

APPLICABILITY OF GEOGRAPHICAL INFORMATION SYSTEM AND REMOTE SENSING TECHNIQUES IN INVESTIGATING THE OCCURRENCE OF HEAT WAVES: A CASE STUDY OF NGABU

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ABSTRACT

Interest in heatwaves and extreme heat events have increased globally over the past few years following the high profile of heat events across the globe. Heatwaves historically received little attention but with the rising temperatures on average, they are becoming more variable and extreme coupled with the increase in the concentration of greenhouse gases in the atmosphere. Several studies have been conducted worldwide addressing the phenomena with different approaches. In this research, the occurrence of heatwaves at Ngabu was investigated using remote sensing techniques and geographical information systems. The study examined the changes in land surface temperature for Ngabu from 2000 to 2020 and determined the occurrence of heatwaves using a percentile-based threshold justified by literature and study area climatology. The United States Geological Survey and Malawi meteorological department provided data used in the study. The results revealed that there are significant changes in LSTs between 2000 and 2020 and heatwaves are occurring of events influenced by high temperatures. The changes in LSTs can be attributed to reduction in vegetation and land use/ landcover change. Future climate trends is predicted to increase the magnitude of heatwave events; therefore, it is recommended to develop adequate adaptation, preventive strategies for societal vulnerability reducing and creating a culture of safety.

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ACRONYMS/ABBREVIATIONS

DCCMS	Department of Climate Change and Meteorological Services

WHO	World Health Organization
DoDMA	Department of Disaster Management Affairs
IPCC	Intergovernmental Panel on Climate Change
LSTs	Land Surface Temperatures
TM	Thematic Mapper
RS	Remote Sensing
GIS	Geographical Information System
USGS	United States Geological Survey
OLI	Operational Land Imager
QGIS	Quantum GIS
TM	Thematic Mapper
TOA	Top of Atmosphere
TIR	Thermal Infrared
NDVI	Normalized Difference Vegetation Index

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1. INTRODUCTION

Heatwaves seriously affect the productivity and the daily lifestyle of citizenry. Therefore, they carry great risks and uncertainties for the further development of nations. In recent years, extreme heatwave events have occurred frequently in many parts of the world causing serious casualties and property losses. For example, in 2003, Western Europe experienced one of its worst heat waves that resulted in an estimated 70,000 heat-related deaths (Cheung and Robine, 2008). France was the worst affected country with over 14,800-recorded heat-related deaths (Claessens et al., 2004). In 2010, a heatwave lasted for three weeks in Russia and killed approximately 56,000 people (https://www.reuters.com/article/us-russia-heat-deaths-idUSTRE6904LB20101025).
Investigating the occurrence of heatwaves can inform decision-makers and the public about the extent of a hazard and its possible consequences. Remote sensing techniques and geographic information systems are particularly useful during this context as they are now unrestrictedly available at a worldwide scale with high spatial resolution and with long-term records. Many satellite-derived products relevant to the hydrological (soil moisture, terrestrial water storage), vegetation (leaf area index, biomass) and, energy (land surface temperature, albedo) cycles are readily available.

The Intergovernmental Panel on Climate Change (IPCC) classified heatwaves as one of the extreme weather events associated with climate change (Field et al., 2012). Furthermore, according to the Firth Assessment IPCC report (IPCC, 2013), more frequent and intense heatwaves are expected in response to recent climate change. Climate change estimates to increase the frequency, duration and, severity of extreme heatwave events (IPCC, 2007; Tebaldi and Meehl, 2004). Malawi could as well expect such events with serious impacts hence need to prepare for them.

Heatwaves form during a stagnating, stationary, high weather situation when a high-pressure system slowly subsidizing in the upper atmosphere traps heat near the ground. The high-temperature events during heatwaves can cause strong negative impacts ranging from human health, cardiovascular and respiratory damage even death (Jahan et al., 2019; Mansouri et al., 2015; Schwartz et al., 2018), increased demand for water and electricity surges, putting pressure on water and electricity supplies (Wood et al., 2016). They can affect labour efficiency and reduce productivity (Hansen et al.,

2019), heatwaves also cause drought, which affects crop growth, and reduce crop yield (Mikkelsen

Frequently heatwaves do not cause dramatic visual impacts just as many other extreme weather events as such they are disregarded. In Malawi, heatwaves being an emerging hazard receives little attention and not recognized by the public. They also lack documentation. The table below summarizes heatwave events in Malawi.

Heatwave events	Impact
Late October 2019	Tea leaves were scorched in Mulanje (source: www.worldteanews.com) Affected livelihoods
30 October 2019	Malawians advised staying hydrated (source: www.malawi24.com)
2 November 2019	Suspension of wearing wigs and gowns in the courtroom by Malawi constitutional court (source: www.africa.cgtn.com) Reported by Jerry Omondi
25 November 2020	Three students were knocked down (source: www.nyasatimes.com)

Heatwave impacts are largely preventable if populations are prepared. Identifying the specific locations of vulnerable populations to heat is beneficial for targeting public health interventions (Keramitsoglou et al., 2013). The delineation of high-risk zones is critical for the adaptation of effective targeted measures in areas of public activity. The evaluation of extreme events may support decision-makers, stakeholders and, interested parties to agree on the preventive measures to take and to prepare in ways to avoid the immediate heatwave consequences. Studying heatwaves in Malawi can provide a basis for heatwave risk reduction beyond mere warnings and effectively help

the government to implement clear and efficient policies to prevent and address the problems impo

This study combined the techniques of remote sensing and geographic information system (GIS) to calculate land surface temperatures (LST) and to determine heatwave occurrence at Ngabu. Remote sensing is defined as the science and art of obtaining information about an object, area or, phenomenon through the analysis of data acquired by a device that is not in contact with the object, area or, phenomenon under investigation(Tomlinson et al., 2011). GIS is an invaluable tool for the integration, analysis and, visualization of spatial information. Geospatial databases help bring multiple datasets together for a comprehensive analysis of research questions. Remote sensing usage is growing within fields of meteorology and climatology and works in unison with the utelization of GIS for spatial analysis. The advancement in these geospatial technologies for mapping heatwave-prone areas influence monitoring and assessment of impacts to reduce risk caused by heatwaves (Sanyal J, 2005). GIS together with remote sensing data offers a variety of techniques such as measurements of LST through thermal band sensors (thermal mapping) which detect thermal radiation emitted by the ground objects. Thermal data permit the researcher to quantify and map temperatures, which assist in the mapping and identification of heatwave hazard areas.

Several studies that applied remote sensing and GIS exists in this general area. For example, see Albergel et al. (2019) for an overview of monitoring and forecasting heatwave impact on vegetation state of the 2018 summer heatwave over Western Europe (Albergel et al., 2019). Stachlewska et al. (2017) recognized the potential for applying remote sensing in the study of effect of heatwave conditions on aerosol Optical properties derived from satellite and ground-based remote sensing over Poland. Aekbal et al. (2013) also used remote sensing in the investigation of factors contributing to the formation of an urban heat island in Putrajaya, Malaysia. Quantification of the urbanization and its impacts towards the thermal behaviour of an urban area used land surface/land cover and land surface temperature maps. However, this study differs as it details the applicability of remote sensing technique and geographical information in investigating heatwave occurrence at Ngabu.

1.1. PROBLEM STATEMENT

Many studies conducted by several researchers focus on well-known disasters that

occur in the country but no study was conducted on heatwaves. There is little information that can s

Extreme hot temperature anomalies experienced in the lower shire valley pose a greater risk of heat wave hazard occurrence in the area. Different parts of the country register higher temperatures but for Chikwawa and Nsanje the situation is unbearable. Due to acclimatization, people suffer in silence. Acclimatization means an adaptive response to a hot environment in which an individual “learns” to better tolerate exposure to excessive heat (Knochel and Reed, 1994; Guyton and Hall, 2000; Kinney et al., 2008). The country records high temperatures particularly, the lower shire valley but the difference is that the temperatures being experienced currently are quite extensive, almost cutting across the country. October is the hottest month in Malawi. However, the hotness Malawians have experienced in the past three years surpasses true description of the summer months. Ngabu is one of the traditional authority in Chikwawa that registers higher temperatures, which is a hazard that leads to heatwaves if it persists for a number of days.

In the face of climate change and associated warming, communities need to adapt and mitigate the effects of heat waves. Usually, the population is also not fully aware of the risk posed by extreme heat events (Australia & Bandala, 2018). Therefore, any effort that spread heat wave events relevance helps to mobilize governments, social organizations and individuals towards better prevention and a greater awareness is of great importance before, during and after a heat wave event. Combination of reliable data with local expertise that makes better prediction of heatwave events.

1.2. OBJECTIVES

1.2.1. Main Objective

To assess heatwave occurrence at Ngabu in Chikwawa.

1.2.2. Specific Objective

- To analyze changes in land surface temperatures at Ngabu between 2000 and 2020.
- To determine the occurrence of heat waves in the study area.

1.3. RESEARCH QUESTIONS

- Which areas are at risk to heatwaves?
- How big is the area where heatwaves are occurring?
- What are the observable changes in land surface temperatures of the study area?

1.4. SIGNIFICANCE OF STUDY

This research will make an important contribution to understanding of what heat waves are and how are people living in the lower shire valley susceptible to the hazard. Relatively little or research has been carried out on the occurrence of heat waves here in Malawi despite the nation being on the list of SADC heat wave watch. This research will help fill the gap knowledge and inform decision makers and the public to be alert to impeding dangerous hot weather extremes and make better informed decisions and plans. It will also help in the implementation of a range of actions designed protect people to the increasing hot weather extremes (Heatwaves and Health: Guidance on Warning-System Development, 2015). Furthermore, it will help in the formulation and/or enforcement of clear and efficient policies to minimize and address the issues imposed by heatwaves on citizens. The identification of at-risk areas will mobilize actions to manage the hazard.

2. LITERATURE REVIEW

2.1. INTRODUCTION

Recently heat waves became one among the deadliest natural hazards recognized as 'silent killers". This has made many researchers all over the world to conduct researches in regards to heatwaves with different objectives and methodological approaches. However, there is insufficient information in this country on heatwaves, their occurrence and impact in different sectors of life. Therefore, this study objective was to assess the occurrence of heatwaves by applying remote sensing techniques and geographic information system. This section reviews literature written on the same by other researchers focusing much on the application of remote sensing and GIS and heatwave definitions and thresholds used in different studies.

2.2. Understanding Heatwaves Events: Definitions and Thresholds

Even though there is no universal consensus definition of a heatwave despite the strides in the field, a plethora of definitions within the literature each that specialize in a specific application or target group. A heatwave refers to prolonged periods of high temperatures and excess heat with significant impact on humans, regional economies and natural ecosystems. The temperatures rise above a particular threshold (either percentile based or fixed value) for a number of consecutive days. Ta et al. (2007) describes that a heatwave occur when the temperature exceeds a particular threshold for a given number of consecutive days. Consistent with this understanding of a heat wave Keeling's and Waylen's (2014) constructed complete definition of a heatwave, which involve two main variables 1) a heat threshold and 2) the consecutive number of days over which the temperature exceeds the edge (threshold). These authors further said that the 2 variables vary in different locations counting on the varying influence of temperature.

He et al. (2019) defines a heatwave employing a temperature threshold where a heatwave event is defined because the highest temperature (T_{max}) and lowest temperature (T_{min}) for a given day that are greater than the 90 percent of the values for the other days of the year with a number of continuous days. In their research, if the interval between the heat events is less than three days then the events were considered one single event otherwise the events were considered multiple or independent events.

According to the World Meteorological Organization (WMO, 2009) a heat wave is a period of 'marked unusual hot weather over a region persisting for at least two consecutive days during the hot period of the year based on the local climatology conditions with thermal conditions recorded above a given threshold. The WMO also identifies a heat wave event when the daily maximum temperature of more than five consecutive days exceeds an average maximum temperature by 5^0c. Another definition of a heatwave by WHO is: a marked unusual hot weather over a region persisting at least two consecutive days during the hot period of the year based on local climatological conditions with thermal conditions recorded above given threshold.

Beniston (2004) discussed that heatwave is when temperature exceeds the 90^{th} percentile of the summer maximum temperatures in three successive days. while Gosling et al (2007) defined heatwaves as periods lasting three or more consecutive days when the daily maximum temperature is equal to or greater than 95^{th} percentile of the summer maximum temperature over the whole period of record. Furthermore, a heatwave is defined as a period of at least three consecutive days for which daily maximum temperature on each day exceeds the 90th percentile threshold of climatological daily maximum temperatures, centred on a 31 day window for an outlined study period (Russo, Wilson & Pozzoli, 2019)

Martinez and Bandala (2016) defines a heat wave as a period usually of several days, when the temperature significantly higher than average temperatures are registered. They argue that the importance of a heat wave is more evident when their effect on human health are considered. At this point, because of corresponding consequences the definition of a heat wave temperature threshold becomes necessary in order to define when temperature values are higher than average to be considered a heat wave. Several thresholds or heat indexes are developed everyday across countries to determine danger. A threshold is set by defining specific or limit percentile and they are local in nature. In South Australia, the Bureau of Meteorology defines a heatwave as a period of maximum temperatures of 35 ^{0}C or over, for a period of five or more consecutive days or three or more consecutive days of temperature of 40 ^{0}C or above (Mayner et al., 2010).

Khan et al. (2019) proposed a number of heatwave related indices considering both

daily maximum and minimum temperature to assess the changes in different characteristics of heat

All the definitions provided by many researchers explain one-thing that constitute a heatwave that is temperatures must exceed a certain threshold for a number of days. This threshold is either a fixed limit or percentile based dependent on the mortality rate or climatology of a region. For example in Mexico City, a threshold for heatwave events is equal to a certain number based on the mortality rate. The threshold is determined based on the criteria of an identified temperature value where mortality increases over average values that lead to heatwaves (Erick & F, 2018). The second group of thresholds is defined by statistical analysis, usually selecting temperature value percentile as the upper boundary. Some heat indices use the average daily temperature as reference temperature, while others, most of them use maximum temperature values. As for extreme temperature events duration, some indices consider at least a heatwave when temperature exceeds the threshold limit during two or more days while others estimate a heatwave occurs when the limit is exceeded in a single day (Erick & F, 2018).

However, the WHO task team on the definition of extreme weather and climate events encourages the report of the number of days in a month above percentile 90th. In France, after the 2003 heatwave, a warning system was defined with an index based on the maximum and minimum temperatures on average of 3 days. Limits were determined by studying excess mortality caused by extreme heat and the 98th percentile temperature value was used in the 2004 warning system. Subsequently in 2005, the limits were updated for some cities based on a more detailed analysis, adopting the 99.5th temperature value percentile as the threshold.

This study chose the percentile-based method as it gives the true reflection of the region of interest. Nevertheless, mortality information may not be available or the cost of a study may not be suitable to many communities and protecting of the population remains important. In this cases, it is advisable to use a boundary based only on maximum temperature with a consecutive threshold used in national or international experience, for example the 90th percentile, while detailed studies are conducted (Erick & F, 2018). This study adopted the percentile-based threshold in meeting its objectives.

2.3. Heatwave Causes and Impacts

Heatwaves are significant but underestimated emerging hazard. While they do not cause significant damage to the landscape similar to cyclones and earthquakes, the impacts of heatwaves are nonetheless serious and costly. High-pressure system that hovers over an area cause heatwaves. The high-pressure system traps air beneath the surface, normally air circles the globe in large prevailing winds, however if trapped over one region it is allowed to warm to uncharacteristic temperatures due to sunlight. So the high pressure system forces the air downwards and being trapped it is unable to rise into the cooler upper atmosphere as hot air on the ground cannot escape until a new high pressure system is strong enough to push the high pressure system away . Heat waves negative impacts range from decreased agricultural yields reduced economic productivity to human health problems. The occurrence of heat waves may lead to illness, particularly in children and the elderly, which may increase mortality rate. Heat waves can affect water supply through increased evaporation rates, and can damage crop and vegetation. They may minimize crop production since environmental factors such as temperature and soil moisture are determinant factors of yield. Heat waves can induce wildfires because they usually occur during droughts, due to enhanced subsidence and coinciding with dry vegetation (Mbokodo et al., 2020) and prevent precipitation.

2.4. Application of Remote Sensing and Geographic Information System in Heatwave Studies

Remote sensing and GIS are key applications in global-change science. They are widely applied in several sectors to understand better scientific processes. Application of GIS and remote sensing include thermal mapping, hazard modelling and mitigation, integration, analysis and visualization of spatial data. By integrating high-resolution and medium-resolution satellite imagery with other geospatial information, several land surface parameters including land surface temperatures can been investigated. Remote sensed data offer the ability to estimate land surface temperature for a multitude of points across an entire region. The use of just a single instrument in measuring LST has advantage over data of network terrestrial thermometers that can potentially be both inconsistent in their readings and insufficient in their distribution across the region of interest (Dousset, Gourmelon & Mauri, 2007).

Measurement of land surface using remote sensing is possible via thermal band sensors on publica

In the study of urban heatwave hazard and risk assessment, Jedlovec et al. (2017) applied remote sensing techniques through the use of moderate resolution thermal imagery from earth orbiting satellites to develop a heatwave risk map as a potential warning tool for public health decision makes and the general public. In their work, extreme heatwave events were examined in order to develop a satellite-based heatwave hazard and risk product. A heatwave hazard map was developed using satellite-derived ambient temperature maps, locally derived temperature threshold indicating extreme conditions and the combination of temperature data with demographic information to create a heatwave risk map. Thermal data from NASA satellites with afternoon observations times were used to derive estimates of maximum land surface temperature (LST) over urban regions (Jedlovec et al., 2017). While the satellite observation approach is subject to some limitations, it has the potential to capture more spatial variation than the existing excessive heat warnings. Better warnings of the potential hazards may help lower deaths associated with heatwaves.

Meggio et al. (2019) evaluated the potential of satellite based remote sensing in detecting the effects of high temperatures on grapevines in a South Australia vineyard. In their study of assessing the feasibility of using sentinel-2, imagery to quantify the impact of heatwaves on irrigated vineyards satellite data enabled the implementation of cost effective method of evaluating the effects of heatwaves on the vineyards. Buscail et al. (2014) in mapping heatwave risk at the community level for public health action demonstrated a simple and flexible conceptual framework relying upon satellite thermal data and other digital data with the goal of easily reproducing this framework in a variety of urban configuration. Acquired during a localized heatwave Landsat images were used to estimate land surface temperature and derive a hazard index. All these studies shows the power of remote sensing and GIS in carrying out heatwave studies. Therefore, this study applied the techniques to investigate heatwave occurrence through mapping and reclassification of land surface temperatures to identify heatwave areas using a percentile-based threshold based on literature.

3. METHODOLOGY

3.1. Study Area

Ngabu is located in the southern region of Malawi in Chikwawa district. It has a population of about 157, 742 and is the largest traditional authority in Chikwawa. Southern Malawi is mostly low-lying and drier than central and northern regions and experiences only one short rainy season between December and February (Future Climate for Africa, 2017). The altitude drops to sea level and consequently, characterized by higher temperatures, which range from 9^0c to 39^0c on average. The highest maximum temperatures far reach 49^0c during the summer months between October and November in the Lower Shire Valley and it becomes extensive. The only months when the temperatures are bearable is June, July and August. The Shire Valley, Nsanje and Chikwawa districts in the south, are most at risk to climatological hazards such as floods, dry spells, droughts, pest and disease and heat waves(In, 2019). Ngabu was chosen for this specific study because of notoriously high summer temperatures that make it prone to heat waves. It also often experiences high humidity and low wind speed and when such conditions coincide with high temperatures, the frequency of casualties due to heat stress increase. The fact that Ngabu is a location where increased temperatures may have dramatic impact emphasizes the importance of understanding the trend of occurrence of heat waves in the area.

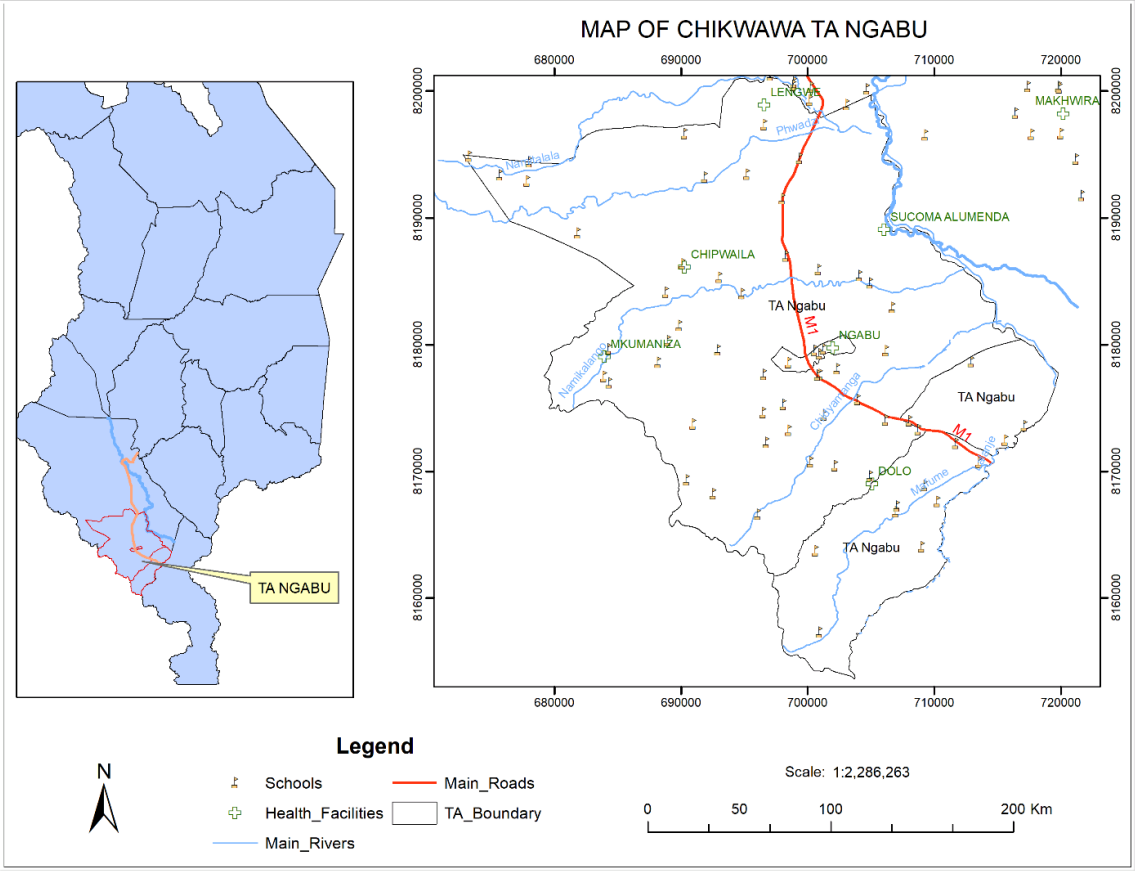


Figure 1: Study area map for Ngabu

3.2. Datasets and Data collection

The department of climate change and meteorological services provided temperature data for the period of twenty years (2000-2020) for Ngabu. This temperature data consisted of daily maximum and minimum temperature. The data was used to identify the hottest 90th percentile days based on the air temperature over the preceding 20 years for the study area. The temperature threshold was used to identify pixels in the satellite

derived LST maps that exceed the heatwave hazard value to classify it as heatwave hazard zone for

Landsat 5 Thematic Mapper sensor (TM) and Landsat 8 Operational Land Imager (OLI) images for Ngabu were downloaded from United States Geological Survey website (https://glovis.usgs.gov). The Landsat 8OLI and Thermal Infrared Sensor (TIRS) images consists of nine spectral bands with a spatial resolution of 30 meters for bands ranging 1 to 7 and 9. Band 10 was used for estimating land surface temperature. Landsat 5TM consists of 7 bands with a spatial resolution of 30 meters for the visible, nears infrared and short wave infrared bands. Band 6H was used for estimating land surface temperature.

To avoid the effects of seasonality, all images were acquired during the dry season (October and November). Moreover, the choice of the imageries was done in consideration of the cloud cover and images with minimum cloud cover were selected. The choice of Landsat dataset was also guided by its availability and quality, which is multispectral, medium spatial resolution imagery. Landsat was chosen because it provides medium to high-resolution remote sensing data that is often used for small-scale retrievals or detailed studies that require high-resolution imagery just as this study is. Table 1 below presents datasets used in the study.

Table 2: Dataset Information Table

Data type	resolution	Acquisition date	Path/Row	Level of processing	source
Landsat 5TM	30m TIRS 120m	8 October, 2000	167/071	Level 1	USGS
Landsat 5TM	30m TIRS 120m	18 October, 2010	167/071	Level 1	USGS
Landsat 8OLI	30m TIRS 100m	13 October, 2015	167/071	Level 1	USGS
Landsat 8OLI	30m TIRS	31 October, 2016	167/071	Level 1	USGS

	100m				
Landsat 8OLI	30m TIRS 100m	8 October 2019	167/071	Level 1	USGS
Landsat 8OLI	30m TIRS 100m	10 October 2020	167/071	Level 1	USGS
Temperature	Daily	2000-2020			MET, Department, Malawi

3.3. Data analysis

3.3.1. Land surface temperature estimation and change analysis

LST is the radiative skin temperature of the land derived from infrared radiation. In general, terms, LST means the hotness of the surface of earth in a particular location. From RS satellites perspective, the surface is whatever it sees when it looks through the atmosphere to the ground. Remotely sensed data is widely used for LST estimation by using thermal data. Thermal infrared bands and NDVI are used to generate LST. The thermal bands of Landsat 5TM and Landsat 8OLI sensor were used to derive LSTs over the study area (NASA, 2010).

3.3.1.1. Retrieval of satellite brightness temperature (BT) from the landsat-8 images

Step 1: Conversion of Digital Numbers to Spectral Radiance

Digital numbers (DNs) store thermal data in the Landsat sensor and provide a manner of representing pixels that are not yet calibrated and converted into radiance units. To calculate LST, the DN of the thermal infrared band is converted into spectral radiance (L□□) by using equation 1.

L□□ = ((LMAX□□ – LMIN□□)/ (QCALMAX – QCALMIN) * (QCAL – QCALMIN) + LMIN□□ (Equation 1)

Where: L□□ is the spectral radiance at the sensor's aperture in $Wm^{-2}sr^{-1}\mu m^{-1}$; LMIN□□ is

the spectral radiance that is scaled to QCALMIN; LMAX□□ is the spectral radiance that is scaled to Q

The Landsat Project Office (2001) supplied the values, with reference made to the metadata, which accompanied the Landsat images.

Step 2: Conversion of band radiance into Brightness Temperature in Celsius

After the digital numbers (DNs) were converted to reflection, the thermal bands spectral radiance was converted to brightness temperature (BT). This was accomplished using the thermal constants provided by the metadata file. The following equation is used.

BT = (Equation 2)

Where BT is the satellite brightness temperature in Celsius and K1 and K2, represent thermal constants from the metadata.

Brightness temperatures assume that the Earth is a blackbody, which it is not, and this can lead to errors in surface temperature. In order to minimize these errors. Emissivity correction was done to retrieve the LST from BT.

Step 3: Estimation of Spectral Emissivity Using the NDVI Technique

Landsat red and near-infrared bands were used for calculating Normal Difference Vegetation Index (NDVI). The basic premise of calculating the NDVI is essential because the amount of vegetation present in an essential factor, and the NDVI helps to understand the general vegetation condition. Below is the formula for acquiring emissivity:

□□ = 1.0094 + 0.047 ln (NDVI) (Equation 3)

NDVI was calculated using the following formula:

NDVI = (Equation 4)

Where NIR = Near Infrared wave band (band 5 of Landsat 8)

RED = the reflectance of visible red wave band (band 4 of Landsat 8)

Step 4: Conversion of Brightness Temperature to LST

LST based on satellite brightness temperature was calculated by the following equation.

LST = (Equation 5)

Where LST = land surface temperatures

T_{sensor} = band 10 brightness temperature in K

□□ = the wavelength of emitted radiance in meters

□□ = 1.438* 10^{-2}Mk

□□ = surface emissivity

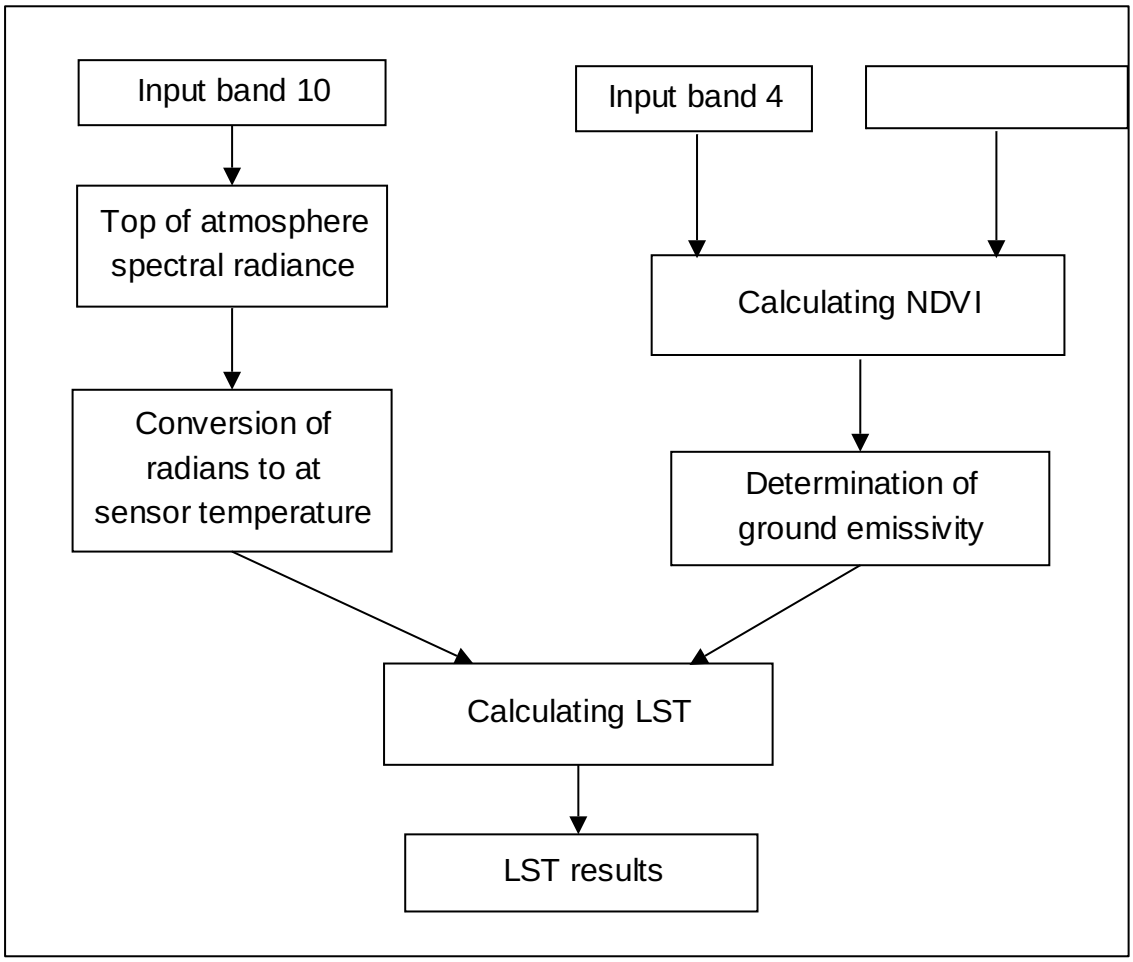


Figure 2: Flowchart Landsat-8 OLI image processing methodology

3.3.2. Retrieval of satellite brightness temperature (BT) from the landsat-5TM images

Step 1: Infrared thermal band was selected which is band 6 for Landsat-5

Step 2: Conversion of digital number to spectral radiance

The DNS of band 6H from the Landsat image were first converted to spectral radiance. Amount of spectral radiation is equal to radiance multiplicative scaling factor for the band multiplied by DN value of the pixel plus radiance additive scaling factor for the band. Here is the formula.

L□□ = **(**Equation 6)

Step 3: Conversion of spectral radiance to brightness temperature in kelvins

Spectral radiance values for band 6H were converted to radiant surface temperature under an assumption of uniform emissivity using pre-launch calibration constants for the Landsat 5TM sensor implemented into the following equation:

T **=** (Equation 7)

T is brightness temperature (in kelvin); K1 and K2 are correction factors (calibration constants) provided by the USGS in the metadata file.

L□□ = spectral radiance at sensor in $Wm^{-2}sr^{-1}\mu m^{-1}$

Table 3: Constants for band 6 and band 10

Band type	K1	K2
Band 6	607.76	1260.56
Band 10	774.8853	1321.0789

Under an assumption of uniform emissivity, spectral radiance values are converted to

brightness temperature, which means that the calculated brightness temperatures are referred to a b

Step 4: Conversion of brightness temperature to LST

The calculated brightness temperature was corrected for emissivity using the following equation:

LST = T/ (1 + □□T/ρ) In□□ (Equation 8)

Where LST is land surface temperature (in Kelvin); T is brightness temperature (in kelvin); □□ is the wavelength of emitted radiance (11.5μm); ρ is hx*c*/σ ($1.438x10^{-2}$m K); h is Plank's constant ($6.26x10^{-34}$J s); c is the velocity of light ($2.998x10^{8}$ m/sec); σ is Stefan Boltzmann's constant ($1.38x10^{-23}$ J K^{-1}); and □□ is emissivity.

Finally, the LST was converted into Celsius by subtracting 273.15 from the value calculated in Equation (7) as indicated in the following equation.

LST (in °c) = (Equation 9)

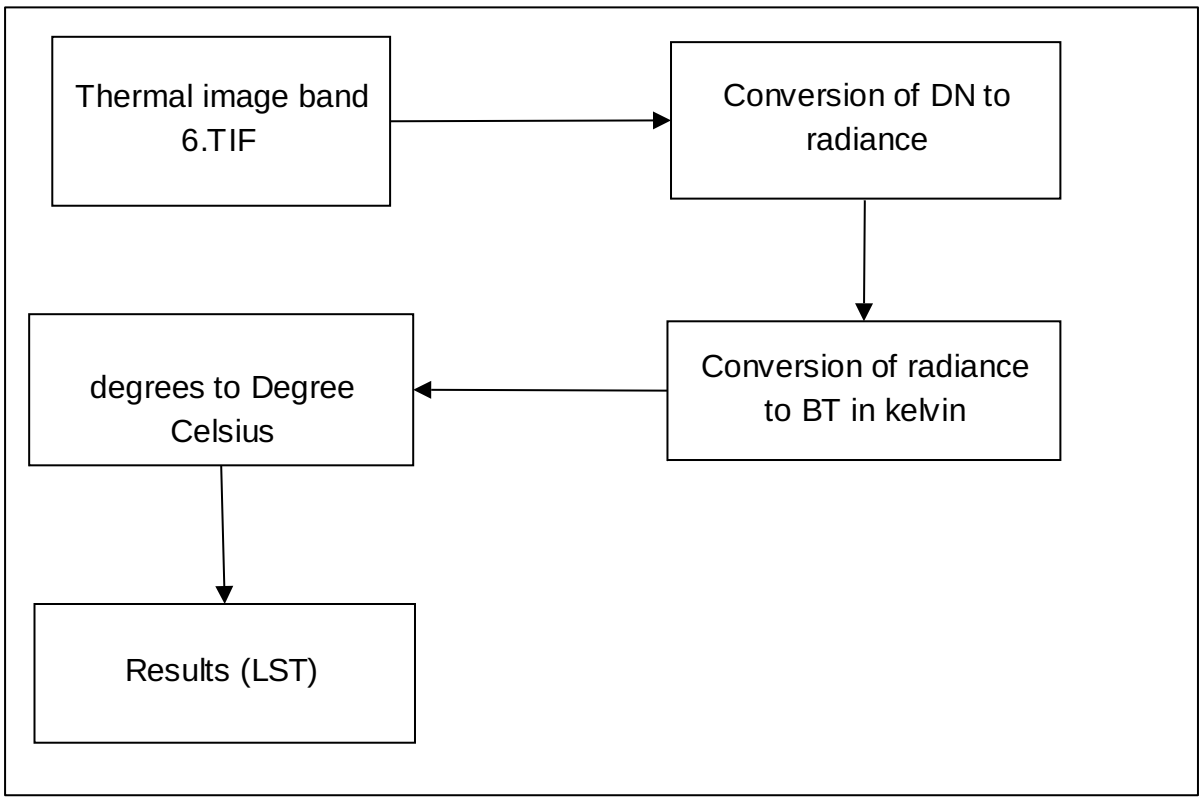


Figure 3: Flowchart for landsat-5TM image processing

3.3.3. Determining Heatwave Threshold

No absolute universal value defines what extreme heat is, heatwaves are relative to location's climate. This means that climatological conditions that constitute a heat wave in one place cannot in another *(Heatwaves and Health: Guidance on Warning-System Development*, 2015). Therefore, as discussed in chapter 2, there are two ways of determining threshold (either fixed value or percentile-based). This study adopted the latter (90th percentile) of the climatological distribution of daily maximum temperature as widely used in climate related researches (Perkins and Alexander, 2013). The 90^{th} percentile was calculated from the ranked temperature averages of the study period using Microsoft Excel. 38^{o}C was the resulting threshold.

3.3.4. Determining Heat wave Occurrence

In order to determine the occurrence of heatwaves, land surface temperature maps for 2015, 2019 and 2020 were classified into zones of heatwaves using spatial analyst tools embedded in ArcGIS software. The choice of these years was guided by the occurrence of heatwaves in those years. The reclassification was based on the calculated threshold whereby all areas with this temperature threshold and above were considered as heatwave zones while those below were considered as no heatwave zones. Boolean output (true or false/ 1 or 0) was used to demarcate these two zones. All areas above the threshold temperature were assigned one (true) and the areas below the temperature threshold were assigned a zero (false). Villages in the heatwave risk zone were identified.

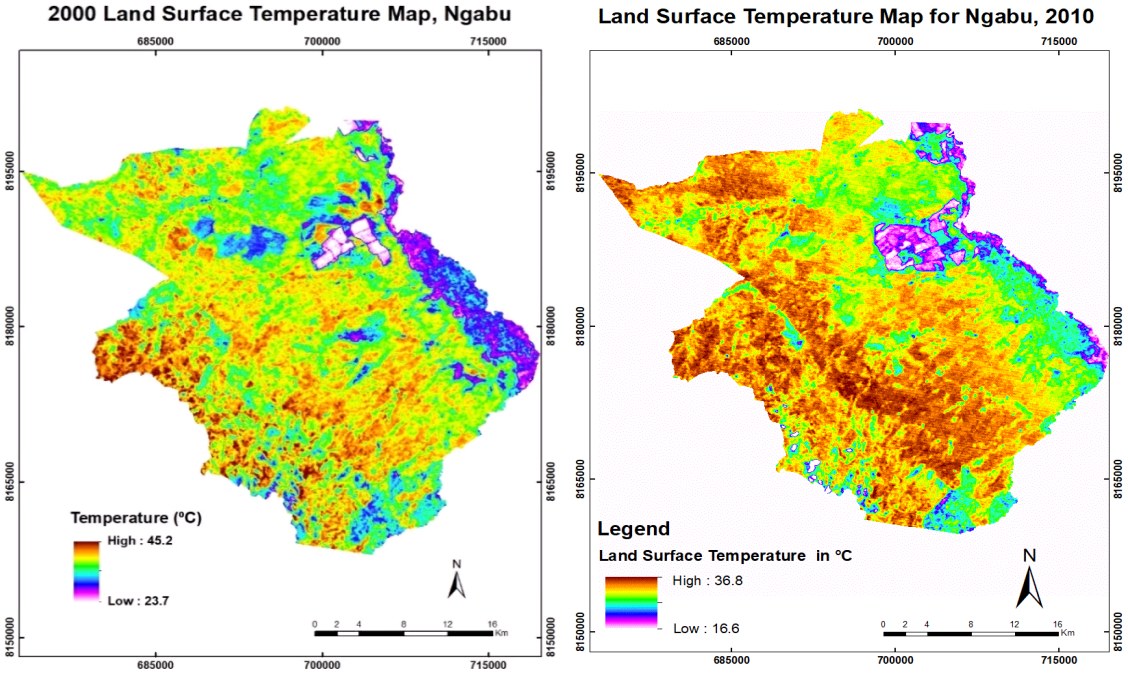
4. RESULTS AND DISCUSSION

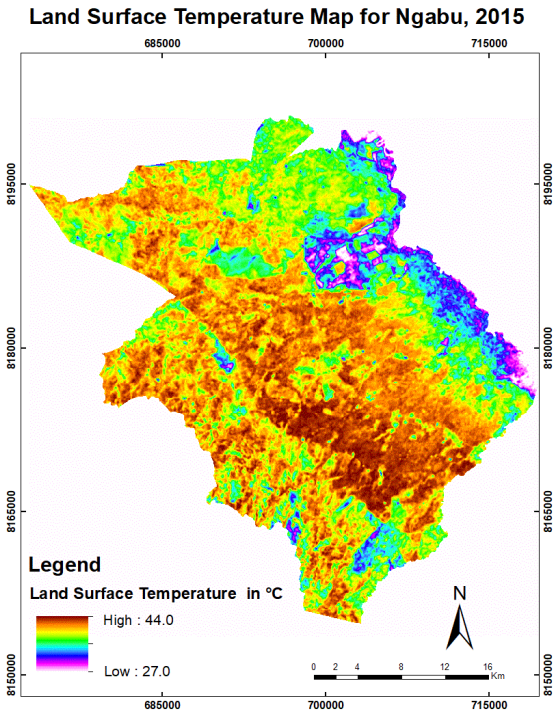
This chapter describes the findings of the research obtained from the applied methodologies used to address the study objectives.

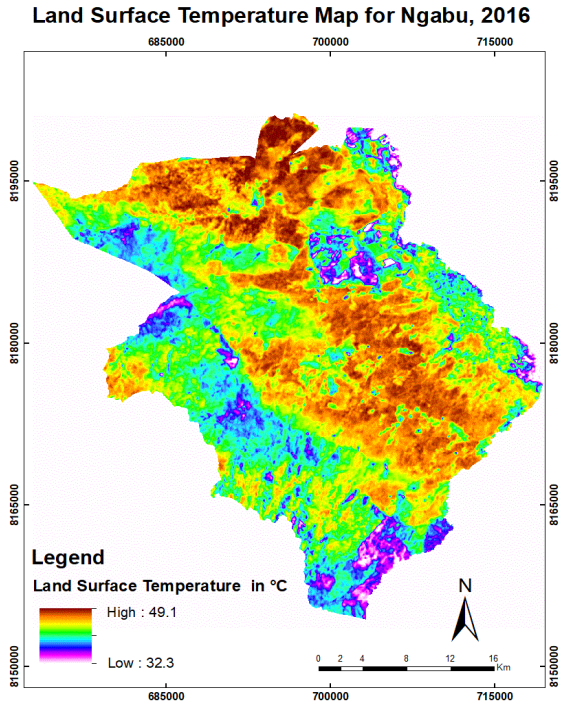
4.1. RESULTS

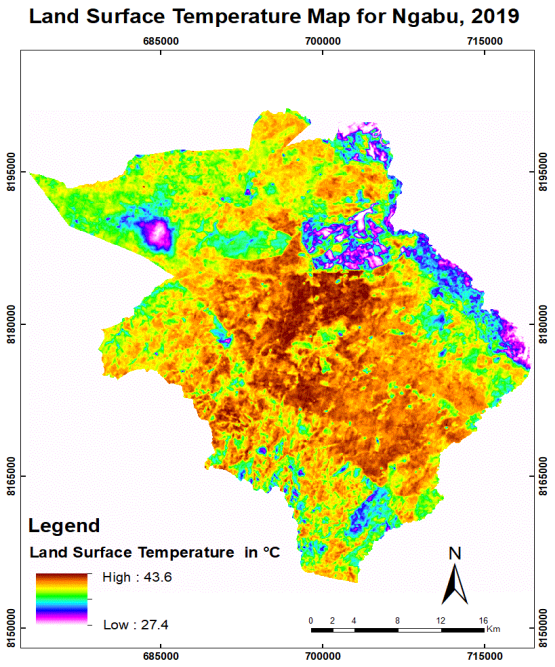
4.1.1. Land Surface Temperature Change Analysis

After processing the imageries as discussed in chapter three, the figure below presents the retrieved LST maps for Ngabu between 2000 and 2020. The interval for acquiring the imageries was 10 years (thus from 2000 to 2010 then 2020), however, 2015, 2016 and 2019 was added for referral and analysis of heatwave occurrence as these are years when heatwaves were noticed (refer to table 1).




Land Surface Temperature Map for Ngabu, 2015
685000
700000
715000
8195000
8180000
8165000
8150000
Legend
Land Surface Temperature in °C
High : 44.0
Low : 27.0
N
0 2 4 8 12 16 Km


Land Surface Temperature Map for Ngabu, 2016
685000
700000
715000
8195000
8180000
8165000
8150000
Legend
Land Surface Temperature in °C
High : 49.1
Low : 32.3
N
0 2 4 8 12 16 Km


Land Surface Temperature Map for Ngabu, 2019
685000
700000
715000
8195000
8180000
8165000
8150000
Legend
Land Surface Temperature in °C
High : 43.6
Low : 27.4
N
0 2 4 8 12 16 Km

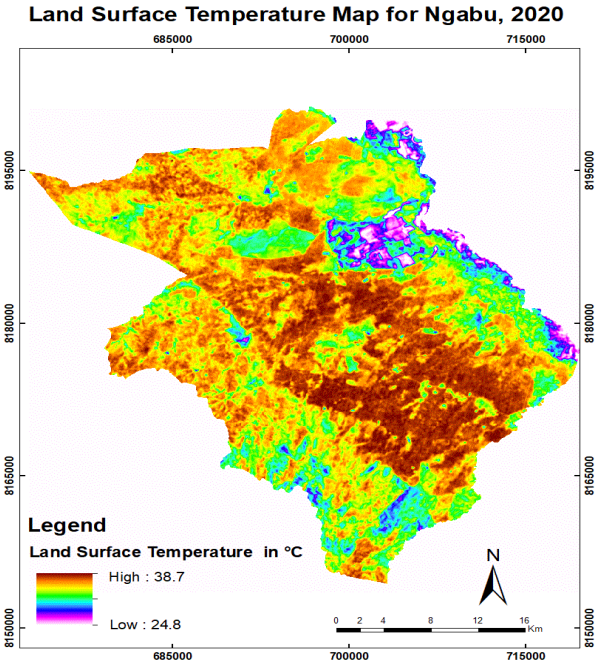
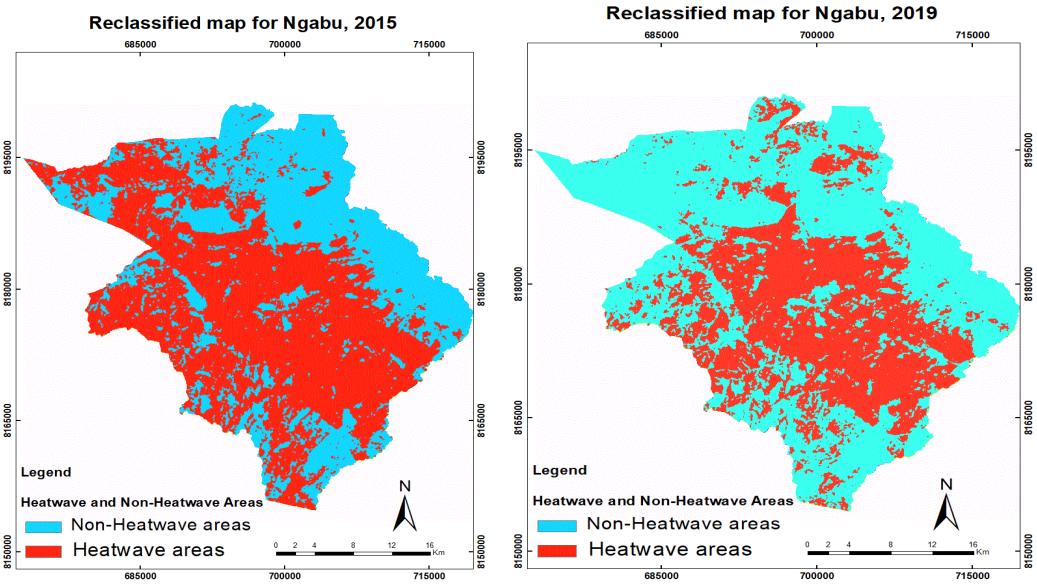

Land Surface Temperature Map for Ngabu, 2020
685000
700000
715000
8195000
8180000
8165000
8150000
Legend
Land Surface Temperature in °C
High : 38.7
Low : 24.8
N
0 2 4 8 12 16 Km

Figure 4: Land Surface Temperature (LST) change between 2000 and 2020

4.1.2. Determination of Heatwave Occurrence

Figure 5 below shows the reclassified maps indicating heatwave zones and non-heatwave zones. The heatwave zone is displayed in reddish colour while the non-heatwave zone is in bluish colour. Identified villages in the heatwave zone are in table 3.



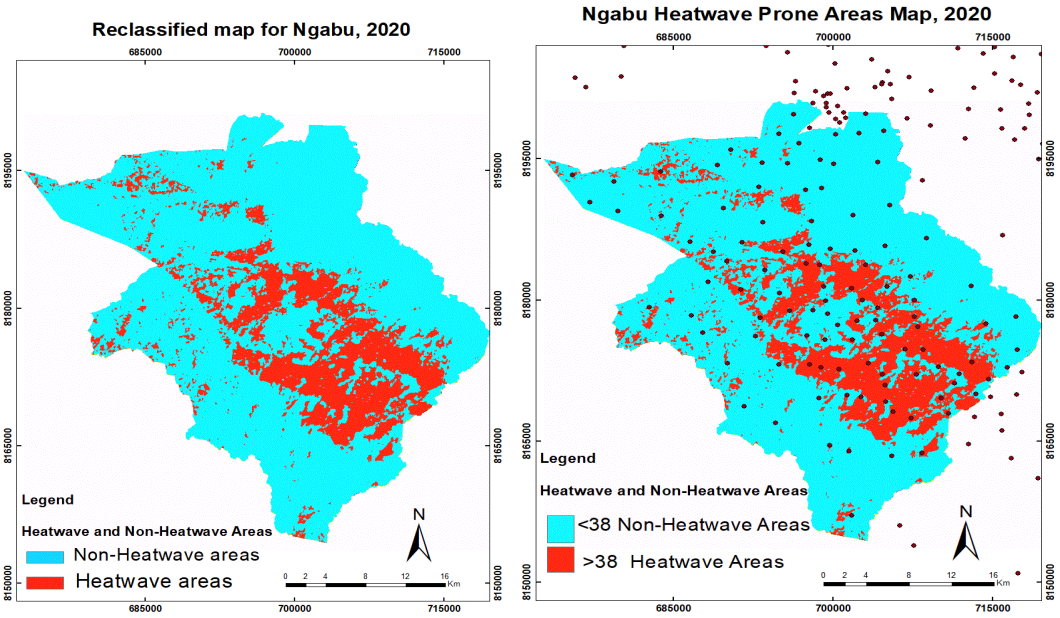


Figure 5: Reclassified LST maps showing Heatwave and Non-Heatwave Areas

Table 4: Showing Heatwave and non-heatwave areas

category	**Identified heatwave areas and non-heatwave areas**
Heatwave risk areas	John beke, khimisi, zunde, thayo, chideu, chindoko, mapingo, khokhwa, nyadeka, nyamizinga, mwanakulula, sathu, gogo, mchacha, john, jeke, kodyera, kadyamba
Non-heatwave risk areas	n'gabu, guta, mpoza, chokwe, jomba, therere, belethe, chikafa. Sala beni, malikopo, mozesi, thenesi

4.2. DISCUSSION

4.2.1. Land surface temperatures change analysis

The results shows the variation in temperature values with the year of 2000 having few scattered higher temperature values observed in the eastern regions, moderate values at the central region of the map, low and very low temperature values in the far northwest and southwest. In 2010, most areas have high temperature values that are increasing as shown in 2015 and 2016 with 2016 being the hottest year for Ngabu. The northern part of the map that was in moderate temperatures in 2015 have highest temperature values in 2016. However, there is a reduction in temperature for the high-elevated region in 2016 compared to 2015. In 2019 and 2020, higher temperatures are observed in mountaneous regions when the Digital Elevation Model (DEM) is studied along with the LST maps. Low temperature values are observed in few areas only, which tells that most areas experiences hot weather.

High-elevated areas tend to have low temperatures due to altitude since pressure decreases with altitude. Therefore, as elevation increase LST tend to have a falling trend. LST is influenced by several parameters such as solar incident radiation, angle of incidence of solar radiation, surface properties such as surface roughness, moisture content, extent of vegetation and air temperature. The observation in this case can be attributed to deforestation (careless clearance of vegetation) of the upland areas evidenced by settlement (you can see the villages), charcoal burning as a source of livelihood and cultivation along riverbanks (refer to figure 1). It should be noted that vegetation plays a greater low in reducing land surface temperatures (LST) because it has a cooling effect on LSTs, therefore removal of vegetation not only does it reduce soil moisture but also increase LST.

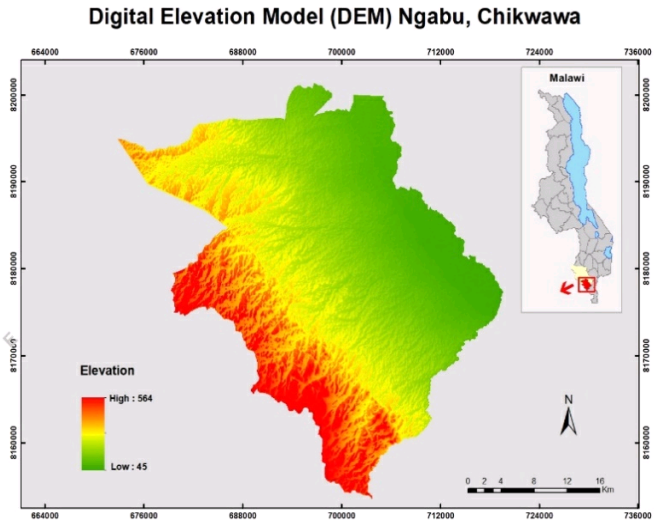


Figure 6: DEM for Ngabu

Other driving factors of LST include geometry of the study area, meteorological characteristics, landscape features, changes in land use types, geology, topography and geomorphology (Zhou et al., 2019; Li et al., 2017). Climatic factors such as wind speed, precipitation, sunshine duration and climate of the region of interest also have an impact on LST. Reductions in natural features (such as water bodies and vegetation cover) and intensification of human activities accelerate and contribute to a significant increase in the LST (Pal & Ziaul, 2017). Zhi et al. (2020) found that natural factors contribute significantly in suppressing the increase in LSTs in their analysis of land surface temperature driving factors and spatial heterogeneity research. These factors include vegetation which increase ecological sensitivity, promote ecological cycles and fix carbon dioxide and proximity to water bodies which brings cooling effect (Zhi et al., 2020).

However, other studies have proposed that changes in land cover are the primary factor driving changes in LST and have suggested that land use planning can alleviate the LST effect (Zhang et al., 2019; Yang et al., 2020). This study agrees with Zhang et al (2019) and Yang et al (2020) that land use and land cover changes are the primary factor driving changes in LST. In addition, proximity to water bodies and its quality is also another important factor. Tan et al (2011) discovered that pure water would decrease surface temperatures and the polluted water would increase the surface temperatures when their study results revealed a negative relationship between LST and Modified Normalized Difference Water Index (MNDWI) in the analysis of the relationship between land surface temperature and land use/land cover in Guangzhou, China. In his research on climate change signals based on rainfall and temperature trends in Malawi, Pagona's (2014) study results showed that high temperatures are recorded near water bodies (e.g along lakeshore and Lower shire valley). Ngabu is proximal to the Shire valley, which is at a very low altitude above sea level. Learning that proximity to water bodies can also have an impact in increasing LST, relating the quality of water of the Shire valley to LST can be worth further investigation. Also further studies can explore to find the exact cause of heatwaves at Ngabu as this study only focused on analysing changes in LSTs and examining the occurrence of heatwaves in the study area due to time factor.

4.2.2. Determining the Occurrence of Heatwaves

It is noted that in 2015 almost three quarters of Ngabu registered temperatures above the threshold of heatwave occurrence hence lying in the heatwave risk zone. In 2019 and 2020, the areas risk decreased due to the reduction in temperatures. A decrease in temperatures means a reduction in risk area as noted that extreme temperatures increase the susceptibility to heatwaves since threshold are exceeded in such scenarios. However, nothing changed for some areas in the central portion of the map. These are the high-risk areas, which are prone to heatwaves.

Therefore, the high-risk areas are prime candidates for heat warning and heat reduction resource programmes. Community sensitization in such areas is important for the management of the hazard. This can increase the awareness level of the hazard. Their participation in heatwave management can build their capacity and reduce vulnerability to the hazard. Communities in these risk areas should be engaged in developing heatwave action plans and activities towards suppressing the factors that contribute to the increase in temperatures (such as deforestation). Development of heatwave warning systems can ensure timely action of the at-risk individuals towards the occurrence of the hazard and this can reduce casualties. Land use planning need also to be checked in such areas and wherever possible relocating people to safer areas.

5. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

Studies of past events in terms of occurrence, assessment and distribution of heatwaves are important tools to support decision makers, stakeholders and organizations to agree on the preventive measures to take and to prepare in ways to avoid the immediate consequences of heatwaves. The methodology of this research utilized a combination of state-of-art technologies such as satellite remote sensing and geographical information system to produce land surface temperature maps of Ngabu between 2000 and 2020 and to determine the occurrence of heatwaves. The results revealed that there is a steady change in LSTs and the occurrence of heatwaves. The importance of these results include showing the trend pattern of LSTs which is significant when it comes to monitoring temperatures for forecasting and future predictions of hazardous events that may results from the same. The results have also

shown at-risk areas. This is useful for allocating resources and developing programmes designed t

5.2. Recommendations

Documentation and reporting of heatwave events is important as it can contribute to awareness of the hazard and help at-risk communities to know and understand their exposure to the hazard. There is also need to strengthen and improve the coordination between government stakeholders such as department of disaster management affairs (DoDMA) and the meteorological department in understanding disasters to ensure valid, reliable, accurate and up-to-date warning information. This can breed desirable behaviours during threatening events. It can also ensure that authorities' warnings are unlimited to the minimum actions. Increase in LSTs can be suppressed by vegetation abundance therefore; government needs to set public policies that encourage preservation of vegetation and better planning for land use.

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