Emergence and Re-emergence of Surface Lakes in the Kalambaina Formation Sokoto Basin, Northwest Nigeria

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Abstract

The Kalambaina formation is part of a series of sediment deposits that forms the Sokoto sedimentary basin. The formation is mainly limestone deposit characterised by caves and caverns in some locations within the sub-surface and numerous springs around the valley side of river Rima during rainy seasons. Several literature show that these springs sustained the river Rima flow during dry seasons but ceases after the rains. Recently there are evidences of springs emerging and surface lakes formed on this formation. This research investigate, explore and confirmed the lakes and the sources of their water to see if they are new or re-emerging water bodies. Landsat 7 Enhanced Thematic Mapper (ETM) of 13/01/2003 and Landsat 8 Operational Land Imager Thermal Infrared Sensor (OLI-TIRS) of 19/01/2014 and 22/01/2015 were combined with standard algorithms to map water areas and perform change detection. The research found that there is an evidence of emergence of lakes that are actually being formed from the new springs emerging and some old springs re-emerging. Results obtained was in agreement with our hypothesis that gradual tectonic movement and hydro-geomorphological processes are responsible for the probable collapse of the caves containing huge water storage within the Kalambaina formation.

Keywords

Kalambaina Formation, Surface Lakes, River Rima, Sokoto Basin.

Introduction

A natural lake is a fairly large body of water occupying an inland basin (low-lying geographic area). Lakes cover only about 1 percent of the continents, and contain less than 0.02 percent of the world's water, but they are important ecosystems and may be sources of water supply in certain regions.

Lakes are extremely varied in terms of origin, occurrence, size, shape, depth, water chemistry, and other features. Lakes can be only a few hectares in surface area (i.e., less than a square kilometer), or they can be thousands of square kilometers. Their average depth can range from a few meters to more than a thousand meters.

Natural lakes can form by various processes. Although many of these processes occurred in the geologic past, lakes continue to form and to be destroyed. For example, an earthquake-triggered landslide created Lake Sarez in Tajikistan only three generations ago. In May 1980, Spirit Lake at the foot of Mount Saint Helens, Washington (USA) was greatly reduced in size when the volcano erupted, pouring rock, mud, and debris into the one-popular resort lake.

Many lakes have formed as a result of tectonic movements of the Earth's crust. Lake Baikal, located in eastern Russia, formed in the Baikal Rift of the Siberian Platform. Lakes Tanganyika, Malawi (formerly Nyasa), Kivu, Turkana, Mobutu, Magadi, Naivasha, and Natron lay along the East African Rift Valley. Other crustal movements influencing lake formation include uplift of the seafloor (Caspian Sea and Aral Sea), and uplift around a central basin (Lake Victoria).

The study area which falls within the arid and semi-arid regions are characterized by having low annual rainfall, high evaporation and sparse vegetation. Nevertheless, these regions also can have large water bodies seasonally or unpredictably. They can range in size from shallow lakes which contain water only intermittently, to large, permanent and deep lakes. Most are relatively shallow.

A closer look at the relationship between lakes and sedimentary formations, could be linked to the theory of lake formation due to tectonic activities. The study area is characterized by the sedimentary rocks overlaying the Sokoto basin with characteristic caves and caverns storing large volume of ground water.

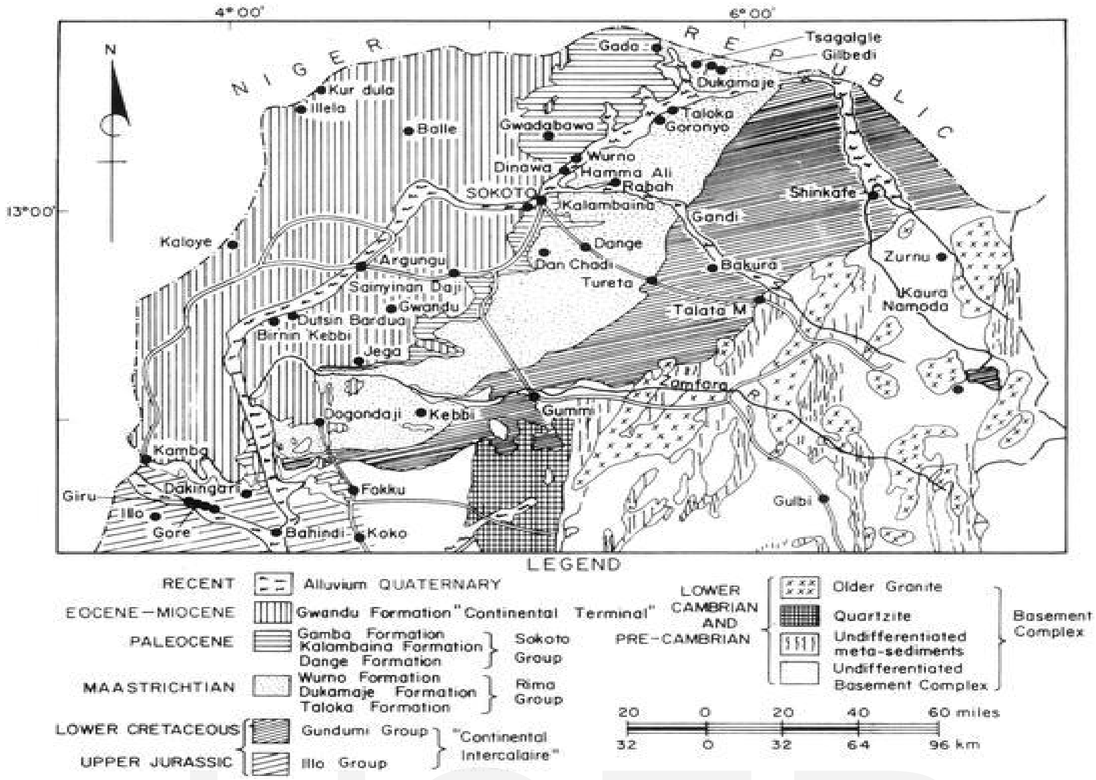
The disturbances on the earth, though gradual, over a period of time has led to the collapse of the caves paving way for the upward movement of the water through the areas of weakness and faults.

This paper examines the emergence of new lakes, the possible return of old ones and the sources of their water in Nigerian segment of the Illumeden basin (the Sokoto basin). Specifically, the paper examined the geological formation, the ground water characteristics of the area and identified the role these caves, aquifers and other ground water sources played in the recent emergence of the lakes.

STUDY AREA

The Sokoto Basin is the south-eastern portion of the larger Iullemmeden Basin. The Iullemmeden Basin covers northwestern Nigeria, most parts of Niger Republic, Benin Republic, Mali, Algeria and Libya. The Sokoto Basin covers mainly Zamfara, Sokoto and Kebbi States of Nigeria (Obaje, Aduku, Yusuf, 2013). It lies in the sub-Saharan Sudan belt of West Africa in a zone of savannah-type vegetation. Rainfall, averaging about 30 inches annually in much of the basin, occurs chiefly in a wet season which lasts from May to October. A prolonged dry season extending from October to April is dominated by dusty harmattan winds from the northeast. April and May are the hottest months, when temperatures occasionally reach 105^0F

The Iullemmeden Basin in north-western Nigeria is known locally as the “Sokoto Basin”. It consists predominantly of a gently undulating plain with an average elevation varying from 250 to 400 m above sea-level. This plain is occasionally interrupted by low mesas. A low escarpment, known as the “Dange Scarp” is the most prominent feature in the basin and it is closely related to the geology.



Geological map of the Sokoto Basin (Modified from Kogbe, 1981)

The sedimentary rocks of the Sokoto Basin range in age from Cretaceous to Tertiary and are composed mostly of interbeded sand, clay, and some limestone, with the beds dipping gently toward the northwest. Alluvium of Quaternary age underlies the lowlands of the Sokoto River, Rima River and their principal tributaries. The sediments of the basin lie unconformably on the Basement Complex and have been affected by a series of marine transgressions during the Mesozoic and Tertiary with consequent deposition of a sequence of sediments. These transgressions progressively affected a large portion of the basin, resulting in an overlap series (Kogbe 1989) and outcrops becoming younger as one moves towards the northwest. Underlying the sedimentary rocks of the Sokoto Basin and rising to the land surface in the uplands to the south and east of the basin are crystalline rocks of pre-Cretaceous age.

The Kalambaina Limestone Formation

The Kalambaina formation is one of the series of sediments that forms the Sokoto basin which is the southernmost part of the famous lullemeden basin. The formation is deposited during the late Palaeocene and is marine in origin consisting mainly of calcareous limestone.

Other sediments that make up the Sokoto basin are the Gundumi/Illo, the Rima group formations (Wurno, Dukamaje and Taloka), the Sokoto group formations (Dange and Kalambaina and Gamba) and Gwandu formation (Kogbe, 1989).

Groundwater in the basin occurs in the gritty members and the conglomeratic and gravelly beds of the Gundumi/Illo; the thin beds of semi consolidated fine sand of the Wurno and semi consolidated fine to medium grained sand and sandstone of the Taloka; the limestone beds of the Kalambaina and the interbedded semiconsolidated sand and clay and lignite beds of the Gwandu aquifers in the basin (Oteze, 1979; JICA, 1990; Adelana, 2006). Along the river valleys, perched groundwater can also be found in the area. Alluvial aquifers ranging from 2 m sometimes to a depth of up to 20 m can be found consisting of materials such as gravels, sands, silt and clay resulting in locally confined conditions (Offodile, 2002).

Groundwater potential in most of these aquifers is generally moderate to high yielding with Gwandu formation as the most prolific aquifer. The recharge to the aquifers was through rainwater infiltration from the surface at their outcrop areas, and partly by effluent seepage from streams and probably through leakage from the overlying perched water body.

In the Kalambaina formation, water occurs as perched water body especially in the outcrop areas supplying water to hundreds of dug wells generally less than 18m deep, but downdip the limestone is impermeable and forms a confining layer with the shales of Dange formation. The limestone is characterised by many springs along the valleys and depressions discharging water into rivers Rima and Sokoto and some lakes e.g. Kware and Bodinga lakes. Some cavities tapped by well shafts into this limestone aquifer can produce artesian flow such as the one that occur in Tungar Tudu (about 60 km away from Sokoto town). The transmissivities increases towards the upper part sandy zone of the formation around Tureta area.

The springs discharging from Kalambaina aquifer serve as a major source of water to Kware Lake and the discharge from this lake increases and sustain the flow of river Rima during dry season (JICA, 1990; SARDA, 1988; Offodile, 2002).

Historically, many lakes and streams fed by springs from the Kalambaina formation have disappeared along depressions and valleys where they formally occur e.g. the Lake extending from Gwadabawa to Meli which is about 10 km long. Water can only be found during heavy rainy season in some depressions and quickly disappear after few days of rain.

Materials and Methods

Data Capture

Data used for the study includes waypoints of the area obtained through ground truthing with a 3-meter accuracy hand-held GPS receiver, Landsat 7 Enhanced Thematic Mapper (ETM) of 13/01/2003 and Landsat 8 Operational Land Imager Thermal Infrared Sensor (OLI-TIRS) of 19/01/2014 and 22/01/2015. The Landsat data represent path/row 191/051 in the active archive centre of the United States Geological Survey (USGS), downloaded via glovis.usgs.gov. Also, they are in Level 1T (precision and terrain corrected) format, cloud free and near-anniversary.

Data Processing

Haze correction was routinely performed on the data sets using Dark Object Subtraction (Eastman, 2009) within the PANCROMA environment. For geometric correction, the 2003 image was corrected to 0.00032 Root Mean Square (RMS) using 12 Ground Control Points (GCPs) obtained from the topographical map covering the study area. The 2014 and 2015 were then registered to the 2003 with RMS values of 0.00061 and 0.00026 respectively. Visual image interpretation was employed for change detection analysis. It is based on man's ability to relate colours and patterns in an image to real world features (Janssen, 2004). Bands 7, 5 and 3 of Landsat 8 data sets, corresponding to 7, 4 and 2 of Landsat ETM (reflective infrared, near infrared and green) (Bakker, 2004; Childs, 2013; USGS, 2014) were combined for colour composite formation (Figures 1, 2 and 3). The band combination clearly defines land/water interphase and moisture variation, with vegetation being green (Horning, 2004). Each composite was pan-sharpened with panchromatic band for image enhancement (Eastman, 2009).

Waypoints obtained from the field were overlaid on each composite for demarcation after which polygons were digitized, first to cover the entire site and, second to cover area known to have water accumulation.

Discussion

For some lakes, rapidly appearing or disappearing is part of a natural process. The lake in Chile did not exist 30 years ago, though, again, global warming is likely affecting the process. Some lakes, including many in Alaska and Florida's Lake Jackson, go through a similar process regularly, disappearing and reappearing during certain seasons, or from year-to-year or decade-to-decade. Global warming seems to be the knee-jerk response lately whenever a dramatic environmental change is observed. Indeed, global warming is a big concern for lakes, as many bodies of water are experiencing receding water levels due to a combination of low rainfall and high temperatures. Lake size and depth can also change over time, owing to various reasons. Through natural processes, lakes will ultimately fill with sediment, thereby "evolving" into a terrestrial ecosystem. But human influences can accelerate the process. For example, Lake Chad, once one of Africa's largest bodies of fresh water, has decreased in size due to an increasingly dry climate and human demands for irrigation water.

One of the characteristic features of limestone are caves and cavities usually developed as a result of solution. This is made easy by the fact that limestone contains bedding planes (horizontal cracks) and joints (vertical cracks) allowing water to pass through the rock. The chemical weathering of limestone, or carbonation, occurs when the rock is attacked by rainwater.

There is always the tendency of top roof collapse where solubility is high and close to the surface. The collapse may be as a result of overburden pressure or gradual tectonic movement which brings about weakening of roof tops. A typical example occurred in 1962 at Dabaga few km away from Sokoto where an artesian rupture caused a well to flow for about a year before subsiding (Anderson and Ogilbee, 1973). A hand dug well at Tungar Tudu also produce an artesian flow for over 10 years before subsiding (Gada, 2010).

For the study area, it is evident that, water and subsequently lake, has emerged after over 30 years of apparent absence of such in the area. The images (figs. I and II), shows dry land while fig. III as well as the field observation reveals the presence of water, and its origin.

A possible explanation for the increase in the ground water volume is the recent high volume but shot cycled precipitation in the basin. The changes in groundwater recharge determines more than precipitation ground water levels. There are two main parameters that could have a significant impact on groundwater levels: recharge and river stage/discharge (Kumar, 2012).

Earlier studies, Anderson, and Ogilbee (1973), shows that in the vicinity of Sokoto, the River Rima flows throughout the year sustained by spring discharge from perched ground water in limestone of the Kalambaina Formation. On the crystalline terrain where most of the streams rise, total annual runoff may exceed 5 inches, very little of which is ground-water discharge.

The sedimentary rocks of the basin range in age from Cretaceous to Tertiary and are composed mostly of interbedded sand, clay, and some limestone; the beds dip gently toward the northwest. These rocks contain three important artesian aquifers, in addition to regional unconfined ground-water bodies in all the principal outcron areas, and a perched water body in the outcrop of the Kalambaina Formation.

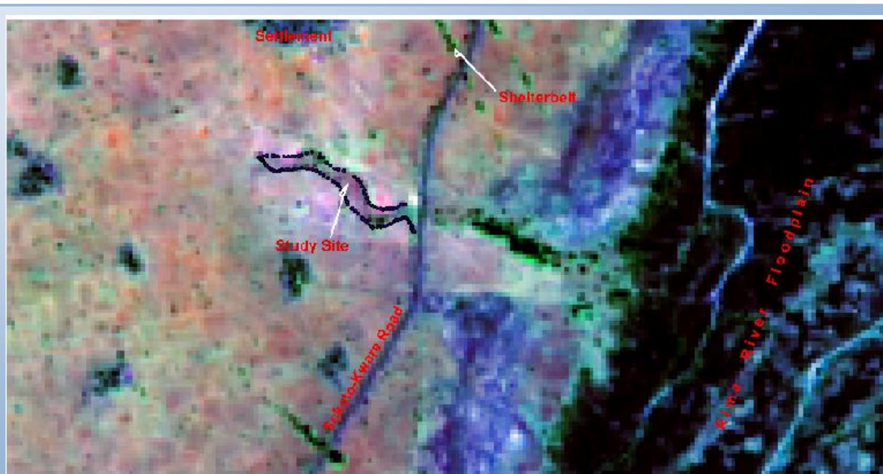
Field study also revealed that farming activities of upland crops has been going on in the area for over thirty years because of the dryness until November 2014 (well after then rains), when water started gulping out of the source.

Plate 1 Emerging Lake showing remnants of the upland crop during the dry periods.

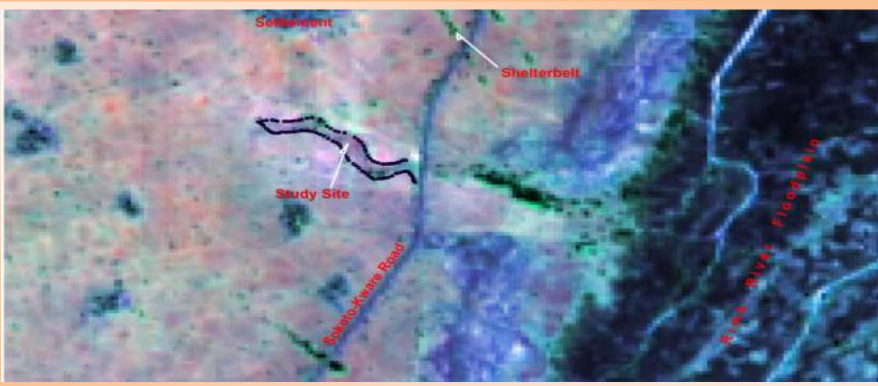
Plate I: Sight view of the emerging lake (Feb. 2015)

Results

Result shows that all the composites present different land cover types for the study site, indicating a change in the land cover in 2003, 2014 and 2015. While the 2003 and 2014 composites show a bare surface.



2003



2014

The 2015 shows a wet area akin to what is obtainable in the adjacent floodplain. As at field time, the area within the bounds of the site measuring 4.02ha was wet and subjected to multiple Fadama (lowland) crop cultivation.

2015

The base of the area in Figures 3 shows a darker tone than the upper part which corresponds to the portion where the water became stranded. This portion is estimated to be 1.06ha.

Plate II: One of the Emerging Lakes at the study area

Conclusion

From the foregoing, the researchers have come to assert that new lakes as well as old ones are re-emerging in the Kalambaina formation of the Sokoto basin; and that this re-emergence took place during the dry season of 2014 after over 30years of dryness. This is as a result of geomorphic tectonic activities, as well as the rate of ground water recharge in the Sokoto basin consequent upon global climatic variation or simply put, Climate change.

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