DETECTING WATER CHANGES IN A LAKE USING GEOSPATIAL TECHNIQUES:
IN KIBIRA NATIONAL PARK NORTH WESTERN OF BURUNDI

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Abstract: The human activity and climate change greatly affect the biodiversity and natural resources of Kibira Park. This study focuses on the assessment of water level fluctuations in the Rwegura dam from 1986 to 2016 and its impacts. The spatial analysis of the NDWI index from Multi-dated satellite images allowed the extraction of spatial temporal fluctuation of water. The results show a linear decrease in surface water in the Rwegura reservoir. The proposed recommendations include the restoration of degraded areas and the delimitation of the area to be protected. The results will improve the guidelines for decision-making by the local administration.

Keywords: Water change detection, geospatial technologies, NDWI

INTRODUCTION

In Burundi: (1) The probability is high that annual average air temperatures gradually increase during the 21st century, (2) The air temperature will increase especially during the dry season, (3) Future water surpluses are likely to increase the risk of extremes rainfall, (4) Changes in the regimes and amounts of rainfall as well as temperature may have important implications for production agricultural, including crops (Biswas, 2008).

Water resources and land are indispensable for sustainable economic and social development. Today, in Burundi, and particularly in the northern region, these resources are under severe pressure due to population growth, overexploitation of the land and growing demand for natural resources. Reflectance spectroscopy is useful and can be used to provide useful information on surface materials with limited in situ measurement (Rostom, Shalaby, Issa, & Afifi, 2017). The extraction of information on water is important for the study of water resources, the evaluation of water resources, the protection of wetlands, the change of coastline (Rostom et al., 2017).

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Due to uncertainty related to climate change, the use of satellite images in the assessment of water resources has increased (Nath & Deb, 2010).

Several techniques have been developed for surface water extraction including NDWI commonly used for surface water assessment (Bhandari, Kumar, & Singh, 2015; Jha & Khare, 2017; Mohsen, Elshemy, & Zeidan, 2016; Nsubuga et al., 2017).

The NDWI index can be used to compare, quantify and map surface water content at different times over several years (Benabdelouahab et al., 2015). The use of satellite imagery to extract information on changes in lake water surface is faster and more accurate than other observational methods, particularly to identify changes between two and three different time intervals (Sarp & Ozcelik, 2017). Monitoring surface water change is very important to gather useful information about specific locations at different times and changes and to analyze these changes to better manage natural resources (Nsubuga et al., 2017). Energy is tightly interlinked with water (Biswas, 2008). The change detection technique by using remote sensing can also be applied in water resources management and monitoring studies (Eitel, Gessler, Smith, & Robberecht, 2006). The NDWI index has been successfully used to characterize surface waters and the method uses a multispectral remote sensing technique to find the spectral signature of water bodies (Bhandari et al., 2015). Landsat satellite images have been analyzed to study the spatio-temporal variability of surface water bodies (Nsubuga et al., 2017). Kibira supplies the Rwegura dam and this dam produces most of the energy in the country. The decrease in the water of this lake caused disturbances of the current in the city of Bujumbura.

The aim of the present study is to evaluate change in the water area in Rwegura dam from 1986 to 2016 by using NDWI with combination of bands of multi-dated satellite data provided by USGS.

MATERIAL AND METHODS

Study area and regional settings

Kibira National Park, located in north-western Burundi, dominantly a mountainous tract, having an elevation ranges from 1288m to 2664m and covers an area of 427 km² and is a great source of or the water or the water ‘pole’ for the country. The precipitation is in the range of 75 mm to 137 mm (Source: IGEBU). In fact, many rivers originate in Kibira National Park, including Kagunuzi, Masango, Munyiri, Ntamba, Gitenge, Rushiha Mwokora and Gitenge. Gitenge and Mwokora drain into Rwegura dam which generates ~ 28.9% of the national electricity production (Source: Service in charge of electricity and water/Regideso-Burundi).

Data used

In the present study, multi dated satellite image data have been used which include: Landsat TM with 30 m spatial resolution with 3% of cloud cover from 1986 to 2011 and Landsat L8OLI/TIRSC1 with 30 m resolution with 4.44% cloud cover of 2016. Daily weather data, viz., maximum and minimum temperature (°C), rainfall (mm) from 1970 to 2016, have been collected from Geographical institute of Burundi: IGEBU for 5 meteorological stations (viz., Bujumbura, Imbo, Mparambo, Rwegura and Teza meteorological stations) in and around Kibira (see Fig. 2). Daily
water level data of Rwegura reservoir for 2005 to 2016 has been collected from Ministry of Energy and Mines in charge of water and energy (REGIDESO-Burundi).

Multi-dated satellite data used

<table>
<thead>
<tr>
<th>Data Set Attribute</th>
<th>L5 TM 1986</th>
<th>L5 TM 1990</th>
<th>L5 TM C1 Lavel-1 2011</th>
<th>L8 OLI/TIRS C1 2016</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acquisition Date</td>
<td>19-07-86</td>
<td>30-07-90</td>
<td>08-07-11</td>
<td>05-07-16</td>
</tr>
<tr>
<td>Map Projection</td>
<td>UTM/35</td>
<td>UTM/35</td>
<td>UTM/35</td>
<td>UTM/35</td>
</tr>
<tr>
<td>Spatial Resolution (m)</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Cloud Cover</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>4.44%</td>
</tr>
</tbody>
</table>

Image pre-processing

Atmospheric corrections
Atmospheric correction of satellite images is important for the assessment of surface water by NDWI. After the combination of the bands the surface waters are easily identifiable. In this work, with the geospatial software ArcGIS 10.2, the conversion of the radiance to TOA (Top-of-atmosphere) reflectance for the Landsat 5 of 1986, 1991 and 2011 has been carried out by using the following formula:

\[
\rho_p = (\pi \cdot L_\lambda \cdot d^2) / (\text{ESUN}_\lambda \cdot \cos(\theta_s)), \quad \text{and} \quad L_\lambda = G_{\text{rescale}} \cdot \text{Qcal} + B_{\text{rescale}} \text{ or} \\
L_\lambda = ((\text{Lmax}_\lambda - \text{Lmin}_\lambda) / (\text{Qcalmax} - \text{Qcalmin})) \cdot (\text{Qcal} - \text{Qcalmin}) + \text{Lmin}_\lambda
\]

Where: \( \rho_p \) = at sensor reflectance unitless, \( \pi \) = constant 3.14 unitless, \( d \) = Earth–sun distance in astronomical unit, \( L_\lambda \) = at sensor radiance in \( \text{W}/(\text{m}^2\cdot \text{sr} \cdot \text{cm}) \), \( \text{ESUN}_\lambda \) = band mean exoatmospheric solar irradiance \( \text{W}/(\text{m}^2\cdot \text{sr} \cdot \mu\text{m}) \), \( \cos(\theta_s) \) = solar zenith angle in degree, \( G_{\text{rescale}} \) = called gain in \( \text{W}/(\text{m}^2\cdot \text{sr} \cdot \mu\text{m})/\text{DN} \), \( \text{Qcal} \) = the quantized calibrated pixel value in DN, \( B_{\text{rescale}} \) = called bias in \( \text{W}/(\text{m}^2\cdot \text{sr} \cdot \mu\text{m}) \), \( \text{Lmax}_\lambda \) = the spectral radiance that is scaled to \( \text{Qcalmax} \) in \( \text{W}/(\text{m}^2\cdot \text{sr} \cdot \mu\text{m}) \), \( \text{Lmin}_\lambda \) = the spectral radiance that is scaled to \( \text{Qcalmin} \) in \( \text{W}/(\text{m}^2\cdot \text{sr} \cdot \mu\text{m}) \), \( \text{Qcalmax} \) = the maximum quantized calibrated pixel value, \( \text{Qcalmin} \) = the minimum quantized calibrated pixel value.

The conversion in TOA reflectance Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) 2016 ref the following equation has been used: \( \rho' = \rho_\lambda / \sin(\theta_sz) \) and \( \rho_\lambda' = M_\rho \cdot \text{Qcal} + A_\rho \) and \( \rho_\lambda' = M_\rho \cdot \text{Qcal} + A_\rho \)

Where: \( \rho_\lambda' \) = TOA planetary reflectance, \( \rho_\lambda \) = TOA planetary reflectance without correction for solar angle, \( \theta sz \) = solar sun elevation angle, \( M_\rho \) = band-specific multiplicative rescaling factor from the metadata file, \( \text{Qcal} \) = quantized and calibrated standard product pixel values (DN), \( A_\rho \) = band-specific additive rescaling factor from the metadata.

The coefficients used for these equations are collected from database of Landsat and (Chander, Markham, & Helder, 2009).

### Coefficients used of Landsat 5 TM

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Landsat 5: 9/7/1986</th>
<th>Landsat 5: 30/7/1990</th>
<th>Landsat 5: 8/7/2011</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cos((\theta_s))</td>
<td>0.7236</td>
<td>0.720</td>
<td>0.769</td>
</tr>
<tr>
<td>d</td>
<td>1.0162</td>
<td>1.015</td>
<td>1.017</td>
</tr>
<tr>
<td>ESUN_Band2</td>
<td>1796.0000</td>
<td>1796.0000</td>
<td>1796.0000</td>
</tr>
<tr>
<td>ESUN_Band4</td>
<td>1031.0000</td>
<td>1031.0000</td>
<td>1031.0000</td>
</tr>
<tr>
<td>G_{rescale}B_2</td>
<td>1.3222</td>
<td>1.3222</td>
<td>1.3222</td>
</tr>
<tr>
<td>B_{rescale}B_2</td>
<td>-4.1600</td>
<td>-4.1600</td>
<td>-4.1600</td>
</tr>
<tr>
<td>G_{rescale}B_4</td>
<td>0.8760</td>
<td>0.8760</td>
<td>0.8760</td>
</tr>
<tr>
<td>B_{rescale}B_4</td>
<td>-2.3900</td>
<td>-2.3900</td>
<td>-2.3900</td>
</tr>
</tbody>
</table>

### Coefficients used of Landsat 8: 5/7/2016

<table>
<thead>
<tr>
<th>Coefficients</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflectance_add_band_3</td>
<td>-0.1000000</td>
</tr>
<tr>
<td>Reflectance_mult_band_3</td>
<td>0.0000200</td>
</tr>
<tr>
<td>Reflectance_add_band_5</td>
<td>-0.1000000</td>
</tr>
<tr>
<td>Reflectance_mult_band_5</td>
<td>0.0000200</td>
</tr>
<tr>
<td>Sun Elevation</td>
<td>52.1846995</td>
</tr>
<tr>
<td>Sin(sun Elevation)</td>
<td>0.7899913</td>
</tr>
</tbody>
</table>
Normalized Difference Water Index (NDWI)

Several techniques have been developed for feature extraction in which NDVI (Goward, Markham, Dye, Dulaney, & Yang, 1991; Van De Griend & Owe, 1993) and NDWI (Gao, 1996) are the most widely used measures or proxies of vegetation health and water bodies based on satellite image analysis.

The equation of an NDWI used is:

\[
NDWI = \frac{\text{Green} - \text{NIR}}{\text{Green} + \text{NIR}}, \text{ (where } -1 < \text{NDWI} < 1) \quad (1)
\]

Table 1: Flowchart showing approach used to monitor water area change
Here, the cover type is water if NDWI > 0, or non-water if NDWI ≤ 0 (El-Asmar, Hereher, & El Kafrawy, 2013; Elsahabi, Negm, & Hamid M.H. El Tahan, 2016; McFeeters, 1996; Sarp & Ozcelik, 2017).

In equation, green band and NIR bands correspond to band 2, 4 and 3, 5 respectively of the Landsat TM and Landsat OLI/TIRS.

Therefore, for Landsat 4-5 Thematic Mapper (TM) and Landsat 7 Enhanced Thematic Mapper Plus (ETM+), the NDWI equation may be re-written as:

\[
NDWI = \frac{\text{band}_2 - \text{band}_4}{\text{band}_2 + \text{band}_4}
\]  

(2)

For Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) NDWI equation may be written as:

\[
NDWI = \frac{\text{band}_3 - \text{band}_5}{\text{band}_3 + \text{band}_5}
\]  

(3)

The range of NDWI value is from -1 to +1. (Bhandari et al., 2015; Huang & Wang, 2010; Ranjan et al., 2015).

RESULTS AND DISCUSSION
Figure 2: Maps showing the spatial distribution of NDWI based on multi-dated satellite data and water surface area of Rwegura dam located in Kibira National Park of Burundi

Figure 3: Change of surface water area in km² for different classes in Rwegura dam located in Kibira National Park
**Table 3.3**
Summary Statistics of estimated extent of surface water for 1986 to 2016 and per measures of NDWI

<table>
<thead>
<tr>
<th>Acquisition data</th>
<th>Monitoring of surface water in Rwegura dam from 1986-2016</th>
<th>NDWI&gt;0</th>
<th>Area (km$^2$)</th>
<th>Variation (%)</th>
<th>Perimeter (km)</th>
<th>Area, Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 19, 1986</td>
<td>0&lt;NDWI&lt;0.91</td>
<td>2.13</td>
<td>21.83</td>
<td>21.83</td>
<td>1.8</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>July 30, 1990</td>
<td>0&lt;NDWI&lt;0.51</td>
<td>2.1</td>
<td>1.4%</td>
<td>20.44</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July 8, 2011</td>
<td>0&lt;NDWI&lt;0.38</td>
<td>1.75</td>
<td>16.7%</td>
<td>17.52</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>July 5, 2016</td>
<td>0&lt;NDWI&lt;0.10</td>
<td>1.22</td>
<td>30.3%</td>
<td>12.13</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 4:** Declining surface water cover for Rwegura dam from 1986 to 2016

**Figure 5:** C.H.E.R located in Kagunuzi watershed: one turbine out of three works, Source: author (January 2017)
NDWI has been evaluated after the combination of bands, i.e., green and NIR bands corresponding to band 2 and 4 of the Landsat TM, and bands 3 and band 5 of Landsat OLI/TIRS. Negative value of NDWI corresponds to zone of no water and positive value corresponds to water area. The water potential in the Rwegura dam has decreased considerably from 1986 to 2016 with the decrease of the NDWI index calculated in Kibira. The occupied water surface decreased from 2.13km² in 1986 to 2.1km² in 1990 and from 1.75km² in 2011 to 1.22 km² in 2016. The positives values index NDWI calculated for Kibira varies between 0<NDWI< 0.91 in 1986, 0<NDWI< 0.51 in 1990, 0<NDWI< 0.38 in 2011 and 0<NDWI< 0.10 in 2016. The decrease in positive values of the NDWI index calculated in Kibira corresponds to the decrease in water potential of the Rwegura dam. Field data collected on observed water level fluctuation in the Rwegura dam confirm the results. The maximum water level in the Rwegura dam was 2152m in September 1986 and decreased to a level of 2142.38m in July 2014. The water surface in the Rwegura Dam has decreased to 1.45% from 1986 to 1990, 11.7% from 1990 to 2011, and 30.3% from 2011 to 2016. It is observed that there is a decrease of 42.7% from 1986 to 2016.

Conservation water in Kibira National park

The conservation of Kibira requires the collective participation of the local population and the administration and the regional and international participation of the actors in the protection of the environment. Integrated water resources management to promote the development and coordinated management of water, land and related resources to achieve equitable economic and social well-being without compromising the sustainability of ecosystems. According to the principle of participation of water stakeholders, water development and management should be based on a participatory approach, integrating users, planners and decision-makers at all levels.

The following recommendations can be considered for the development and conservation of Kibira and its surroundings:

Control of illegal activities in Kibira including sawmills, honey lovers, medicinal plants and bamboos, poachers, illegal miners and charcoal makers.

Ensure erosion control and restore degraded natural habitats. The natural regeneration of degraded areas outside the Kibira, include the planting of native species and, where appropriate, the removal of exotic species and avoid the planting of eucalyptus, a plant that participates in the drying of water sources.

Establish the tourist development zone and rehabilitate and build adequate infrastructure.

By extending the Kibira protection zone of 150m, 300m and 450m the area of Kibira becomes 449km², 470km² and 491km respectively, an increase of respectively 22km² (5%), 43km² (10%) and 64km² (15%) of the total area of Kibira.

Delineate the buffer zone between Kibira and other lands that would be protected and avoid agricultural activities around the Kibira forest to reduce or mitigate the adverse effects on Kibira’s biodiversity.

Protecting the watershed by banning activities that could disrupt the ecosystem balance of Kibira and conserve the forest ecosystem by planting trees in degraded areas. Delimit and
prohibit illegal activities including agricultural activities around and in Kibira, prohibition of grazing for pastoralists and uncontrolled mining in the region. Sensitize the local population to protect the forest against illegal activities such as felling of trees for charcoal and avoiding bush fires. To the administrative authority to build infrastructure and promote tourism in the region because the Kibira has a varied biodiversity of fauna and flora. There is a need to construct erosion control structures (contour bunds, anti-erosion hedges, vegetated trenches) on slopes.

Figure 6: Buffer zones of Kibira National Park
These structures will curb runoff and therefore reduce soil erosion, promote sedimentation of fine particles to increase water retention, and improve water infiltration and hence water recharge. The combination of afforestation with these developments and the planting of grass will help protect the cultivated lands from erosion and improve their fertility. The work can be done by involving local people through associations. It is also required to build dams downstream of the Rwegura Reservoir to reinforce the hydroelectric power of the Rwegura hydroelectric power station and for the irrigation plan in the localities of the region of Bubanza and Cibitoke.

CONCLUSIONS

In the present work, the Normalized Difference Water Index (NDWI) has been calculated by using the multi-spectral remote sensing data after atmospheric correction, to find water index with various band combinations of the remote of sensed data. An attempt has been made to evaluate the water area change in Rwegura dam for the period: 1986 to 2016. The multi dated Landsat thematic mapper (TM) and Landsat operational land imager and thermal infrared sensor (OLI/TIRS) images have been downloaded from the portal of USGS and data acquired during dry month of the year (July 1986, July 1990, July 2011 and July 2016).

There is a linear decrease in NDWI values in Rwegura dam from 1986 to 2016 and consequently a decrease in surface water of 42.7%. That is to say 2.13 km² of area occupied by water in 1986 and decreasing to 1.22km² in 2016.

This decrease has a negative impact on the hydro-electric power supply in the Rwegura power station and on irrigation that can be envisaged in the downstream localities of the Kagunuzi watershed. In fact, the Rwegura reservoir located in Kibira and in the Kagunuzi watershed is one of the country’s major hydropower resources. There is a variation in the level of water in this tank. The hydropower plant and Rwegura reservoir inaugurated in 1986, the water level in the reservoir was 2152m in 1986 and this level decreased to 2149.95m in July 2005 to 2144.97m in July 2014. The lowest level was recorded in November 2012 with 2141.9m, i.e there is a decrease of 6% in the water level in the Rwegura reservoir from 1986 to 2012. During the fieldwork in January 2017, it was found that, on three turbines installed at the Rwegura hydroelectric power station located in the Kagunuzi watershed only one turbine was operational following the decrease in the water level recorded in the Rwegura reservoir as a result of the water loss observed in the Kibira natural forest. During the field investigation, the officer in charge of the Rwegura hydropower plant told us that the water levels have decreased remarkably in the Kagunuzi, Masango, Ntamba, Munyiri, Gitenge and Mwokora rivers. The reduction of surface water in Kibira is having a detrimental impact on the socio-economic, energy and environmental sectors of the region. The protection and conservation of the Kibira ecosystem is urgent.

The study has demonstrated the importance of NDWI index for monitoring the water cover, i.e., change in the water area by using geospatial technologies, and the results obtained have helped to suggest some remedial measure such as:
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Note

1. Rwegura Hydroelectric Power Station (Centrale Hydro-Électrique de Rwegura)

References


