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Assessment of Trend of Surface Water in Kiri Dam, Adamawa State, Nigeria

Bilham Frichi,[1] Muhammed Ibrahim[2] and Takana Abubakar[3*]

Department of Surveying and Geoinformatics, Modibbo Adama University, Yola[1,2&3]

Corresponding Author: *takana.abubakar@gmail.com

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ABSTRACT

Water from the Kiri dam is meant for irrigation purposes of the Savanna Sugar Company. For the dam to achieve its goals, there is a need to regularly monitor the trend of changes in the dam's surface water. The dam usually experiences some changes in the surface water that resulted in a large-scale transformation, mostly during the dry season. The trend seems to be on the increase as the dam experiences large reductions in the size of surface water. The study, therefore, focuses on the surface water area extraction of the Kiri dam reservoir in Shelleng, Adamawa State, Nigeria. The study demonstrates the use of a water index algorithm in the extraction of surface water area using Landsat OLI satellite imagery to study the variation in size, and shape and to monitor surface water fluctuations in the dam. A combination of six indices was investigated. The indices showed different approaches in the separation of water with background cover. The result shows that the MNDWI is most suited to mapping surface water. The dam surface area was noticed to be about 67.15 km² in 2013, 63.57 km² in 2014, 68.68 km² in 2015, 63.28 km² in 2016 and 52.64 km² in 2017. The results, therefore, indicate that the change in the surface area of the dam between 2013 and 2017 is about 14.51 km². This shows a decreasing trend in the surface water area of the dam, apart from 2015 which indicated a slight increase.

Keywords: Water index, Kiri Dam, Landsat Imagery, Irrigation, Surface Water

1.0. Introduction

A dam is a wall built across a river that stops the river's flow and collects water, especially to make a reservoir that provides water for an area to support the life and production of human societies and also to provide huge environmental and ecological benefits. Dams are amongst the most productive and biodiverse ecosystems on Earth (Youdeowei et al., 2019). They are essential for the development and management of a river basin's water resources, no matter their size (Liebe et al., 2005; Leemhuis et al., 2009). Dams in Nigeria are used for irrigation, water supply, and hydroelectric power generation, while others are used as tourist centres or a combination of both.

Kiri Dam was completed and commissioned in 1982 to serve as a source of irrigation for the Savanna Sugar Company in Adamawa State, Nigeria. Recently, it was discovered that the dam is witnessing a reduction in its surface water which could eventually result in a shortage or lack of water for the irrigation it was primarily constructed (Gadiga and Garandi, 2018). Therefore, there is a need for regular monitoring and assessment of the dam's surface water to be alerted to the situation of water at the dam at all times. This is because monitoring the dynamics of surface water is very helpful for irrigation (Vidya et al., 2021).

Remote sensing is highly effective in monitoring the dynamics of areas of surface water. In applying remote sensing methods to study the dynamics of surface water, Plaug et al.,(2008), Linrong. et al.,(2020), Vinicius (2021) and Ma et al.,(2011) utilized Landsat images to monitor water environments in different places. Meanwhile Feng. et al.,(2012) and Wu and Liu (2015) used MODIS data to study the short and long-term characteristics of Poyang Lake inundation and the regional differences of water inundation in different geographic regions respectively. Satellite radar altimeter data have also been used to monitor water levels and area (Jarihani et al.,2013;). Recently, sentinel-1 data were evaluated for monitoring reservoirs (Amitrano et al., 2014). The monitoring results are valuable for hydrological settings and provide information for preparation and precautions against extremely harmful hydrological events.

Assessment of trends of surface water change is helpful to the study of irrigation, drinking water requirement, climate change factors on the surface water, natural environmental health and understanding the impacts of global changes and human actions on the planning and development of the water resources in the dam and surrounding communities (Vidya et al., 2021).
This study on the kiri Dam intends to assess the trends of changes in the surface water area of the dam. The study utilized different water indexes to achieve its aim. The water indices used are the normalized difference water index (NDWI), Modified Normalized Difference Water Index (MNDWI), land surface water Index (LSWI), Automated Water Extraction index (AWEI) and the water ratio index (WRI). According to Tri. et al., (2019), these indices are believed to be useful and efficient in mapping water features and their changes.

2.0. Methodology

2.1 Description of the Study Area

Kiri Dam is located on the floodplain of the lower Gongola River basin in Adamawa state, Nigeria (Figure 1). The dam is situated about 29 km upstream of its confluence with River Benue at Numan. Specifically, the dam is located between Latitude 09º 50 N and 10º 10′ N and Longitude 11º 90′ E and 12º 04′ E in Shelleng Local Government Area. The area has a sedimentary rock of shale and thin bands of limestone and lignite. It contains a wide range of alluvial deposits, along wide channels of River Benue and Gongola which overlies the cretaceous deposit. It is generally a lowland area, between 500 – 700 meters above sea level. The landforms of the area are characterized by extensive floodplains and alluvial swamps. Most of the locations are liable to flooding, water logging or swamps along river catchments. The subsoil and shale formation allow an underground flow of water, which raises the water table during the rainy season and drops very low during the dry season.

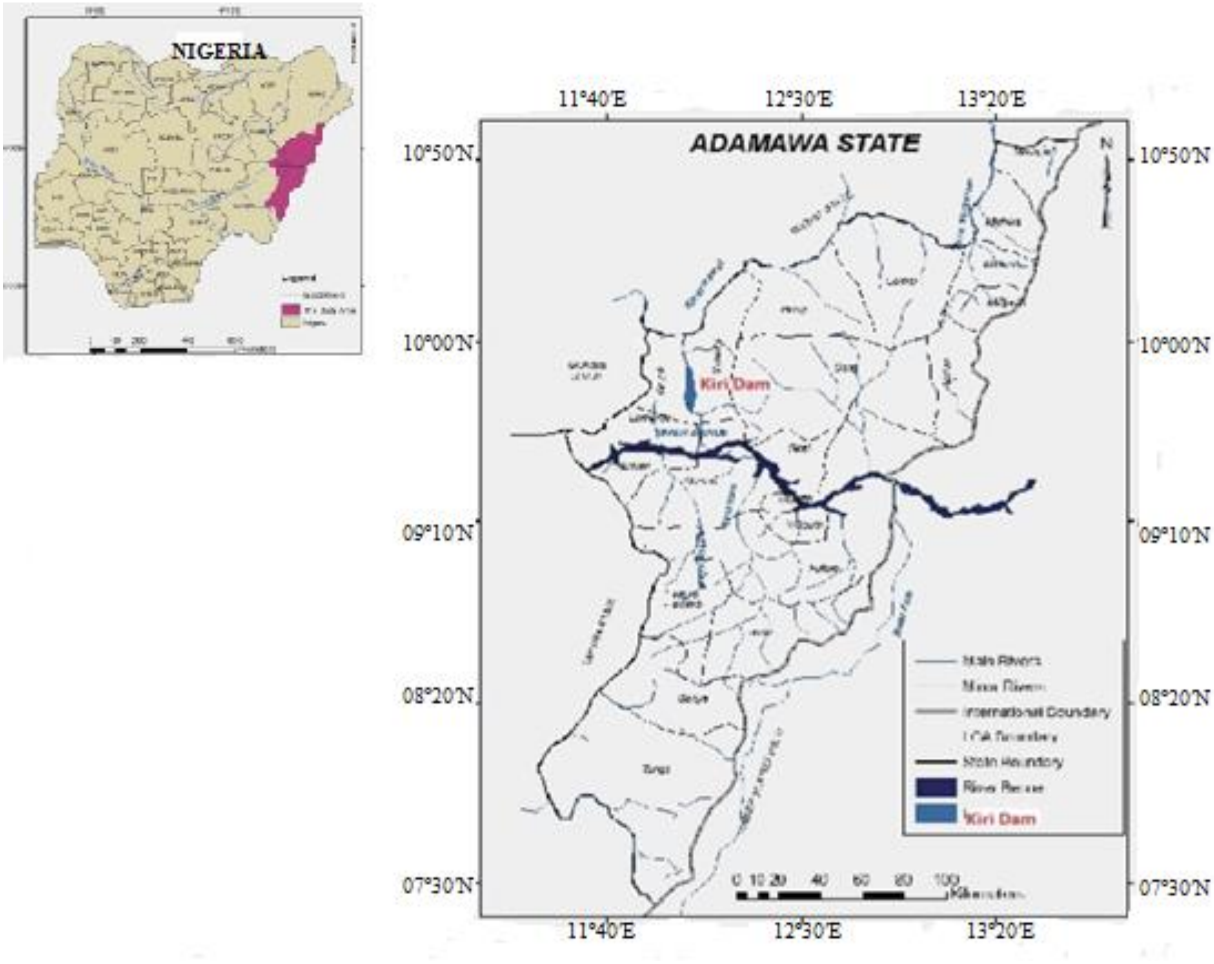

Figure 1: Kiri Dam Source: Adopted from Orosun *et al.*, (2019)

The rainfall regime in the area is a tropical continental type of single peak toll usually in August or September. The wet season ranges from April to October, with annual rainfall values of 510 – 1040 mm and the dry season lasts for about 7 months. Kiri area has a warm temperature with a mean annual minimum value of 18^0 C in December and a mean annual maximum of 38^0 C in March. Kiri Dam was built following the mandate given to the Upper Benue River Basin Development Authority (UBRBDA) by the federal government of Nigeria to supply water by gravitational irrigation to the 29,000 hectares sugar project of Savanna. It has a length of 1,250 meters, a height of 20 meters, and a surface area of 134 km^2.

The data used in this research include Landsat (Operating Land Imagery) OLI from Dec.2013 to Dec. 2017 with a path and row number of 186 and 053 respectively. All the satellite images were obtained during the December period from the US Geological Survey (USGS) Website (http://earthexplorer.usgs.gov). The choice of the same date for the five different years in the acquisition of the data is to avoid water fluctuations due to rainfall, sun illumination difference and difference in vegetation and soil condition. The Landsat image acquired was free from snow, ice or cloud cover.

Table 1: Data Specification

Satellite/Sensor	Band	Name	Resolution
Landsat 8 OLI	2	Blue	30 m
	3	green	
	4	Red	
	5	Near Infrared (NIR)	
	6	Shortwave NIR1 (SWIR1)	
	7	Shortwave NIR2 (SWIR2)	

2.1 Data Preparation and Correction

The major data preparation process for this research is by clipping to the area of interest. A spatial subset of a raster, including a raster dataset and image service layer was created. The operation was used to extract the band required for the exact study area.
The image has undergone two main corrections

2.1.1 Conversion from Digital Number (DN) to Reflectance Value

The conversion is important for studies regarding the reflectance of river surfaces, by extracting the information from Landsat images, a single pixel (digital numbers, DN) was converted to a reflectance number as follows:

$$\lambda, = MQcal + A. \quad (1)$$

where:
λ, = TOA Planetary Reflectance without correction for solar angle
M = Band-specific multiplicative rescaling factor
Qcal = Quantized and calibrated standard (DN)
A = Band-specific additive rescaling factor
and,

$$\lambda = \frac{\lambda,}{\cos(\theta sz)} = \frac{\lambda,}{\cos(\theta se)} \quad (2)$$

where:
λ = TOA Planetary Reflectance
θsz = Local solar zenith angle
θse = Local sun elevation angle

2.1.2 *Sun Elevation Correction*

The following equation was used for the sun elevation correction:

$$\theta = 90^0 - sun\ elevation$$
$$\lambda\theta = \theta * 3.14/180 \rightarrow cos\lambda\theta n$$
$$corrected = Reflectance\ value/cos\theta$$

λ = Top-of-Atmosphere Planetary Reflectance.
θ = Solar Elevation Angle (from the metadata)

2.2 Data Analysis

The data obtained were processed using ArcView10.3 to produce the water indices map of the study area. A combination of green and SWIR bands performed better in detecting the water bodies. The surface water reflectance values were extracted from each spectral band based on Landsat 8 (2,3,4,5,6, 7 Bands) sample points of the land cover types. The result displays the surface reflectance of the spectral bands of both sensors based on the sample point. NIR is sensitive to vegetation and SWIR is sensitive to the exposed soil surface. The models from the various indices were used to get the index that performed better in the extraction of surface water area. The index that performed better in the extraction of surface water area was used to calculate the changes that occur between December 2013 and December 2017

Table 2: List of water indices

S/No.	Index	Name	Formula
1	NDWI	Normalized difference water index	Green-NIRGreen+NIR
2	MNDWI	Modified Normalized difference water index	Green-SWIR1Green+SWIR1
3	LSWI	Land Surface Water Index	NIR-SWIR1NIR+SWIR1
4	AWEI	Automated Water Extraction Index	4G-SWIR1-(0.25*NIR+2.75*SWIR2)
5	WRI	Water Ratio Index	Green+RedNIR+SWIR2

3.0. Results and Discussion

The surface water was extracted using the selected five index methods which were derived according to the equations in Table 2. As stated in the introduction, most of the studies focus on scenes containing water bodies or a subset with a higher percentage of water in the study area, water index methods are simple and show high accuracy while extracting the surface water. However, after evaluation of this study, it is evident that it is not always the case.

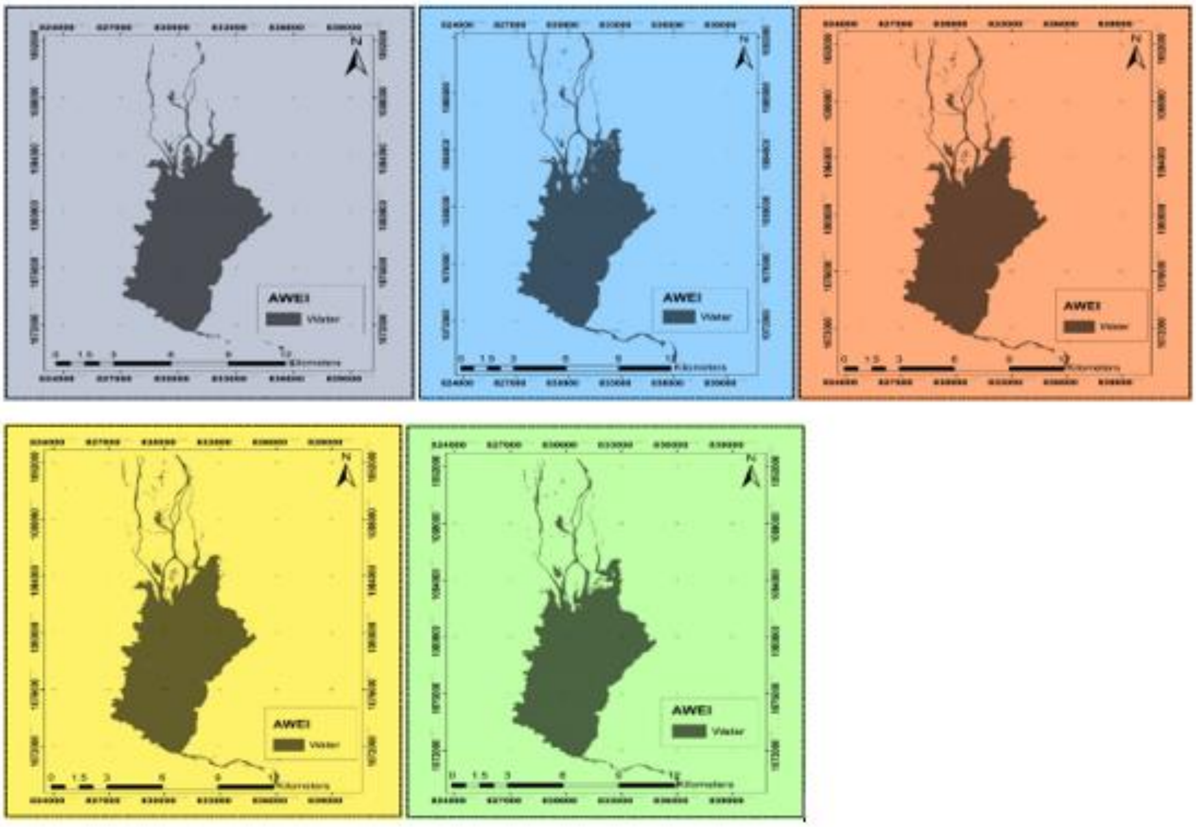

Figure 2: AWEI: (a) 2013 (b) 2014 (c) 2015 (d) 2016 (e) 2017

Water bodies were extracted using the Automated Water Extraction Index (AWEI) and the result is shown in Figure 2 (a, b, c, d, and e.). The results show that AWEI is effective in eliminating dark background shadow because it can be challenging to separate water pixels from dark surfaces due to their similar reflectance, the AWEI approach is suitable for scenes with shadows and other dark surfaces. The shadow trend was the same as those reported in other studies (Ding 2009).

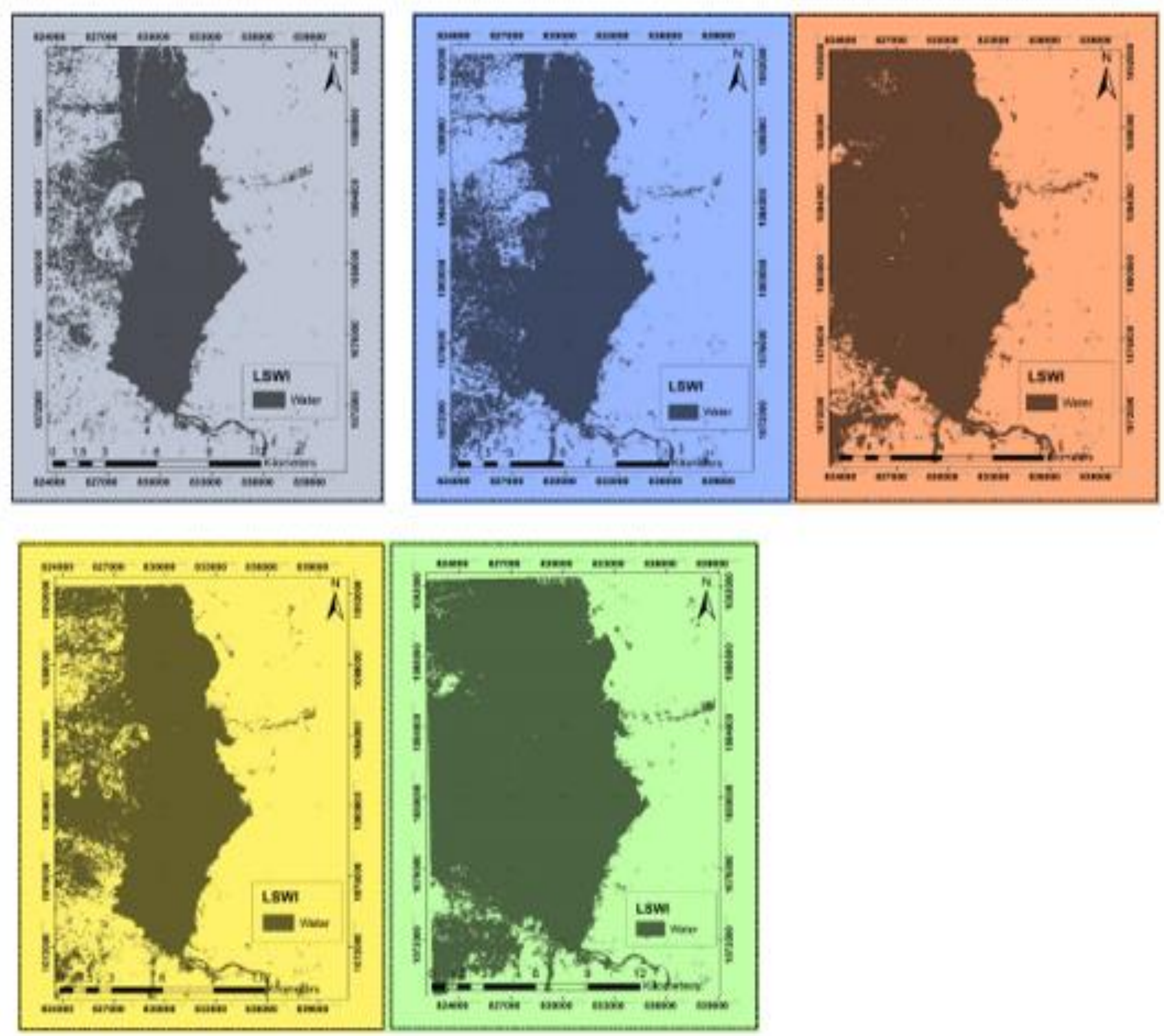

Figure 3: LSWI: (a) 2013 (b) 2014 (c) 2015 (d) 2016 (e) 2017

The Land Surface Water Index (LSWI) was used to extract water bodies and the result is presented in Figure 3 (a, b, c, d. and e). LSWI was incapable of extracting the water surface area because it has been observed that there's a strong absorption of liquid water in the SWIR as reported in other studies by Sheng and Li (2010). The LSWI is rather noticed to be very sensitive to the total amount of wetness in the study area as shown in Figure 3 (a, b, c, d and e).

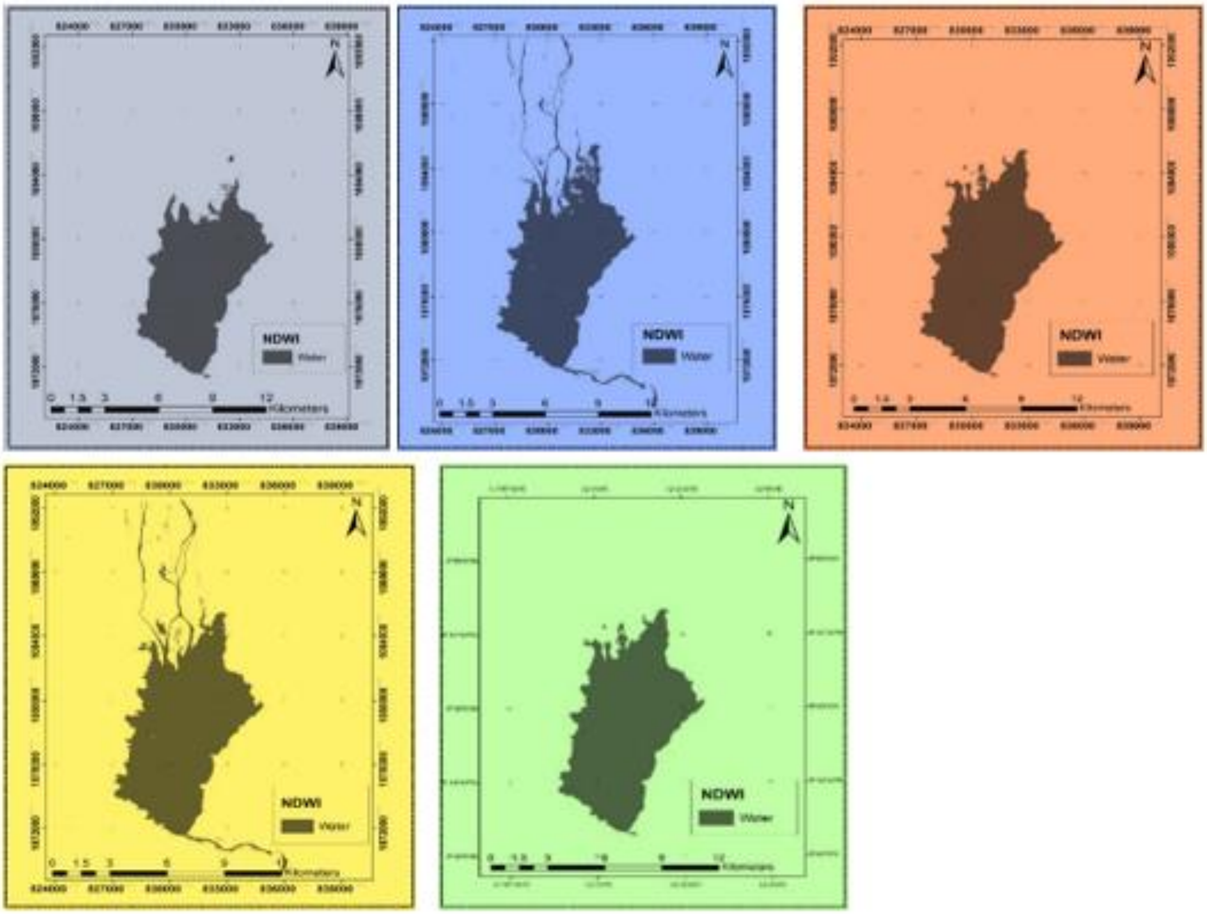

Figure 4: NDWI: (a) 2013 (b) 2014 (c) 2015 (d) 2016 (e) 2017

Figure 4 (a, b, c, d, and e) shows images obtained using the NDWI. NDWI was observed to have the ability to separate water bodies from other features in Figure 4 (a, b, c, d and e), but it has limitations on plants, soil and build-up areas. The spectral trends of plants and bare land were the same as those reported in previous studies (Ding 2009; Xiao, Zhao, and Zhu 2010; Xu 2005). The spectral trend of water was also the most common and differed only from water bodies with high levels of suspended sediment (Xu and Tang 2013).

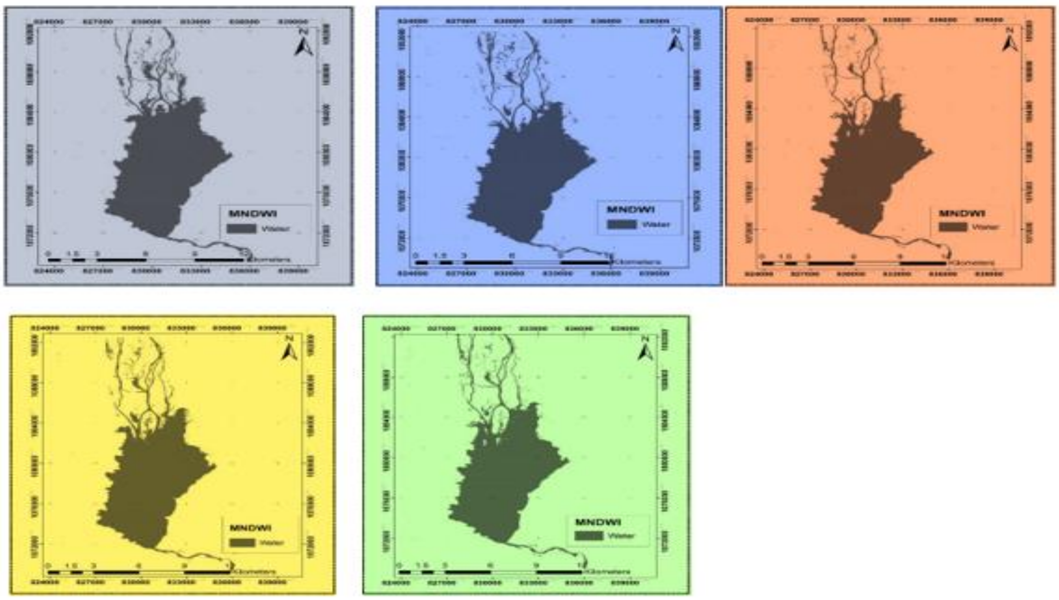

Figure 5: MNDWI: (a) 2013 (b) 2014 (c) 2015 (d) 2016 (e) 2017

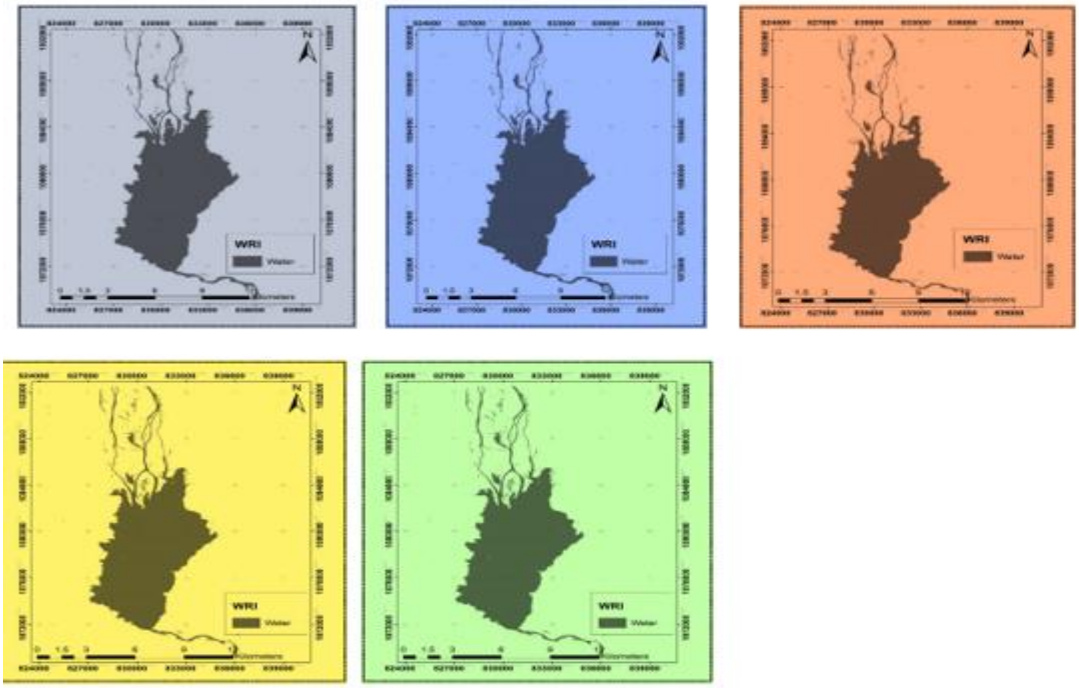

Figure 6: WRI: (a) 2013 (b) 2014 (c) 2015 (d) 2016 (e) 2017

The MNDWI shows the extracted water bodies in Figure 5 (a, b, c, d and e). The WRI depicts the water bodies for years in studies as shown in Figure 6 (a, b, c, d and e). MNDWI and WRI provided the highest accuracy results in the extraction of surface water, the water ratio indexes in previous studies showing values, in general, greater than 1 for water pixels (Sheng *et al.*,2010). The result in Figure 5 (a, b, c, d and e) shows that MNDWI has been used to determine the open water extent of wetlands successfully. By using the MIR band, it is possible to achieve reliable quick discrimination of open water features. This method works well due to the extremely high absorption of water throughout the infrared region, particularly relative to the visible region (represented by the green band). This was found to suppress all other negative features such as land, and vegetation as reported by Xu (2006) and provide an estimate of open water extent accurately.

The results indicate the superiority and higher performance of the MNDWI as compared with other indexes for the extraction of surface water from Landsat data. The MNDWI was found to be the most probable index in the extraction of water surface area.

Table 3: changes in Surface Water Area

Year	Area (Km^2)
2013	67.15
2014	63.57
2015	68.68
2016	63.28
2017	52.64

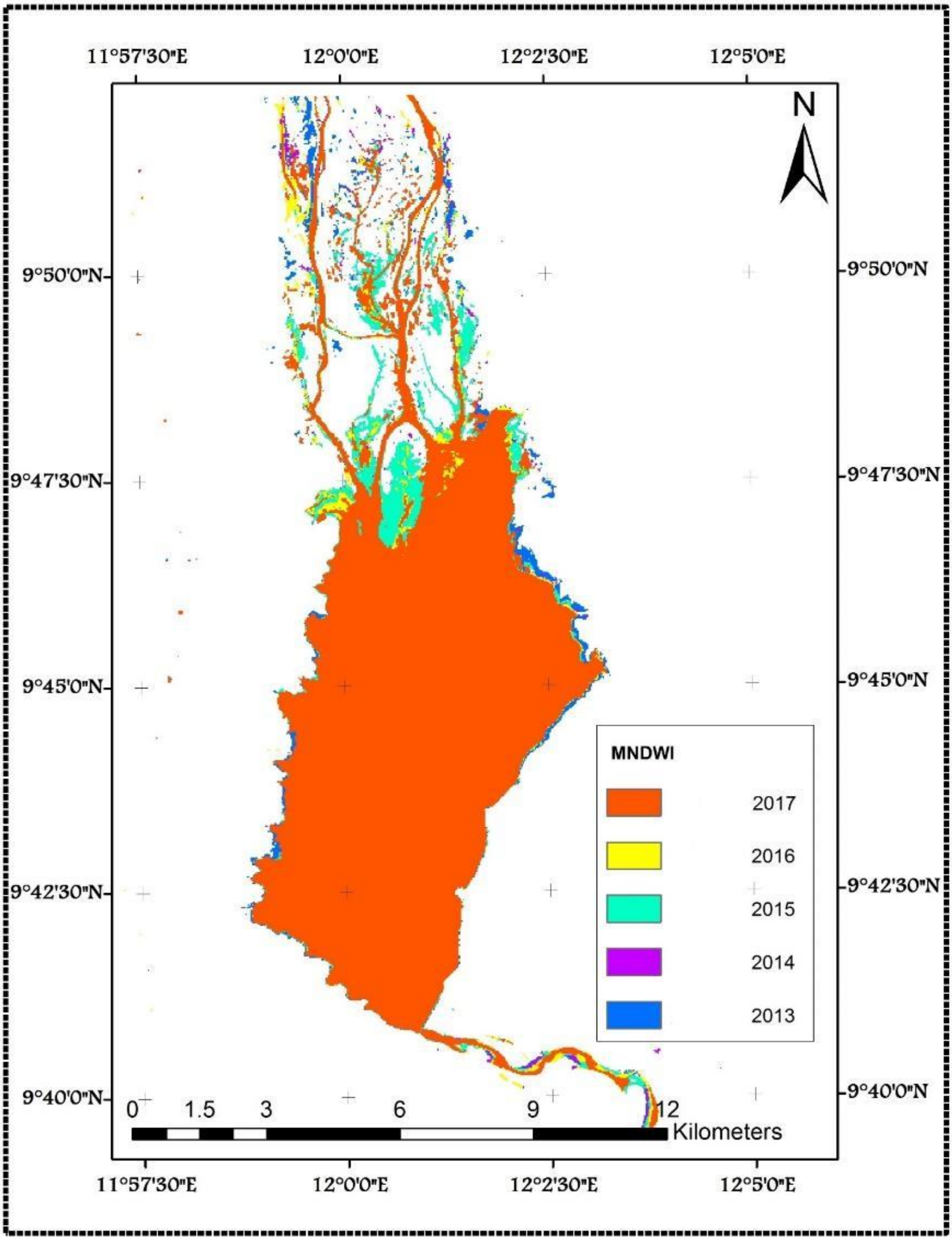

Figure 7: Change Map of MNDWI

The Changes that occurred in the surface water of the study area using the MNDWI of Dec. 2013-Dec.2017, show a change in the shape and spatial coverage of the area. The changes in the area extension and on the map are presented in Table 1 and Figure 5 respectively. Figure 7 shows the superimposed results of MNDWI of Dec. 2013-Dec.2017. The changes that occur between the periods of Dec.2013-Dec.2017 were used to model the spatiotemporal changes of Kiri Dam by calculating the most probable surface water index which is the MNDWI to produce the change in the surface area model as shown in Figure 7.

MNDWI was adopted as the most probable index for extraction of water surface area and was used to determine the trend and changes in the water extends from 2013 to 2017. It is noticed that the dam was decreasing as the years went by. However, an increase in the year 2015 was noticed. In 2015 the surface area of the water increased by 5.11 km² as shown in Table 2. This could be due to impounding of water in the dam to avoid scarcity during the dry season. Table 2 shows the spatial extent of the water; the dam surface area was about 67.15 km² in 2013, 63.57 km² in 2014, 68.68 km² in 2015, 63.28 km² in 2016 and 52.64 km² in 2017. The results further reveal that the total changes in the dam surface area between 2013 to 2017 are about 14.51 km². This shows a decreasing trend in the dam's surface water, apart from 2015 which indicates an increase which is probably due to human influence.

4.0. Conclusions

In this study, a combination of five indices: AWEI, LSWI, MNDWI, WRI and NDWI were used to derive the surface water map of Kiri Dam. Landsat 8 OLI image was processed using ArcView10.3. After pre-processing, each index was derived and summed up to find the most optimal one for the extraction of land surface area water. The result shows that the MNDWI can extract surface area water better compared with the rest of the indices. MNDWI was therefore used to model the changes in the Dam between 2013 and 2017.
Through a comparative analysis, the results showed a decreasing trend in the dam surface area in the period 2013-2017, especially when the lake lost about 14.51 km² of its surface area, except in 2015 when there was an increase.

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