Land Surface Temperature Trends and Applications - Case Study at the Mining Areas of Tarkwa, Ghana*

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Abstract

Land surface temperature (LST) is an important factor to consider in the location of appropriate sites for landfilling and incineration due to their association with the emission of harmful gases. The objectives of this study were to map, assess and discuss the trends of LST changes, the contributing factors and their applications in landfilling and temperature inversions to reduce their negative effects. The techniques applied include remote sensing, GPS, GIS and basic statistics for the data collection, processing and analysis. Five LST maps and associated statistical tables and graphs were derived as the main results, using Landsat8 aerial images as the main input data and ArcGIS and Microsoft Excel as processing software. From the results, LST values were generally on the increase from 2015 to 2020. The LST variations were not uniform for some areas, especially the southern parts, and this was attributed to intermittent farming and illegal mining activities. In the central, western, eastern and northern parts, where major ongoing settlements and mining activities exist, uniform increases in LST were observed from moderate to high levels from 2015 to 2020. The results thus revealed some correlation between the LTS changes and the land use patterns of the study area. Two recommended applications of the observations are that; (1) in the areas with uniform LST increases, uncontrolled landfilling, mining and similar land uses can compound the negative effects of high LST through emission of unwanted gasses and particulate matter and temperature inversions, and (2) the LST maps from this study or similar ones may be used as references to check the suitability of proposed land uses or the locations of development projects such as landfilling in terms of their pollution risk or potentials in relation to high LSTs. Appropriate decisions can thus be arrived at such as disapproving the proposal or requesting more stringent mitigation measures.

Keywords: Land Surface Temperature, Remote Sensing, Landfill, Pollution, Land use, Mining, Inversion

1 Introduction

Ghana and similar countries in the developing world are grappling with uncontrolled urbanization, surface mining, deforestation, waste disposal and environmental problems such as contamination of soil, air, surface and underground water, with significant health threats to the public (Kwesi *et al*, 2018; Sackey, 2016; Asante, 2011). Negative waste disposal impacts can be controlled if proper attention is paid to the selection of disposal sites. Among the factors to consider in landfill site selection to improve its environmental friendliness are variations in land surface temperature (LST) and temperature inversion and their impacts on human health, particularly in dry and hot climate areas such as Ghana (Vescovi, *et al.,* 2005; Trinh *et al.,* 2019). LST is an important factor that influences the physical, chemical and biological processes of the earth's environment. It relates to the effective radiating temperatures of the earth's surface that control surface heat and water exchange with the atmosphere (Qin, 2010). It is generally monitored and estimated by remote sensing methods and involves the temperatures of vegetation canopies the soil and bare land surfaces. It is thus affected by the characteristics of the land surface such as land use and land cover types and variations in surface imperviousness and topographic relief. Rapid urbanization and deforestation activities such as surface mining and emission sources like open landfills have been observed to contribute significantly to changes in land surface temperatures (Khandelwal, 2017). Increasing LSTs can lead to increases in the frequency, intensity and negative impacts of temperature inversions, atmospheric emissions, smog formation, freezing rains, and respiratory problems (Blaettler, 2019; Osmond, 2018). The mining areas of Tarkwa have been experiencing wide spread surface mining activities, deforestation, urbanisation and related waste disposal and environmental pollution problems for over three decades now (Kwesi *et al*, 2015). The trends in LST variations and their associated impacts need to be assessed and applied in managing emerging environmental problems. Thus, the objectives of this study are to map, assess and discuss the trends of land surface temperature changes in the mining areas of Tarkwa (TNMA) and potential areas where the results may be applied in to reduce emission and the negative effects of temperature inversions in the study area and similar locations in the world.

1.1 Geographic and Economic Setting of TNMA

The study area is Tarkwa and its surrounding mining areas. Tarkwa is the administrative capital of the Tarkwa-Nsuaem Municipal Area (TNMA) which is

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located in the Western Region of Ghana between latitudes 4° 50′ N and 5° 25′ N and longitudes 1° 45′ W and 2° 12′ W (Fig. 1). The topography of the study area is generally undulating with some scarps ranging from 150 to 300 meters above sea level with small scale mining operations frequently taking place along its ridges and valleys (Kwesi *et al.*, 2015). Geologically, the area forms part of the Birimian and Tarkwain formations and it is characterized by a sequence of coarse, clastic, fluviatile meta-sedimentary rocks consisting of the Kawere conglomerates, Banket Series (Phyllite, Quartzite and Conglomerate hosting gold mineralization). It is marked by faults and joints (with WNW to ESE direction trends) and aquifers possessing dual and variable porosity with limited storage capabilities (Kuma and Ewusi, 2009; Kortatsi, 2004, Kesse, 1985). Climatically, the area lies within the South-Western Equatorial Zone and is marked by double maximum rainfall (March to July, and October to November). It has a mean annual rainfall of about 1878 mm, a temperature range of 26℃ (in August) to 30℃ (in March), sunshine duration of about 7 hours per day and relative humidity of 70% – 80% (Kwesi *et al.*, 2015; Mantey, 2014). The area also experiences the effect of the dry north-east trade winds during the dry and hot seasons with high potentials or frequencies for the occurrence of temperature inversions, atmospheric pollution, fog formation and related health and environmental hazards like respiratory diseases and bushfires (Kwesi *et al.*, 2018; Blaettler, 2019; Trinh *et al.*., 2019; Osmond, 2018; Tang *et al.*., 2016; Sackey, 2016; Wilson *et al.*., 2015; Asante, 2011).

The area is a famous mining centre that attracts many people from other parts of the country, Africa and the world (Kwesi, *et al.*, 2015). Many of the big mining operations in the country are located in and around Tarkwa. The economy of the area thus revolves around mining and its allied services. It is also an important commercial and transit centre linking the western and coastal towns to other parts of Ghana, and travellers from Cote d'Ivoire to Burkina Faso. These factors draw many people to the city daily to look for jobs and do business. Some of these people settle there, contributing to rapid urbanization, high population growth rate (about 3.0%) and huge volumes of waste generation that are beyond the resources and capabilities of the Municipal Authorities (Kwesi, *et al.*, 2018). Other mining impacts and related socio-economic activities include environmental (air, land, water, etc.) pollution, waste disposal problems, land use conflicts and litigation problems, and high cost of living (Seidu, 2018; Kyerematen *et al.*, 2018; Kwesi, *et al.,* 2015; Kwesi *et al*., 2014; Kuma and Ewusi, 2009).

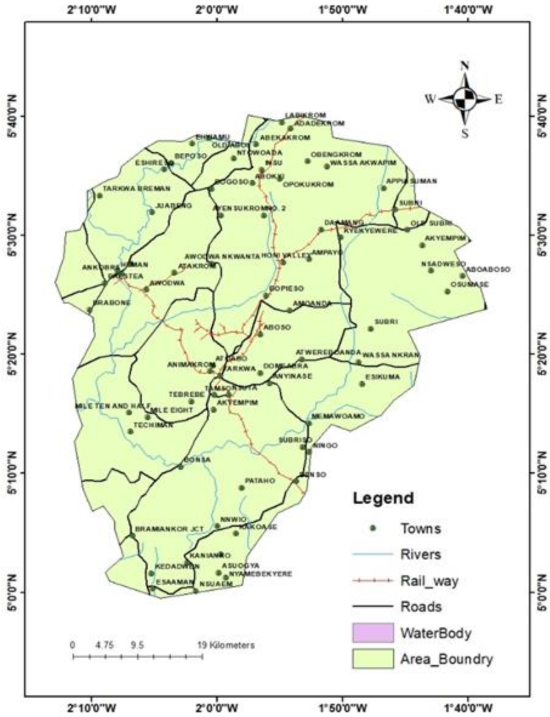

Fig. 1 Map of Study Area

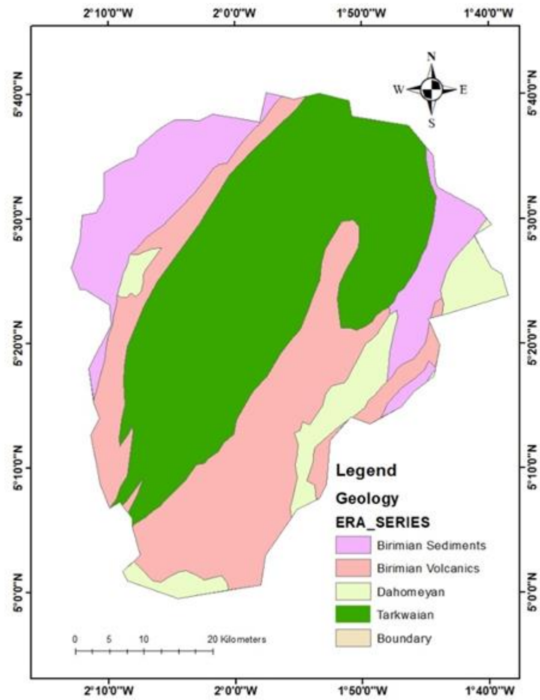

Fig. 2 Geology of Study Area

2 Resources and Methods Used

2.1 Resources

Most of the data used were obtained from secondary sources. The LST maps were derived from Landsat 8 images (Landsat8-OLI/TIRS C2 L2) downloaded from the USGS Earth Explorer site (*earthexplorer.usgs.gov*). Bands 4, 5 and 10 were the major sources for LST derivation. The Digital

Elevation Model (DEM) for the slope analysis was obtained from ASTER Global DEM (GDEM) which is a product of METI and NASA, and Landsat 8 Level 1 image was utilised for the Land Use/Land Cover (LULC) model. ESRI ArcMap 10.3 and 10.7.1 software were employed as main processing software. Preliminary processing of the acquired data include projecting it (in GeoTIFF format) onto UTM zone 30 N and extracting by mask to the study area, conversion from digital numbers (DN) to Top of Atmosphere (TOA) spectral reflectance, and compositing and classifying the TOA reflectance data (bands 2, 3, 4, 5, 6 and 7) using the unsupervised classification technique. The main methods adopted for this research work are summarised in the flow chart in Fig. 3 and discussed in details in the next sections. LST is influenced by other factors such as topographic relief, vegetation, water, and winds (Table 1) for which available related data were also applied. (Khandelwal *et al*., 2017). Detail methods for the relief and land use/cover maps (Fig. 10 and Fig. 11) are presented in a previous paper (Kwesi *et al*., 2023) and thus not discussed in this paper.

Table 1 Factors that Influence Land Surface Temperature and Inversion

Factors	Remarks
Topography/ Relief (elevation, slope and aspect)	Elevation decreases and temperature inversion also increases
Land cover/use (vegetation, bare lands, settlements and mining)	Green vegetation undergoes transpiration which forms surface inversion
Water bodies	Water surface evaporates when the temperature becomes high and leads to the inversion
Wind currents (direction and speed)	The eddies cause air from greater heights where wind speed and temperature are great to mix cool air near the surface
Temperature	Generally the atmosphere becomes hot during the day and cool at night which results in temperature inversion in hot seasons
Waste/Emission Sources	Waste dumps and materials can increase the potential for temperature inversion.

2.2 Data Processing and Analysis Methods

Many approaches have been developed for deriving and analysing LST from remote sensing images but the one adopted for this paper is based on the generalised one presented in Fig. 3 (Mustafa *et al*., 2020; Shaheen *et al.*, 2020; Khandelwal *et al.*, 2017; Tang *et al*., 2016; Herbei, 2013; Qin and Karneli, 2010). The processing involves six vital techniques with distinct mathematical functions that are evaluated to derive the land surface temperature parameters and maps (Fig. 3). These mathematical functions are:

$$L\lambda = ML * Qcal + AL \quad (1)$$

$$BT = \frac{K2}{In\,[\left(\frac{K1}{L\lambda}\right)+1]} \quad (2)$$

$$\mathrm{NDVI} = \left(\frac{\mathrm{Band5}-\mathrm{Band4}}{\mathrm{Band5}+\mathrm{Band4}}\right) \quad (3)$$

$$\mathrm{PV} = \left((\mathrm{NDVI}-\mathrm{NDVI_{Min}}) + (\mathrm{NDVI_{Max}}-\mathrm{NDVI_{Min}})\right)^2 \quad (4)$$

$$\boldsymbol{e} = (0.004\mathrm{Pv} + 0.986) \quad (5)$$

$$\mathrm{LST} \quad = \frac{\mathrm{BT}}{1} + \mathrm{W} * \left(\frac{\mathrm{BT}}{\mathrm{P}}\right) * \mathrm{In(e)} \quad (6)$$

where,

$L\lambda$ is the spectral radiance; ML is the band-specific multiplicative rescaling factor; Qcal is the Band10 and Band11 digital numbers; AL is the band-specific additive rescaling factor; $K1$ and $K2$ are thermal bands conversion constants from the metadata; NDVI is the normalized differential vegetation index; PV is the proportion of vegetation; $\mathrm{NDVI_{Min}}$ is the maximum value of normalized differential vegetation index; $\mathrm{NDVI_{Max}}$ is the maximum value of normalized differential vegetation index; **e** is the land surface emissivity; LST is the land surface temperature; BT is the brightness temperature (K); W is the wavelength of emitted radiance; **p** = (h*c)/(1.438*10^{-34} Js); **h** is Planck's constant (6.626 * 10-34 Js); **c** is the velocity of light (2.998 * 108 m/s); and **s** is the Boltzmann constant (1.38 * 10^{-23} J/K).

The data was first sorted into two subgroups, thermal infrared sensor (TIRS) (Band 10 and 11) and operational land imager (OLI) (Band 1-9) since they needed separate analytical processing routes to produce the required end results (LST). After necessary radiometric corrections, the first processing step for the TIRS bands was their conversion (from digital numbers) to top of atmosphere (TOA) spectral radiance, applying Equation 1, where ML represents the band-specific multiplicative rescaling factor; Qcal is the Band10 and Band11 digital numbers; AL is the band-specific additive rescaling factor; and $L\lambda$ represents the spectral radiance.

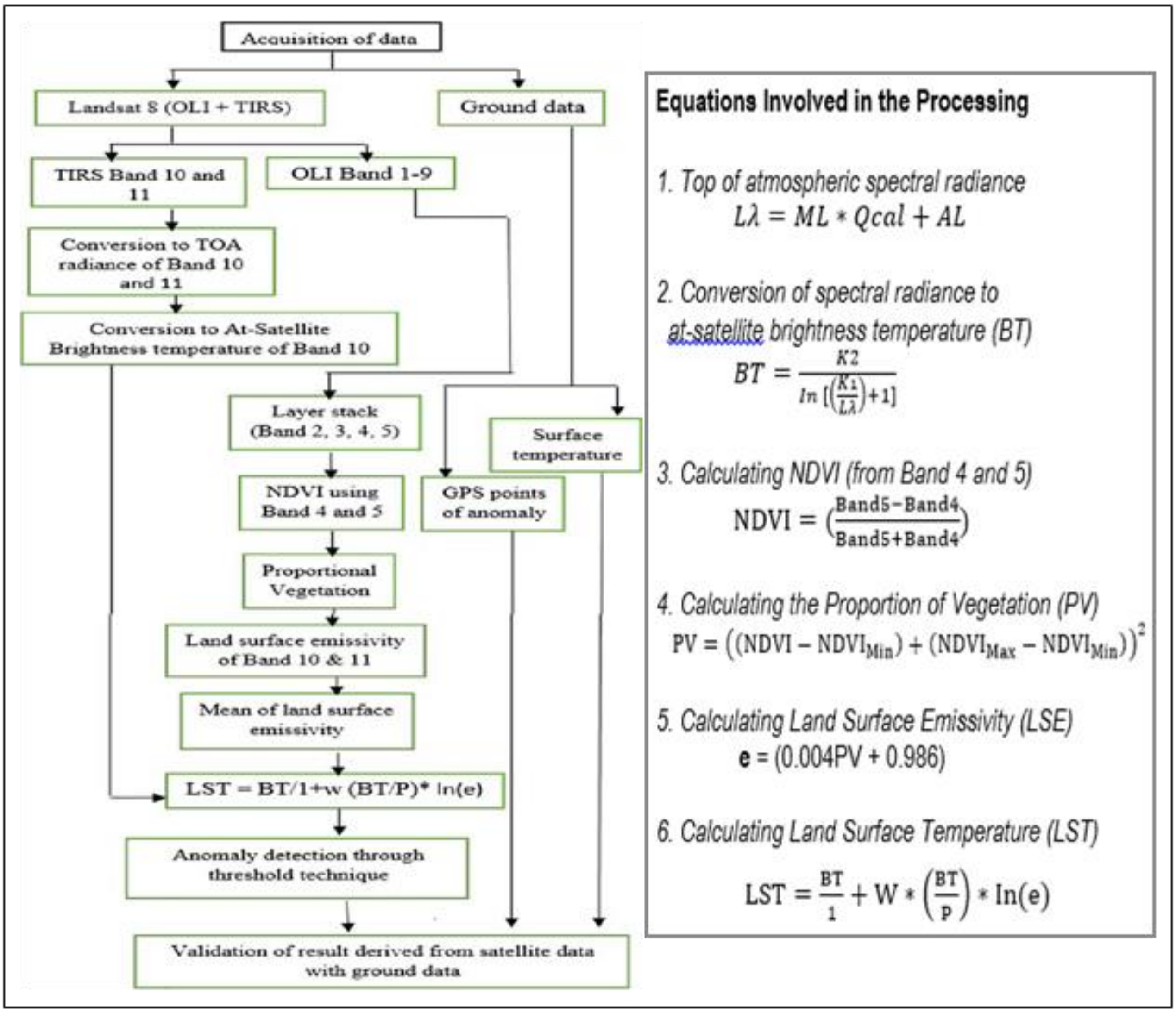

Fig. 3 Land Surface Temperature Retrieval Processing Steps (modified after Shaheen *et al.*, 2020**)**

Table 2 Values for Constants K1 and K2

YEAR	**2020**	**2019**	**2018**	**2017**	**2015**
K1 (BAND 10)	774.89	774.89	774.89	774.89	774.89
K2 (BAND 10)	1321.08	1321.08	1321.08	1321.08	1321.08

The second step was the conversion of the TOA spectral radiance to brightness temperature (BT), applying Equation 2, where, $K1$ and $K2$ are the thermal bands conversion constants from the metadata file (Table 2). The third step of this route was the derivation of LST, applying Equation 6. Using route two, involving the OLI (Bands), the first processing step, after necessary radiometric corrections and layer stacking, was the derivation of NDVI values, mainly from Landsat8 Bands 4 and 5, applying equation 3.

Table 3 Land Surface Temperature Values

YEAR	**2015**	**2017**	**2018**	**2019**	**2020**
Maximum Temperatures (℃)	27.21	31.56	32.77	32.97	33.53
Minimum Temperatures (℃)	7.057	20.32	8.824	11.52	27.57
Mean Temperatures (℃)	17.13	25.94	20.80	22.25	30.55

The second step was the estimation of the proportion of vegetation (PV), using Equation 4. The third step on this route was the derivation of land surface emissivity (LSE), ***e***, applying Equation 5. The value of LSE is an important parameter for measuring LST, and the efficiency of transmitting thermal energy across the earth surface into the atmosphere (Tang *et al.*, 2016). The fourth and final step of this route was the derivation of LST, using Equation 6 (Farzana-Shaheen, *et al.*, 2020; Mustafa, *et al.*, 2020; Herbei, 2013; Kyriacou, 2010; Qin Z and Karneli, 2010).

The final processing step involves the enhancement and validation of the final results through anomaly detection and ground-truth assessment techniques. This was done using control data from primary or reliable secondary sources. The land surface temperature maps were generated from the 2015, 2017, 2018, 2019 and 2020 Landsat8 (OLI + TIRS) images, mainly from band 4, band 5 and band 10.

Table 4 Classification Guide for LST Values

YEAR	2015	2017	2018	2019	2020
High Zone (°C)	> 26	> 27	> 27	> 27	> 28
Moderate Zone (°C)	20 - 26	22 - 27	20 - 27	20 - 27	26 – 28
Low Zone (°C)	< 20	< 22	< 20	< 20	< 26

The results are presented in Fig 4 - Fig 8. Each LST map covers one year with three classes, namely high, moderate and low temperature zones, based on a classification system (Table 4). Using Microsoft Excel, statistical tables, bar graphs and trend lines were prepared to supplement the LST maps. These afforded easy comparisons and trend analysis of the results to make meaningful deductions, conclusions and applications. Table 3 and Fig. 12 are samples of the results of the statistical analysis.

3 Results and Discussion

3.1 Results Presentation

The results of the study are presented in the forms of maps, tables and graphs and are organized (and discussed) under three sub-themes namely basic reference maps, land surface temperature (LST) maps and statistical tables and graphs.

3.1.1 Basic Reference Maps

Fig. 1 and Fig. 2, Table 1, Fig. 10 and Fig.11 are samples of the results of the compilation and/or derivation of reference maps and other data that serve as baseline information from literature and the study area against which the observed study results and trend of changes may be compared and discussed. Temperature, land cover and land use, elevation and water were among the main factors found to influence land surface temperature (LST). A comparison of the results in Fig. 4 - Fig. 8 with Fig. 10 and Fig. 11 reveals some links between the LTS changes observed with the relief and land use patterns of the study area as observed by some other previous researchers (Khandelwal, *et al.,* 2017)

3.1.2 Land Surface Temperature Maps.

Five land surface temperature maps corresponding to the years 2015-2020 were derived from the processing and analysis and these are presented in Fig. 4 - Fig. 8. Each LST map covers one year with three classes, namely high, moderate and low temperature zones. The red colour represents areas with high land surface temperatures, yellow represents areas with moderate land surface temperatures and green represents areas with low land surface temperatures.

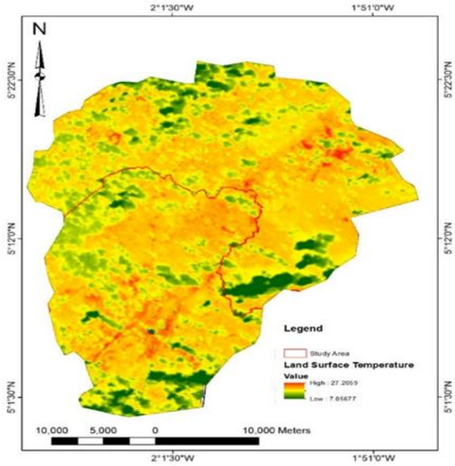

Fig. 4 LST Map of Study Area in 2015

3.1.3 Statistical Tables and Graphs

Tables 3 and 4 and Fig. 9 are samples of the statistical products derived from the processing and analysis. Table 3 indicates the lowest, highest and mean land surface temperatures derived for each year, while Table 4 provides the classification criteria for grouping the derived land surface temperatures into appropriate zones for the mapping. Fig. 9 is a representation of each year's land surface temperatures placed side by side with each other on one bar graph for easy comparison, and a trend line is fitted to them for assessing the trend of land surface temperature changes over the study period.

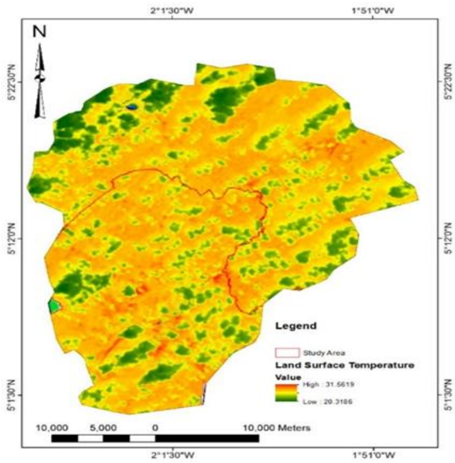

Fig. 5 LST Map of Study Area in 2017

3.2 Discussion and Applications of Results

3.2.1 Discussion of Results

the study period, and interactions with some residents in the area, the main factors that could account for the observed outlier were local small-scale mining (including 'galamsey') and farming which involved intermittent clearing of the forest and abandoning the area to revegetate. Also, the high LST zones on the maps (Fig. 8) appear to occur in areas where main settlements and mining activities exist (Fig. 11), and there appear to be uniform increases from moderate to high LST values from 2015 to 2020. In such areas with uniformly increasing LST values, uncontrolled landfilling, mining and similar land uses can compound the negative effects of increasing LST through the emission of unwanted gasses and particulate matter and the occurrence of temperature inversions. Comparison of Fig. 8 and Fig. 11 also shows some association between the LST changes and the relief. The high LST zones appear to occur near or around areas with high lands and slopes, especially in the central, eastern and southern parts of the maps.

Again, looking at the spatial distribution of LST over the maps (Fig. 4 to Fig. 8), low to medium-range temperatures (7-20 ℃) dominate the entire area with isolated places of high-range temperature values from 2015-2018, but the map of 2019 is dominated by moderate to high temperatures (20-28 ℃) with few or no low-temperature zones, whiles the 2020 map is (Fig. 8) is generally dominated by moderate to high range LST values, with few concentrated low LTS values in the north-eastern parts. Thus the year 2018 had the highest concentrations and distributions of low LST values while 2020 registered the highest concentrations and distribution of high LST values— occurring mainly in the southern, central, western and parts of the eastern areas (Fig. 8). One possible reason accounting for the contrast between the 2018 and 2020 LST distributions may be the banning of small scale mining (including 'galamsey') from 2017-1019 by the Ghana government, and its resurgence from 2019 onwards after the ban was relaxed or lifted.

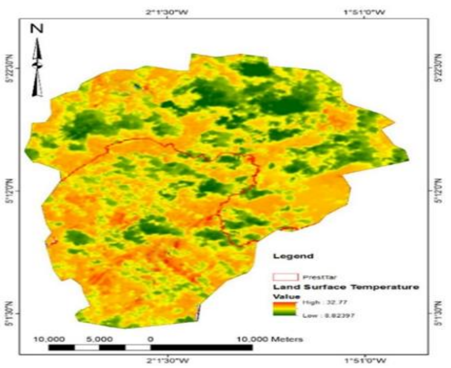

Fig. 6 LST Map of Study Area in 2018

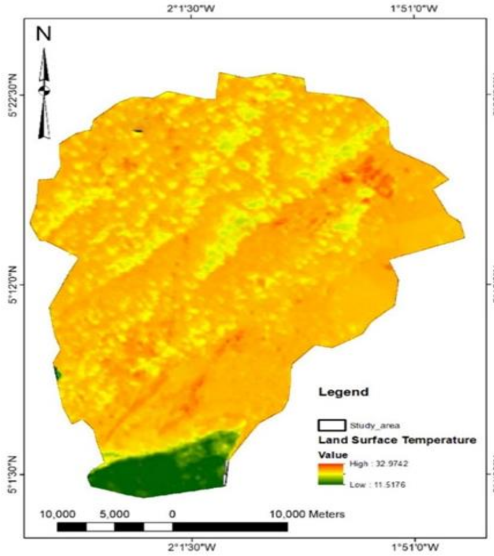

Fig. 7 LST Map of Study Area in 2019

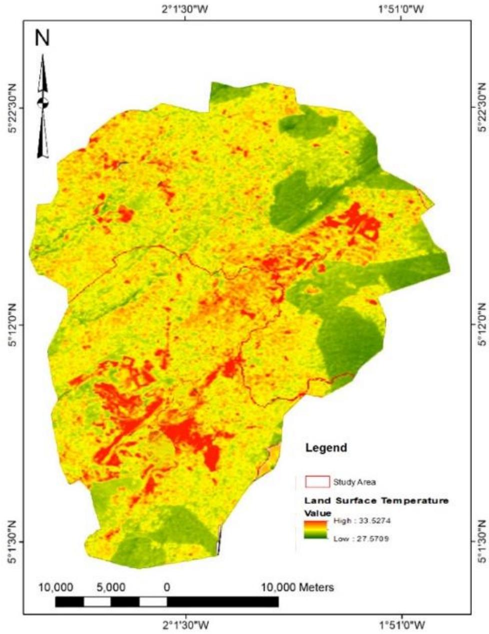

Fig. 8 LST Map of Study Area in 2020

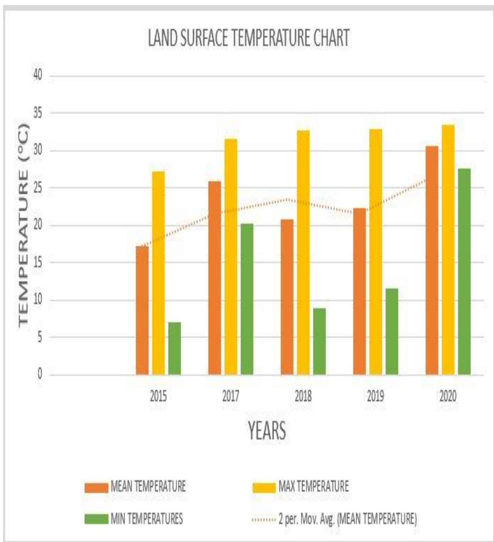

Fig. 9 Comparison and Trend of LST

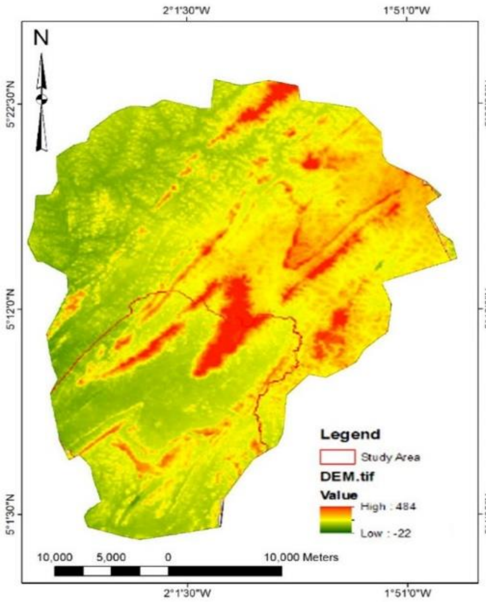

Fig. 10 Topography of the study Area

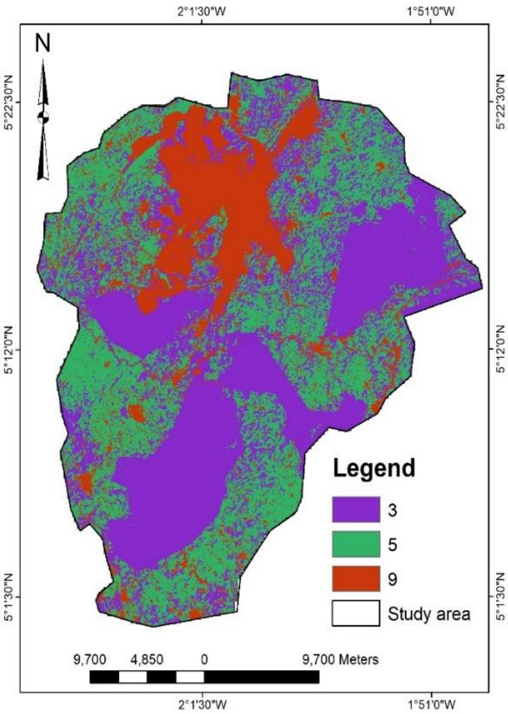

Fig. 11 Land Use Land Cover Map

3.2.2 Application Areas of Results

From the results, in the areas with uniform LST increases, uncontrolled landfilling, mining and similar land uses can compound the negative effects of high LST values through the emission of unwanted gasses and particulate matter and intense temperature inversions. These areas can thus be mapped and protected from unsuitable land uses.

Also, the results from this study and similar ones can be applied as inputs for mapping temperature inversion potentials as a further step to support effective management of the negative impacts of rising land surface temperatures and global climate change issues.

Furthermore, the land surface temperature maps such as shown in Fig 8 can be used as references or criteria to check the suitability of proposed land uses or the locations of development projects such as landfilling in terms of pollution risk or potentials. Appropriate decisions can thus be arrived at such as rejecting or disapproving the proposal or requesting more stringent mitigating measures against negative impacts that may result from the combined effects of high LST, emissions from landfills and temperature inversions, before allowing or approving the use of such sites.

4 Conclusions and Recommendations

The objectives of this study were to map, assess and discuss the trends of land surface temperature changes in the mining areas of Tarkwa and how the results may be applied in landfilling to reduce emission and the negative effects of temperature inversions in the study area and similar locations in the world. Remote Sensing, GIS and basic statistics were the main techniques deployed for the data collection, processing and analysis. Using Landsat8 Satellite Images (2015-2020) as the main input data and ArcGIS 10.7.1 and Microsoft Excel processing software, five LST maps and associated statistical table(s) and bar graphs with trend lines were derived as the main results for the study. Each LST map covered one year's temperature distribution classified into three, namely high, moderate and low temperature zones. The bar graphs and trend lines combined all the LST values for all the years under study (2015-2020) on one graph to afford easy comparison, trending and deduction from the results to make meaningful conclusions and applications. From the results, land surface temperatures were observed to be generally increasing from 2015 to 2020, except the year 2017 where the lowest temperature value appears to be an outlier.

Temporally and spatially, it was observed that the LST variations were not uniform for some years and areas, especially in the southern parts of the study area. The year 2018 had the highest concentrations and distributions of low LST values while 2020 registered the highest concentrations and distribution of high LST values. The irregular variations and sharp contrast between the 2018 and 2020 LST distributions, were attributed to the sporadic nature of farming and 'galamsey' activities in the study area, as well as the temporary ban and resurgence of legal and illegal small-scale mining operations within the period. However, in some parts of the central, western, northern and easting areas, where major settlements and mining activities exist, there were uniform increases in LST values from moderate to high levels from 2015 to 2020. Thus, the results reveal some correlation between the LTS changes observed and the land use patterns of the study area. Similar links were observed between the LST changes and the relief.

The recommended application of the results are that to help reduce the emission of unwanted gasses and particulate matter and intense temperature inversions, (1) landfilling, mining and similar land uses should be restricted or controlled within athe areas that have high LST values in the study area, through (2) the land surface temperature maps may be used as references to check the suitability of proposed land uses or the locations of development projects before permiting the use of such sites (3) and using results as inputs for mapping temperature inversion potentials to support effective management of rising land surface temperatures and global climate change issues.

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