Monitoring the Spatiotemporal Dynamics of Surface Water Area of Goronyo Reservoir Sokoto, Nigeria Using Remote Sensing

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Abstract. *Water stored in dams and reservoirs is essential element for hydrological cycle and other human activities like irrigation farming, fishing and transportation. Reservoirs in arid and semi-arid environments tend to change in volume and area extent over time as a result of natural and human factors causing water shortage. This study examines the spatiotemporal changes of Goronyo reservoir, Nigeria from 2000-2020. Landsat imageries were used to extract the surface water area using Modified Normalised Difference Water Index (MNDWI). The changes in the spatial and temporal pattern of the surface water over were obtained by calculating the differences in the surface area over the study period (2000-2020). The results show a continuous decrease in the surface water indicating loss of water. The surface area changed from 105.24km^2 (98.35%) in 2000 to 72.01km^2 (67.30%) with a total constriction of 33.22km^2 (46.13%). Increase in temperature and evaporation and anthropogenic activities are the major factors responsible for the changes. Planting of trees around the water and dredging the silt to restore the water to its full capacity will mitigate the high rate of water loss for sustainable socio-economic development.*

1. Introduction

Reservoirs and dams are mostly built in drought affected areas to store water in order to meet the needs of the people (Mustafa and Noori, 2013). The water is important for domestic and industrial water supply, irrigation agriculture, transportation, fishing and electricity generation (Du et al., 2010; Melendo, 2015; Edokpayi et al., 2017; Sreekanth et al., 2021). Changes in seasons usually affect water bodies which also cause changes in their volumes and spatial extents (Jiang et al., 2020; Yue et al., 2020; Jiang et al., 2018; Jiang et al., 2021). The changes usually caused by natural or human factors led to the expansion or shrinking of water bodies (Karpatne et al., 2016; Huang et al., 2018).

Mapping surface water bodies to study the spatiotemporal variation becomes possible with the recent development in remote sensing (Crétaux et al., 2016; Kang and Hong, 2016; Arthur and Godfrey, 2017). The method provides a wide area coverage, low cost, rich information and high temporal resolution (Zurqani et al., 2018; Ruimeng et al., 2020). These make remote sensing method better than in situ measurements and modelling because of insufficient in situ gauge and difficulty in modelling (Alsdorf et al., 2007; Baup et al. 2014; Vörösmarty et al., 2001; Arthur and Godfrey, 2017). These methods require a lot of time and effort which make them not always suitable for mapping water bodies. In remote sensing, both optical and microwave sensors are used for measuring water surface. Microwave has the ability to penetrate the cloud and vegetation cover to obtain information about the surface water (Huang et al., 2018). On the other hand, data from optical sensors are widely available because of the sufficient spatial and temporal resolution (Huang et al., 2015; Huang et al., 2018).

The accuracy of water extraction from satellite data depends on the spatial resolution which can be low, medium or high (Huang et al., 2018). Low resolution data (greater than 200m) have low accuracy; medium resolution imageries (5-200m) have a better accuracy while high resolution imageries (less than 5m) provide detailed information with some limitations (Huang et al., 2018). The high resolution imageries are suitable for mapping small water bodies, but the presence shadow has a serious effect on water detection (Sawaya et al., 2003; Huang et al., 2018). Also, the satellites have low temporal resolution and are not freely (Huang et al., 2018). These limitations of the low and high resolution satellites make the medium resolution satellites suitable for mapping the spatiotemporal changes of surface water. Landsat with its long time series is one of the satellites used for mapping changes in surface water bodies considering its resolution, spectral consistence and free access (Pekel et al., 2016; Hansen et al., 2014; Yamazaki et al., 2015; Hou et al., 2017; Ruimeng et al., 2020).

Ways of extracting surface water from satellite imageries involved the machine learning and traditional algorithms methods (Zhou and Dong, 2019; Ruimeng et al., 2020). The former includes Random Forest (RF), Deep Learning (DL), Decision Tree (DT) and Support Vector Machine (SVM) while the later involved the single and multi-band methods (Ruimeng et al., 2020). Multi-band method has higher quality than single-band method because of its ability to discriminate between water and non-water (McFeeters, 2007; Ruimeng et al., 2020). Among the multi-band methods, index method is the most convenience because of its high accuracy in providing information on surface water (Jiang et al., 2021). The commonly used water indices include Normalised Difference Water Index (NDWI), Modified Normalised Difference Water Index (MNDWI), Automated Water Extraction Index (AWEI) and Water Index (WI_{2015}) (Huang et al., 2018). NDWI was first proposed and green and near infrared bands were used in water extraction (Jiang et al., 2021). Because of the high sensitivity of near-infrared to sediments in water, MNDWI was later proposed using Short-wave Infrared (SWIR) which is less sensitive sediments concentration (Huang et al., 2018). It also differentiates between shadow and water bodies (Xu, 2006; Linye et al., 2021).

Goronyo reservoir located in the semi-arid region of Sokoto, Northwest Nigeria was constructed in 1984 and commissioned in 1992 by the Federal Government of Nigeria (Augie et al., 2020). The reservoir supplies water for domestic use, irrigation agriculture most especially in dry season and control flooding during rainy season in the area and surroundings (Sembenelli, 1992; Augie et al., 2020). More than 200 million people in the area and surrounding depend on the reservoir for drinking, fishing and irrigation farming (Ahmed, 2018). In the recent years, there is decrease in the water where the reservoir holds only 10 percent of its 1 billion cubic metres capacity (Ahmed, 2018). This has become a threat to the socio-economic development and the ecological system of the area. Monitoring these changes is important for proper water management for socio-economic development. Therefore, this study examines the spatiotemporal dynamic of the surface water of the reservoir.

2. Material and Methods

2.1. Study Area

Goronyo reservoir is located between Latitude 30^o 30^1 and 14^o North and Longitude 5^o 30^1 and 6^o East (Figure 1). The reservoir is 5km East of Goronyo town and 90 km away from Sokoto town (Aminu et al., 2018). It has 20km length and 10km width with an area of almost $200km^2$ and a storage capacity of about 942,000,000 cubic metres (Ita et al., 1982; Abubakar and Aliyu, 2017; Lukman et al., 2020). The climate of the area is semi-arid with distinct long dry season and short wet season. The dry season begins from late October to early May while the wet season is from late May to early October (Udo, 1970; Ogheneakpobo, 1988; Adeniyi, 1993; Abubakar and Aliyu, 2017). The average annual rainfall is almost 740mm (Yakubu et al., 2019). The rainfall is higher in the south with an annual rainfall of about 800mm while 500mm is recorded in the north (Elisha et al., 2016). According to the Federal Ministry of Water Resources (FMWR), highest rainfall is recorded in August with a high relative humidity up to 83% indicating the peak of wet season (FMWR, 2020). The annual temperature is high with an annual average of 28.3^oC (Elisha et al., 2016). The minimum daily temperature is also high reaching 36^oC (Yakubu et al., 2019). The maximum daytime temperature is about 40^oC almost throughout the year with the highest daytime temperature is recorded from February to April with over 45^oC (Elisha et al., 2016). The temperature is low from late October to February as a result of the effect of harmattan wind that is dry, cool and dusty blows from Sahara desert (FMWR, 2020). During the harmattan the daily minimum temperature below 17^oC (Yakubu et al., 2019). The vegetation is Sudan Savanna of Northern Nigeria which is characterised with scattered short trees with abundant grasses (FMWR, 2020). Arenosols, Fluvisols and Leptosols are the main soils in the area which are further classified into the reddish brown soils, hydromorphic soils and ferruginous tropical soils. The soil is mostly sandy with 80-90% sand and 2-4% clay with poor chemical content (FMWR, 2020).

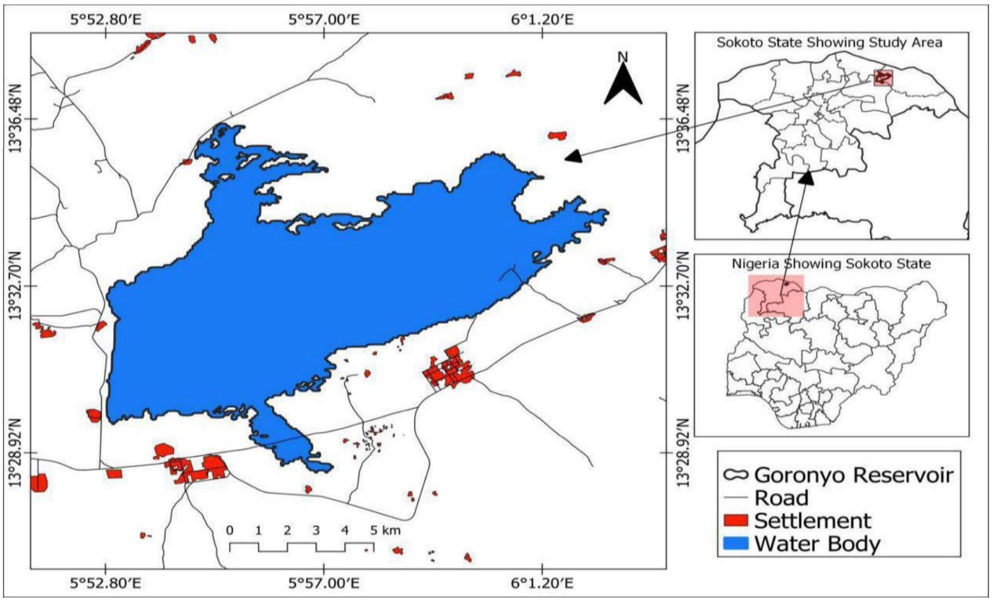

Figure 1. The study area showing Goronyo reservoir

2.2. Data Source

Landsat data is commonly used for mapping the spatiotemporal changes surface water because of its medium resolution and long time series. Landsat imageries obtained from the United State Geological Survey (USGS) were used. Five Landsat imageries acquired by Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensors (TIRS) were used. Seasonal change is one of the factors responsible for changes in the surface area of water. The imageries acquired in dry season were used to examine the changes in the water extent during the dry season. Spatial and temporal pattern of the surface water can be easily detected in dry season. Also, there is less atmospheric effect on the imageries as a result of minimum cloud cover. The description of the imageries used is displayed in Table 1. QGIS 3.14 ‘Pi’ was used for the Pre-processing, processing and post processing of the data.

Table 1. Description of the Landsat data used

Acquisition Date	Sensor	Path	Row	Resolution
15/02/2000	ETM plus	190	051	30m
27/01/2005	ETM plus	190	051	30m
10/02/2010	ETM plus	190	051	30m
16/02/2015	OLI/TIRS	190	051	30m
29/01/2020	OLI/TIRS	190	051	30m

2.3. Image Pre-processing

The satellite imageries were pre-processed using Semi-Automatic Classification Plugin (SCP) for QGIS. It is an open source plugin that is used for image pre-processing and post processing (Congedo, 2021). SCP tool was used to perform atmospheric correction to remove the scattering and absorption effects on the reflectance values of the imageries. The SCP converts Digital Numbers (DN) to top-of-atmosphere (TOA) reflectance (Congedo, 2021). The atmospheric corrections were performed using Dark Object Subtraction (DOS1) method to obtain the reflectance of the surface. This provides the true reflectivity of the surface to discriminate between water and non-water areas.

2.4. Image Processing

Satellite data obtained were processed to extract water body by distinguishing water body from other land covers as water body and non-water body respectively. Water index was chosen among the methods of water extraction because of its simplicity, accuracy and rapid extraction of water information (Zou et al., 2017; Houming et al., 2019). Among the indices, Modified Normalised Difference Water Index (MNDWI) was used for the water extraction. The index uses short wave infrared (SWIR) that is less sensitive to water sediments which makes it to remove noise from the surrounding land covers. It is more reliable than Normalized Difference Water Index (NDWI) and widely used for water extraction (Huang, 2018). Despite the limitation of MNDWI to discriminate water and snow, it is still good for the study area because of the absence of snow. MNDWI was calculated using the following equation (Huang et al., 2018):

$$MNDWI = (GREEN - SWIR) / (GREEN + SWIR) \quad (1)$$

Where:

Green is the reflected values of green band

SWIR is the reflected values of the short wave infrared

2.5. Calculation of Classification Accuracy

The classified Landsat imageries were assessed to identify possible errors. Semi-Automatic Classification Plugin (SCP) for QGIS was used for the assessment. Random points were created over the classified Landsat imageries to create region of interest. The region of interest was used as reference to calculate the accuracy of the classification. Confusion matrix was generated with overall accuracy, kappa statistics, user and producer's accuracy to access the accuracy of the results of the classified imageries (Table 2). This method is suitable in accessing the accuracy of homogenous surfaces (Congedo, 2021). Kappa statistics was used to assess the accuracy of the classified imageries. The values range between 0 and 1 with values above 0.80 as good result, 0.40 to 0.80 as average and less than 0.40 as poor result (Lillesand, Kiefer and Chipman, 2004; Ishaq, Sen, Din Dar and Kumar, 2017).

2.6. Change Detection

The surface area of the reservoir was calculated by obtaining the area coverage of the surface water. The surface area of water changes over time due to natural or human factors. The results of the classified imageries were used to detect changes by comparing the area of the surface water. This was done to obtain the spatiotemporal dynamics of the surface area of the reservoir.

3. Results

3.1 Accuracy of Water Extraction

The result of the accuracy assessment of the classified shows a high accuracy. The overall accuracy for the five imageries range from 87.53 to 100 (Table.4) The kappa statistics also shows good results that range from 0.67 to 1.00 indicating good and strong average results respectively.

Table 2. Accuracy assessment of the classified imageries

Year	Overall accuracy %	Kappa statistics	User's accuracy %		Producer's accuracy %	
			Water	Non-water	Water	Non-water
2000	99.59	0.75	100.00	60.00	99.59	100.00
2005	100.00	1.00	100.00	100.00	100.00	100.00
2010	94.40	0.85	100.00	80.00	92.78	100.00
2015	87.53	0.67	100.00	60.00	84.66	100.00
2020	95.56	0.89	100.00	85.00	94.07	100.00

3.2 Spatial Distribution of Surface Water

The total surface area of the reservoir is 107 km^2 which comprises of the water and non-water area. The number of pixels for the two classes formed the shape and the size that determine their spatial pattern. The results show changes in size of the surface water area over the study period as a result of its decrease that led to the increase in the non-water. The spatial pattern of the surface water is shown in Figure 2.

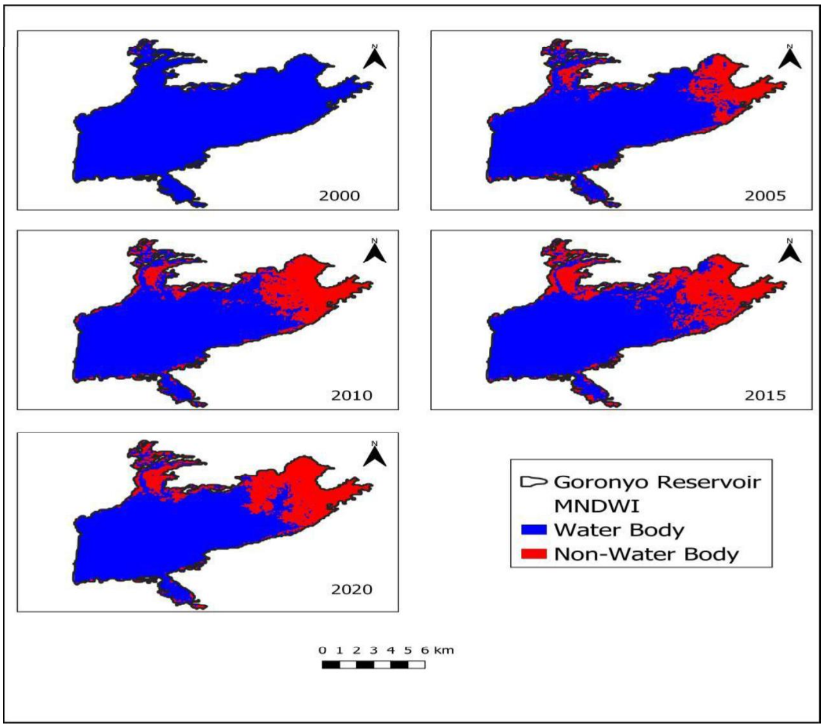

Figure 2. Spatial pattern of surface water area of Goronyo Reservoir

The imageries show the spatial extent of water and non-water areas in the reservoir that vary with time. In 2000, the spatial pattern of the surface water covered most of the reservoir with relatively insignificant area of non-water. The water area occupied 105.24km^2 (98.35%) while the non-water was 1.76km^2 (1.65%). After five years in 2005, there was a change in the spatial pattern of the surface water showed a decrease in its size. The northern and eastern parts of the reservoir dried up and turned to non-water area. The water area decreased to 84.92km^2 (79.36%) while the non-water area expanded to 22.08km^2 (20.64%). There was further constriction in the area of the surface water in 2010 that decreased to 76.70km^2 (71.68%) while the non-water area expanded to 30.30km^2 (28.32%) of the total area. In 2015, there was continuous decrease in the surface water mostly from the northern and eastern part of the reservoir. The water area shrank to 73.27km^2 (68.48%) while the non-water enlarged to 33.73km^2 (31.52%). The non-water area further expanded by the decrease of water area in 2020. The non-water area expanded to 34.99km^2 (32.70%) with the decrease of water area to 72.01km^2 (67.30%).

Table 3. Surface area of water and non-water

Year	Water area (km^2)	Percentage	Non-water area (km^2)	Percentage
2000	105.24	98.35%	1.76	1.65%
2005	84.92	79.36%	22.08	20.64%
2010	76.70	71.68%	30.30	28.32%
2015	73.27	68.48%	33.73	31.52%
2020	72.01	67.30%	34.99	32.70%

3.3 Temporal Variation of Surface Water

Differences in the area of water and non-water of the reservoir over the study period showed its temporal variation. The temporal variation shows a continuous constriction in water body and increase in the non-water area. The temporal variation shows a continuous decline in the area of water body (Table.2). The highest change was recorded between 2000 and 2005 with a decrease of 20.32 km^2 (-23.92%). The surface water continued to have gradual decline with a decrease of 8.22km^2 (10.72%) from 2005-2010, 3.43km^2 (4.68%) from 2010-2015. finally, the lowest change was recorded from 2015-2020 where the area of the surface water decreased with 1.26km^2 (0.06%). The total change in the area of water from 2000-2020 was a decrease of 33.22km^2 (46.13%) which is half of the reservoir.

Table 4. Temporal variation of water surface from 2000-2020

Year	Change in Area (km^2)	Percentage (%)
2000-2005	-20.32	-23.92
2005-2010	-8.22	-10.72
2010-2015	-3.43	-4.68
2015-2020	-1.26	-0.06
2000-2020	-33.22	-46.13

4. Discussion

The pixels showing water body indicated the spatial extent of the surface water because of its sensitivity to short wave infrared band. This made it possible to distinguish between water and non-water body. The high accuracy of the classification achieved could be as result of the number of land cover classes in the area. The major land cover classes are the reservoir and the surrounding irrigation land. The changes in the spatial pattern of the surface water indicated its decrease over time. The water area is the part of the reservoir that is relatively deep and store water in both rainy and dry season. The non-water area found at the edge and mostly the northern and eastern part of the reservoir indicated a shallow area that dried-up in dry season due to drop in the level of water. This shows the impact of climate on surface water because of the longer period of dry season. Precipitation is one of the major sources of water in the reservoir. Changes in the shape and surface area of water bodies are usually determined by the occurrence of rainfall (Shankarnarayan and Singh, 1979; Sharma et al., 1989). Also, increase in temperature and high rate of evaporation contributed in the loss of water resulting in the drying up of the parts of the reservoir. It is reported that increase in temperature over the years despite the increase in rainfall resulted in increase in evaporation which led to the loss of water (Ahmed, 2018). There is increase in temperature in the semi-arid area in Sokoto that resulted in high evaporation, drought and desertification (Odjugo and Ikhuoria, 2003; Adefolalu, 2007; Ikpe et al., 2016). The temperature increased with almost 2 percent in the last century (Odjugo, 2010; Ifabiyi, 2013). The effect of the high rate of evaporation was severe in the shallow parts that can quickly dry up. Transportation and deposition of sediments by Rima River, runoff and wind into the reservoir contributed to the shallowness of the dry-up part. The deposition of silts also decreases the water holding capacity of the dam. The reservoir holds only 10 percent of its total 1billion cubic meters capacity (Jeremiah, 2018). Increase in the usage of the reservoir water through irrigation and other domestic uses may also contribute to the decline in the reservoir.

The shrinkage of the reservoir has led to shortage of water in the area that affected various activities of the people. Farmers cultivated less than 10 percent of their usual cultivation because of the shortage of water (Ahmed, 2018). There was also shortage of water in the treatment plant that supplies water to Sokoto town and environs which resulted in the supply of water by water tanks (Ahmed, 2018).

A similar result was found by Mustafa and Noori (2013) that accessed changes in water level in the Duhok dam between 2001 and 2012. They found an increase in surface water in 2006 and decrease in 2012. They attributed the increase to increase in rainfall and decrease in evaporation while the decrease was as result of decrease in rainfall, increase in evaporation and other anthropogenic factors. Contrary to the findings of Mustafa and Noori (2013), the downward trend in the surface water of Goronyo reservoir despite the increase in rainfall could be attributed to differences in climatic condition, geology, soil and anthropogenic factors. For instance, In Goronyo, the highest daytime temperature in dry season (from February to April) is over 45^{o}C (Elisha et al., 2016). The maximum summer temperature in Duhok is 43.30^{o}C indicating the possibility of higher evaporation in Goronyo reservoir. With these findings, it can be concluded that climate change and anthropogenic activities are the key factors responsible for the spatiotemporal change in surface water.

4. Conclusion

This study examined the spatiotemporal variability of Goronyo reservoir from 2000-2020. The study area located in a semi-arid area is characterised with high temperature and prolong dry season. Modified Normalised Difference Water Index (MNDWI) was used to extract water by distinguishing water from non-water land cover from multi-temporal Landsat imageries. The result showed changes in spatial and temporal pattern of the surface water as a result of continuous shrinkage of the water body. This was as a result of increase in temperature and evaporation, less rainfall, intensive irrigation, increased demand for water and deposition of sediments by river Rima, wind and run-off. Remote sensing is a powerful technique for image classification and change detection for resource management. Further studies should focus on the impact of climate change and human activities on the surface water change.

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