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Spatial distribution of surface energy fluxes in selected south-south states, Nigeria

*Nworah, O.A.; Weli, V.E.; and Nwagbara, M.O.
Department of Geography and Environmental Management, University of Port Harcourt, Port Harcourt, Rivers state

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ABSTRACT
The study carried out a spatial distribution analysis of surface energy fluxes in Akwa Ibom, Cross River and Rivers states. The remote sensing data sources using Surface Energy Balance Algorithm for Land (SEBAL) Algorithm with Landsat 8, OLI& TIRS sensors data downloaded from USGS site (2021). The downloaded imageries were imported into the ArcGIS 10.7 environment where further geospatial analyses were performed.SEBAL was employed to determine the surface energy fluxes across selected states.The NDVI values for vegetation quality index for each selected state were generated for the study. The obtained data for the study were presented in Tables and maps. Findings revealed that surface temperature (K) for Akwa Ibom state ranged between 295.97K and 302.19K; for Rivers state, it ranged between 297.03K and 303.97K; and for Cross River state, the surface temperature ranged between 294.50K and 304.22K. Findings for soil heat fluxes across selected states revealed range values between 24.5905 w/m^2 and 78.7936 w/m^2 for Akwa Ibom state; range values between 65.6154 w/m^2 and 236.788 w/m^2 for Cross River state; and range values between 59.0249 w/m^2 and 203.814 w/m^2 for Rivers state. Comparatively, based on the vegetation index quality the results indicated that minimum soil heat flux (w/m^2) is experienced over vegetated area while maximum soil heat flux is observed over poorly vegetated areas. The study therefore recommended proper land use planning in cities across Nigeria as this will help to decrease urban heat islands building up as a consequence of improper land use planning.
Keywords: Spatial distribution, Surface energy fluxes, Soil heat flux, SEBAL algorithm, LS-8 OLI satellite, ArcGIS 10.7

I. INTRODUCTION

The Gross Domestic Product (GDP) and population of Nigeria have continued to rise with corresponding pressure on the environment. According to Trading Economies (2020), while the GDP grows at 6-8% per annum with 1.9% year-on-year increase in the first quarter of 2020, the population of the country as at 2019 stood at about 200 million, representing 2.35% of the world's total population. This invariably translates to higher demand for energy, exacerbating atmospheric pressure. For instance, from 1990-2011, population grew 71% (to 167 million), in same period energy-use grew 68% (to 721 kiloton of Oil Equival[ent (KOE)) (Federal Ministry of Environment, 2016). The report further noted that industry and residential energy demand grew by 3.5 and 2.5 times from 1990-2005 (from 240 to 900 PJ and 700 to 1800 PJ respectively), with steeper growths after 2019.

The penchant to meet the energy needs of Nigerians has resulted in over exploitation of the natural environment to the detriment of surface and atmospheric energy balance. This is so considering that sensible and latent heat fluxes are key components in the terrestrial energy and water cycles (Morakinyoet al., 2019). These turbulent fluxes are the main forces of the atmosphere by the land and provide a link between the land surface and the atmospheric boundary layer (Betts, 2007). Instances of environmental exploitation activities that have impacted surface energy flux include deforestation of vegetative cover, urbanization promoted by rural-urban drift. Nigeria consumes over 50 million metric tonnes of fuel wood annually, which is a major cause of deforestation, desertification and erosion in the country (Federal Ministry of Environment, 2016). This sad reality perpetuates deforestation to the detriment of surface–atmospheric energy balance in the environment.

Similarly, projections according to Oyeleye (2013) suggest that the number of people living in Nigeria urban centres will reach 100 million by 2020. Going by the rate at which

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vegetative covers are removed and land degraded, it suffices to expect a corresponding decline in water loss from soil and crop surfaces in the year 2020. The process by which water is lost from soil surface by evaporation and from crop by transpiration is regarded as evapotranspiration (ET) (Allen et al., 1998). This whole process of evapotranspiration impacts the surface energy flux in the sense that the energy balance at earth's land surface requires that the energy gained from net radiation be balanced by the fluxes of sensible and latent heat to the atmosphere and the storage of heat in soil (Bateni and Liang, 2012). The solar and long wave radiation that impinges on Earth's surface heats the surface, and the surface in turn reflects some of the incoming solar radiation and also emits outgoing long wave radiation. The remaining radiation is the net radiation at the surface, which dissipated through convection, conduction and radiation. The heat exchanged through convection is called sensible heat (Gordon, 2013).Sensible heat from surface energy fluxes are harnessed in some instances for adaptive production process, such as in the creation of Greenhouse microclimates (Bateni and Liang 2012).

Describing the energy balance, Khaldiet al., (2011) noted that the annual energy balance at the land surface varies geographically in relation to incoming solar radiation and soil water availability. Over land, annual evapotranspiration is highest in the tropics and generally decreases towards the poles. Energy fluxes vary over the course of a day and throughout the year, also in relation to soil water availability and the diurnal and annual cycles of solar radiation. Thus, through remote sensing data with imagery resolution surface heat flux could be monitored as the remote sensing data provides information related to mass and energy transfers and particularly to evapotranspiration fluxes (Bateni& Liang, 2012). Remote sensing technology according to them are effective in understudying land surface parameters like vegetation indices and surface temperature, which are indispensable to remote sensing-based energy balance models for scaling up surface energy fluxes to larger spatial and longer temporal scales. It is recognized as the only way to retrieve evapotranspiration at several temporal and spatial scales (Zuo et al., 2011).

Consequently, the dearth of satellite imagery on surface energy flux in cities in Niger Delta due to lack of empirical findings undermines the study of net surface irradiance, ground heat flux, sensible heat flux, latent flux for onward environmental remediation, mitigation and or adaptation. Findings of the study will assist policy makers determine implications for moderating adverse effects of high energy flux density, and also for providing some adaptation measures suitable for an area like Niger Delta prone to environmental degradation. The findings of the study shall assist public and private environmental protection agencies provide reliable basis for developing and maintaining robust environmental climate-change stimulus policies and programmes in the study area. Thus, the importantresearch questions the studyanswered are: what is the spatial distribution of soil heat fluxes in the selected states? What are their implications?

II. MATERIALS AND METHODS

Description of the Study Area

The study is carried out for selected south-south states (Akwa Ibom, Cross River and Rivers states) in the Niger Delta, Nigeria. The Niger Delta lies in southern part of Nigeria where the River Niger divides into numerous tributaries. It extends between latitude 4.15° N and longitude 6.01° N and 5.05° E and 7.35° E (Adejuwon, 2011). The region consists of about 2,370 Square kilometers of the area of rivers, creeks and estuaries, while about 8600 square kilometers covers the stagnant swamp. The ecosystem are highly supportive and diverse various species of terrestrial and aquatic flora and fauna and human life (Uyigue and Agho, 2007). The States of the Niger Delta are nine in number, namely: Abia, Akwa Ibon, Bayelsa, Cross River, Delta, Edo, Imo, Ondo and Rivers. The Delta is of great strategic importance to Nigeria’s food security and the world’s oil resources. The wetlands provide food, water and livelihood security for the poor people living around the delta area. Coastal regions are vulnerable to extreme events, such as storms, which impose significant costs on coastal area and expose it to higher risks of flooding. Generally the Niger Delta witnesses two seasons of Wet and dry (April to October) and dry (November to March), respectively. These seasons are influenced by two air masses namely south-westerly’s coming from the Atlantic Ocean and north-easterlies from the Sahara desert respectively. The study area states are Akwa Ibom, Rivers and Cross River States respectively (Figure 1). Rivers state cover an area of 8,539Sq.Km, Akwa Ibom cover 6,733sq.km and Cross River cover 21, 288sq.km. These states are all in the tropical rain forest belt of Nigeria. Their climate is generally humid because of the proximity to the sea. Based on their geographical location, their climate can be described as a tropical rainy type, which experiences abundant rainfall. Thick

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cumulonimbus type of cloud is experienced between the months of March and November.

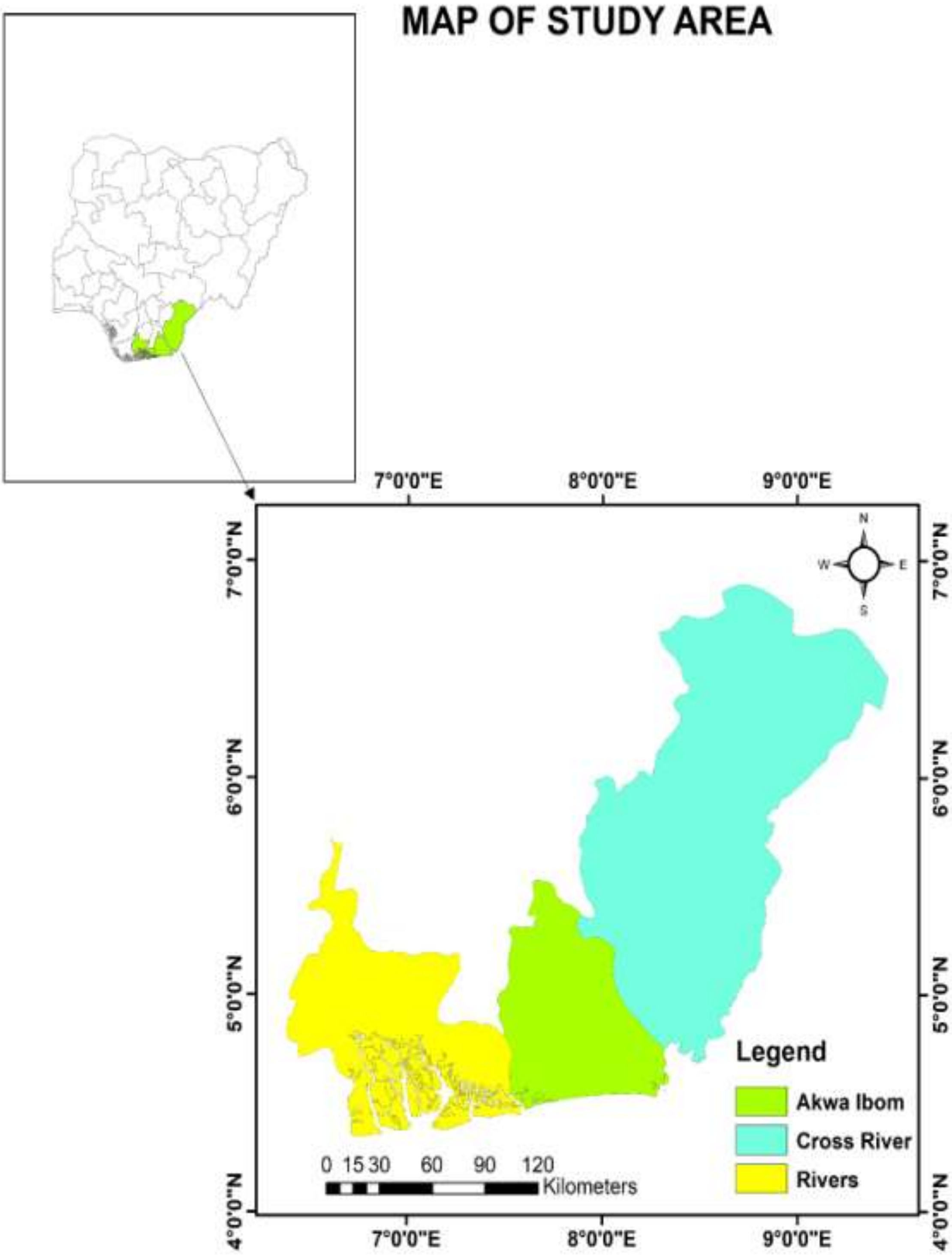

Figure 1: Study Area

Data Acquisition

Data Sources

Remote sensing data are supplemented by ground measurements which were performed on two points located in Weather Stations. These measurements correspond to the radiometric surface temperature, the reflected radiation and the components of surface energy balance, i.e. soil heat flux (G). The meteorological station also provided measurements on the reference variables which are air temperature, relative humidity, wind speed, air pressure, sunshine duration and daily potential evapotranspiration.

The Soil Heat Flux is the rate of heat storage in soil and vegetation as a result of conduction. The net radiation, Land surface temperature, albedo and NDVI were the parameters used to retrieve the soil heat flux of the study area. Surface temperature is the most important parameter for estimation of surface heat fluxes

The three remote sensing-based methods that provide spatially distributed surface fluxes maps using airborne and satellite data were utilized for the study and these include: Surface Energy Balance Algorithm for Land (SEBAL), Mapping Evapotranspiration with Internalized Calibration (METRIC), Simplified Surface Energy Balance Index (S-SEBI), Surface Energy Balance System (SEBS) and Trapezoid Interpolation Model (TIM model); and Dual-source models like Two Source Energy Balance (TSEB), that discriminate the soil and vegetation component, aiming at a more physical description of heterogeneous surfaces when dealing with radiative and aerodynamic properties(French et al., 2015; Boulet et al., 2015).

Surface heat fluxes for Akwa Ibom, Rivers and Cross River states were computed using SEBAL algorithm. LS-8 OLI satellite data and ArcGIS 10.7 which were used for all analysis and maps generations. Selection of anchor pixel has an important role to determine the heat fluxes accurately (Silva, da Silva, & Santos, 2019).

III. DATA ANALYSIS

The descriptive statistics in form of Tables and maps was employed for data presentation for the study. The rate of transfer of energy to a surface of unit area is expressed in J m−2 s−1 which is equivalent to W m−2. It is associated to the process of absorption and Emission of 'natural' electromagnetic radiation by the surface; thermal Conduction of heat energy within the ground; turbulent transfer of heat energy towards or away from the surface within the atmosphere; evaporation of water stored in the soil or condensation of atmospheric water vapour onto the surface.

The energy balance of a surface layer of finite depth and unit horizontal area can be written as:

$dQ/dt = Rn - G - H - \lambda E$ …………………..(1)

Where:

Q = the total heat energy stored in the surface layer.

Rn = is the net surface irradiance (commonly referred to as the net radiation). It represents the gain of energy by the surface from radiation. It is a positive number when it is towards the surface.

G = the Ground Heat Flux. It is the loss of energy by heat conduction through the lower boundary. It is a positive number when it is directed away from the surface into ground. The valueat the surface is denoted G0.

IV. RESULTS OF THE ANALYSES

Soil Heat Fluxes across selected states

The information provided on Tables 1, 2 and 3 shows the weight coefficients for the various bands of Landsat OLI satellite data utilized for αacross selected states. The surface temperature (K) for Akwa Ibom state ranged between 295.97K and 302.19K; for Rivers state, it ranged between 297.03K and 303.97K; and for Cross River state, the surface temperature ranged between 294.50K and 304.22K.

Table 1: Akwa Ibom State Instantaneous parameters and Heat flux during Landsat overpass at hot and cold pixels

Parameter	Unit	Cold Pixel	Hot Pixel
NDVI		0.44	0.23
SAVI		0.29	0.13
Surface albedo		0.199	0.17
Surface Temperature	K	295.97	302.19
Net Radiation	Wm^{-2}	1002.13	1016.40

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Soil Heat Flux	Wm^{-2}	114.39	146.68
LET	Wm^{-2}	907.26	803.29
Sensible Heat Flux	Wm^{-2}	19.52	66.42

Table 2: Rivers State Instantaneous parameters and Heat flux during Landsat overpass at hot and cold pixels

Parameter	**Unit**	**Cold Pixel**	**Hot Pixel**
NDVI		0.43	0.25
SAVI		0.27	0.15
Surface albedo		0.18	0.19
Surface Temperature	K	297.03	303.97
Net Radiation	Wm^{-2}	1012.85	973.37
Soil Heat Flux	Wm^{-2}	119.53	154.29
LET	Wm^{-2}	896.45	672.05
Sensible Heat Flux	Wm^{-2}	168.45	147.02

Table 3: Cross River State Instantaneous parameters and Heat flux during Landsat overpass at hot and cold pixels

Parameter	**Unit**	**Cold Pixel**	**Hot Pixel**
NDVI		0.50	0.18
SAVI		0.22	0.11
Surface albedo		0.09	0.18
Surface Temperature	K	294.50	304.22
Net Radiation	Wm^{-2}	1161.84	990.99
Soil Heat Flux	Wm^{-2}	102.47	155.84
LET	Wm^{-2}	1108.92	732.85
Sensible Heat Flux	Wm^{-2}	168.68	102.30

The results for the spatial distribution of soil heat fluxes across selected states are displayed on Figures 1, 2 and 3.Soil Heat Flux is the rate of heat storage in soil and vegetation as a result of conduction. Figure 1, 2, and 3 shows the soil heat flux of each of the study area. The net radiation, Land surface temperature, albedo and NDVI were the parameters used to retrieve the soil heat flux of the study area.Similarly, the spatial distribution for the soil heat fluxes across selected states revealed

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that in Akwa Ibom state, it ranged between 24.5905 w/m^2 and 78.7936 w/m^2; in Cross River state, the soil heat flux ranged between 65.6154 w/m^2 and 236.788 w/m^2; while in Rivers state, the range values for soil heat flux was between 59.0249 w/m^2 and 203.814 w/m^2. The lowest value of soil heat flux of 24.5905 w/m^2 experienced across the south-south states was recorded in Akwa Ibom state while the highest soil heat flux of 236.788 w/m^2 was recorded in Cross River state. Thus, more heat soil heat flux index is experienced in Cross River state.

Comparatively, Figures 4, 5 and 6 for vegetation index using NDVI values across selected south-south states further revealed that the minimum soil heat flux (w/m^2) is experienced over vegetated area while the maximum soil heat flux is observed over poorly vegetated areas.

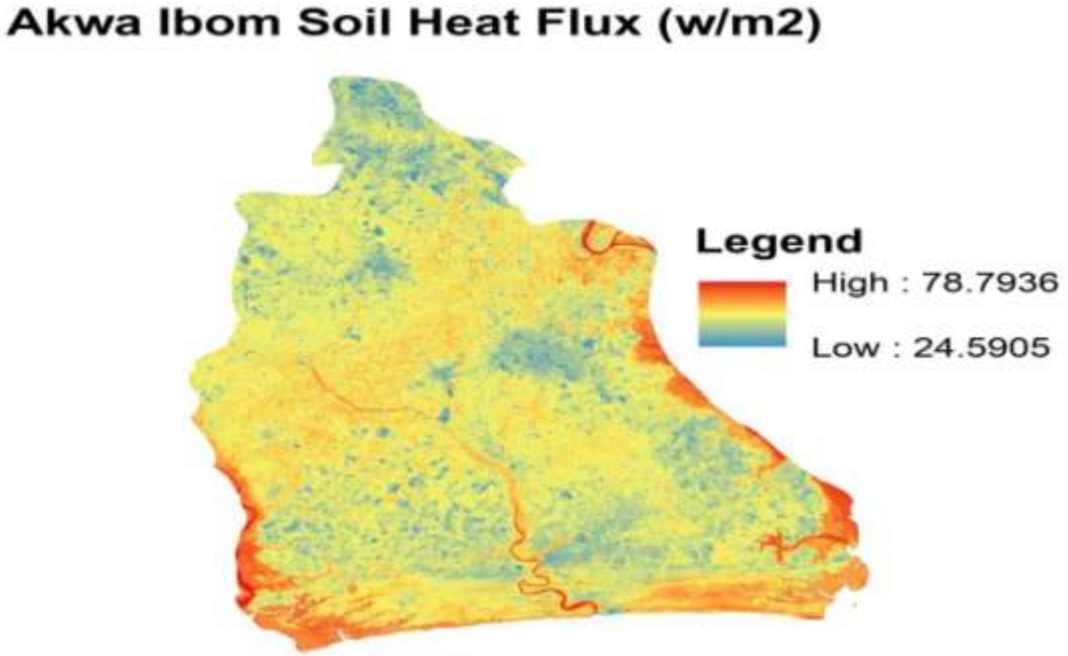

Figure 1: Spatial distribution of Soil Heat Flux for Akwa Ibom state

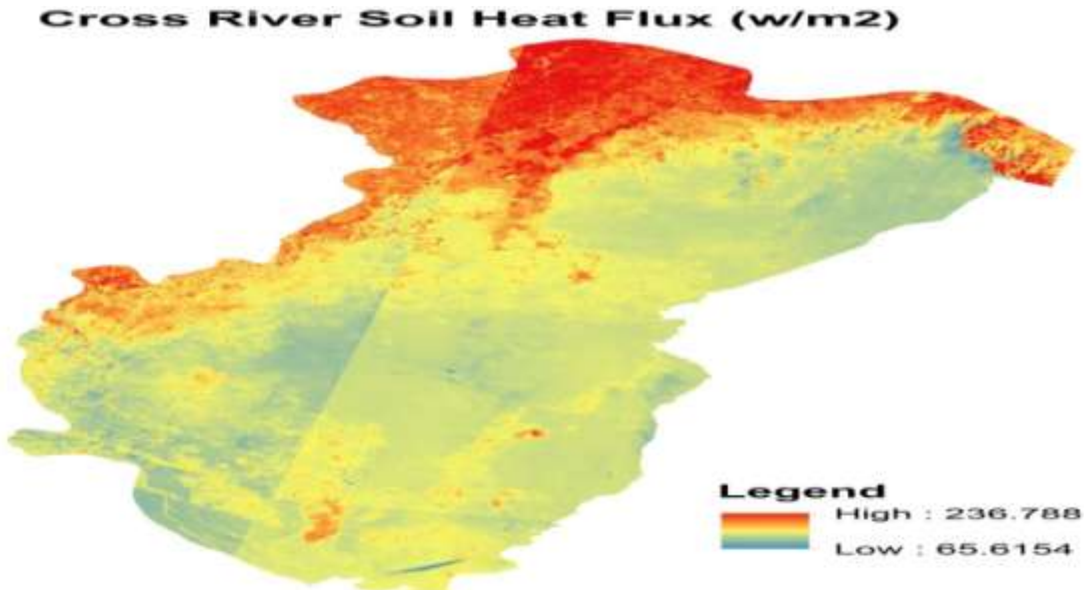

Figure 2: Spatial distribution of Soil Heat Flux for Cross River state

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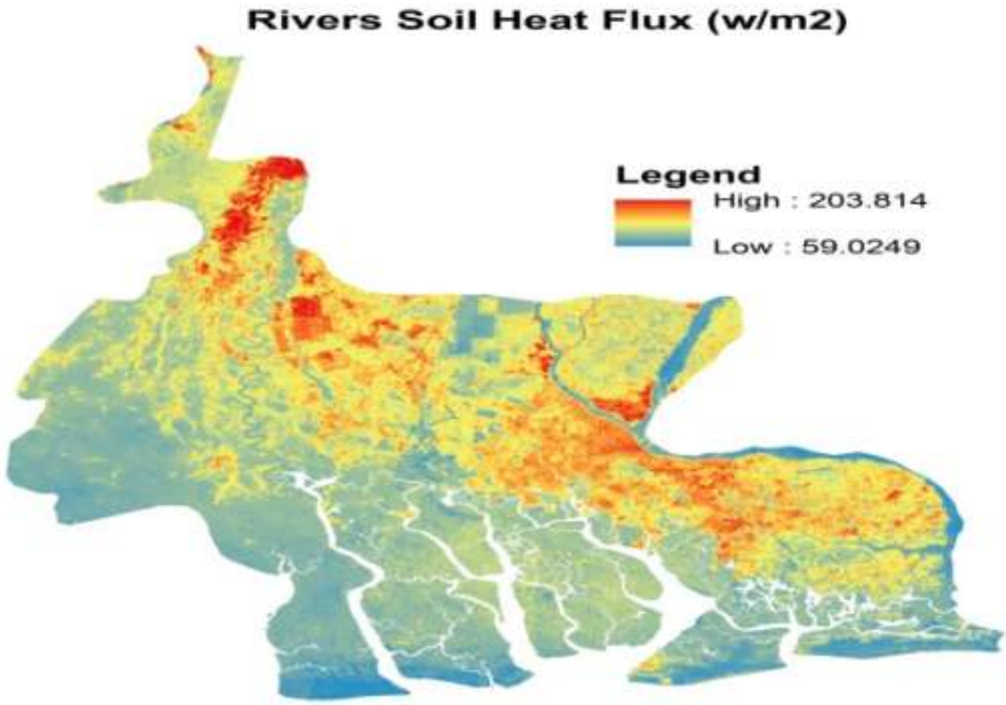

Figure 3: Spatial distribution of Soil Heat Flux for Rivers state

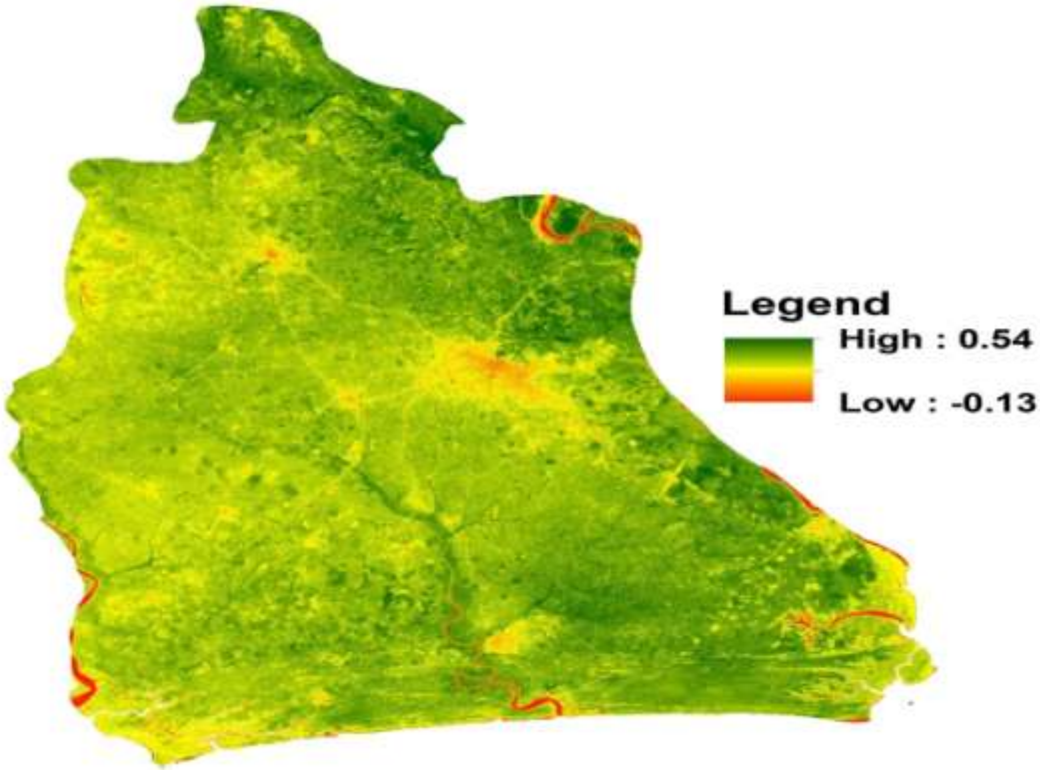

Figure 4: Vegetation index for Akwa Ibom state

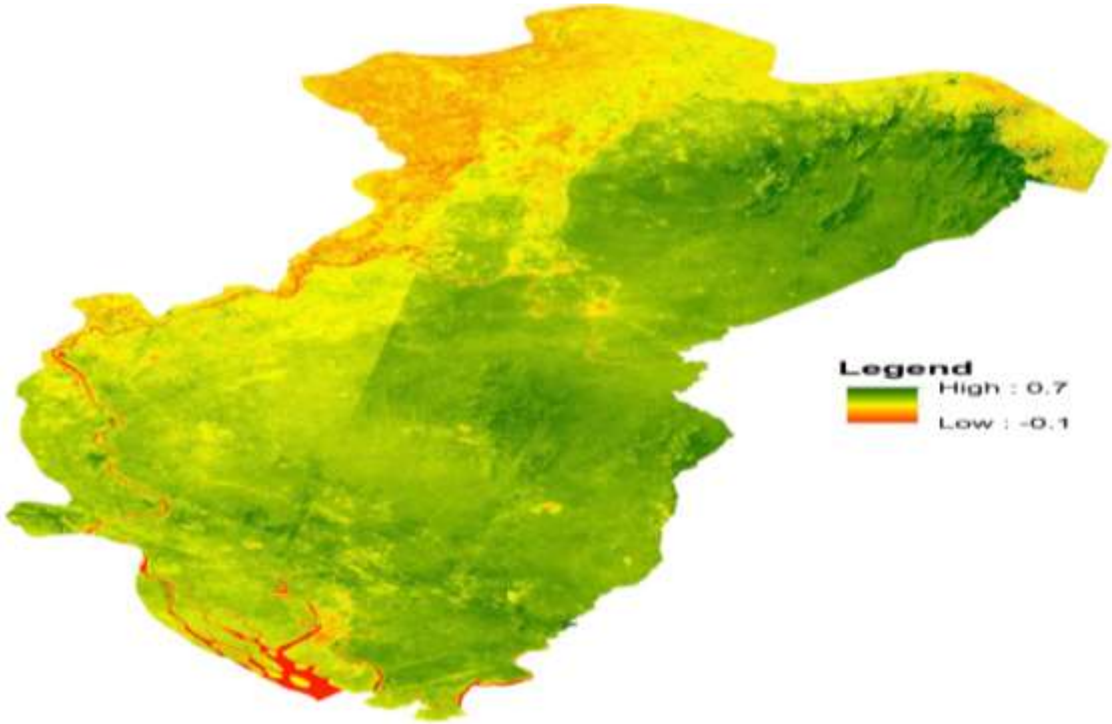

Figure 5: Vegetation index for Cross River state

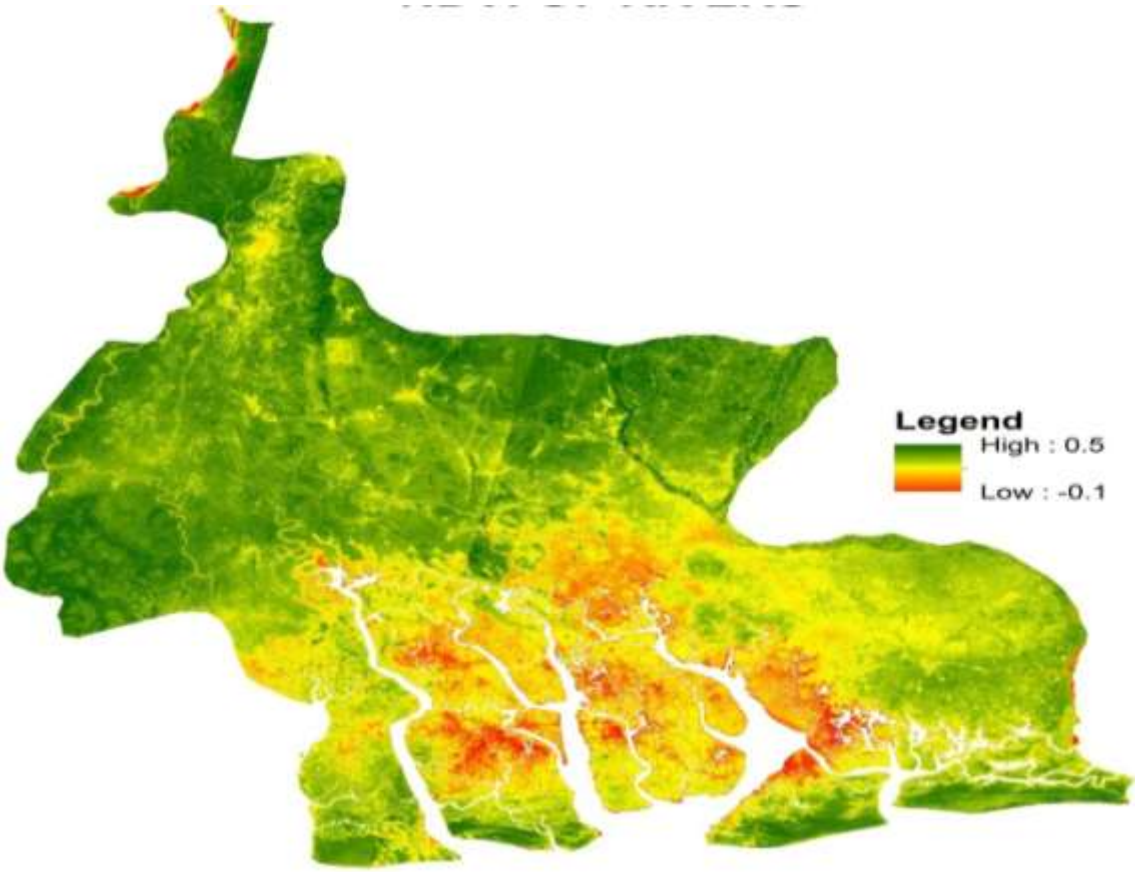

Figure 6: Vegetation index for Rivers state

Implications

The results of the spatial distribution of soil heat fluxes across selected south-south states indicates that vegetation coverusually decrease soil heat flux. The intensity of soil heat flux lowers as a result of temperature drop brought on by the blockage of incident solar radiation at the vegetated surface. The maximum soil heat flux occurs in the urban areas while minimum soil heat flux cluster around the vegetative areas. Anthropogenic activities influencing urbanization through deforestation are responsible factors that leads to high soil heat fluxes observed in cities across the selected states. In other words, activities emanating from urban areas resulting in the replacement of natural surface with impervious surfaces such as concrete and asphalt leads to increased soil heat fluxes while areas with high vegetative cover normally leads to reduced soil heat flux**.**In other words, the higher the vegetal cover the lower the soil heat flux of the area and vice versa.

V. DISCUSSION

The spatial interpretation of energy fluxes revealed that the surface energy fluxes vary according to the land use land cover. This study demonstrated that remote sensing data can be applied to determine the surface energy fluxes across a large area. The spatial variation of the surface energy fluxes at any point on the earth's surface can be retrieved with remote sensing data. The SEBAL model has been used in various studies globally (Adeniyi and Nymphas, 2013; Ayorinde et al., 2015; Cronin et al., 2019). The information displayed on Figures 1, 2 and 3 shows that the surface energy fluxes have similar patterns of expression across the study area, although the intensity of the energy fluxes varies due to land use Land cover characteristics. This finding of the study agrees with the findings of Gordon (2013) that land cover characteristics like vegetation influence surface heat energy. The study discovered categorically that canopies amongst critical features that influence energy budget and enhance adaptation to surface energy fluxes. The use of plant canopy is greatly affected by the amount of leaf area and quantified by leaf area index of the plant used.

VI. CONCLUSION AND RECOMMENDATION

The study spatially analyzed the soil heat fluxes of selected south-south states in Nigeria. Findings revealed that the distribution of soil heat fluxes varied with land use characteristics. In other words, areas with reduced vegetation recorded higher soil heat index when compared with areas with vegetal cover. The findings of the study provides knowledge critical in planning, designing and locating infrastructure, environmental activities, materials and tools that are sensitive to energy. This informs the use of adaptive and mitigation measures in needful instances. The study therefore recommended proper land use planning in cities across Nigeria as this will help to decrease urban heat islands building up as a consequence of improper land use planning; activities contributing to removal of vegetal cover should be addressed; the government should introduce policies that will be directed at ensuring effective planning of human activities in cities.

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