JOURNAL OF METEOROLOGY AND CLIMATE SCIENCE
J. Met & Clim. Sci. 19(1): 10-21 (June, 2021)

N.Met.S
Nigerian Meteorological Society

Loss of Wetlands in Lagos (Nigeria) and the adjacent territory: Implications for flood control

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Abstract: *Population growth, with its concomitant pressure for more housing developments and eventual urban sprawl have been touted as chief contributors to the problem of urban flooding in Lagos (Nigeria). It has, therefore, become necessary in the light of the frequent flooding in Lagos in the recent years, to study one major surface feature by which nature has always managed the occasional abundant surface water flow (flooding) within the urban space - wetlands. Landsat TM and Sentinel-2 images obtained via remote sensing and processed with ENVI software were used to study the loss of wetlands in the Lagos conurbation and the adjoining areas within the last 30 years to see how this loss of wetlands has impacted the ability of the environment to manage superfluous surface water flow. Using the Supervised Maximum Likelihood classifier technique, it was found that within the 30-year period, the study area has lost about 59% (representing about 540.8 Km^2) of its original area mainly to the built-up area, ostensibly for housing and infrastructural development. The implications of this tragic situation for flood control and other ecosystem services are discussed. Recommendations have also been put forth for future research.*

Keywords: *Flooding, wetlands, urban sprawl, Landsat TM, Sentinel-2.*

INTRODUCTION

This paper is the sequel (Part 2) of a two-part consideration of landscape and wetland management in the control of floods in the Lagos (Nigeria) conurbation (see [15]). In Part 1 [15], it was noted that man's interference in nature's own way of draining its basins or catchments in the context of the study area often upset the balance, thereby creating, or worsening the flood problem. The focus in this paper is on remote sensing analyses of the wetlands of the study area (Lagos) to see how they have changed over three decades and impacted the flood situation.

Urban flooding is often attributable to increased surface pavements that are very frequently a part of the urban space. Urban climate literature is awash with this fact (e.g., see [2, 3, 4, 33]). Often overlooked though, in the Lagos situation, and not exhaustively discussed is the role of wetlands in the natural management of the floods, and how the changes in their quantity or distribution may impact or has impacted the flood scenario.
Without doubt, a sizeable proportion of the flooding in the Lagos conurbation is attributable to the encroachment of development on the surrounding wetlands with their subsequent depletion. Equally depleted are the natural channels that conduct surface water, thereby inhibiting them from effectively carrying out the vital ecosystem service of flood control. These facts were echoed in [15]. Unfortunately, there do not seem to be extant laws expressly prohibiting housing development on sensitive ecosystems like wetlands by landowners and developers, or where these laws exist, they do not seem to be vigorously implemented. So, such owners and developers seem to be at liberty to do as it seems good to them – sell or sandfill the wetland of interest and build on them [23, 24]. This has been christened "reclamation" in many parts of the world where such practices hold (e.g., [14]). It becomes necessary, therefore, in the light of the ecosystem services that wetlands offer, particularly to the environment, and to the society at large [5, 7, 10, 16, 25, 31], to take stock of them over time, and see how much of this vital natural resource has been lost to other uses, and then contextualize this loss to a surge of flooding in recent years in, and around the city of Lagos.

A couple of studies have been conducted to document the loss of wetlands within the Lagos urban space (e.g., [23, 24]). However, these studies have either covered only a segment of the area covered in this work (see [24]) or used a method of analysis that may not be entirely without inherent error (see [23]).

For instance, the parallelepiped supervised classification technique used in [23] in mapping the spatial changes in the wetlands of Lagos/Lekki lagoons of Lagos has an inherent error of having some pixels being omitted in the classification because of the computational constraints involved in the algorithm [17]. In this work, a better classification algorithm – the supervised Maximum Likelihood Classification (MLC) scheme – is used. The MLC technique ensures that all pixels are classified. It is the most common supervised classification method for wetlands [25].

Research investigations in the study area have been "unfairly" tilted towards relations between wetland loss and urban growth than the effect of wetland loss on other areas of ecological and environmental importance like urban flood control. Most of the land use land cover (LULC) classifications encountered in the literature for the region include forest, or their sub-classes; water bodies; the built area or their sub-classes – industrial, commercial, low, medium, and high density, etc [1, 23, 24]. Wetlands as a class for special research has not featured prominently. However, as already noted, because of the enormous benefits of these wetlands, they have been given greater focus in this study. In the larger Nigerian context, there have been more studies devoted to the use of remote sensing and GIS in the study of flooding, and flood vulnerability, than land use/land cover change. Therefore, the effect of wetland loss on flooding as an ecosystem service of wetlands is needful for the region and this paper intends to fill this void.

This study has been discussed in seven sections, namely, the meaning of wetlands and the convention that established its ramifications; the study area; a review of existing literature on Lagos wetlands with some comparison to similar cases elsewhere. These comparisons reveal that, perhaps no reliable and comprehensive inventory of wetlands of the study area presently exists. The other sections discussed include a focus on the data and the methodology adopted for this study – defining the area of focus of this research and systematically going through the procedure for the classification and change detection; a reflective discussion of the findings; the implication of the outcome of changes detected and what it means for flood control and a couple of other ecosystem services for the study area; and finally, a run-down of the highpoints of the paper in the conclusion section with some recommendations that are proposed.

What are Wetlands?

Under the 1971 Ramsar (Iran) Convention on Wetlands, also known as the Convention on Wetlands of International importance (The Convention), a "wetland" is defined as "any land area that is saturated or flooded with water, either seasonally or permanently" [28]. According to [29], before the mid-1970s, aquatic ecosystems were known by different terminologies including bogs, marshes, swamps, and so on. Wetlands are scattered in all biogeographic regions of the world where they directly and indirectly provide a range of vitally important ecosystem services that support the livelihoods and well-being of many populations [18]. However, The Convention has noted that recent estimates of global loss of wetlands could exceed 64% [28]. This means that wetlands are disappearing very fast due to changes in land use, particularly increased agricultural use and grazing; development of infrastructure, especially in urban areas; and the use of dams, dikes and canals to divert water. While inland wetlands include rivers, lakes, streams, aquifers, peatlands, marshes, ponds, swamps and floodplains, coastal wetlands consist of all coastlines, saltmarshes, mangroves, lagoons, estuaries, seagrass meadows and coral reefs [28].

In the context of this study, it is important to note the unique location of Lagos (State) within southwestern (SW) Nigeria and its unique endowment of wetlands. Lagos provides a suitable exit point for the rivers and streams within the catchment of SW Nigeria to empty into the Atlantic Ocean. Again, being adjacent to the ocean uniquely allocates to it barrier islands with the associated wetlands. So, this situates Lagos in a unique location of having ample wetlands both within the riparian zones, and farther away from them. These wetlands have acted as willing receptors of surplus surface water, and consequently flood control over the years.

Wetlands worldwide are known to perform this very important hydrological function in addition to providing a rich biodiversity of flora and fauna [13, 18, 27, 28]. Perhaps this is summarized by the National Research Council [20], that wetlands perform three major roles, namely, hydrologic, where wetlands reduce downstream flood peaks, act as groundwater recharge or surface water detention area; bio-geo-chemical, in which they improve water quality through the removal of nutrients, pathogens and pollutants; and as a habitat for numerous plant and animal species.

STUDY AREA

Lagos State is situated in the south westernmost corner of Nigeria and bounded by Latitudes 6° 22' 7" & 6° 42' 36" N; and Longitudes 2° 42' 22" & 4° 18' 0" E (see Fig. 1a).

Fig.1a: Location of Lagos state in Nigeria (Source: Adapted from www.maphill.com)

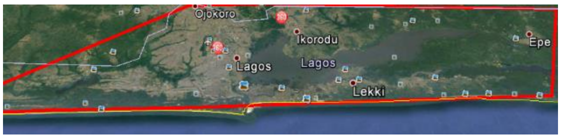

Fig.1b: Google satellite map of Lagos showing the study area.

Figure 1a above shows the location of Lagos State, within the African continent, while Figure 1b is the Google satellite map showing the built area, the water bodies, and their adjoining wetlands. The rainy season in Lagos lasts from March/April to October/November while the dry season lasts from November through February. Considering that December and February are within the dry periods of the year, there is low possibility that sizable puddles of water will be found outside of water bodies or wetlands during this period. So, it can be assumed that surface water observed in a remotely sensed image during this period (November – February) over the study area, may either be a water body, or water mixed with vegetation in the swamps of the riparian zones, or water associated with other wetlands. The population, soil types, expected yearly patterns of cloudiness, cumulative rainfall and dominant wind regimes were discussed in [15].

Literature

Land use/land cover is a subject of great interest in many climes. This is because changes in land use/land cover have grave implications beyond merely telling the story of urbanization; but also, for instance, of the changes in the distribution and characteristics of tropical forests [9]; international policy matters on climate issues [22]; and global environmental change in general [30]. According to Ozeismi and Bauer [25], many countries around the world have lost wetlands, but as their value to the society becomes recognized, it becomes more important to conserve them. Chief among these values in the context of this study is their ability to store floodwaters. Others include their ability to improve water quality, recharge groundwater aquifers, and protect shorelines [7]; support of a rich biodiversity for fish, other wildlife, and threatened and endangered species; and provide the opportunities for recreation and aesthetics. So, in the light of the services that these wetlands provide, it is important to study and inventory them, and to continually monitor them as well as to stem the tide of further losses [25].

Most of the previous researchers who have studied land use land cover (LULC) change for parts of Lagos have used remote sensing, and in some other cases coupled with GIS, to determine the effect of urbanization on land use, especially the conversion of certain land uses for other purposes for which they were not originally meant (e.g., [1, 19]. While [1] studied the LULC that have taken place in Lagos between 1984 and 2002, [19] studied the larger region of southwest Nigeria of which Lagos is only a small part to see how LULC has changed between 1986 and 2002. The land cover change map results of [1] (which did not consider wetlands), show that low density, forest, and agricultural land uses are the most impacted land uses as much of the land allocated for these land uses have been converted to other land use types. Mengistu and Salami [19] showed results similar to that of [1] for their chosen study area.

They showed that degraded forest was the most prevalent land use/land cover (LULC) type, pointing out that increased population, and economic activities were putting pressure on land resources. In a time-series study using three Landsat images (1990, 2000 and 2011) to map the wetlands of Ikorodu Local Government Area, a suburb of Lagos, Orji and Pepple [24] observed a conversion of wetlands into the built area, which was evident in the built area, increasing from 3.12 to 182.25Km² within 21 years (1990 to 2011). In another study of the spatial changes of the wetlands of Lagos/Lekki Lagoons, another suburb of Lagos, [23] attempted to quantify the wetlands and establish their precise locations. Their results showed that mangrove, and swamp wetlands decreased from 88.51 to 19.95 Km², and from 344.75 to 165.37 Km² respectively from 1984 to 2006.

DATA/METHODOLOGY

Wetland classification is very challenging because of spectral confusion with other landcover types, and among diverse types of wetlands. Using multi-temporal or time-series data improves its classification [25]. Time series data was used in this work. Satellite remote sensing images of Landsat TM, and Sentinel-2 separated by 30 years were employed to determine as accurately as possible what quantity of the wetlands have been lost to various land uses, and how this loss has impacted, and may continue to impact flooding. This loss of wetland also helps to determine the impact on several other ecosystem services within the study area, until there is an intervention of policy decisions to turn things around.

The dataset for this work consists of two satellite sensor images from Landsat TM, acquired on December 24, 1986, and Sentinel-2 satellite image acquired on February 20, 2017, covering Metropolitan Lagos (Nigeria) and surrounding areas, obtained from the United States Geological survey website (https://earthexplorer.usgs.gov). The choice of these images for the study is dictated by availability, clarity (cloudlessness), and season. The images selected are the only ones that meet these key conditions. As discussed in the preceding section, the months of December and February are within the dry season in Lagos, and therefore the images are temporally homogeneous.

Landsat Thematic Mapper (TM)

The Landsat Thematic Mapper (TM) was carried on board Landsat 4 and Landsat 5 which were launched on July 16, 1982, and March 1, 1984, respectively. The TM data files have 7 spectral bands with a spatial resolution of 30m for all the bands from 1 to 7. However, the thermal infrared band (Band 6) was acquired at 120m resolution but resampled to 30m (https://www.usgs.gov/). Table 1 below shows the band designations.

The Satellite(s) carrying the Thematic Mapper maintains a circular sun-synchronous near-polar orbit at a height of 705Km (438 miles), has a repeat cycle of 16 days, a swath width of 185Km (115 miles), and an equatorial crossing time of 9:45 am (± 15 minutes). The radiometric resolution of the TM is 8bits. This means that the system has the ability of recording 256 brightness levels. Only the visible, near-, and mid-infrared (NIR) spectral subset bands were extracted and saved ENVI-standard using ENVI software. These are bands 1, 2, 3, 4, 5 and 7 with central wavelengths of 0.485, 0.560, 0.660, 0.830, 1.650, and 2.215μm respectively. The thermal band of 11.450μm was not considered. The TM image had been geo-referenced.

Sentinel-2

The Sentinel-2 satellite was launched on June 23, 2015, and presently conducting routine imaging operations. It has a wide swath of 290 Km, and fine spatial resolution over several bands (see Table 2). The satellite was developed in the framework of the European Union Copernicus program whose main objective is data continuity and the enhancement of the SPOT and Landsat missions [32]. Data from this satellite was intended to support global land services including vegetation monitoring, soil and land cover, inland waterways, and the coastal areas [32]. The repeat cycle of the Sentinel-2 is 5 days and covers areas between -56° to 84° latitude. The Satellite also has a high range radiometric resolution of 12 bits. Therefore, it can record a wide range of brightness colours (4,096).

Table 1: Band Designation of Landsat TM (* TM Band 6 was acquired at 120-meter resolution, but products are resampled to 30-meter pixels)

	Band	Wavelength (Micrometers)	Resolution (Meters)
Landsat 4 and 5 Thematic Mapper TM	Band 1 - Blue	0.45 - 0.52	30
	Band 2 - Green	0.52 - 0.60	30
	Band 3 - Red	0.63 - 0.69	30
	Band 4 – Near Infrared (NIR)	0.76 - 0.90	30
	Band 5 - Shortwave Infrared (SWIR) 1	1.55 - 1.75	30
	Band 6 - Thermal	10.40 - 12.50	120*(30)
	Band 7 - Shortwave Infrared (SWIR) 2	2.08 - 2.35	30

Source: Adapted from https://lta.cr.usgs.gov/TM

Table 2: Band designations of Sentinel-2 satellite

Resolution (m)	Band Number	Central Wavelength (μm)	Bandwidth (μm)
10	2	0.490	0.065
	3	0.560	0.035
	4	0.665	0.030
	8	0.842	0.115
20	5	0.705	0.015
	6	0.740	0.015
	7	0.783	0.020
	8a	0.865	0.020
	11	1.610	0.090
	12	2.190	0.180
60	1	0.443	0.020
	9	0.945	0.020
	10	1.380	0.030

Source: Adapted from https://www.usgs.gov/

The Sentinel-2 sensor has 12 spectral bands (plus an extra band – Band 8a). As can be seen in Table 2, the spatial resolution of the bands of Sentinel-2 are different and in three categories – 10m, 20m, and 60m. To use the number of bands like the Landsat TM in this study, it became necessary to downscale the two mid-infrared bands of 1.610, 2.190μm from spatial resolution of 20m to 10m by resizing. Thus, both the number of bands, and band wavelengths become similar in the two images used.

Image Processing

Digital image processing is the use of computer algorithms to accomplish the processing of digital images in order to improve its pictorial form, and the information it contains for human interpretation. Several stages are involved in the processing of digital images from remotely sensed images.

Spatial Sub-setting

Due to the relatively large area of the satellite digital image compared to the study area of interest it was necessary to reduce the image size for ease of processing. This was achieved by using the spatial subset tool in ENVI, and the aim is to make both images spatially compatible. The spatial subset tool of ENVI is used to set the top left and bottom right coordinates, ensuring that the same study area is used. These are then the images used for the subsequent processing.

Radiometric correction

Radiometric or atmospheric correction (also radiometric normalization) is done to eliminate or reduce errors in the digital numbers of images. It is done to obtain the real reflectance or irradiance at the ground since the actual energy emitted or reflected from a surface at the ground often differs from the energy that sensors on board satellites or aircrafts receive and record. The procedure is performed in ENVI by using the Empirical Line Calibration (ELC) tool. The whole essence of ECL is to use actual field (in situ) data to regress against the remotely sensed spectra by choosing a bright spot (e.g., sand/quartz) and a dark spot (e.g., deep, non-turbid water). However, in the absence of in situ data from the study site, data of clear water and sand (quartz) stored in the spectral library of NASA's Jet Propulsion library (https://speclib.jpl.nasa.gov/) can be used. The NASA spectral library data was used in this study.

Radiometric correction was performed for the Landsat TM image. A comparison of the spectral response using three known ground features, notably a built-up area, vegetation, and the nearby Atlantic Ocean as water body (not included) showed that the original image yielded better spectral response closer to the standard spectral signature of these ground features than the "corrected" image. So, the ELC image was not considered. The original Sentinel-2 image was a better-quality image than the Landsat TM by visual observation. The ELC procedure produced better spectral responses for the ground features mentioned above that are similar to the standard spectral signatures. Hence, the ELC image was adopted for further image processing.

Geometric referencing

The image-to-image technique was used to perform geometric referencing using the Landsat TM (TM) image which had been georeferenced by NASA as the base map, and the Sentinel-2 image as the warp image. The first order polynomial model with the nearest neighbour resampling technique was applied. This means that the 10m resolution of the Sentinel image will be scaled up to 30m to match the spatial resolution of the Landsat TM image. The first order polynomial model was used because it is the most popular and has been known to work best for near-uniform terrain [17] of which Lagos is an example.

Masking

The shape file of the study area was used to carve out the region of interest (ROI) from the Landsat TM, and then converted into a mask using the special tool in ENVI.

Principal component analysis (PCA)

Digital image spectral bands are often correlated; and it is desirable to choose bands that contribute most to the image spectra, thereby removing redundancy of information. The Principal Component Analysis (PCA) is used to reduce dimensionality when there is strong correlation between observed variables [26]. The PCA is a statistical technique that linearly transforms an initial set of variables into a considerably smaller set of uncorrelated variables that represents most of the information in the original set [8]. Covariance matrix was used in the transformation matrix to compute the PCA, for both the TM and the Sentinel-2 images (Table 3).

Table 3. Band contributions in the image classifications

	Sensor		
Landsat TM		Sentinel-2	
Component	Variance (%)	Component	Variance (%)
Band 1	96.58	Band 2	98.56
Band 2	2.59	Band 3	0.94
Band 3	0.58	Band 4	0.32
Band 4	0.19	Band 8	0.14
Band 5	0.04	Band 11	0.03
Band 6	0.02	Band 12	0.01

Source: Author

Image Classification

Classification is the assigning of individual pixels in the digital image to themes or classes. The individual pixels are classified based on spectral information in the form of digital numbers in one or more spectral bands. The supervised classification technique was used in this study, and four classes or features were chosen – the wetlands, vegetation, built-up area, and water. Wetlands have been treated as a single feature, since, according to [12], it is hard trying to separate different wetland types from one another because of the intersection in their spectral signatures.

Supervised classification uses training (and testing) data from areas of pixels with known class type. The training data are so called because the spectral characteristics of these known areas are used to train the classification algorithm of the ENVI software for eventual land-cover mapping (classification) of the remainder of the image [17].

Thus, for classification to be carried out, both training and testing datasets for the ENVI software must be developed based on the field (or expert) knowledge of the geographic locations in the image containing the desired or known class types. Marshy wetlands are often regions of transition between the open water surface and the forested dry land. Such marshy areas in the study area known this author were the locations that training and test pixels for the software for wetlands were picked from. Another reasoning for selecting training and testing pixels for wetlands is that any location that is presently a wetland based on the field knowledge of this writer was most probably a wetland as well in 1986 when the first image for this study area was captured. Pixels for vegetation were picked along known forested highways. It was much easier picking up pixels from the built-up area and water bodies as they were very distinct. These pixels picked from the images are representative of the landcover or land use classes of interest. The general rule in picking pixels is that if training data are being extracted from n bands, then pixels of training data must be more than ten times the number of bands (i.e., >10n pixels, where n is the number of bands) for each class [17]. The pixels used in the training were by far more than 10 times the number of bands used. The training data was then used to perform the supervised maximum likelihood classification (MLC). The MLC generally gives better results than the parallelopiped classifier because the covariance of the data is considered [25]. Because of its performance, MLC is the most used supervised classification technique for mapping wetlands [6, 11]. Based on the classification scheme, Figures 2 and 3 were generated.

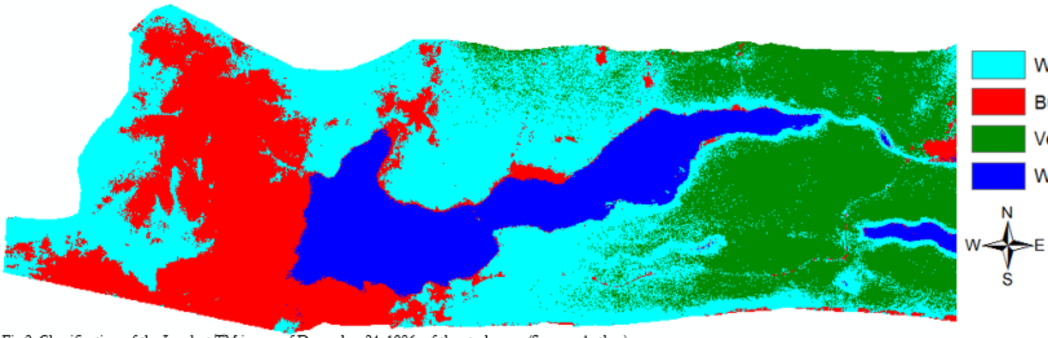

Fig.2: Classification of the Landsat TM image of December 24, 1986, of the study area (Source: Author).

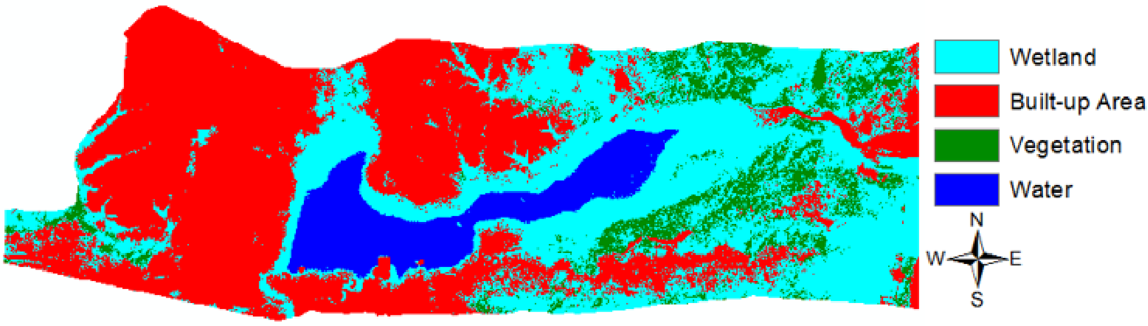

Fig.3: Classification of the Sentinel-2 image of December 24, 1986, of the study area (Source: Author).

Post classification change detection

To determine where change has occurred within the study area, change detection analysis is carried out using test data and "ground truth" data; and the confusion (Tables 4-7) and aerial change tables (Tables 8 and 9) are constructed from the statistical output from ENVI for both the Landsat TM and Sentinel-2.

To assess the accuracy of the TM and Sentinel-2 images that were classified, an accuracy table (or confusion matrix) is created, where the classification results are compared with ground truth information. The confusion table identifies the quantity, and nature of the classification errors.

(a) Accuracy Table (Confusion matrix)

Table 4: Confusion matrix (Accuracy) table for Landsat TM (1986) classification (pixels) for the study area.

Classification	Reference (Pixels)						
	Wetland	Built Area	Vegetation	Water		Sum	User's Accuracy
Unclassified	0	0	0	0		0	0
Wetland	1875	1296	5	0		3176	59.04
Built Area	0	668	0	238		906	73.73
Vegetation	176	146	1104	0		1426	77.42
Water	0	0	0	2976		2976	100
Sum	2051	2110	1109	3214		8484	
Producer's Accuracy	91.42	31.66	99.55	92.59			

Overall accuracy = (6623/8484) = 78.06% (Source: Author)

Table 5: Confusion matrix (Accuracy) table for Landsat TM (1986) classification (percent) for the study area.

Classification	Reference (Percent)						
	Wetland	Built Area	Vegetation	Water		Sum	User's Accuracy
Unclassified	0	0	0	0		0	
Wetland	91.42	61.42	0.45	0		37.44	59.04
Built Area	0	31.66	0	7.41		10.68	73.73
Vegetation	8.58	6.92	99.55	0		16.81	77.42
Water	0	0	0	92.59		35.08	100
Sum	100	100	100	100		100	
Producer's Accuracy	91.42	31.66	99.55	92.59			

Overall accuracy = 78.06% (Source: Author)

Table 6: Confusion matrix (Accuracy) table for Sentinel-2 (2017) classification (pixel) for the study area.

Classification	Reference (Pixels)						
	Wetland	Built Area	Vegetation	Water		Sum	User's Accuracy
Unclassified	0	0	0	0		0	
Wetland	1970	0	510	1698		4178	47.15
Built Area	21	2140	0	3		2134	98.88
Vegetation	60	0	599	0		659	90.90
Water	0	0	0	1513		1513	100
Sum	2051	2110	1109	3214		8484	
Producer's Accuracy	96.05	100	54.01	47.08			

Overall accuracy = (6192/8484) = 72.98% (Source: Author)

Table 7: Confusion matrix (Accuracy) table for Sentinel-2 (2017) classification (percent) for the study area.

Classification	Reference (Percent)						
	Wetland	Built Area	Vegetation	Water		Sum	User's Accuracy
Unclassified	0	0	0	0		0	
Wetland	96.05	0	45.99	52.83		49.25	47.15
Built Area	1.02	100	0	0.09		25.15	98.88
Vegetation	2.93	0	54.01	0		7.77	90.90
Water	0	0	0	47.08		17.83	100
Sum	100	100	100	100		100	
Producer's Accuracy	96.05	100	54.01	47.08			

Overall accuracy = 72.98%

(b) Aerial change

Aerial change tracks the changes that have occurred for the classes of land cover of interest over the study period (between 1986 and 2017).

Table 8: Aerial change between 1986 and 2017 (Km^2) for the study area.

		Initial State (1986)					Class
		Wetland	Built Area	Vegetation	Water	Row Total	Total
	Unclassified	0	0	0	0	0	0
Final	Wetland	372.63	46.96	350.14	132.59	902.32	902.32
State	Built Area	481.8	478.11	87.1	10.9	1057.91	1057.9
(2017)	Vegetation	57.04	1.66	139.78	0.06	198.55	198.55
	Water	1.99	1.53	0	205.63	209.15	209.15
	Class Total	913.46	528.26	577.03	349.17		2262.7
	Class Change	540.84	50.15	437.24	143.54		
	Image Difference	-11.15	529.65	-378.48	-140.02		

Source: Author

Table 9: Percent change between 1986 and 2017 (%) for the study area.

		Initial State (1986)					Class
		Wetland	Built Area	Vegetation	Water	Row Total	Total
	Unclassified	0	0	0	0	0	0
Final	Wetland	40.793	8.889	60.681	37.972	100	100
State	Built Area	52.744	90.507	15.095	3.121	100	100
(2017)	Vegetation	6.245	0.315	24.225	0.017	100	100
	Water	0.218	0.289	0	58.891	100	100
	Class Total	100	100	100	100		
	Class Change	59.207	9.493	75.775	41.109		
	Image Difference	-1.220	100.264	-65.591	-40.102		

Source: Author

RESULTS AND DISCUSSION

From the classification maps, it can be seen that areas west of the built-up area in Figure 2 had been predominantly wetland in 1986; but by 2017 (Fig. 3), the same area had become overrun by development. The same can be said of the areas east of that region and separated by the long stretch of wetland in the north-south orientation and linking with the water body (Lagos lagoon). Another area worthy of note are the vegetated (green) portions in Figure 2 (eastern portions of the study domain). It can also be seen that this area has been heavily depleted in Figure 3 (i.e., in 2017).

The losses in land cover, particularly the wetland and vegetation discussed above can be seen in quantitative terms in the change tables of Table 8 and 9 (aerial and percentage changes). While the wetland has lost 540.84 Km^2 out of its original 913.46 Km^2 representing 59.207% during the 30 years, vegetation has lost 437.24 Km^2 of its original 528.26 Km^2 representing 75.775 % during the same period.

The other features worthy of mention from the confusion table are the classification of 176 wetland pixels as vegetation, and 238 pixels of water as built-up area (Table 4 of the TM image). The former is explained by the fact that parts of the wetland often become heavily forested and may be confused with vegetation to satellite sensor while in the latter case, some communities have built considerable structure on parts of the water body and wetland and have lived there for many years (see Fig. 4). These are likely to introduce spectral confusion into the classification. In the Sentinel-2 image table (Table 6), 1698 pixels of water are classified as wetland. This wrongful classification of 1698 pixels of water as wetland, which constitutes a substantial portion of water bodies in the study area, is likely to have been caused by seaweeds growing on the water surface as seen in Figure 5. Since the surface of the weeds appears smooth, with breaks at certain points, they may produce the same spectral signature as wetlands. As seen from this study, a total of 37.972% of water area was lost because of such seaweed situations in the two aerial images.

Implications of the loss of wetlands within Lagos on flood control and the environment

Regarding the loss of wetlands within the Lagos conurbation with implications for flood control, results indicate that 481.8 Km^2 of the original 913.46 Km^2 in 1986 (52.744%) has been lost due to urban development. Considering that these new developments on wetlands on their own generate more surface water [4] that can no longer be absorbed by the lost wetlands, it becomes easy to see why there appears to be an exponential increase in flooding. This is because development or construction on a given area of wetland displaces water that could have been absorbed within that space and throws it out to add to the volume of water that needs some space to be absorbed. It is no surprise then that since the turn of the millennium the city has witnessed flooding of unprecedented magnitude (see [15]).

Urban farming, and consequently urban food security is another sector most likely to suffer the effect of wetland conversion for the purpose of urban development and other uses. This is because many wetlands are used to grow many crops that would be out of season in the dry season. In many sub-Saharan African cities, eating food grown locally has become a standard [21]. Up to 40% of families in urban cities of sub-Saharan African cities are urban farmers and produce food not just for subsistence but for the teeming millions of others. Such food crops include fruits and vegetables [21]. According to the news item, a survey conducted by the Food and Agricultural Organization, FAO, found that such a trend puts African cities in jeopardy because as the population of African cities double in the years ahead, horticultural land will give way to housing and industry.

Among numerous other services, the diverse kinds of animals and plants found in these wetlands appears huge and serves as a sanctuary, especially for endangered species. With the loss of these wetlands, however, the environment is deprived of the aesthetics and the tempering of the weather and climate of the area that they hitherto provided.

CONCLUSION AND RECOMMENDATIONS

The loss of wetlands within the Lagos (Nigeria) conurbation within the last 30 years and the implication for flood control has been the subject of this research. Previous researchers either focused only on segments of the study area in this work or did not include wetlands in their classification scheme or used a classification scheme (Parallelopiped) that may not be among the best for classification purposes. However, in this study, the Maximum Likelihood Classifier, with a superior classifying algorithm was used to classify the two remotely sensed images of Landsat TM and Sentinel-2 of the study area separated by 30 years (1986 and 2017 respectively). Applying change detection, it was found that 540.84 Km^2 of wetlands, representing 59.207 % of the original area in 1986 had been lost to other land uses particularly for the built-up area. This huge loss of wetland will likely lead to frequent problems of flooding as surface water can no longer find enough wetlands to settle. Again, wetlands previously available for urban farming is no longer in surplus supply, and this will threaten food security in the urban centre. Under the present situation, biodiversity will also suffer in the wetlands. It therefore becomes necessary to make several recommendations to forestall a run-away, uncontrollable flood situation: All encroachment into wetlands, whether owned by the state or in private hands for urban and infrastructural purposes must stop forthwith; the government should engage in a buy-out of wetlands in private hands for the purpose of conservation or to be turned into green spaces; the thriving of water hyacinth and other vegetation on Lagos waters and waterways must not be allowed to continue and must be removed periodically since they obstruct the ease of water flow – the Environmental Agency of the State should be empowered financially to meet this challenge as this will go a long way in the control of flooding; very regular change detection analyses using the latest available satellite images should be conducted over the entire space to monitor violations; and the government should develop policy instruments to accommodate these recommendations and give environmental laws the teeth to bite. It is suggested that future research considers quantifying the contribution of wetland loss to flood water increase over a given urban space. Perhaps this will lead to a better appreciation of the invaluable contribution of wetlands in urban flood control.

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