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ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

REMOTE SENSING BASED MICROCLIMATE CHANGE STUDY IN CLUSTERED INDUSTRIAL AREAS OF ADDIS ABABA CITY.

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REMOTE SENSING BASED MICROCLIMATE CHANGE STUDY IN CLUSTERED INDUSTRIAL AREAS OF ADDIS ABABA CITY.

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A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Geodesy and Geomatics Specialization in Geomatics.

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Declaration

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university, and that all sources of material used for the thesis have been duly acknowledged.

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Addis Ababa University

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This is to certify that the thesis prepared by Kemal Husen Ali, entitled: “Remote Sensing Based Microclimate Change Study in Clustered Industrial Areas of Addis Ababa City” and submitted in fulfillment of the requirements for the Degree of Master of Science in Geodesy and Geomatics with Specialization in Geomatics.

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List of Acronyms

DN – Digital Numbers

MRLC – Multi-Resolution Land Characteristics

TM – Thematic Mapper

ETM+ - Enhanced Thematic Mapper Plus

UTM – Universal Transverse Mercator

LST – Land Surface Temperature

UHI – Urban Heat Island

UHR – Urban Heat Rise

WGS84 – World Geodetic System 1984

NASA – National Aeronautics and Space Administration

O3 - Ozone

CO2 - Carbon dioxide

USGS – United States Geological Survey

GPS – Global Positioning System

GIS – Geographic Information System

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Abstracts

Microclimatic warming is the major effect of industrial expansion in urban areas like Addis Ababa. Monitoring of microclimatic warming at local scale is very required to take proper decision. However, microclimatic warming with respect to recent industrial development in Addis Ababa city is not yet investigated. Thus, in this study multi temporal Landsat satellite images are used to evaluate the spatio-temporal trend of microclimate warming in urban areas of Addis Ababa. Thermal infrared and near infrared portion of the electromagnetic spectrum of Landsat satellite imageries are employed to compute land surface temperature which is used as a warming indicator of microclimatic warming. Landsat imageries which were taken up during 1985 G.C to 2018 G.C are considered in this study. Apart from satellite imageries, temperature data from ground station is obtained from National Meteorological Agency of Ethiopia. This data is used to evaluate against satellite derived land surface temperature. Result from this study shows that in general temperature in Addis Ababa has been increased in the last 33 years and this particularly exhibited in clustered industrial zones of the city whereby the rate of temperature increment is higher compared to the whole city. This clearly indicates that the association of industries expansion and temperature rise is directly associated. Based on this information, solutions are suggested to manage the effect of industrial expansion on local microclimatic warming.

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CHAPTER ONE

INTRODUCTION

1.1. Background of the Study

Microclimate is the climate that characterizes the state of the air layers in adjacent to a surface that transforms energy. Microclimate is the most important element in modern global climate study as far as the world-wide climate change is a cumulative result of local microclimate's impact and it is a result of the interaction between the local topography, landscape characteristics and the regional climate. It is composed out of a many of climatic conditions that come together in localized areas on the earth's surface (Chen, 1999).

In this world, cities and their citizens already have begun to experience the effects of climate change like Urban Heat Island, drought and other public health problems. Understanding and anticipating these changes will help cities prepare for a more sustainable future. This means making cities more resilient to climate-related disasters and managing long-term climate risks in such ways that protect people and encourage prosperity. It is also a means of improving cities' abilities to reduce greenhouse gas emissions. While projections for future climate change is most often defined globally, it is becoming increasingly important to assess how the changing climate will affect cities. In response to the wide range of risks facing cities and the role that cities play as home to more than half of the world's population, urban leaders need to join forces with multiple groups including city networks and climate scientists. They also need the methodologies of assessing conditions within their cities in order to take science-based actions that increase resilience and reduce greenhouse gas emissions and carbon emission from large-scale industries, thus limiting the rate of climate change and the magnitude of its impacts. In Ethiopia, most of our industries are located in the main cities which gradually result in microclimatic warming in cities and their surroundings.

Addis Ababa is one of the heavily industrialized cities in Ethiopia and industrial expansion is still undergoing in the city. During the last decade, Addis Ababa City became the biggest industrial area, in Ethiopia. According to (Chigbo A. Mgbemene, 2016), the effect of industrialization can be described in terms of opportunities and challenges. The opportunities that arise from industrializations are well known, for example, the economic transformation from agrarian in to industrial one and growth, which leads to better amenities, improved life standards, accumulation of capital, employment creation, improved food production, more effective water conservation, reducing dependencies on fossil fuels and natural wood fuels, improved infrastructure and increased ecotourism potentials (Chigbo A.

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Mgbemene, 2016). To the contrary, the challenges of industrialization includes contribution to local and global warming, higher energy demand, higher amount of industrial wastes, exposure to dangerous machineries and equipment, health problems, over exploitation of natural resources, destruction of arable lands, poverty, isolation, homelessness, destruction of communal living, changes in the family structure, imbalance in wealth distribution changing human life styles, changing the philosophies and the like (Chigbo A. Mgbemene, 2016).

This study is focusing on the impact of the industrial expansion which is one of human being's developmental activities and its effect on the local microclimate warming around the industrial areas within Addis Ababa city.

1.2. Problem Statement and Justification

Micro climate is the most important constituent for both local and global (macro) climate systems. It is also the most sensitive global issue, especially the developed countries are the most contributors to the climate warming because of their huge carbon emitting industries.

Some previous research (Dr. N Sai Bhaskar Reddy, 2010) shows that Industries contribute to the rise in atmospheric temperature called 'Heat island' and this phenomenon is experimentally proved for many large cities. The greenhouse gases and the dust allow the solar radiation but they prevent the outgoing long radiation, therefore heat is trapped. Consequently, the microclimate in and around an industrial area would be warmer than the surrounding open countryside. There is weather fluctuation along Addis Ababa city, down from the northern tip of Entoto to the southern part of Addis Ababa up to the boundary of Gelan city, due to industrialization especially from the year 1997 E.C to the recent time that directly affects the microclimate of the city. (Tesfai, 2017) indicates in his research that factories are evidently essential for producing consumer goods; providing jobs as well as foreign currency saving and, in some cases, gains. But, on the other side, they are being sources of pollution and microclimatic warming (Tesfai, 2017).

Generally, whenever industrial expansion exists in the city, there should be pre and postindustrial installation control and scientific investigation on the microclimate of the locality in order to cope up with the effect of this industrialization process which leads to realization of resilient and conducive living environment for the surrounding local population. Even though there are researches conducted in Addis Ababa regarding urbanization, those researches focus on the impact of urban expansion on the livelihood of the local communities. The impact of industrial expansion on microclimate have not been done so much. Therefore, the study initiated to investigate the effect of industrial expansion on

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local microclimatic warming taking Addis Ababa as a case study site and develop a method for continuous monitoring of microclimatic warming trend using satellite imageries.

1.3. Objectives of the Study

1.3.1. General objective of the study

The general objective of the study is that analyzing the microclimatic warming in industrial expansion areas of Addis Ababa city.

1.3.2. Specific objectives of the study

- To map and analyze the trend in microclimatic warming using satellite derived land surface temperature within the study area in the past and present times and
- To generate evidence on the effect of industrial expansion on microclimatic warming in the study area.

1.4. Research Questions

- What is the trend in microclimatic warming and land surface temperatures within the study area?
- Is there any cause-effect relationship between industrial expansion and land surface temperature change in the study area?

1.5. Significance of the Study

The research is significant especially for the municipalities and industry and company holders found in the study area. There are many benefits sharing bodies such as the local residents of the Addis Ababa city. The study also has some scientific contributions to the current environmental and climatic issues of the urban environment. There is also the far-reaching implication of the research output in the environment like the urban micro climatic impact assessment and the recommendation of the copping strategies. In this paper, the impact of industrialization on the microclimate of the locality and the way to rehabilitate the affected environment will be recommended as a result of the research findings.

Furthermore, the study of micro climate warming/change as expense of industrialization is not only the concern of Addis Ababa city in Ethiopia, but also necessary for different industry hosting cities like Mekelle, Bahir Dar, Hawassa, Adama, and all other cities where modern industry parks are under construction. So, this study further indicates the awareness for the respective administrative body or perhaps municipalities of those industry hosting cities need to know the resultant city-wide impact of those industries in order to maintain the environment and resilient cities.

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1.6. Scope of the Study

The micro climate issue is the concern of every country and a world as a whole because even though the geography is far apart; the atmosphere and the climate impact is common to all over the world. This study is done to analyze the impact of rapid industrialization on the local microclimate with in Addis Ababa City.

1.7. Limitations of the Study

Even though the problem is mostly common in different parts of the country, this thesis is limited to the Addis Ababa City Administration.

1.8. Organization of the Thesis

This thesis is organized in a precise way that shows the sequential steps in analyzing of the micro climatic changes. The introduction part about the microclimate and land surface temperature was explained in the first chapter of the thesis. Chapter two is all about the pertinent literature regarding the previous works related to the title of the research and all the methodologies and the utilities considered for the achievement of the result of the study was discussed in the chapter three of the study. Chapters four and five are about the data analysis and conclusion and recommendation respectively.

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CHAPTER TWO

LITERATURE REVIEW

2.1. Conceptual View of Microclimate and Microclimate Warming

Microclimates are the localized, dynamic interplays between different processes in the surface layer, such as energy and matter exchange, radiation processes and effects of the underlying surface (Foken, 2008). Microclimates are also caused by local difference in the amount of heat or water received or trapped near the surface. A microclimate may differ from the surroundings by receiving more energy, so it is a little warmer than its surroundings (Bechtel, et al., 2012).

On the other hand, if it is shaded area, it may be cooler on average, because it does not get the direct heating of the sun. Its humidity may differ, water may have accumulated there making things damper, or there may be less water so that it is drier. Also, the wind speed may be different, affecting the temperature and humidity because wind tends to remove heat and water vapor. All these influences go in to making the microclimate (Zina Mitraka, 2015).

The microclimate of cities is strongly influenced by man-made structures and human activities and thus differs from that of the surrounding natural areas, a phenomenon widely known as the urban heat island (Arnfield, 2003).

The growing interest in urban climatic phenomena like the urban heat island (UHI) is motivated by increasing vulnerability to health risks due to rapid urbanization and industrialization in developing countries and climate change. The urban heat island indicates increased air temperatures in the urban atmosphere compared to a preurban state (Lowry, 1977) or more often to a rural reference station of identical regional and topo-climate.

The urban heat island (UHI) is the important phenomenon in urban geographic studies, which traps heat in thermal mass like asphalt, concrete, bricks, stones and roads, which absorb, store and then re-emit this heat to the urban air at night. The urban temperatures are 2-5 higher than those in rural surroundings are. It is a key variable for the detection of climate change and assessing the relative importance of anthropogenic and natural influences. It is a prime driver of many impacts of natural and human created systems. The urbanization and industrialization are a main factor for island heat (Ali ar, 2016).

Besides the urban heat island estimations based on urban canopy temperature differences between the urban core and the peri-urban areas, the respective land surface temperature (LST) differences are commonly used to both characterize the surface urban heat island and support urban energy budget

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studies (Voogt, 2004), since LST is closely related to human comfort and the city energy use. Since then, with recent progress in remote sensing and satellite thermal data acquired at daytime have been widely used to detect surface UHIs on large scales when heat island intensities are greatest.

2.2. Industrialization

Industrial expansion is the gradual process by which the natural cover of an area is demolishing and the newly planned industrial projects are to be installed. Industrialization is also the process of transformational change of the human society socially and economically from an agrarian society into an industrial one (Chigbo A. Mgbemene, 2016).

Industrialization has always seemed to be the key to wealth and better living but in reality, it has been shown that, although it leads to better conditions of living in certain respects, it affects environment and ultimately contributes to climate change. Industrialization not only involves technological innovations, it also involves economic and social transformation of the human society.

2.3. Causes of Micro Climate Warming

2.3.1. Urbanization/ Industrialization

The process of urbanization has a great impact on the pertinent environmental elements like local landscape, land use, and hence the surrounding climatic condition. According to recent studies (Bechtel, 2012), it is well known and documented that urbanization can have significant effects on local weather and climate. The buildings, concrete, asphalt and industrial activity of urban areas causes the urban heat island. Replacing natural land cover with pavements, buildings and other infrastructures takes away the natural cooling effects. Also, heat from vehicles, factories and air conditioners adds warmth to the surroundings, further exacerbating the heat island effect.

The urban heat island has been described as ‘‘one of the most clearly established examples of inadvertent modification of climate’’ (Roth M., 1989). The heat island intensity is greatest during the day and least at night (Roth M., 1989).

Climate change can be described as the persistent change in the weather pattern engendered by anthropogenic activities mostly linked to industrialization. It manifests in a long-term shift in the statistics of the weather condition of the locality.

There are many challenges of industrialization like; coping with higher temperatures, extreme weather conditions, changing of human life styles and changing philosophies of the locality (Chigbo A. Mgbemene, 2016).

Industrialization and urbanization usually overtake large area of potential agricultural lands. The conversion of agricultural land to these systems has impact on the micro-climatic warming of the surrounding atmosphere, which has a great impact on the health condition of the surrounding

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community and even the workers of the industries themselves. As industrialization is often accompanied with pollution, gas effluents have to be characterized to determine the humidity contents of surface air (Ali ar, 2016).

However, very few studies have examined the physical effects of industrial development on cities and villages hosting these industries, which indicates the lack of sufficient work in this field.

The use of a daytime radiant surface temperature to monitor the impact of land-use change emphasizes urbanization's influence on the surface energy balance, a feature which also allows for the extraction of surface moisture properties.

2.4. Approaches to study micro climate warming

2.4.1. Thermal Remote Sensing Approaches

Remote sensing has widely been used in urban climatology since it has the advantage of a simultaneous synoptic view of the full urban surface. Satellite thermal infrared (TIR) observations are widely used to assess the extent and the intensity of the surface urban heat island, because of the well-known advantage of satellite spatial coverage (Zina Mitraka, 2015). Methods include the analysis of surface temperature patterns, spatial (biophysical) indicators for urban heat island modelling, and flux measurements. Another approach is the automated classification of urban morphologies or structural types (Bechtel, 2012).

Thermal infrared remote sensing proved its capability in monitoring temperature and affecting microclimate in urban areas. The climatic elements are almost observed by climate stations in cities, almost each city contains one station, and it does not express actual microclimate conditions in many cases. LST and emissivity data are used in urban climate and environmental studies, mainly for analyzing LST patterns and its relationship with surface characteristics, for assessing urban heat island, and for relating LSTs with surface energy fluxes in order to characterize landscape properties, patterns, and processes.

Thermal temperature data are recorded as a digital number (DN) in the thermal band (band 6-1 and 6-2 in ETM+) of the Landsat images which is rectified to the UTM projection system on the datum of WGS84 and it is possible to convert these DN values to degrees of kelvin and also in to degree Celsius. Radiances are in units of w/ (m^2*sr*µm) and the transmission and emissivity are unit less. The radiances in TM band 6 (high gain on ETM+) could be calculated from digital numbers (DN) to correct for gain and offset at the detector. In ETM+, band 6 captures the radiant thermal energy between *10.4* and *12.5* am, at the atmospheric window between O_3 and CO_2 atmospheric absorptions.

There is also advantage from satellite remote sensing method in such a way that satellite remote sensing has a temporal resolution that a satellite sensor can revisit a specific area within some limited time

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interval. For example, landsat Satellite sensor has 16 days temporal resolution and 30 meters spatial resolution which is a good option to monitor the persistent temperature frequently within the study area. Therefore, by using thermal remote sensing technologies, these frequent environmental issues can be predicted and managed. This method is adopted for this research due to the above advantages.

2.4.2. Direct field observation method

By using different sensors, the temperature data can be collected through direct field experimentation method. According to the recent studies (Bechtel, 2012), the Urban Heat Island data was collected by using a mobile measurement campaign with public transportation buses during the vegetation period from the 23^{rd} of May until the 29^{th} of October 2011. Cooperation with the Hochbahn Hamburg allowed for the collection of spatially dense air temperature data in the inner city of Hamburg.

By equipping different transportation facilities in the cities with different temperature and humidity sensors together with GPS-loggers, the micro climatic warming issues could be monitored frequently through direct field experimentation by day to day movement which is relatively costly and time consuming.

2.5. Trends in studying micro climate warming

The impact of green vegetation and water surfaces in the urban areas effect were measured and found each 10% vegetative reduce the temperature 0.6K and commented that trees can reduce the effect substantially (Md.Nuruzzaman, 2015). However, they concluded that the existence of water bodies does not decrease the temperature; rather it increases the effect.

Other study, (Adinna, 2009) , assessed the impact of urban heat island effect in the Enugu city of Nigeria and suggested adaptive measures to keep UHI effect under control in the city (Adinna, 2009). The study concluded that the use of high dense green vegetation roofing materials and lightening of pavement materials can reduce the effect in Enugu urban center. There is also another case study like; (Akbari, 2001) studied that: the effect of cool surfaces and shade trees on the UHI effect which was come up with the conclusion, that surfaces with high albedo (the proportion of the incident light or radiation that is reflected by a surface, typically that of a planet or moon) materials and urban trees have a significant contribution to reversing the heat island.

According to previous studies, (Akbari, 2001), for every 1^0c increase of temperature, the electricity demand may rise by 2-4%. On the other hand, 20% energy can be saved which is used for air conditioning if mitigation measures are taken in order to reduce the UHI effect.

Other scholars also simulated using ENVI-met to observe their usefulness to mitigate the UHI effect in Tehran. They considered the following three measures: (1) High Albedo Materials (HAM) (2) Vegetation and Green roofs (VEG) and (3) Combination of both of them (HYBRID) (Sodoudi, 2014).

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According to Sadoudi et al., 2014, Hybrid was the most effective mitigation measure as the result showed that it reduces the temperature of Tehran city by 4.2K at daytime (Sodoudi, 2014). On the other hand, only 0.5K of cooling effect can be achieved at daytime by using High Albedo Material.

The other scholar, Rosenweig et al. (2006), used regional climate model combining meteorological data, satellite and GIS data to determine the influence of urban forestry, living roofs and light surfaces on UHI effect in the New York metropolitan area (Rosenweig, 2006). They heat island effect model of New York City was analyzed by taking six case study areas and tested the mitigation strategies. It was found that vegetation helps to keep surfaces cool more effectively than increasing the albedo. But they suggested that in order to reduce the temperature in New York City, replacement of low albedo materials with high albedo light colored materials will work great as 64% of the surface area of the city can be replaced easily.

After studying numerous literatures which are based on numerical simulation and field measurements, most of the scholars commented that increasing albedo and vegetation cover prove to be effective to reduce both surface and air temperature substantially.

Evapotranspiration is the process of transferring water from the surface to the atmosphere, which takes a high amount of energy compared to heating the air. Thus, areas with available soil moisture have a more balanced microclimate with lower air and soil temperatures.

Surface temperature can be directly derived from remotely sensed data, which provides a powerful way to monitoring urban environment and human activities. This information enhances understanding of urban environment. The land use types; that increased by factories and decreased by the green and water land cover mainly affect the surface temperature. It is recommended to surround the industrial areas by green belt buffers to more than 500-1500 m for improving temperature condition and to decrease pollution effects to the acceptable limits (El-Nahry . H. and Rashash, 2012).

Generally, it could be stated that the surface temperature is increasing rapidly throughout the study area due to huge agglomeration of settlement, industry and clearing the original species or the natural vegetation. It has been observed that the surface temperature is higher in urban areas than vegetation and water body areas, because of lower contributions of evaporation and transpiration in non-vegetation areas.

2.6. Strategies to Reduce Urban Heat Island/Micro Climate warming

According to the justification from previous studies (Sailor, 2006) urban heat island effect mitigation can be done in two ways. One is by increasing the albedo of the urban surface and the other is by increasing evapotranspiration. However, the major strategies to mitigate the urban heat island (UHI) effect are described below (Sailor, 2006).

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High Albedo Roofing Materials

As indicated in different studies, (Md.Nuruzzaman, 2015), Dark roofs absorb heat from the sunlight and make houses warm. In contrast, light colored roofs with similar insulation properties do not get warmed significantly by reflecting solar radiation (Akbari, 2001). So, the choice of roofing color can contribute to temperature reduction and also temperature warming. Roofing materials with low albedo absorb solar heat and make the house warm which results in high consumption of energy for air conditioning. So, one of the mitigation strategies is using high albedo roofing materials. The different materials which have a rubber like nature, have no impact on cost for change of color (Sailor, 2006) and it was suggested that white materials which have albedo greater than 0.60 instead of black materials having albedo of 0.05 to 0.10 can be used as roofing materials. Other scholars (Akbari, 1998) observed the effectiveness of albedo by using roofing materials of different albedo ranging from 0.20 to 0.60 and they found that the roof temperature dropped by 25^0C for 0.60 albedo compared to that of 0.20 albedo. According to (Sailor, 2006) the action of convection of the roofing materials has a role to play to the effectiveness of UHI effect mitigation strategies (Sailor, 2006). Other studies also show that one of the problems which are incorporated with the reflective roofs is that the reflection capability lessens with age because of the dust and other rusting issues (Berdahl, 2002). However, it can be easily compensated by cleaning it periodically. Again, for cool roofs, there is an issue of aesthetics. On the other hand, cooling roofs glares at daytime.

High Albedo Pavements

The reflecting capacity of different artificial structures on the surface of the earth's surface determines the amount of received incident rays from different sources of light to be reflected back to the atmosphere. Studies (Md. Nuruzzaman, 2015) shows that, more solar radiation could be reflected if the road and highway pavements were of high albedo materials (Akbari, 2001). So, proper selection of pavement materials can also contribute to the reduction of UHI effect. (Sailor, 2006) suggested that white cement mixtures can be made for which the albedo should be higher than the most reflective gray cement mixtures. However, use of high albedo materials for roads and highway pavement may not be so much effective because of the sky view factor. Even if, it is used, some of the reflection will be intercepted by the buildings surrounding it. In addition to it, a large proportion of it is covered by vehicles in most of the daytime. The problem of glaring which is associated with cooling roofs is also accompanied with the high albedo pavements. (Sailor,2006) states that high albedo pavements may increase visibility at night, thus reduces the requirement of light.

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Green Vegetation

Previous studies (Md. Nuruzzaman, 2015) says that increasing the amount of vegetation is one of the most effective strategies to mitigate the effects of the urban microclimate (Wilmers, 1988). This can be achieved by tree plantation both in residential and municipal tree plantation programs (Sailor, 2006). Trees contribute to reducing the heat island effect by their evapotranspiration (Akbari, 2001). Trees have also direct effect on reducing the urban heat island effect as it absorbs carbon dioxide (Akbari, 2001). According to (Robitu, 2015). empirical derivations also demonstrated reduced temperature by applying green vegetation methods. In the heart of cities, where the population density is high, the emission of huge amount carbon dioxide leads to the frequent increase of temperature. Large number of trees plantation will help to mitigate the condition by absorbing the exhaled carbon dioxide within the city centers.

Shade Trees

Shade trees are those with a huge canopy and can provide protection to houses and pedestrians from direct sunlight keeping them comparatively cool. Shade trees also help to cut down the temperature by evapotranspiration process (Sailor, 2006). The study performed in the United States shows that, near about 200,000 shade trees were planted every year between 1992 and 1996 G.C as a strategy to mitigate heat islands, protect climate, and improve air quality in urban areas (Scott Greene, Mark Morrissey and Sara E. Johnson, 1999). The principal role of shade trees is that sunlight is intercepted by it keeping the buildings comparatively cool (Akbari, 2001). The shade trees can also reduce the building air conditioning, lowers the air temperature and improves the air quality. Planting shade trees involve some sort of maintenances and cost pertaining to it. Estimation given by scholars (Akbari, 2001) states that the savings associated with the benefits of shade trees may be up to $200 in its' entire life and the maintenance cost may range between $10 to $500 per tree. At the same time, shade trees need several years to grow up and start protecting a building from severe heat. Shade trees are also vulnerable to extreme storms posing threat to human life (Sailor, 2006).

Pervious Pavements

Pervious materials at residential buildings and also at industrial compounds is most important not only to maintain the cooler surface but also to reduce the probability of the urban over flooding to occur. Impervious pavements do not allow water to infiltrate and cooling effect by evapotranspiration is not significant in this case (Sailor, 2006). If the impermeable pavements are replaced with pervious pavements which will allow water to infiltrate, it can be expected that it will be able to reduce the

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temperature to a reasonable extent. Infiltrated water will help keep the pavement cool and directly affecting the temperature.

Water Bodies

Water bodies with in most of the cities are being abused and kept as drainage for the solid and liquid waste materials produced from the residential and commercial centers of the cities. As noted by previous studies (Robitu, 2015), increased amount of water bodies and its treatment may reduce temperature due to their evaporative action and enhanced wind speed. (Robitu, 2015). And also, since the heat absorption capacity of water is high, it will help to reduce the urban temperature. In contrast to this proposition, the bike traverse experiment by other scholars, does not support this statement and opposes that it exacerbates the condition. The reason behind this was described as the high thermal inertia limits of water prevent nocturnal cooling once it is warmed. The stable nocturnal condition which limits the wind speed may also be another reason. So, it is needed to investigate more whether extended water bodies in urban areas help to lower the temperature or not. The above statement can be replaced by the term "urban blue belt" which is being the most important way of trapping the urban heat island that use for managing the microclimate of cities.

Urban Planning

As recommended by previous studies, (Md.Nuruzzaman, 2015), Proper urban planning can also play a vital role in the mitigation of the UHI effect. (Yamamoto, 2006) has described an urban planning approach situated on the bank of river. His suggestion was to build the buildings in the pattern that takes in to account that wind path is created for cool airflow from the river into the city. As per the suggestion of this scholar, if buildings are built parallel to the direction of river, no airflow will occur in to the city, if buildings are positioned at a 45^0 angle to the direction river flow, wind will get channel if it flows only in one direction. But if it flows from the opposite direction, it cannot get away inside the city. However, airflow will occur in case if the buildings are positioned perpendicular to the river. This method of managing microclimatic warming in the cities is the most natural and economical way as (Yamamoto, 2006) also mentioned that this option is expected to play a major role in the fore coming days and it deserves further attention. On the other hand, in other types of cities, it is expected sufficient amount of free space and channel to circulate the wind, will be helpful to minimize the effect of the urban microclimate. Therefore, the plan of a city and the way it was implemented also has a great contribution for the cities to maintain the cool environment.

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Green Roofs

As indicated by (Md.Nuruzzaman, 2015), previous researches (Wong E, 2005), shows that, roofs in the cities represent about 21% to 26% of the city area. So, if the roofs are made green by vegetating, it will act a major role in mitigating the urban heat island effect (Wong, E, 2005). Green roofs absorb heat and filter the air, keeping the temperature low (Getter, K.L and Rowe, D.B., 2006). Plants utilize heat energy to continue their evapotranspiration process, making the environment cool. In addition to it, green roofs help to delay the runoff duration which will keep the cities cooler for a longer period (Getter, K.L and Rowe, D.B., 2006). Since the green vegetation roofs also absorbs water through infiltration process, it keeps itself cooler, helping to reduce the temperature. Again, green roofing will bring energy balance to the corresponding building by reducing the energy demand.

CHAPTER THREE

MATERIALS AND METHODOLOGIES

3.1. Historical Background of Addis Ababa

3.1.1. Location Map of the Study Area.

Addis Ababa is located in the heart of the country surrounded by Oromia special zones and cities. Addis Ababa covers about 540 Km^2 of which 18.2 Km^2 are rural.

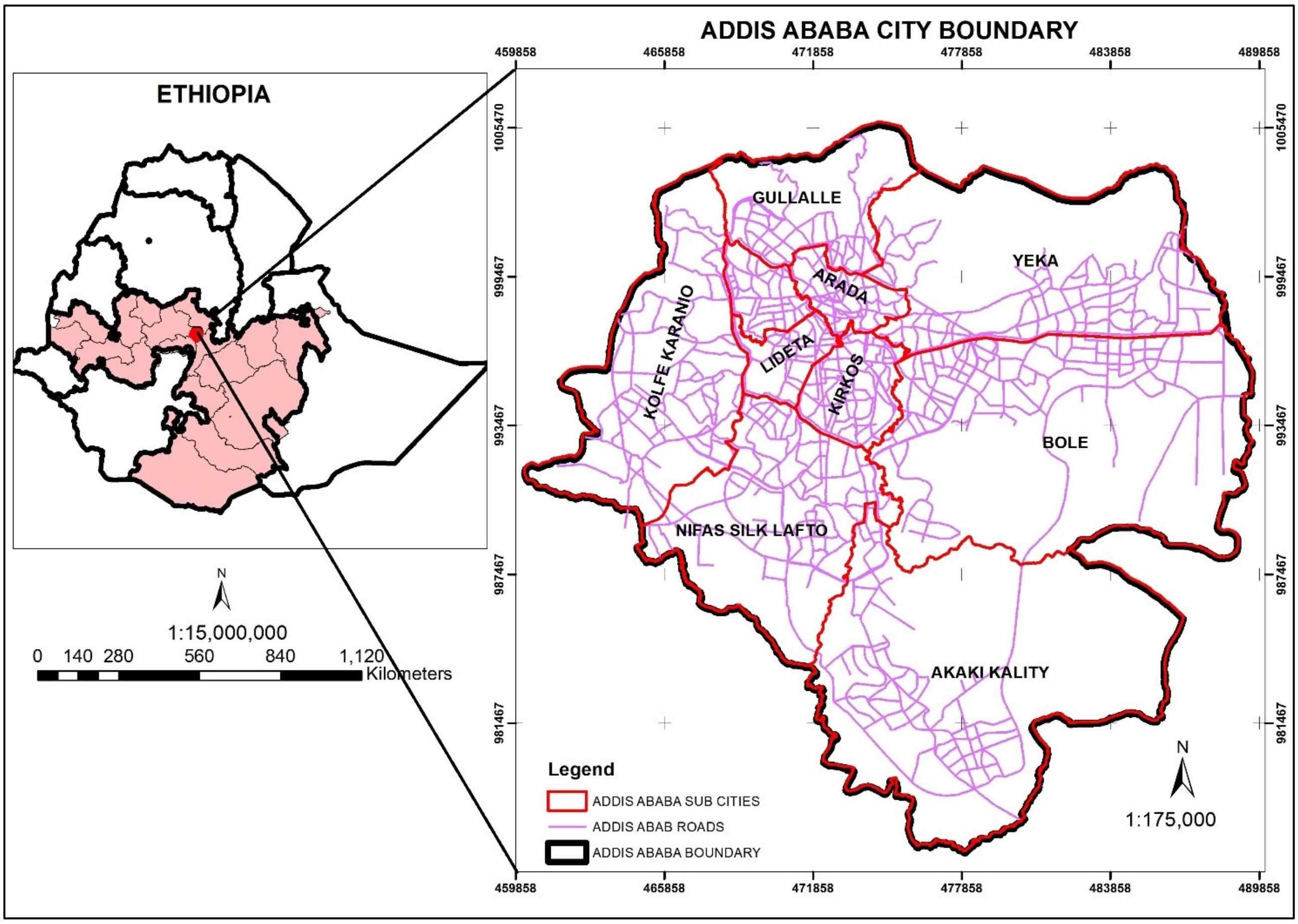

Figure 3.1. Location map of the study area.

3.1.2. Topography and Climate

Addis Ababa and its surrounding cities lie between 2,200 and 2,500 meters above sea level. The Addis Ababa city lies at the foot of the 3,000 meters high Entoto, yarer and wochecha Mountains. Despite its proximity to the equator, the city enjoys a mild, Afro-Alpine temperate and warm temperate climate. The lowest and the highest annual average temperature are 9.89^0c and 24.64^0c respectively. The cities

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resemble pleasantly across many wooden hillsides and gullies cut through with fast flowing streams especially during the rainy seasons from July-September.

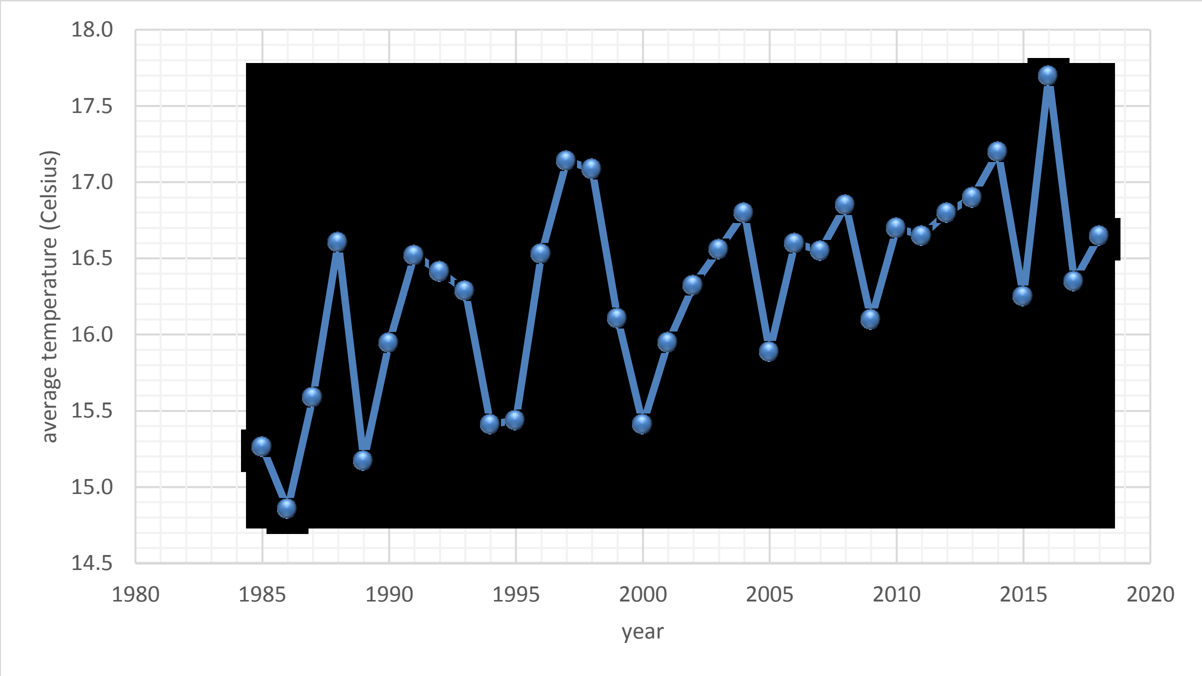

Figure 3.2: Average yearly (1985-2018) temperature of Addis Ababa (source: National meteorology Agency of Ethiopia)

3.1.3. Socio-economy

The day to day life activities of the city's population is predominantly based on different sorts of occupation. These include trade and commerce; in manufacturing and industry; home makers of different varieties; in civil administration; in transport and communication; in education, health and social services; in hotel and catering services; and in agriculture. Besides the residents of rural parts of Addis Ababa, the city dwellers also participate in animal husbandry and cultivation of gardens.

3.1.4. Geological and soil profiles

The primary basaltic rocks are among the most known geological foundation of Addis Ababa and the surrounding cities and the area is mostly dominated by vertosols among the existed soil types.

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3.2. Methodology of the Study

3.2.1. Data Sources

3.2.1.1. Primary data sources

The primary data used for this research are:

- X, Y coordinates of recent industrial areas that were delineated using Handheld GPS.

3.2.1.2. Secondary data sources

- Aerial photo of Addis Ababa City and google earth were also used for the locating of the industrial areas at the time back to 1985 G.C.
- Monthly temperature data were obtained from Ethiopian National Meteorological Agency.
- Satellite image of the Ethiopian sunny season (January- February) of year 1985, 1990, 1995, 2000, 2005, 2010, 2015, and 2017 in Gregorian Calendar (G.C) was downloaded from the United States Geological Survey page (http://www.usgs/earthexplorer.com)..
- Addis Ababa City Administrative Boundaries including Sub cities were collected from the City Administration Land Holdings Registration and Information Agency.
- EthioGIS data layers were used to locate the study area from the Country and regional perspective.

3.3. Image pre-processing and Preparation

3.3.1. Image subseting

The thermal bands of the images of the Ethiopian sunny (January- February) season of year from 1985, 1990, 1995, 2000, 2005, 2010, 2015 and 2018 G.C by five years interval were extracted by using the Administrative boundary of Addis Ababa City to limit the study with in the specific study area which is spatially delimited.

All of the images of the study area for the last 33 years by five-year interval consecutive years were extracted in the same way by using the administrative boundary of Addis Ababa city.

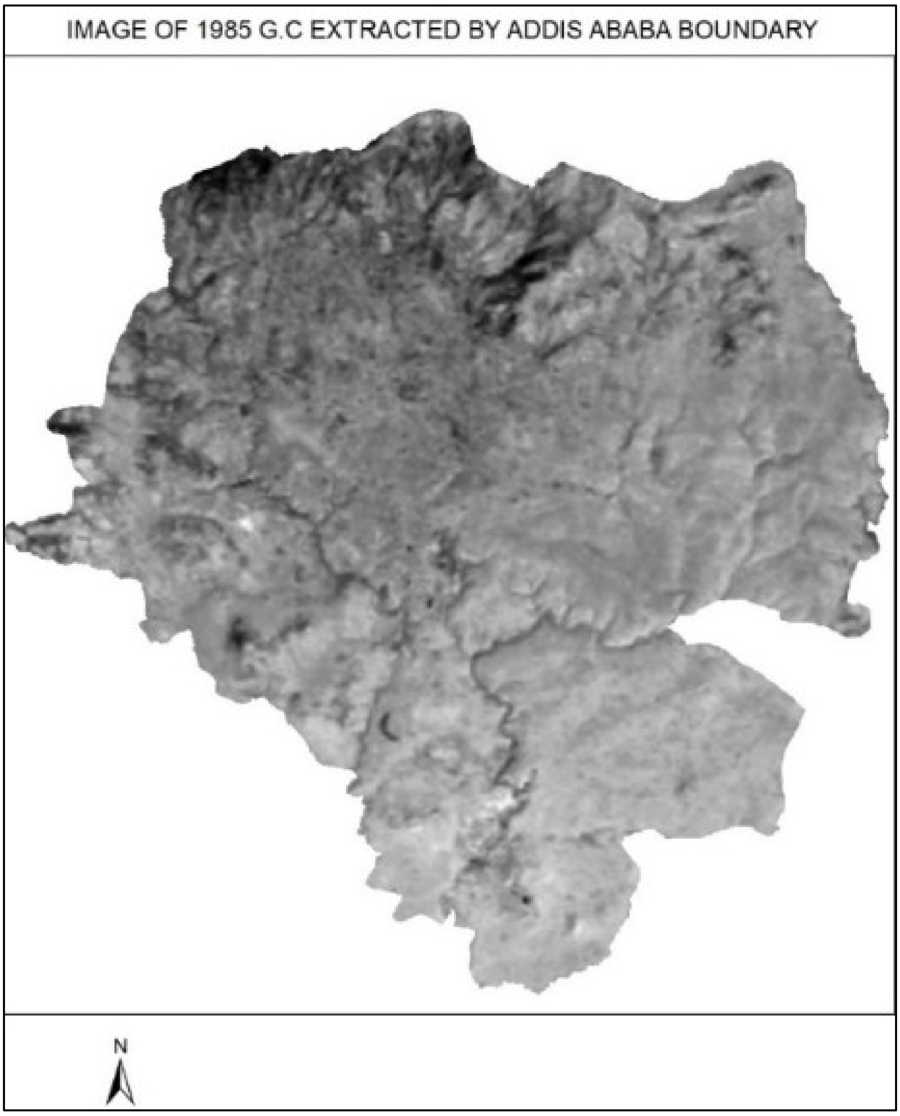

Figure 3.3: Thermal band of Landsat image of 1985 G.C of Addis Ababa.

3.4. Trends of Land Surface Temperature over Addis Ababa.

3.4.1. LST extraction process

The sunny season in Ethiopia are mainly January, February and March so that the central part of the country gets more sunshine and the season is also season of the clear sky where the effect of cloud cover in the atmosphere on the remote sensing process is minimal. The study then used the Landsat images of these months specifically January and February downloaded from the website of United states geological survey Earth Explorer (http://www.usgs/earthexplorer.com).

The land Surface Temperature was extracted from the Landsat imageries of the year 1985, 1990, 1995, 2000, 2005, 2010, 2015, and 2018 G.C respectively.

For image of the year 1985 to 2018 G.C, the sensor prelaunch Sensor's calibration parameters are:

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YEAR	LANDSAT IMAGE PARAMETERS					
	Radiance _max	Radiance _min	Quantized cal_max	Quantized cal_min	k1	k2
1985	15.303	1.238	255	1	607.76	1260.56
1990	15.303	1.238	255	1	607.76,	1260.56
1995	15.303	1.238	255	1	607.76,	1260.56
2000	15.303	1.238	255	1	607.76,	1260.56
2005	1=17.040 2=12.650	1=0.000 2=3.200	255	1	1=666.09	1=1282.71
2010	1=17.040 2=12.650	1=0.000 2=3.200	255	1	666.09	1282.71
2015	10=22.00180	10=0.10033	65535	1	10=774.8853 11=480.8883	10=1321.0789 11=1201.1442
2018	10=22.00180	10=0.10033	65535	1	10=774.8853 11=480.8883	10=1321.0789 11=1201.1442

Table 3.1: Landsat images Sensor calibrations Parameters.

Hence, by using the above parameters, the LST extraction step by step graphical model was developed. The detail explanation about the model made is explained as below:

3.4.1.1. Conversion of the Digital Number (DN) to Spectral Radiance (L)

According to the NASA equation for the Land Surface Temperature extraction, the first step for calculating Land surface temperature from Landsat imagery is to convert the Digital Numbers (DN) of band 6 (thermal band) to spectral radiance using the equation below;

$$\mathbf{L = LMIN + (LMAX - LMIN) * DN / 255 \ (QCALMAX - QCALMIN)}$$

Where,

L = Spectral radiance

LMIN = (Spectral radiance of minimum DN value)

LMAX = (Spectral radiance of maximum DN value)

DN = Digital Number

Furthermore, L is spectral radiance at sensor's operative in wm-2Sr-1µm-1 and LMIN is the spectral radiance that is scale to QCALMIN, LMAX – is the spectral radiance that is scale to QCALMAX, LMAX and LMIN are obtained from the Meta data file available in the image file, QCAL – is the

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digital number (DN), QCALMIN – is the minimum quantized calculated Pixel value in DN and QCALMAX – is the maximum quantized calculated pixel value is DN.

3.4.1.2. Conversion of Spectral Radiance to Temperature in Kelvin

Spectral radiance values were then converted to radiant surface temperature under the assumption of uniform emissivity using pre-launch calibration constant for Landsat satellite sensor and inserting into the formula stated below;

$$\mathbf{T} = \frac{\boldsymbol{K2}}{\boldsymbol{Ln}\left(\frac{\boldsymbol{K1}}{\boldsymbol{L}}+\mathbf{1}\right)}$$

Where

T is radiant surface temperature in kelvin

K1= Calibration Constant 1

K2 = Calibration Constant 2

L= is the spectral radiance at the sensor in $Wm^{-2}Sr^{-1}$ μm^{-1} calculated in the 3.4.1.1 section.

3.4.1.3. Conversion of Kelvin to Celsius

TC (in degree Celsius) = LST-273

where LST = at sensor temperature in Kelvin and TC is land surface temperature in degree Celsius.

273 is the value for the black body or absolute zero which is -273^0c

Based on the above formulas, a graphical model estimating Land Surface Temperature was developed.

3.4.2. LST Validation/Accuracy Assessment

The land surface temperature estimated from the Landsat imageries were cross validated against the in-situ measurement data which was received from the Ethiopian National Meteorological principal station in Addis Ababa city administration.

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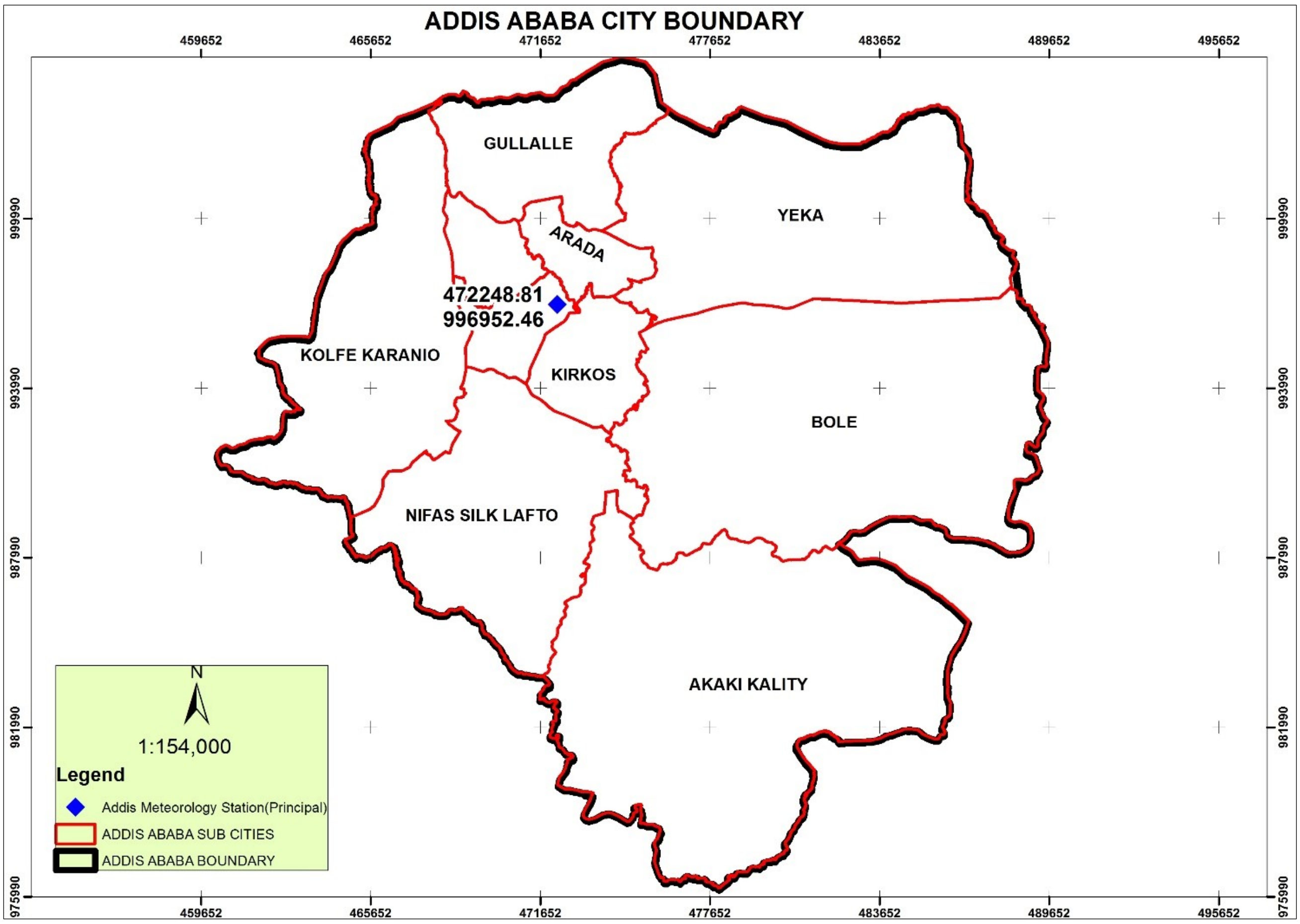

Figure 3.4: Addis Meteorology Station

The accuracy assessment of the calculated temperature from the satellite data was performed a method of root mean square error calculation (rmse) and linear regression functions by using the equation as follows:

RMSE = $\sqrt{mean(T - Tr)^2}$

Where,

RMSE = Root Mean Square Error

T = Maximum Estimated Temperature

Tr = Maximum Reference Temperature

Since it is recommended to validate such data with the help of the in-situ measurements from the Meteorological stations, the temperature data, were obtained from the principal station from Addis

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Ababa Station and correlation analysis is used to cross validate the estimated and measured temperatures within the study area.

Correlation function is employed to evaluate the relationship between the estimated average temperature and measured average temperature from measured weather station. the correlation function is:

$$\mathbf{CC= corr\ (T_1,T_0)}$$

Where,

CC = correlation coefficient

T_1 = average temperature from meteorology station

T_0 = average temperature estimated from satellite image

3.5. Field Survey

There are many industrial sites found within the study area like bole lemi industry zones in the Bole Sub City, Kaliti thermos site industry site found within the Akaki Kaliti Sub city, and the like to be surveyed. After surveying coordinates of the industrial sites in Addis Ababa in the form of X, Y coordinate using the WGS 1984 datum and Universal Transverse Mercator (UTM) Zone 37N, the points are to be connected to form polygon showing industrial sites as a polygon feature type.

3.6. Overlay Analysis

Land surface temperature, one of the main indicators of the microclimatic warming analysis, was extracted from the thermal bands of the Landsat satellite sensor for the time interval of the Study area (1985,1990,1995,2000,2005,2010, and 2015 G.C to the recent years).The calculated temperature map was overlaid with the map of industrial sites within Addis Ababa city and the spatial correlation of the two maps was performed to analyze the direct impact of industries on the microclimatic warming of the study area. Hence, the spatial relationship between the two maps is used to show if there is cause and effect relationship between industries and the land surface temperature increment. The following diagram shows the process throughout the analysis adopted with in this study from the data collection method up to the desired output generation.

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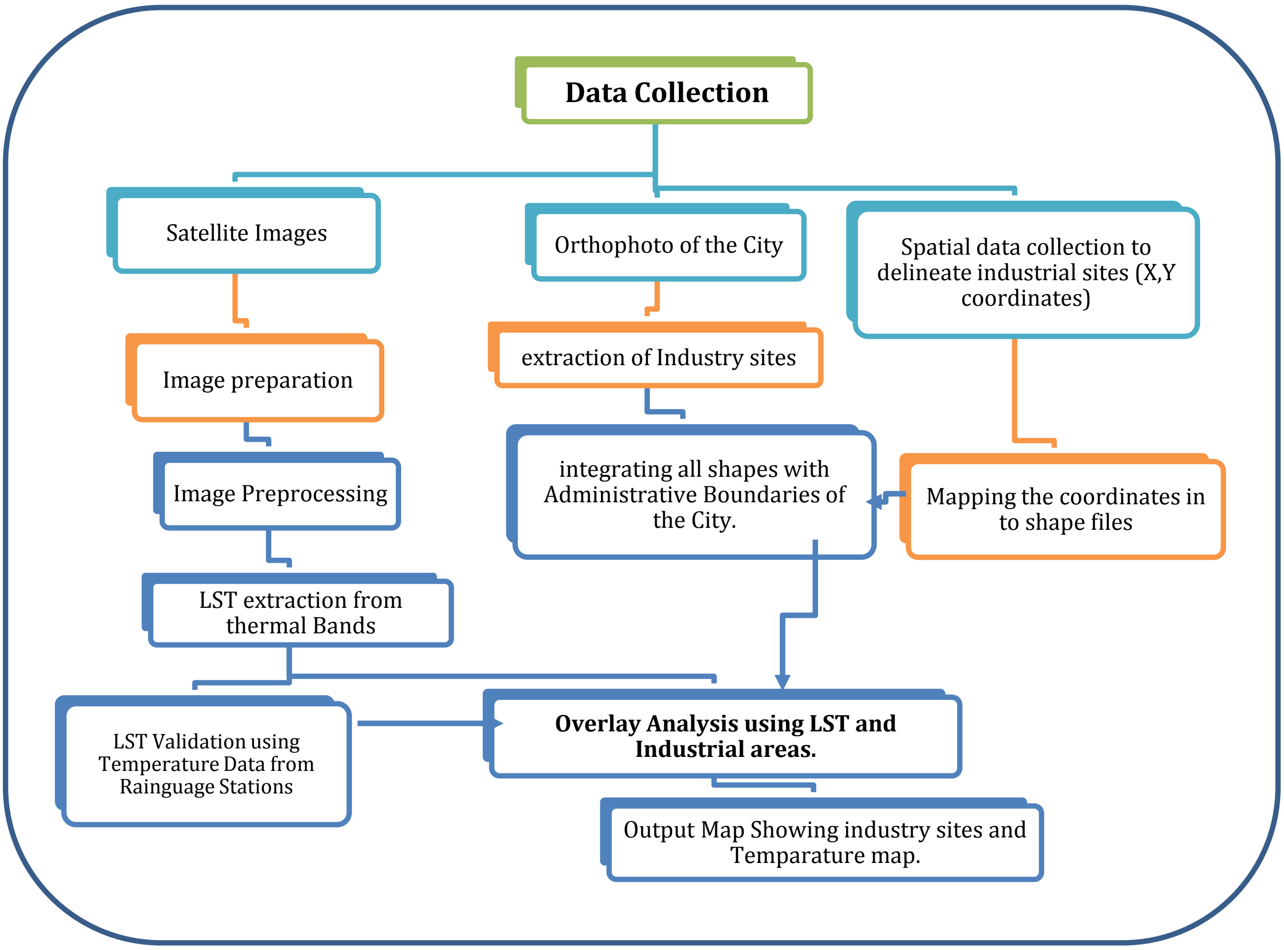

Figure 3.5: work flow of the study

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CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Mapping Industrial Expansion of Addis Ababa City

There are many industrial sites in Addis Ababa today. Some of them were extracted from the aerial photograph of the city taken at 2010 GC. The other industry sites are located by using Google earth for locating of the industry sites and are surveyed on the ground using Handheld GPS receiver having a better positional accuracy to capture the new clustered industry sites like Bole Lemi industry park did not exist on the orthophoto of the city at the time of flight.

After surveying coordinates of the new clustered industrial sites in Addis Ababa in the form of X, Y coordinate with the same spatial reference system with the LST map estimated from the landsat imageries and the collected points were connected by using digitization process to form polygon showing industrial sites.

Generally, the industrial expansion in Addis Ababa can be grouped into two main phases based on the time of development and expansion. The first phase was during 1985 to 2000 G.C, where the industrial expansion was not that much significant. The second phase of industrialization has been after 2000 G.C.

In the second phase of industrialization period, record shows that many industry sites have been built, especially expanded in the eastern and southern parts of the city. Figure 4.1 presents industrial sites in Addis Ababa categorized as old and recent industrial sites. Bole, Akaki Kaliti and Nifas silk lafto sub cities are the main industrial areas of Addis Ababa.

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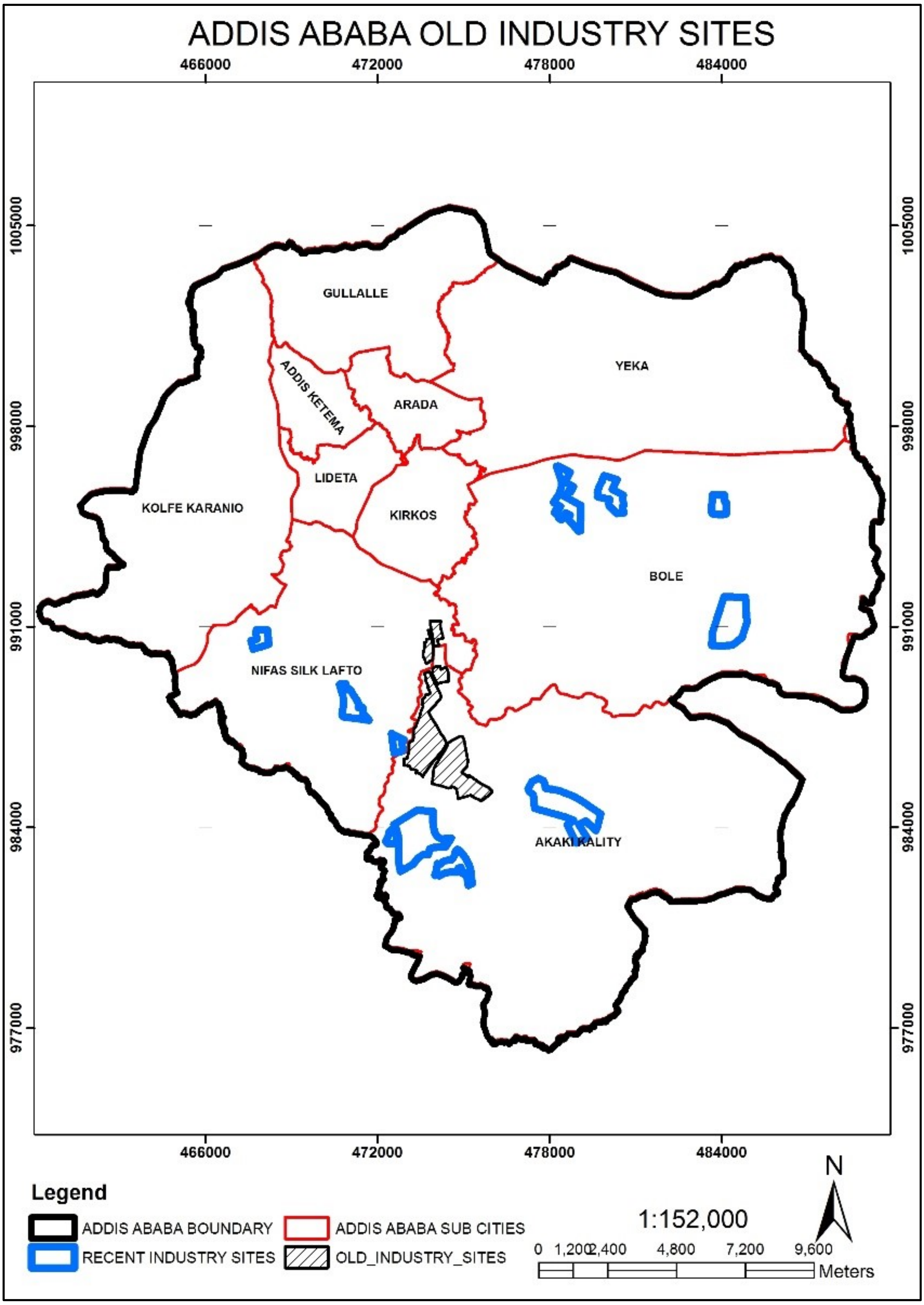

Figure 4.1: Major industrial sites in Addis Ababa City.

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From the year 2000 up to the recent time was the years of industrial expansion where most of the clustered industry sites were developed. The Kaliti thermo industry sites, Bole lemi industry sites, kuskuam Mariam industry sites, and other sites was among those industry sites developed within the mentioned period of time.

4.2. Microclimate warming of the past 33 years in Addis Ababa

Figure 7 shows the pattern of land surface temperature of Addis which is estimated from multi temporal satellite imageries. It is used as a proxy to microclimatic warming in the city. It is observed that the land surface temperature follows a certain pattern but in generally raised since the start of the estimation period considered in this study.

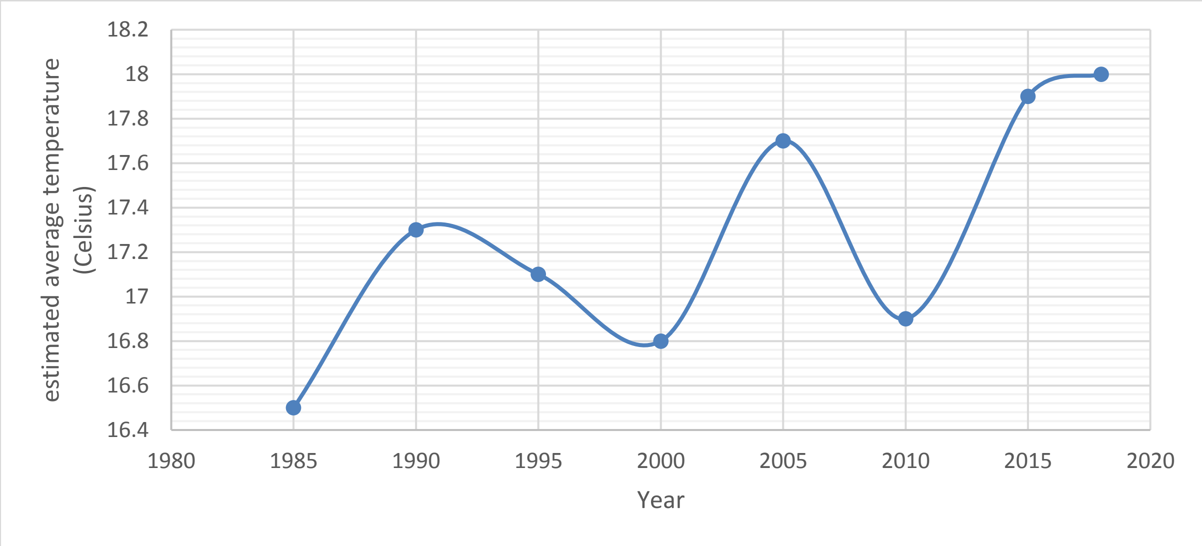

Figure 4.2: Average estimated temperature of Addis Ababa from Satellite measurement during Ethiopian sunny seasons (January – March) from 1985 to 2018.

The land surface temperature estimated from the Landsat imageries are cross validated against the in-situ measurement data which was collected from the meteorological station. The accuracy assessment of the calculated average temperature from the satellite data is performed by root mean square error calculation (rmse) method against the measured average temperature at the principal meteorological station. The root mean square error is 0.363.

Correlation analysis was also done and found positive correlation with a correlation coefficient of 0.8. As indicated by (Hana STREDOVA, 2015), The land surface temperature estimated are highly correlated with those calculated from in situ measurements, with a correlation coefficient of 0.696. It is also observed that there is a good correlation between the estimated average temperature and the average temperature of weather station for Addis Ababa city.

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According to (Ugur Avdan and Gordana Jovanovska, 2016) the LST results from thermal bands of satellite comparing with the ground measurements may have an error up to 5 ^{0}C in the case of Srivastava. The accuracy of the results in some area showed difference of $\pm$2 ^{0}c with actual ground temperature measurements. It should also be taken into consideration that there is 1.1 to 2 meters difference between the LST and the air temperature, which means that differences in the temperatures are normal and expected (Ugur Avdan and Gordana Jovanovska, 2016). This is also come to be true in the case of the estimated average land surface temperature of Addis Ababa city where the extracted average temperature from landsat had got the average difference of about 1.3 ^{0}c from the temperature at the weather station. The detail of the calculation process is found in the annex part at the end of this study.

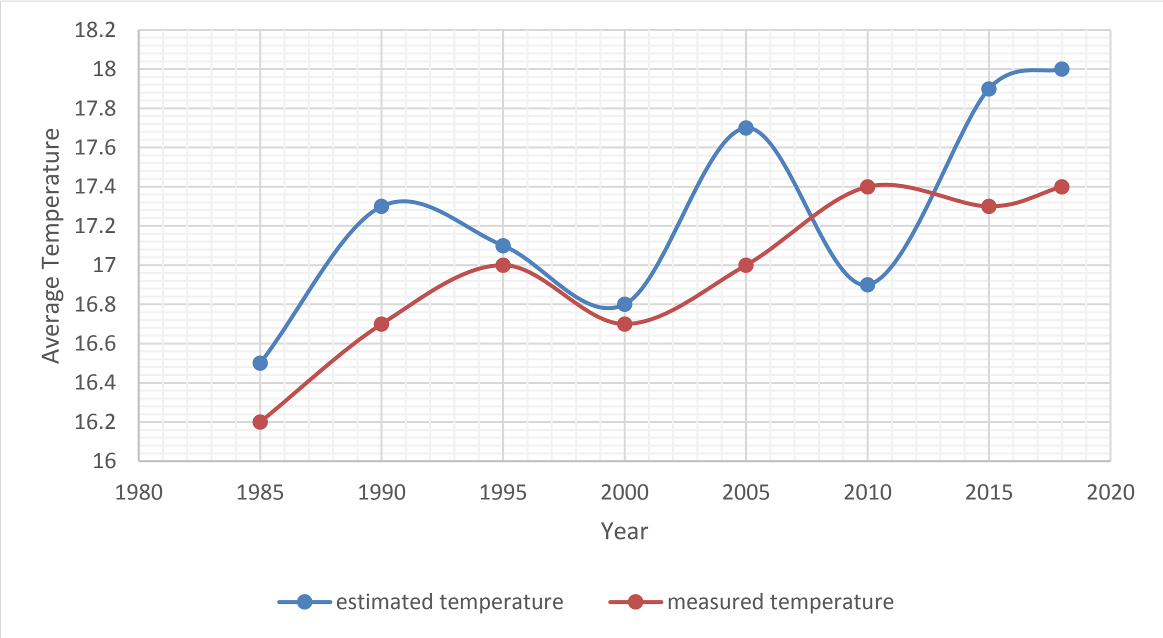

Figure 4.3: LST validation using average temperature (^{0}c) from weather station in Addis Ababa.

The figure 4.3 above shows that the estimated average temperature and the in-situ measurement at weather station in Addis Ababa. As per the temperature value from thermal remote sensing technology of Landsat satellite shown in the table 5 below, the calculated average temperature in the Addis Ababa city was 16.5 ^{0}c at the year 1985 G.C which was later grown up to 16.8 ^{0}c at the year 2000 G.C having difference of about 0.3 ^{0}c where the industrial development was less significant.

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Year	1985	1990	1995	2000	2005	2010	2015	2018
Average temperature (^{0}c)	16.5	17.3	17.1	16.8	17.7	16.9	17.9	18

Table 4.1: Estimated yearly average land surface temperature (^{0}c) from the thermal band of Landsat imageries Ethiopian sunny season of Addis Ababa (January- February) (Source: the researcher).

The temperature increment of the study area from the year 2000 G.C to 2018 G.C was 1.2 ^{0}c which shows that the increment in the local temperature is directly causing the microclimatic warming of the city as indicated in the table 5.

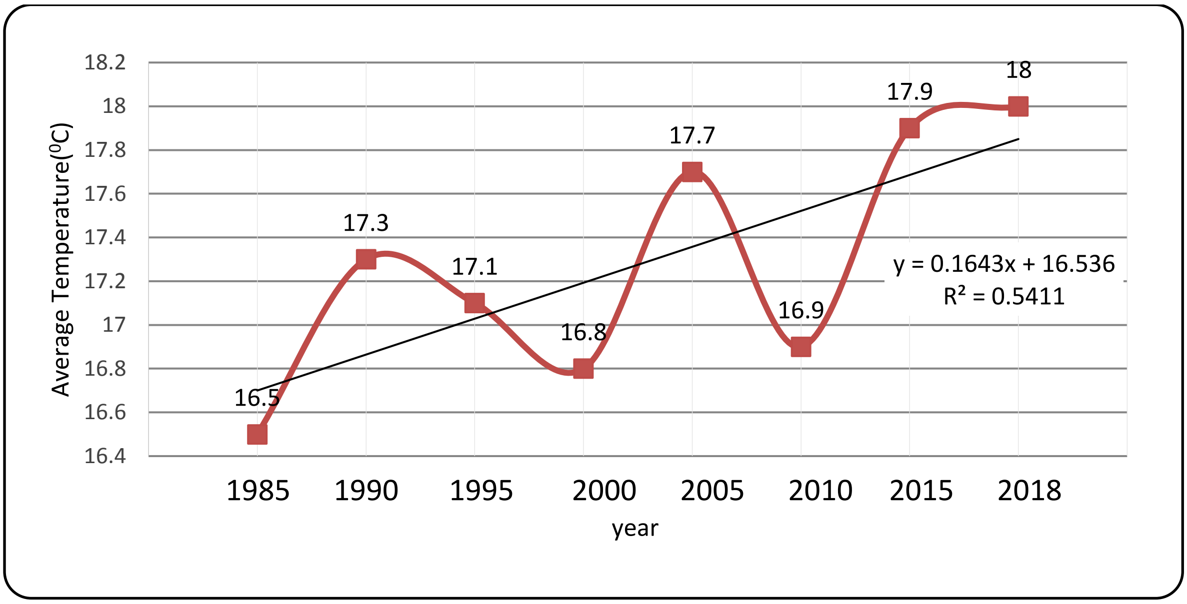

Figure 4.4: Trends in estimated average land surface temperature (^{0}c) from Landsat imageries Ethiopian sunny season of Addis Ababa (January- February) (Source: the researcher).

Figure 4.4 shows the trend of the local microclimatic warming of the city by using average temperature calculated from satellite imageries. The progressive warming change in temperature is taken place by the rate of 0.1643 per year from 1985 G.C to 2018 G.C. this shows that the temperature change is linear over change in time and most of the value fall on the trend line.

It is straight forward that from the graph, that the city is becoming warm, based on the average temperature calculated from the thermal band of the landsat imageries, as far as urbanization and industrialization exists. This temperature warming directly concerns the industrial expansion in the city from time to time. For example, the temperature from the early beginning of the study (1985 G.C) to the year 2000 G.C, where the industrial expansion was less significant, was increased by small amount of change while the temperature from 2000 G.C up to the last period of the study at 2018 G.C, where the industrial expansion is significant, has relatively higher change with respect to the earlier period. This result indicates that the impact of rapid industrialization on the temperature change or microclimatic warming of the city is becoming inevitable from time to time.

In this analysis, to develop further evidence that industrialization made a city to become warmer, the site-specific analysis of the temperature at and around the industry sites in Addis Ababa city was analyzed using the land surface temperature derived from the satellite data and the industry site maps developed through ground surveying by using spatial overlay analysis in the GIS environment.

4.3. The Relation between Land Surface Temperature and Industrial Sites

Land surface temperature, one of the main indicators of the microclimatic warming analysis, was extracted from the thermal bands of the Landsat satellite sensor for the Study area (1985,1990,1995,2000,2005,2010,2015 and 2018 G.C). The calculated temperature map was overlaid with the map of industrial sites within Addis Ababa city and the spatial correlation of the two maps was performed to analyze the direct impact of industries on the microclimatic warming of the study area using overlay analysis. Hence, the spatial relationship between the two maps is used to show if there is cause and effect relationship between industries and the land surface temperature increment.

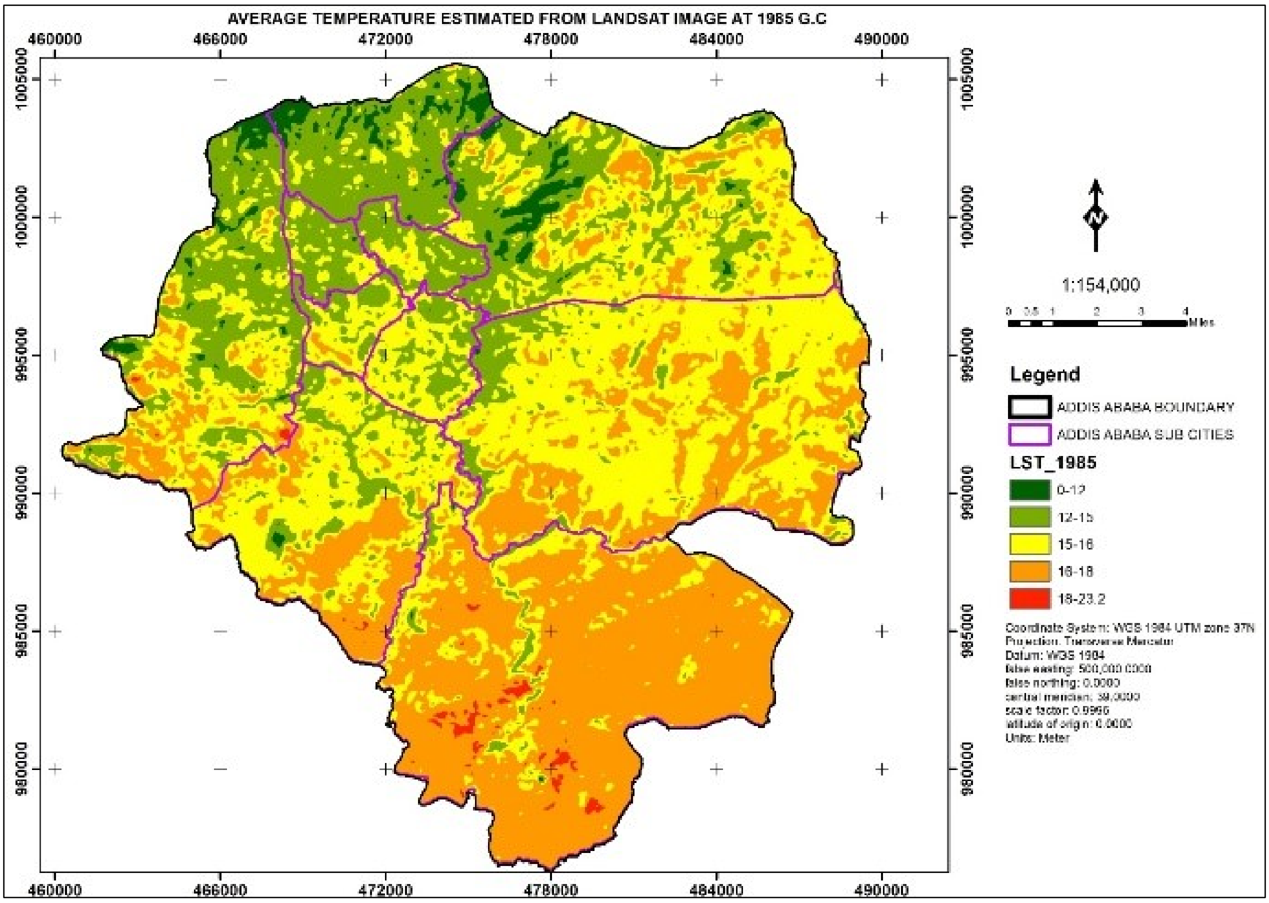

Figure 4.5: estimated temperature of Addis Ababa from Satellite measurement during Ethiopian sunny seasons (January– February) at 1985 G.C.

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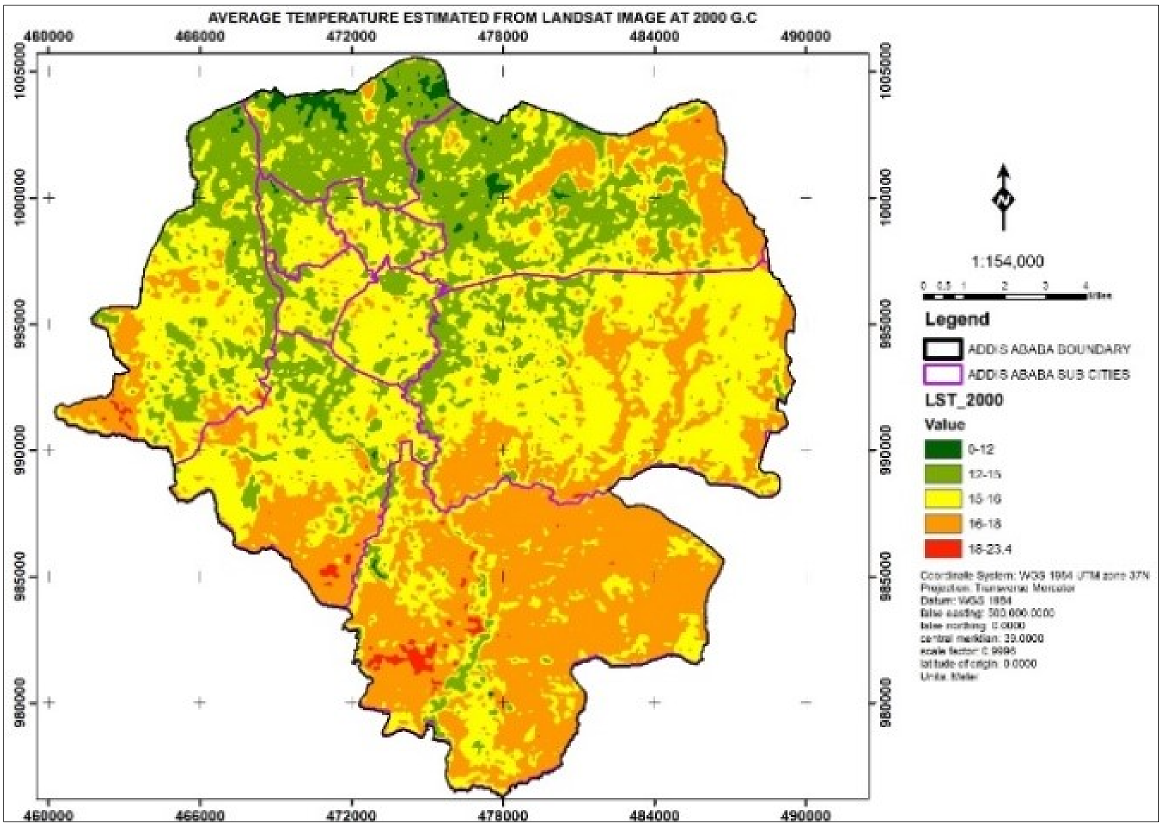

Figure 4.6: estimated temperature of Addis Ababa from Satellite measurement during Ethiopian sunny seasons (January– February) at 2000 G.C.

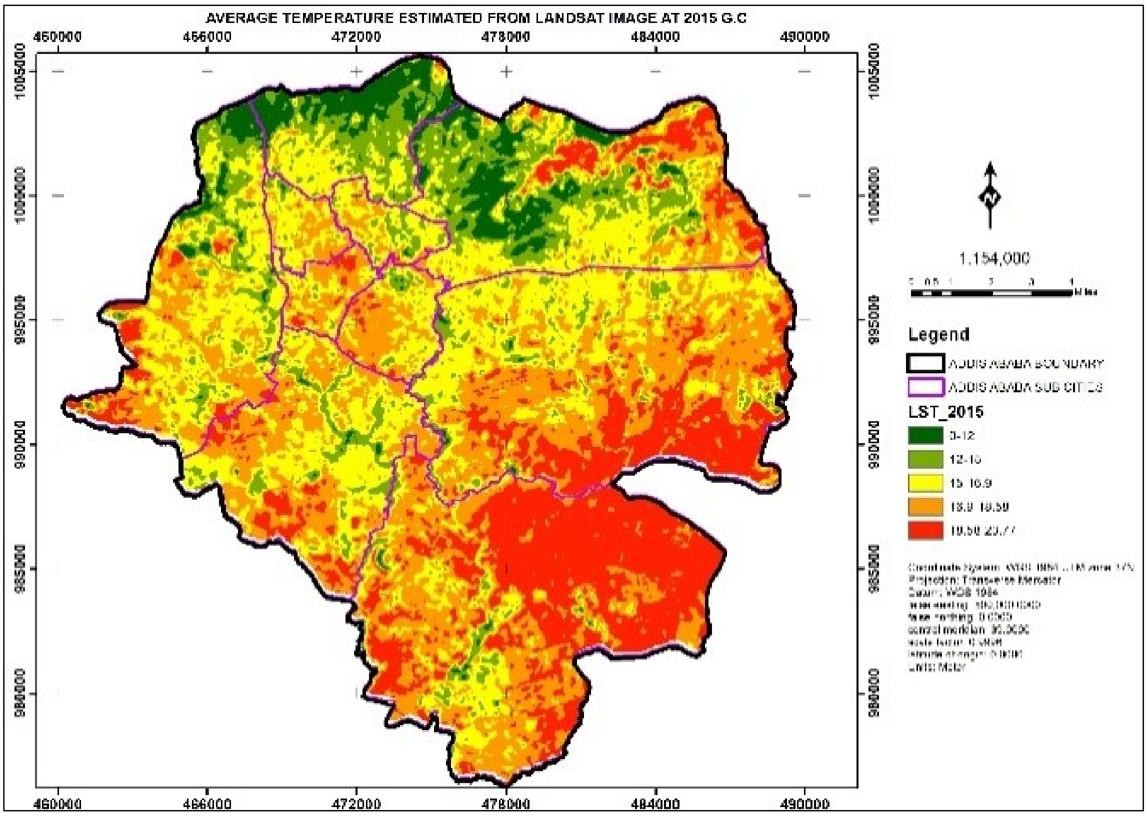

Figure 4.7: estimated temperature of Addis Ababa from Satellite measurement during Ethiopian sunny seasons (January– February) at 2015 G.C.

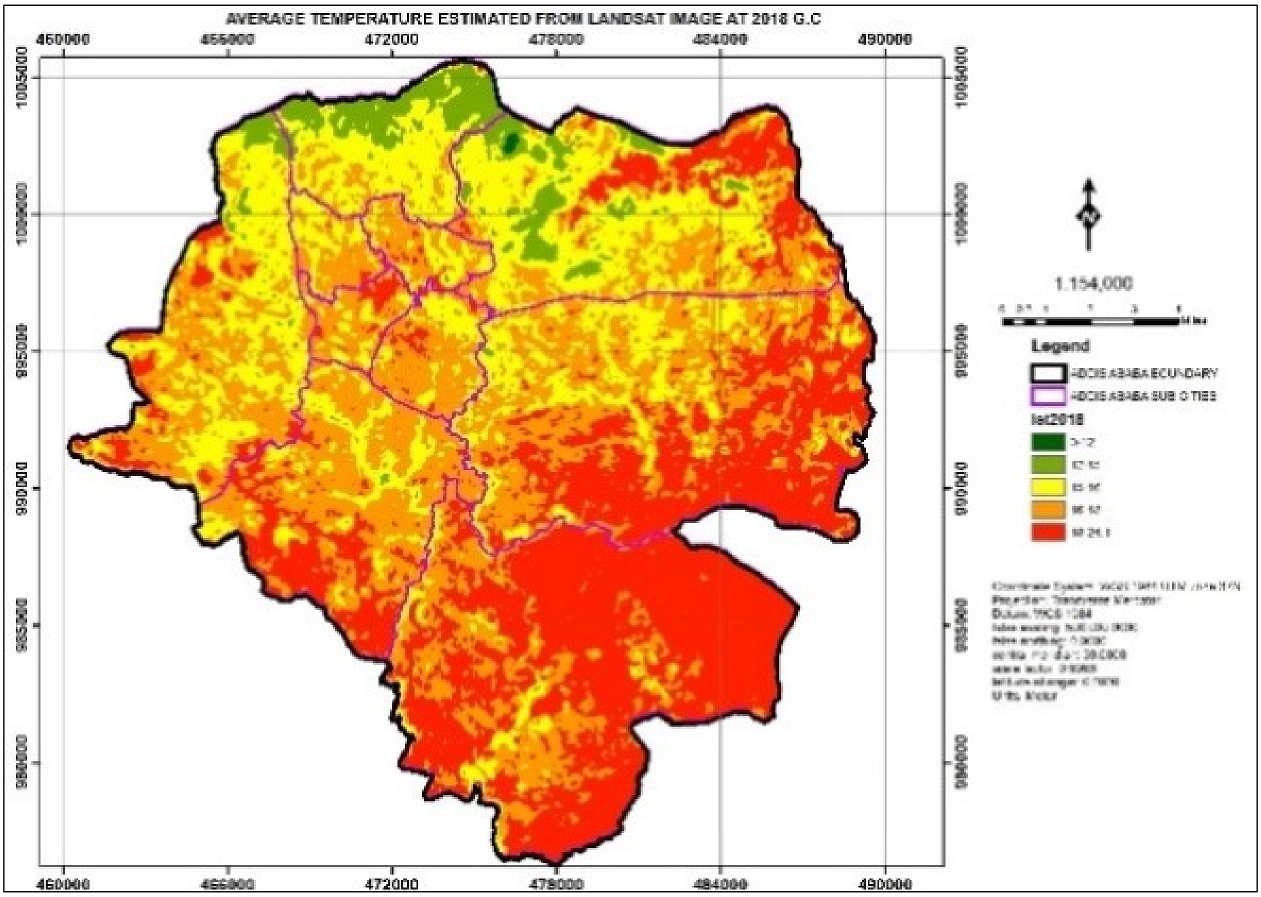

Figure 4.8: estimated temperature of Addis Ababa from Satellite measurement during Ethiopian sunny seasons (January– February) at 2018 G.C.

Figure 4.5 figure 4.6, figure 4.7 and figure 4.8 indicate, the microclimatic warming of Addis Ababa city for the last thirty-three years from 1985 G.C – 2018 G.C has been increased and this could be associated with the industrial expansion in the city that causes the local temperature to becoming hot compared to the surrounding environment. The first two figures (figure 4.5and 4.6) shows that there is a small change in the average temperature from the year 1985 to 2000 GC where the difference in temperature between the two years was observed to be 0.3 ^{0}c. This comes to be true even though the industrial development within the indicated period of analysis were less relative to the current period of study. Whereas the next two consecutive maps (figure 4.7 and figure 4.8) shows that the microclimatic warming resulted from the increment in the land surface temperature is significant, where the average land surface temperature of the city increased by 1.2 ^{0}c. This is mainly because of the rapid expansion of the clustered industrialization in the Addis Ababa city during the indicated period of time. The period from 2000 up to 2018 GC was a period in which most of the industries in Addis Ababa were built and the clustered industrial zones like Kaliti thermo industry zones, Bole lemi industry park, Haile Garment industry zones and others. Previous studies also show that in the factory chimneys site with temperature from 60^{0}c to 80^{0}c and Industrial zones with temperature from 50^{0}c to

60^0c are caused by Aluminum roofs material plus the thermal energy resulted from production activities that due to exhibited the highest temperature. Hence, factories could be considered the main source of heat in the Jubail industrial area as well as buildings (El-Nahry . H. and Rashash, 2012). This is also true for industry sites in Addis Ababa where the average temperature rises up from 20 ^{0}c to 26 ^{0}c. This clustered industry program is continued to exist in Addis Ababa like the industry sites located at local area called kilinto area where Heineken brewery factory exists. Especially, the result shows that the time from 2000 G.C to 2015 G.C were the turning point for the temperature of the city to increase compared to other time period.

Overlay analysis in the GIS environment is performed to see the most hotspot temperature area that can be compared to the temperature at the surrounding environment. The below site-specific result in figure 4.9 – 4.12 shows that whenever industrialization is taking place in the city, for a single industry sites, there is a gradual increment in land surface temperature which causes microclimatic warming in the city.

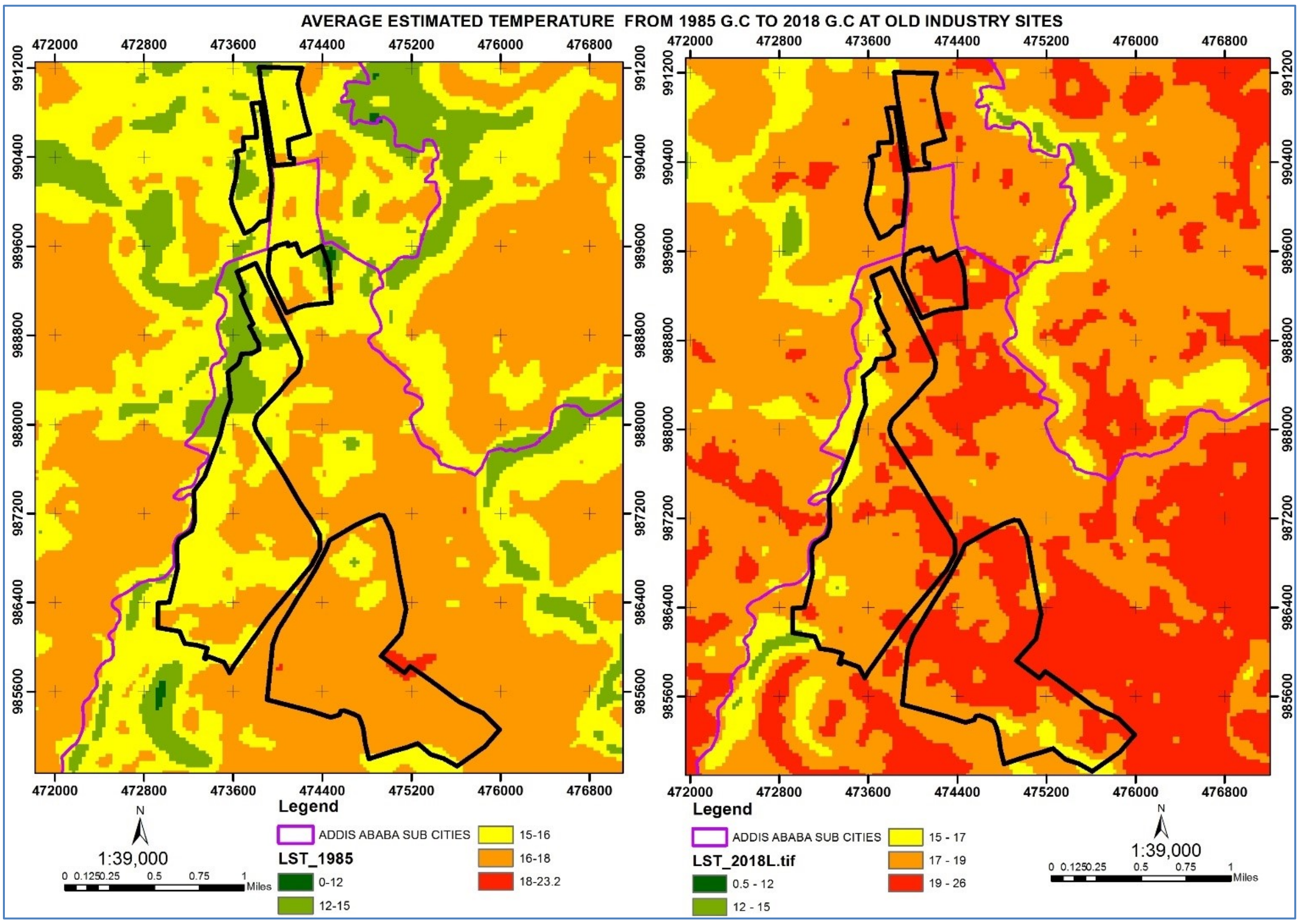

Figure 4.9: Industry sites and Land surface temperature difference at Sarice Bridgestone during 1985 and 2018 GC.

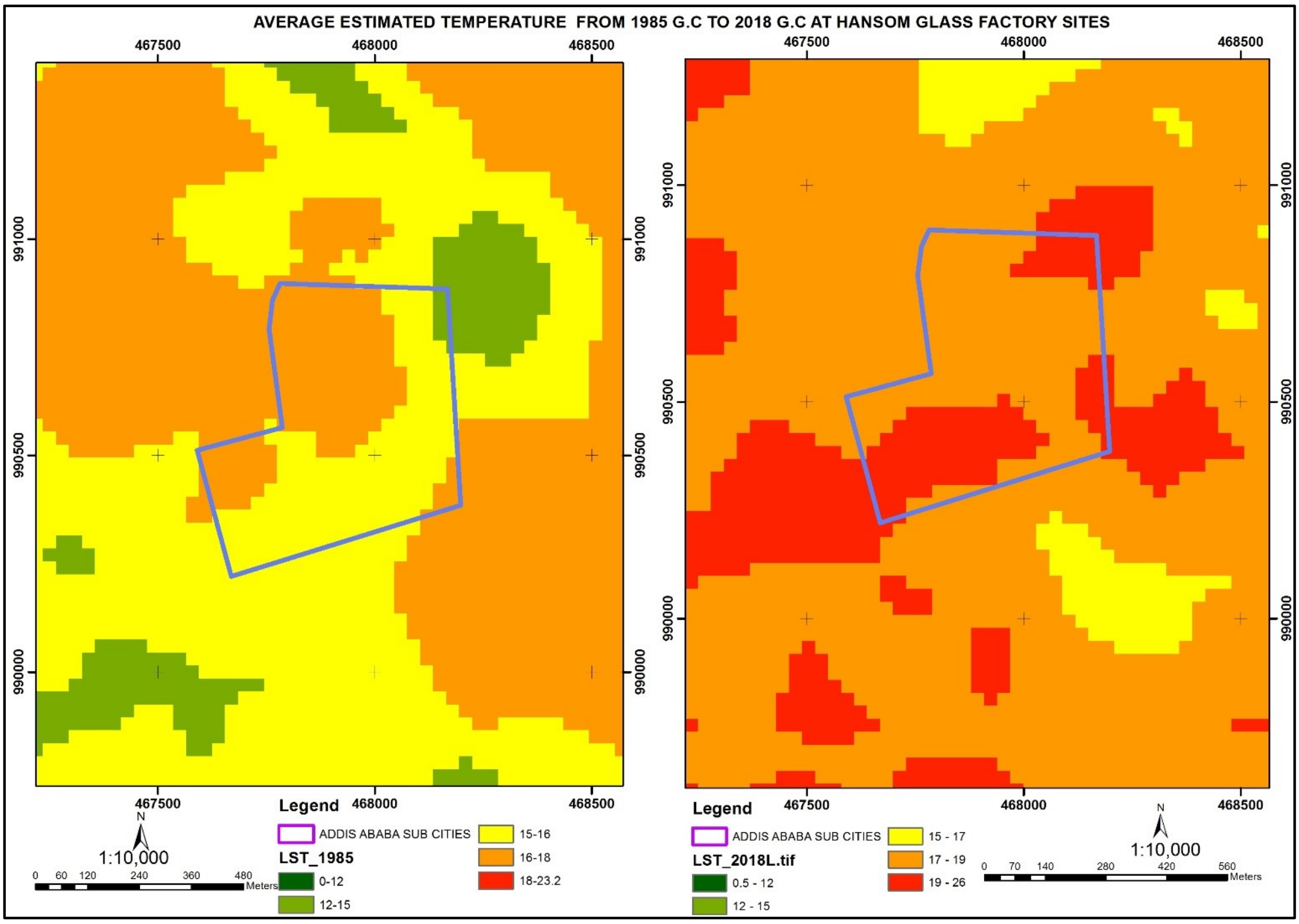

Figure 4.10: Industry sites and Land surface temperature difference at Hansom Glass factory during 1985 and 2018 GC.

Figure 4.9 and 4.10 illustrates that the temperature variation between the year 1985 and the recent time 2018 G.C is radical at old industry sites like Bridge stone tyres, Ries Engineering, FAFFA food complex, Addis Tyre share company, Awash Leather production and others found in this site. Figure 4.11 and 4.12 also realized that the temperature at this specific site has been increased and shown to be greater than the average temperature estimated as whole Addis Ababa city.

The temperature observed at Hansom Glass factory as indicated in figure 15, has shown the significant increment over the period of the study. Temperature at and around Hansom Glass factory from 1985 up to 2000 G.C were cooler compared to the temperature at this site after 2000 G.C to rise and come up to be hotter than the estimated average temperature of Addis Ababa city.

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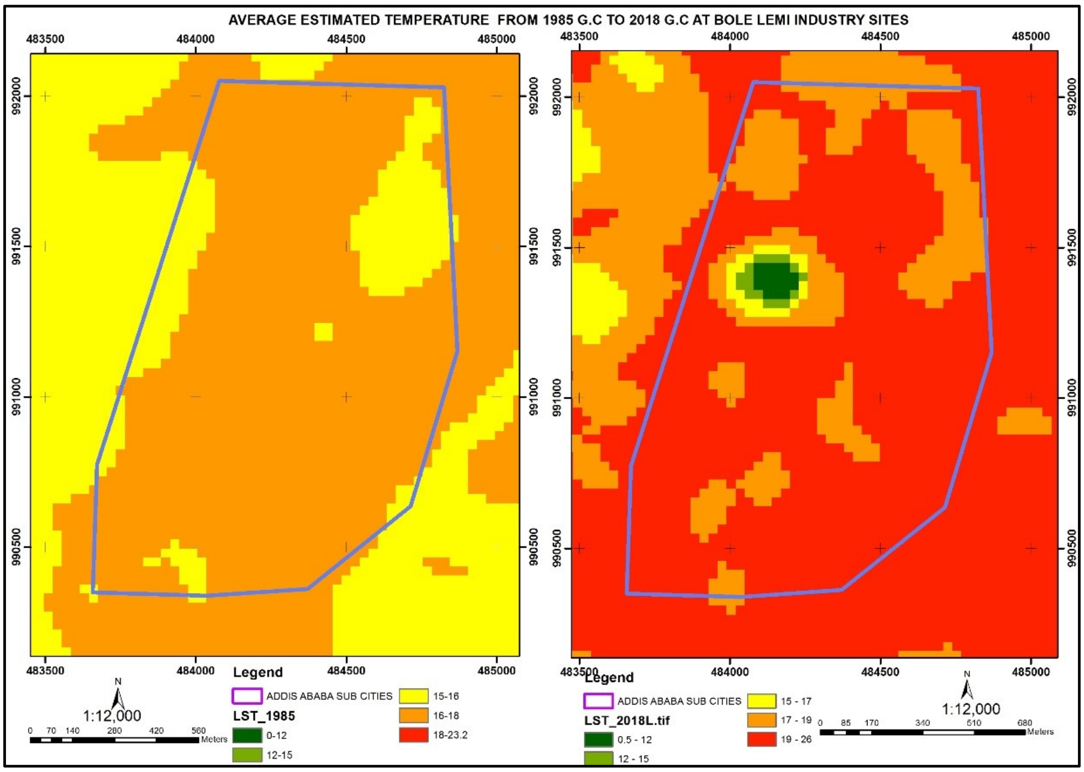

Figure 4.11: Industry sites and Land surface temperature difference at Bole Lemi industry park during 1985 and 2018 GC.

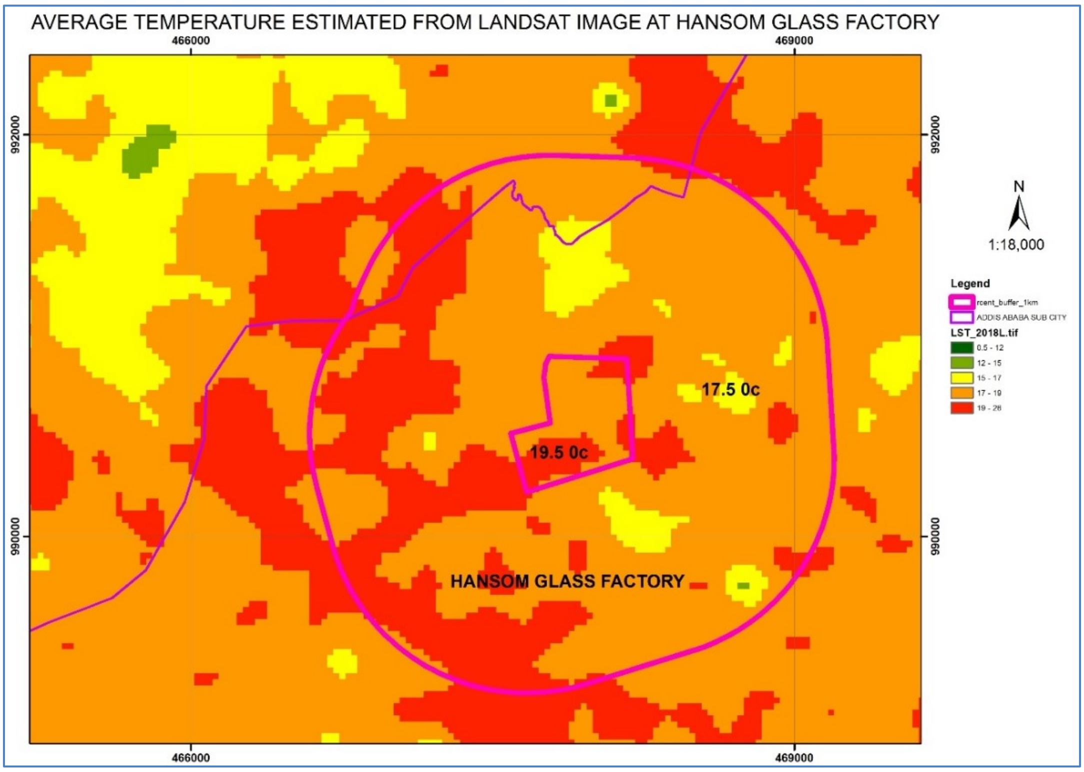

Figure 4.12: Temperature comparison between Hansom Glass Factory sites and surrounding 1km buffer areas.

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By observing the above maps (figure 4.9 to 4.12), it is clearly indicated that the temperature at the different industry sites of the study that was extracted from the thermal bands of satellite image has been increasing significantly from time to time. The same result is observed for all other industry sites within the study area. Also, from the result of the study, it is clear that the industrial expansion and temperature increment is directly proportional. This means that, as industries expand within the study area, the surrounding temperature also increases. The temperature in the industrial areas is relatively higher than the temperature in the surrounding area, for example, in the case of Kuskuam Mariam industry and Hansom glass factory areas, there is at least 1^{0}c to 2 ^{0}c temperature difference between the industry sites and the surrounding area within about 1-kilometer buffer zone. Studies showed that the temperature at chimney of iron factories rises to 80 ^{0}C in the industrial zones of Jubail city, affecting the temperature of nearby areas where the effect may extend into the distance between 500-2000 meters that could be considered as a buffer (El-Nahry . H. and Rashash, 2012). Other study shows that the thermal energy responses of different land forms indicates the great variation in surface temperature of different surface patterns and the surface temperature, where Industrial zones exhibited the highest temperature due to the aluminum roof material and the thermal energy resulted from production activities (Dr. N Sai Bhaskar Reddy, 2010). The following is the graphical representation of the temperature trend of some of the industry sites compared to the temperature of Addis Ababa city.

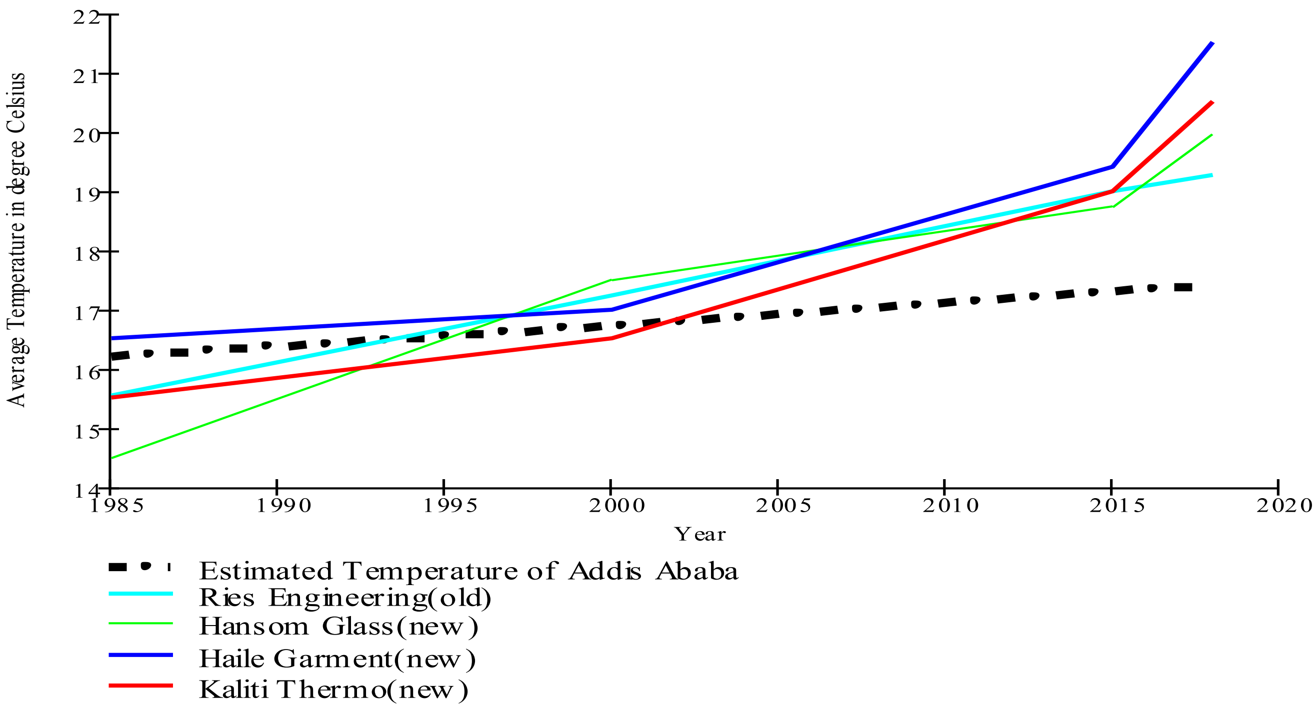

Figure 4.13: comparison between average estimated temperature of the whole city and some of industry sites in Addis Ababa city (January – February during 1985 to 2018 G.C).

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Figure 4.13 illustrates that the average temperature at different year of investigation has increased at different industrial expansion sites of Addis Ababa. It is observed that, the estimated temperature from each industrial site is equal or less than the average temperature of Addis Ababa from 1985 to 2000 GC, whereas the temperature at most of the industry sites after the year 2000 GC has been shown the greater value than the estimated average temperature of Addis Ababa. The graph also illustrates that the estimated average temperature observed at those industry sites cross up the average estimated temperature observed at Addis Ababa city especially at about 2000 GC. This is because most of the industries found in Addis Ababa city were developed after 2000 GC. This shows that the industrial expansion has evidently contributing to the warming up of the city especially from 2000 to 2018 G.C where the line graph got higher slope as shown on the figure 18. The older industry sites found at Ries Engineering site shows that the temperature has been raised through 1985 to 2018 GC in a linear way. Even though the industry was developed at 2000 GC, since the area were a center for urban activities like markets and shops, the temperature at this site has shown a progressive increment as shown in the Figure 4.13. The graph also realized that the industrial development in Addis Ababa city is the major cause for the temperature of the city to become warmer from time to time. This leads to the development of evidence that the industrialization is the main source of the microclimatic warming in the Addis Ababa city.

Therefore, the industrial expansion and the land surface temperature increments with in the study area shows the positive relationship as cause and effect relationship between the two phenomena. The temperature at all industry sites covers the hotter part of the temperature map produced from the satellite image. (Adejompo Fagbohunk ,2015) also found that the gas emission from the industrial sectors contributes more next to the energy supply sectors which contribute 24 % of gas emission which has hired credence to the significant contribution to the climate change as a result of industrialization of which industrial cluster remain a potent factor and the year of industrial revolution all over the world has been imposing the significant alteration to the pertinent temperature which all over caused warming (Adejompo Fagbohunk, 2015). This shows that the temperature around the industries are hotter than the surrounding area. This is also seen in the case of Addis Ababa where the increment in the local land surface temperature at different clustered industry zones is directly affecting the city to becoming warmer.

This study generally shows that surface temperature could be directly derived from remotely sensed data, which provides a powerful way to monitoring urban environment and human activities which enhances understanding of urban environment.

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CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

From the result found in the Chapter four above, it can be generally concluded that land surface temperature increases in the study area during 1985 – 2018 G.C.

Even though urbanization and industry development in Ethiopia is in its infant stage, which is still capable to hold more, the current result as per the above analysis is the arguing issue for the pertinent local climate of the city. Indeed, for policy and decision makers, it appears that development is constrained to constructing buildings and factories with little regard to their social, environmental and health impacts.

Most of the scholars proved that land surface temperature at the industrial sites are greater than that of the surrounding areas. As the result from the thermal remote sensing used in this paper, the increment in the local average land surface temperature as a result of industrial expansion lies between 17.5 ^{0}c to 19 ^{0}c. Hence, there is about 1.5 ^{0}c to 2 ^{0}c overall average increment in the temperature from 1985 G.C to 2018 G.C. based on the average temperature variation at different industry sites.

Overlay analysis was performed in order to visualize the interrelationship between the derived land surface temperature map and the map of industry sites within the study area. The result from the overlay analysis shows that, parts of the land surface temperature that fall in to the industry sites has got a greater amount of temperature value compared to that of the surrounding environment. This indicates that, the industrial development has come with the microclimatic warming in the city. The clustered industry system is among the causes of these change in the land surface temperature increment as per the result of the above study.

From the overlay analysis, the temperature warming trend is directly proportional with the industrial development sites. The temperature at those industries shows higher value with respect to the surrounding areas. This is observed by the average estimated temperature from landsat image. The temperature estimated from the satellite also shows a little bit higher temperature compared to the average temperature calculated from the weather station of Addis Ababa city.

Whenever industries are clustered together over the industrial zones, their impact on the surrounding environments like land surface temperature or air temperature and other elements will be considered prior to launching of the industries using different copping strategies.

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5.2. Recommendations

Standing on the findings of the analysis obtained and concluded issues above, the following recommendations are indicated:

- Most of the industry developed with in the study area did not apply mitigation method as observed at the time of ground surveying in industry areas. Hence, it is recommended that the existing industries has to consider the adaptation method of solution that emphasizes responding and adjusting to the results of microclimatic warming, while reducing the damage it causes, and the new industry development needs to apply mitigation method as proactive method of microclimatic warming.
- Municipalities and administration of the city are ought to use thermal remote sensing technology and perform the microclimate analysis over the defined time interval sot that microclimate management method is applied in the city.

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Annexes

1. The correlation analysis between the temperature data from satellite data and that of meteorological station in Addis Ababa from 1985 G.C to 2018 G.C by five-year intervals using Mathcad.

$$data := \begin{pmatrix} 16.2 & 16.5 \\ 16.7 & 17.3 \\ 17 & 17.1 \\ 16.7 & 16.8 \\ 17 & 17.7 \\ 17.4 & 16.9 \\ 17.3 & 17.9 \\ 17.4 & 18 \end{pmatrix}$$

$$Data := csort(data, 0)$$

$$line\left(data_0, data_1\right)$$

$$vx := Data^{\langle 0 \rangle} \qquad vy := Data^{\langle 1 \rangle}$$

$$n := length(vx) \qquad n = 8$$

$$fit := line(vx, vy) \qquad fit = \begin{pmatrix} 2.209 \\ 0.888 \end{pmatrix}$$

$$Slope := fit_1$$

$$Intercept := fit_0$$

$$Intercept = 2.209 \qquad Slope = 0.888$$

$$Fx := fit_0 + fit_1 \cdot vx$$

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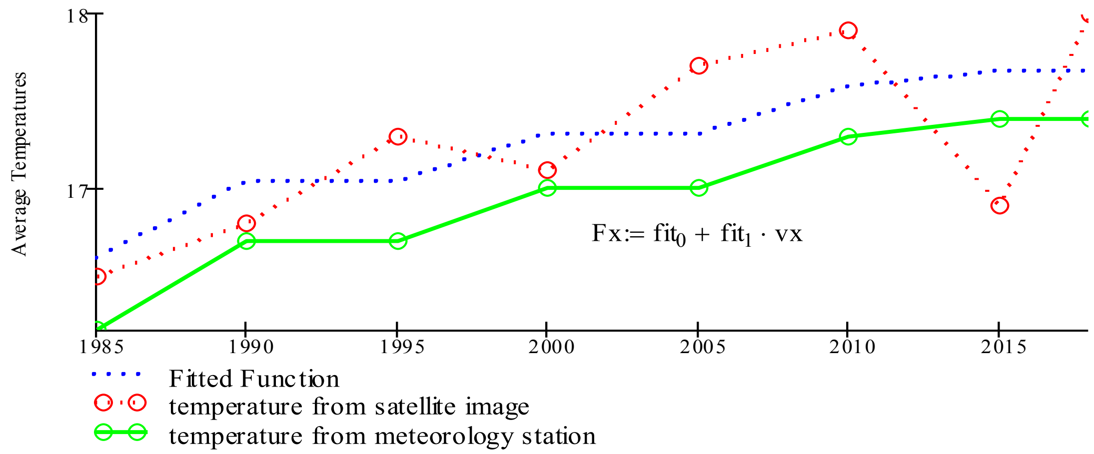

Where, Fx is the fitted line function, fit_0 is the intercept of the function and fit_1 is the slope.

2. Root mean square error analysis result.

$$\textbf{RMSE} = \sqrt{\boldsymbol{mean(T - Tr)^2}}$$

Where,

RMSE = Root Mean Square Error

T = Maximum Estimated Temperature

Tr = Maximum Reference Temperature

$$rms := \sqrt{mean\left(data^{\langle 0 \rangle} - data^{\langle 1 \rangle}\right)^2}$$

rms = 0.363

corr(vy, vx) = 0.8

The closer this value is to 1, the better the fit.

Where,

Data $^{(0)}$ is the average temperature data from meteorology station

Data $^{(1)}$ is the estimated temperature from the satellite image.

rms is root mean squared error.

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by inserting the above result in to the *rmse* equation above, the error of closure between the measured average temperature at principal meteorological Station and that of estimated average temperature from the Landsat imageries were calculated and the root mean square error of ***0.313*** were found.

The line function below returns the parameter of the least square line of the best fit to show the trend of the temperature warming. For a given x- and y- values in the vector vx and vy, respectively, the least squares line of best fit is given by:

$$Y = line\ (vx, vy)_0 + line\ (vx, vy)_1 .\ x$$

In the form of $y = ax + b$

The following matrix is the data value of measured temperature (vx) in the first column and the estimated temperature (vy) in the second column to show the linear analysis and correlation coefficient of the two data values.

$$data := \begin{pmatrix} 16.2 & 16.5 \\ 16.7 & 17.3 \\ 17 & 17.1 \\ 16.7 & 16.8 \\ 17 & 17.7 \\ 17.4 & 16.9 \\ 17.3 & 17.9 \\ 17.4 & 18 \end{pmatrix}$$

Therefore, the land surface temperature obtained from the satellite image has a correlation coefficient of **0.8** with that of temperature data from the weather stations.

3. The graphical model for extraction of land surface temperature.

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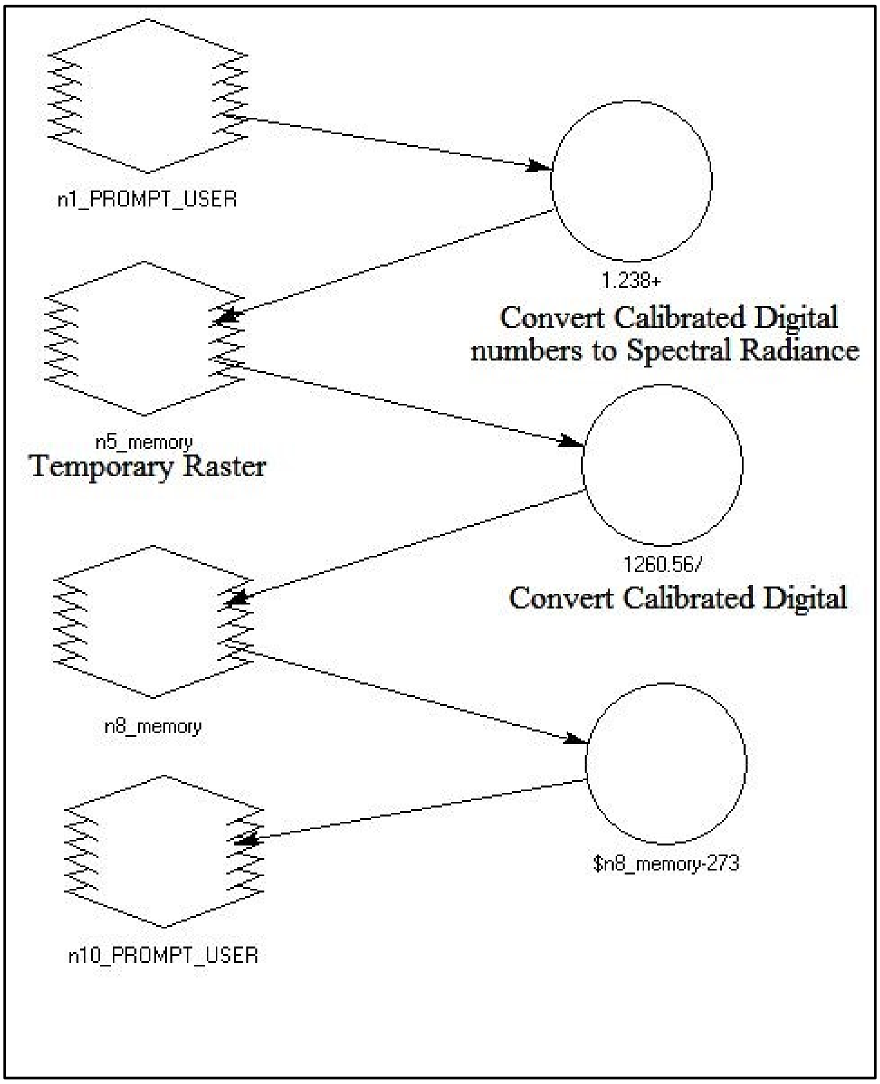
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numbers to Spectral Radiance
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Temporary Raster
1260.56/
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n8_memory
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n10_PROMPT_USER