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Forest Vegetation Dynamics and their Response to Land Surface Temperature in West Arsi Zone Southwest Ethiopia

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Abstract— Extreme weather and climate events have increased as a result of global warming, particularly the intensity and frequency of droughts. Vegetation is the dominant component of terrestrial ecosystems on the earth's surface, playing an important role in the regulation of climate change, carbon cycling, and energy exchange between the atmosphere, the earth's surface, and hydrological processes. Vegetation cover has a significant effect on the distribution of land surface temperature (LST). The overarching objective of the study was to determine the influence of forest vegetation dynamics as well as its response to surface temperature in the western Arsi zone of Southwestern Ethiopia. The study used satellite images from Landsat 5 TM and Landsat 8 OLI for the periods of 1991, 2001, 2011, and 2021. The study used QGIS software and Microsoft Excel software to determine NDVI, LST and for correlation analysis of NDVI and LST. Finally, a regression technique is used to obtain the correlation between LST and NDVI. The highest NDVI values were recorded in 1991 (-0.43 to 0.78), corresponding to a densely vegetated area, and the lowest NDVI values were recorded in 2021 (-0.42 to 0.65), due to forest land change to another land scape. The result shows that the high LST values are in year of 2021 (11.8 ^{o}C to 54.02 ^{o}C) and the lowest LST values are in year of 1991 (0.84 ^{o}C to 36.85 ^{o}C). The result shows that NDVI and LST had linear regression analysis (R^2) for four years in which the analysis indicated that LST and NDVI are negatively correlated to each other which is 0.65, 0.71,0.63 and 0.66 for the years of 1991, 2001, 2011and 2021, respectively.

Keywords— Normalized Difference Vegetation Index (NDVI), land surface temperature (LST), Correlation analysis

I. INTRODUCTION

Extreme weather and climate events have increased as a result of global warming, particularly the intensity and frequency of drought [1,2].Vegetation is the dominant component of terrestrial ecosystems on the earth's surface, playing an important role in regulating climate change, carbon cycling, and energy exchange between the atmosphere, land surface, and hydrological processes [3,4,5].Vegetation is considered an intermediate link in the pedosphere, atmosphere, and hydrosphere of the earth system. The dynamics of climate and forest vegetation are linked: regional and local climate affects temperature processes at the earth's surface at a large range of rates [6], while forest vegetation in turn affects climate feedbacks through photosynthesis and evapotranspiration, albedo changes, and biogenic volatiles (emission of organic compounds) [7]. Drought can prevent normal vegetation growth, and persistent drought can cause vegetation to die due to a lack of water, thereby greatly reducing vegetation productivity and causing regional dieback [8].

Since the outcome of land cover type is sensitive to environmental changes, which are the result of climate fluctuations and human activities in particular, understanding the factors of vegetation dynamics has been identified as a key issue in global climate variability [9], especially in terrestrial ecosystems [10]. Changes in terrestrial vegetation can alter local, regional, and global climates on daily, seasonal, and long-term scales [11]. Earth remote sensing provides an effective tool for monitoring the land surface temperature of a large and complex ecosystem using the Normalized Difference Vegetation Index [12, 13].

Remote sensing is used to measure radiative surface temperature and collect measurements of reflected energy in the red and near-infrared parts of the electromagnetic spectrum, which can be calculated by the range and changing conditions of vegetation indices [14]. Higher normalized difference vegetation index (NDVI) maps show the presence of vegetation on a pixel-by-pixel basis. Land surface temperature (LST) is one of the key factors in the physics of land surface processes, combining surface-atmosphere interactions and energy fluxes between the atmosphere and land. The lowest LSTs are usually found in areas with high NDVI [15]. Monitoring the dynamics of large-scale vegetation (degradation and restoration), identification, analysis of their relationship, and impact on the ecosystem has thus become a fundamental problem in global climate variability research and important for understanding the mechanisms of vegetation ecosystem behaviour [16, 17].

The primary objective of the study is to determine the response of forest dynamics to NDVI, land surface temperature, and their relationship using multi temporal images from Landsat 5 TM and Landsat 8 OLI satellites.

II. RELATED WORKS

Vegetation is one of the primary factors that influenced the change of LST at regional and global scales [17, 18, 19, 20, 21, 22]. In recent decades, changes in vegetation cover caused by deforestation and afforestation had a significant impact on LST [19]. Vegetation dynamics are sensitive to climate change due to its effects on plant respiration, photosynthesis, and evapotranspiration [23, 24, 25]. Monitoring vegetation dynamics and analysing their relationship with climate variability is becoming an important aspect of global climate change research [17]. The decrease in urban vegetation cover caused by human activities could accelerate the rise of LST, which was also an important reason for the emergence of the urban heat island [26, 27]. [28] found that the vegetation fraction has a slightly stronger negative correlation with LST. [29] reported that the mean LST and NDVI values associated with different land use types differ significantly. Vegetation and water bodies have lower temperatures compared to built-up areas [30]. The correlation between LST and NDVI is positive for the winter and negative during warm periods [31].

III. METHODOLOGY

Description of the study areas

The study was conducted in west Arsi zone, Oromia regional state, located about 250 km from Addis Ababa in the south of Ethiopia. Astronomically, the zone lies between 7°11'42.18"N and 38°35'1.10"E. West Arsi zone is bounded by Bale zone in the west, Arsi zone in the east, southern national and people's regional states in the south, and east Shewa zone in the north. The city of Shashamane is the capital of the western Arsi zone. The west Arsi zone includes distinct agro-ecologies, namely highland, midland, and lowland. Highland agroecology (47.92%) was more covered in the zone, followed by medium (42.50%) and lowland (9.82%) agro-ecology. The zone lies at an altitude of 1500–3800 meters above sea level [32].

The total population in the zone was 2,290,280, of which 45.50% were males and 50.50% annual rainfall and has a bimodal rainfall pattern. The annual temperature of the study areas is 12oC-27oC.The zone has a total area of 1,286,277.50 hectares of land. Arable land accounts for 0.36% of total land, cultivated land for 29.27%, forest land for 19.50%, pasture for 17.05%, construction land for 4.58%, and 29.26% used for other purposes [32].

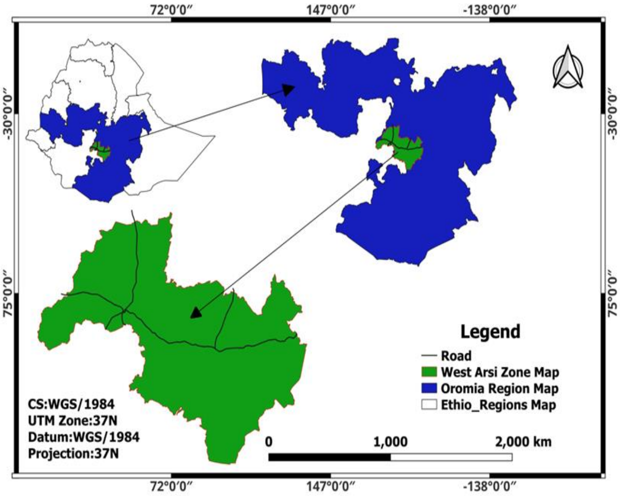

Figure.1 Study area location map.

Landsat Satellite Imagery

For the study, Landsat imagery for the years 1991, 2001, 2011, and 2021 was acquired on February 10th, March 3rd, January 10th, and March 26th, respectively, and was used as the primary data source for deriving the land surface temperature and vegetation indices that would be used to determine the land cover changes. To avoid cloud cover and other land cover reflectance, data sets were collected during the hot season.

Image pre-processing and enhancement

The Landsat images were combined into false color composites by using QGIS and RS&GIS Version 17.0 software. The band combinations were 4-3-2 for Landsat 5 TM, and 5-4-3 for Landsat 8 OLI and enhancement was carried out to improve the appearance of the imagery. Finally, the false color composite image was clipped to the study area for NDVI and LST determination (Figure 2).

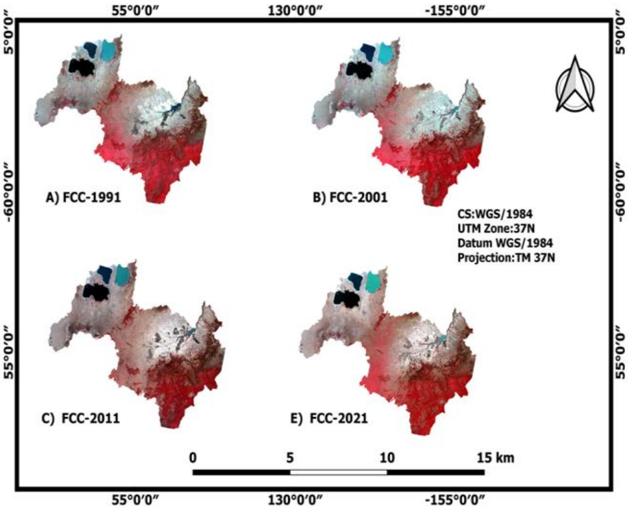

Figure.2.False color composite images for the year 1991(a),2001(b), 2011(c), 2021(d).

Normalized Difference Vegetation Index (NDVI)

The Normalized Difference Vegetation Index (NDVI) is a standard algorithm designed to estimate the amount of above-ground green vegetation cover from measurements of red and near-infrared reflectance, which help in delineating vegetation and non-vegetation areas. Healthy vegetation will absorb most of the visible light that falls on it and reflect a large portion of the NIR light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared (NIR) light [33]. The Normalized Difference Vegetation Index (NDVI) measures the amount and vigour of vegetation at the surface [34]. NDVI is very sensitive to changes, and variations in NDVI might cause changes in land surface temperature. The given equation (1) was used to calculate NDVI using NIR Band 4 and Red Band 3 data for Landsat 5 TM and NIR Band 5 and Red Band 4 data for Landsat 8 OLI [35, 36, 37, 38]. The NDVI rate was calculated by using the raster calculator in QGIS.

NDVI= (NIR-RED)/ (NIR+RED)…………equation (1)

Where,

NIR is the near infrared band value

RED is the red band value.

The values of NDVI ranged from -1 to 1, with -1 and 1 referring to non-existence and existence, respectively. According to [39], NDVI values of -1 to 0 represent water bodies; -0.1 to 0.1 represent barren rocks, sand, or snow; -0.2 to 0.5 represent shrubs and grasslands or senescing crops; and 0.6 to 1.0 represent dense vegetation or tropical rainforest. Healthy vegetation represents vigor and greenness, which can be directly correlated with NDVI as well as crop conditioning. High values of NDVI depict the crop, orchard, and forest as a result of high levels of green biomass, while low values of NDVI represent the bare soil and urban area.

According to [40], the NDVI below 0.2 represents non-vegetated areas, which include water bodies, dry river beds, shadows, barren lands, built-up areas (both residential and industrial), and areas having no vegetation. NDVI values between 0.2 and 0.5 represent sparse vegetation and are covered with shrubs, herbs, small trees, etc.; NDVI values above 0.5 represent moderate to dense vegetation and are covered with natural forests and dense vegetation.

Land surface Temperature (LST)

Land surface temperature acquired from satellite data represents the surface temperatures of each object within a pixel, which may be composed of several land cover types. With the help of the below equation (2), the Landsat 5TM of band 6 and the Landsat 8 OLI of band 10 were used to convert the raw value of the land surface temperature into degrees Celsius using QGIS.

From the LST images, it was determined that the highest land surface temperatures exist at agricultural land, bare land, and built-up areas with no vegetation cover, and the lowest land surface temperatures exist at vegetation areas and water bodies. Evaluation of LST from land-sat 5TM and land sat 8 OLI data in QGIS raster calculation processing involves the following steps:

1) Conversion of the Digital number (*DN*) to Spectral Radiance ($L\lambda$)

Lλ=LMIN+ (LMAX–LMIN)*DN/255……....equation (2)

Where,
Lλ= Spectral radiance,
LMIN=Spectral radiance of DN value 1
LMAX= Spectral radiance of DN value 255
DN=Digital Number

2) Conversion of spectral Radiance to temperature in Kelvin.

Tb=K2/ ln ((K1/L) +1))………………………equation (3)

Where,
K1= Calibration constant 1
K2= Calibration constant 2
Tb=Land surface temperature

Table 1: Calibration constants for thermal band

S.no	Sensor	K1	K2
1	Land sat 5/TM	607.76	1260.56
2	Land sat 8/OLI	774.8853	1321.0789

3) Conversion of Kelvin to Celsius.

Tb= Tb-273…………………………...equation (4)

Where,

Tb is effective at satellite temperature in absolute temperature,

Correlation analysis of NDVI and LST

For further analysis, the relationship between NDVI and LST was investigated over the different LULCs through correlation analysis and regression analysis. The peaks of the LST are usually the areas where there are built-up areas, bare land, and farmland, while the low peaks of LST are where the water bodies and vegetation are found. The highest peaks of the NDVI appear in vegetated areas of forest land and shrub land. For this study the samples pixels that corresponded to the water body were excluded from the study to improve the accuracy of NDVI and LST regression and to assess the effect of foreground dynamic on LST.

IV. RESULTS AND DISCUSSION

Extensive studies were carried out to find the vegetation dynamic, relationship between vegetation coverage and land surface temperature by using vegetation indices of NDVI [41, 42, 43, 44, 45].

Normalized Difference Vegetation Index (NDVI)

The NDVI is the most common measurement used for measuring vegetation cover. It ranges from values of -1 to +1. Figure 3 shows the distribution of NDVI for the years 1991, 2001, 2011, and 2021 for the west Arsi zone in south-west Ethiopia. The range of the NDVI was - 0.43 to 0.78 in 1991, -0.41 to 0.75 in 2001, -0.40 to 0.68 in 2011, and -0.42 to 0.65 in 2021 (Figure.3). The lowest negative NDVI value and red color indicate a water body (lake) and the highest and deep green color of NDVI value indicated a richer and healthier vegetation area. The yellow color value indicated that agricultural land, bare land, and built-up areas. According to the results of the study in the west Arsi zone, very high values of NDVI were recorded in 1991 (-0.43 to 0.78), which corresponded to dense areas of vegetation, and the lowest values of NDVI were recorded in 2021 (-0.42 to 0.65), due to the change of forest cover to other land cover (Table 2).

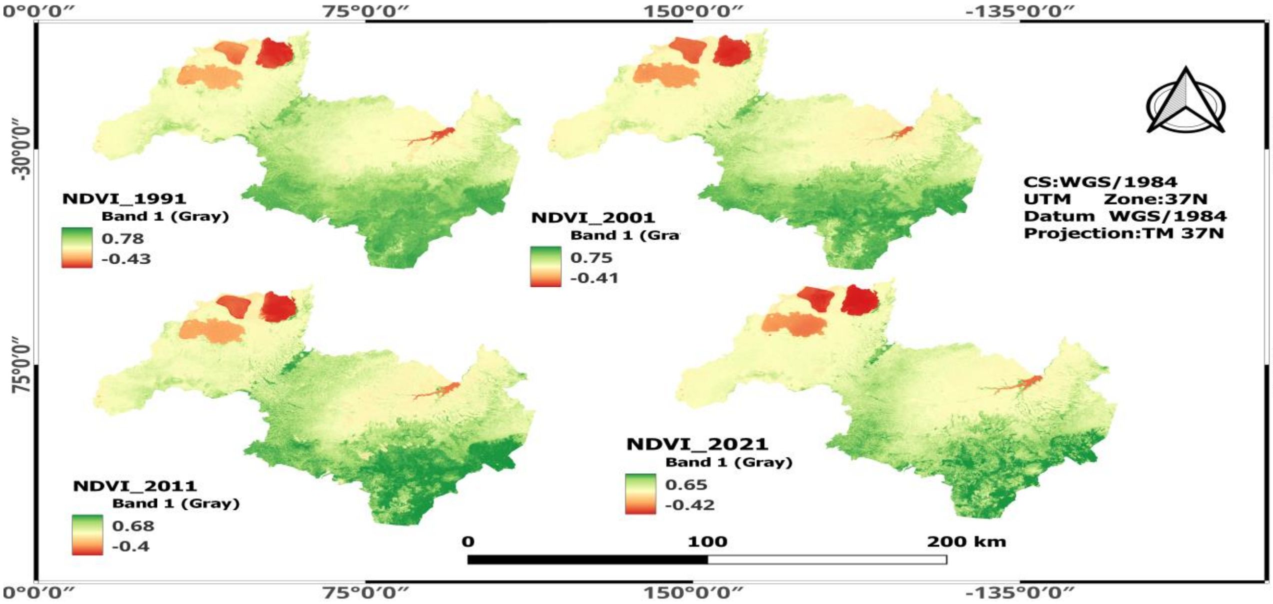

Figure 3: Illustration maps of NDVI from for the year 1991(a), 2001(b), 2011(c), 2021(d).

Land surface temperature (LST

The maximum and minimum LST are graphically represented in (Figure 4), where it is seen that the land use changes have a high impact on the land surface temperature in the study area. However, the vegetation body and water body had lower temperatures as compared to agricultural land, bare land, grass land, and built-up areas. The correlation between NDVI and LST is inverse which means that where NDVI is lower, land surface temperature is higher, and where NDVI is higher, land surface temperature is lower. Table 2 shows the maximum and minimum LST temperatures. From the study in the west Arsi zone, very high values of LST are in the year 2021 (11.8 ^{o}C to 54.02 ^{o}C$^{),}$ and the lowest values of LST are indicated in the year 1991 (0.84–36.85^{o}C).

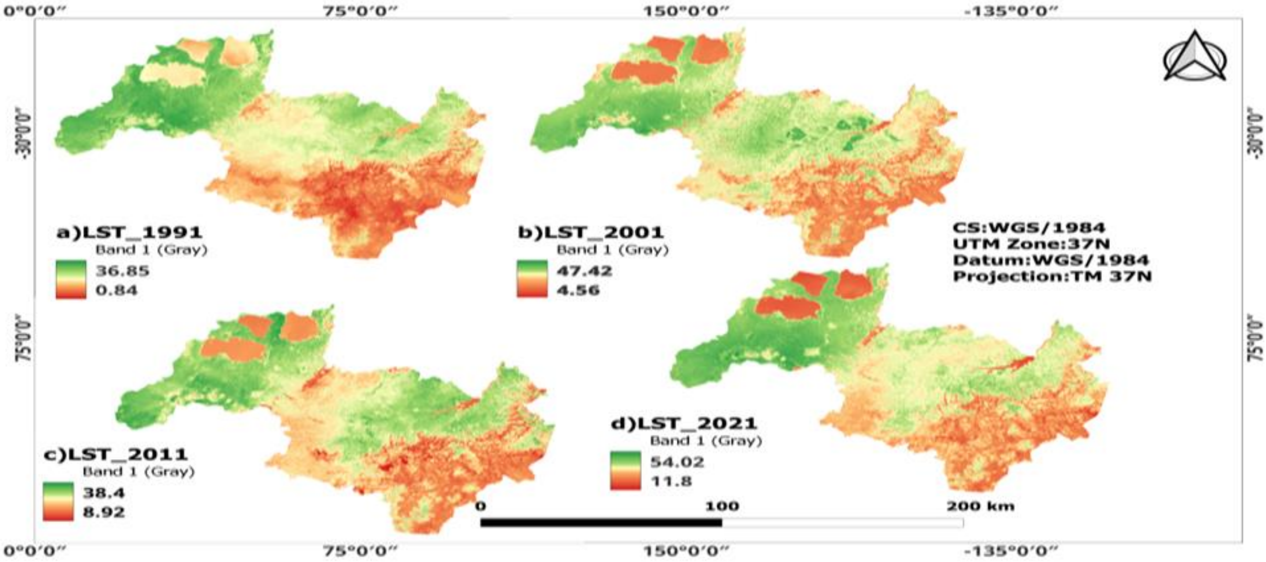

Figure: 4 Illustration maps of LST from for the year 1991(a), 2001(b), 2011(c), 2021(d).

Table.2. NDVI and LST statics for year 1991-2021

	Year							
	1991		2001		2011		2021	
NDVI	Min	Max	Min	Max	Min	Max	Min	Max
	-0.43	0.78	-0.41	0.75	-0.40	0.68	-0.42	0.65
LST (°C)	0.8	36.8	4.56	47.4	8.92	38.4	11.8	54.0

Correlation between NDVI and LST For the period of (1991, 2001, 2011, 2021)

The relationship between LST and NDVI has also been observed by various researchers in the past [46, 47, 48], observed a negative LST-NDVI relationship in their study. The spatial distribution characteristics of the LST and NDVI (figures 5-8) show that the LST and NDVI have opposing spatial distribution patterns. The LST showed the opposite trend from the corresponding NDVI in two different directions. The regression analyses and scatter plot showed an obvious significant inverse correlation between LST and NDVI in each of the four years (Figure 9-12). It means that areas with more vegetation have lower temperatures, while areas with less vegetation have higher LSTs because the available energy is directed more toward evapotranspiration. The result shows that NDVI and LST had linear regression analysis (R^2) for four years in which the analysis indicated that LST and NDVI are negatively correlated to each other which is 0.65, 0.71,0.63 and 0.66 for the years of 1991, 2001, 2011and 2021, respectively. (Figure 9-12).

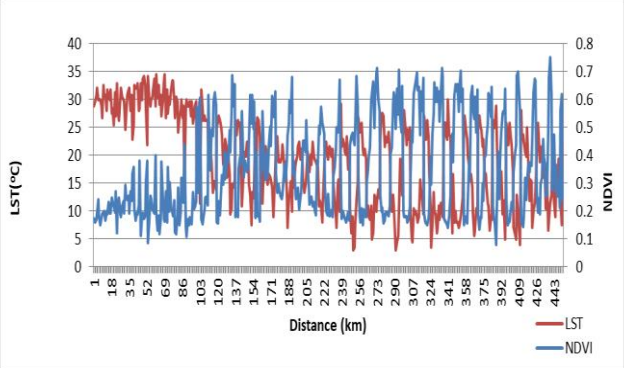

Figure 5.Correlation curves of NDVI and LST images of year 1991

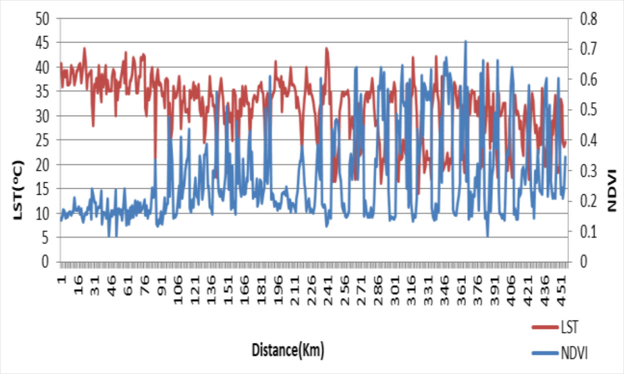

Figure 6.Correlation curves of NDVI and LST images of year 2001

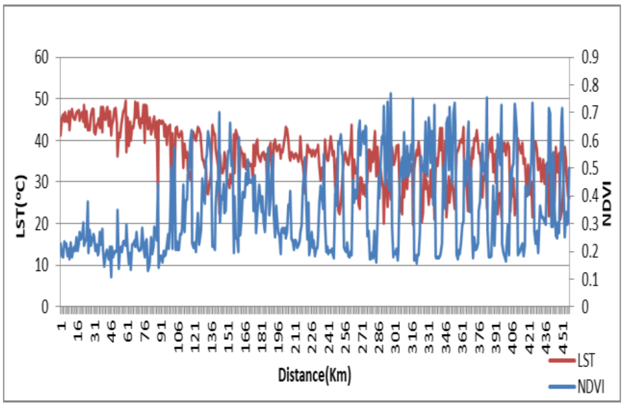

Figure 7.Correlation curves of NDVI and LST images of year 2011

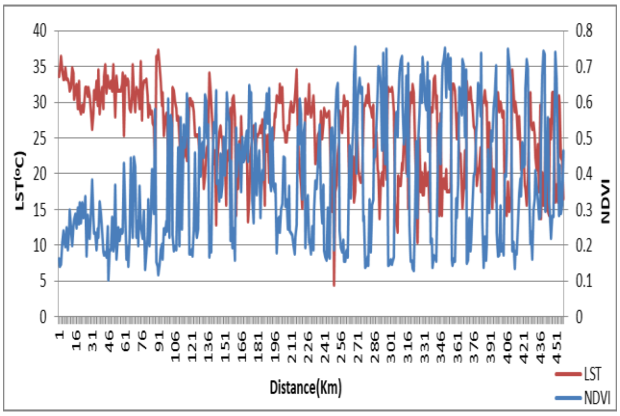

Figure 8.Correlation curves of NDVI and LST images of year 2021

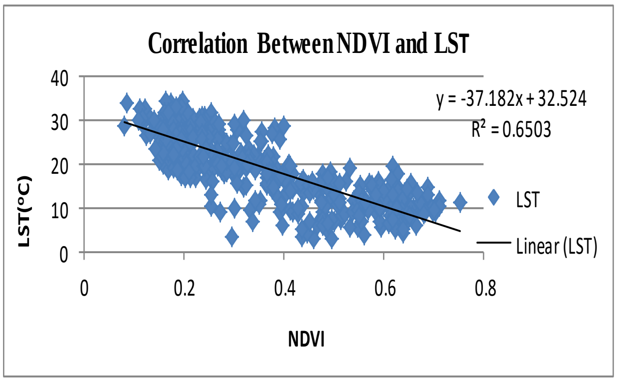

Figure.9 Scatter plot of linear regression analysis between LST and NDVI year 1991

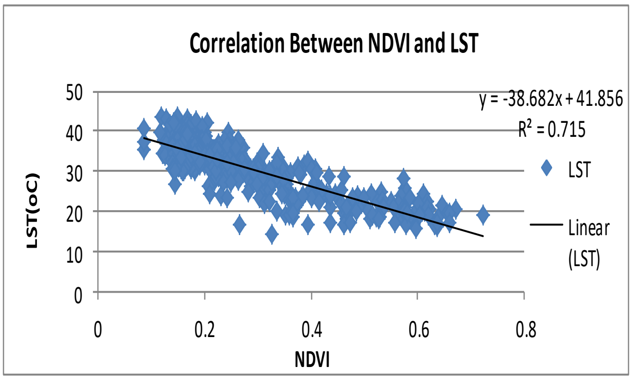

Figure.10 Scatter plot of linear regression analysis between LST and NDVI year 2001

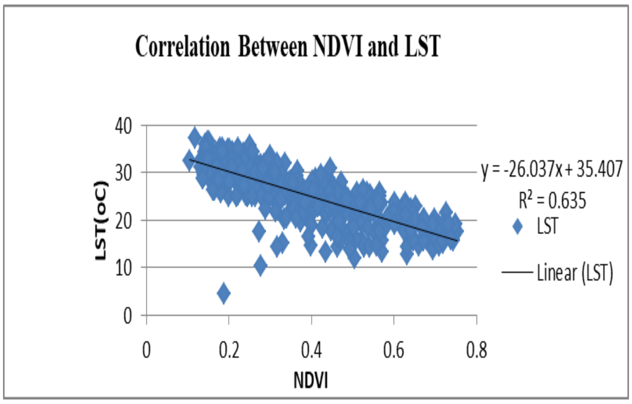

Figure 11.Scatter plot of linear regression analysis between LST and NDVI year 2011

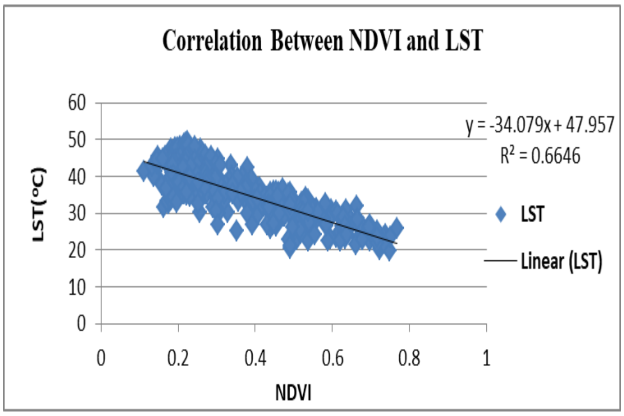

Figure.12.Scatter plot of linear regression analysis between LST and NDVI year 2021.

V. CONCLUSION AND FUTURE SCOPE

The dynamics of forest vegetation on NDVI and LST and the interrelationship between NDVI and LST in the western Arsi zone were studied using different Landsat satellite sensors for a specific time interval (1991–2021). In this study, the correlation between NDVI and LST was found which depend on land cover type. Comparing LST with NDVI shows that LST peaks are usually in areas without vegetation cover, such as built-up areas, bare land, and agricultural land, while NDVI peaks appear on forest and shrub land, and vice versa. The highest NDVI values were recorded in 1991 (-0.43 to 0.78), corresponding to a densely vegetated area, and the lowest NDVI values were recorded in 2021 (-0.42 to 0.65), due to forest change to another landscape. The result shows that the high LST values are in 2021 (11.8 ^{o}C to 54.02 ^{o}C) and the lowest LST values are in 1991 (0.84 ^{o}C to 36.85 ^{o}C).

The correlation of NDVI and LST was significantly negative for the study area over the entire period. This confirms the effect of vegetation and natural cover on reducing the intensity and spread of heat on the earth's surface. The result shows that NDVI and LST had linear regression analysis (R^2) for four years in which the analysis indicated that LST and NDVI are negatively correlated to each other which is 0.65, 0.71,0.63 and 0.66 for the years of 1991, 2001, 2011and 2021, respectively.

Thus, it can be concluded that the surface temperature is largely controlled by the type of land use, such as vegetation, built-up land, shrub land, agricultural land, and water bodies. The results presented in this study will significantly help in future zone planning and also provide a database for upcoming climate regulation goals.

The future scope of the study area is that instead of degradation and deforesting forests for fuel wood and expanding to agricultural land, the government and charitable organizations should raise community awareness on sustainable forest management and utilization, establishing explicit policy on forest management, organize youths on forest management**,** promote entrepreneurship which reduces unemployment, increases people's efficiency, resources and ultimately, increases community people's income.

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