Title of the Article

A Remote Sensing Imagery and Geographic Information System in Investigation of Limnological Characteristics of a Unique Lake Ngozi, Tanzania

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Abstract

Remote sensing technique simplified a timely measurement and assessment of inaccessible Lake Ngozi. I used remotely sensing satellite imagery for investigation of limnological characteristics of Lake Ngozi Crater Lake in Southern Highlands of Tanzania. I analysed geospatial data to get geological, climatic and biotic information for the lake. I also extracted spectral reflection signatures from water and vegetation from atmospheric corrected OLI Landsat 8 TIRS imagery. A lake lies in the andosol soil, its annual rainfall ranges between 1200 and 1400 mm influenced by leeward and windward meteorological effects. Unpalatable plants dominate MRFR that also protects the reserve from livestock grazing pressure. MRFR contains healthy and dense vegetation canopy. A lake contains high concentration of CO₂ that heightens a primary production of phytoplankton making it naturally eutrophic. It also contains large amount of suspended sediments and organic matters. A heightened primary production of algae contributes to regular change of water colours in the lake. A high concentration of salts makes the islands unfavourable habitations for fauna and flora in the lake. I recommend for a comprehensive biodiversity inventories and a study on abundance and diversity of algae and cyanobacteria.
1.0 Introduction

Remote sensing technique simplifies distant measurement and assessment of inaccessible inland lakes (Jawak, Kulkarni, & Luis, 2015). A use of remotely sensing imageries for limnological studies of inland lakes has a long history (Powell, Brooks, French, & Shuchman, 2008). Researchers with different background and interests use remote sensing (RS) and geographic information system (GIS) techniques to understand location, bathymetry, water quality and quantity of different types of water bodies (Kulkarni, 2011). In nutshell, remote sensing and GIS are fundamental environmental management tools for limnological studies (Talling, 2006). In this study, I used RS and GIS to explore limnological characteristics and geospatial configuration of Lake Ngozi. A lake is in the southern highlands of Tanzania, it has outstanding sceneries and powerful spiritual benefaction (Edwin, 2009). A lake provides the neighbouring communities with social-cultural values (Kiama, 2017). It holds exceptional natural and cultural resources. A recent geothermal investigation has shown undoubted opportunity of geothermal energy exploration (Mgejwa, 2015). Strategic location and natural resource richness of the lake fascinate researchers and tourists of different descriptions (Hudson, 2016).

A knowledge on limnological characteristics and geospatial configuration is crucial for sustainable conservation of any lake. As a subdivision of ecology, limnology investigates biological, chemical, physical, natural resources and hydrological features of inland lake (Bertoni, 2011). Inland aquatic ecosystems are complex to understand because of interdependences and interactions between biological, chemical, physical, social and political dimensions (Gâştescu, 2009). Limnological characteristics provide valuable information necessary for understanding of such interdependences and possible impacts emanating from anthropogenic and non-anthropogenic activities (Hart, 2004). Also, limnological features provide scientific descriptions on functions and structure of the lake, which is crucial for problem-solving and sustainable resource conservation (Bertoni, 2011). Furthermore, the
features are crucial during lake’s planning process for tourism managers, energy explorers, farmers, conservationists and engineers (Gâştescu, 2009; Satyanarayan, Chaudhari, & Dhadse, 2008).

Limnological studies on crater lakes are either lacking or unpublished. In a meanwhile, Crater Lake in United States, have been extensively studied more than any other crater lake in planet earth. As an example, Larson (1993) investigated a long-term hydrological status of Crater Lake in US for about 10 years. In comparison, limnological studies in non-crater lakes are many in the world. Such studies started in Africa since 1920 (Talling, 2006). The studies used in situ sampling and laboratory techniques to identify long-term changes in water quality and quantity. Conventional methods are expensive in logistical resources, purchase and maintenance of laboratory equipment. Researchers have studied Lake Ngozi in the areas of geothermal energy (Alexander, Cumming, & Marini, 2016; Mgejwa, 2015), biodiversity (Mwakisunga, 2017; WCST, 2013) and tourism (Edwin, 2009; Hudson, 2016). However, a few published studies looked into limnological characteristics of the lake Ngozi (Delalande-Le Mouëllic et al., 2015). Limnological studies in the lake adopted conventional assessment techniques. I adopted remote sensing and GIS techniques for this study. A distant investigation of lake Ngozi reduced the research costs, time and energy (Jawak et al., 2015).

Limnological information about Lake Ngozi is unreliable, and an in-situ investigation technique requires enormous logistical costs and time. I used free satellite imagery to get limnological information of the lake. A remote sensing technology uses sensors for measurement of lake’s characteristics at a distant without becoming physically in contact with it (Jawak et al., 2015). A remote device measures several aspects of limnology including water quality and quantity measurements and land cover (Kulkarni, 2011; Wanga, Brownb, & Baic, 2014). Sensors record reflected electromagnetic radiations of interested features from earth’s surface (Powell et al., 2008). Remote sensors come in different designs to fit specific purposes (Jawak et al., 2015; Powell et al., 2008). Therefore, when deciding which sensor to choose for limnological survey, it is necessary to have an simplifies
knowledge about the fundamental specifications of the sensor that match the requirements of the study. Since the lake lacks details about chemical, biological and geophysical processes. I used RS and GIS to find out the underlying limnological features of Lake Ngozi. A convenience of free satellite imagery provided a researcher opportunities to investigate and observe various natural processes and features in the lake. In this study, I specifically determined a geographical configuration, chemical, physical and biological features of the lake and Mporoto Ridge Forest Reserve (MRFR).

2.0 Methods and Materials

2.1 Study area

Figure 1: A map showing Lake Ngozi in Mporoto Ridge Forest Reserve
Ngozi is a second crater lake in Africa (Delalande-Le Mouëllic et al., 2015; Hudson, 2016). It is an endorheic and saline lake found in southern highlands of Tanzania. A lake is located about 38 km from Mbeya city and Tukuyu Township. Lake Ngozi borders 22 villages of Isyonje, Idweli, Mbeye One, Goye, Ntokela, Swaya, Shunga, Malangali, Nsebelo, Igembe, Kipande, Igale, Shongo, Ngoli, Idunda, Nsenga, Swaya, Wimba, Nsongwi, Matanji and Iwalange (Kiama, 2017). The surface area of the lake measures about 3.3 km² (figure 3). Ngozi is a rift valley volcanic lake belonging to Poroto-Rungwe Volcanic Province (P-RVP). Lake Ngozi holds nearly 72.7 x 10⁻³ km³ volume of water, with water depth approaching 75 meters (Delalande-Le Mouëllic et al., 2015). It is a part of Mporoto Ridge Forest Reserve, which is the montane forest endowed with endemism and diversity of various plant and animal species. It is one of world class tourism attractions in southern highlands of Tanzania (Hudson, 2016).

2.2 Research methods

2.2.1 Geospatial data analysis

I obtained the ESRI shapefile from Lincoln University GIS server. I processed the shapefile using a geoprocessing tool in ArcGIS 10.5 to obtain specific climatic, vegetation and physical information of the lake (figure 2).

2.2.2 Acquisition and analysis of satellite imagery

I used Bulk Downloading Application (BDA), from USGS earthexplorer to acquire Landsat 8 (OLI) Operational Land Imager Sensor. I processed the imagery using ArcGIS 10.5 and ENVI 5.2. I used ArcGIS for NDVI. I deployed ENVI 5.2 for atmospheric correction and extraction of spectral
reflectance signatures. I chose Landsat 8 satellite instrument because of adequate spatial resolution for water quality assessment, free accessibility and convenience. USGS launched Landsat 8 (OLI) Operational Land Imager Sensor in 2013. While it is similar to Landsat 7 ETM, it has additional spectral bands, which are band 1 for water resources, and band 9 for detection of cirrus clouds. The imagery has a spatial resolution of 30 m. I extracted water quality and vegetation information from Landsat instrument by using ENVI 5.2. I performed supervised classification to cluster pixels into training classes to get spectral signatures for the lake and vegetation. ENVI treated each pixel as individual unit having values across several spectral bands. I created six (6) regions of interest (ROIs) as water samples and six as forest in imagery. I developed training data to match several visible colours in the satellite imagery. Training data simplified identification of pixel that represents spectral variation in each region of the lake and vegetation. A spectral angle mapper used n-dimension angles to match pixels to reference spectrum. It compared angles between endmember spectrum vector and each pixel spectrum vector. The closer the pixel the closer the match to the reference spectrum.

2.2.3 Normalised Difference Vegetation Index

I performed NDVI to understand vegetation heath of Mporoto Ridge Forest Reserve and Lake Ngozi. A green plant absorbs visible light from 0.4 to 0.7µm, and reflects any wavelength from 0.7 to 11.1µm. A chlorophyll pigment enables green plants to absorb solar radiation for photosynthesis. Plant avoids absorbing any wavelength longer than 0.7µm to prevent itself from overheating and damaging its crucial tissues. As results, plant appears dark at visible and bright at near-infrared regions of electromagnetic spectrum. In contrary, clouds, water and soil appear dark at near-infrared and bright at visible regions. In this study, NDVI computation adopted the formula, NDVI = (NIR-RED)/(NIR + RED).
2.3 Results

Results showed Lake Ngozi is a part of Mporoto Ridge Forest Reserve. A reserve is widely dominated by unpalatable plants (Fig 2d). Annual average rainfall for Lake Ngozi varies from 1200mm to 1400mm. Geospatial results indicate that Lake Ngozi has a different annual rainfall range from other parts of reserve (Fig 2a). A dominant soil in the lake is vitric andosol but a reserve has eutric leptosols and umbric nitisols types of soils in other parts (Fig 2c). The findings reveal the presence of six streams around Mporoto Ridge Forest Reserve (Fig 2d).

Figure 2: Geographical maps Geographical maps from geospatial analysis, showing land use and land cover of Mporoto Ridge Forest Reserve (figure: 2a), climatic condition of MRFR (figure: 2b), soil classification and dominant soil type in MRFR (figure: 2c) and the dominant vegetation type in MRFR (figure: 2d).

A google earth ruler estimated a perimeter of the lake to be 3.3313 km² (fig 3a). It also provided a shapefile for preparation of a map of the lake.
Figure 3: An estimation of surface area for Lake Ngozi using google earth imagery. A researcher used a ruler from google earth to measure the surface area and clipped to get a current map of the lake figure 3a. Location and distribution of water samples in the lake figures 3b.

Spectral reflectance characteristics of varied according to the location of the sample in the lake. Sample1 radiated enormous wavelength at coastal and aerosol region, however its reflectance weakened across the spectrum. Reflectance for sample2 climaxed at near-infrared region. Other samples showed similar spectral reflectance by radiating high at coastal and aerosol region and low across the spectrum (Fig 4a). On the other hand, spectral reflectance signatures revealed the presence of vegetation types in Mporoto Ridge Forest Reserve. In this case, I identified montane forest, woodland, bamboo, grassland and stressed vegetation in the lake. (Figure 4a).
Figure 4: Spectral reflectance characteristics of different vegetation in Mporoto Ridge Forest Reserve (Fig 4a). Spectral signature of water collected from different portions of the Lake (fig 4b).

Also, I performed normalised vegetation index to understand vegetation health of the reserve. NDVI showed (high) positive and negative (low) index values. The positive values represented areas containing dense vegetation canopy (fig 5). Low or negative index values represented areas with poor reflectance including standing water (Lake Ngozi), soil and unhealthy vegetation.

Figure 5: A Normalized Difference Vegetation Index for Mporoto Ridge Forest Reserve
4.0 Discussion

Mporoto ridge forest reserve encircles the lake from all directions. As a forest reserve, MRFR regulates human activities and access to lake resources. It usually isolates and protects the lake against severe destructive anthropogenic activities while enhancing biodiversity conservation. A geospatial information disclosed a dominance of unpalatable vegetation in and around the forest reserve, which also restricts livestock grazing. Those are untasteful or poisonous native plant species unsuitable for livestock grazing. It is a defensive mechanism for unpalatable plants and neighbouring tasty plants (Callaway, Kikodze, Chiboshvili, & Khetsuriani, 2005). Many unpalatable plants may indirectly upsurge a community composition of tasteful plants. It may equally affect community composition of aquatic and terrestrial organisms.

A dominance of andosol soil throughout the lake and reserve evidences Ngozi is a volcanic lake. In other words, a chemical content of volcanic landscape surrounding the lake shows that andosol is the dominant soil in the reserve. It is a black soil characterised by volcanic ash as parent materials. The ash influences physical, chemical, biological and mineralogical composition of the lake and reserve (Barois, Dubroeucq, Rojas, & Lavelle, 1998). It is a fertile soil with good rootability and water storage property (Takahashi & Shoji, 2002). Thus, a suitability of andosol’s ingredients and properties affects the biodiversity the reserve and limnological status of the lake. In other words, andosol dictates physical, chemical and biological composition of the soil in the reserve. Its fertility determines vegetation health and structure. NDVI (figure 2) evidences Mporoto Ridge Forest Reserve contains dense vegetation canopy with healthy green plants. Because of its heath, the forest attracts endemic species toad athrolepsis kutogundua, several species of primate, avifauna and rare three-horned chameleons (Kiama, 2017).
Annual rainfall variation between Lake Ngozi and other areas in MRFR is an indication of meteorological effects of leeward and windward. In meteorology, leeward side is a downwind side obstructed from prevailing wind by the mountain. While windward is upwind side directly faces a prevailing wind (Means, 2017). In windward side of the reserve, Mporoto Mountain obstructs air flowing across by pushing air to ascend along the slope due to high terrain (Viale & Nun˜ez, 2011). A lifted air along mountain slopes undergo adiabatic cooling resulting into cloud formation and eventually high rainfall range amounting 1400mm – 1600mm in windward. In contrast to windward side of the reserve, leeward side is dry because the air drops majority of its moisture contents before reaching it (Arora, Singh, Goel, & Singh, 2006; Means, 2017; Viale & Nun˜ez, 2011). As the air descends the mountain it dries by adiabatic warming. It therefore scatters clouds and creates a possibility of having low rainfall ranging between 1000mm – 1200mm (Means, 2017; Viale & Nun˜ez, 2011). It is a reason annual rainfall range is the highest in windward, 1400mm – 1600mm, (South), average in the crater (Lake Ngozi) between 1200mm – 1400mm and the lowest in leeward side, 1000mm – 1200mm, (North) of Mporoto Ridge Forest Reserve (Figure 2b).

Remote sensing measured reflected or emitted radiation from water and vegetation (Sánchez-Azofeifa et al., 2009). Coastal or aerosol can estimate fine particles of aerosol, monitor chlorophyll concentration and suspended sediments in the lake., Landsat imagery showed that, all samples contained chlorophyll, fine particles, algal blooms, phytoplankton and other types of suspended sediments. Limnologists use chlorophyll-a concentration as a parameter for water quality index determination. It is a greenish pigment contained in plants, algae and cyanobacteria for photosynthesis. In remotes sensing, chlorophyll exhibits efficiency absorbencies at red and blue sections of electromagnetic spectrum by reflecting and transmitting green light. A greenish refraction at visible regions of spectrum indicated the presence of algae, plants and cyanobacteria.

Mouellic, (2005) declared Lake Ngozi as CO₂ condenser because of its high concentration. A high level of CO₂ is an indication of accumulation of dead organic matters from a surrounding forest.
undergoing decomposition in the lake. As dead organic materials normally sink, it is a reason a concentration of CO₂ caused by their decomposition is high near the bottom of the lake (Whitfield, Aherne, & Watmough, 2010). In short, an elevated level of CO₂ evidences a primary production of the lake is high. A chlorophyll-algae converts CO₂ and water to carbohydrate making Lake Ngozi naturally eutrophic. Consequently, a large quantity of algae blooms causing eutrophication may distort physical, biological and chemical characteristics of the lake (Wanga et al., 2014). It is a reason the lake changes its colours and clarity in some parts of the years.

Local people and tourists tell stories about regular colour change of the lake. Some visitors named the lake after Chameleon because of its colour-changing abilities. Kiama (2017) noted seasonal colour change and regarded it as one of powerful magnets for tourists. Some believe the colour reflects blue sky. Cameron (2005) described that, a light hitting a lake contain all wavelength of electromagnetic spectrum. Water absorbs most of wavelength and reflects the blue colour that we can see. In limnology, many lakes show green, blue and brown colours (Li & Li, 2004). Colour change suggests many things happening in and around lake ecosystem (Rose, 2017). In those cases, colouration alerts about water quality, suspended sediments, algae blooms and trophic level.

Like other mountain lakes, Lake Ngozi receives tones of suspended materials from a surrounding montane forest and rocks. When lights hit water surface, the suspended organic and inorganic matters cause distortions on wavelengths, reflecting blue and green colours (Cameron, 2005). In that case, lake colouration tells existence of photosynthetic algae. Green water is a testament to rapid algae growth that normally occurs in spring months, and blue colour means low concentration of algae and suspended matters (Rose, 2017). A green colour changes to blue shortly as zooplankton emerge and forage the algae. However, the rate of its disappearance depends on abundance and diversity of zooplanktons in the lake, which is unclear to Lake Ngozi.
Sample2 showed incomparable spectral reflectance characteristics at near-infrared. A sample emittance exceeded the emissions from other samples. It evidenced the presence of vegetation within the lake. A spectral reflectance characteristic showed the presence of vegetation in the lake. Similarly, Kiama (2017) observed two rocky islands inside the lakes. As a matter of confirmation, I extracted spectral reflectance signatures of all vegetation form MRFR for comparative analysis. In remote sensing, shape of reflectance spectrum can provide ideas for identification of vegetation types. Because all vegetation exhibit similar reflectance characteristics in electromagnetic spectrum, though some are higher than others. All vegetation are higher at near-infrared and lower at visible region of spectrum. Even the same vegetation type, reflectance may vary because of factors like moisture contents and health of the plant.

Confirmation of spectral reflectance characteristics for each vegetation type requires ground verification and assessment accuracy. In this study, I used findings from previous studies and google earth imagery as references of ground verification and assessment accuracy. The findings matched with actual position and assessment efficiency. WCST (2013) classified Mporoto Ridge Forest Reserve and identified woodland, grassland, montane forest and woodland as main vegetation zones in the reserve. A classification matches spectral reflectance signature of forest 5 to that of grassland vegetation (Wanga et al., 2014), forest 4 to bamboo trees (Jusoff, 2007), forest 3 to montane rainforest (Sánchez-Azofeifa et al., 2009), forest 2 to woodland vegetation and forest 1 to stressed woodland vegetation (Mayes, Mustard, & Melillo, 2015). However, a spectral reflectance characteristics of island matches to severely stressed vegetation (Anderson & Perry, 1996).

A Spectral reflectance signature confirmed the presence of vegetation in two islands of the lake. The vegetation in two islands are similar to woodland but are severely stressed. Because plants in islands are emerging in harsh aquatic environment. Mouellic, (2005) discovered high salinity and chloride salts in lake Ngozi. A presence of high salt level in the soil contradicts the ability of vegetation to absorb water. As consequences, vegetation are severely stressed by having water-deficit effects of
salinity (Oliveira, Alencar, & Gomes-Filho 2013). According to Oliveira Na+, Cl- and K+ contribute significantly to reduction of cellular osmotic potential in salt stressed plants. As results, there are transitional decrease in photochemical efficiency, accumulation of stress metabolites such as MDHA and Glutathione, increase in antioxidative enzymes such as SOD and CAT. Likewise, a shape of reflectance spectrum supports that vegetation have least plant vigour, low biomass content, low moisture contents and low concentration of chlorophyll (figure 4a).

5.0 Conclusion

Remote sensing technology simplifies understanding of natural resources management. A free accessible satellite imagery reduced a quantity of resources required to understand spectral signatures and limnological characteristics of Lake Ngozi. It also provides access to a geographically challenging Lake Ngozi. Similarly, geographical information systems provided essential geographical attributes to understand the configuration of the lake. In this study, geospatial data indicated a dominance of unpalatable vegetation around the lake, which are crucial in protecting the lake from livestock grazing pressure and siltation. However, it is unclear on how unpalatable plants may shape the diversity and composition of wildlife species in MRFR.

Remote sensing enabled investigation of spectral and limnological characteristics of Lake Ngozi by disclosing its physical and biochemical spectral signatures. A high concentration of CO2 heightens primary production of phytoplankton making a lake naturally eutrophic. Spectral reflectance characteristics of Ngozi Crater Lake showed immense emissions of suspended sediments and chlorophyll-algae in aerosol region. In that case, eutrophication and sediments suspension contribute mostly to seasonal colouration of the lake. Inside the lake, there are two vegetation islands acting as refugia for water birds. An elevated concentration of salts makes the islands unfavourable habitations for plants and animals. Consequently, harsh environment shapes species diversity, composition and abundance of plants and animal in the lake.
Mporoto rainforest has dense canopy and healthy vegetation with endemic species of plants and animals. I would be very glad to recommend for a comprehensive plant and animals species inventories in the reserve to understand species composition, diversity and abundance. Also, fish resources assessment survey is compulsory to understand fishery resources and benthic diversity in the lake. Moreover, I suggest a study on abundance and diversity of algae and cyanobacteria to identify species diversity. Such information may assist the government, limnologists and tourism stakeholders when planning for sustainable conservation of the lake.

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**Statement of competing interests**

I have carefully read and understood the journal policy and therefore I declare that I had no financial and logistical support with political, apolitical, governmental and non-governmental organizations that might have interest in the submitted manuscript. I also confirm that I do not have any competing interest in the submitted work.


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