Evaluation of Agriculture Development Projects status in Lake Tana Sub-basin applying Remote Sensing Technique

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ABSTRACT
This study aims at the evaluation of water resources use in Lake Tana sub-basin based on the status of eight development projects that are planned to be executed in this region. Remote sensing and satellite imaging have been used in addition to their product applications. This is vital due to its hydrological significance and direct impact on Egyptian water resources. The Normalized Difference Vegetation Index (NDVI) has been calculated, for the year 2017, to recognize the agriculture land use and land cover. Then, by integration with the potential agriculture projects basic data, such as water consumption and crop pattern, water resources use in the basin was evaluated and quantified. The analysis performed in this study showed the following: the Koga project was the only implemented project from the proposed eight irrigation and drainage projects; the Megech and South-West (SW) Tana projects are still under construction. The density of the vegetation cover varies yearly from 75% to 100% in the Gumera project, whereas it did not exceed 40% in the North-East and North-West Tana projects. It varies from 15% to 100% in the Megech, Ribb, South-West Tana, and Gilgel Abbay projects. Projects’ calculated NDVI coverages reflect the behavior of the local community in cultivation depending on rainfall (green water), or by direct extraction from rivers as supplementary irrigation (Blue Water). This behavior may be based on their own interests and uses, not based on planning or investment, except for the Koga project. The water consumption from those projects is estimated at about 933 million m³/year.

Introduction

Being one of the world’s most arid countries, the first in Africa, due to low annual rainfall ranging from 0 mm in the western desert to 200 mm in the northern coast, Egypt depends mainly with a percentage of 97% on the Nile waters originating from outside its borders. Small amounts of additional resources can be developed by rainfall and flash flood harvesting and the use of brackish groundwater (MWRI, 2010). These severe circumstances lead Egyptians, since the dawn of civilization, to tame the Nile River and to maximize its benefits by establishing one of the most robust irrigation and drainage systems in the world.

The Egyptian water resources development and management strategy 2050 horizon (Ministry of Water Resources and Irrigation, Egypt, 2010) has been developed to describe how Egypt will safeguard its water resources in the future. This includes the regional aspect through promoting cooperation in the Nile basin: Regionally, through the Nile basin initiative programs and actions, and bilaterally, through bilateral cooperation projects.

Lake Tana is the largest lake in Ethiopia. It is located in the north-western part of Ethiopian. The Lake Tana sub-basin comprises an approximate area of 15096 km² including the lake area. The mean annual rainfall of its catchment area is about 1280 mm. The mean annual actual evapotranspiration and water yield of the catchment area are estimated to be 773 mm and 392 mm, respectively (Setegn, Ragahavan, & Bijan, 2008).

As Lake Tana is considered the main source of the Blue Nile, providing Egypt with more than 50% of the natural river flow at Aswan (Melesse, Abtew, & Setegn, 2014), it can be concluded that any development of this Sub-basin must be carefully assessed due to its direct impact on the Egyptian water resources.

Therefore, it is necessary to evaluate periodically the status of the agriculture development projects in Lake Tana sub-basin as it has an undeviating influence on the water resources in the region. In the field of agriculture, there are many uses of satellite imagery such as mapping for agricultural areas, identification, and forecasting of agricultural crops, desertification control, land cover, etc. Vegetation indices can be derived from the spectral channels and are good indicators for the state of vegetation (Tucker, 1979).
The green biomass and leaf area and NDVI are closely correlated, and thus NDVI is one of the most widely used indices for agriculture monitoring (Rouse, Haas, Schell, & Deering, 1973).

Several techniques have been used over the years for this kind of assessment such as:

- **SWAT (Soil and Water Assessment Tool)** was applied to Lake Tana Basin and showed that a base flow of (40% to 60%) is an important factor of the total discharge that feeds more than the surface runoff. More than 60% of losses in the watershed go through evapotranspiration. The results indicated that land use factor plays an important role in the rate of soil erosion and land degradation. Furthermore, Lake Tana contributes more than 7% of the total annual Nile River flow, and any possible change in the basin may contribute to the reduction of Nile flow. (Setegn, Ragahavan, Assefa, & Bijan, 2010; Setegn et al., 2008; Setegn, Ragahavan, Bijan, & Assefa, 2009; Setegn, Rayner, Assefa, Bijan, & Ragahavan, 2011).

- The traditional water resources assessment, land use and land cover change depending on ground data can lead to poor estimates of key drivers of hydrologic processes due to the reliable and lack of these ground data. Therefore, conventional hydrological measurements combined with satellite and airborne remote sensors can be useful and cost-effective for mapping, monitoring water resources, and assessment of land use and land cover changes (Belal & Moghanm, 2011; Dewan & Yamaguchi, 2009; Klemas & Pieterse, 2015).

It is concluded from the above, the sensitivity of the water resources of Lake Tana basin to the developments in its vicinity, meanwhile, the importance of the remotely sensing data in case of the lack of ground data. Therefore, due to the lack of Lake Tana basin ground data, specially the uses of its water resources, the current study will get benefit from the satellite images to identify the agriculture land use and land cover in the basin. Then, by the integration with the potential agriculture projects basic data, such as water consumption and crop pattern, the water resources use in the basin will be evaluated and quantified.

The Lake Tana sub-basin is a part of one of the major river basins in Ethiopia, Blue Nile (Abbay) basin. According to Setegn et al. (2008), it comprises an approximate area of 15,096 km² including the lake area. The lake is the largest lake in Ethiopia and the third largest in the Nile basin and it is considered as the main source of the Blue Nile river. It is located in the north-west of the Ethiopian highlands (Lat. 12° 0’ North, Lon. 37° 15’ East). The lake is a natural freshwater body with approximately 84 km long, 66 km wide; it covers an area of about 3000–3600 km² at an average elevation of 1800 m. It is a shallow lake with 15 m maximum depth. The Digital Elevation Model 90 m (DEM 90) was used to identify the different elevations of the study area. The levels range from 1790 to 1800 m around the lake, whereas the elevations range from 4000 to 4100 m at the external borders of the basin as shown in Figure 1. The lake area and levels have such a large range of values due to the seasonal fluctuation of water based on the amount of rainfall and inflow from different feeders.

The basin has vital importance for Ethiopia based on its high irrigation potential, hydroelectric power development, cash crops and livestock production, and tourism. The climate of the region is ‘tropical highland monsoon’ with a main rainy season between June and September. The air temperature shows large daily and small seasonal changes with an annual average of 20°C. The mean annual relative humidity (1961–2004) at Bahir Dar station, as shown in Figure 2, is 0.65. The annual average rainfall of the catchment is about 1280 mm. The annual mean actual evapotranspiration and water yield of the catchment area are estimated to be 773 mm and 392 mm, respectively. The main tributaries of Lake Tana are the Gilgel Abbay, Gumera, Ribb, and Megech rivers as shown in Figure 2. These rivers contribute about 45% of the annual lake water balance. The hydrographs of the average monthly flows of these tributaries are shown in Figure 3, from which it can be concluded that the only surface outflow, which is the Blue Nile (Abbay) river, has an average annual flow of 4 billion m³ measured at Bahir Dar gauge station. (Setegn et al., 2009).

The forest canopy density over some area in West Bengal was investigated using some indices such as NDVI. It was found that the northern part of the area has low density of forest canopy compared with the southern part which has very high density. It has been detected that the area is divided into 7.48%, 12.63%, 24.84%, 23.92%, and 31.13% as very low density, low density, medium density, high density, and very high forest canopy density, respectively (Subodh, Rabin, Sadhan, & Biswajit, 2018).

The accuracy of vegetation condition index, standard scores, and non-exceedance probability using NDVI (MODIS) anomalies were assessed. The results show that the earlier estimates were affected by a large estimation error which was reduced in the following updates. Moreover, the type of application and the employed anomaly are important factors to compute anomalies. Meanwhile, spatial pattern in the magnitude of near real-time anomaly estimation errors was mapped over the globe and relate it to average cloudiness (Meroni et al., 2019).

The vegetation status temporal variation was assessed using Landsat 8 NDVI OLI data of 2014 in terms of pixel. Meanwhile, in order to understand the dynamic of
vegetation, their statuses were employed monthly on the watershed of Sali River. The results show that there is a spatial and time variation over the region. Moreover, there was synchronization between the natural vegetation and the rainfall with single peak with moderate NDVI standard deviation (St. D) and coefficient of variation (CoV). Conversely, it was noticed that there are multiple peaks in the area with high population density and agriculture land coincide with high NDVI (St. D) and (CoV) during three months (April, August, and December) (Malik et al., 2019).

Materials and methods

Data sources

The current Study uses the Eastern Nile Irrigation and Drainage project reports, Nile Basin Initiative, Eastern Nile Subsidiary Action Program (ENSAP, 2009), to identify the proposed eight projects that the Ethiopian Government is planning to implement as agricultural development projects in the region. The basic data of these projects are as shown in Table 1 (ENSAP, 2009).
MODIS-NDVI, with 250 m accuracy, data from satellite imaging for Rainfall Estimate (RFE) with 8 km accuracy for the year 2017 and Landsat 8 satellite images with 30 m accuracy for November 2017 were used to evaluate the implementation status of these eight projects in Lake Tana Sub-basin.

**Data analysis method**

The Erdas Imagine 2017 (ERDAS Field Guide Fifth Edition, 1999), the Arc Map 9 (ArcGIS * 9 ArcMap Tutorial, 2006), and Arc Catalog 9 (ArcGIS * 9 using Arc Catalog Tutorial, 2005) were used in the analysis of the data obtained from the satellite images, as follows:

- The boundaries of these projects were digitized using ArcGIS tools (ArcGIS * 9 using Arc Catalog Tutorial, 2005; 2006), also the Erdas Imagine 2017 (ERDAS Field Guide Fifth Edition, 1999) was used to make the necessary preparation on the satellite images in order to be able to use them in the analysis process. Figure 4 shows the distribution of these projects around Lake Tana.

The NDVI was calculated as follows (ERDAS Field Guide Fifth Edition, 1999; Subodh et al., 2018; Michele et al., 2019; Sadhan et al., 2019):

(a) MODIS-NDVI with 250 m accuracy used to study the area of vegetation cover and its distribution throughout the year (2017) in the study area based on the following:

(b) Landsat 8 image of November 2017 with 30 m accuracy used to verify the NDVI during the month with the highest intensity.

After the needed atmospheric correction, NDVI has been calculated for the shown dates and quantifies vegetation by measuring the difference between near-infrared (which vegetation strongly reflects) and red light (which vegetation absorbs), as shown in the following formula, NDVI itself thus varies between $-1.0$ and $+1.0$.

**Table 1. Potential development projects basic data.**

| Projects   | Digitized Area (1000 Feddan*) | Coordinates | Crops                                              | Land Use in 2009                                      |
|------------|-------------------------------|-------------|---------------------------------------------------|-----------------------------------------------------|
| Koga [1], [17] | 23                            | 37° 07’ E   | Wheat, Barley, Corn, Bean, Potato, Cabbage, Garlic, Onion, G. Pepper | Cultivated land (54%), Cultivated + Eucalyptus (12%), Grass land (21%), Shrub land (1%), Settlement (2%), Sparserly cultivated (4%), Wetland (6%) |
| NE Tana    | 20                            | 37° 50’ E   | N.A                                               | Cultivated land (67.6%), Grazing land (11.7%), Bushes land (7%), Settlement (6.4%), Others (7.3%) |
| Gumera     | 45                            | 37° 47’ 40” E, 11° 44’ 30” N | Coffee, Maize, Onion, Potatoes, Tomatoes, Carrot, Spinach, and Rice | N.A                                               |
| Ribb       | 60                            | 37° 50’45” E, 12° 02’ 30” N | N.A                                               | Cultivated land (80%), Settlement (15%), Grazing (5%) |
| Megech     | 100                           | 37° 28’ E   | N.A                                               | N.A                                               |
| SW Tana    | 35                            | 37° 04’ E   | N.A                                               | N.A                                               |
| NW Tana    | 22                            | 37° 06’ E   | N.A                                               | N.A                                               |
| Gilgel Abbay | 40                           | 37° 02’ N   | Finger millet                                     | Cultivated land (40–90%), Grazing land (2–52%), Bush land (2–6%), Settlement (3–4%), Wetland (30%) |

* Feddan = 4200 m$^2$
NDVI = \frac{(NIR - Red)}{(NIR + Red)}

where NIR and RED stand for the spectral reflectance measurements acquired in the near-infrared and red regions, respectively. In this study, the NDVI threshold for the cultivated land will be assumed to be >0.25, according to Nichiporovich and Radevich (2012).

- The Rainfall on Lake Tana Sub-basin was monitored using RFE with 8 km accuracy as products from the satellite images for the year 2017.

**Results**

The analysis of Landsat 8 satellite images in November 2017 for the study area shows that the vegetation cover of Lake Tana basin increases in the eastern side and south-west of the basin as shown in Figure 5.

The analysis of MODIS-NDVI satellite imagery product with 250 m accuracy for the study area and the calculation of vegetation cover variation on Lake Tana Sub-basin in 2017 are shown in Figure 5. It is clear that there is a fixed percentage of about 30% (1.1 million feddan) of the basin area with a continuous vegetative cover throughout the year. The total vegetation cover was between 30% and 80% of the basin area (1 and 2.9 million feddan), throughout the year. Based on the analysis of the rainfall satellite images product (RFE) with 8 km accuracy for the year 2017, it was observed that the rainfall on the Lake Tana sub-basin continued throughout the year. The average monthly rainfall ranged from 0.02 billion m$^3$ in December to 4.5 billion m$^3$ in July as shown in Figure 6. It was observed that the density of vegetation cover increases in the season of increasing rainfall, starting to increase the proportion of vegetables beginning in May.

Figures 7–14 show the distribution of the vegetation cover represented by NDVI for the eight projects generated from Landsat 8 data dated November 2017.

The projects were classified according to the following:

**Discussions**

**Implementation status**

The eight proposed projects were classified according to the presence of irrigated or rainfed agriculture using Landsat 8, MODIS images, and Google Earth program. They have been classified as:
Existing projects
These projects are irrigated directly from Lake Tana or one of its tributaries. Only the Koga Project fits these specifications. Figure 15 demonstrates the Koga dam, the pump station, and the main canal of the project that are already constructed and it is irrigated area.

Potential projects
These are the remaining seven projects that are included in the Irrigation and Drainage Project but have not been implemented yet. Only three projects out of these projects are under implementation. The first one is the Megech project, where the required dam for irrigation is under construction, as shown in Figure 16. The second one is
the SW Tana Project where there is a small area of about 1200 Feddan irrigated on rainfall, as shown in Figure 17, the third one is the Ribb project where the dam of the project is already constructed and the reservoir is filled as shown in Figure 18.

**NDVI pattern**

In this classification, the MODIS-NDVI has been used for the year 2017. By comparing the results for these projects, they can be divided into three groups as shown in Figure 19:

(a) Group A, where the densities of the vegetation cover around the year are less than 40%. Two projects are specified under this group: The North-East Tana and North-West Tana projects.

(b) Group B, where the densities of the vegetation cover around the year vary from 15% to 100%. Four projects fall under this group: The Megech, Ribb, South-West Tana, and Gilgel Abbay projects.

(c) Group C, where the densities of the vegetation cover around the year vary from 75% to 100%.

Only one project is categorized under this group which is the Gumera project.

It is noticed that the beginning of an increase in vegetation cover intensity of these projects coincides with the rainfall season, which confirms the fact that agriculture is mainly rainfed crops.

Based on the results from the implementation status of the Koga project as confirmed by the NDVI distribution all along 2017 obtained from MODIS as shown in Figure 20. The figure shows clearly that the cultivated area reaches a maximum value of about 29600 Feddan, with an average percentage of 93% of this area and a maximum percentage of 100% from July to November then begins to decrease in December to reach a minimum value of 65% in April.

**Projects water consumption**

Even though the study results indicated that only one project has been implemented which is Koga Project, there is obvious cultivation in all projects, which appears in the NDVI analysis. This may be due to the behavior of the local community in the basin to cultivate these areas depending on the Green Water
for their own interests and uses, not based on planning or investment.

According to the African Development Fund (2001); ENSAP (2009); Simon (2013), the main purpose of these projects is to improve the formerly used rainfed agriculture by allowing two crop seasons, to increase the yield. No hard and fast crop calendar will be imposed, but rather farmers are encouraged to choose from
a basket of possible options, according to their circumstances and personal preferences. Table 2 shows the planned projects’ area and the water requirement of each project (ENSAP, 2009).

It is worth mentioning that the study indicated that there is a difference between the areas which were planned to be cultivated after ENSAP (2009) and the digitized areas calculated from the satellite images. Therefore, the study calculated the Actual Water Consumption (AWC) based on the water requirement/Feddan obtained from Table 2 for each project based on Equation (1).

\[
AWC = \frac{(OA)(\%\text{NDVI})}{WR} \tag{1}
\]

The calculations took into consideration the percentage of the vegetation cover (NDVI) distributed along the different months of the year for the projects shown in Figures 18 and 19 and the Observed Area (OA) of the cultivated land calculated from satellite images.

The project AWC distribution along the different months of the year is shown in Figure 21. Table 3 shows the average yearly (AWC) of each project for the cultivated areas calculated from satellite images.
It is clear from the table that there is water consumption from these projects estimated at about 933 million m$^3$/year which may be mainly covered by rainfall (Green Water) or by direct abstract from the rivers in the area of each project as supplementary irrigation (Blue Water).

**Summary and conclusions**

Different data types have been used: such as “RFE” for calculating rainfall, Landsat 8, and MODIS-NDVI for calculating the aggregated area.

The Digital Elevation Model 90 m (DEM 90) was used to identify the elevation difference in the study area. It was found that the average levels range from 1790 to 1800 m around the lake itself; and, the elevations are around 4000 to 4100 m at the external borders of the basin.

The “RFE” shows that the rainfall on the Lake Tana sub-basin has an average monthly value ranged from 0.02 billion m$^3$ in December to 4.5 billion m$^3$ in July and it continued throughout the year.

The water resources in the region and consequently the water resources flowing to Egypt and Sudan will be
directly impacted by any developments in the vicinity of Lake Tana.

Lake Tana basin and its proposed agricultural projects have been studied using the available collected...
The study focused only on one year (2017) to evaluate the current situation of these projects, taking into consideration the density of vegetation cover and rainfall.

NDVI values are good indicators for the agriculture presence in irrigation projects. It has been used for detecting the aggregated area and calculating its percentage for the potential projects.

The NDVI threshold for the cultivated land in this study was assumed to be >0.3.

Only one project from the proposed eight projects of the irrigation and drainage project was already implemented which is the Koga project, whereas three projects are still under implementation: the Megech, SW Tana, and Ribb projects.

The increment of the vegetation cover density of the projects coincides with the rainfall season, which confirms that agriculture is mainly rainfed crops.

The density of the vegetation cover varies from 75% to 100% around the year in the Gumera project and varies from 15% to 100% around the year in the Megech, Ribb, South-West Tana, and Gilgel Abbay projects, while it did not exceed 40% around the year in the North-East Tana and North-West Tana projects.

It was concluded that there is water consumption from these projects estimated at about 933 million $m^3$/year which may be covered from rainfall (Green Water) or from direct abstract (Blue Water) from the rivers in the project areas as supplementary irrigation.

The water consumption may reflect the behavior of the local community in the basin to cultivate these areas depending on the Green Water for their own interests and uses, not based on planning or investment.

**Recommendations**

- It is important to take into account the local usage of rainfall (Green Water) in the upstream countries as if it is a water share to these countries.
- It is important to evaluate the status of these projects periodically based on the hydrological significance of this Sub-basin to the Egyptian main water resource, which is the Nile River, and its direct impact on it.
Acknowledgments

The authors are grateful to the staff of the Water Resources Development Centre (WRDC) – Nile Water Sector – Ministry of Water Resources and Irrigation, for their continuous support and making all the required data available. Special thanks go to Eng. Rania Abd Elhady and Eng. Rania Kamel, Senior Hydrologists in WRDC.

Figure 19. Project grouping according to the NDVI pattern all over the year 2017.

Figure 20. NDVI variation on Koga project all over the year 2017.

Table 2. Planned projects’ area and water requirement.

| Project   | Area (Feddan) | Water Requirement |
|-----------|---------------|-------------------|
|           |               | M³/Total Area     | m³/Feddan |
| Koga      | 30950         | 98.8              | 3200      |
| NE Tana   | 13095         | 46.2              | 3530      |
| Gumera    | 33333         | 113.4             | 3400      |
| Ribb      | 47620         | 180               | 3780      |
| Megech    | 75715         | 254.4             | 3360      |
| SW Tana   | 12143         | 41.8              | 3440      |
| NW Tana   | 15950         | 53.6              | 3360      |

Figure 21. Actual water consumption distributed for the eight projects all over the year 2017.
Table 3. Average annual water consumption.

| Project  | Observed Area (OA) (Feddan) | Calculated Actual Water Consumption (AWC) (M.m$^3$) |
|----------|-----------------------------|----------------------------------------------------|
| Koga     | 30000                       | 88.37                                              |
| NE Tana  | 20000                       | 45.45                                              |
| Gumera   | 45000                       | 144.86                                             |
| Ribb     | 61000                       | 161.06                                             |
| Megech   | 100000                      | 229.88                                             |
| SW Tana  | 36500                       | 99.93                                              |
| NW Tana  | 22000                       | 62.15                                              |
| Gilgel Abbay | 40000                | 101.30                                             |
| The total yearly calculated Actual Water Consumption (M. m$^3$) | 933.00 |

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