Spatial and Temporal Variation of Surface Energy Fluxes Due to Land Use Changes and Atmospheric Variables Assessment across South African regions

Submitted By: Md Minhaz Rahman Talukder (3814344), Tasin Siraj (3944410)

1. Introduction:

The climate system can be directly affected by land-use and cover change (LUCC). LUCC leads to a huge number of bio-geochemical and bio-geophysical processes locally, regionally and globally [1–3]. Due to LUCC several physical properties of land such as: albedo, moisture content, fractional vegetation coverage and surface roughness change or alter during the time. While determining the absorption, emission and exchange of energy at the Earth's surface, several other key factor like the energy fluxes, moisture into the atmosphere and radiation come into account [4-8]. All these factors have a combined effect on the climate system [9-11]. Furthermore, the interaction between land surface and atmosphere mainly works through the exchanges of momentum, energy and water, among which the exchange of energy plays a crucial role in affecting climate system. In this context, it is essential to investigate the effects of LUCC on surface energy fluxes.

The effects of LUCC on climatic change have raised growing concern and have been widely Studied [1,12–14]. Land-cover change is now a common phenomenon which is growing rapidly in magnitude due to the booming economy and population of the world. Changes in land cover include the conversion of natural vegetation to agricultural crops and forest plantations, changes to natural vegetation through bush encroachment and overgrazing, soil erosion, invasion by alien plant species, and accelerating urbanization. The increasing land-cover changes are related to climate and atmospheric changes in ways that are poorly understood till to date. But it has a potentially significant effect especially in terms of compromising or enhancing the delivery of vital ecosystem services from agricultural croplands, rangelands, conservation areas and water catchments.

Many studies attempted to reveal the impacts of Human-induced Land Cover Changes (HLCCs) on the regional climate in Africa and all over the world [3,13,15,16]. However, most of these studies only focused on the effects of HLCCs on temperature and precipitation [17–20]. The effects of surface energy fluxes such as latent heat flux and sensible heat flux have very little information to offer. Moreover, extensive research on surface energy fluxes in the African zone is important if we want to understand the global climate change. To date, an integrated analysis at South Africa which has the second largest economy in Africa remained underexplored. And the country needs to make comprehensive policies regarding land planning and management.

In order to address this knowledge gap, we analyzed the heat flux changes caused by land transformation over two years (2003 and 1019) across South Africa to improve the understanding of the impacts of land dynamics on regional climate. In the later part of the report, we have described the study area and introduced the primary datasets used in this study. After that, we have described some fundamentals theories behind surface energy fluxes. Then, we have analyzed the variation and deflection of energy fluxes in two selected years. Lastly, we tried to interpret the climate diagram of the two mentioned years and spot the changes.

2. Study Area and Data:

ERA5 is the latest climate reanalysis produced by ECMWF, providing hourly data on many atmospheric, land-surface and sea-state parameters together with estimates of uncertainty. ERA5 data are available in the Climate Data Store on regular latitude-longitude grids at 0.25o x 0.25o resolution, with atmospheric parameters on 37 pressure levels afforestation and urbanization. The target area of the analysis is focused on South Africa and covers Longitude 14° to 34°, Latitude -6°to -26°.Specifically, the Forest and agriculture were the most dominant land use type in 2003 and 2019, as can be seen on Figure 1. Although some wetland transformed into grassland in 2019, settlement areas remain the same with the slightest changes. However, here only the impacts of the dominant type of land use changes on surface heat flux in each zone are presented. In other words, we merely considering the reclamation, overgrazing, afforestation, and urbanization.

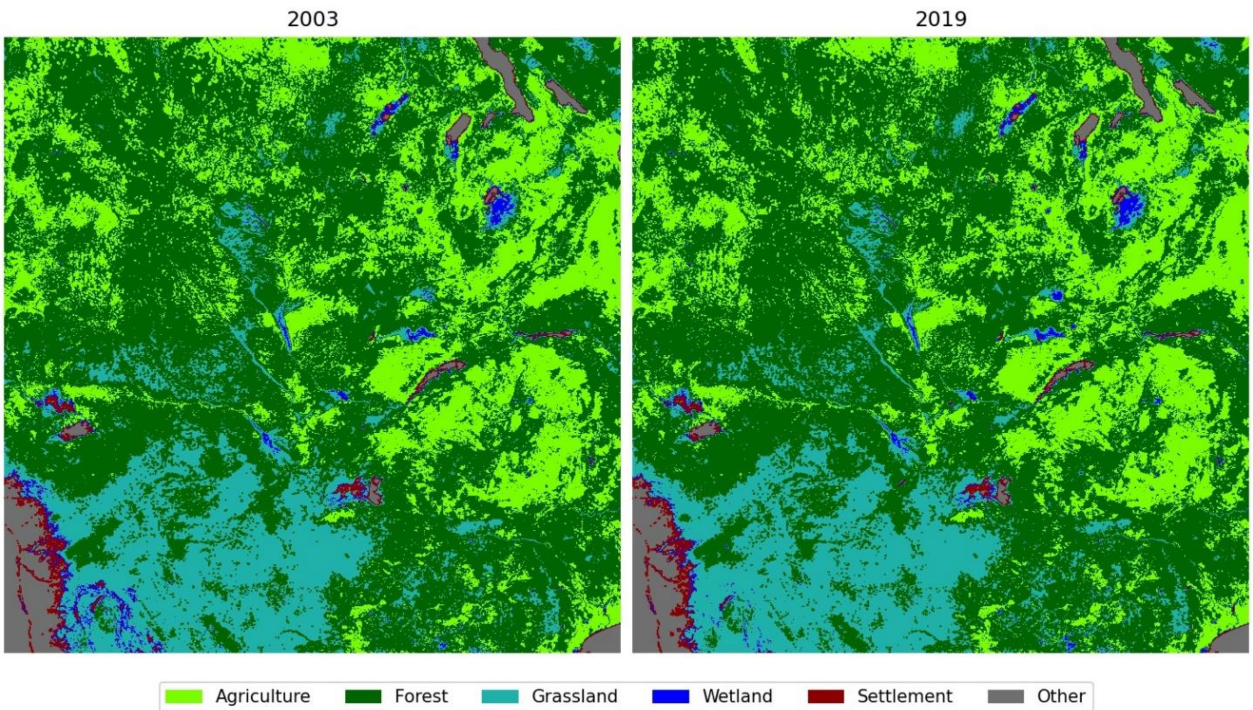

Figure 1: Land use cover classes of South African zone in 2003 and 2019.

The primary data is grouped into 21 land cover classes. We have changed them into six categories based on six IPCC land categories, i.e., cropland, forest, grassland, wetland, settlement and other lands. From Figure 2, we can see that forests and grasslands account for 44 % and 38% respectively of the total land area of the selected zone and there is no noticeable difference between 2003 and 2019. The noticeable change can be seen in wetland and settlement areas where the wetland area has increased in 2019, but the settlement area decreased in 2019.

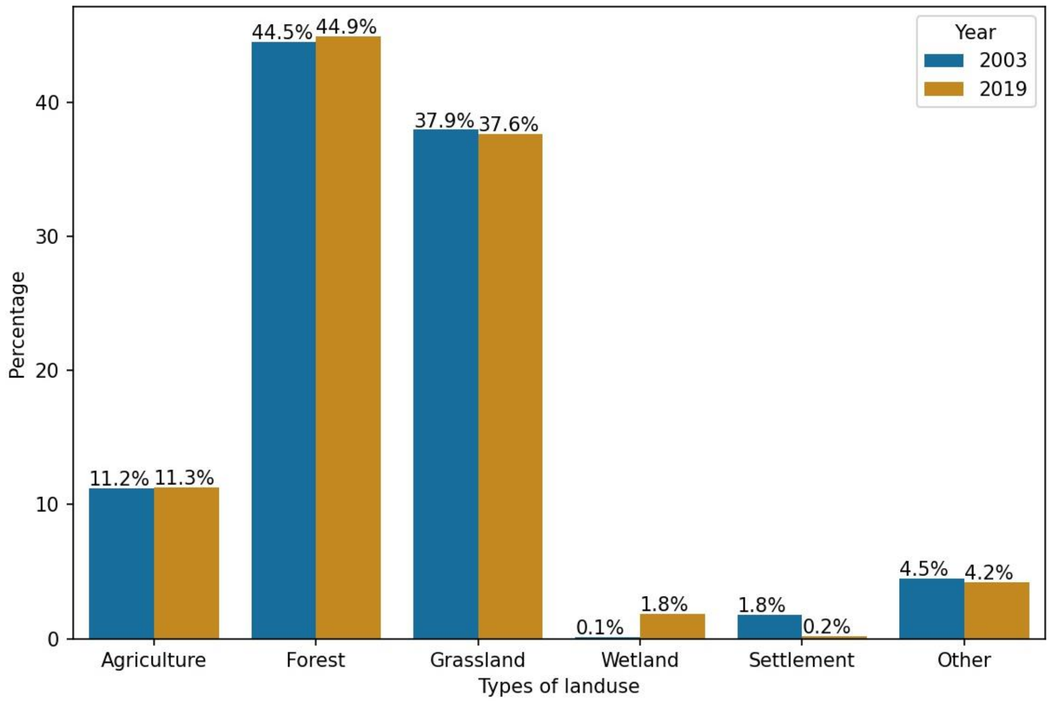

Figure 2: Percentage in the land use cover classes in South African zone.

3. Fundamental theories of energy budget:

According to the surface energy budget equation, there is a close relationship between the surface net radiation, land surface albedo, downward shortwave radiation, downward long-wave radiation and land surface emissivity. Energy comes into the system when sunlight penetrates the top of the atmosphere, and it goes out in two ways: reflection by clouds, aerosols, or the surface; and thermal radiation heat emitted by the surface and the atmosphere, including clouds (Figure 3). The net radiation can be expressed as follows:

$$R_n = (1 - albedo)\ SWDOWN + GLW + LW_{out} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . (1)$$

$$LW_{out} = emmissitivity \times \sigma \times T^4 \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots . . (2)$$

where *Rn* is the net surface radiation as a function of the surface albedo, incoming short-wave flux (*SWDOWN*) and long wave flux (*GLW*) radiation, and outgoing long wave radiation (*LWout*); σ is the Stefan-Boltzmann constant (σ = 5.67 × 10−8 J s−1 m−2 K−4) and *T* is the land surface temperature.

The net radiation is the balance between incoming and outgoing energy at the top of the atmosphere. It is the total energy that is available to influence the climate. This report focuses on how the underlying surface change affects the land surface albedo, downward shortwave radiation, downward long-wave radiation, and land surface emissivity to clarify the key influencing mechanism of the future land use changes on the regional surface radiation across Africa.

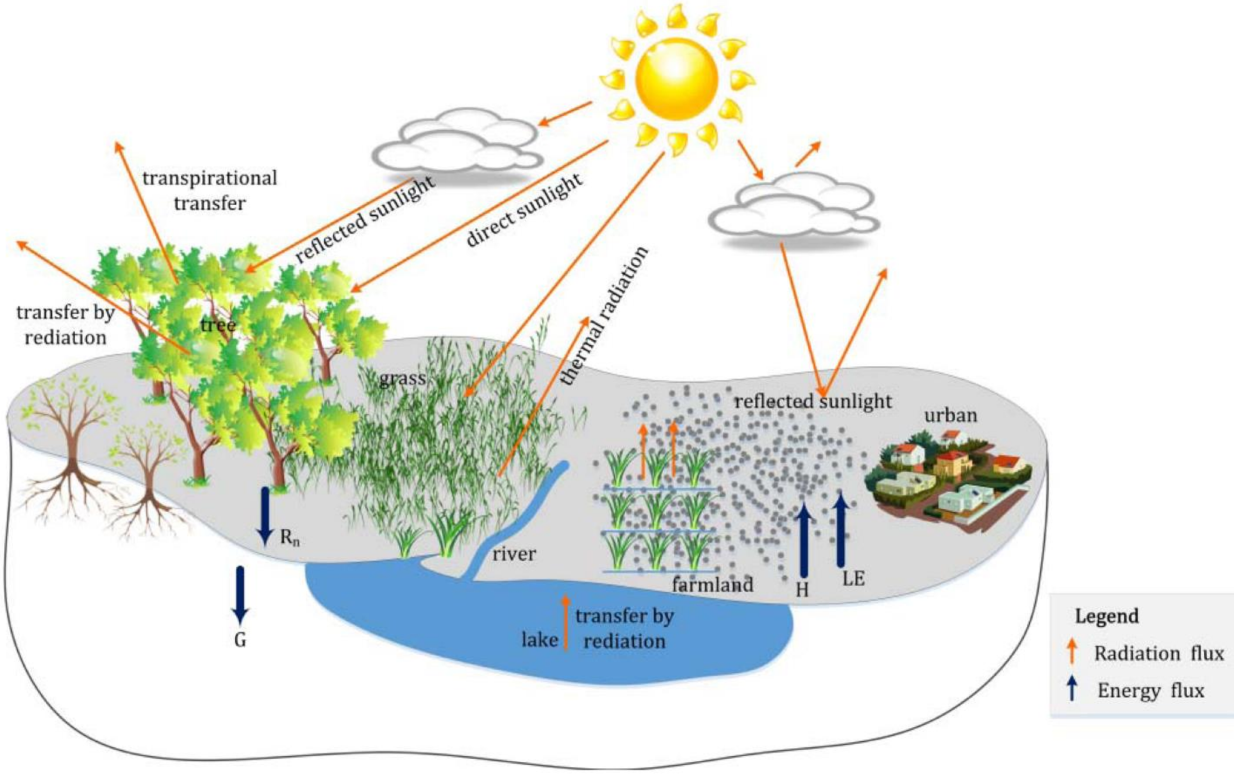

Figure 3: Diagram of the energy balance (Source: Ma E et. al, 2014).

4. **Biomes and Ecozones:**

A biome is a geographically extensive type of ecosystem. A particular biome occurs wherever environmental conditions are suitable for its development, anywhere in the world. Biomes are characterized by the life forms of their dominant organisms, but not necessarily by their particular species. On land, biomes are generally identified by their mature or older-growth vegetation. In contrast, aquatic biomes are usually distinguished by their dominant animals. Biomes are classified using a system that is used at an international level—that is, by ecologists working in many countries. Figure 4 shows a map of the distribution of the most extensive terrestrial biomes. The distribution of biomes is determined by environmental conditions, which must be appropriate to support the dominant species. Moisture and temperature are usually the most important environmental influences on the distribution of terrestrial biomes (Figure 4). The distribution of various types of wetlands within terrestrial biomes is mostly influenced by the amount and permanence of surface water and the availability of nutrients. Marine biomes are most strongly influenced by water depth and upwellings, which affect the amounts of light and nutrients that are available to support primary productivity.

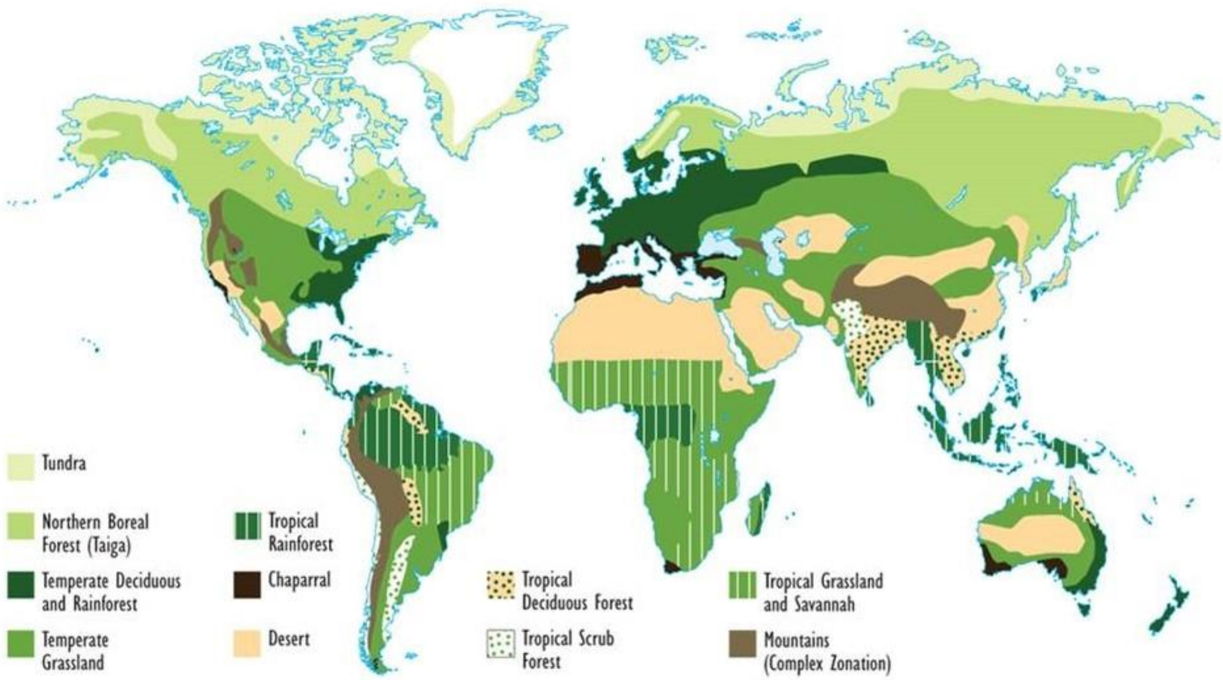

Figure 4: Environmental Influences on the Distribution of Terrestrial Biomes (Source: Odum 1993).

5. **Climate data analysis of zone:**

Figure 5 shows the climate conditions in selected zones in 2003 (left) and 2019 (right). Left and right vertical axes represents temperature and precipitation. Annual average temperature in 2013 was 22.2 Celsius but in 2019 it increased by .8 degree to 23.0 degree Celsius. In these two years precipitation remain the same. In 2013, the highest maximum and minimum temperature were 24.7 and 17.7 respectively. But in 2019 it increased to 25.5 and 18.7 respectively. From the two figures we can conclude that overall climate condition of that zone is per arid.

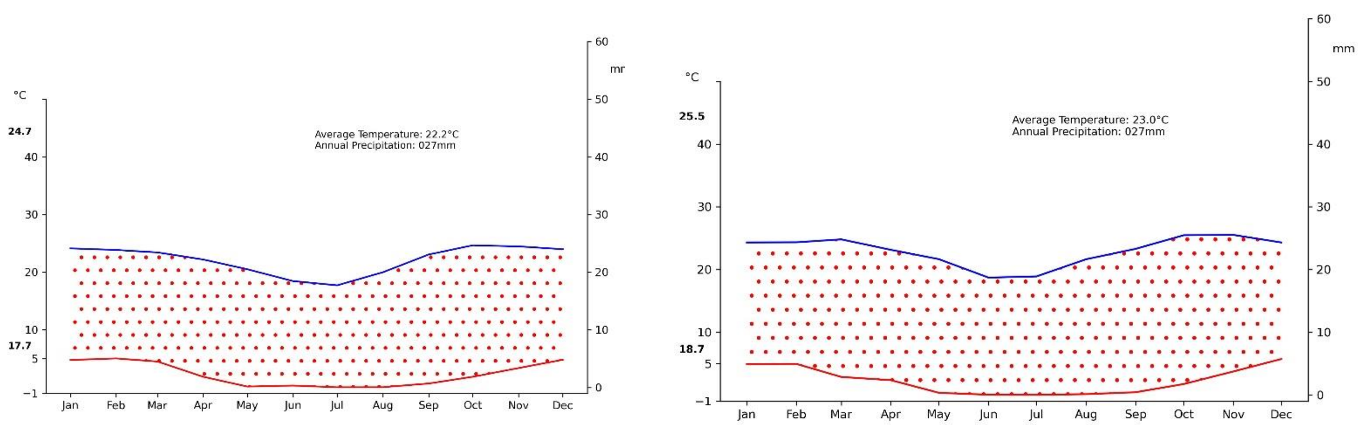

Figure 5: Climate diagram of African zone in 2003(left) and 2019 (right).

6. Spatial and temporal variation of flux changes:

We havbe found that latent heat flux increases in left down corner of the zone on an average of 30 W/m^2 due to high settelemet areas, while in the forest area it mostly remained the same (Figure 6). In agricultural zone on middle right corner it showed some sharp increase by 10 W/m^2 . In the left side of the figure 6 showing a decrease in left down corner of the zone by 20 w/m^2.But in Agricultural zone ,sensible heat flux decresd by 10 W/m^2 from 2003 to 2019.

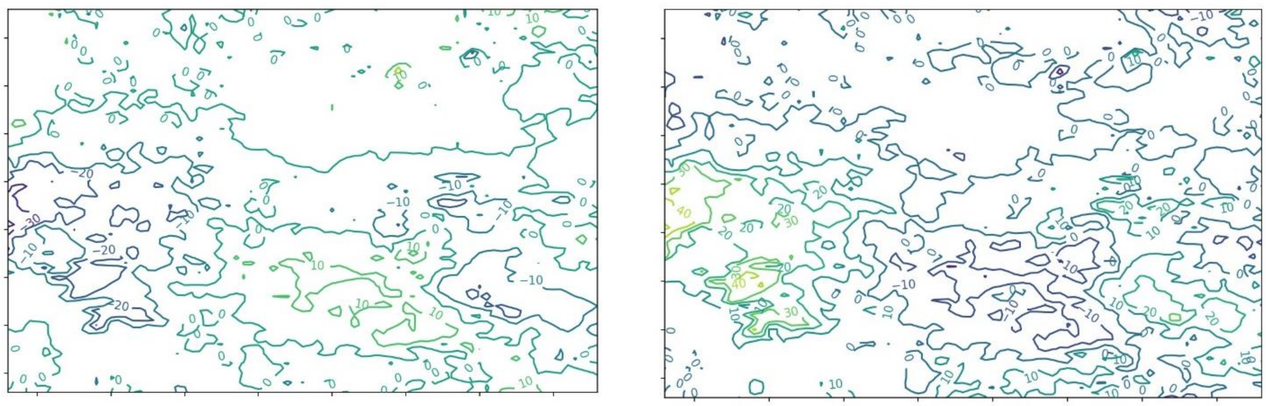

Figure 6: Changes in sensible heat flux (**left**), latent heat flux (**right**) from 2003 to 2019.

Figure 7 is showing the flux changes (letent and sensible) over a years in both 2003 and 2019. Latent heat had shown increasing values in 2019 compare to 2003 values.The diiference between in latent heat flux is maximum in these two years in between month from september to november.But the sensible heat flux is showing scatterd pattern in of change in these two years. But ovearll we can say that , sensible heat flux slightly from 2003 to 2019.

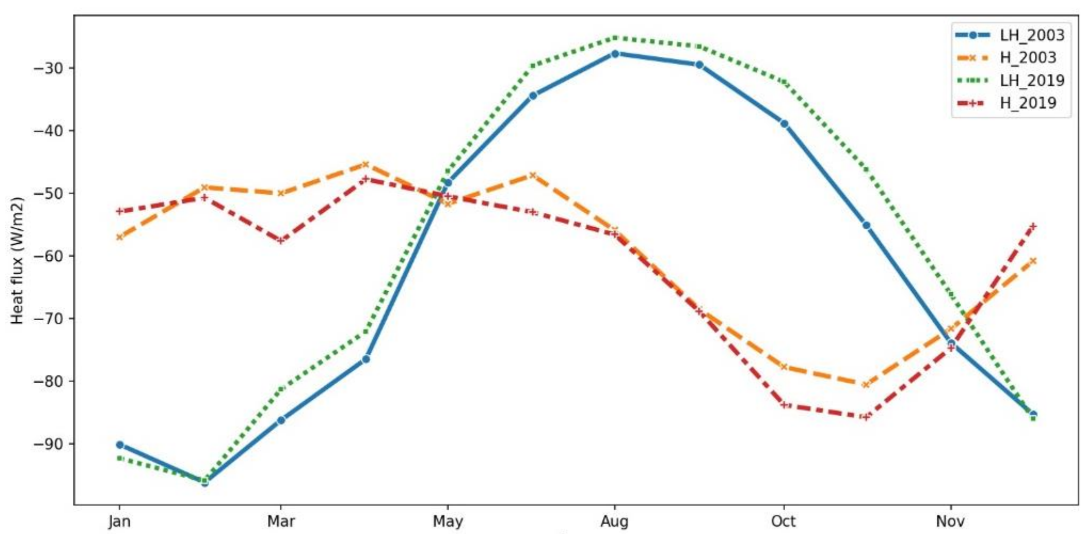

Figure 7: Monthly temporal variation of latent heat flux (LH) and Sensible heat flux (H) in 2003 and 2019.

Leaf Area Index (LAI), one half the total green leaf area per unit horizontal ground surface, is an important structural property of vegetation. Because leaf surfaces are the primary border of energy and mass exchange, important processes such as canopy interception, evapotranspiration, and gross photosynthesis are directly proportional to LAI. Figure 7 interprets the leaf area index in the African zone in 2003 and 2019. It is clearly visible that leaf area index decreases from 2003 to 2019. Highest leaf area index can be seen in March of both years and lowest in October.

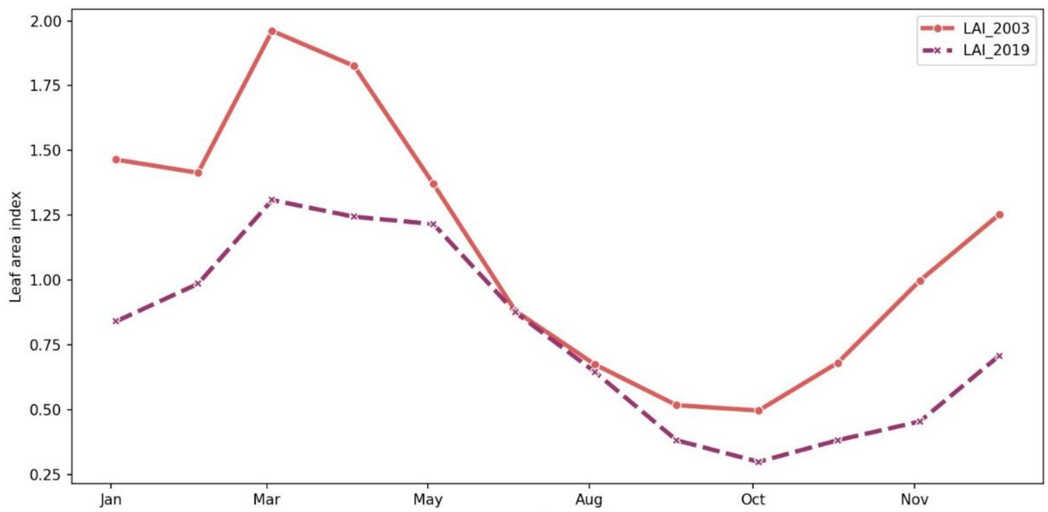

Figure 8: Monthly leaf Area index in South African zone in the year of 2003 and 2019.

The Fraction of Absorbed Photosynthetically Active Radiation (FAPAR) is the fraction of the incoming solar radiation in the Photosynthetically Active Radiation spectral region that is absorbed by a photosynthetic organism, typically describing the light absorption across an integrated plant canopy. This biophysical variable is directly related to the primary productivity of photosynthesis and some models use it to estimate the assimilation of carbon dioxide in vegetation. In the middle of the year from may to June, FAPAR is higher in 2019 as compare to 2003 but from October to December FAPAR is higher in 2003.

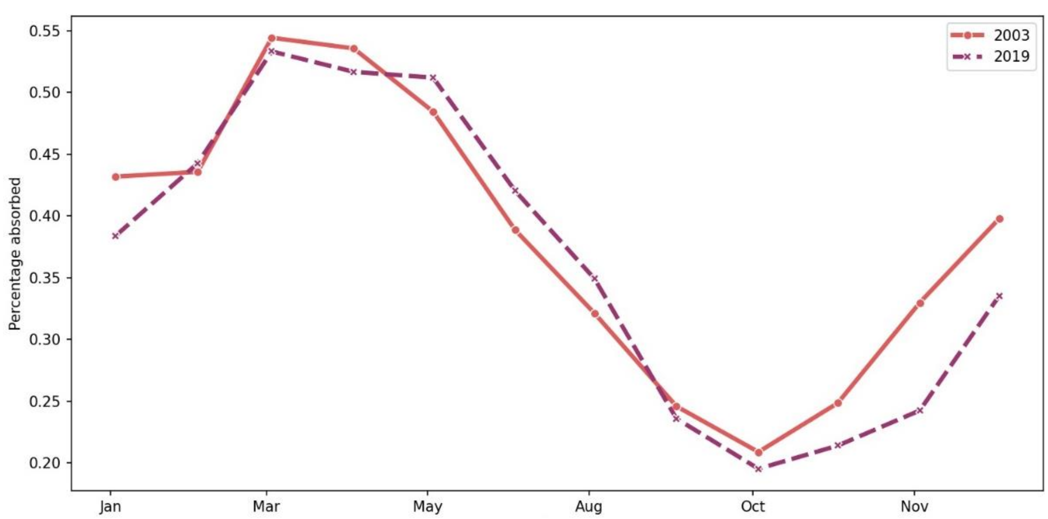

Figure 9: Fraction of Absorbed Photosynthetically Active Radiation in south African zone in 2003 and 2019

Conclusion:

In this report we tried to investigate changes in the surface fluxes in the south African regions from 2003 to 2019. We also tried to analyze to variation of atmospheric variables in these two periods.

References:

1. Foley, J.A.; Defries, R.; Asner, G.P.; Barford, C.; Bonan, G.; Carpenter, S.R.; Chapin, F.S.; Coe, M.T.; Daily, G.C.; Gibbs, H.K.; et al. Global consequences of land use. Science 2005, 309, 570–574.
2. Arora, V.K.; Montenegro, A. Small temperature benefits provided by realistic afforestation efforts,Nat. Geosci. 2011, 4, 514–518.
3. Deng, X.; Huang, J.; Lin, Y.; Shi, Q. Interactions between climate, socioeconomics, and land dynamics in Qinghai province, China: A LUCD model-based numerical experiment. Adv. Meteorol. 2013, 2013, 297926:1–297926:9.
4. Zhang, X.; Wang, W.; Fang, X.; Ye, Y.; Zheng, J. Agriculture development-induced surface albedo changes and climatic implications across northeastern China. Chin. Geogr. Sci. 2012, 22, 264–277.
5. Mahmood, R.; Quintanar, A.I.; Conner, G.; Leeper, R.; Dobler, S.; Pielke, R.A.; Beltran-Przekurat, A.; Hubbard, K.G.; Niyogi, D.; Bonan, G.; et al. Impacts of land use/land cover change on climate and future research priorities. Bull. Am. Meteorol. Soc. 2010, 91, 37–46.
6. Pielke, R.A.; Marland, G.; Betts, R.A.; Chase, T.N.; Eastman, J.L.; Niles, J.O.; Niyogi, D.D.S.; Running, S.W. The influence of land-use change and landscape dynamics on the climate system: Relevance to climate-change policy beyond the radiative effect of greenhouse gases. Philos. Trans. A. Math. Phys. Eng. Sci. 2002, 360, 1705–1719.
7. Fu, C. Potential impacts of human-induced land cover change on East Asia monsoon. Glob. Planet. Chang. 2003, 37, 219–229.
8. Kant, Y.; Badarinath, K.V.S. Regional scale evapotranspiration estimation using satellite derived albedo and surface temperature. J. Indian Soc. Remote Sens. 1998, 26, 129–134.
9. Betts, R.A. Offset of the potential carbon sink from boreal forestation by decreases in surface albedo. Nature 2000, 408, 187–190.
10. Chase, T.N.; Knaff, J.A.; Pielke Sr, R.A.; Kalnay, E. Changes in global monsoon circulations since 1950. Nat. Hazards 2003, 29, 229–254.
11. Douglas, E.M.; Beltrán-Przekurat, A.; Niyogi, D.; Pielke, R.A.; Vörösmarty, C.J. The impact of agricultural intensification and irrigation on land–atmosphere interactions and Indian monsoon precipitation—A mesoscale modeling perspective. Glob. Planet. Chang. 2009, 67, 117–128.
12. Betts, R. Biogeophysical impacts of land use on present-day climate: Near-surface temperature change and radiative forcing. Atmos. Sci. Lett. 2001, 2, 39–51.
13. Deng, X.; Zhao, C.; Yan, H. Systematic modeling of impacts of land use and land cover changes on regional climate: A review. Adv. Meteorol. 2013, 2013, 317678:1–317678:11. Energies 2014, 7 2205
14. Silalertruksa, T.; Gheewala, S.H. Food, fuel, and climate change. J. Ind. Ecol. 2012, 16, 541–551.
15. Watson, R.T. Land Use, Land-Use Change, and Forestry: A Special Report of the Intergovernmental Panel on Climate Change; Cambridge University Press: Cambridge, UK, 2000.
16. Wessels, K.J.; Prince, S.D.; Malherbe, J.; Small, J.; Frost, P.E.; VanZyl, D. Can human-induced land degradation be distinguished from the effects of rainfall variability? A case study in South Africa. J. Arid Environ. 2007, 68, 271–297.
17. Qu, R.; Cui, X.; Yan, H.; Ma, E.; Zhan, J. Impacts of land cover change on the near-surface temperature in the North China Plain. Adv. Meteorol. 2013, 2013, 409302:1–409302:12.
18. Yu, R.; Wang, X.; Yan, Z.; Yan, H.; Jiang, Q. Regional climate effects of conversion from

grassland to forestland in Southeastern China. Adv. Meteorol. 2013, 2013, 630953:1–630953:9.
19. Li, Z.; Deng, X.; Shi, Q.; Ke, X.; Liu, Y. Modeling the impacts of boreal deforestation on the near-surface temperature in European Russia. Adv. Meteorol. 2013, 2013, 486962:1–486962:9.
20. Lin, Y.; Liu, A.; Ma, E.; Li, X.; Shi, Q. Impacts of future urban expansion on regional climate in the Northeast Megalopolis, USA. Adv. Meteorol. 2013, 2013, 362925:1–362925:10.