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Evaluation and Mapping of Evapotranspiration in Forest-Savanna Transition Zone of Ogun State, South-Western Nigeria

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ABSTRACT: Evapotranspiration's impact on crop production, determined by water consumption in plants, varies across locations due to surface and climate differences. Traditional ground-based methods for measurement fall short in capturing these variations. In order to address this, the study evaluated and mapped the evapotranspiration in the forest-savanna transition zone of Ogun State, South-western Nigeria using a geo-informatics approach. Over six years, 12 Landsat images were collected, representing dry and wet seasons. These images were used to estimate the Normalized Difference Vegetative Index (NDVI), indicating vegetation density, and compute evapotranspiration values across the area. During the dry season, NDVI ranged from -0.326 to 0.376, and during the wet season, it ranged from -0.435 to 0.780, showing higher vegetation cover in the wet season. Evapotranspiration values varied across different regions. In Abeokuta South, Abeokuta North, and Odeda Local Government Areas, values ranged from 2.83 to 6.37 mm/day, 0.12 to 2.64 mm/day, and 3.12 to 5.44 mm/day, respectively, influenced by varying vegetation characteristics. The geo-informatics approach offered a realistic representation and spatial understanding of evapotranspiration, proving cost-effective and accessible. In conclusion, the study recommends the geo-informatics approach for evapotranspiration measurement due to its ability to consider spatial characteristics. This understanding is essential for effective water resource management and crop planning in the Forest-Savanna transition zone of Nigeria.

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Water moves in a constant cycle within and above the earth surface in a process known as hydrologic cycle. The hydrological cycle comprises of six major components which are Condensation, Precipitation, Infiltration, Percolation, Runoff and Evapotranspiration (ET) (Thorsteinsson., 2013) out of which evapotranspiration is a major component (Irmak., 2010). Evapotranspiration can be described as loss of water by evaporation from bare soils (as well as waterbodies) and transpiration from plants and vegetation (Allen *et al.*, 1998). The pathways, through which each of the combined processes of evapotranspiration follow, are categorized into two which are the biotic and the abiotic processes. The loss of water from the environment via the soil and water bodies describe the abiotic process while the water-loss through the plant leaf stomata or vegetation is called the biotic process. Evapotranspiration is the highest outgoing water flux from the earth surface (Yuei-An and Sanjib, 2014) and it is known to consume about 70%-90% of precipitation depending on the geographical location (Brutsaert, 1982; Glenn *et al.*, 2007). It performs a major role in crop production and the overall amount for a crop over an entire growing season is regarded as being nearly equal to the seasonal water requirement. Khaldi *et al* (2011) also recognized evapotranspiration as one of the essential land surface processes that control the

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equilibrium of the entire earth. It is useful in explaining the interaction between the energetic and hydrological equilibrium at the soil-vegetation-atmosphere interface. The estimation of evapotranspiration can help irrigation farmers to manage water resources effectively and efficiently and at the same time getting value for their agricultural produce thereby helping to improve water productivity. The proper monitoring of evapotranspiration is necessary for assessing food security, and improving agricultural water use efficiency (Akbari *et al.*, 2007). Furthermore, evapotranspiration estimation is important for comprehending water cycle of natural systems (Cristina *et al*., 2010). Accurate mapping of evapotranspiration is essential to agricultural sustainable development and climate change research (Zhenzhen, 2013). Gieske (2001) categorized the evapotranspiration methods of estimation into three namely; hydrological method, direct method and remote sensing method. Of these three methods, Kustas and Noman (1996) singled out remote sensing method as the best method for estimating evapotranspiration efficiently and economically due to its ability to provide data locally, regionally and even globally. It is an integral part of geo-informatics, which involved the integration of several areas of discipline relating to spatial data (Srivastava, 2014). This method involves the application of geo-informatics to estimate evapotranspiration in space and time. Kushwaha (2008) listed Remote Sensing (RS), Geographical Positioning System (GPS) and Geographical Information System (GIS) as integral components of geo-informatics. The remote sensing method adopts the use of satellite or image capturing device to get data from the earth surface which is then subjected to further analysis and computation. According to Allen *et al.* (2007), researchers have adopted this technology to estimate evapotranspiration successfully. Tarboton and Kilic (2012) estimated evapotranspiration through the adoption of empirical/semi-empirical model by using the Normalized Difference Vegetative Index (NDVI) to estimate evapotranspiration from Landsat images successfully. The earlier methods designed to estimate evapotranspiration (like Covariance techniques, Eddy Energy Balance Bowen Ratio, weighing lysimeter, Scintillometer, Pan Measurement etc.) take field or point measurements and are considered as estimates for a particular area. These methods also require contact with humans to take measurement and limits evapotranspiration data to areas accessible to men while inaccessible areas remain unknown. They are also limited by instruments used for data collection which are in scarce quantity. This has brought a great limitation on the evapotranspiration estimation within a given area. The objective of this study is to evaluate and map the evapotranspiration in the forest-savanna transition zone of Ogun State, South-western Nigeria.

MATERIALS AND METHODS

Study Area: The study was conducted in Abeokuta North, Abeokuta South and Odeda LGA in Ogun State situated in the South-western Nigeria. Its coordinates are between latitude 7° 03'N and 7° 30'N and, longitude 3° 01'E and 3° 47'E. Ogun State is bounded on the east by Ondo State, on the north by Oyo State, Lagos State and the Atlantic Ocean shared a boundary with it in the south, while on the west, by Republic du Benin. The adjoining Local Government Areas (LGA) surrounding the study area are Imeko-Afon LGA, Yewa North LGA, Ewekoro LGA and Obafemi-Owode LGA. It is a tropical region characterized by wet and dry seasons and has a double maxima rainfall trend with an annual temperature of about 30°C with a mean annual rainfall of 1200mm. The study area fell under Path 191 and on Row 55 of Landsat satellite image products. Landsat 7 images of the study area were downloaded from Earth Explorer (https://earthexplorer.usgs.gov). A total of 12 images were downloaded from 2012 to 2017. Two images were downloaded for a year particularly for February and October each representing the dry season and wet season respectively.

Method of Analysis: The study area was extracted from the larger scene by cropping out the study area in the geo-processing window of Arcmap to estimate NDVI and produce the evapotranspiration estimate. The images were then computed from the False Colour Composite (FCC) using bands 4, 5 and 2 of the Landsat 7.

The Normalized Difference Vegetative Index was then calculated from satellite image bands (particularly band 3 and band 4) using their respective reflectance values. Below is the NDVI equation;

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{NIR})} \quad (1)$$

Where; NIR: Near Infra-Red band; RED: Red Band; NDVI: Normalized Difference Vegetative Index

$$\text{F of Veg} = \left[\frac{(\text{NDVI} - \text{NDVI0})}{\text{NDVImax} - \text{NDVI0})}\right]^2 \quad (2)$$

Where: F of Veg is the Fraction of Vegetation Cover; NDVI is the Normalized Difference Vegetative Index; $NDVI_0$ is the Normalized Difference Vegetative Index for bare soil; $NDVI_{max}$ is the maximum Normalized Difference Vegetative Index of the scene.

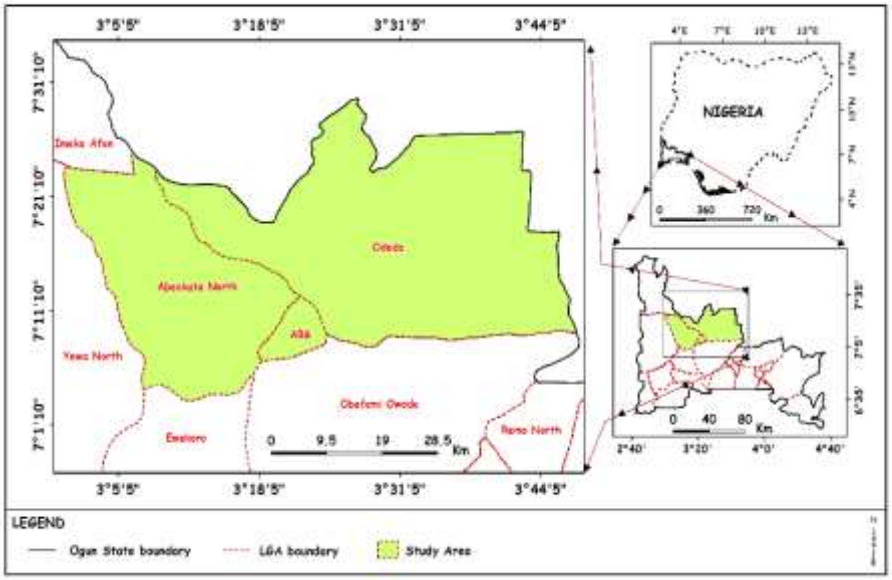

Fig 1: Study Area Map of Abeokuta South, Abeokuta North and Odeda Local Government Areas
Data Collection

Evapotranspiration was then computed using the raster calculator for computation in the ARCGIS environment. This was done by multiplying FofVeg with reference evapotranspiration data obtained from the weather data of the study area.

$$\text{Evap} = \text{Ref Evap} * \text{FofVeg} \quad (3)$$

Where; Evap = evapotranspiration; Ref Evap = Reference evapotranspiration; FofVeg = Fraction of Vegetation Cover

RESULTS AND DISCUSSION

The NDVI values showed a general decline in February while it increased in October which are representative of vegetation cover of the study area.

Table 1: NDVI values computed from Satellite Images

Year	NDVI February	NDVI October
	High	High
2012	0.096	0.468
2013	0.226	0.747
2014	0.191	0.622
2015	0.250	0.446
2016	0.116	0.502
2017	0.376	0.780

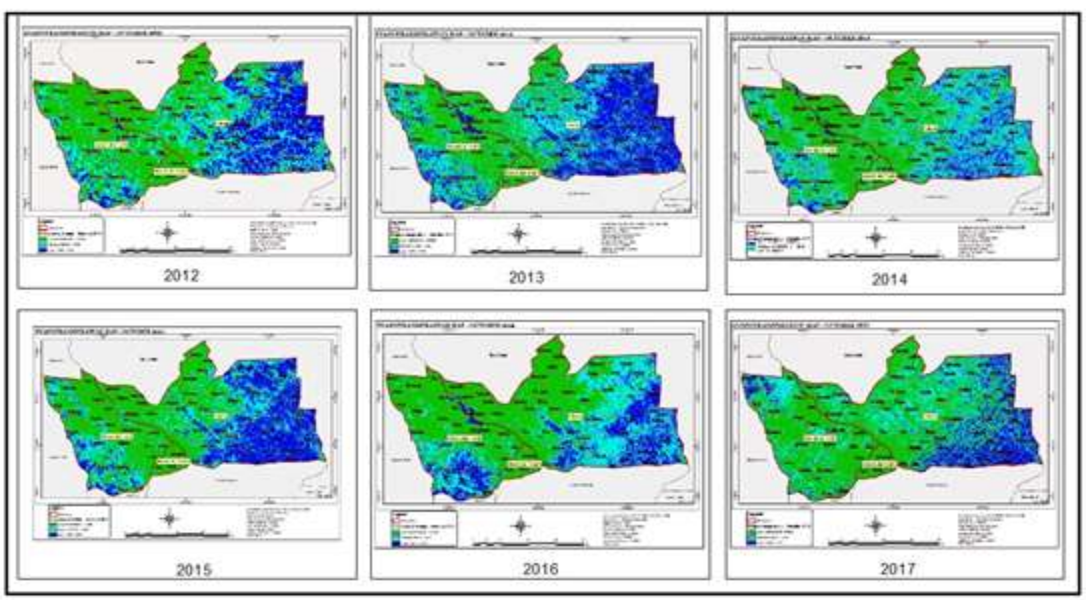

Fig 2: Wet Season Evapotranspiration Map

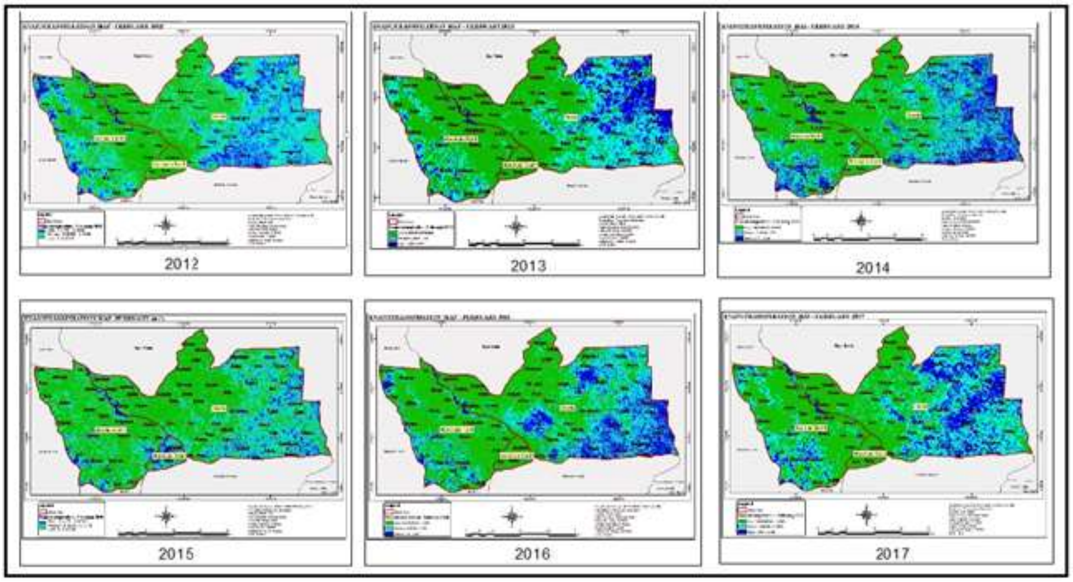

Fig 3: Dry Season Evapotranspiration Maps

Year	Parameters	February		October	
		Low (mm/day)	High (mm/day)	Low (mm/day)	High (mm/day)
2012	ET Communities	0.02 Abo	3.39 Kebo	0.0002 Otere	3.56 Alofe
2013	ET Communities	0.001 Awo	3.72 Ajagi	0.0014 Ogun Oke	3.77 Ida
2014	ET Communities	0.01 Kebo	3.54 Okasha	0.0 Kere, Alufa	4.12 Alli, Ade, Kole
2015	ET Communities	0.0004 Ariwo, Shokunbi	5.44 Lisa	0.001 Ijebu	3.17 Olofin, Olosan
2016	ET Communities	0.0001 Ijebu	3.35 Oba Imala	0.00004 Balekan	3.78 Akilagun
2017	ET Communities	0.0007 Apa	3.83 Oba Imala	0.00006 Apa	3.23 Imolisa

Table 2: Communities with Highest and Lowest Evapotranspiration values in Odeda LGA

Year	Parameters	February		October	
		Low (mm/day)	High (mm/day)	Low (mm/day)	High (mm/day)
2012	ET Communities	0.0 Abeokuta	3.12 Akingbala	0.00005 Kuto	1.99 Ijapo
2013	ET Communities	0.0 Aro	2.21 Ilugun	0.0 Ijapo	2.76 Abeokuta
2014	ET Communities	0.0 Abeokuta	2.64 Akingbala	0.00001 Sokenu	0.12 Abeokuta
2015	ET Communities	0.0 Aro	2.32 Abeokuta	0.0 Abeokuta	1.45 Ilugun
2016	ET Communities	0.0 Aro, Ijapo	1.12 Ilugun	0.00 Kuto	2.10 Ijapo
2017	ET Communities	0.0 Ijapo, Ojere, Kuto	0.82 Abeokuta	0.0 Aro	1.81 Oye

The NDVI values obtained in February revealed a relatively lower vegetation coverage according to Jwan *et al.* (2013) who classified sparse vegetation to range from 0.2 to 0.4. The reason for the sparse vegetation was due to little or no rainfall available during this period.

However, the values recorded in October were higher than their February counterpart and they fell under the category of moderate (0.4 to 0.6) and dense vegetation (0.6 and above) according to the classification made by Jwan *et al.* (2013). Moderate vegetation was observed in 2012, 2015 and 2016 while dense vegetation was observed in 2013, 2014 and 2017 respectively. This result agreed with Alademomi *et al*

(2020) result who got a similar result and also concluded that there was dense vegetation.

Evapotranspiration from Satellite Images: The lowest and highest evapotranspiration value obtained during the study period was 2.27 mm/day and 3.83 mm/day in the dry season of 2012 and 2015 respectively while 2.42 mm/day and 3.40 mm/day were recorded in the wet season of 2017 and 2016 respectively. The lowest average evapotranspiration value of 2.50 mm/day was recorded in 2012 while the highest of 3.16 mm/day was recorded in 2015. This value agreed with Odusanya et al (2019) who obtained an annual actual evapotranspiration of 839mm/yr with an average of 2.29mm/day in 2012 within the study area. During the dry season (February), evapotranspiration increased from 2012 to 2013 while it dropped in 2014 after which it increased in 2015 to reach the peak. It later declined in 2016 but rose again in 2017. In the wet season (October), evapotranspiration repeated increased from 2012 to 2013 after which it dropped for two consecutive years (that is, 2014 and 2015) after which it increased in 2016 to attain the peak and finally declined in 2017. The maximum values obtained for each year ranged from 3.12 mm/day to 5.44 mm/day. Abo, Awo, Kebo, Ariwo, Apa, Otere, Ogun-oke, Kere and Balekan communities had low evapotranspiration values close to zero. The lowest and highest values for Abeokuta North Local Government were shown in Table 3. The maximum values obtained for each year ranged from 2.83 mm/day to 6.37 mm/day. Arikola, Jumo, Kuta, Iboro Akute, Irelu, Adimo, Raji, Agbori-odo, Apa, Akaa and Araromi communities had low evapotranspiration values close to zero. However, the evapotranspiration values were higher in Ola, Sangote, Iboro-Akute, Olowo, Rodeye, Igba-Osan, Akala and Omileye communities in February and October respectively. The lowest and highest values for Abeokuta South Local Government were shown in Table 4. The maximum values obtained for each year ranged from 0.12 mm/day to 2.64 mm/day. Abeokuta, Aro, Ijapo, Kuto, and Aro communities had low evapotranspiration values close to zero. However, the evapotranspiration values were higher in Akingbala, Oye and Ilugun communities in February and October respectively.

Table 3: Communities with Highest and Lowest Evapotranspiration values in Abeokuta North

Year	Parameters	February		October	
		Low (mm/day)	High (mm/day)	Low (mm/day)	High (mm/day)
2012	ET Communities	0.0009 Arikola	4.85 Ola	0.00008 Irelu	3.36 Oloro
2013	ET Communities	0.00004 Agbori-Odo	3.57 Kuta	0.0004 Adimo	3.77 Rodeye
2014	ET Communities	0.00004 Arikola	3.45 Sangote	0.00002 Raji	4.31 Kuta
2015	ET Communities	0.00003 Aro	6.38 Iboro-Akute	0.00008 Rodeye	3.53 Oloro
2016	ET Communities	0.00001 Araromi	3.25 Akala	0.00001 Agbori-Odo	5.21 Akaa
2017	ET Communities	0.00004 Akaa	4.17 Omileye	0.0 Apa	2.83 Igba Osan

Table 4: Communities with Highest and Lowest Evapotranspiration values in Abeokuta South

Table 5: The average evapotranspiration result calculated from Landsat Image

Year	February (mm/day)	October (mm/day)	Average ET (mm/day)
2012	2.27	2.73	2.50
2013	3.10	2.89	3.00
2014	2.41	2.83	2.62
2015	3.83	2.48	3.16
2016	2.05	3.40	2.73
2017	2.64	2.42	2.53

This map displayed the spatial extent and values of evapotranspiration as they vary from place to place within the study area. It showed places with high values as well as medium and low values. Communities noted for high evapotranspiration were singled out from the map which were places where water loss from both plant and soil were highest. The high rate of evapotranspiration occurring in these communities pointed out the presence of readily available water which would impact the yield of crops produced according to Aina, (2007) who asserted that crop yield is highly dependent on available moisture. The yield of crops in these communities would be positive because of the readily available moisture supply to crops. The photosynthetic rate in such communities would be high because of prolonged stomatal opening due to enough moisture available which Buckley (2019) pointed out when he showed the strong relationship between them. Also, water resources in these arears would have to be well managed by farmers and conserved to prevent drought occurrence. Communities noted for low evapotranspiration values were indicators of moisture deficit areas and farmers in these communities need to apply soil moisture conservation techniques such as mulching to obtain maximum yield from their crops which Chimdessa *et al* (2019) corroborated after his findings on the relationship between applying moisture conservation techniques and crop yield. In addition to this, irrigation practices would also help improve the yield of crops. *Conclusion:* The research approached the estimation of evapotranspiration using remote sensing. This approach showed the variation of evapotranspiration rate across the study area which is a major advantage against traditional approach that only takes point measurement. The study also showed that proper and adequate decisions can be made for specific areas in the study areas without assumption through the data obtained. The result therefore recommends the adoption of remote sensing approach to key stakeholders for effective and relevant decision making.

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