Cloud Publications
International Journal of Advanced Remote Sensing and GIS
2019, Volume 8, Issue 1, pp. 3145-3155
ISSN 2320 – 0243, Crossref: 10.23953/cloud.ijarsg.440

Research Article

To Assess the Impact of Urbanization-Associated Land Use Changes on Actual Evapotranspiration and Water Balance in the Kelani River Basin, Sri Lanka

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Publication Date: 22 November 2019

DOI: https://doi.org/10.23953/cloud.ijarsg.440

Abstract Actual Evapotranspiration (AET) is a major component of the river basin hydrological cycle over land surface and energy balances. More than 60% of input water on land is returned to the atmosphere through evapotranspiration and it greatly influences the water availability on the land surface. Estimation of AET is an essential part in various fields. Thus, this study mainly aims at assessing the impact of urbanization-associated land use changes on actual evapotranspiration and water balance in the Kelani River Basin, Sri Lanka. Thronthwaite equation and land use conditions are mainly considered in this study to estimate AET. Average monthly temperature data has been obtained from NASA MOD1C3 and data has been validated using observed temperature data processed by the Meteorological Department in Sri Lanka. Potential Evapotranspiration (PET) was calculated using monthly average temperature and fractional vegetation cover was calculated using Landsat images (TM, ETM and OLI) to identify the land use and land cover changes from year 2000 to 2018. Both potential evapotranspiration and fractional vegetation cover are used to estimate AET. TRRM data was used to get Digital Elevation Model (DEM) and Landsat images were used to calculate Normalized Differential Vegetation Index (NDVI), Normalized Differential Building Index (NDBI). All the analysis used in this study have been carried out using raster calculator, zonal statistics and pivot tools in ArcGIS 10.1 software. The study revealed that land use and land cover is a major fact to determine AET. Upper catchment of Kelani River has obtained high AET values due to the vegetation cover and the elevation. Lower part of the catchment is associated with the low values due to build - up areas. AET has decreased by 2018 and urbanization is the main reason for it. Rainy seasons reduce the AET since high humidity and reducing AET can be highlighted when considering the temporal changes of AET in Kelani river basin. Evapotranspiration as a major component of water cycle should be considered because it can be a significant fact to reduce precipitation.
Keywords *Evapotranspiration; AET; PET; NDVI; NDBI*

1. Introduction

High population growth rate, rapid urbanization and industrialization in the world increase human production and consumption, which has led to increasing demand for freshwater resources. "It is estimated that by 2050, global water demand would increase by 55% due to different anthropogenic activities such as; manufacturing, thermal electricity generation and domestic water use" (Ubantu, 2016). Due to this reason, water management is a very essential requirement at the present world and it is important to know that major factors of water resource such as; evapotranspiration, rainfall and run-off mainly influence the water resource management in a river basin. Also, evapotranspiration is considered as a major component in the river basin hydrological cycle. It is the combination of two processes named evaporation and transpiration. Evaporation is the process through which water is transferred to the atmosphere from soil & other surfaces and transpiration is from stomata in plants (climate.ncsu.edu, 2019). Moreover, ET plays an important role in the atmospheric process since it controls the water supply from the ocean and earth's surface to the atmosphere. It is an energy-driven process and it is important in the water cycle since it is responsible for 15% of the atmosphere's water vapor (Sanand et al., 2018).

Water demand of crops, soil moisture condition, and water cycle balancing can be considered through estimating ET. Water demand of the crops may help to determine whether or not to irrigate and soil moisture condition helps to farmers to make decisions on farming. As an example, too much water in the soil causes to bog down the farm machinery and too dry soil causes to increase the stress of plants due to lack of available water. So ET can be used as a decision making tool for farming. ET helps to make decisions not only in farming but also in improving the well-being of biodiversity since ET acts a major role in water cycle. In other words clouds can't form without input of water vapors and it will cause lack of precipitation. Precipitation also can be predicted through ET.

There are a numbers of methods to estimate the ET as the (FAO56) Penman-Monteith equation, Thornthwaite equation, Hargreaves equation, Hamon equation, Priestly-Taylor equation, Solar radiation (Rs) based method and Net radiation (Rn) based method (Irmak et al., 2003) but these methods are not always easy to implement and supportive data sources are very limited and expensive. Many river basins in Sri Lanka are ungaged, and it is very difficult to obtain appropriate data at spatial and temporal scale to support any decision making of water management. With the development of technology, remote sensing method has been carried out to find ET and as examples remote sensing and SEBAL Algorithm (Kumar et al., 2014), Soil Plant Atmosphere and Remote Sensing Evapotranspiration (SPARSE) model (Saadi et al., 2018), using color composite (FCC) and Normalized Difference Vegetation Index (NDVI) in ArcGIS environment (Kilic and tarboton, 2012) can be shown. The ET computation by Remote Sensing is mostly based on the energy balance from satellite sensor and it is very effective to give an estimation output over large area.

Land use change is a major factor that influences the river basin hydrological cycle and its major components of rainfall, evapotranspiration and run-off. Land use changes alter the spatial patterns of ET distribution, with significant impact on water balance in a river basin. "Actual evapotranspiration (AET) is the water quantity which is transferred to the atmosphere as water vapor from and evaporating surface under actual conditions; vegetation type, climate, Physiological mechanism and water availability" (Sanand et al., 2018). Assessment of AET is very essential because it can control the exchange of water and heat energy between the atmosphere and earth surface. Also, AET can determine climate drought in arid and semi-arid areas through studying temperature and land use pattern. Further, it is a good tool to identify the crop water requirement and improving any practices of water management at the river basin level is important for future decisions.

Evapotranspiration is a major component of water cycle. Nowadays anthropogenic activities have changed the natural process of Evapotranspiration. Therefore, Evapotranspiration should be considered because it can be a significant fact to reduce precipitation. Water demand of crops, soil water necessity and drought condition can be identified through evapotranspiration and the findings would help to develop the practices for agriculture sector. Moreover, principles can be carried out for anthropogenic activities to balance friendly evapotranspiration process.

The main purpose of this study was to identify the impact of rapid urbanization on AET in a river basin level and GIS and Remote Sensing techniques being used for that purpose. The specific objective of this study are:

- To identify the spatial and temporal variability of Actual Evapotranspiration in Kelani river basin.
- To analyze the spatial and temporal changes in land use at the river basin level.
- To assess the relationship between the evapotranspiration and different types of land use.

2. Literature Review

Evapotranspiration estimation based researches are common conducting in these days. Many researches have documented the impact of reference evapotranspiration and potential evapotranspiration changes on crop water requirement. Several of them focused mainly on water balance effects in a river basin. However, very limited number of studied have been done to analyze the rapid urbanization and its impact on Potential Evapotranspiration.

Alkaeed et al. (2006) have done a research using six reference evapotranspiration (ETo) methods to compare each, based on their daily performances under the given climatic condition in the western region of Fukuoka City, Japan. Penman-Monteith method was considered to be the best method for estimating ETo in which the calculated ETo values correspond to lysimeters and other precise devices where real ETo can best obtained. The performances of the Thorthwaite, Hargreaves, Hamon, Rs-based and Rn-based equations for monthly ETo estimates are significantly correlated with the ETo estimates in Food and Agriculture Organization Penman – Monteith equation (FAO56-PM) method although the Thorthwaite method was found to have highly significant estimates. In this study Thorthwaite method, with the minimum required weather data is used to estimate the potential evapotranspiration.

Kumar et al. (2014) have carried out estimation of ET using MODIS Sensor Data in Udupi District of Karnataka, India. The direct relationship between land use/land cover classes and evapotranspiration is well noticed in the study as in the study carried out here.

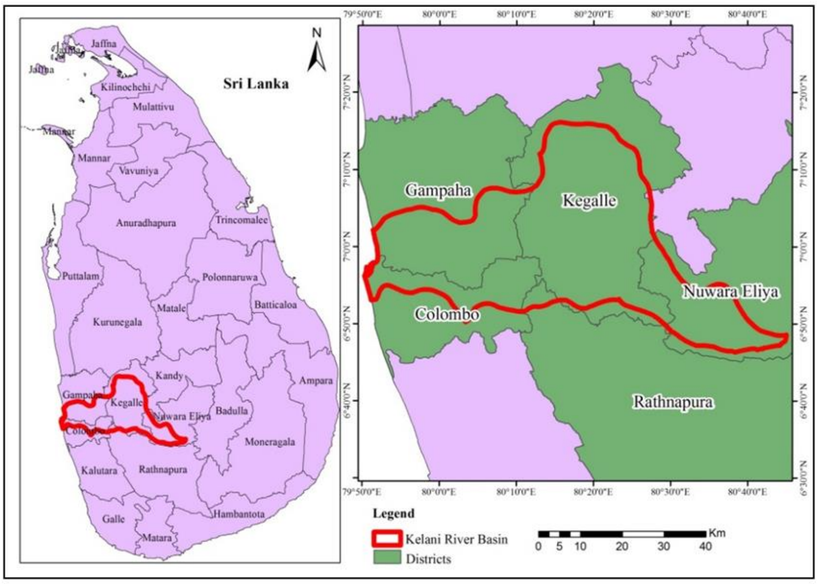
Maftei and Barbulescu (2010) implemented an ETo estimation algorithm, the Triangle Method, which is based on the modified Priestly-Taylor equation to estimate the evapotranspiration using remote sensing data and grid computing in Dobrogea, Romania. Their results have shown that the method utilized can derive reasonable estimates for surface temperature (LST) and evapotranspiration (ET). A Web-based client interface was built to make the applications usable to study the geographical distribution of evapotranspiration, consequently water demand in large cultivated areas for irrigation purposes and sustainable water resources management. In this study, remote sensing data has been calculated to find the evapotranspiration although Thornthwaite method was used instead of using Priestly-Taylor equation.

Kilic and Tarboton have conducted a study in 2012, with the purpose of utilizing raw Landsat 5 TM data in order to display a false color composite (FCC) of the Landsat bands from a scene (path 29, Row 32), calculate vegetation index (NDVI) and estimate evapotranspiration (ETo) in the ArcGIS environment. NDVI was calculated to find the AET in this study but FCC was not used.

Sun et al. (2011) have found that synergistic use of the polar-orbiting MODIS data and the geostationary-orbiting SEVIRI data have potential to produce reliable daily ET (actual or reference evapotranspiration) and a measure of drought exclusively from satellite data and weather forecast data. They have applied the methodology over East African highlands, and calculated the daily AET, daily ETo and dryness index for the year 2007. In this study, monthly AET has been calculated for particular months and 2000, 2013 and 2018 has been considered for finding the seasonable variations.

3. Study Area

The study was conducted in the Kelani River basin in Sri Lanka (Figure 1). The Kelani River originates from the Western face of the central highlands located in the Horton Plains National Park and Peak Wilderness Sanctuary. It drains approximately 2,292 square kilometers of land area. It is the second largest river basin and fourth longest river in Sri Lanka. This area is exposed to the south west monsoon and belongs to wet zone in Sri Lanka.



Source: Prepared by the author based on survey department of Sri Lanka, 2019

Figure 1: *Study area*

4. Materials and Methods

Seasonal based AET analysis is carried out for the Period of 2000 to 2018. January and May were considered to depute wet and dry seasons in the area.

Data

This study is mainly based on secondary data. MODIS temperature data and Landsat TM, ETM and OLI satellite images (Red, NIR, swir bands) were used. Year 2000, 2013 and 2018 images were downloaded from earth explorer and less than 10% cloud cover were considered for the analysis. Third sub database which is mean monthly temperature included was extracted from MOD1C3 satellite image. TRMM data were used for Digital Elevation Model (DEM) Sunshine hours were calculated using secondary data from timeanddate.com. Observed data set from Metrological Department is used to verify the accuracy of the temperature data.

Calculate Potential Evapotranspiration

Among several equations for measuring evapotranspiration Thornthwaite's equation was used to find the potential evapotranspiration. This equation mainly focused on mean monthly temperature and mean monthly sunshine hour. The main advantage of this method is that only the temperature information is needed beside the sunshine hours.

To calculate Potential Evapotranspiration (PET) using Thornthwaite method, first the Annual Thorthwaite Heat Index (i) calculation is required, using the equation 01:

$$I = \sum_{i=1}^{12} (T_i / 5)^{1.514} \quad \dots (1)$$

Potential Evapotranspiration (PET) estimation is obtained for each month using the formula below,

$$PET_{non\ corrected} = 16 \times (10T_i / I)^a \dots (2)$$

$$\text{Where } a = (492390 + 17920\, I - 771\, I2 + 0.675\, I3) \times 10 -6 \dots (3)$$

Obtained values are later corrected according to the real length of the month and the theoretical sunshine hours for the latitude of interest, with the formula:

$$PET = PET_{non\ corrected} \times N \times 30 \dots (4)$$

Where T is the mean monthly temperature (c^0), N is the mean monthly sunshine hour.

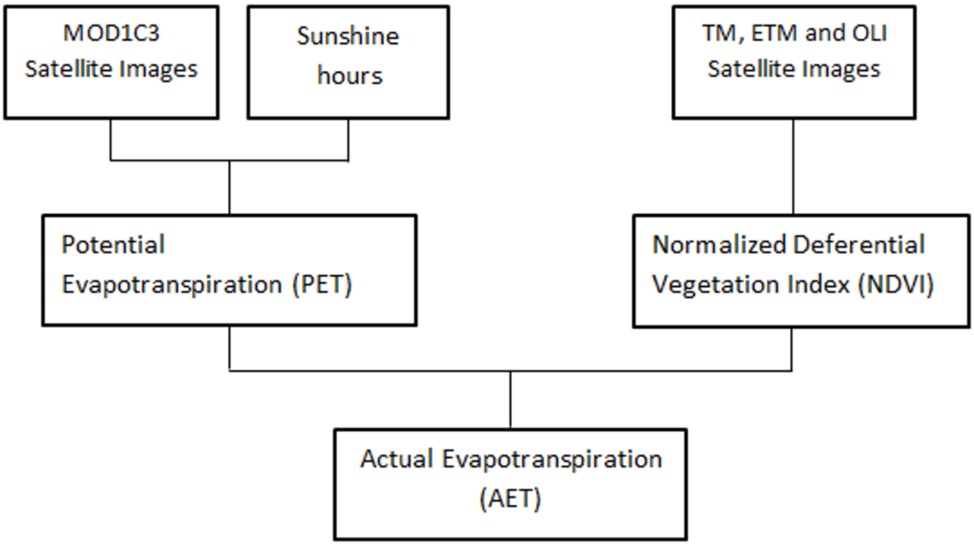


Figure 2: *Methodology for AET*

Fractional Vegetation Cover

The method proposed by Brunsell and Gillies (2003) to obtain the fraction of vegetation cover has been used in this study.

Firstly NDVI was calculated through the below equation using the TM, ETM+ and OLI Landsat Data for year 2000, 2013 and 2018.

$$NDVI= (NIR-RED) / (NIR) + (RED) \dots (5)$$

Then, fraction of vegetation cover using the raster calculator was done based on the equation:

$$\text{Square} ((\text{"NDVI"} - 0.14) / (0.75 -0.14)) \dots (6)$$

Estimate Actual Evapotranspiration

Actual Evapotranspiration (AET) was calculated by multiplying fraction of vegetation cover with the potential evapotranspiration. Whole method of calculating AET can be presented as Figure 2:

Calculate Normalized Difference Built-up Index (NDBI)

The Normalized Difference Build-up Index (NDBI) was calculated to identify the impact of urban-associated land use changes on actual evapotranspiration and NDBI was also calculated for above data period using Equation 07.

$$NDBI = (NIR-swir)/(NIR+swir) \quad \ldots (7)$$

ArcGIS environment was used to Calculate above methods and prepare the maps. Spatial analyst methods, raster calculator, pivot tables and zonal statistical tools were used for the analyze data.

5. Results and Discussion

Evapotranspiration was calculated for Kelani river basin and its spatial and temporal variation was significant.

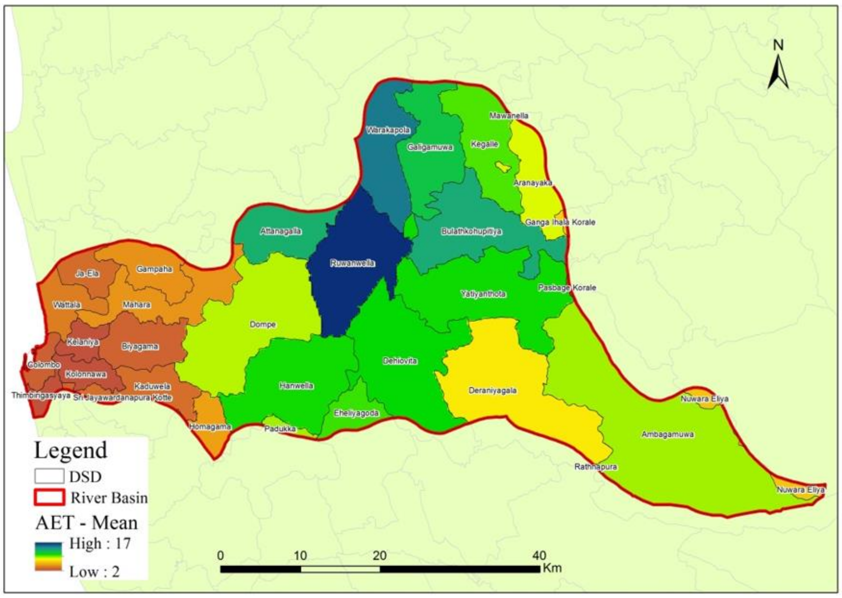


Figure 3: *Mean actual evapotranspiration*

Spatial distribution of the AET shows the significant pattern all over the Kelani river basin. Upper catchment is associated with high AET values while lower catchment is associated with low AET values. Mean AET regarding the Divisional Secretariat Divisions which belong to Kelani river basin shown in Figure 3, clearly reveals its distribution throughout the whole river basin. Figure 4 shows the changes of mean AET in DSD along the Kelani River.

DSDs in lower part and middle parts of the river have obtained low AET values and high AET values respectively although, DSDs which are in upper part of the river have obtained low AET values. Not only the spatial AET but also the temporal AET is shown in the map Figure 5.

Temporal changes have been identified from 2000 to 2018 along January and May. AET has decreased from 2000 to 2018. AET in May is higher than the values in January. This result reveals that rainy season reduce the AET due to high humidity. The low values of evapotranspiration reported in May are attributed to low temperature and sunshine conditions due to south west monsoon.

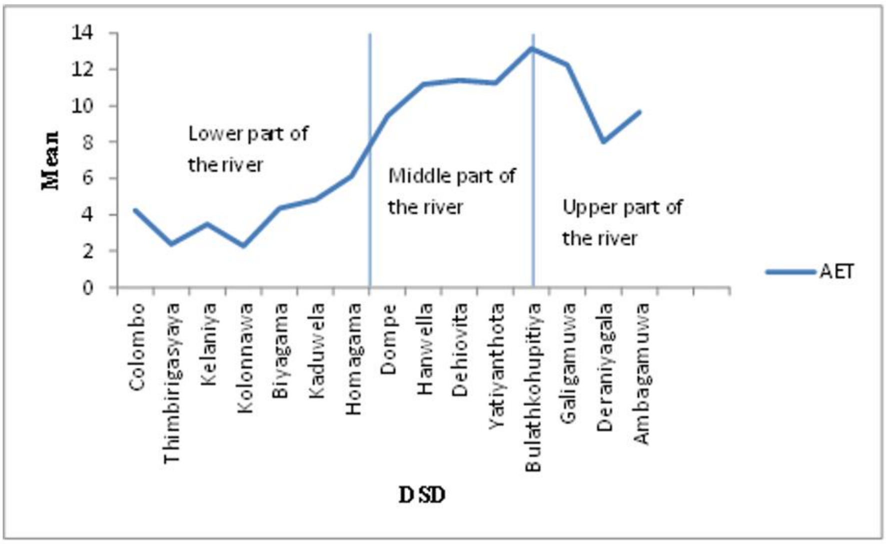


Figure 4: *Mean actual evapotranspiration (mm) of DSD*

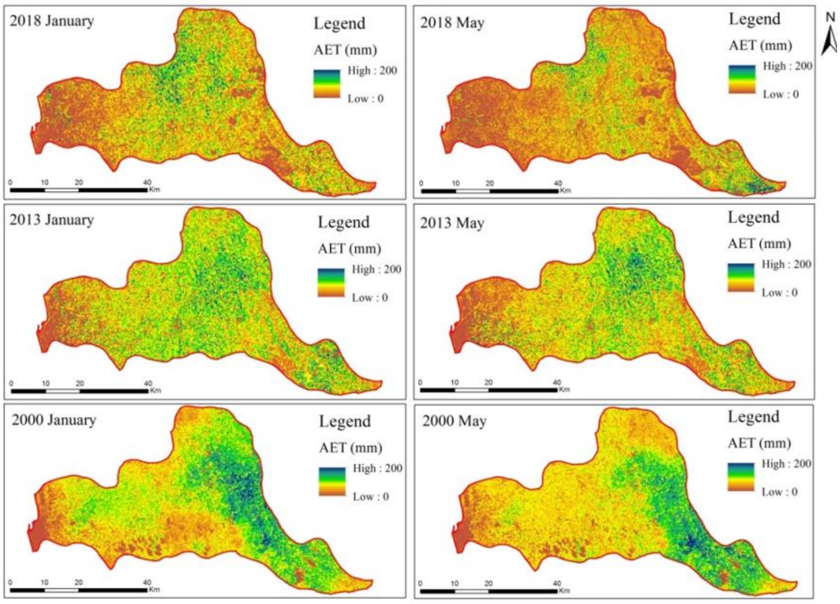


Figure 5: *Actual evapotranspiration*

Affected factors for these variations will be discussed further in this paper. Temperature, Land use, Land cover, Wind and Sunshine are the factors for evapotranspiration. Slope and aspect also play key roles in evapotranspiration as they determine the effectiveness of insolation.

Temperature is the most significant factor for evapotranspiration. It has a positive relation in which the rate of evapotranspiration increases as temperature increases because there is a higher amount of energy availability to convert liquid to water vapor. Therefore, average monthly temperature data has been obtained from NASA MOD1C3 and this data has been validated using observed temperature data processed by the Metrological Department in Sri Lanka. The result showed a validity of more than 80%.

Elevation affect to evapotranspiration due to high canopy layer and effectiveness of insolation. Elevation and AET is shown in Figure 6.

High elevation area has obtained high AET but this situation can be changed with the land use pattern.

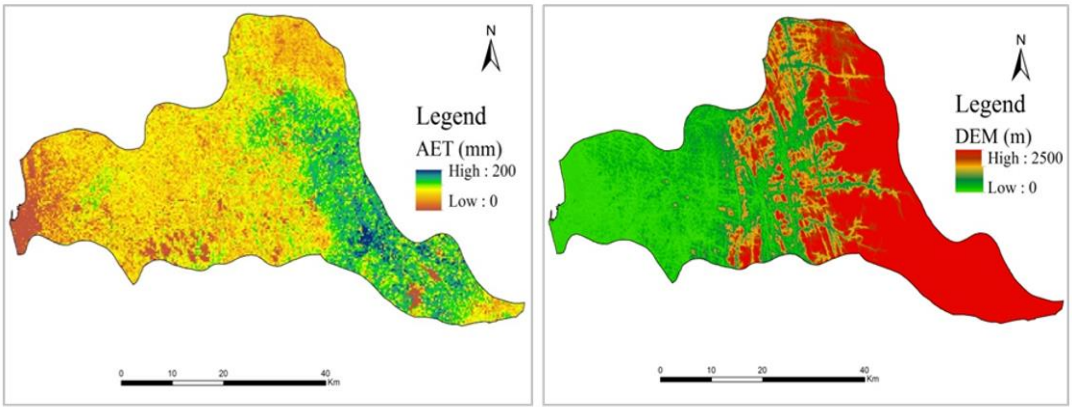


Figure 6: *Actual evapotranspiration and elevation*

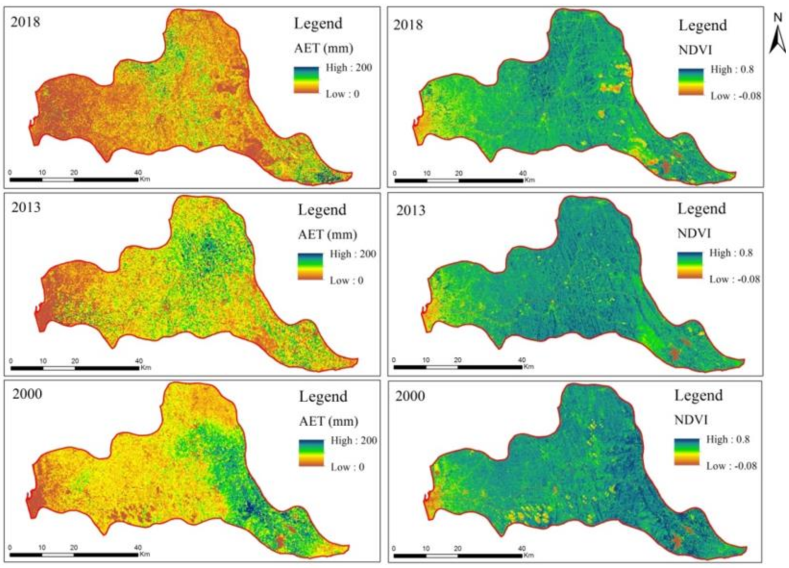


Figure 7: *AET and NDVI*

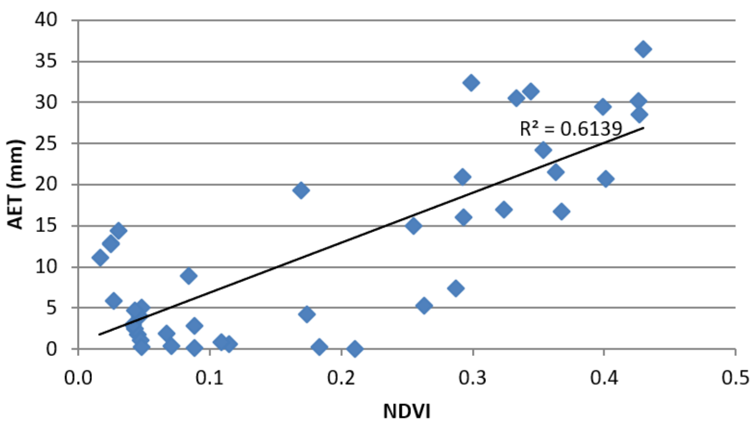


Figure 8: *Correlation between AET and NDVI values*

NDVI and NDBI were calculated to study the relationship between land cover - land use and AET. NDVI helps to reveal how the canopies affect AET while NDBI gives a clear idea of how the buildings affect AET.

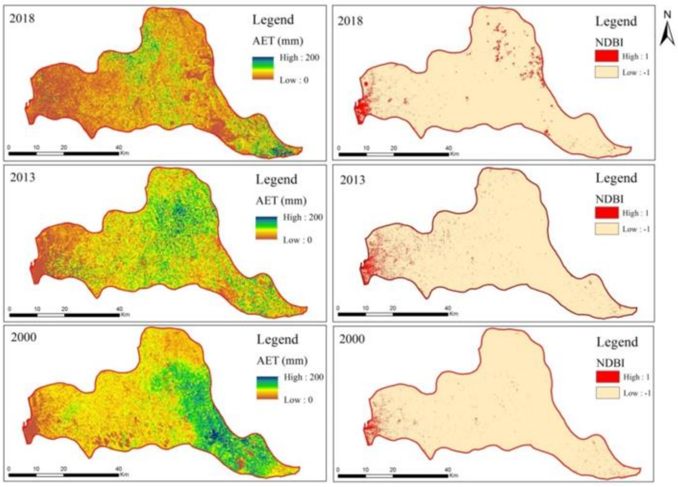


Figure 9: *Actual evapotranspiration*

AET and NDVI are shown in Figure 7 and temporal changes of NDVI can also be identified. Moreover, changes of AET and NDVI resemble throughout the years. When AET decreased, NDVI has also decreased by 2018. It means that there is a correlation between AET and NDVI.

The relationship between NDVI and AET is positive and it is shown in Figure 8. When the NDVI value is high AET value is also high. Low values of NDVI are identified in the areas with low canopy. Nowadays canopy layer is decreasing with the new constructions. Therefore temporally AET has decreased in the built up areas.

Table 1: *The AET values of land use and land cover*

Land Use/Land Cover	AET(mm)
Buit-up areas	2.66
Road	6.71
River (Lower part)	11.27
River (Middle Part)	45.22
River (Upper Part)	79.32
Paddy Fields	26.51
Tea	47.26
Rubber	70.58
Water Bodies	12.46
Open land	19.17
Marsh Land	32.2
Forest	21.63
Forest	36.06
Mountain with forest	85.72

AET is poor in lower catchment of the area as settlements and built-up classes dominate over vegetation cover in this region. Integrating the Table 1, the AET is classified as poor in the built-up areas, moderate in the agricultural lands and plantations, good to very good in upper part of the river. Mountain areas with forests considered in the study show higher evapotranspiration.

Increasing of the built up area and reducing of the canopy cover is the main reason to reduce AET temporally. AET and building distribution is shown in Figure 9. Built up area has increased by 2018 and according to it, AET has decreased. Built-up area has reduced the AET due to rough surface.

6. Conclusion and Recommendation

AET is very important to identify the water necessity of trees and the contribution to water cycle. AET in Kelani river basin was calculated in the study. Spatial and Temporal changes of AET along the Kelani river basin could be clearly identified and affected factors for evapotranspiration were discussed.

When the elevation is high, AET is also high due to high canopy layer and effectiveness of insolation. Land use and land cover are major factors to determine AET. Upper catchment of Kalani River has obtained high AET due to the vegetation cover and the elevation. Lower part of the catchment is associated with the low values due to built up areas. AET has decreased by 2018 and urbanization can be the main reason for it. Reducing AET can be highlighted when considering the temporal changes of AET in Kelani river basin. Rainy seasons reduce the AET since high humidity and temporal changes of AET can be seen in monsoon seasons.

Further researches are needed to identify crop water necessity, cloud analysis, drought index and Soil water requirement through evapotranspiration. Identifying the crop differentials may help to calculate the water necessity.

References

Alkeed, O., Flores, C., Jinno, K. and Tsutsumi, A. 2006. Comparison of several reference evapotranspiration methods for Itoshima Peninsula Area, Fukuoka, Japan. *Memoirs of the Faculty of Engineering, Kyushu University*, 66 (01), pp.1-14.

Kabantu, M. 2016. *Estimation of evapotranspiration and its relationship to land use and water resources in Lufumi catchment, Kinshasa*. M.S. Thesis, Department of Civil Engineering, University of Zimbabwe, p.75.

Kumar, G.D., Purushothaman, B.M., Vinaya, M.S. and Suresh, S. 2014. Estimation of evapotranspiration using MODIS sensor data in Udupi District of Karnataka, India. *International Journal of Advanced Remote Sensing and GIS*, 03 (01), pp.532-543.

Liu, W., Hong, Y., Khan, S.I., Huang, M., Vieux, B., Caliskan, S. and Grout, T. 2010. Actual evapotranspiration estimation for different land use and land cover in urban regions using landsat 5 data. Journal of Applied Remote Sensing, 4(1), p.041873.

Maftei, C. and Barbulescu, A. 2010. Estimation of evapotranspiration using remote sensing data and grid computing: A case study in Dobrogea, Romania. *Theme paper for the International conference on Computers*, p.1.

Matarrese, R., Portoghese, I. and Vurro, M. 2011. *Actual evapotranspiration by use of MODIS data*. International Meeting on Meteorology and Climatology of the Mediterranean.

Sameh, S., Gilles, B., Malik, B., Aurore, B., Émilie, D., Pascal, F., Bernard, M., Vincent, S. and Zohra L.C. 2018. Assessment of actual evapotranspiration over a semiarid heterogeneous land surface by means of coupled low-resolution remote sensing data with an energy balance model: comparison to extra-large aperture scintillometer measurements. *International Journal of Hydrology and Earth System Sciences*, 22, pp.2187-2209.

Sun, Z., Gebremichael, M., Ardo, J. and Bruin, H.A.R.D. 2011. Mapping daily evapotranspiration and dryness index in the East African highlands using MODIS and SEVIRI data. *International Journal of Hydrology and Earth System Sciences*, 15, pp.163-170.

Silva-Fuzzo, D.F. and Rocha, J.V. 2016. Simplified triangle method for estimating evaporative fraction over soybean crops. *Journal of Applied Remote Sensing*, 10(4), p.046027.

Yanfang, X., Zhen, W., Min, H. and Haoxue, A.L. 2011. *Investigation of the impact of surrounding light on monitor' color showing*. International Conference on Environmental, China. pp.499-504.

North California Climate Office, 2019. Evapotranspiration*.* Available form: *https://climate.ncsu.edu/edu/Evap.*

Timeanddate, 2019. Sunshine. Available form: *https://www.timeanddate.com/.*