Comparison between Temperature Data Derived From LANDSAT 8 Band 10 using Geographic Information System (GIS) and Manual Ground Measurement.

Asa, Sunday and Zemba, Ambrose, A.
Department of Geography, Modibbo Adama University of Technology, Yola, Nigeria
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Abstract

Land surface temperature (LST) is one of the key parameters in the physics of earth surface processes from local to global scales, as such, its importance is being increasingly recognized. There are strong interests in developing methodologies to measure LST from the space. Landsat 8 Thermal Infrared Sensor (TIRS) is the newest thermal infrared sensor in the Landsat project, providing two adjacent thermal bands, which have a great benefit for LST inversion. In this paper, the results of temperature inversion from TIRS landsat8 band10 and ground measurement approaches of temperature measurement in Greater Yola were compared to ascertain which approach is more accurate with less error. Landsat8 band10 image of the study area was acquired on the 15/1/2016 and ground measurement of temperature was carried out across a network of three weather stations (MAUTECH, Yola, Yola Airport and UBRBDA weather stations) in the area simultaneously on the same date. Temperature was derived from the landsat8 band10 image and analyzed. The results showed a mean temperature of 32.5^{o}C for Landsat 8 measurement, while the ground measurement mean temperature was 32.1^{o}C. Analysis of Variance (ANOVA) was then used to test for variations. The results indicated a slight difference of 0.4 ^{o}C in the measurements. T-test was then employed to test the significance of the variation. It showed that the variation was not statistically significant even though some variation was observed. Accuracy of the two methods was tested in all the three stations and the results showed average manually measured temperature mean standard deviation (SD) = 3.32 and mean standard deviation error (MSE) = 3.35, while the automated temperature mean SD = 2.90 and MSE = 2.05. The results show higher accuracy for temperatures derived using landsat8 band10 when compared with manually measured temperature in Greater Yola, as the results indicate high MSE for ground measurement and low for automated- derived temperatures. The research concluded that there were variations between the results of the two approaches but not statistically significant and recommended the use of temperature data derived from landsat8 band10 for research temperature data collection because of its high accuracy as compared with ground measurement.
Key words: Landsat8, Atmosphere, Greater-Yola, Radiance,, LST, TIRS.

Introduction

Land surface temperature (LST) is a key consideration in the physics of earth surface through the process of energy and water exchange with the atmosphere, which plays an important role in a wide array of scientific studies such as urban heat island studies, urban climate studies, climate resilience research, climate change, ecology, thermal comfort, hydrology etc (Liang et'al., 2012; Zang and He, 2013). Therefore, LST is an input data set for a wide variety of researches. Thermal infrared remote sensing (TIR) provides a unique method for obtaining land surface temperature information at local, regional and global scales since most of the energy detected by the sensors in this spectral region is directly emitted by the land surface.

Many efforts have been devoted over the years to establish methods of retrieving land surface temperature from remote sensing data with significant progress made over the past decades (Xiaolei *et'al*., 2014). The Landsat project provides particular opportunity for the land surface temperature retrieval as it has a relatively long data record period, with the lunch of landsat3 in 1978. From Landsat3 to the Thematic Mapper (TM) of Landsat 4, 5 and 6, followed by the Enhanced Thematic Mapper Plus (ETM+) of Landsat 7, there was only one thermal infrared channel available (Markham, et'al 2004). While landsat8 (TIRs) has two spectral adjacent thermal bands which are suitable for land surface temperature estimation, Table1 shows Landsat missions and their characteristics. Landsat8 was successfully launched on 11/2/ 2013 and deployed into orbit with two instruments on-board: (1) The Operational Land Imager (OLI) with nine spectral bands in the visual (VIS), near infrared (NIR), and the shortwave infrared (SWIR) spectral regions; and (2) the Thermal Infrared Sensor (TIRS) with two spectral bands (band10 and 11) in the long wave infrared (LWIR). The two TIRS bands on Landsat8 are collected across slightly different wavelengths. However, Barsi, et. al., (2014) observed notable stray light contamination of the TIRS data collected by Band 11 when calibrated. Thus, Band 10 is selected as the primary TIRS dataset for this study.

There is growing interest in exploring climate change impact resulting from increased surface temperature and extreme heat events in the world LST variations in space and time, measured by satellite remote sensing, are used for the estimation of a multitude of geophysical variables, such as thermal inertia, evapotranspiration, vegetation water stress, and soil moisture, which leads to increasing recognition of the importance of land surface temperatures. This exploration and the importance of land surface temperatures in environmental studies necessitated this study. It is however pertinent to show some Landsat mission characteristics to buttress the preposition held here. This is as shown on table 1.

Study Area

Greater Yola covers the expanse of three Local Government areas; Yola North, parts of Yola South, and Girei LGA of Adamawa state. It lies between latitudes $9^0 07^1$ to 9^0 23^1 N and longitudes 12^0 17^1 to 12^0 33^1 E. The study area is bounded to the south and east by Fufore, to the West by Demsa and to the North by Song Local Government Area of Adamawa state, Northeast Nigeria. (Gongola Urban Areas Designation Order 1985 and Yola Topographical Sheet 48/48A, 1974). Figure 1A shows the map of the study area while figure 1B shows satellite image of the area.

Table 1 Landsat Mission Characteristics

System	I(S)	Resolution (meters)	Communications	Alt. Km	R Days	D Mbps
Landsat1	RBV	80	Direct downlink	917	18	15
	MSS	80	With recorders			
Landsat2	RBV	80	Direct downlink	917	18	15
	MSS	80	With recorders			
Landsat3	RBV	40	Direct downlink	917	18	15
	MSS	80	With recorders			
Landsat4*	MSS	80	Direct downlink	705	16	85
	TM	30	TDRSS			
Landsat5	MSS	80	Direct downlink	705	16	85
	TM	30	TDRSS**			
Landsat6	ETM	15(pan)	Direct downlink	705	16	85
		30(ms)	With recorders			
Landsat7	ETM+	15(pan)	Direct downlink	705	16	150
		30(ms)	With recorders			

I(S)= Instrument(s), R = Revisit interval, D = Data rate, *TM data transmission data failed in August 1993, ** current data transmission by direct downlink only. No recording capability. Source: Landsat 7 Data User's Handbook.

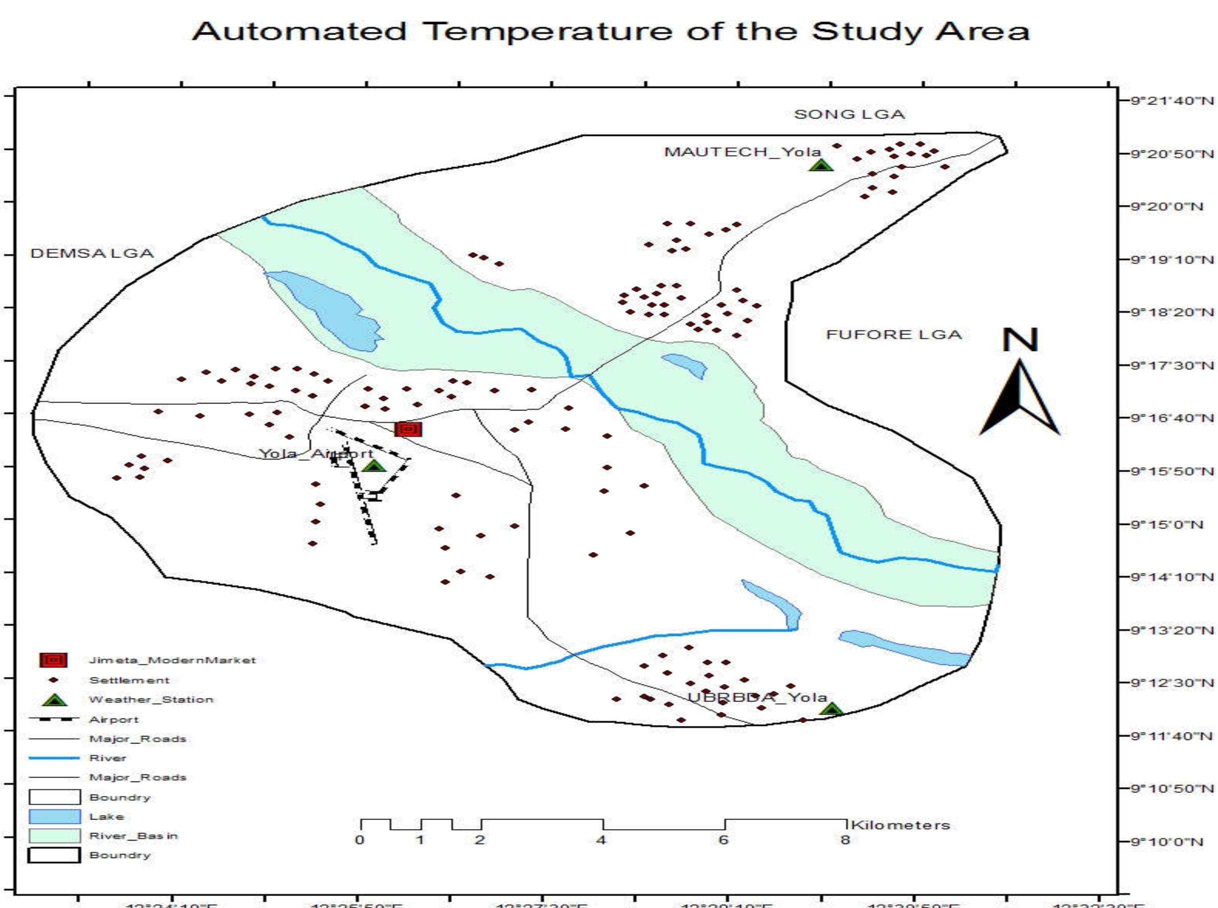

Figure1A: Greater Yola showing the weather stations

The climate of greater Yola area exhibits typical tropical climate (Zemba, 2010). The study area has average sunshine hours of about 7-8 hours daily and the wind speed average of 76.1Km/hr. It has monthly mean sunshine hours of about 220 hours from January to April. This decrease to a mean value of 207 hours between May and September due to increases in cloud cover during the rainy season. The mean sunshine hours increase again to about 255 hours between October and December. The average sunshine hours for the year as a whole stand at about 2750 approximately Adebayo, (1999).

Land surface temperature in the study area is generally high throughout the year; typical of a tropical climate, as such, it can be referred to as West African Savannah Climate. Yola has a seasonal change in temperature, from January – April; the temperature increases as the sky becomes clear of cloud, allowing for the reception of high solar radiation. Maximum temperature within this period is about 43^0C and the minimum temperature is 18^0C between December and January. There is a distinct drop in temperature at the onset of rains due to the effect of cloud cover in the study area. This is usually around May to its cessation usually between late October and early November before the arrival of harmattan between December and January which leads to drop in temperature (Adebayo, 1999).

Greater Yola has two distinct seasons; the rainy and dry seasons. The rainy season runs from the months of May through October, while the dry season commences in November and ends in April/May. The average annual rainfall is put at about 960mm with the highest occurrence in August and September, when intensity assumes over 20% of the annual value (Zemba, 2010). In fact, in the past few years, the highest occurrence of the rainfall has shifted to September, as opposed to August previously. The wind direction in the area is characterized by northeast and westerly winds. The northeast trade winds bring harmattan from the north during November to March through the influence of tropical continental air mass while the influence of tropical maritime air mass from the south brings about rains during the period from May to October. The monthly distribution pattern of evaporation in the area is similar to that of temperature, with significant decline during the rainy season. Record of evaporation in the area shows that the minimum value of about 2.5ml occurs in August, while the highest value is in March (about15ml) (Adebayo, 1999; Zemba, 2010).

According to Usman, (2005), the study area has a composite soil type comprising gleyic combisols, gleyic luvisols, eutric regosols, ferric luvisols, pellic vertisols, chromic luvisols and euric combisols. Vegetation within the study area is Savannah woodland. It has the characteristic of an open biotype. It takes a form of grass in association with more or less densely interspersed shrubs and trees

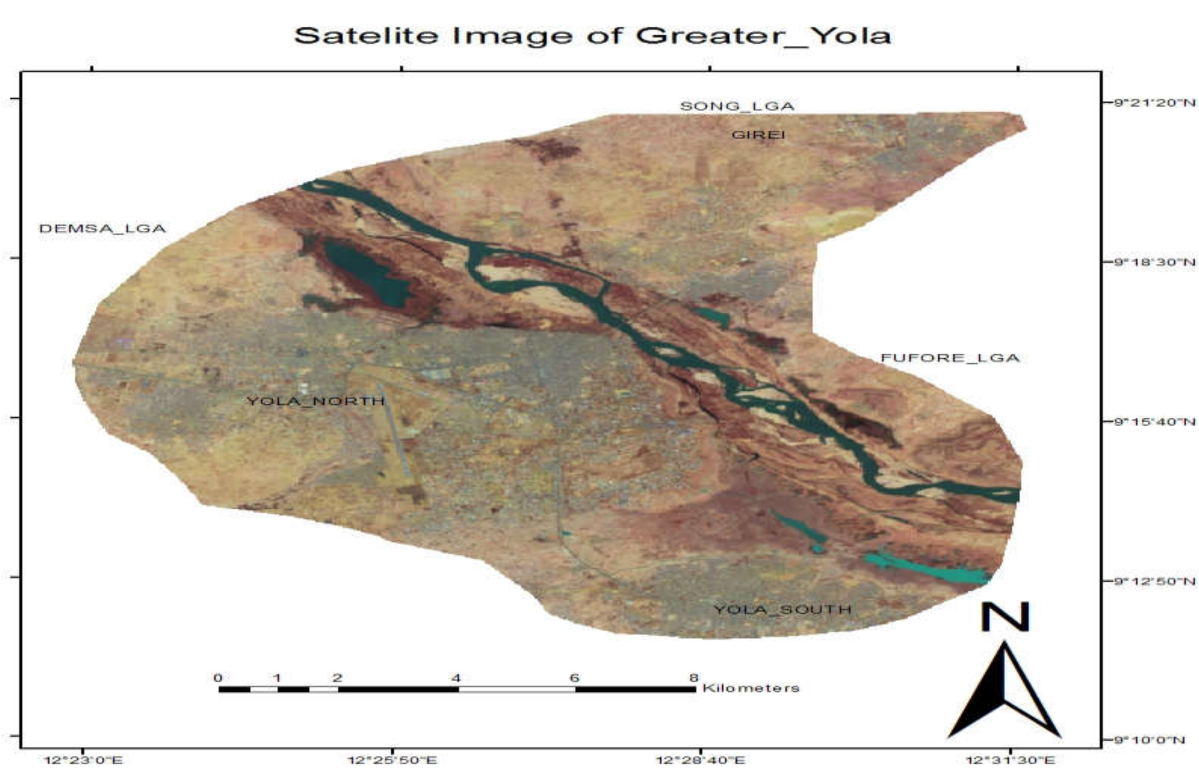

Figure 1B: Satellite image of the study area

The most common tree species in the study area include; Gum Arabic, Baobab, Neem and Mango, while grass species include; Bristly starbur, Water hyacinth, Snake weed and Wild lettuce Tasiu, (2006). The study area contains the two important industrial layout of Adamawa state; the Kofare industrial layout and the Bajabure industrial layout with both small and medium scale industries including: Adama Beverages, producers of Faro products; Bajabure industrial complex (BIC), producers of NIMA foam and Adama Plast Company.

Methodology

The data required for this study were; the manually measured temperature and landsat8 image containing all the11 bands. The data inputs (DN, radiance and temperature) that were used to generate LST estimates for this study were collected using the Landsat8 satellite. Landsat 8 was selected because it was deemed to be the best source since it provides free, medium-resolution data at a frequent re-visit period (every 16 days) and has two TIRS bands, Band 10 and band 11.ArcGIS version 10.2 was used for image analysis in temperature derivation and Minitab16 statistical package was used for statistical analysis of the data generated to determined the variations, significance of the variations and accuracy of the approaches. The aim of this study is to compare land surface temperature data retrieved from landsat8 band10 image, and land surface temperature manually measured to ascertain which data is more accurate, with less error. Accordingly, landsat8 band10 image was acquired and analyzed; while land surface temperatures were also measured across a network of three weather stations (MAUTCH, Yola weather station, Yola Airport weather station and Upper Benue River Basin Development Authority (UBRBDA) weather station) located within the study area and obtained data were statistically analyzed as well. The following hypotheses guided the study, A hypothesis was stated in the null form thus:

H_o = there is no significant difference between temperature derived from landsat8 band10 and manually measured temperature in the study area.

H_1= there is a significant difference between temperature derived from landsat8 band10 and manually measured temperature in the study area.

Data Acquisition Method

Data inputs for this study were made available through the EROS Center's Science Processing Architecture (ESPA) interface which generates provisional data products on-demand. To obtain data from the website for this study, the exact Landsat scenes and desired secondary products; location and date range (2016/01/15), the space ID, the sensor ID and the PATH = 185/ROW = 54 were specified through USGS Earth Explorer. Results were clicked to generate a list of available scenes and the Landsat Scene Identifiers of interest were noted and a text file was created with each Scene Identifier. The manual temperature data on the other hand were collected on the same date of the landsat8 image acquisition (2016/01/15), across a network of three meteorological stations simultaneously within the study area. The stations were: Yola international airport located on 12°25'42.941"E 9°16'2.035"N, Geography Department MAUTECH located on Latitude 12°30'17.811"E 9°20'39.835"N and the UBRBDA, Yola located on 12°33'19.093"E 9°10'15.807"N weather Stations. These stations were chosen because they conformed to the World Meteorological Organization (WMO) set rules for setting up weather station for collecting meteorological data.

Land surface Temperature Derivation

The procedures for LST estimates are detailed below. A geographic Information System (GIS) package ArcGIS 10.2 was used for the temperature estimation from the landsat8 image and downloaded following three steps: Converting the raw bands into Top of Atmosphere Radiance (TOA_r), Converting TOA_r into degrees Kelvin and Converting degrees Kelvin into degrees Celsius.

Converting the Raw Bands into Top of Atmosphere Radiance

To convert the raw bands into Top of Atmosphere Radiance Brightness Temperature we use the Top of brightness provision Temperature designed by the US Geological Survey (USGS) product, which converts the spectral radiance values stored in TIRS Bands to brightness temperature in Kelvin. DN's were first converted to radiance unit using the equation below:

$L\lambda$ = Grescale * QCAL + Brescale U.S. Geological Survey, (2016).

This is also expressed as:

$L\lambda = ((LMAX\lambda - LMIN\lambda) / (QCALMAX-QCALMIN)) * (QCAL-QCALMIN) + LMIN\lambda$

Converting from Top of Atmosphere Radiance to Temperature in Degree Kelvin

The Brightness temperature was calculated using the formula shown below (U.S. Geological Survey, 2015).

$$T = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda} + 1\right)}$$

Where:

T = Effective at-satellite temperature in Kelvin

K2 = Calibration constant 2 from Table

K1 = Calibration constant 1 from Table

L = Spectral radiance in watts/(meter squared * ster * µm)

This is effective at-satellite temperatures of the viewed Earth-atmosphere systems under the assumption of unity emissivity using pre-launch calibration constant. The calibrated constant (K) is presented in table 2.

Table2: Calibration constants K1 and K2

	Constant 1- K1 watts/(meter squared * ster * µm)	Constant 2 - K2Kelvin
Landsat8 Band11	480.89	1201.14
Landsat8 Band10	774.89	1321.08

Source: Landsat 8 Data User's Handbook

Conversion from Degree Kelvin to Degree Celsius

The derived temperature in degree Kelvin was then converted to degree Celsius using the formula = K-273.15 Where K= temperature in Kelvin.

Results and discussion

Results of Top of Atmosphere Radiance (Brightness Temperature) derived from landsat8 band10 using GIS are presented in figure 3. The results show Radiance in the area ranges from 9.1 to 11.8. On the other hand, results of the conversion from Top of Atmosphere Radiance to Temperature in Degree Kelvin and subsequently degree Celsius derived from landsat8 band10 are presented in figure4. The results in figure 4 show that Greater-Yola has mean temperature of 32.5 ^{o}C on the date of the image acquisition (15/01/2016) with maximum temperature of 41.7^{o}C, minimum of 23.4^{o}C, and a temperature range of 18^{o}C.

Manually measured average mean temperature of the three stations as presented in table3A is 32.1 ^{o}C, which indicates a slight differences of 0.4 ^{o}C between the mean temperatures derived from landsat8 band10 and the mean ground measured temperature in Greater Yola.

Table 3A and B shows manually measured and the summary of automated temperature results from the three stations (MAUTECH, Yola Airport and UBRBDA) respectively. The maximum temperature, minimum temperature, temperature range and the mean in degree Celsius (^{o}C) for the date of the satellite image acquisition are presented in the tables so as to enable spatial differences analysis.

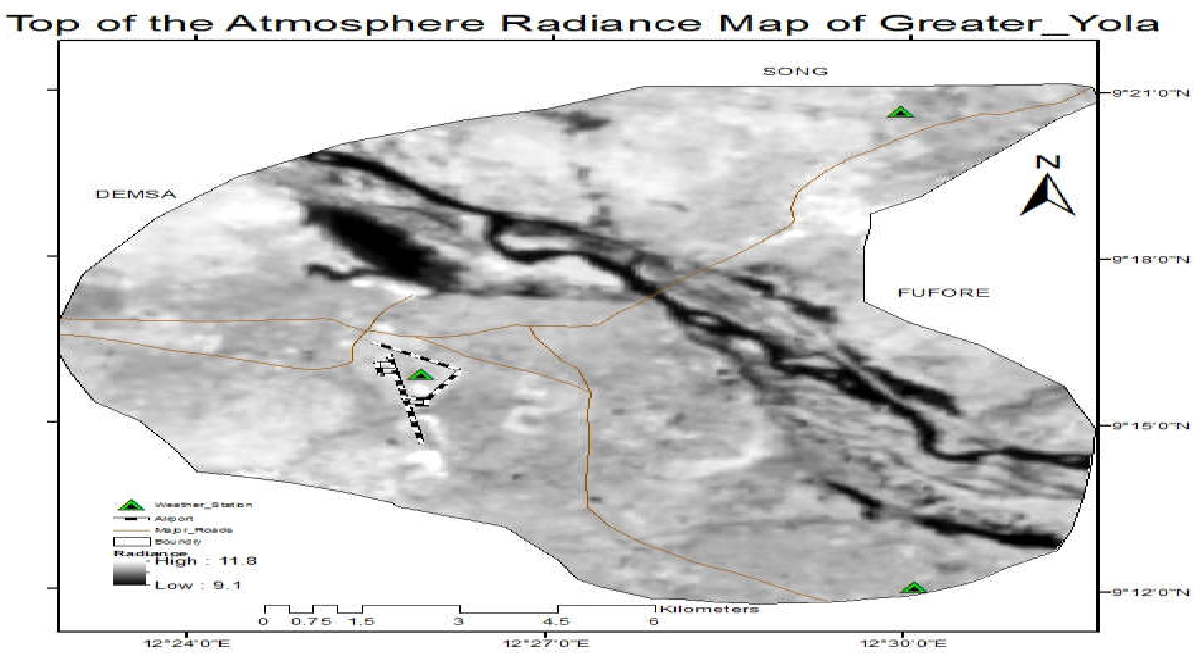

Figure2: Radiance map of Greater_ Yola

Table 3A: Measured Ground Temperature Result for the three Stations

	LST$_{GM}$ 1 MAUTECH	LST$_{GM}$ 2 YOLA AIRPORT	LST$_{GM}$ 3 UBRBDA
Max$_{temperature}$	32 ^{o}C	36.7 ^{o}C	34.6 ^{o}C
Min$_{temperature}$	29^{o}C	28.8 ^{o}C	31.4 ^{o}C
Temperture$_{Range}$	3^{o}C	7.9 ^{o}C	3.2 ^{o}C
Mean$_{temperature}$	30.5^{o}C	32.8 ^{o}C	33.0 ^{o}C

LST$_{GM=}$Ground measured land surface temperature at station.
Sources: MAUTECH, Yola, Yola Airport and UBRBDA weather stations (01/15/2016)

Table 3B: Derived LST from landsat8 band10 for the three Stations

	LST$_{Derived}$ MAUTECH	LST$_{Derived}$ YOLA AIRPORT	LST$_{Derived}$ UBRBDA
Max$_{temperature}$	31.8 ^{o}C	36.0 ^{o}C	34.4 ^{o}C
Min$_{temperature}$	27.8^{o}C	30.3 ^{o}C	31.8 ^{o}C
Temperture$_{Range}$	4^{o}C	5.7 ^{o}C	2.6 ^{o}C
Mean$_{temperature}$	29.8^{o}C	33.15 ^{o}C	33.1 ^{o}C

LST $_{Derived}$ = land surface temperature derived
Sources: field work

Figures 4, 5 and 6 show temperature map derived from landsat8 band10 at the three stations (MAUTECH, Yola Airport and UBRBDA) with the image showing results of maximum and minimum temperatures. One way analysis of variance (ANOVA) was applied for these results (band10 derived and the ground measurement of all the stations), F-value and P-value of the ANOVA were 0.39 and 0.839 respectively which indicated a slight difference between the results. Thus, we accept the null hypothesis which says there is no variation between the temperature measured manually and the one computed automatically and reject the alternative.

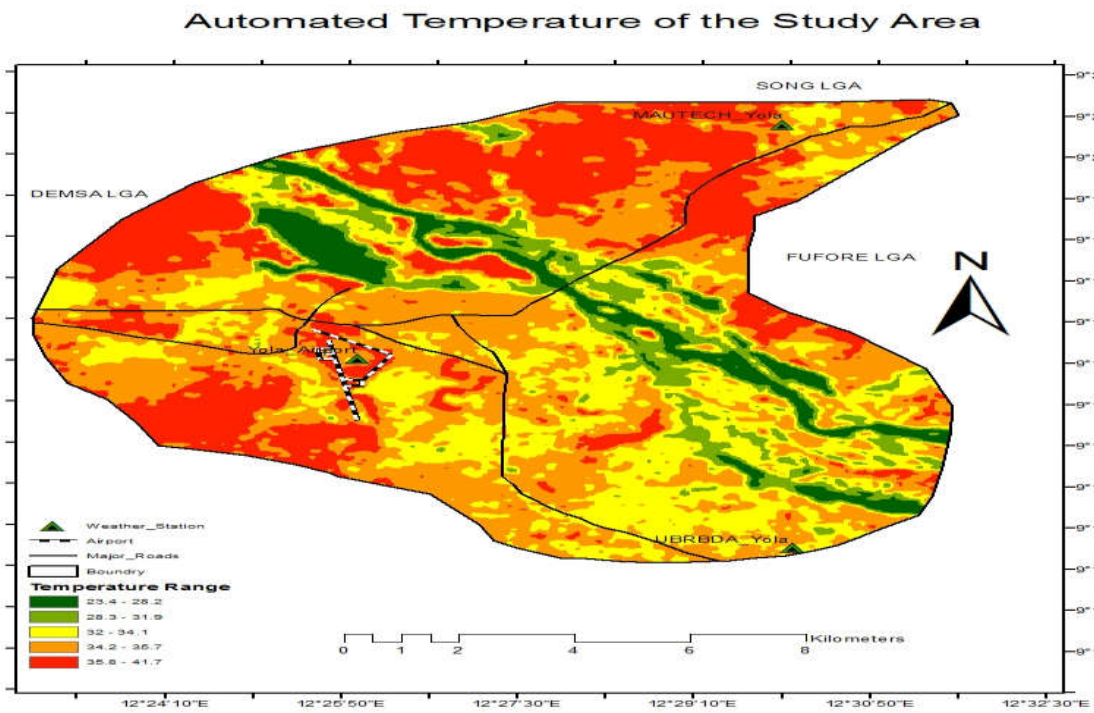

Figure3: Landsat8 Band10 Automated Temperature

T- test was then used to test for significance of the variation at 5% level of significance between the results of landsat8band10 and ground measurement for each station. The results show that at MAUTECH station, the t-value 1.40 which is less than the critical value at chosen significant level, which suggests that the difference is not significant at the station. T-value for Yola Airport station is 036 is less than the critical value at chosen significant level this also indicates the difference between the temperature derived and ground measurement in the station is not significant.

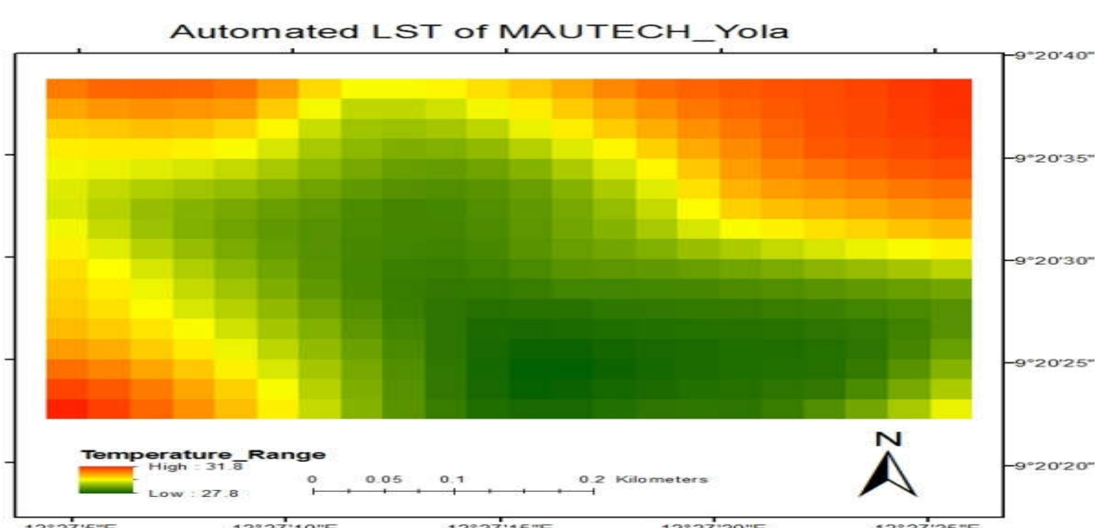

Figure: 4 Automated LST of MAUTECH Yola

Lastly the t-value of the T-test results of UBRBDA is 0.33 which is also less than the critical value at chosen significant level which shows that the difference between the results at the station is not significant. This confirms the earlier analysis of variance (ANOVA) results, which showed that there was variations in the mean measured temperature and automated derived temperature from landsat 8 band10 in the study area but the variations was not statistically significant. As such we accept the null hypothesis which says the variations between the results of temperature manually measured and automatically generated is not significant and reject the alternative.

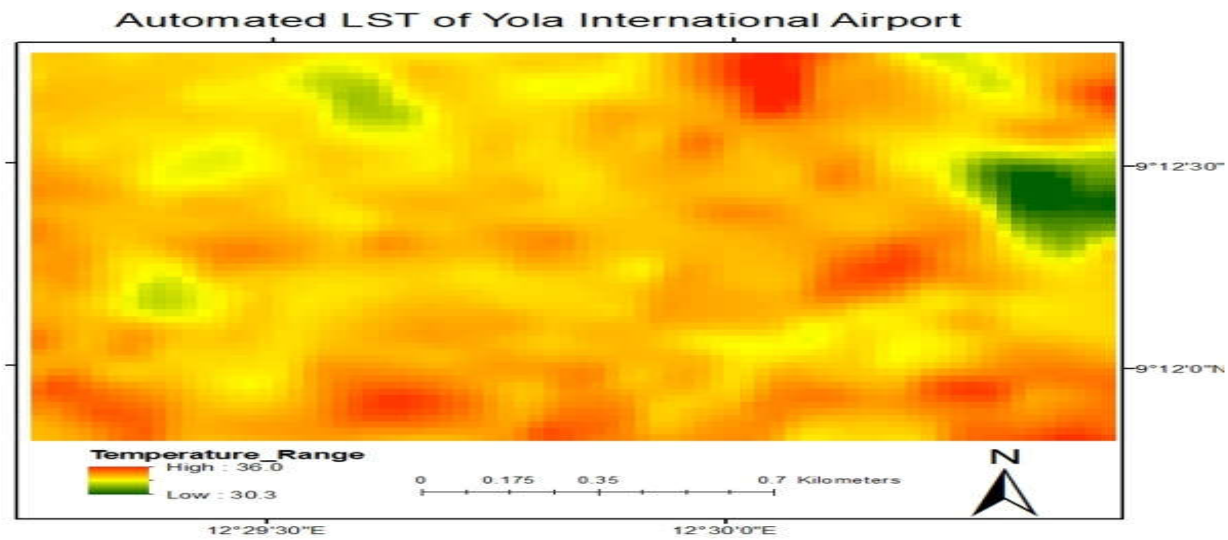

Figure5: Automated LST of Yola International Airport

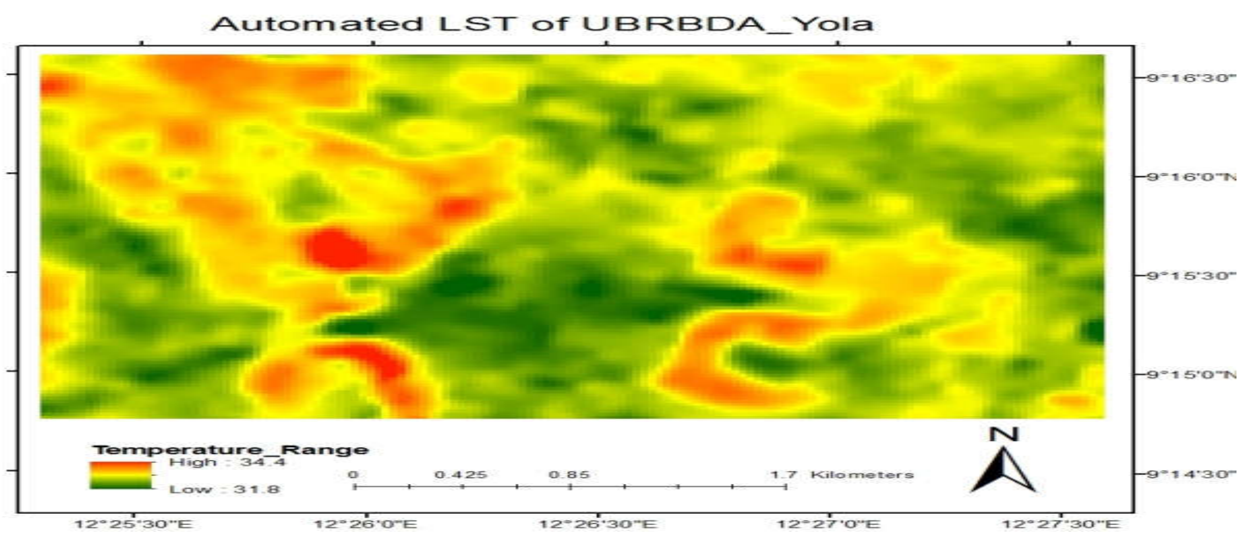

Figure: 6. Automated LST of UBRBDA

The bias (differences between the automated derived temperature from Landsat8 band10 and the ground measurement), standard deviation of the bias and the root mean standard error for each measurement site was calculated and the results are presented on table4.

The results show that there is negative bias at MAUTECH and UBRBDA stations, indicating a slight overestimation, while at the airport the results show positive bias, meaning there is an underestimation at the station. The bias can be attributed to common errors that are likely to be found, which may include instrument error, human error or the timing for the temperature measurement

LST_{GM} = Ground measured land surface temperature at station

To determined which method is more accurate with less error, mean standard deviations (SD) and the mean standard errors (MSE) for the ground measured temperature and the automated temperatures were calculated. Average for manually measured temperature mean SD = 3.32 and MSE = 3.35 while the automated temperature mean SD = 2.90 and MSE = 2.05. The results show higher accuracy for temperatures derived using landsat8 band10 when compared with manually measured temperature in Greater Yola. Thus, it can be concluded by the results of this analysis that more precision will be obtained when researches are conducted with temperature data generated automatically from landsat8 band10 images in the study area.

Taable 4 : Derived LST using TIRS Band10, and ground measured and the difference between them for the study area

	LST Band10 MAUTECH 12°30'17.811" E	$LST_{GM}1$ MAUTECH 12°30'17.811" E 9°20',	LST Band10 YOLA AIRPORT 12°25'42.941" E 9°16'2.035"N	LST_{GM} YOLA AIRPORT 12°25'42.941" E	LST Band10 UBRBDA 12°33'19.093" E	$LST_{GM}3$ UBRBDA 12°33'19.093" E 9°10'15.807" N
Max	31.8 °C	32 °C	36.0 °C	35.7 °C	34.4 °C	34.6 °C
Min	27.8°C	24°C	30.3 °C	27.3 °C	31.8 °C	31.4 °C
Mean	29.8°C	30.5°C	33.15 °C	31.5 °C	33.1 °C	33.0 °C
Bias	-0.7		2.7		-0.100	
SE	2.83		1.91		0.424	
RMSE	2.00		1.35		0.300	

This result is in agreement with the work of Xiaolei Y *et al* (2014) who compared land surface temperature retrieved from landsat8, ground measurement and other equation based methods and the work of Jimenez-Munoz *et al* (2006) who study error sources on temperature retrieved from thermal infrared TIRS channels. However, there are limitations attached to the used of Landsat images especially in a developing country like Nigeria. This has to do with inadequate finance for image acquisition, inadequate personnel and poor finance for image acquisition, inadequate personnel and poor communication network in downloading satellite images among others.

Conclusion

The results obtained in this study show negative bias at MAUTECH and UBRBDA area sites, indicating a slight overestimation from landsat8 band10, whereas at the airport the result shows positive bias, meaning there is an underestimation at the site. However on an average, there is a slight over estimation. Higher accuracy for temperatures derived using landsat8 band10, when compared with manually measured temperature in Greater Yola was also observed. Variations in temperatures data derived from landsat8 band10 within the study area was revealed, but the variations were not statistically significant. Therefore it was concluded that higher accuracy and greater precision of temperature data can be obtained when temperature data were derived from landsat8 band10 in the study area for thermal or temperature related researches such as urban heat island study, thermal comfort and thermal comfort indices.

Recommendations

This study recommends the use of landsat8 band10 image for the collection of temperature data for use in research work in the study area based on the results of the findings of this research

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