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Signature Based Geo-Spatial Analysis to Find Out the Suspended Sediment Concentration in Indus River Delta, Pakistan

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Abstract

This study was aimed to find the signature based spatial patterns of suspended sediment concentration (SSC) by using satellite data for Indus river delta district Thatta, Sindh Province of Pakistan. The Normalized Difference Suspended Sediment Index (NDSSI) was used to find out the presence of SSC spatial patterns. In this study two types of satellite data, Landsat 7 ETM+ and Sentinel-2 were selected for a period of 16 years i.e. from 2000 to 2016. The Internal Average Reflectance (IAR) method was also used for enhancing to get highly accurate signatures of SSC. The Landsat 7 ETM + remotely sensed satellite data was acquired for pre-monsoon and post-monsoon season. Inter-satellite validation was also done using Sentinel-2 data and Landsat 7 ETM+ satellite sensor, the coefficient of correlation was calculated to be $R^2 = 0.84$*. Through NDSSI analysis, it was observed that in 16-year period seawater intruded due to the insufficient supply of water with SSC. For year 2000 to 2009 and year 2010 to 2014, similar spatial patterns of SSC were observed. After 2010 flood, district Thatta of Sindh faced widening of brackish lakes along both sides of Indus river channel. In year 2015, the southwest and southeast coastal area creeks of Indus deltaic region were more widened and seawater intrusion progressively increased on the land of district Thatta. Most of the coastal area creeks were submerged under the seawater, 4.1 square kilometer area erosion of Waddi Khuddi creek was observed and the condition of SSC deposits really worsted. It is utmost important to design a durable water regulation system which maintains a steady water flow containing sediments to indus delta creeks which is also important for the survival of mangroves.*

Keywords: SSC, NDSSI, IAR, Sentinel, Landsat 7 ETM+.

1. Introduction

Indus River delta sustains fifth position in the world [1]. The Delta covers an area of 41,440 km^2 and 210 km across from where it joins the Arabian Sea [2]. The Indus extends from Northern parts of Himalayan Mountains points towards the arid Southern alluvial plains of province Sindh and has created the second leading sediment body in the Indus delta basin to Arabian Sea [3]. All the rivers which join the Indus River have the seasonal and annual river flows exhibiting water variability [4, 5]. Approximately comparable trend in monsoonal rainfall and annual flow movement has been observed [6]. Due to the melting of snow in monsoonal period, large flow with sediments has been recorded in Indus River channel.

According to Vö rö smarty et.al [7], construction of dams for flash flood control, water usage, and for electricity generation has essentially diminished the supply of water as well as SSC discharge released to coastal area districts by the rivers. Wells and Coleman [8] reported that the Indus delta carries an excessive top wave energy where coast is vulnerable to disintegration, causing fast sea water intrusion because of sea level ascent [9]. District Thatta, especially Indus Delta and its coastal area creeks are facing the seawater intrusion due to the storage of river water from Indus River channel at Kotri barrage. Reduced deposits of suspended sediments and improper regulation of fresh water are a threat for survival of Indus river delta at Khobar creek (mouth of Indus Delta).

Number of studies have already used different satellite platforms such as Landsat, Moderate Resolution Imaging Spectroradiometer (MODIS), Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and high spatial resolution satellite sensor IKONOS imagery to find out the suspended sediment concentration [10,11]. Remote sensing satellite imagery is a great technology to map the wide extent of seawater constituents. Remote sensing is helpful in finding the phytoplankton for biomass, dissolved colored organic matter and for its effect on benthic habitat and also for measuring the water quality by finding the suspended sediment concentration i.e. SSC [12, 13]. Signature based analysis through remote detecting, extract information about the objects according to their reflectance. The signature based study through remote detection gives data on non-biogenic particle support from the area and generation of the sediments in aquatic water. The higher visible electromagnetic radiation (EMR) wavelength (red) and reflected infrared (also called Near-Infrared) are absorbed more by clear water whereas shorter wavelength EMR of (blue) is reflected by clear water. In the presence of SSC, the clear water reflectance is changed through visible part as well as through Near-Infrared (NIR) part of electromagnetic radiation. These changes can help to track the objects and to extract the information [14]. The SSC signature reflectance from water bodies is highly affected due to their sizes and shapes [15].

2. Study Area

The River Indus starts from the Tibet Peaks with height of 5182 m and finishes at the Arabian Sea. The Indus River delta is recorded under the Ramsar convention on swampy wetlands, in 1971, and is the fifth largest delta of the globe. It is situated at latitude 24.15 N, longitude 67.63 E. The delta has moved its position southward in the past periods. Presently, it is situated in south of District Thatta of Pakistan and it is 41, 440 km^2 in zone and 210 km across from where it joins the Arabian Sea. Delta covers 563 km of the total coastal territory of Sindh, holding seventeen large creeks, 3-major lakes, several brackish lakes and broad mud flats. The Indus River delta receives precipitation from July to September all through monsoonal season which conveys around 100 to 500 mm of precipitation. The study area map is shown in Figure 1.

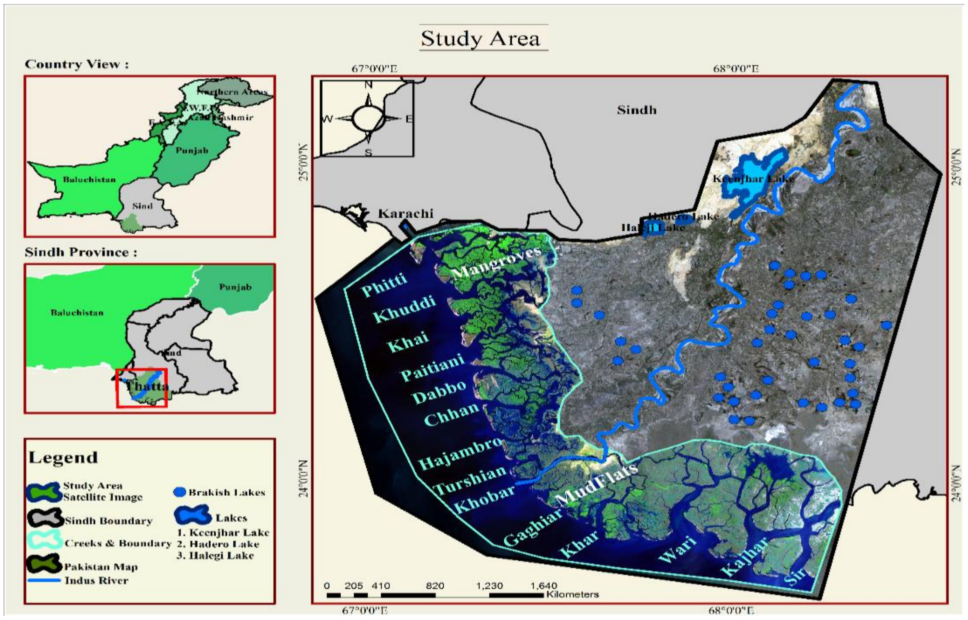

Figure 1. Study area map of Indus River Delta and its coastal area Creeks.

3. Materials and Methodology

Data collection and the methodologies used in this research work are describes as follows.

3.1. Materials

In this research, two types of satellite data were used i.e. Landsat 7 ETM+ data having the spatial resolution of 30m and the Sentinel-2 satellite sensor data having a finer spatial resolution of 10m. All the data was downloaded from an open source named as Earth explorer by USGS [16]. The path and the row of satellite raw images are 152P and 43R. For observing the 16-year periods of SSC changes, the pre-monsoon and post-monsoon season images of Landsat satellite sensor were selected for years 2000 to 2015. The inter satellite validation was done, using the Sentinel-2 satellite sensor and Landsat 7 ETM+ satellite sensor. For validation purpose of both the satellite sensors and images for February 2016 were selected for presentation. Sentinel-2 (an earth observation mission developed by European space agency, launched in 23 June, 2015) has 13 spectral bands in visible, near infrared and short wave infrared. Among these, blue visible range and near infrared band having 10m spatial resolution were selected.

3.2. Methodology

After acquiring the data, the study area shape file was made. Sub-setting of study area was made based upon impact of sea water intrusion in Indus Delta and its surrounding area of district Thatta, Sindh. Preprocessing was done by using Dark subtraction method and a new method, IAR. IAR can be used in the absence of ground data to find the approximately true signature based values of SSC from satellite images. De-striping and preprocessing of satellite imagery was done using Environment for Visualizing Images (Envi 5.1) techniques. After preprocessing, de-striping was done for 2015 Landsat 7 ETM+ images and for 2016 image of validation. The Figure 2 shows the scan line correction-off and after de-striped scanline correction-on image. After image enhancement, the NDSSI was applied to find out the SSC, the equation of NDSSI is given in equation 1. This method was developed by the Hossain et.al [15]. The NDSSI value ranges from -1 to +1. Values closer to +1 indicate presence of higher SSC. A blue to red color ramp was used whereas values closer to red depict higher concentration of SSC and the values closer to blue represent lesser amount of SSC. For inter satellite validation, sampling was made on NDSSI results and co-relation of two different satellite sensors was obtained.

$$\text{NDSSI} = \frac{(\rho_{Blue}) - (\rho_{NIR})}{(\rho_{Blue}) + (\rho_{NIR})} \quad (1)$$

Where NDSSI stands for Normalized Difference Suspended Sediment Index. ρ_{Blue} represents the blue spectral visible band wavelength and ρ_{NIR} represents the NIR spectral band wavelength.

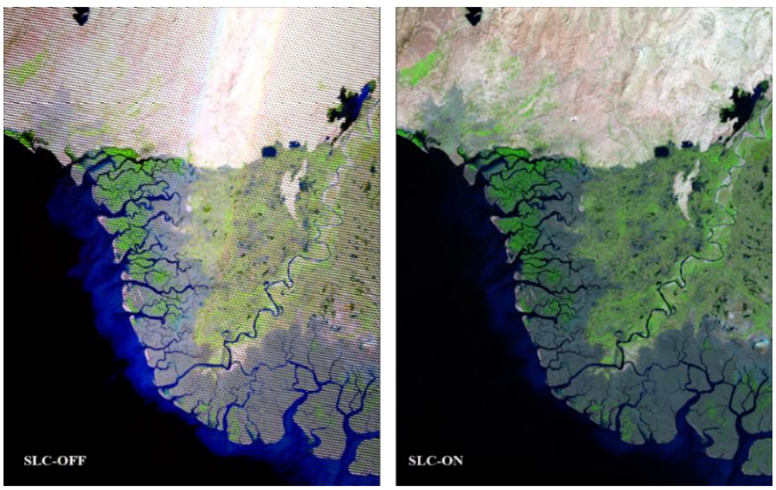

Figure 2. Landsat 7 ETM+ satellite image with scan line corrected-off and after de-stripe scan line corrected-on**.**

4. Results

For better visualization, we selected those results from 16 years of study where huge variations and impact of SSC and seawater intrusion were visible in Indus River Delta and its surrounding areas. The similar variations of SSC and seawater intrusion was observed from 2000 to 2009, because these years showed spatial patterns of SSC similar to year 2000. After 2010 flash flood, the years from 2011 to 2014 have same results that were observed in year 2010.

4.1. SSC spatial variations for year 2000

Normalized Difference suspended sediment index based variation of SSC of pre-monsoon and post-monsoon is illustrated in Figure 3 respectively. Two differences during March and

November were observed in both images. First, the SSC signatures were observed more inside the creeks of South-Eastern region in November as compared to March as illustrated in red and black arrows. Second, in south-western side of Indus River Delta, closer to the Khobar Creek, more SSC were observed in November as compared to March, as depicted by red arrows. During November, massive SSC pattern was observed in Keenjhar Lake. After monsoon, in November, along the South-Eastern and Western region of Indus River channel more prominent brackish lakes were observed as compared to March. The random open sea surface area closer to creeks of district Thatta along the coastline showed feather like SSC patterns in November.

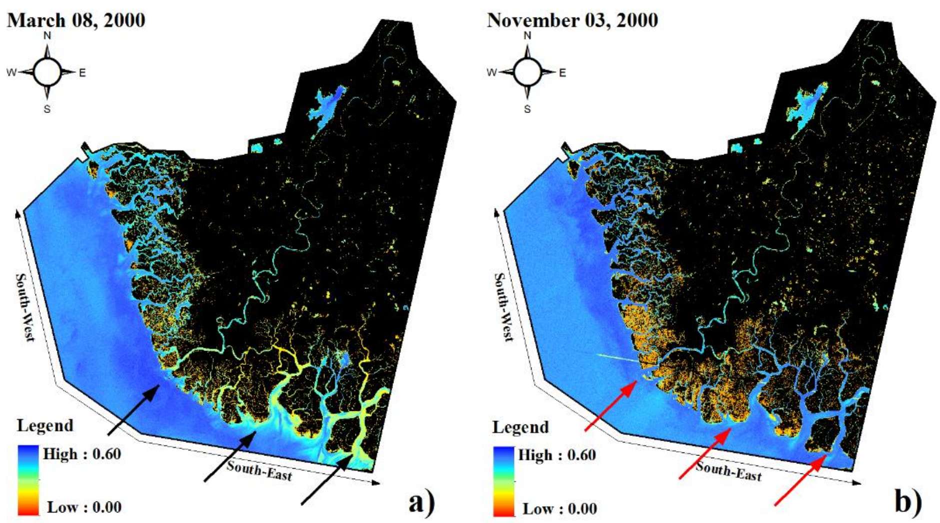

Figure 3. NDSSI analysis based results for pre-monsoon and post-monsoon season**.**

4.2. SSC spatial patterns and flood effects in year 2010

Flood always carries many suspended materials as well as higher concentrations of SSC, these SSC are present on the upper surface of water. When flood is diverged from its channel path, the suspended material which it carries also follow it and is deposited across the delta. Similar phenomenon happened in year 2010 in Pakistan, when heavy monsoonal rains turned into a flash flood. The day by day movement of flood can be seen in Figure 4. When this huge flood passed through the Sukhar Barrage, located in Sindh, 50 percent flood water was diverted from its channel path [17]. After that, the flood reached Kotri Barrage and was again diverted towards the southeast side of the Indus River channel where the brackish lakes are present. The Figure 5 shows that in March the brackish lakes were normal but after the monsoon season, in November, these lakes expanded and carried the flood discharge as indicated by the red arrow. The coastal area of District Thatta did not show significant SSC as the Kotri Barrage failed to receive SSC from the flood. The 2010 flash flood changed the brackish lakes geography, on the other hand the deltaic region did not receive the expected amount of fresh water as well as SSC. Afterwards these spatial patterns remained same till 2014.

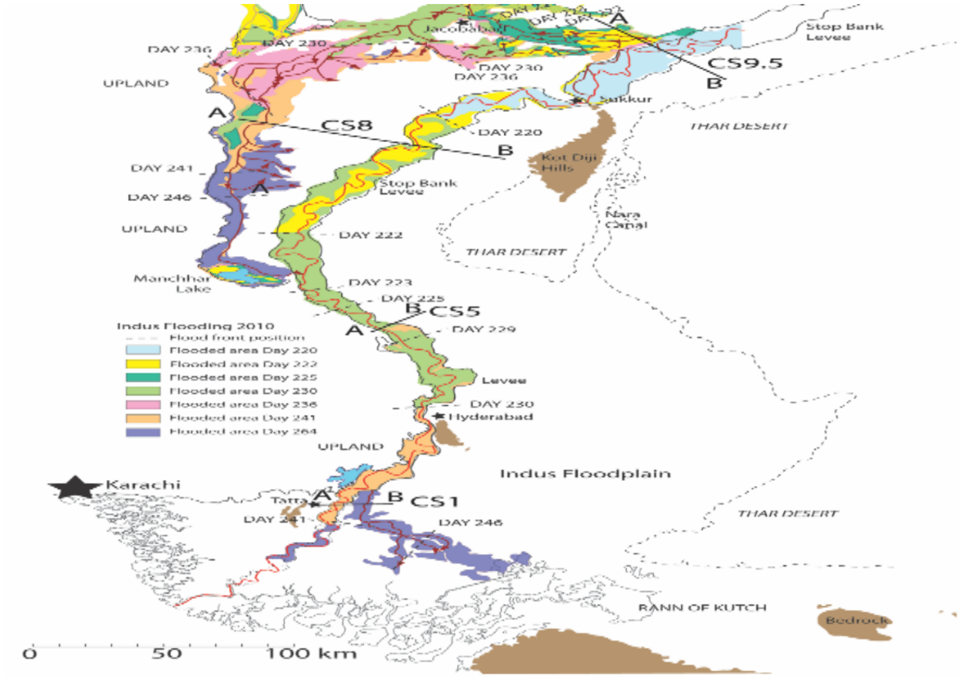

Figure 4. Flash flood occurred in 2010. Day by day movement of flood [13].
Source http://www.geosociety.org/gsatoday/archive/23/1/article/i1052-5173-23-1-4.htm

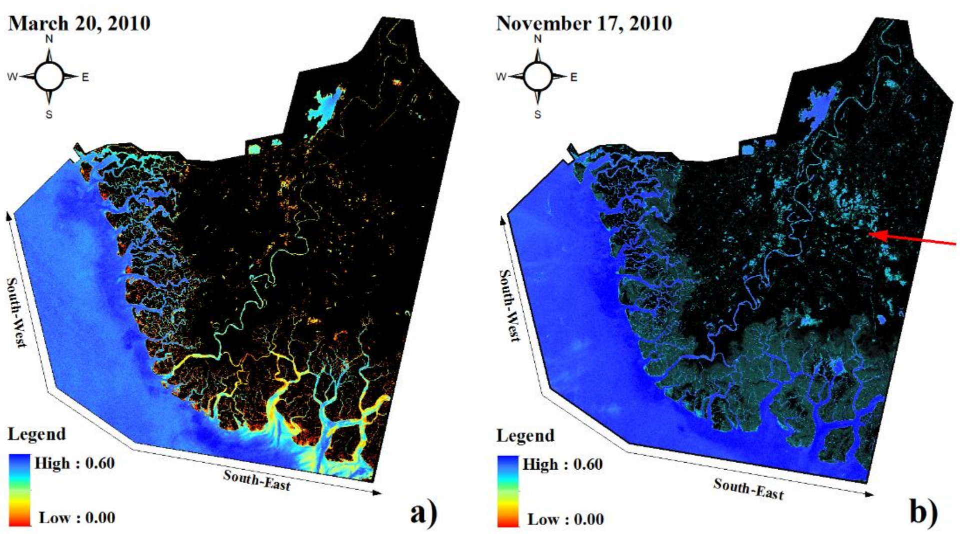

Figure 5. NDSSI results for year 2010, in November the Delta facing the huge seawater intrusion.

4.3. SSC spatial variations for year 2015

In 2015, the SSC patterns were also observed for pre-monsoon and post-monsoon season along the coastline of the Delta as shown in Figure 6, highlighted by black and red arrows. Yellow rectangular boxes highlight the land that vanished into the sea; these areas can easily be seen in 2000 satellite observations. The SSC condition was better in 2000, whereas in 2015 the SSC in Indus River channel, Delta and coastal area was not in immense amount in both the seasons as in Figure 6. Green arrows indicate the brackish lakes area. Brackish lakes became more prominent and widened in area during 16-years period at both sides of Indus River channel. In 2015 these brackish lakes remained approximately same in both the seasons. Keenjhar, Haleji and Hadero lakes widened and carried SSC as well. As compared to year 2000, the land of Thatta faced immense seawater intrusion in 2015. The yellow rectangular boxes indicate the submerged area of Thatta district region due to the seawater intrusion in both the seasons. Many south-west creeks near the coastline were influenced by the seawater intrusion.

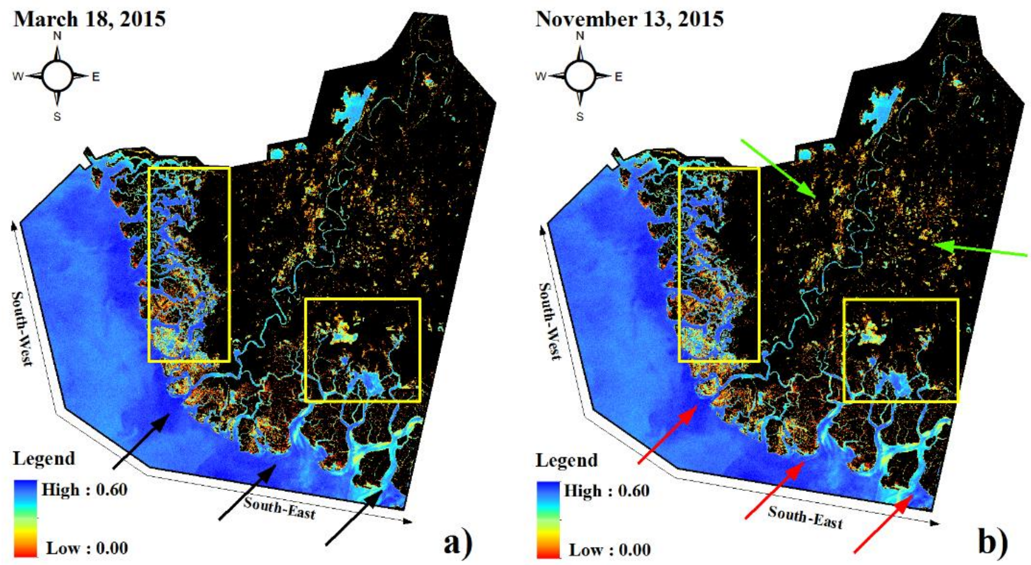

Figure 6. NDSSI analysis shows the huge variation of SSC and seawater intrusion in both pre-monsoon and post-monsoon season.

4.4. SSC spatial variations in study area lakes during 16-years

The keenjhar, Haleji and Hadero lakes showed random SSC patterns which were more prominent in 2000 as compared to 2015, but all of these lakes widened more at their edges during the 16-years, as seen in Figure 7. The source of SSC in these lakes is from Indus River link channels and movement of suspended sediments through wind. The brackish lakes were more prominent in 2015, huge difference was observed in image analysis as seen in brackish lakes image.

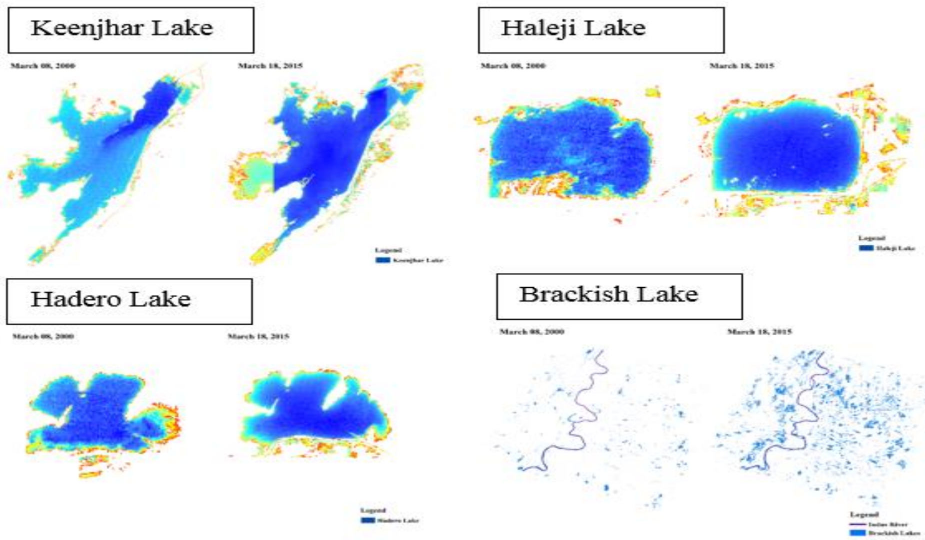

Figure 7. Thatta district lakes are showing widening at their edges and the brackish lakes are more expended along the both sides of Indus River Delta.

4.5. Effects of seawater intrusion on creeks during year 2000 to 2016

Figure 8 a) shows the overall difference during the 16-years period, the red patterns indicate the area which was reduced in 2015 but was present in year 2000. These creeks (Chhan, Hajambro, Turshian and Khobar creek, which is mouth of delta opening) are still facing erosion by sea tides and sea water intrudes into them day by day.

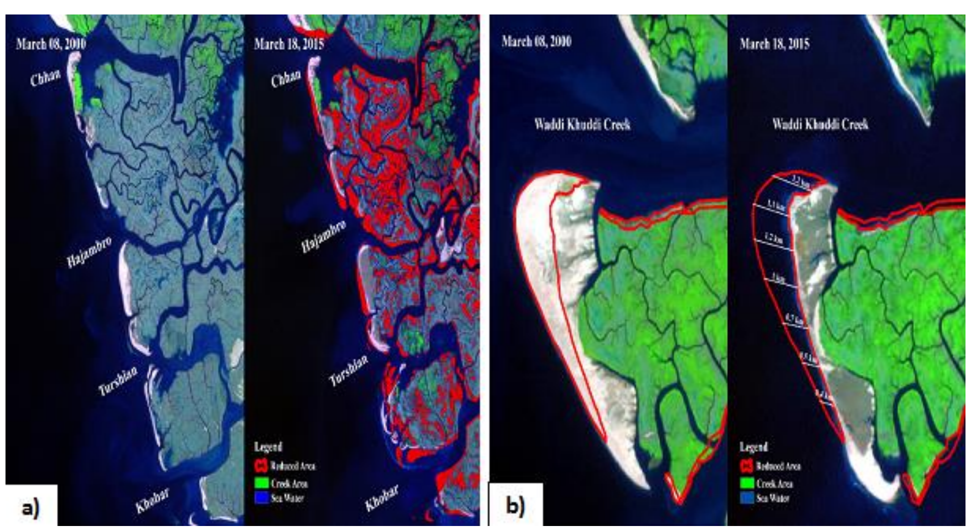

Figure 8. Erosion occurred in coastal area creeks from year 2000 to 2015.

The above Figure 8 b) indicated the Waddi Khuddi creek which is one of the most vulnerable creek of coastal area, this creek was reduced about 4.1 km^2 in area and 1.2 km in length (hatch area) from its sharp edge. The variations occurred during 16-years on Waddi

Khuddi creek can be seen in Figure 9. Mangroves are present on these creeks; these mangroves are facing serious problem due to seawater intrusion as they require a certain amount of fresh water for their survival which is solely provided by the Indus river channel through Khobar creek (mouth of Indus Delta). However, in this area the coming supply of fresh water from Indus River gets diverged into irrigation channels at Kotri barrage which can be seen in Figure 10.

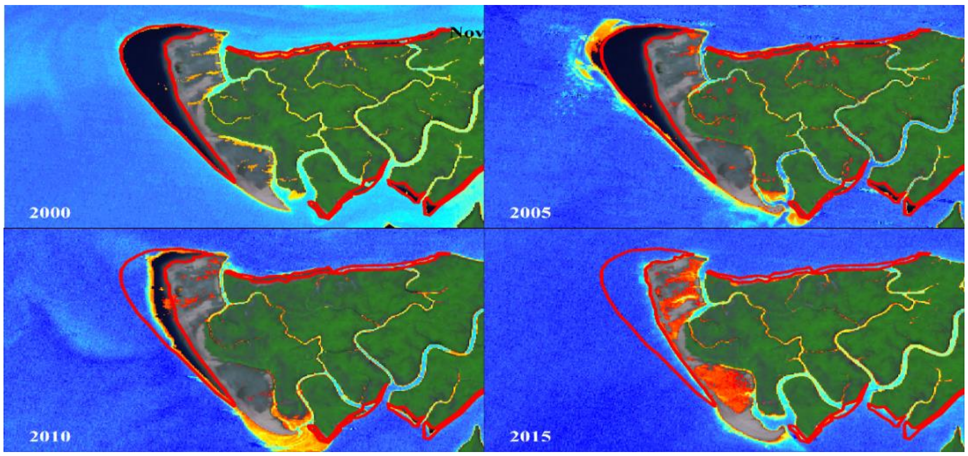

Figure 9. Erosion of Waddi Khuddi creek due to seawater intrusion during 16-years.

The Kotri barrage is situated just up-stream of Indus River Delta in district Hyderabad, Sindh. Due to this barrage the downstream regulation of water to the Indus River Delta blocked many years ago. The Figure 10 shows SSC condition at kotri barrage.

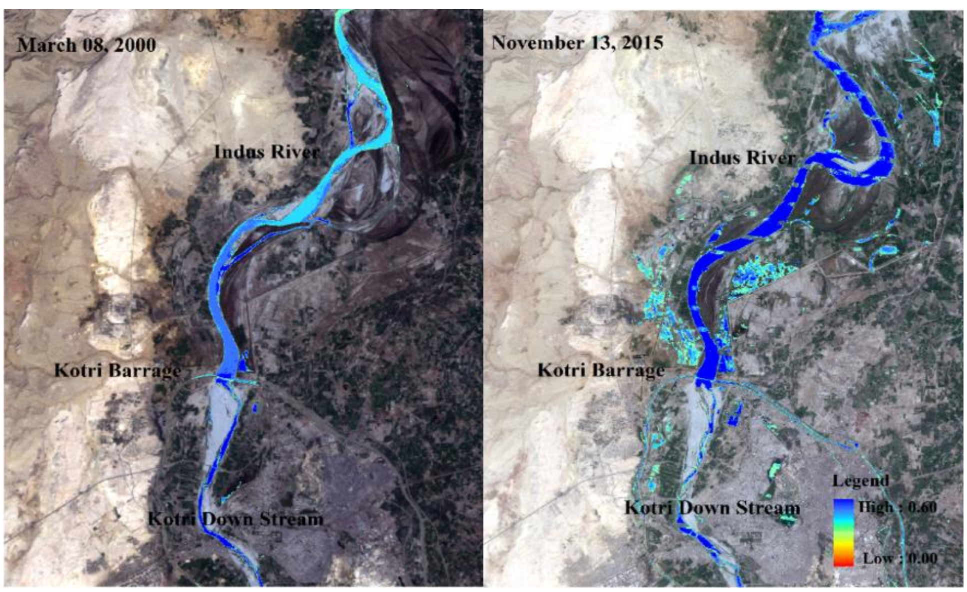

Figure 10. Water storage at Kotri barrage. In 2016 small irrigation channel was observed, these channel can be easily seen towards Indus River, Delta downstream.

It can easily be seen that in 2000 the SSC was present in the water which was blocked by barrage, but in year 2015 the water was diverted to irrigation channels and link channels just after the barrage due to which the downstream supply of water was massively blocked, whereas no SSC amount was present in kotri barrage and in main Indus river channel as well.

According to WWF [18] the seawater has intruded about 67 km into land of district Thatta. According to NIO [19], 80% of seawater intrusion occurred along the both sides of Indus River Delta, Thatta district. The south-west and south-east area in year 2015 is shown in Figure 11 a) and in Figure 11 b). Both the images show the land submerged under the influence of sea water intrusion and the sea water tapped on the land.

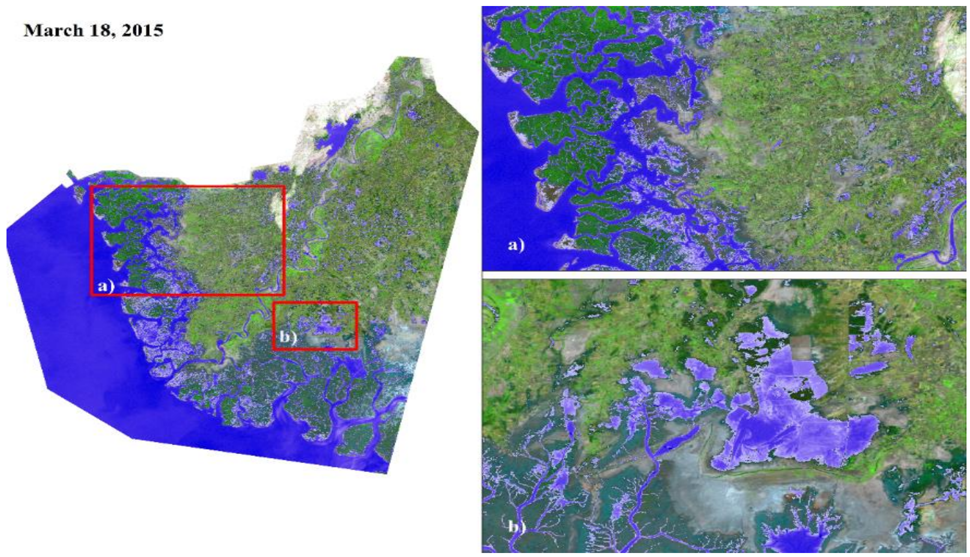

Figure 11. Over all visualization of seawater intrusion in district Thatta.

4.6. Inter-Satellite validation

A high spatial resolution satellite is needed to clearly observe the SSC patterns. For this purpose, Sentinel-2 sensor was selected to validate the SSC results. The inter-satellite validation was done using the 30m spatial resolution of Landsat 7 ETM+ sensor and Sentinel-2 satellite sensor having 10m spatial resolution. Pixel based sampling was done using the NDSSI signatures. Shorter wavelength blue band (0.45-0.52µm) and NIR band (0.77-0.90µm) wavelength were selected for both the satellites. Blue band (shorter wavelength) has the capability to reflect back solar radiation from clear water, in the presence of SSC in water; the shorter visible wavelength and NIR wavelength show different reflectance signatures. Whereas, the NIR band (longer wavelength as compared to blue wavelength range) gets absorbed in the presence of clear water and appears as dark. The Figure 12 shows the inter-satellite validation which was done using the 2016 same month imagery for both the satellite sensors.

NDSSI result is clearer in Sentinel-2 image because it has the finer spatial resolution as compared to the Landsat 7 ETM+ sensor image as shown in Figure 13. In Figure 12 the Landsat

7 ETM+ values are shown on x-axis and the Sentinel-2 sensor are represented on y-axis. Due to the courser spatial resolution of Landsat 7 ETM+ sensor the values are lower as compared to the Sentinel-2, due to which the values of sample points were retrieved slightly different from each other. Through validation a stronger coefficient of determination was observed i.e. $R^2 = 0.84$, as shown in Figure 12. Through validation it can be established that the Sentinel-2 satellite sensor can also be used for NDSSI analysis to find the SSC which can be mapped more accurately as compared to Landsat 7 ETM+ data. The comparison of both the satellite images can be seen in Figure 13.

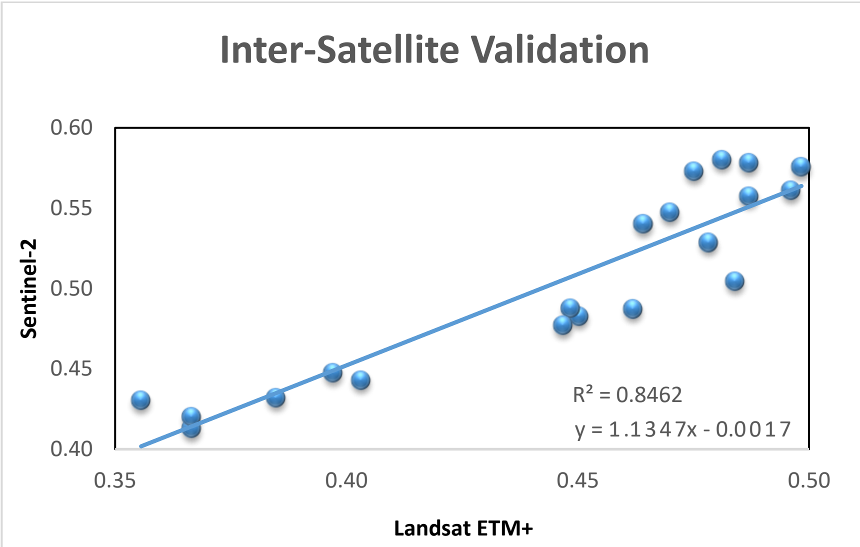

Figure 12. Inter-Satellite validation of Sentinel-2 and Landsat 7 ETM+ Imagery.

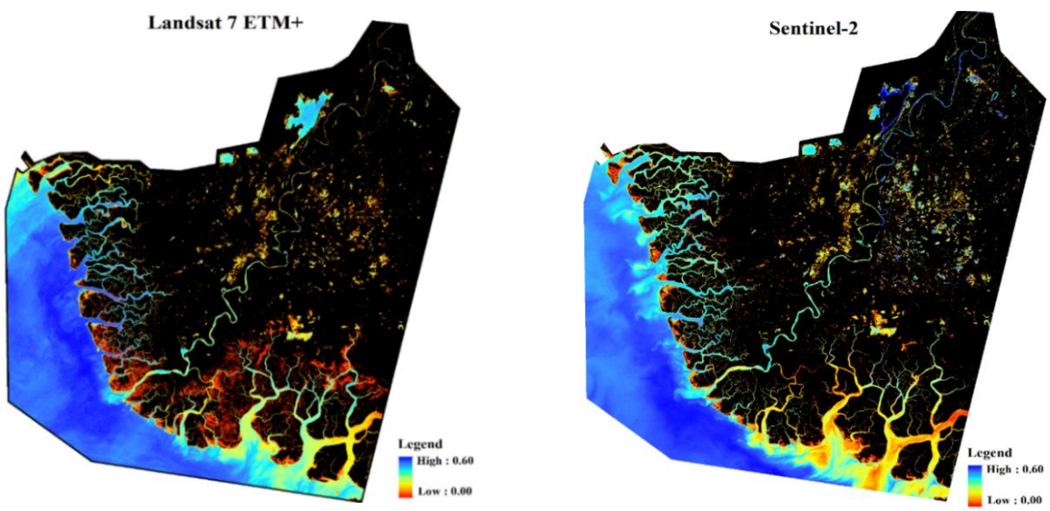

Figure 13. NDSSI analysis based, SSC spatial pattern showing significant variations. Landsat 7 ETM+ and Sentinel-2 images gave approximately same results for NDSSI analysis.

5. Conclusion

In this signature based study, the SSC was observed using NDSSI to find out the vulnerable areas near the coastal areas of Indus River Delta, district Thatta of Sindh, Pakistan. This study revealed that the SSC amount has progressively reduced over the years and the seawater is intruding into the land due to the deficiency of these sediment deposits in the deltaic area. The amount of SSC is not significant enough to maintain the life of delta and its coastal area creeks. Therefore, it can be concluded that the water coming from Indus River channel without SSC can cause a change in Pakistan's coastline after some years and the whole district Thatta might get under the influence of sea water intrusion. It is highly suggested that the suspended sediment concentration must be observed by the implementation of gauges along coastal areas creeks. Continuous monitoring of Indus delta and its surrounding areas through signature based satellite imagery techniques can provide data regarding sedimentation which can be helpful for the coastal area designers and decision makers. This study can also be used to develop a method to control the seawater intrusion and to improve the ecosystem of the deltaic area.

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