MAPPING OF LAND SURFACE TEMPERATURE TRENDS IN THE MINING AREAS OF TARKWA-PRESTEA, GHANA

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Keywords: Land surface temperature, waste disposal, harmful gas emission, remote sensing, Tarkwa mining areas, Landsat

SUMMARY

One of the emerging factors to consider in locating appropriate municipal waste disposal sites is land surface temperature (LST) due to its association with the emission of harmful gases and heat. The objectives of this study were to map, assess and discuss the trends of LST changes in the mining areas of Tarkwa, the factors involved and their applications in landfilling to reduce emission and the negative effects of temperature inversions. The main techniques applied were remote sensing, GPS, GIS and basic statistics for the data collection, processing and analysis. Five LST maps and associated statistical table(s) and graphs were derived as the main results, using Landsat8 Aerial Images (2015-2020) as main input data, and ArcGIS (10.7.1) and Microsoft Excel as software. From the results, land surface temperatures were generally on the increase from 2015 to 2020 but exhibited irregular variations at some times and places, especially in 2017 and in the northern parts of the study area, and this was attributed to intermittent farming and illegal mining activities. Other areas in the southern, eastern and north-western parts where major 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 observed and the land use patterns of the study area. Similar links were observed between high LST values and the relief. One application of the observations was that in the areas with uniformly increasing LST values, uncontrolled landfilling, mining and similar land uses can compound the negative effects of increasing LST through emission of unwanted gasses and particulate matter and temperature inversions. A further application or recommendation was that the land surface temperature maps developed from the study or similar ones may be used as references or criteria to check the suitability of proposed land uses or locations of development projects such as landfilling in terms of their pollution risk in association with high LST values.

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1. INTRODUCTION

Ghana is among the developing countries 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 physical, chemical and biological processes of the earth's environment. It is generally monitored and estimated by remote sensing methods and involves the temperatures of vegetation canopies or bodies, soil and bare land surfaces and the effective radiating temperatures of the earth's surface that control surface heat and water exchange with the atmosphere (Qin, 2010). It is 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 the land surface temperatures (Khandelwal, 2017). Increasing LSTs and atmospheric emissions can increase temperature inversions and its negative impacts such as high concentrations and frequencies of fog or freezing rains, deadly smog and related health problems like respiratory diseases (Blaettler, 2019; Osmond, 2018). The mining areas of Tarkwa has, over three decades now, been experiencing wide-spread surface mining activities, deforestation, urbanisation and related waste disposal and environmental pollution problems (Kwesi, *et al*, 2015). The trends in LST variations and its associated impacts need to be assessed and applied in managing the 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 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.

2. BACKGROUND OF STUDY AREA

2.1 Geographic and Economic Setting

The study area is located generally between latitudes 5° 10′ N and 5° 35′ N and longitudes 1° 52′ W and 2° 14′ W in Ghana (Fig. 1). It lies across two administrative districts in Ghana, namely, the Tarkwa-Nsuaem Municipal Area (TNMA) and the Prestea Hunivalley Municipal Area (PHMA). It is a famous mining centre that attracts many people from other parts of the country, Africa and the world (Kwesi, *et al*., 2015). It is thus refered to as the Tarkwa-Prestea Mining Areas (TPMA) of Ghana in this study. The economy of the area 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 travelers 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 urbanisation and high population growth rate (about 3.0%) and huge volumes of waste generation that are beyond the resources and capabilities of the Municipal Authorities to manage effectively (Kwesi, *et al.,* 2018). Other impacts from the mining 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.,* 2014; Kuma and Ewusi, 2009).

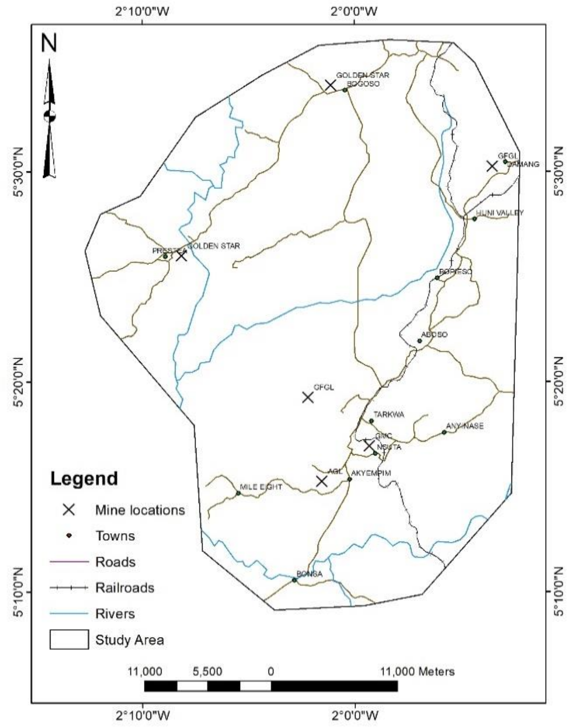

Fig. 1 Map Showing Study Area (TPMA)

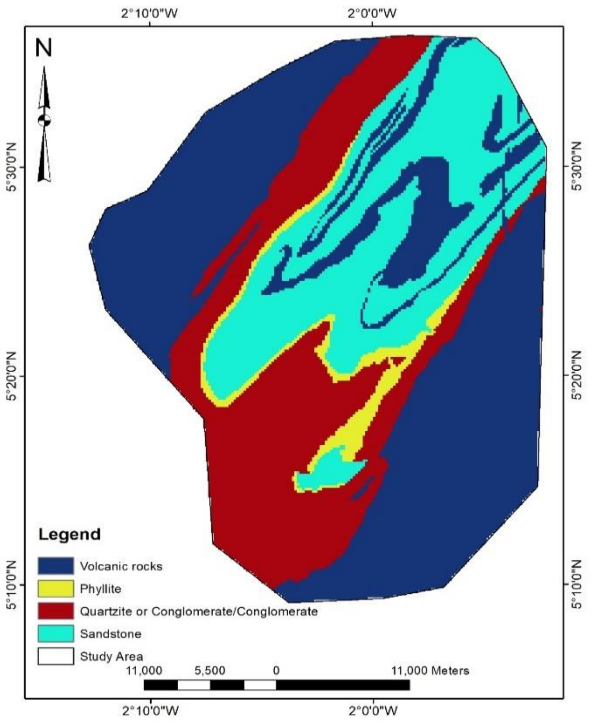

Fig. 1 Map Showing Study Area (TPMA)

2.2 Topography, Geology and Climate

The topography of the study area is generally undulating with some scarps ranging from 150 - 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 mean annual rainfall of about 1878 mm, a temperature range of 26℃ (in August) to 30℃ (in March), sun shine 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, fog formation, atmospheric pollution and related health and environmental hazards like respiratory diseases and bush fires (Kwesi *et al.*, 2018; Blaettler, 2019; Trinh *et al*., 2019; Osmond, 2018; Sackey, 2016; Tang *et al.*, 2016; Wilson *et al.*, 2015; Asante, 2011).

3. RESOURCES AND METHODS USED

2.1 Resources

The LST maps in this study were derived from Landsat 8 images (Landsat8-OLI/TIRS C2 L2) downloaded from the USGS Earth Explorer website. 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. For the Land Use/Land Cover (LULC) model, Landsat 8 Image (March 29, 2020 scene; path: 194, row: 56) was downloaded from US Geological Survey's website (earthexplorer.usgs.gov). It was downloaded from the Landsat Level 1 Collection. The data in geotiff format was projected onto UTM zone 30 N and then extracted by mask to the study area. It was then converted from digital numbers (DN) to Top of Atmosphere (TOA) Planetary Spectral Reflectance. The TOA Reflectance data (bands 2, 3, 4, 5, 6 and 7) was composited and classified using the unsupervised classification technique in ESRI ArcMap 10.3 and 10.7.1 software. 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). The methods adopted for this study are summarized in the flow chart in Fig. 3 and discussed in detail in the next sections.

Table 1 Factors that Influence Land Surface Temperature and Inversion

Factors	Remarks
Topography/ Relief (elevation, slope and aspect)	Altitude/elevation decreases and temperature inversion also increases
Landcover/use (vegetation, mining sites, settlements and bare lands	Green vegetation undergo transpiration which thereby form surface inversion
Water bodies	Water surface evaporate when temperature become high and leads to the inversion
Wind currents (direction and speed)	The eddies cause air from greater height where wind speed and temperature are great to mix cool air near the surface
Temperature	When the temperature is high the earth surface and atmosphere become hot in the day and cool in the night but at different rates and degrees and this induces temperature inversion
Waste/Emission Sources	Waste rocks or dumps and other sources of air pollution increase the potential for Temperature inversion.

2.2 Data Processing and Analysis Methods

There are many approaches for deriving and analyzing LST from remote sensing images but the one adopted for this paper is based on the generalized one presented at 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). The data is first sorted into two sub groups, TIRS (Band 10 and 11) and OLI (Band 1-9) since they undergo separate analytical processing routes to produce the required end results (LST). After necessary radiometric corrections, the first processing step for the TIRS bands is 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. The second step is 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). (BT values were subtracted from 273.15 K to convert them to degree Celsius). The third step of this route coincides with the final step which is the derivation of LST, using equation 6.

Table 2 Values for Constants *K1 and K2*

YEAR	2020	2019	2018	2017	2015
K1 (BAND 10)	774.8853	774.8853	774.8853	774.8853	774.8853
K2 (BAND 10)	1321.0789	1321.0789	1321.0789	1321.0789	1321.0789

Table 3 Land Surface Temperature Values

YEAR	2015	2017	2018	2019	2020
Maximum Temperatures (°C)	27.2059	31.5619	32.7700	32.9742	33.5274
Minimum Temperatures (°C)	7.05677	20.3186	8.82397	11.5176	21.5709
Mean Temperatures (°C)	17.1310	25.9400	20.7970	22.2459	30.5492

Using route two, involving the OLI (Bands), the first processing step, after necessary radiometric corrections and layer stacking, is the derivation of *normal(ized) difference vegetation index* (NDVI) mainly from Landsat8 Bands 4 and 5, applying equation 3, where Band 4 represents the visible infrared and Band 5 is the near infrared of the spectrum. The second step is the estimation of the *proportion of vegetation* (PV), applying equation 4, where $NDVI_{Max}$ is the maximum value of the normalized differential vegetation index; and $NDVI_{Min}$ minimum value of the normalized differential vegetation index. The third step on this route is the derivation of *land surface emissivity* (LSE), applying equation 5, where PV is the proportion of vegetation; and ***e*** represents the land surface emissivity. The value of LSE is an important parameter for estimating or measuring LST, and the efficiency of transmitting thermal energy across the earth surface into the atmosphere (Tang *et al.*, 2016). The fourth step of this route coincides with the final step which is the derivation of LST, using equation 6, where LST = Land surface temperature; BT = at-satellite brightness temperature (K); W = wavelength of emitted radiance (11.5µm); **p** =h×c⁄(1.438 * 10-34 Js); **h** = Planck's constant (6.626 * 10-34 Js); **c** = velocity of light (2.998 * 108 m/s); and **s** = Boltzmann constant (1.38 * 10-23 J/K). (Farzana-Shaheen, *et al.,* 2020; Mustafa, *et al.,* 2020; Tang *et al.,* 2016; Herbei, 2013; Kyriacou, 2010; Qin Z and Karneli, 2010).

The final processing step involves enhancement and validation of the final results through anomaly detection and ground truth(ing) techniques using control data from primary (ground) or reliable secondary sources. The land surface temperature maps were generated from the 2015, 2017, 2018, 2019 and 2020 Landsat8 (OLI + TIRS) image, mainly from band 4, band 5 and band 10. The results are presented at Fig 4- Fig 8. Each LST map covers one year with three classes, namely high, moderate and low temperature zones. Using Microsoft Excel, statistical tables, bar graphs and trend lines were prepared to supplement the LST maps (see Table 3 and Fig 9).

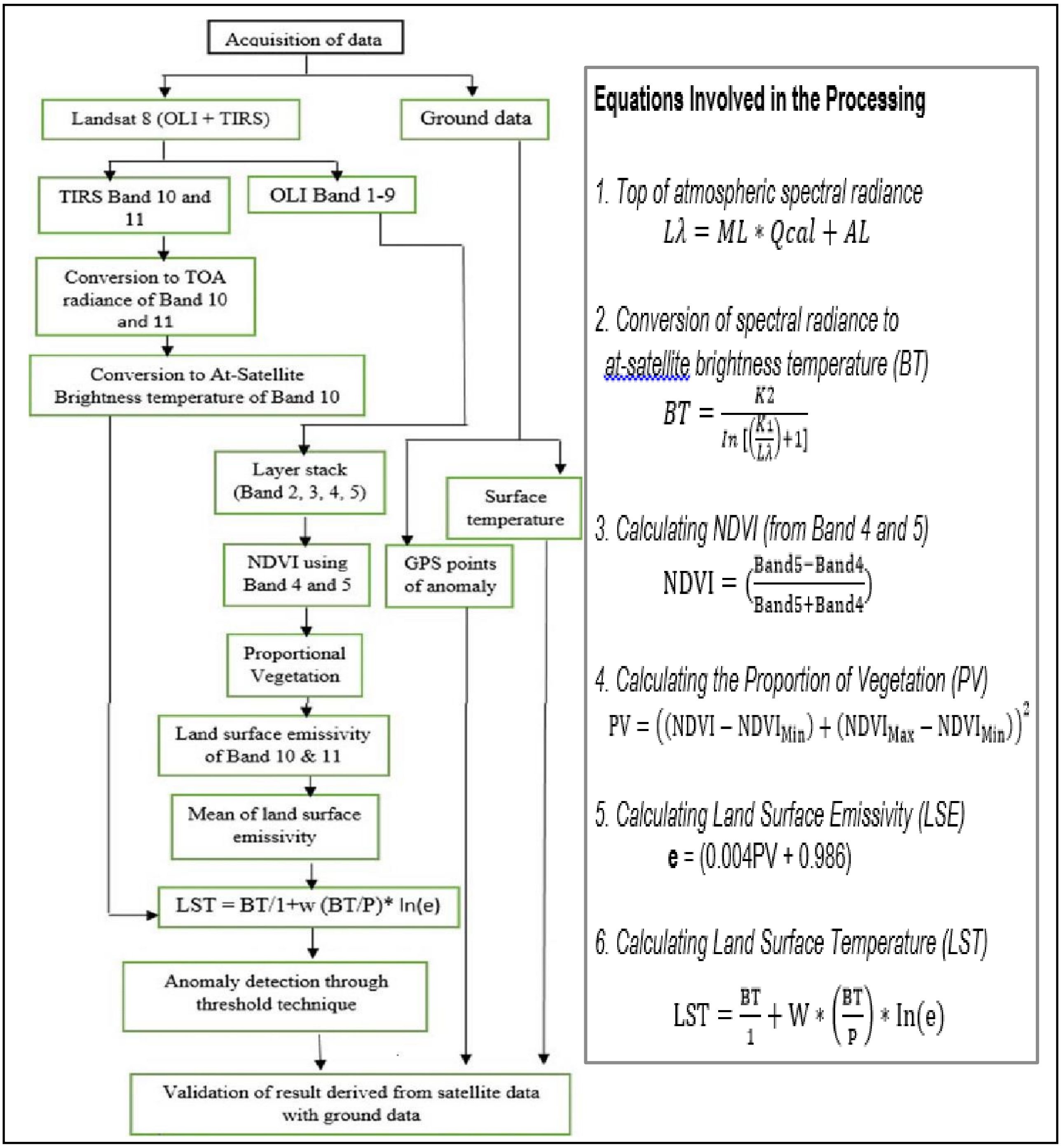

Fig. 3 Land Surface Temperature Retrieval Processing Steps (after Shaheen, *et al*., 2020)

4. RESULTS AND DISCUSSIONS

4.1 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.

4.1.1 Basic Reference Maps

Fig. 1 and Fig. 2, Table 1 and Fig. 10 and Fig.11 are examples 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 at Fig. 4 -Fig. 8 with Fig. 9 and Fig. 10 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).

4.1.2 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 at 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.

4.1.3 Statistical Tables and Graphs

Tables 3 and 4 and Fig. 9 are examples 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, and the derived land surface temperatures were classified 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 fitted to them for assessing the trend of land surface temperatures over the years.

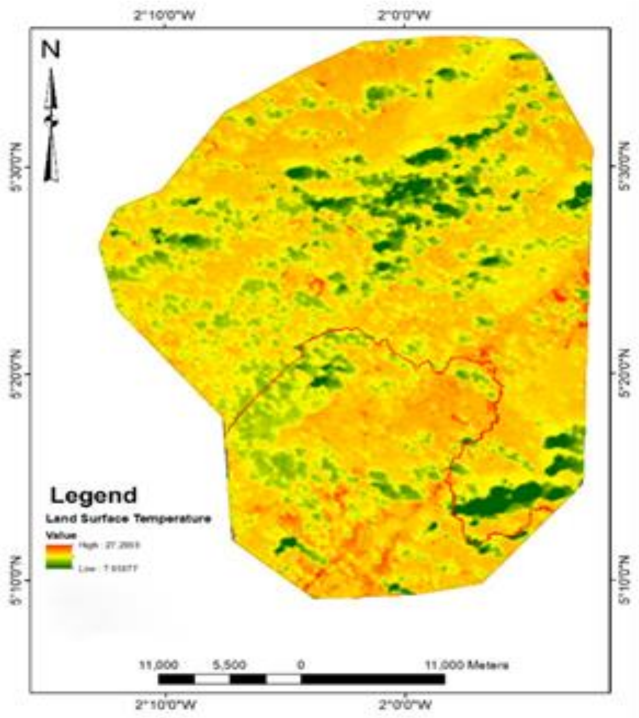

Fig. 4 LST Map of Study Area in 2015

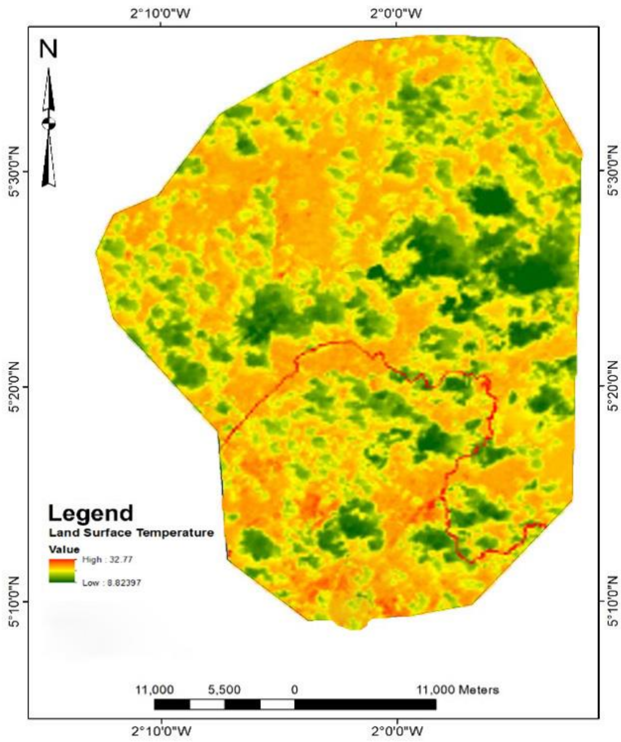

Fig. 6 LST Map of Study Area in 2018

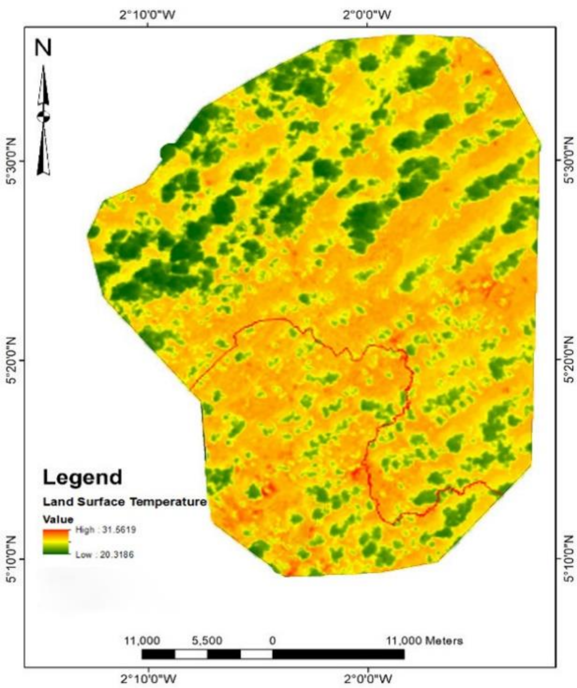

Fig. 5 LST Map of Study Area in 2017

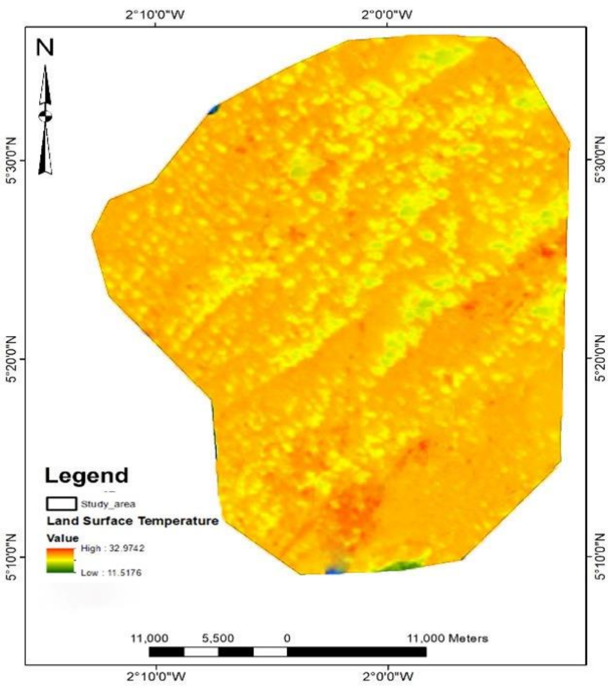

Fig. 7 LST Map of Study Area in 2019

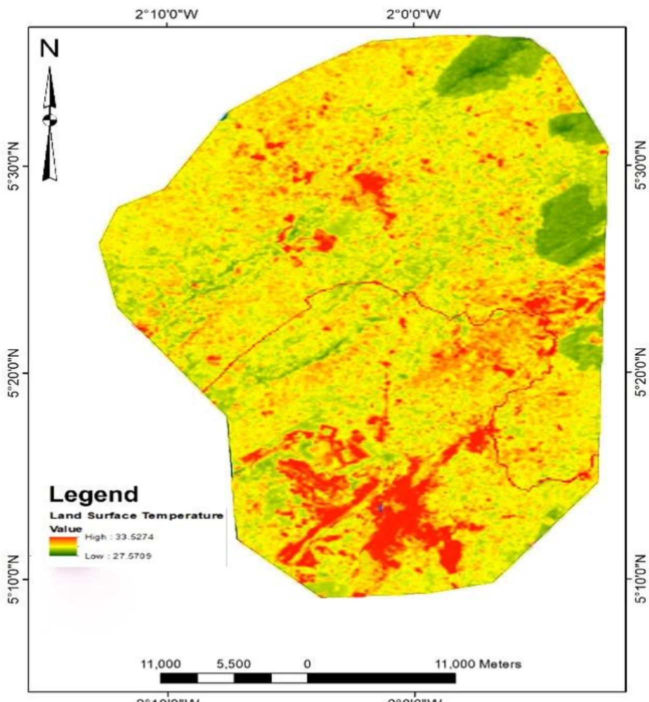

Fig. 8 **LST Map of Study Area in 2020**

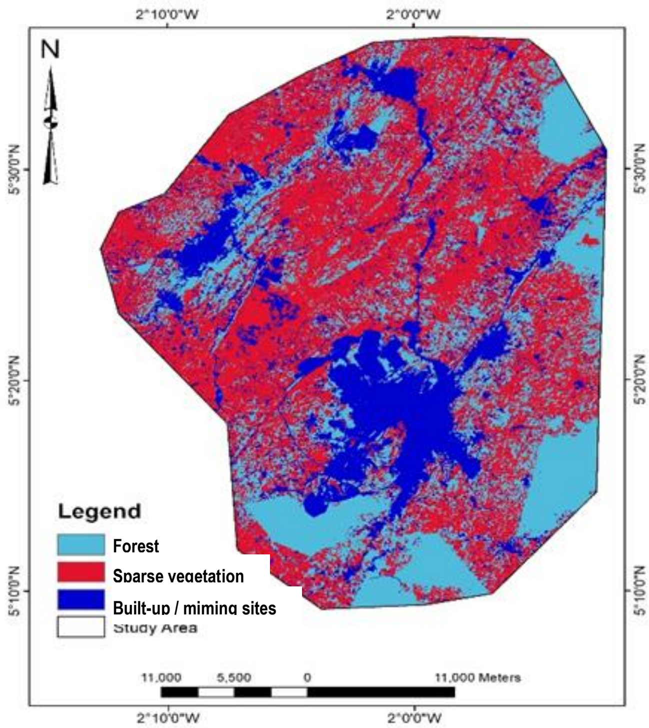

Fig. 10 Land use/cover of the Study Area

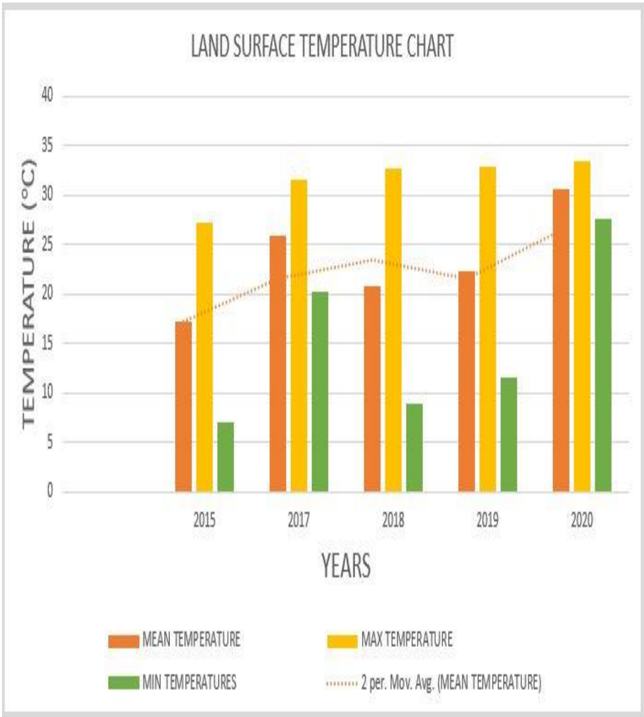

Fig. 9 Comparison and Trend of LST

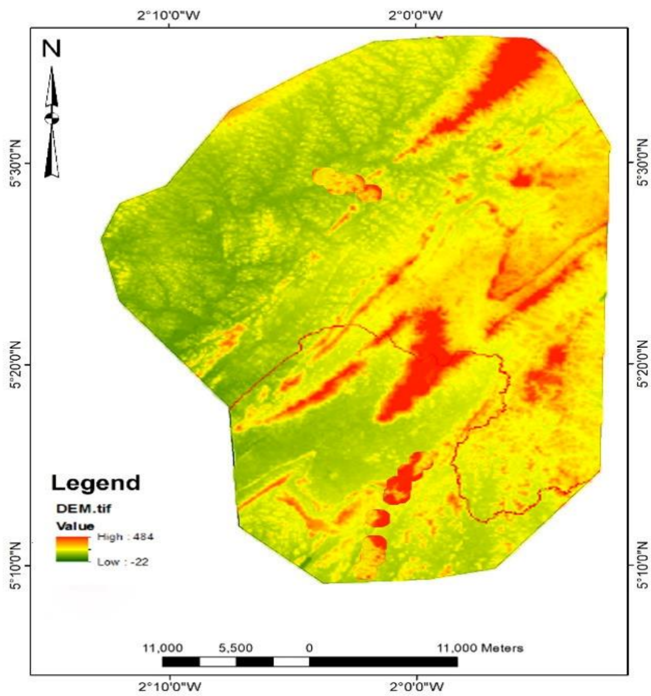

Fig. 11 DEM of the Study Area

4.2 Discussions and Applications of Results

As can be seen from Fig. 4 to Fig. 8 and Table 3, the derived LST values cover a period of 5 years, and range from 7.1 to 33.5 degrees celsius, with the lowest occurring in year 2015 and the highest in year 2020. Also, the maximum, average and minimum LST values were generally on the increase from 2015 to 2020, except the year 2017 where the lowest LST value appears to be too high or an outlier, suggesting that some significant local factor may have influenced it. Inferring from the land cover and land use changes in the study area within the study period, and from 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. Also, the high LST zones on the maps (Fig. 8) appear to occur in areas where major settlements and large scale mining activities exist (Fig. 10) and there appear to be a uniform increase from moderate in 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 emission of unwanted gasses and particulate matter and temperature inversions. A comparison of Fig. 8 and Fig. 11 also shows some association between the LST changes and the relief, in that the high LST zones appear to occur near or around areas with high lands and slopes, especially in the southern, eastern and northing areas on both 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 of the map. Thus the year 2020 registered the highest concentrations of high LST values, occurring mainly in the southern, eastern and north-western parts of the study area from 21015-2020. One possible reason accounting for this may be the resurgence and increases in small mining activities in 2020, after some successful efforts of the Ghana government to barn and restrict small scale mining operations (especially galamsey) from 2017-2019.

4.2.1 Applications in Landfilling

The land surface temperature maps such as shown at Fig 8 may 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 heat, gaseous and particulate 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. LST maps may be used as criterion map to improve landfill site screening through sieve mapping.

5. CONCLUSIONS AND RECOMMENDATIONS

In this study, remote sensing, GIS and basic statistics have been deployed as main techniques for data collection, processing and analysis 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 emissions of harmful gasses, heat and particulate matter in the study area and similar locations in the world. Using Landsat8 Aerial 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 covers 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 or influenced by some significant local event such as mining and farming.

Spatially, the LST variations observed were not uniform for some areas and periods of the observation, and a possible cause for this was farming and illegal mining activities which involved intermittent clearing of the forest and abandoning the area to revegetate. However, in the southern, eastern and north-western parts of the study area where major settlements and mining activities exist, there appeared to be a uniform increases in LST 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 high LST values and the relief.

One application of the results is that, in areas with uniform LST increases, uncontrolled landfilling, mining and similar land uses can compound the negative effects of high LST values through emission of unwanted gasses and particulate matter and intense temperature inversions. Another application is that the land surface temperature maps such as shown at Fig 8 may 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 their pollution risk or potentials in association with high LST values.

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BIOGRAPHICAL NOTES

Authors

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