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Spatial Shrinkage of Vembanad Lake, South West India during 1973-2015 using NDWI and MNDWI

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Abstract: ***Vembanad Lake is the largest estuarine- Lagoon system in Kerala. Considering its ecological significance and high biodiversity, it had been designated as the Ramsar site by the UNESCO in the Iranian city of Ramsar in1981 and also classified as an Ecologically Sensitive Zone by the Ministry of Environment and Forests, India. In recent years, this estuary had undergone shrinkage due to various developmental and agricultural activities, which has been computed using remote sensing and GIS techniques coupled with field validation. A set of four Landsat satellite images that were acquired between 1973 and 2015 was employed to map the change in surface area of the Vembanad Lake using the water index methods. In the present study Normalised Difference Water Index (NDWI) and Modified Normalised Difference Water Index (MNDWI) methods were used to qualify the changes in the water area of the Vembanad Lake. The estuarine area were mapped using visual interpretation and ArcGIS 10.2.1 environment. The present study shows that the estuarine area is declining due industrial and agricultural developmental activities. The total shrinkage of the estuary during the study period was found to be 12.28sq.km (6.93%).***

Keywords: Estuary, Water index methods, NDWI, MNDWI, Vembanad Lake

1. Introduction

Vemaband Lake has been subjected to multifarious studies by many authors. Its evolution, water-sediment chemistry, biology, pollution indices, siltation, tourism potential etc have been addressed in several publications over the years (Mallik and Suchindan, 1984; Menon et al., 2000; Narayana et al., 2006; Selvam et al., 2012 and Padmalal et al., 2014). The decline of spatial coverage and reclamation of water body in many sectors have also been reported (Dipson et al., 2015). This study highlights the spatial shrinkage of the lake assessed by water index method for improving the management of the lake. This method can provide data about the shrinkage and thus help in formulating necessary measures for the protection of the lake which is an important water resource of the region.

Estuaries are unique systems with an unquestionable economical, ecological and recreational values (Taborda, 2009) which are partially enclosed coastal wetlands with one or more rivers or streams debouching into it. They possess a direct link to the open sea and hence are subjected to strong seasonal changes in chemical composition, flow patterns, sedimentation rate etc. (Dipson et al., 2015; Boschker et al., 2005). They are subjected to marine influences such as tides, waves, incursion of saline water as well as riverine influences like influx of fresh water and sediments (Nayak et al., 2002). However, in recent years many lakes around the world are changing rapidly mainly by the climatic change and human activity (Coe and Foley, 2001 and zhang et al., 2015).

Remotely sensed images can be used as a tool to map ecosystems and to detect, monitor and evaluated changes within them thereby supporting the development of resources management strategies. Satellite and airborne systems offer major opportunities for monitoring large scale, earth surface characteristics and provide a data base for change detection studies (Ahamed et al,. 2009). Generally the near infrared (NIR) and the middle infrared (MIR) bands have higher potential for detecting water bodies (Lillesand and Kiefer,1994) ,therefore this would be useful in wetness detection and monitoring. There are many techniques used for delineating the water body boundaries. Some of them are image classification, Principal component analysis (PCA). Tasselled cap (TC) transformations, Normalised difference Water Index (NDWI) and analysis of digital elevation models (DEM) (Ahmed et al., 2009 and Fei Zhang et al., 2015).

Ahamed et al., (2009) analysed the environmental change of North African coastal lagoons using remote sensing techniques. Song et al., (2012) studied wetland shrinkage in Muleng-Xingkai Plain, China based on landscape metrics and the land use changes transition matrix. Joao et al., (2012) evaluates the performances of $NDWI_{NIR/MIR}$, $NDWI_{G/NIR}$, and $NDWI_{G/MIR}$ for mapping seasonal and permanent water in Sahara-Sahel Transition zone. Kumar andLakshman (2015) have identified the hydrologically active areas using Modified Normalised Differential Water Index (MNDWI) from remote sensing data and a Soil Topographic Index (STI) derived from topographic data in Upper Cauvery Basin, India. Vivek et al., (2015) conducted a study to detect the changes in surface water dynamics in Bangalore using various methods like Water Ratio Index (WRI), Normalised Difference Water Index (NDWI), Modified Normalised Difference Water Index (MNDWI), supervised classification and wetness component of K-T transformation. Sajeeva and Subramanian (2003) have studied the land use/ land cover (LULC) changes in Ashtamudi wetland region in Kerala, from 1967-1997 using remote sensing data and GIS techniques. Rao et al., (1999) have monitored the spatial extent of Sunder bans Delta, India and analysed the wetland changes between 1973 and 1993 using the remote sensing data. Chithra et al., (2015) mapped the change detection of built up impervious surfaces in and around Cochin area, Kerala using the GIS techniques.

The main objective of the present study is to estimate the surface area change in the Vembanad Lake over the past four decades from Landsat satellite images using water indices and GIS techniques.

2. Materials and methods

2.1 Study Area

Vembanad Lake is the longest lake in India, largest lake in Kerala state and it is the largest lagoon – backwater system on the South West coast of India. This Lake had been designated as Ramsar site in 1981 by the UNESCO in the Iranian city of Ramsar. This lake is a part of a Vembanad–Kol wetland system. It was declared as "Ecologically sensitive zone" as per the Environment Protection Act 1985 of Govt. of India. This is an oxbow shaped lake extended for a distance of 96 km, from Azheekode in the North to Alappuzha in the South with a NW-SE orientation. This lake is connected to the Arabian Sea at two places one at Cochin and other at Munanbam. Minimala, Meenachil, Pamba and Achankovil rivers flow into the lake in the southern side of Thannermukom bund and Muvattupuzha, Periyar and Chalakudy rivers flow north of the bund. These rivers carry annually 732560MT of sediments into the lagoon (Narayana et al., 2006). The study area map is given in Fig.1.

2.2 Data used

Landsat satellite data acquired by US Geological Survey (USGS) and Global Land Cover Facility (GLCF) were downloaded. Satellite images pertaining to the years 1973, 1992, 2005 and 2015 were used for this study. The details of the satellite data and toposheets are given in the Table 1 and Table 2.

Table 1: Satellite data used for the present study

Sensor	*Acquisition Date*	*Source*	*Resolution (m)*	*Path/Row*
MSS	10-02-1973	GLCF	60	155/53
TM	31-12-1992	GLCF	30	144/53
ETM+	10-02-2005	USGS	30	144/53
ETM+	22-02-2015	USGS	30	144/53

Table 2: Toposheets used for the present study

Toposheets No	*Year*	*Scale*	*Source*
58C/6,58C/5,58B/8 58B/4	1968	1:50,000	Survey of India

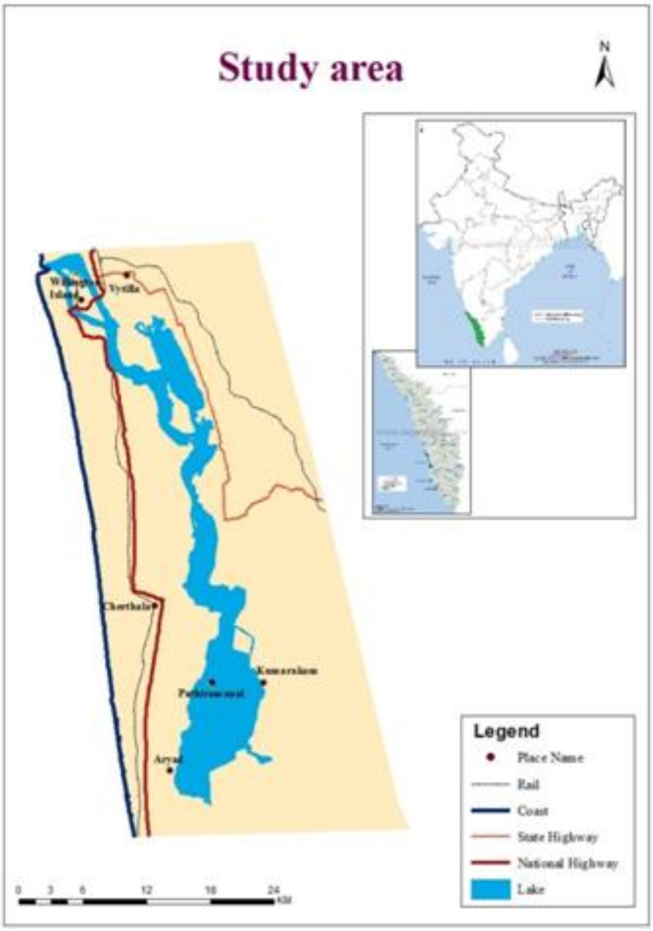

Figure 1: Location Map of the study area.

2.3 Image Preprocessing

In the present study the Erdas image and ArcGIS software were used for the processing of satellite data. The information stored in satellite imagery is not in real spectral indices but it is in the form of digital numbers (DN).The radiance was calculated from these digital number, from which reflectance was calculated. In the present study, the DN values were converted as top of the atmosphere (TOA) radiance using the following equation of Wilson and Rocha (2012).

$$L_\lambda = LMAX_\lambda - LMIN_\lambda \frac{(Q_{cal} - Q_{cal}MIN) + LMIN_\lambda}{Q_{cal}MAX}$$

Where, Lλ is spectral radiance received at the sensor in watts per metre squared * ster * µm (Wm−2 sr−1 µm−1), Gain is rescaled gain contained in the image product header file (Wm−2 sr−1 µm−1), Qcal is quantised calibrated pixel values in DN, Bias (or offset) is the rescaled bias contained in the image product header file (W m−2 sr−1 µm−1), QcalMAX is the maximum quantised calibrated pixel value (corresponding to LMAXλ) in DN, QcalMIN is the minimum quantised calibrated pixel value (corresponding to LMINλ) in DN, LMAXλ is spectral radiance that is scaled to QcalMAX (W m−2 sr−1 µm−1), and LMINλ is spectral radiance that is scaled to QcalMIN (W m−2 sr−1 µm−1).

The atmosphere has a significant impact on satellite data, Such as information loss caused by scattering by the atmospheric constituents and aerosol. Atmospheric correction for the scattering of aerosols can be assumed to be of the order of one percentage of the total reflectance of ground resolution cell. $L_{1\%}$ was estimated using the equation given below (Pacheo et al., 2014).

$$L_{1\%} = \frac{0.01\, E_{Sin\,\lambda i}\, Cos\Theta_0}{\Pi d^2}$$

Where $E_{sun\lambda i}$ is the exo-atmospheric solar irradiance for band $\lambda i(Wm^{-2}\ \mu m^{-1})$, and d is the Earth–Sun distance (in astronomical units).

The surface reflectance was estimated from the TOA radiance reduced for aerosol scattering by using the following equation. (Nazeer, M., 2014).

$$\rho = \frac{\Pi d^2 (L_{sat\lambda} - L_{haze\lambda})}{E_{Sun\lambda} cos\Theta s}$$

Where Lhazeλ is the path radiance for band λ (W m–2 sr–1 μm–1), Esunλ is the Exoatmospheric solar irradiance for band λ (Wm–2 μm–1), and d is the Earth–Sun distance (astronomical units).

2.4 Method of water body information extraction

Different pairs of band combinations are used to calculate the wetness index (Kumar et al 2015). In general, green and near infrared (NIR) (McFeteers, 1996; Leiji, 2009; Joao, 2012,; Feizhange et al. 2015), NIR and Middle infrared (MIR) (Willson and Sader, 2005), Green and MIR (Xu, 2006; Li, et al., 2011; Hezham, et al., 2013; Kumar and Lakshman, 2015; Gautan, et al., 2015), were used to calculate wetness index. In the present study, NDWI and MNDWI were used to extract water body information. The NDWI is expressed as follows

NDWI= (Green-NIR)/ (Green + NIR) (McFeeters, 1996).

Where green is the green band, such as in MSS it is band 4 and band 2 in TM and NIR is the near infrared band, such as band 6 in MSS, band 4 in TM.

NDWI is computed using the green and NIR bands of the spectral band. Using this index water features have positive values while the vegetation and soil usually have zero or negative values. However, the application of NDWI in water region with a built-up land background doesn't achieve its goal as expected. The extracted water information in those regions was often mixed with built up land noise. This means that many built up land features also have positive values in NDWI images. As, a result the computation of the NDWI also produce a positive value for built up land just as for water. However, a detailed examination of the signatures revealed that the average digital number of the TM band 5 representing MIR radiation, is much greater than that of TM band 2 (green). Therefore, if MIR band is used instead of the NIR band in the NDWI, the built up land should have negative value. Based on this assumption, the NDWI is modified by substituting the MIR bands for the NIR band. MNDWI can be expressed as follows (Tebbs et al., 2013 and Feizhang et al., 2015).

MNDWI= (Green –MIR)/ (Green + MIR)

In MNDWI index water will have greater positive values than the NDWI, because it absorbs more MIR light than NIR lights, the built-up land, soil and vegetation will have negative values in this wetness index.

MNDWI was applied only to 2005 and 2015 satellite images, because the MSS images of the year 1973 and 1992 were lacking the MIR band. So NDWI was applied only for those images which lacked MIR band. Theses calculation was done using the spatial analyst extension in ArcGIS. After calculating the NDWI and MNDWI index for corresponding satellite images, the estuary area was manually digitized using Arc GIS software and area was calculated using the same.

2.5 Dynamic Degree of the lake area

In this study, the estuary area of different study periods was derived using following equation (Feizhang, 2015 and Li et al., 2009).

$$K= (U_b - U_a) / U_a \times 1/T \times 100$$

Where, K is the dynamic indicator for lake area, U_a and U are the areas of the lake at start date and at the end date and T is the time scale under consideration.

3. Results and Discussion

In this paper, the author adopted NDWI to extract water body information for 1973, 1992 images and MNDWI to extract water body information for 2005 and 2015 images. As shown in Fig: 2 the estuarine areas have changed in each of the years for which study was undertaken. The result shows that the overall decrease of the estuarine area during the study period is 12.28 sq km (6.93%).

The change in the Vembanad Lake surface area is shown in Fig: 3, which reveals that there occurred a noticeable shrinkageduring the study period (42 years). In 1973 estuary had 177.29 sq km area and in 1992 the area was reduced to 169.22 sq km. The estuary continued to shrink to 166.29 in 2005 and 165.01 in 2015. The total areal loss of the estuary was 12.28 sq km between 1972 and 2015.

From the Table: 3 during the period 1973-1992 the Lake area is decreased by 8.07 sq km and the dynamic degree is -0.25 %. ;during 1992- 2005 the estuarine area had declined by 2.93 sq km and the dynamic degree is -0.14% ; during 2005-2015 the estuarine area decreased by 1.28 sq km and the dynamic degree is -0.18%. This indicates a declining trend. Using the ArcGIS software the area of the estuary is delineated and analysed. The overall decline of estuary during the study period is 6.93% and which is shown in Fig: 4.

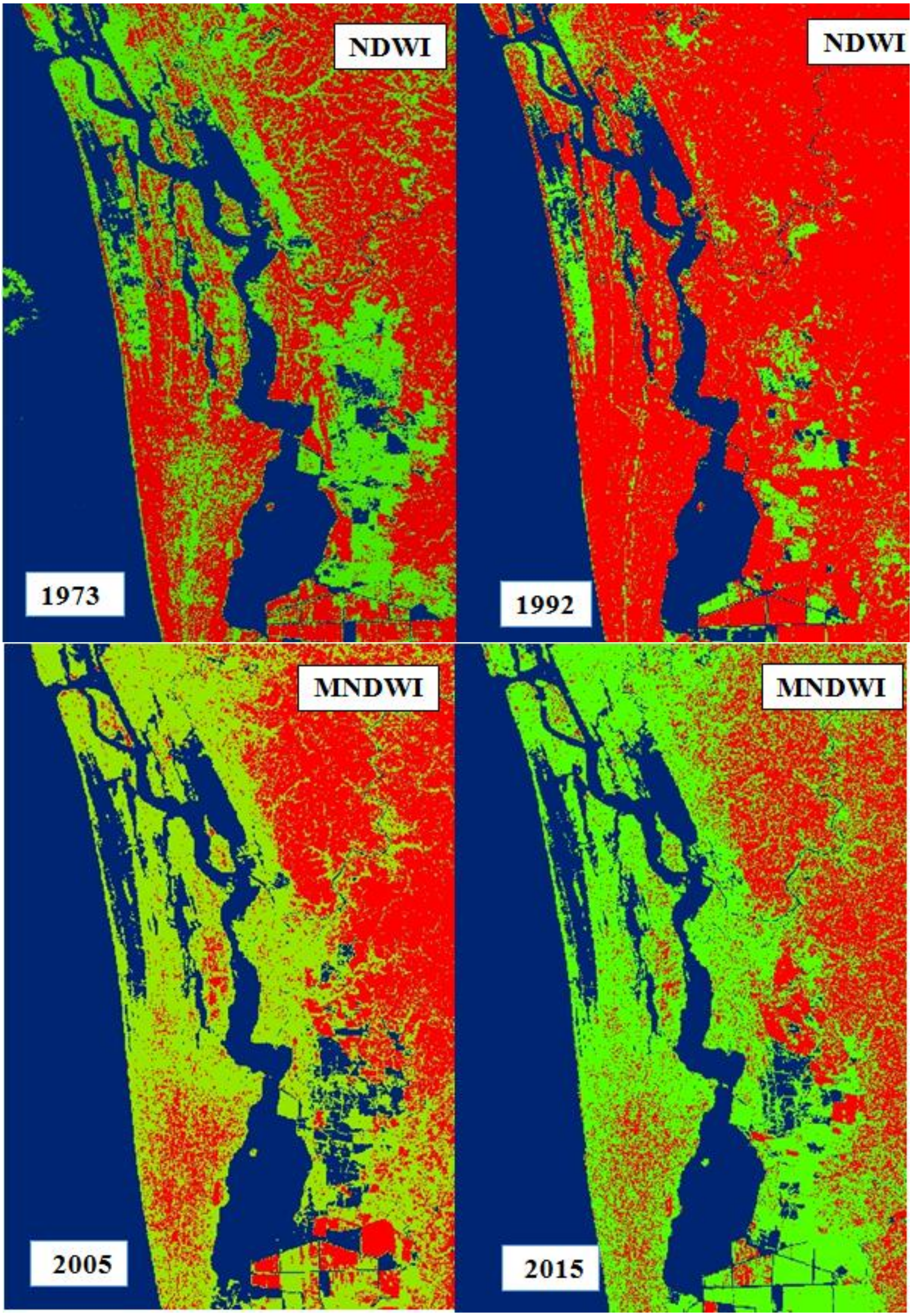

Figure 2: The 1973 and 1992 image shows the water body (blue colour) as extracted from NDWI and 2005 and 2015 Image (blue colour) shows the water body estimated from MNDWI

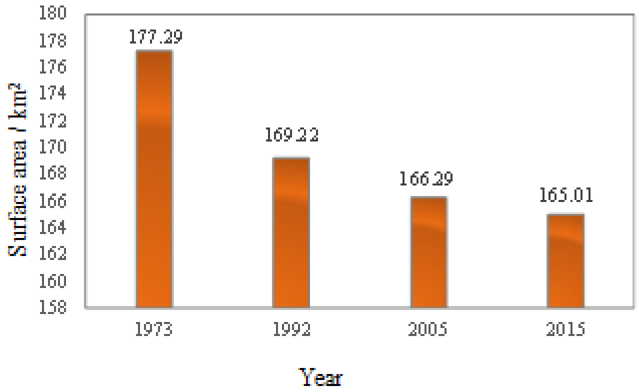

Figure 3: Surface area change of Vembanad Lake between 1973 and 2015.

Table 3: Change in estuarine area from 1973 to 2015.

Period	*Lake area decreases in sq km*	*Dynamic degree (K) %*
1973-1992	8.07	-0.25
1992-2005	2.93	-0.15
2005-2015	1.28	-0.08
1973-2015	12.28	-0.18

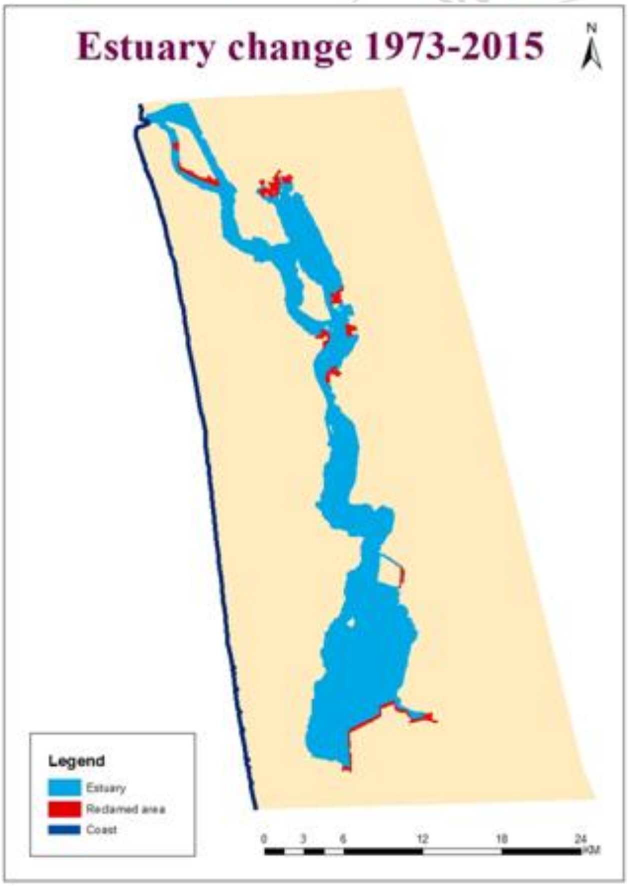

Figure 4: Spatial changes of Estuary during 1973-2015

Figure 5 (a): Lake area reclaimed for Willington Island development.

Figure 5 (b): Lake area reclaimed for paddy cultivation in Southern part of the lake.

During 1973 -1992 the estuary has decreased by an area of 4.45%, where 1.15 sq km estuary near R and H blocks were reclaimed and 0.46 sq km of estuary area was reclaimed for the extension of Willington Island. The field verification of the relevant study is given in Fig: 5a and 5b. The spatial changes during this period is given in Fig: 6a. During 1992-2005 the estuarine area was apparently declined by 1.73% among which a big portion of the estuary (0.61 sq km) was reclaimed for the development of Willington Island and 0.32 sq km area in the North Eastern arm of the estuary is reclaimed for paddy cultivation. Spatial changes during this time are shown in Fig: 6b. In 2005-2015 periods 1.16 sq kmof estuary area is reclaimed for cultivation and plantations which is shown in Fig: 6c.

4. Conclusion

The pace of developmental activities focusaround the Vembanad Lake area has eventually led to the decline of the estuarine area. The developmental activities include expansion of island area and agricultural processes. Firstly the expansion of the port and container terminal area of the Willington Island has made a decrease in the area of northern part of the estuary. Secondly the conversion of a portion of southern part of the estuary for agricultural purposes, mainly for the implementation of reclamation of lake waters into paddy fields. These factors have gradually reduced the area of the lake during this period as evident from the study conducted. The combined use of satellite images and NDWI & MNDWI techniques has proved to be flawless in the estimation of differences in area of the Vembanad Lake. The study also warrants ceasing unauthorised encroachment of lake area and seeks intervention of authorities to implement necessary regulation and better estuary protection protocols for Vembanad Lake.

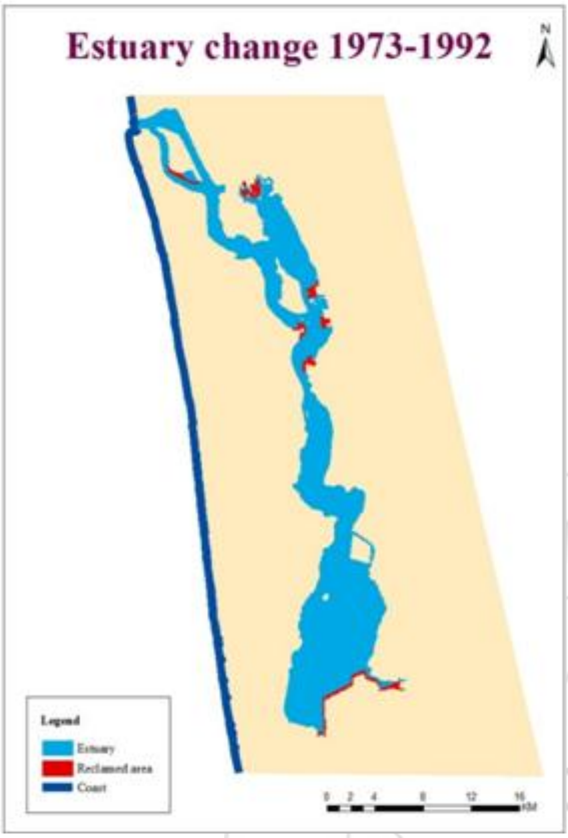

Figure 6 (a): Spatial change during 1973-1992

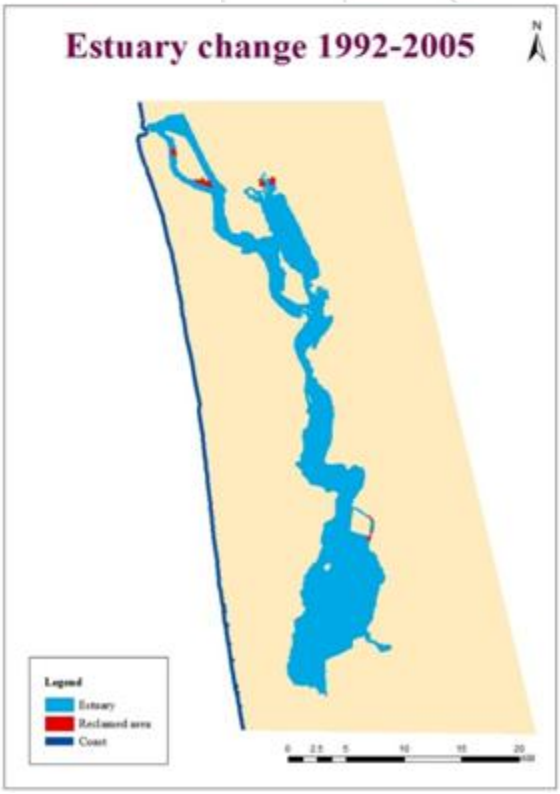

Figure 6 (b): Spatial change during 1992 – 2005

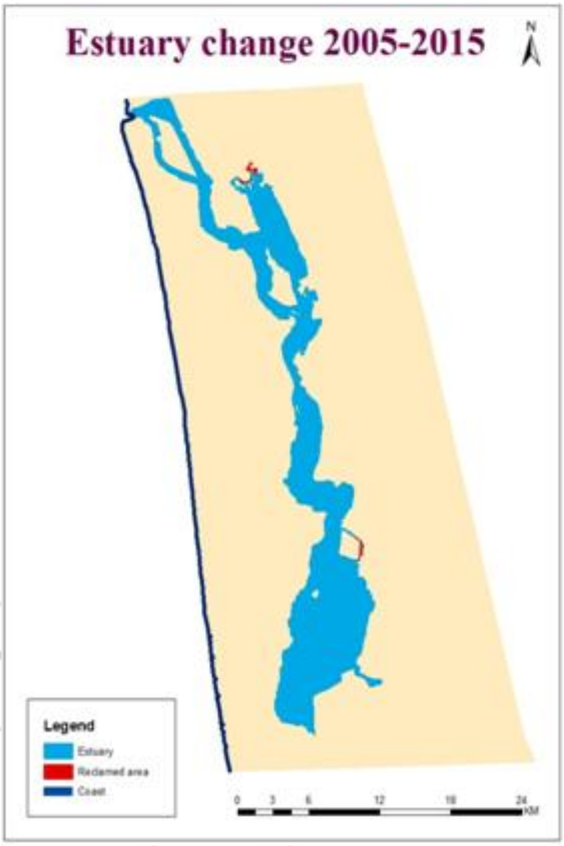

Figure 6 (c): Spatial change during 2005 - 2015

5. Acknowledgement

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