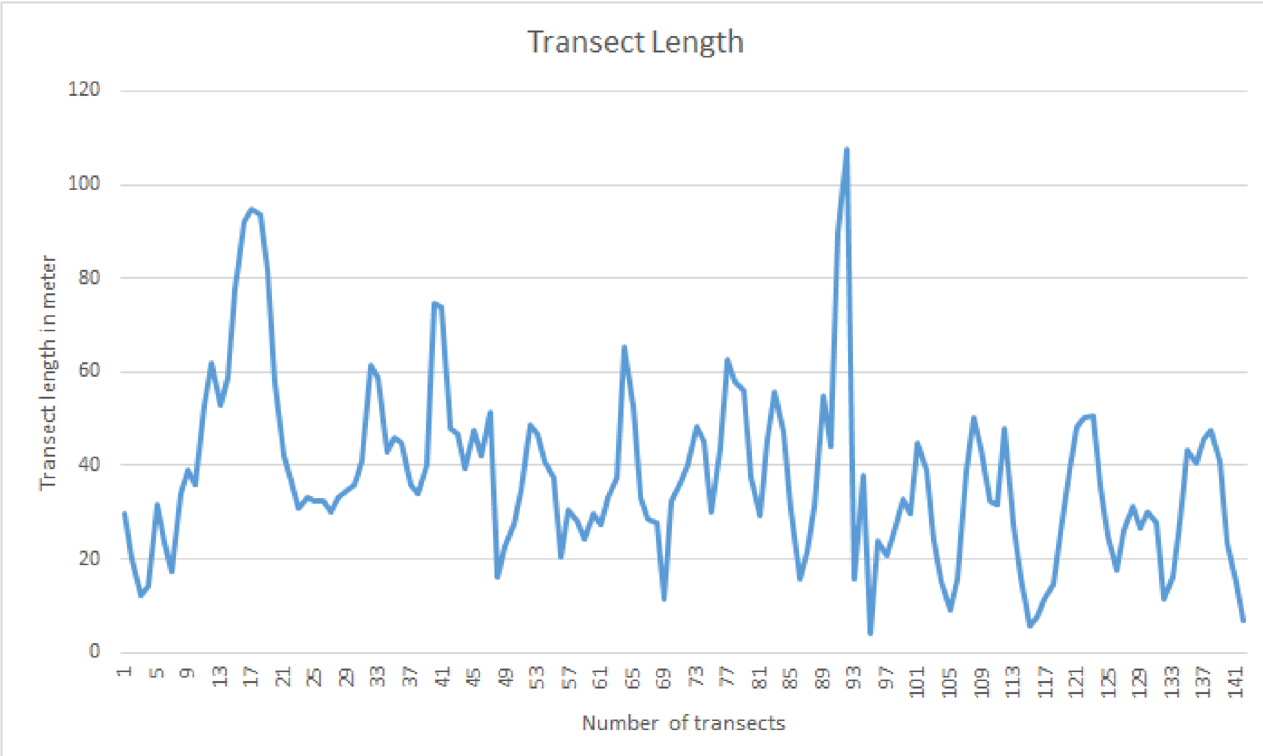


Figure 25: SCE vs Transect number Hub

The region here incorporates the Hub river delta, leading to the least change in trend accounted for in the study. (The table below is a misprint with the name Isa&Hub.)

Segment	Statistcs	EPR	SCE	NSM
Isa & Hub	Max	3.16	107.5	47.4
	Min	-6.21	4.18	-93
	Median	-0.74	35.2	-11.17
	SD	1.72	18.65	25.89
	Transect Count	142	142	142

Table 9: DSAS stat Hub

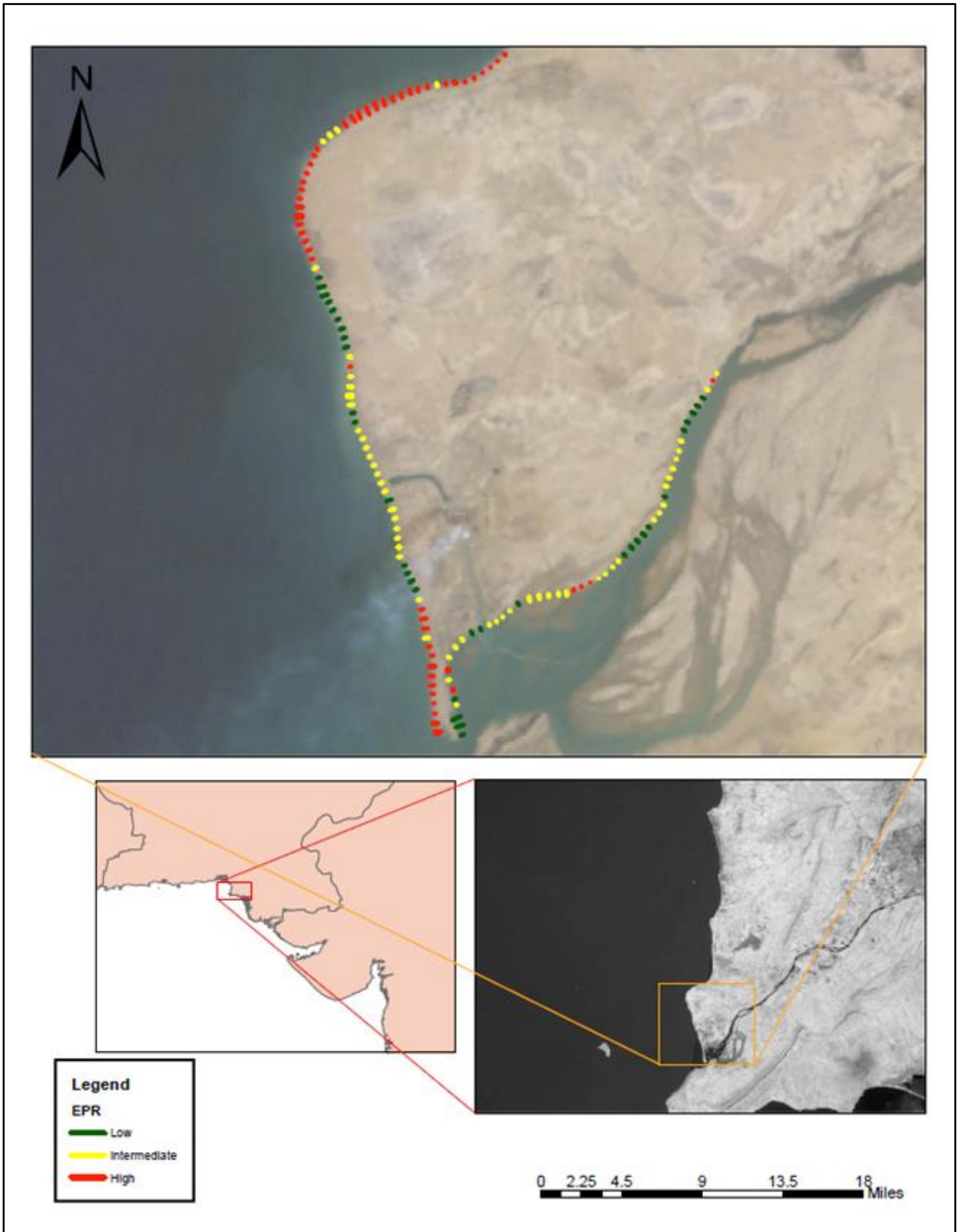


Figure 26: Erosion map of Hub

6. Karachi (west)

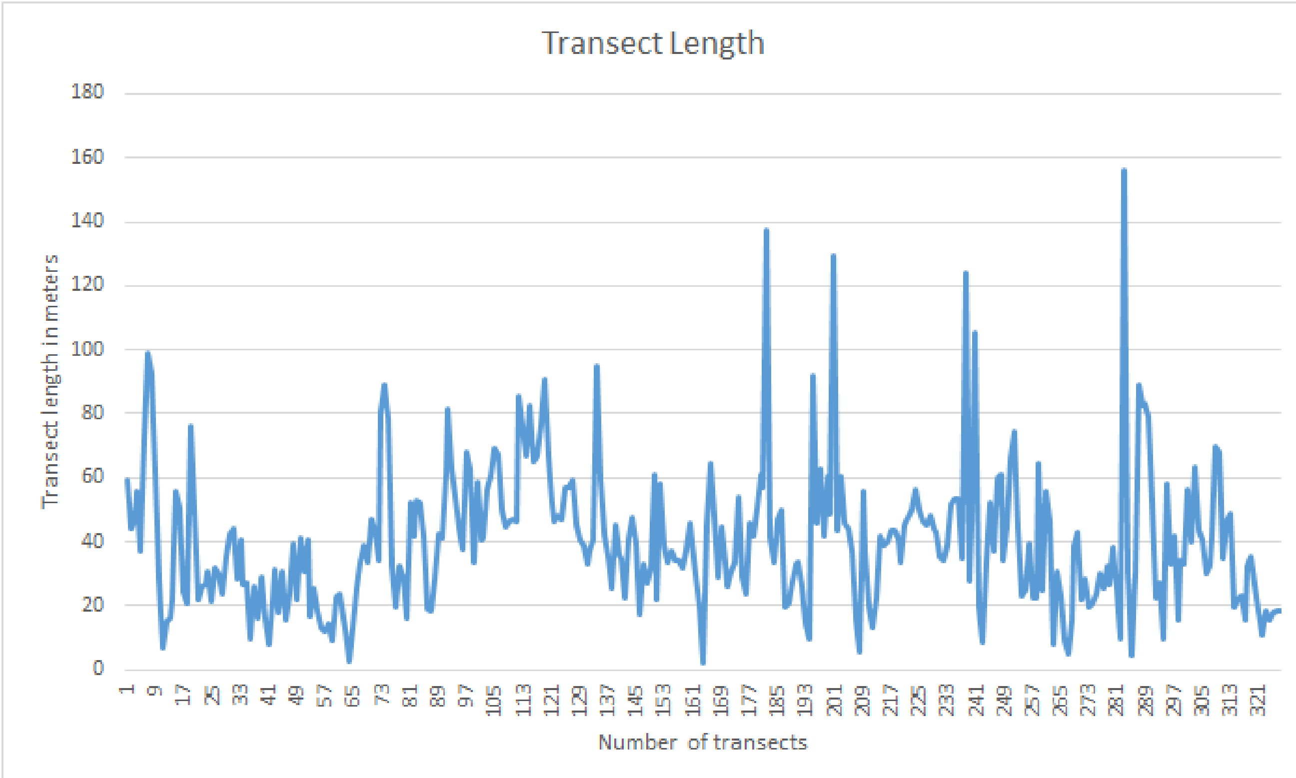


Figure 27: SCE vs Transect number Karachi(west)

The proximity of this area to Karachi and its rocky geology explains the trend seen above, rapid change in a short time line is concurrent. (The table below is a misprint with the name Goth.)

Segment	Statistcs	EPR	SCE	NSM
Goths	Max	10.39	155.7	155.7
	Min	-5.6	2.33	-84
	Median	1.92	37.7	28.8
	SD	1.85	21.9	27.7
	Transect Count	327	327	327

Table 10: DSAS stat Karachi (west)

Figure 28: Erosion map of Karachi (west)

Chapter 4

CONCLUSION

The results derived lead us to conclude definitely some interesting and prevalent trends. The geology and of the areas is sure to be of some influence due to the high rates of erosion in Jiwaani, Gwadar and Ormara. The similarity of the hammer head formations at Gwadar and Ormara suggest a similarity in trend as in the table below. Jiwani, although not being a hammer head formation, is still a cliff, and as common sense suggest, any rock or rough area is more prone to erosion due to them bearing the brunt of the lashing waves of the sea.

Location	**Statistic**	**EPR**	**SCE**	**NSM**
Jiwani	Max	12.5	227.5	187.9
	Min	-10.9	4.01	-163.6
Gwadar	Max	11.1	189.5	166.7
	Min	-3.5	1.06	-52.7
Ormara	Max	7.96	156.3	119.4
	Min	-2.66	1.25	-39.8

Table 11: Gwadar/Ormara/Jiwani comparasion

For Hub and Karachi, this study reveals the least amount of change for the Hub region, which can be attributed due flow of the Hub river east to it, whose mouth divides Sindh and Balouchistan and also Hub from Karachi.

Location	**Statistic**	**EPR**	**SCE**	**NSM**
Hub	Max	3.16	107.5	47.4
	Min	-6.21	4.18	-93

Table 12: Hub stat summarized

Location	**Statistic**	**EPR**	**SCE**	**NSM**
Karachi (west)	Max	10.39	155.7	155.7
	Min	-5.6	2.33	-84

Table 13: Karachi stat summarized

Karachi (west) is the region where the Sulaiman Kirthar ranges rise from the sea floor and travel north up to Afghanistan. Hence the rough nature of this area shows a gradual increase in erosion, departing from the flat beaches of Hub.

Gadani is worthy of discussion here, with the highest recorded change, this shows a very abnormal change. Considering a small time period of 15 years and a flat beach. A further investigation needs to be conducted here as ascertain the reasons for such a fast paced erosion.

Location	**Statistic**	**EPR**	**SCE**	**NSM**
Gadani	Max	32.8	492	492.5
	Min	-11.8	2.61	-117.9

Table 14: Gadani stat summarized

The ship breaking industry at Gadani can be blamed for this fast paced erosion. The result of pollutants especially oil and other effluents from the scrap are free to flow to the sea, altering the turbidity and composition of water. This has been cited in a number of papers recently especially in Bangladesh. A detailed map is shown on the next page, highlighting the EPR rates of Gadani.

Figure 29: Erosion map of Gadani with maximum change

REFERENCES

Addo, K. A., Walkden, M., & Mills, J. P. T. (2008). Detection, measurement and prediction of shoreline recession in Accra, Ghana. *ISPRS Journal of Photogrammetry and Remote Sensing*,*63*(5), 543-558.

Kuleli, T. (2010). Quantitative analysis of shoreline changes at the Mediterranean Coast in Turkey.*Environmental monitoring and assessment*, *167*(1-4), 387-397.

Giosan, L., Constantinescu, S., Clift, P. D., Tabrez, A. R., Danish, M., & Inam, A. (2006). Recent morphodynamics of the Indus delta shore and shelf. *Continental Shelf Research*, *26*(14), 1668-1684.

Islam, M. A., Hossain, M. S., Hasan, T., & Murshed, S. (2016). Shoreline changes along the Kutubdia Island, south east Bangladesh using digital shoreline analysis system. *Bangladesh Journal of Scientific Research*, *27*(1), 99-108.

Hossain, M. M. M., & Islam, M. M. (2006). *Ship breaking activities and its impact on the coastal zone of Chittagong, Bangladesh: Towards sustainable management*. Chittagong, Bangladesh: Advocacy & Publication Unit, Young Power in Social Action (YPSA).

Thieler, E. R., Himmelstoss, E. A., Zichichi, J. L., & Ergul, A. (2009). *The Digital Shoreline Analysis System (DSAS) Version 4.0-An ArcGIS Extension for Calculating Shoreline Change* (No. 2008-1278). US Geological Survey.

Arcsi.py documentation: http://rsgislib.org/arcsi/

Arcsi.py batch processing: https://spectraldifferences.wordpress.com/2015/04/18/batch-processing-atmospheric-correction-using-arcsi/

Landsat imagery and band information Source: http://landsat.usgs.gov/band_designations_landsat_satellites.php