



Wetland shift monitoring using remote sensing and GIS techniques: landscape dynamics and its implications on Isimangaliso Wetland Park, South Africa

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Abstract

Various forms of competition for water and amplified agricultural practices, as well as urban development in South Africa, have modified and destroyed natural wetlands and its biodiversity benefits. To conserve and protect wetlands resources, it is important to file and monitor wetlands and their accompanied land features. Spatial science such as remote sensing has been used with various advantages for assessing wetlands dynamic especially for large areas. Four satellite images for 1987, 1997, 2007 (Landsat 5 Thematic Mapper) and 2017 (Landsat 8 Operational Land Imager) were used in this study for mapping wetland dynamics in the study area. The result revealed that the natural landscapes in the area have experienced changes in the last three decades. Dense vegetation, sparse vegetation and water body have increased with about 14% (5976.495 km²), 23% (10,349.631 km²) and 1% (324.621) respectively between 1987 and 2017. While wetland features (marshland and quag) in the same period experienced drastic decrease with an area coverage of about 16,651.07 km² (38%). This study revealed that the shift in the vegetation and water body extents have contributed detrimentally to the drastic declined in the Isimangaliso Wetland Park in recent years. Consequently, this development might have negative effects on the wetland ecosystem and biodiversity and the grave state of the wetland in the study area requires an urgent need for protection of the dregs wetland benefits.

Keywords Remote sensing · GIS · Wetland monitoring · Landscape dynamics · Isimangaliso

Introduction

Globally, wetlands have been identified to have various benefits to society, such as purifying water, controlling erosion and providing habitat for wetland-dependent species. However, it continues to be destroyed and poorly managed. Wetlands have been recognised as one of the natural assets that provide various important supports to the human community, however, this natural asset has been threatened by various human and

natural events. In South Africa, wetland is threatened by agriculture, urban development, climate change and other damage associated with it, such as invasion by alien species and the impacts of fertilizers and pesticides (Orimoloye et al. 2019; Rebelo et al. 2019). Effective and accurate mechanisms for assessing and monitoring wetlands are required due to the degradation and destruction of natural wetlands, in spite of its crucial services and benefits they contribute to the ecosystem and humankind (Orimoloye et al. 2018a).

Studies have shown that remote sensing data such as derived biophysical information and vegetation indices, have important benefits, unusually high temporal resolution of observations, spatial distribution and data accessibility, for monitoring and assessing temporal patterns of land ecosystems (Adefisan et al. 2015; Stephen et al. 2017; Onamuti et al. 2017; Abdelaziz et al. 2018; Orimoloye et al. 2018a, b). As a result of its indispensable source of multi-spectral information of the land surface features, remote sensing data have been utilized in several studies to appraise important ecosystem characteristics including wetland pattern, land surface temperature, urban

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growth and many other features (Onamuti et al. 2017; Abdelaziz et al. 2018; Orimoloye et al. 2018a, b).

Furthermore, the present setting of changing socioeconomics and climate-related events as well as growing inequalities and extinction of resources, and growing threats to natural assets includes wetlands. There is, without doubt, a need to view conservation and monitoring strategies, including their assessment using spatial science within a wider range of environmental, social and economic values, which included in the concept of sustainable growth. Consequently, there is a need to establish appropriate measures among conservation, sustainability and development at the local and regional levels, so that these natural assets can be protected through proper actions by providing vital information for the economic and social development, and the individual satisfaction of the societies and the environment (Orimoloye et al. 2018a). The information in Table 1 presents relevant studies that used remote sensing technology to assess and monitor wetland incorporated with the period, area of study and satellite data used.

Isimangaliso Wetland Park and its biodiversity benefits

The Isimangaliso Wetland Park (IWP) like other wetlands globally has its various benefits and values. From coral reefs and deep ocean gorges through to the salt and freshwater bogs, vegetation, dry woodland and mangroves. This spacious area in KwaZulu Natal, South Africa comprises of rich collection of biodiversity and spreads from the ocean to the tropical reefs. Due to the uniqueness of the wetland, it was recognized as one of Africa's great tourist sites. The importance of the

IWP, especially during the current climate change, which might also serve as carbon sink (Bonan 2008; Canadell and Raupach 2008). This process is likely a positive value that may lower global temperature through evaporative cooling and carbon sequestration as asserted by Bonan (2008).

There are several wetlands available in various environments around the world, and they all have unique qualities. Moreover, they all have featured in like manner; they are natural habitats of rich biodiversity, and they have a crucial role to play in the lives of wetland creatures and human. Regardless of its nomenclature such as a quag, bog, marsh, swamp, pan, seep or fen, a wetland is a distinct ecosystem – a portion of land overfilled with water, either seasonal or long-term. It is generally a home to numerous types of plants and creatures.

IWP holds a more noteworthy varied variety than Kruger National Park or Botswana's Okavango Delta and is considered as South Africa's third-biggest secured region. The rich biodiversity of the IWP is one of the primary determinants of its special protection status. Several Species are the building-pieces of any given environment, yet in the IWP case there are various misidentifications and diverse invertebrates, which remain inadequately examined, or much-relinquished (Perissinotto et al. 2014). Study has shown that the park has various benefits such as animal habitations (Hansen 2013; Hart et al. 2014). Recently the observations in ISimangaliso Park has displayed a healthy, flourishing and hearty honey bee population with recent sufficient rain boosting all the local flowering kinds in the area which support the bee influx in the area. Furthermore, Wetlands are excellent filters, they trap solid deposit and eliminates pollutants, which helps to purify

Table 1 Relevant satellite-based wetland mapping studies and their geographical locations

S/N	Sensors	Time Span	Locations	References
1	MODIS	2000–2012	Poyang Lake, China	Chen et al. 2014
2	SPOT-5	2004–2006	Camargue, Southern France	Davranchet et al. 2010
3	Landsat	1984–1994	Kafue Flats, Zambia	Munyati 2000
4	1A LISS-II	1991–1992	Punjab, India	Chopra et al. 2001
5	Landsat	1988–2003	Yellowstone National Park, USA	Wright and Gallant 2007
6	RapidEye and Landsat	2010–2012	Plains and Prairie Pothole Region, USA	Gabrielsen et al. 2016
7	Landsat	1985–2011	Delmarva Peninsula, USA	Jin et al. 2017
8	Landsat	1983–2015	Sacramento Valley, California	Schaffer-Smith et al. 2017
9	Landsat	1984–2011	Douglas County, Washington state, USA	Halabisky et al. 2016
10	Landsat TM	2008–2011	Prairie Potholes, USA	Collins et al. (2014)
11	Landsat TM	2002–2003	Western Turkey	Reschke and Hüttich 2014
12	Landsat TM	1984–2007	Doñana National Park, Spain	Gómez-Rodríguez et al. 2010

water for drinking and domestic usage. This defeats the costly, human-made filtration techniques. In a semi-arid nation such as South Africa including the study area, the function of wetlands in filtering debris, before the solid particles in the wetland water joins a river course, is remarkably beneficial. Hence, this study seeks to assess land cover features of IWP from 1987 to 2017 using spatial science (RS and GIS), providing basic information on temporal dynamics of local wetland extent and its potential implications on biodiversity.

Study location and methodology

Isimangaliso Wetland Park is located in Kwazulu Natal Province of South Africa (Fig. 1) and occupies an area of about 3585.34 Km² consisting several ecosystems and a good number of visible and diverse landscapes. The park was identified in year 2000 as a world heritage site and this provides a fundamental responsibility to conserve and protect the wetland values at the local and world at large.

Four Landsat images for years 1987, 1997, 2007 and 2017 were acquired from USGS database freely. The spacing period and the data used were made due to their quality and cloud-free images. These acquired dates and period were selected based on vegetation phenology and seasonal water management of the targeted wetland. The images were geometrically registered and radiometrically normalized to an acceptable map projection. The image was separately classified into four categories include vegetation, sparse vegetation, water body, quag and marshland. Furthermore, supervised maximum likelihood classification techniques were used on all satellite images (Orimoloye et al. 2018b). The classified images produced were analyzed for change in each land feature categories by estimating them in a Geographic Information platform using ArcGIS 10.2.1 tool. This study also evaluated NDVI and NDWI from satellite data.

NDVI uses the NIR and red channels in its formula, which is shown below;

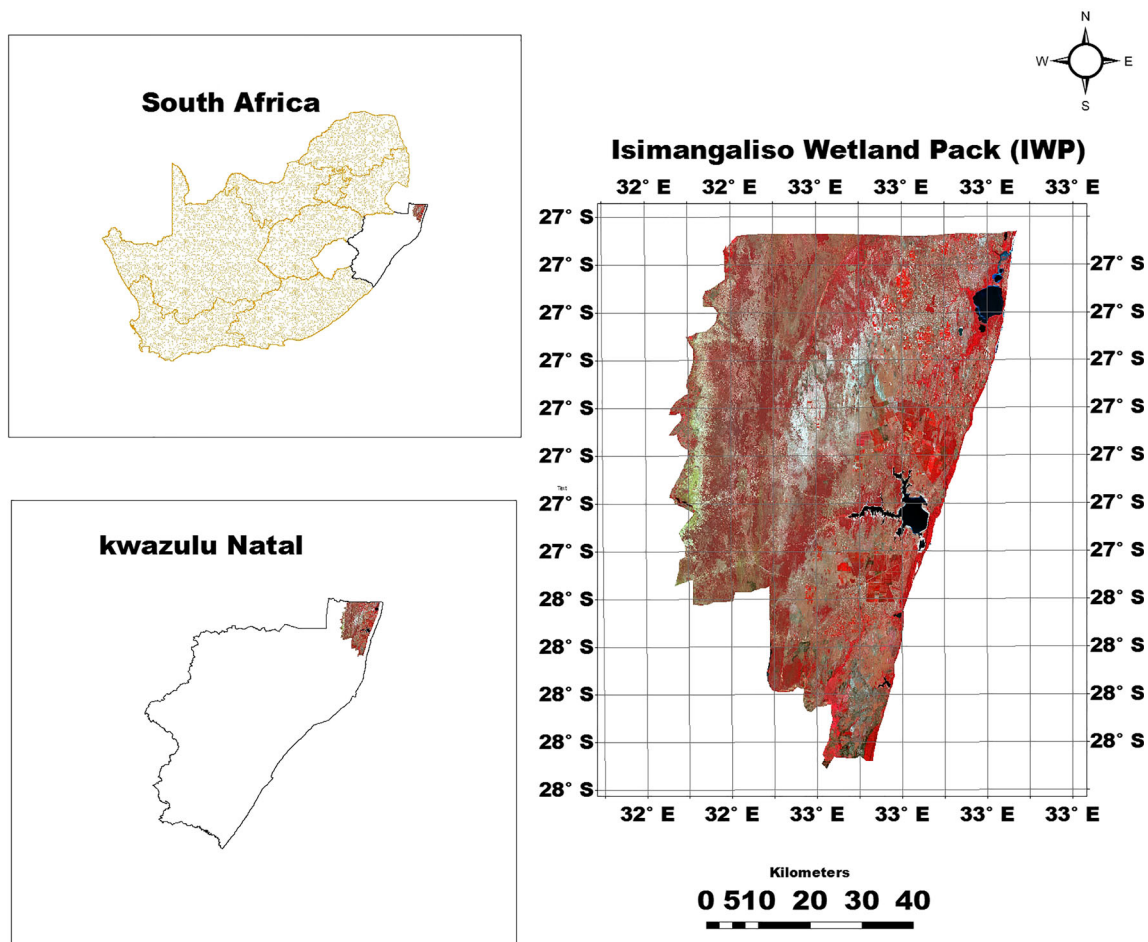


Fig. 1 Map of Isimangaliso Wetland Park (IWP)

Table 2 Matrix of the classified images of IWP land features

Classified Data	Vegetation	Sparse Vegetation	Water Body	Quag/ Marshland	Total	Commission Error (%)	User Accuracy (%)
Vegetation	105	3	5	2	115	8.70	91.3
Sparse Vegetation	2	97	4	4	107	9.35	90.65
Water Body	4	7	118	8	137	13.87	86.13
Quag and Marshland	1	1	6	98	106	8.54	92.45
Total	112	108	133	112	465	–	–
Omission Error (%)	7.25	9.9	11.28	8.25	–	–	–
Producer Accuracy (%)	93.75	90.1	88.72	87.5	–	–	–

Overall Accuracy = 90.02% Kappa Accuracy = 0.91, Bold values = correctly classified values

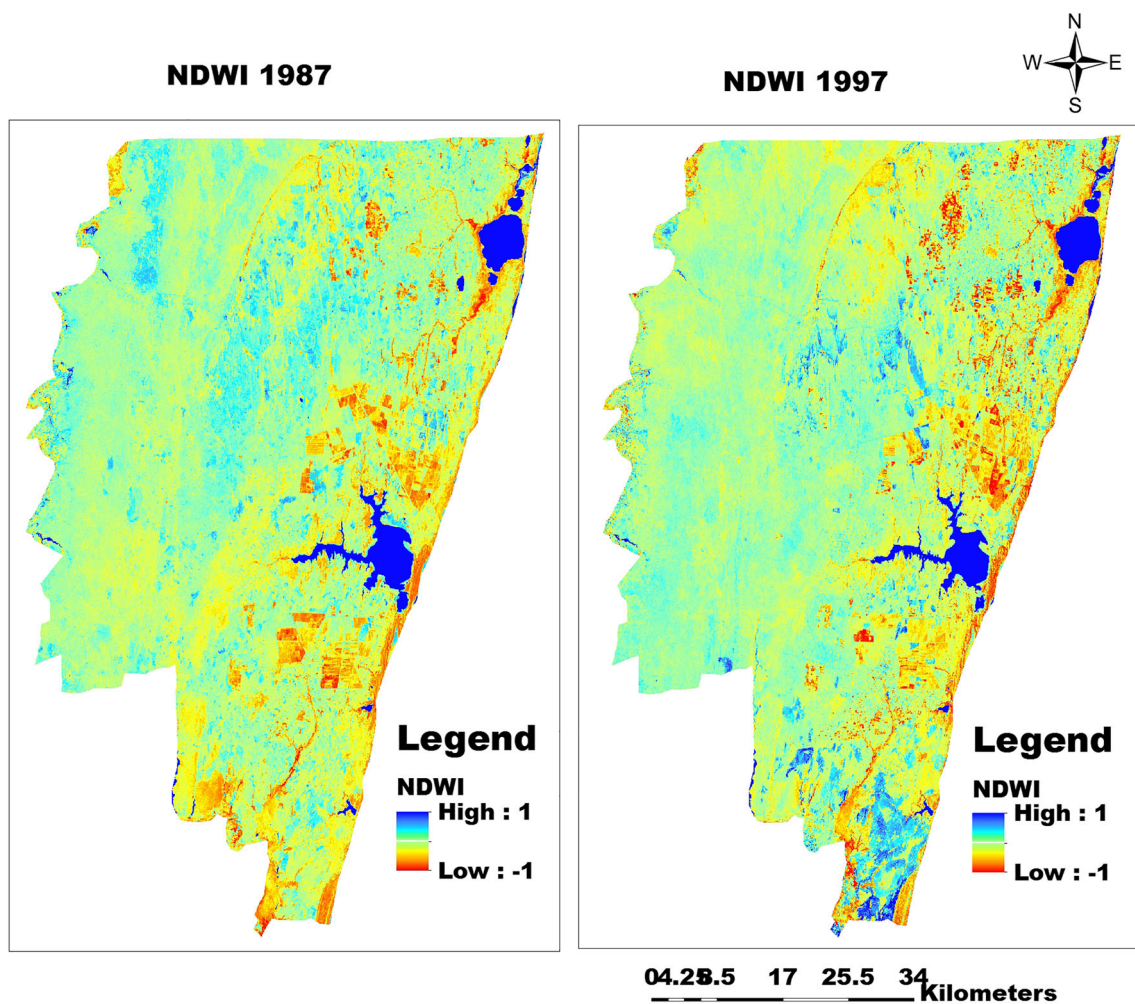


Fig. 2 Spatial pattern of NDWI for 1987 and 1997

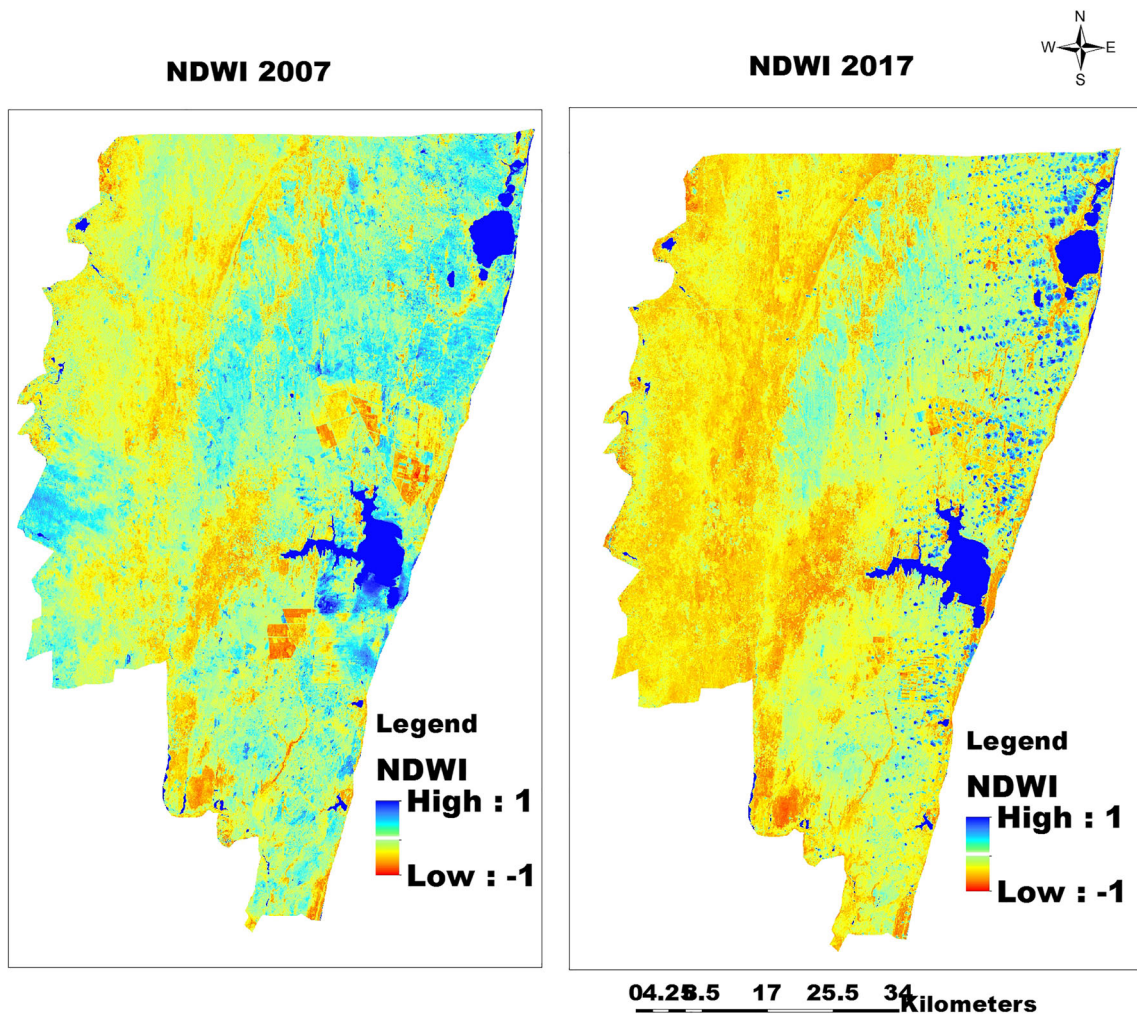


Fig. 3 Spatial pattern of NDWI for 2007 and 2017

$$NDVI = \frac{(NIR - Red)}{NIR + Red}$$

Where red and is the spectral reflectance measurements acquired in the red (visible) and near-infrared regions, respectively. The NDVI thus varies between -1.0 and + 1.0. NDVI is functionally, but not linearly, equivalent to the simple infrared/red ratio (NIR/VIS).

The formula for NDWI is given below;

$$NDWI = \frac{(X_{nir} - X_{swir})}{(X_{nir} + X_{swir})}$$

Where NIR is near infrared and SWIR is short-wave infrared wavelengths, proposed by Gao (1996).

Results and discussion

Classification accuracy assessment

With regard to valuable information extraction from satellite imageries, accuracy reveals the exactness between an accurate standard expected and a classified image of unidentified quality. The level of detail or information found with classification as asserted by Congalton & Green (2002). It is feasible to extend the accuracy of any classification in GIS environment by reducing the number of detail or by integrating the extensive classes rather than a particular feature. More so, lower precision gives the likelihood for higher accuracy. Nevertheless, the user of the map that offers only general classes cannot make precise observations about any given point on the ma (Congalton and Green 2002; Lillesand et al. 2015). The result from this

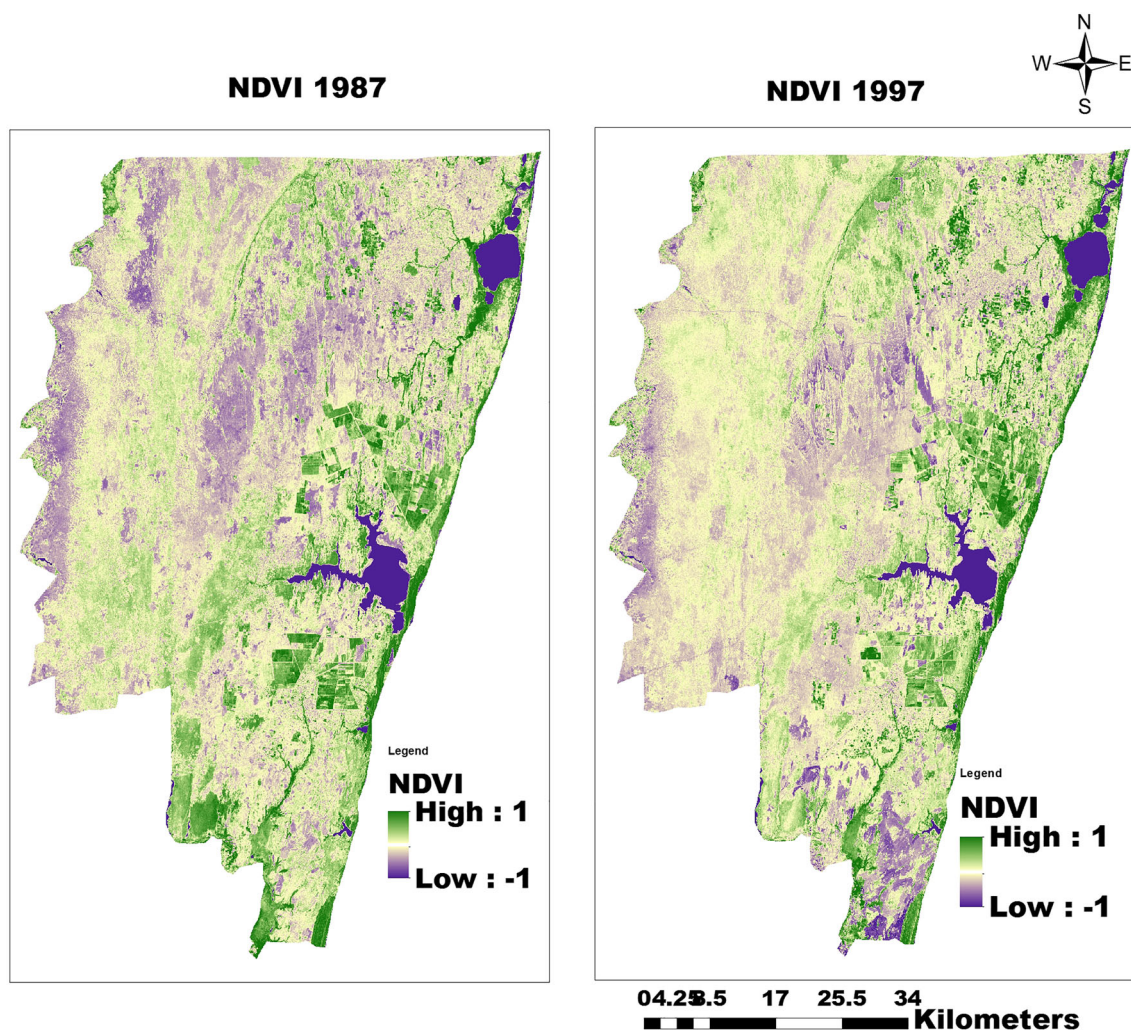


Fig. 4 Spatial distribution of NDVI for 1987 and 1997

study is not complete without its accuracy been assessed as asserted by Congalton and Green (2002). The attribute and the quality of the classified satellite image are determined by its accuracy assessment. The accuracy measurements method were used to verify the exactness for all the classified images (1987, 1997, 2007 and 2017).

The image classification of the study area showed an overall accuracy value of 90.02% and kappa coefficient 0.91. The accuracy assessment estimation revealed that vegetation and sparse vegetation have about 93.75 and 90.1% producer accuracy and 7.25 and 9.9% omission error respectively while water body and marshland have about 88.72 and 87.5 producer accuracy and 11.28 and 8.25 omission errors respectively (Table 2).

Spatial distribution of NDWI and NDVI between 1987 and 2017

This study has presented a spatiotemporal analysis of wetland dynamics in Isimangaliso Wetland using spatial science between 1987 and 2017. Figures 2, 3, 4, and 5 show the spatial pattern of vegetation and water index during the period of study. This study used NDVI and NDWI to assess the current state of water and vegetation pattern in the same period. The results revealed that the areas with low NDWI values are susceptible to wetland depletion while the areas with high NDWI connotes little or no wetland shrinkage occurrence as asserted by previous studies (Orimoloye et al. 2018a). Nevertheless, the study by Orimoloye et al. (2018a), the area

extent of their study focused on a small portion of the IWP. Consequently, the present study examined the entire coverage of the wetland in the area due to the shortcoming of the previous study.

The information in Figs. 4 and 5 presented the NDVI pattern of IWP between 1987 and 2017. The temporal and spatial shifts of the IWP wetland land features for three decades were observed and related to vegetation and water indices and their likelihood relationship. The NDVI was computed for each year to calculate the extent of the vegetated wetland cover in IWP. More so, to verify and to establish the factors influencing the vegetation shift in the area was related to the phenology of the wetland dynamics

as well as water index. The result confirmed that there exists a vegetative relationship between the wetland and vegetation change as asserted by previous studies (Lee and Yeh 2009; Petus et al. 2013; Orimoloye et al. 2018a).

Spatial pattern of landscape dynamics and wetlands shift in the study area between 1987 and 2017

The study area was classified into four land feature categories calculated from remote sensing data (TM and OLI/TIRS) for the years 1987, 1997, 2007 and 2017. In year 1987, wetland occupies the largest area amongst all the four land feature types with about 73% (31,999.06 km²) of the

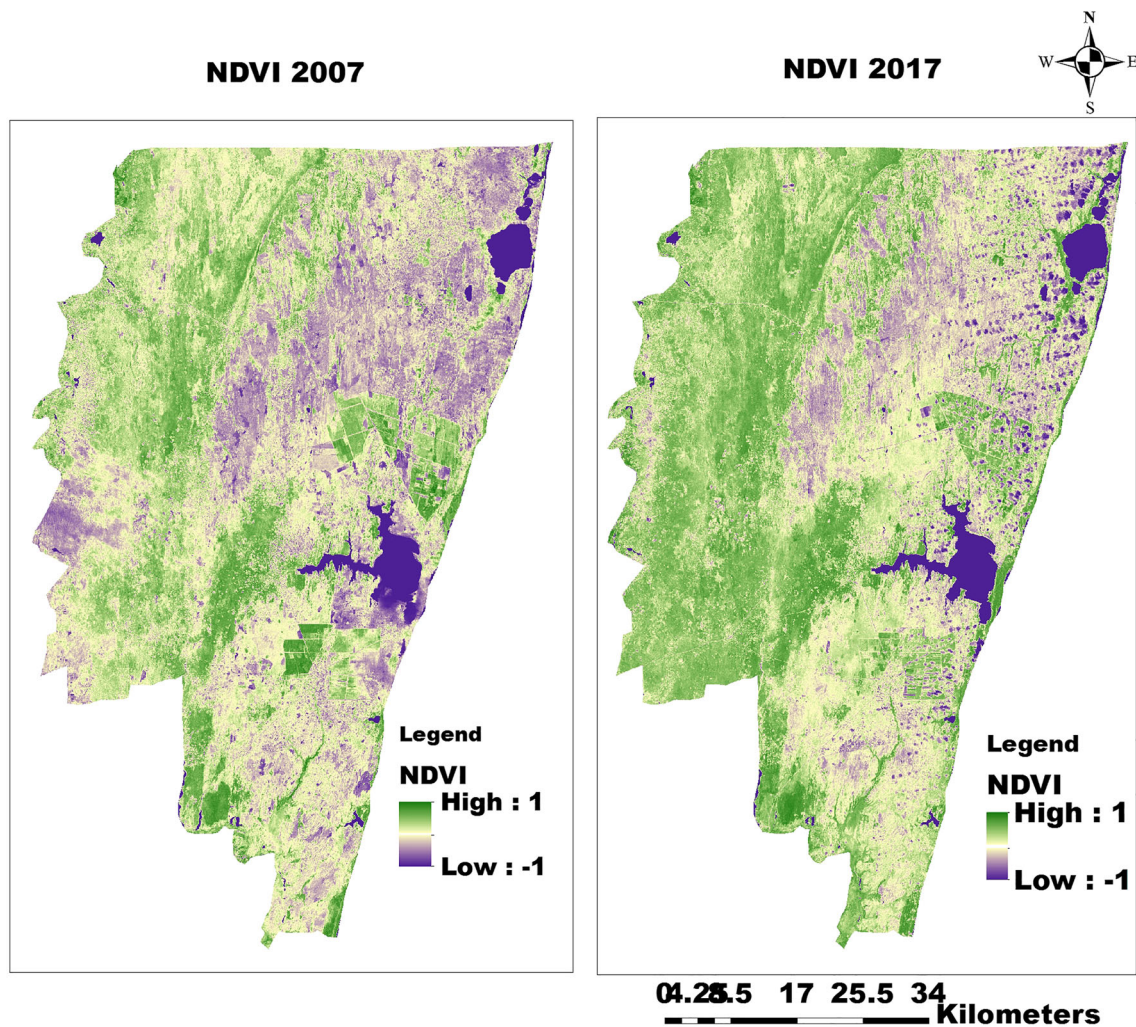


Fig. 5 Spatial distribution of NDVI for 2007 and 2017

total land cover in the area followed by sparse and dense vegetation with about 20% (8549.631 km²) and 5% (2238.912 km²) respectively in the same period. While water body covers about 823.68 km² (2%) which connotes that the area was dominated by wetland features in year 1987. More so, the result further reveals that in year 1997, wetland feature (marshland and quag) declined with about 8% from the previous decade (Figs. 6, 7, and 8) while other land features in the area such as dense and sparse vegetation increased with about 2% and 6% respectively and water body experienced slight increase in the same period.

The information in Fig. 8 revealed that there exists in wetland shift compared to previous decades where marshland and quag declined with about 25% while dense, sparse vegetation and water body cover areas rise by 6%, 18%

and 1% respectively from the previous decade. It was also deduced from this study that in year 2017, there exists a drastic decline in wetland cover in the area with about 5% compared to its extent in year 2007, this development might have a serious impact on the wetland animals and the environment (Petus et al. 2013; Orimoloye et al. 2018a). The result also showed that vegetation increased by 2318.994 km² (6%) while water body declined by 33.74 km² in the same period.

A significant increase has been noticed in area covered by vegetation amongst all land features (Figs. 6, 7 and 8). This development indicates that climate change is providing favorable conditions for growth and development of vegetation (Gabrielsen et al. 2016; Jin et al. 2017; Schaffer-Smith et al. 2017) since the

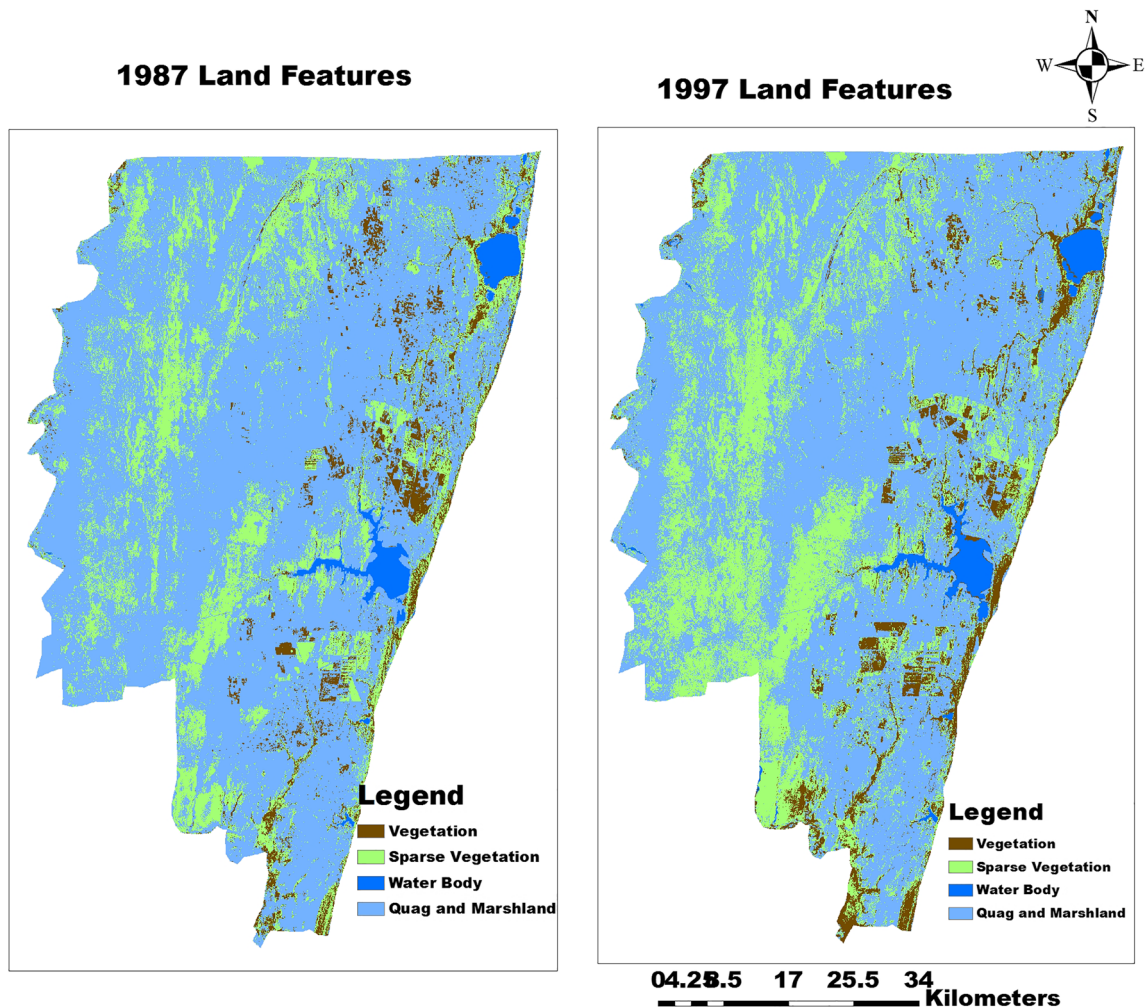


Fig. 6 Land features for 1987 and 1997

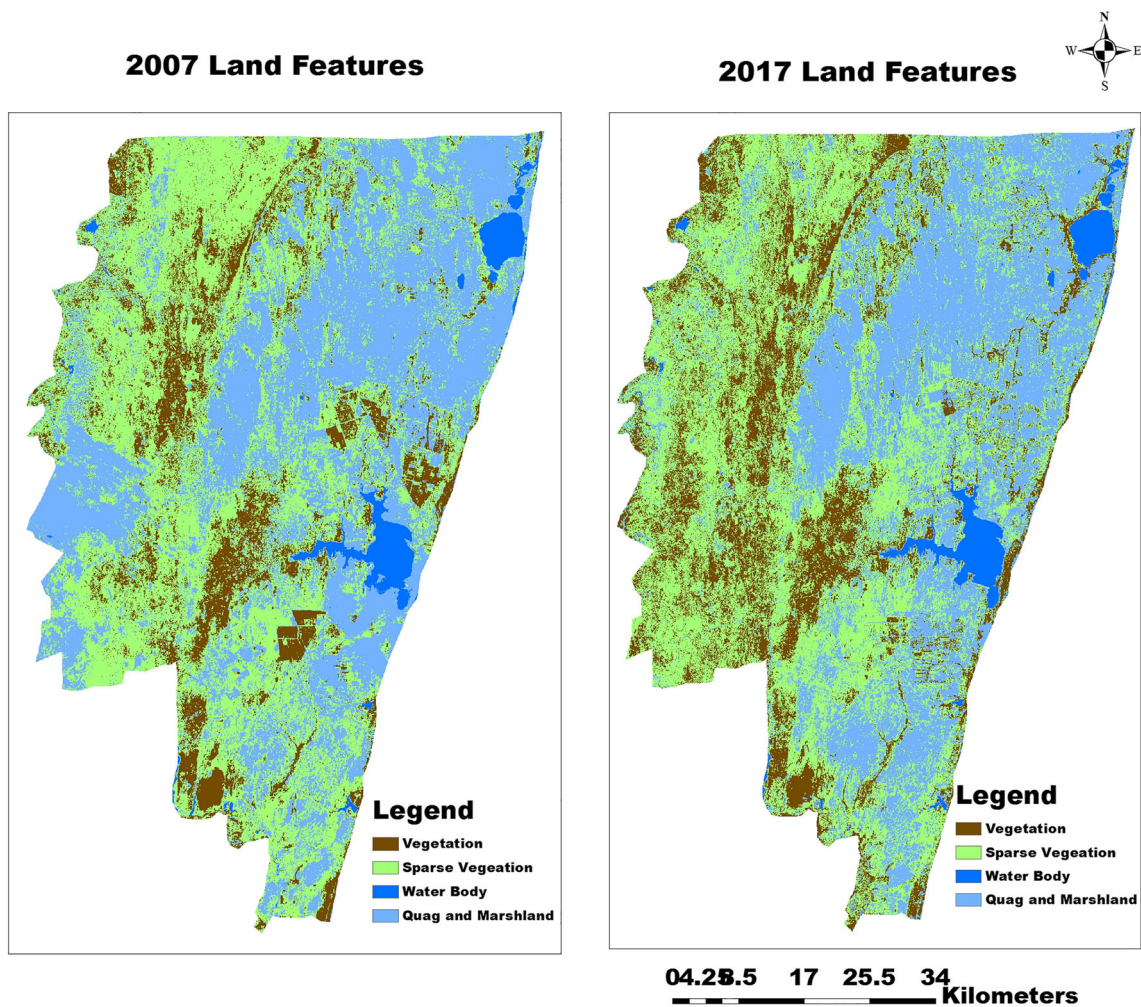


Fig. 7 Land features for 2007 and 2017

anthropogenic events are rare in the area. In addition, environmental degradation and invasive species might also play an important role in the wetland depletion in the area (Houlahan and Findlay 2004; Ehrenfeld 2008; Feng et al. 2017). Increase in the vegetation cover as well as slight increase in water body in the area show a sharp contrast against the world trend in recent years, almost every region of the world is facing the problem of the vegetation and water depletion issues (Onamuti et al. 2017; Orimoloye et al. 2018a, b).

Conclusion

Multispectral and multiyear remotely-sensed information provided a good presentation of wetland dynamics in the study

area. This study reveals that the wetland has witnessed drastic decrement during the period while vegetation cover increased in the same period. The shrinkage of the wetland in the area can be traced to the vegetation invasion in the recent year over the area.

The study found that the NDWI and NDVI indices increased considerably more in recent year (2017) than in the previous decades. This might have contributed to the wetland shrinkage during the period. Conversely, the spatial trend of dense and sparse vegetation increased in recent years, with the NDVI values closed to 1 in the major part of the study area which connotes that vegetation has almost displaced wetland in the region. Consequently, if this wetland shift persists, such development can have negative effects on the ecosystem and wetland animals as well as environmental health deterioration. The results further suggest that the NDWI and NDVI can be

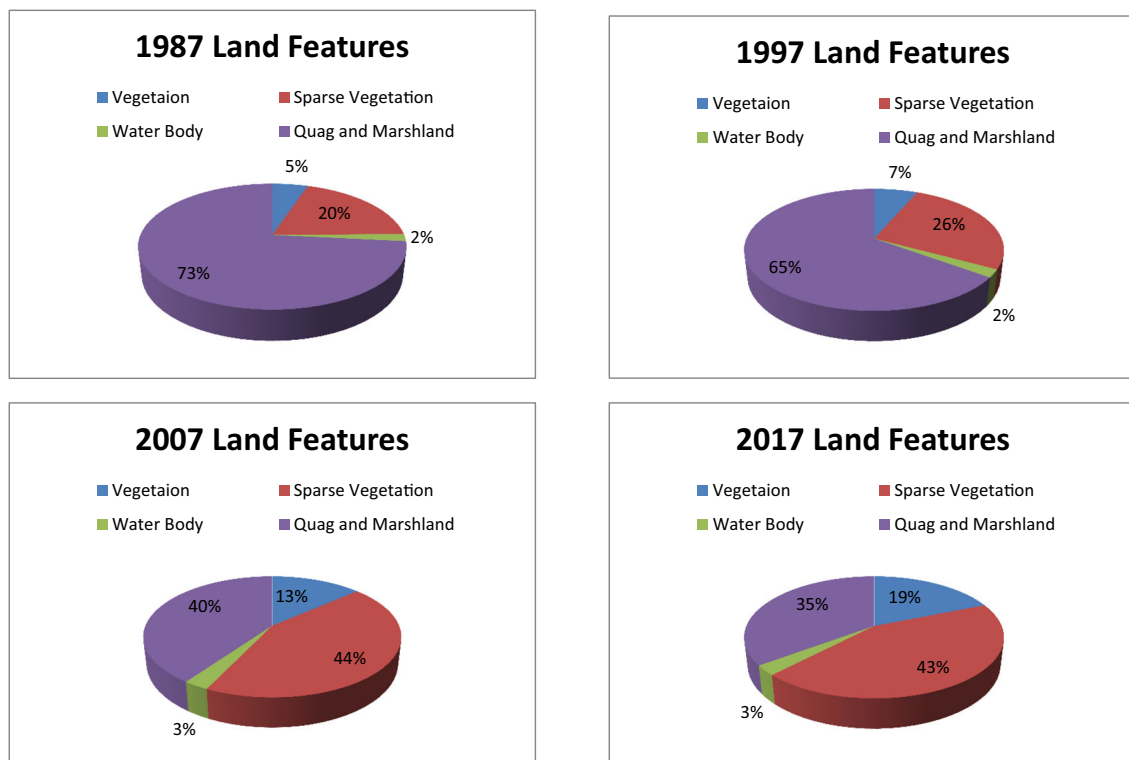


Fig. 8 Land features of IWP between 1987 and 2017

co-joined with land feature classification to identify the state of wetland and its potential implication on biodiversity and the environment. This study further found that the shrinkage of wetland extent in 2017 was more evident than in the previous decades. However, using NDVI and NDWI, as well as land feature classification may not give the ultimate outcome on wetland depletion as other factors can also be assessed. Subsequently, a more thorough wetland dynamics assessment and landscapes monitoring, anthropogenic activities such as agricultural practices, human encroachment and other natural factors include climate variables (rainfall, evapotranspiration, temperature and relative humidity) coupled with remote sensing information are required.

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Compliance with ethical standards

Competing interests The author declare no conflict of interest.

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