Evapotranspiration Modelling in the Pool Malebo Wetlands Using Remote Sensing Technology

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Abstract

The importance of evapotranspiration (ET), in the hydrological cycle, makes its quantification necessary for agricultural production planning and water resources management in general. Moreover, ET plays a key role in the estimation of the soil water balance, either for the detection of water stress conditions, their use as input variable in crop yield models or the study of ecosystem functioning and its relationship to local and regional climate, among others. This research evaluates the ET in the Pool Malebo situated in the Congo River using remote sensing images from different sources (e.g. GLDAS, FEWS NET and MOD16). Monthly global images were collected for the period 2001 to 2016. Furthermore, the ground data points were collected within and outside of the Pool over different land cover. They were used to extract ET values from the collected images. The obtained ET values from each data source and over different land covers are used to identify the effect of the wetland evapotranspiration around the pool for each season during the year. Model results show significant influence of the wetland's ET on the micro climate of the area.

Keywords: Evapotranspiration, Modelling, Pool Malebo wetlands, remote sensing technology

1. INTRODUCTION

Actual Evapotranspiration (ETa) is important for water resources management, hydro meteorological predictions, environmental conservation, and agriculture competitiveness. ETa and related processes are responsible for 70 percent of the lateral global energy transport through latent heat, and therefore play an important role in the redistribution of water on the Earth's surface(Mauser et al., 1998). Accurate and temporally continuous ETa estimation over large areas will provide valuable assistance to efficient water management (Jiang et al., 2009). ETa is an indicator of the rate of change of the global water cycle, and is a necessary variable for most numerical weather forecasting and global climate model simulations. Depending on water availability, climate regimes, and landscape conditions, ETa can represent a substantial portion of the regional water budget. For example, in comparison to the long-term averaged precipitation of 1500 mm per year over the Democratic Republic of Congo, the long-term averaged and spatially variable ETa is around 1300 mm thus representing a substantial portion of the water budget for the ecosystem in general and particularly in wetlands.

Wetlands are one of the most important ecosystems with varied functions and structures. Humans have drained wetlands and altered the structure and functions of wetlands for various uses.

Monitoring wetland hydrology using remote sensing based actual evapotranspiration (ETa) is a useful tool and approach since point measurements for understanding the temporal and spatial parts of the wetland are not effective for large areas (Ceron et al., 2015). Actual Evapotranspiration accounts over 80% of the water budget of the wetlands necessitating the need for spatiotemporal monitoring of ETa flux.

Wetland actual evapotranspiration *(ETa)* is a key hydrologic component, and the importance of its accurate estimation is obvious, however, this is difficult to achieve in practice because actual evapotranspiration cannot be measured directly and varies considerably in time and space.
A large number of more or less empirical methods have been developed over the last 50 years worldwide to estimate actual evapotranspiration from different climatic and meteorological variables (Tsouni et al., 2008). The analysis of the performance of the various algorithms revealed the need for formulating a standard method for the computation of the reference crop evapotranspiration. For this reason the FAO Penman-Monteith method (Allen et al., 1998; Tsouni et al., 2008) has been recommended as a standard.

Although the traditional methods estimate *ETa* on a point basis, recent methods have been successful using remote sensing images for estimates at various spatial scales(Ceron et al., 2015; Mauser et al., 1998; Tateishi et al., 1996). In contrast to point measurements, remote sensing has the capacity to acquire spectral signatures instantaneously for large areas of the watershed across multiple electromagnetic (EM) wavebands and spatial scales. Data in multiple EM wavebands allow for the extraction of land cover, vegetation cover, emissivity, albedo, surface temperature, energy flux information, and data at regional scales allow for greater spatial coverage than possible with in-situ methods (Ceron et al., 2015). Various researchers have used remote sensing tools to estimate wetland evapotranspiration and energy fluxes in various regions of the world (Melesse et al., 2007; Senay et al., 2008).

The objective of this research is to assess the *ETa* of Pool Malebo using remote sensing images from three different sources (GLDAS, FEWS NET and MOD16). The study produces *ETa* estimates and maps for the Pool Malebo, with a focus on wetland areas and around and demonstrates the contribution of remote-sensing technology to the estimation of actual evapotranspiration over wetlands. These products can be used operationally to assess the wetland monitoring and water management. Hence, results of this research will facilitate future possible restoration assessment studies by providing a simple and accessible method of calculating *ET* values.

2. DATA AND METHODS

2.1. Case Study

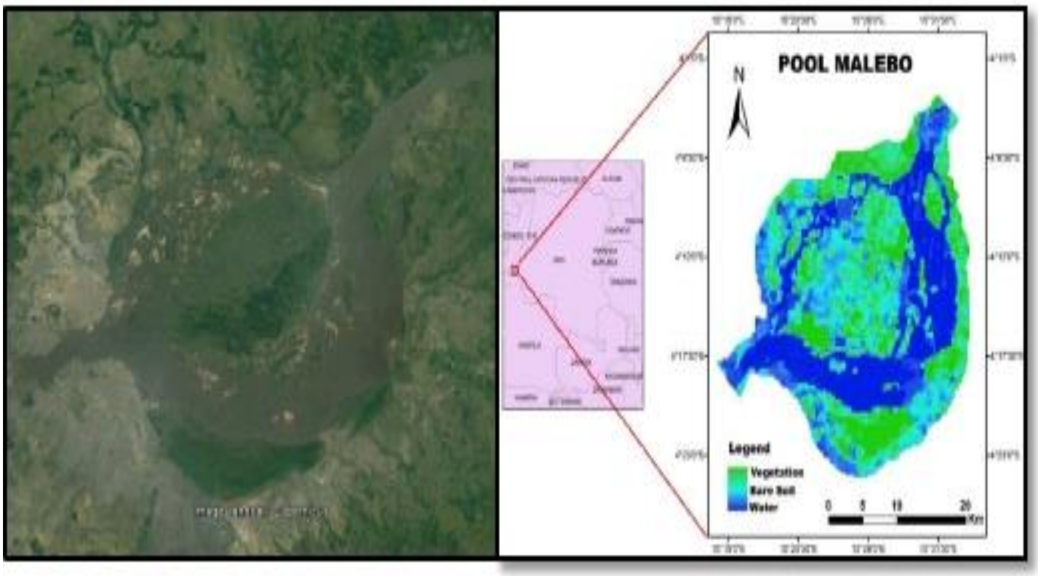

Figure 1: Study Area Location

The Pool Malebo wetland (**Figure 1**) is located in the lower reaches of the Congo River. It is classified among of the 33 wetlands priority area in the DRC (Michele, 2008) and have been selected as a pilot case study of NBCBN Wetlands research group in Congo (Salumu et al., 2011). Small scale agriculture is developed in the pool Malebo allowing the riparian to have access to fresh, nutritious and cheap food. Furthermore, the pool Malebo plays a key role in flood mitigation a major part of the capital of the DRC in the municipalities of Limete, Masina.

2.2. Remote Sensing *ETa* Data Sets

This section describes briefly the evapotranspiration products used in this study. These are all global products extracted for Pool Malebo at a monthly temporal resolution. The period chosen in this study for the evapotranspiration comparison where needed, is 2001–2012, which is the common period to all the products.
Three remote sensing data set; FEWS NET with 1 km spatial resolution and one month temporal resolution from 2001 to 2014, GLDAS with 27 km spatial resolution and one month temporal resolution from 2000 to 2014, and MOD16 with 5 km spatial resolution and one month temporal resolution from 2000 to 2012 were used in this study as *ETa* data sources (Mu et al., 2007; Ross et al., 2009; Zhou et al., 2013). The pixel to point approach included in ILWIS 3.7.2 software (Gorte et al., 1988) was used for the extraction of *ETa* values from the global datasets raster maps of *ETa* products. The extracted values of *ETa* were averaged for the values inside and outside of the wetland respectively. Then the values collected inside the wetland were plotted against those of outside of the wetland during the study period and seasonal (during the wet and dry period). This was done in order to observe the variation and the influence of the wetland around the area. The methodology used to generate the remote sensing products is explained in the following sections.

3. METHODOLOGY APPROACH

The methodology used to come up with the *ETa* values of the wetland area, consists of sampling points collection within and outside of the study area as shown in the **Figure 2**.

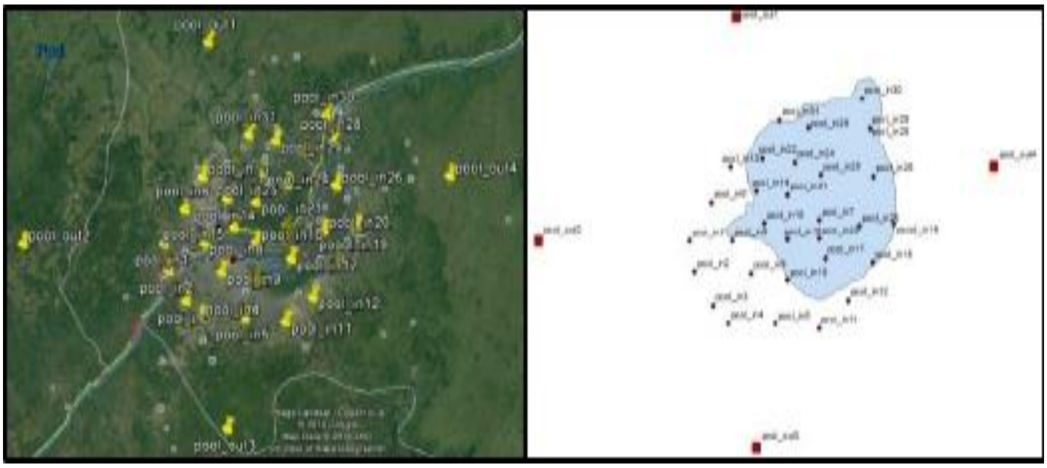

Figure 2: ETa Sampling Point's Collection

3.1. GLDAS Data Processing

The GLDAS evapotranspiration product is obtained from the land surface model (LSM) that uses multiple options for key land-atmosphere interaction processes under NOAH model. NOAH model contains a separate vegetation canopy defined by a canopy top and bottom, crown radius, and leaves with prescribed dimensions, orientation, density, and radiometric properties. The canopy employs a two-stream radiation transfer approach along with shading effects necessary to reach proper surface energy and water transfer processes comprising under-canopy snow processes. NOAH contains a multi-layer snow pack with liquid water storage, melts, and refreezes capability and a snow-interception model describing loading and unloading, melt and refreeze capability, and sublimation of canopy-intercepted snow. Multiple options are accessible for surface water infiltration, runoff, groundwater transfer and storage including water table depth to an unconfined aquifer (Zhao et al., 2015).

3.2. MOD16 Data Processing

The MOD16 *ET* datasets are estimated using the MODIS *ET* algorithm Terrestrial *ET* which comprises evaporation from moisture and wet soil, evaporation from rain water intercepted by the canopy before it touches the ground, the sublimation of water vapor from ice and snow and the transpiration through stomata on plant leaves and stems. The enhanced *ET* algorithms are based on the FAO 56 method (Mu et al., 2007; Mu et al., 2009; Mu et al., 2011; Zhao et al., 2015) shown by Eq.1.

$$\lambda E = s \times A \times \rho \times Cp \times (esat - e)/ras + \gamma \times (1 + rsra/) \quad \textbf{(Eq.1)}$$

Where: λE represents latent heat flux and λ represents latent heat of evaporation. S=d (esat)/dT, is the slope of the curve relating saturated water vapor pressure (esat) to temperature. A is available energy partitioned between sensible heat, latent heat and soil heat fluxes on the land surface. ρ is air density. Cp is the specific heat capacity of air; and ra is the aerodynamic resistance. The psychrometric constant γ is given by γ=Cp×Pa×Ma/(λ×Mw), where Ma is the molecular mass of dry air and Mw is the molecular mass wet air, Pa is atmospheric pressure. The surface resistance is represented by rs and it is an effective resistance to evaporation from the land surface and transpiration from the plant canopy(Mu et al., 2011).

3.3. FEWS NET Data Processing

The FEWS NET evapotranspiration products are acquired like the most energy balance models, including the actual evapotranspiration (ETa) estimation, which requires solving the energy balance equation expressed as:

$$LE = Rn - G - H \quad \textbf{(Eq.2)}$$

Where LE is latent heat flux (energy consumed by evapotranspiration) (W/m2); Rn is net radiation at the surface (W/m2); G is ground heat flux (W/m2); H is sensible heat flux (W/m2). At the land surface, the latent heat flux (comparable to ETa) is calculated as the residual of the difference between the net radiation to the surface and losses due to the sensible heat flux (energy used to heat the air) and ground heat flux (energy stored in the surface) (Senay et al., 2014). The method assumes, for a given day and location, the temperature discontinuity between a bare dry surface and atmosphere (dT) remains nearly constant from year-to-year under clear-sky conditions required for satellite observations, and that most of the surface energy balance is determined by the available clear-sky net radiation (Rn). This simplification allows the estimation of ET fraction as shown by Eq. 3 and 4:

$$ETf = (Th - Ts)\ dT \quad \textbf{(Eq.3)}$$

$$Th = Tc + dT \quad \textbf{(Eq.4)}$$

where ETf is the ET fraction (0–1); dT is a pre-defined (from the clear sky radiation balance calculation) temperature difference between the hot and cold reference boundary conditions that are unique for each day and pixel, ranging generally from 5 to 25 degree Kelvin depending on location and season. This is the hot reference boundary condition, representing the temperature of a dry-bare surface (Th=Tc+dT); Tc is the cold boundary condition, representing the cold/wet-vegetated surface, which is in equilibrium with the air temperature. Tc is resulting from a fraction of the maximum air temperature (obtained from gridded weather fields); Ts is the surface temperature, obtained from MODIS LST. Actual ET is estimated for a period of aggregation defined by the reference potential evapotranspiration (ET0), which is calculated from the Penman–Monteith equation using weather parameters obtained from model-assimilated global fields. Eight-day ETa estimates are then aggregated to monthly and seasonal totals (Tadesse et al., 2015).

4. RESULTS AND DISCUSSION

4.1. *ETa* Variation During The Study Period

4.1.1. Fews net (spatial resolution 1km)

From the **Figure 3** it can be seen that the FEWS NET *ETa* product provided the high *ETa* values within the wetland than outside the wetland most of the time during the study period. From the remote sensing product it was find out that, inside the wetland the month of October 2007 was of the highest of *ETa* (133.6mm/month) and the month of July 2006 (81.5mm/month) was the lower during the study period. Seasonally during the wet period from October to April the *ETa* values within the wetland are observed with little variation **Figure 4** than the values outside of the wetland were we can realise the fluctuation during the wet and dry season. The fluctuation outside of the wetland can be justified by the vegetation stress during the dry season.

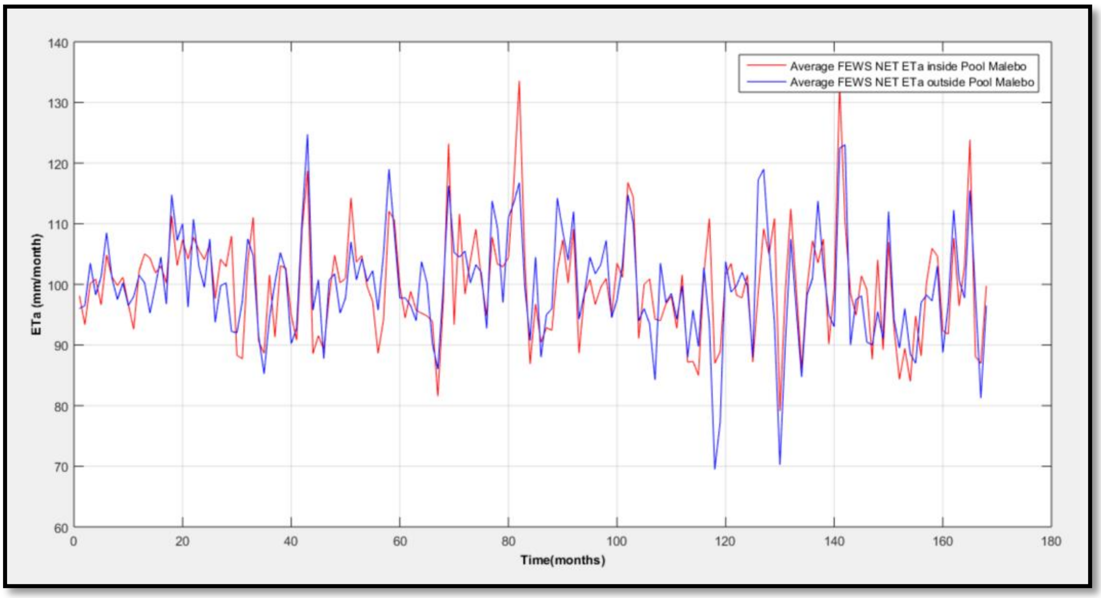

Figure 3: FEWS NET *ETa* Variation During The Period From January 2001 to December 2014

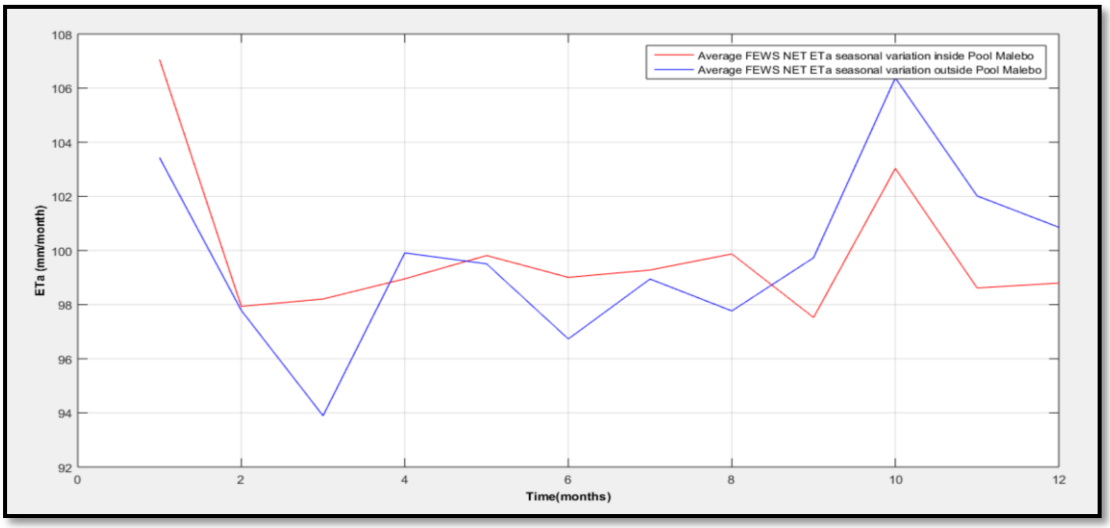

Figure 4: Seasonal Variation of FEWS NET *ETa* over Pool Malebo from September to August (2001-2014)

4.1.2. GLDAS (spatial resolution 27 km)

From the **Figure 5** it was find out that the values of *ETa* within and outside the wetland are almost the same during the study period and seasonally, from the year 2012 to 2014 the *ETa* values outside the wetland are higher than the *ETa* inside the wetland. It was find out that the GLDAS *ETa* product under estimate the values of *ETa* (<40mm/month) during the dry season within and outside the wetland. From the results it can be realised that the spatial resolution (27km) of the *ETa* remote sensing product influence the values of the *ETa* during the study period. The study shows that the GLDAS *ETa* product take in to consideration the variation of climate condition, because during the wet season the product gives high *ETa* values than during the dry season **Figure 6**.

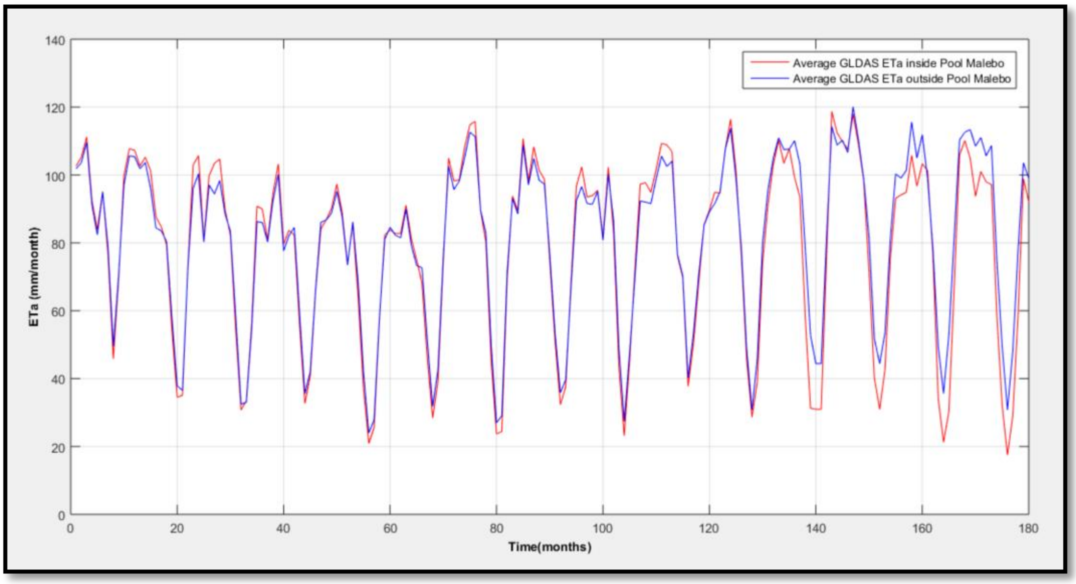

Figure 5: GLDAS *ETa* Variation During The Period from January 2000 to December 2014

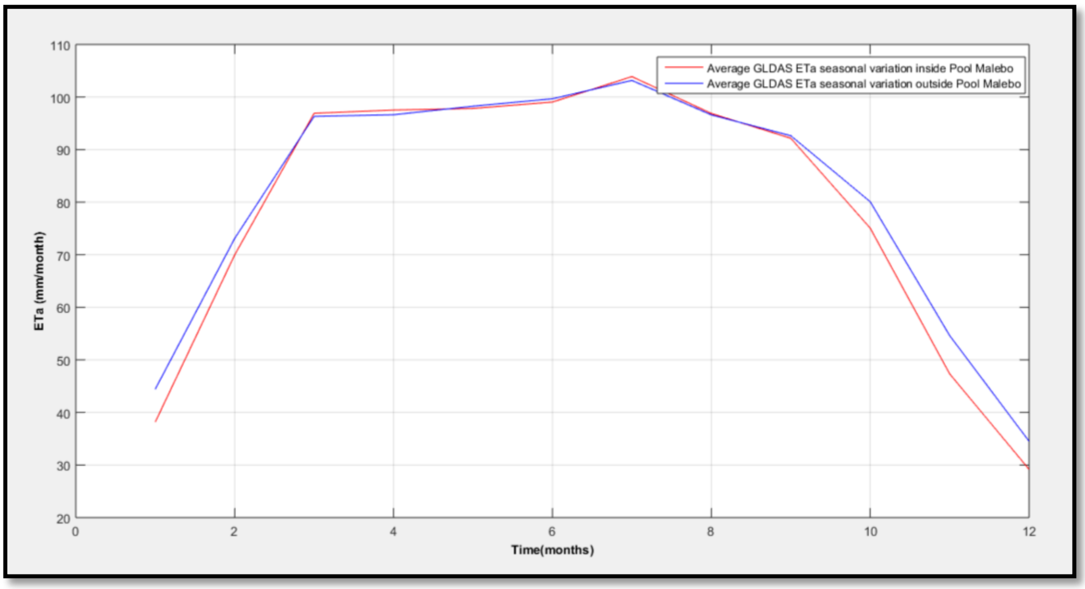

Figure 6: Seasonal Variation of GLDAS *ETa* Over Pool Malebo from September to August (2000-2014)

4.1.3. MOD16 (spatial resolution 5 km)

The MOD16 *ETa* product presents the high *ETa* values within the wetland than outside the wetland. During the wet or the dry season the values of *ETa* within the wetland are always higher than those of outside the wetland. The MOD16 also under estimate the *ETa* outside the wetland from the year 2010 to 2012, this under estimation of the *ETa* can be put on the back of the land used variation out the wetland. The study finds that the MOD16 product distinguished the values of *ETa* within and outside the wetland; this can be due to the approach used to compute the *ETa* product.

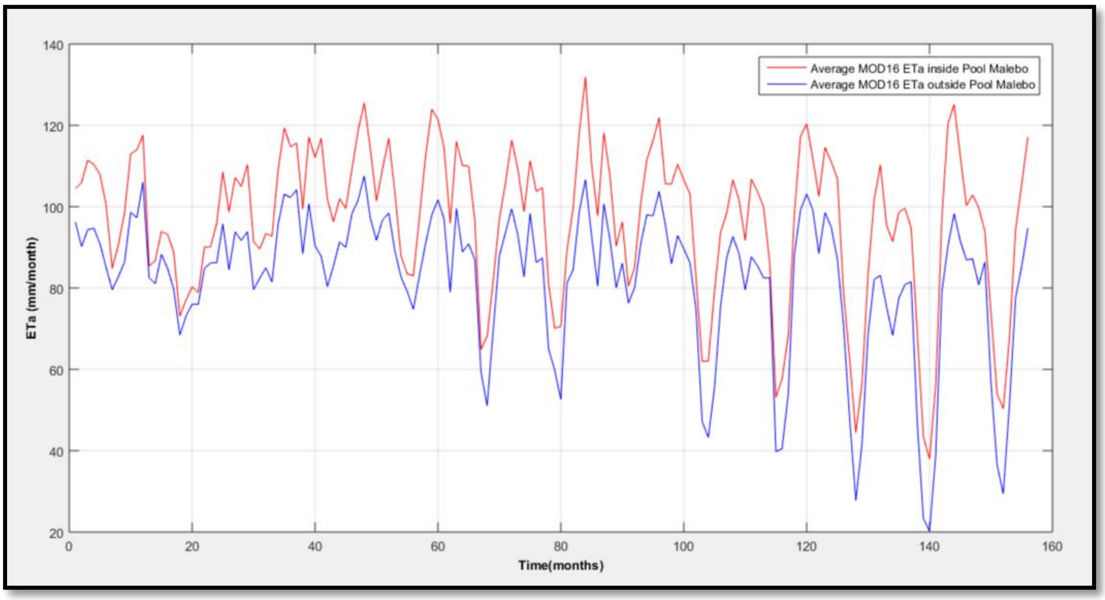

Figure 7: MOD16 *ETa* Variation During the Period from January 2000 to December 2012

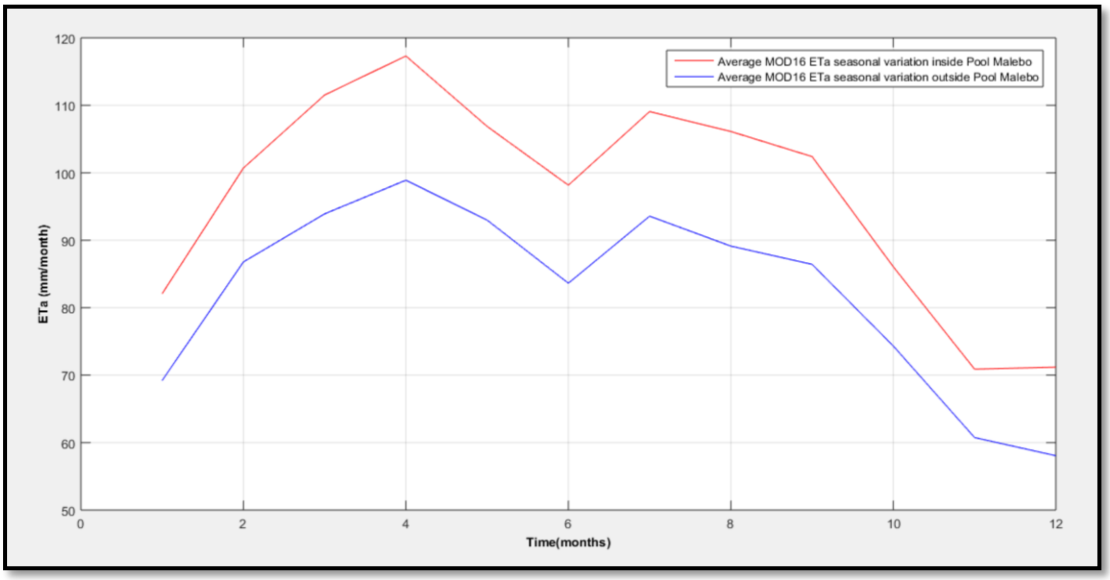

Figure 8: MOD16 *ETa* Seasonal Variation Over Pool Malebo from September to August (2000-2012)

4.2. Influence Of Spatial Resolution

From a general observation it was seen that the FEWS NET *ETa* product with 1km spatial resolution gives the high values of *ETa* than GLDAS (27km) and MOD16 (5km). Seasonally the FEWS NET *ETa* product gives little variation within and outside of the wetland. During the dry season the GLDAS and MOD16 under estimate the *ETa* values of the study area. Based on the MOD16 and FEWS NET *ETa* product it was realised that the wetland influence the *ETa* of the study area during the study period due to constant high values of *ETa* recorded. The study shows that the GLDAS *ETa* product take into consideration the variation of climate condition due to fluctuation of *ETa* values during the wet and dry seasons.

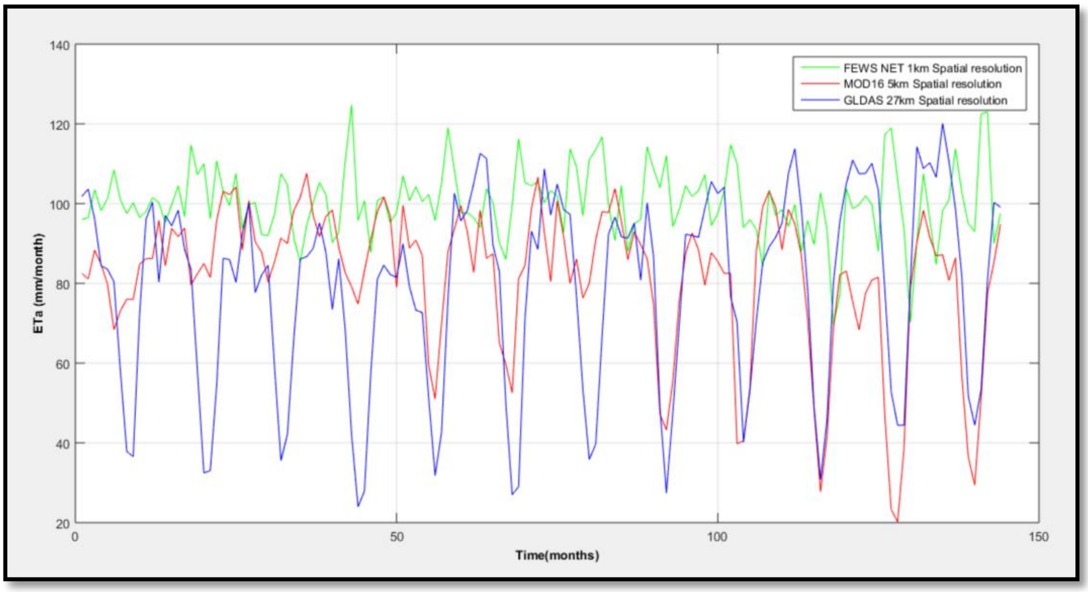

Figure 9: Comparison Between *ETa* Products Outside of The Pool Malebo from 2001 to 2012

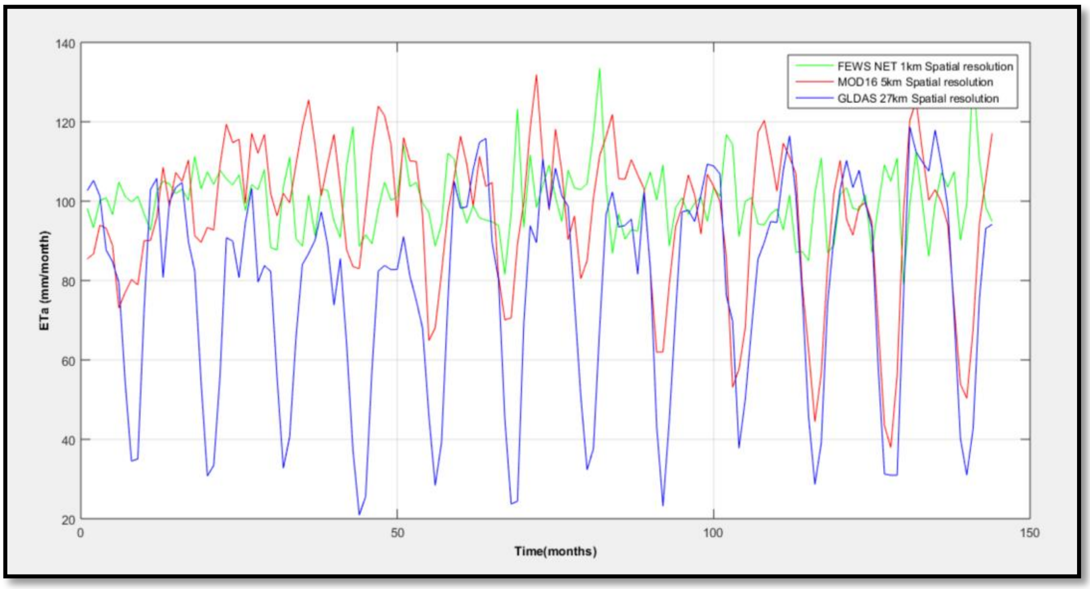

Figure 10: Comparison Between *ETa* Products Inside of the Pool Malebo from 2001 to 2012

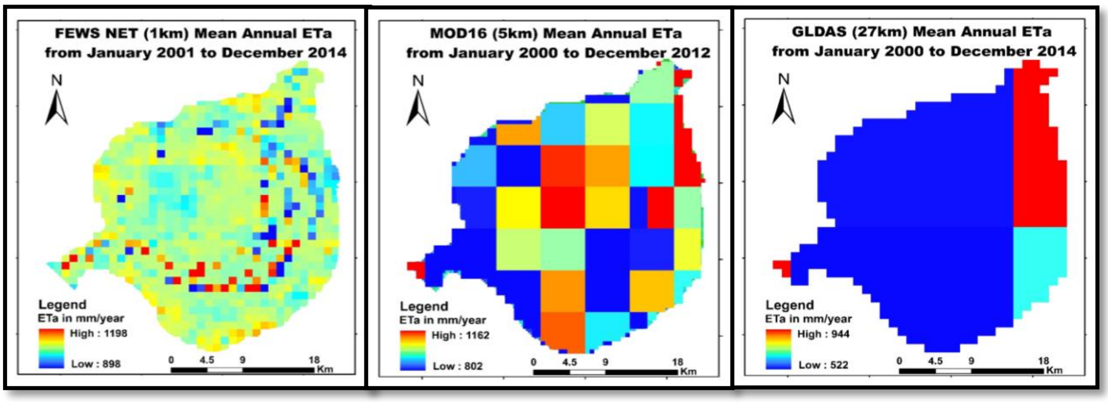

Figure 11: Fluctuation of Mean Annual Value of *ETa* Due to The Spatial Resolution

5. CONCLUSIONS AND FUTURE PROSPECTS

Long-term evapotranspiration patterns can be used to detect the health of wetlands. Remote-sensing technology can provide accurate estimates of actual evapotranspiration (*ETa*). Estimates of *ETa* may be used to provide a consistent, accurate, and efficient approach for estimating regional water withdrawals in wetlands areas. *ETa* in these areas is considered equivalent to consumptive use (CU), and represents the part of water that is evaporated and/or transpired, and is not available for immediate reuse. Three remote sensing products, FEWS NET with 1km spatial resolution, GLDAS with 27 km spatial resolution and MOD16 with 5 km spatial resolution were used to come up with the *ETa* values of the wetland area. The methodology consisted of sampling point's collection within and outside of the study area. The values of the ET from different remote sensing data sets and over different land cover were analysed seasonally in order to quantify the effect of the wetland evapotranspiration around the areas. The results show that the GLDAS *ETa* product identify the variation of climate condition due to fluctuation of *ETa* values during the wet and dry seasons and for the MOD16 and FEWS NET *ETa* product, the wetland influence the *ETa* of the study area during the study period. However, it is difficult to determine whether the exact source of the water that is evaporated or transpired is from Pool Malebo or a natural source, such as rainfall or groundwater. Future research will include an effort to separate the contribution of rainfall towards meeting the seasonal *ETa.*

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