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SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF ENVIRONMENTAL SCIENCE

ASSESSMENT OF URBAN EXPANSION AND ITS EFFECT ON SURFACE TEMPERATURE IN THE SEKONDI-TAKORADI METROPOLIS OF GHANA – A REMOTE SENSING AND GIS APPROACH

A Thesis submitted to the Department of Environmental Science, Kwame Nkrumah University of Science and Technology in partial fulfilment of the requirements for the degree of
MASTER OF SCIENCE (ENVIRONMENTAL SCIENCE)

By

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DECLARATION

I, Eric Stemn hereby declare that this submission is my own work towards the MSc Environmental Science and that, to the best of my knowledge it contains no material previously published by another nor material which has been accepted for the award of any other degree of the University except where due acknowledgement has been made.

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ABSTRACT

The Sekondi-Takoradi Metropolis of Ghana has been experiencing fast urban growth over the past decade. Forest and agriculture lands are being converted to uses concerned chiefly with population growth and increased economic activities. This research sought to assess urban expansion as well as its effects on surface temperature in the Metropolis using an integrated remote sensing and GIS approach. Several remote sensing techniques were used to carry out land-use-land-cover change detection using two multitemporal Landsat images of the years 1991 and 2008. This assisted in determining the changes that have taken place over the 17 year period. Urban growth pattern was also analysed using GIS techniques. The integrated use of remote sensing and GIS was subsequently employed to analyse the effect of urban expansion on surface temperature. Local climate change was also studied using multi-decade temperature data. The results showed that there has been significant urban growth in the study area with an annual rate of change of land cover of 4.06%. The results further showed that urban expansion was uneven in different parts of the metropolis and that there is also a negative correlation between the density of urban expansion and distance to a major road. The annual rate of increase in urban/built-up land was determined to be 4.65%. This urban development had increased surface radiant temperature in the study area by 4.3 ^{o}C in the urbanised areas. The results suggest that urban expansion has a certain effect on the monthly average surface temperature as well as the seasonal average temperature changes of the Metropolis. The integrate use of GIS and remote sensing has also been demonstrated to be an effective and efficient approach of analysing and monitoring urban expansion patterns and assessing its impact on surface temperature.

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LIST OF ABBREVIATIONS AND ACRONYMS

ATLAS	Advanced Thermal and Land Applications Sensor
CBD	Central Business District
CCRS	Canada Centre for Remote Sensing
DN	Digital Number
ETM+	Enhanced Thematic Mapper Plus
GIS	Geographic Information System
GMA	Ghana Meteorological Agency
GPS	Global Positioning System
GSS	Ghana Statistical Service
HIV	Human Immunodeficiency Virus
LST	Land Surface Temperature
LULC	Land Use Land Cover
MLA	Maximum Likelihood Algorithm
NDVI	Normalised Difference Vegetation Index
RM	Remote Sensing
STMA	Sekondi-Takoradi Metropolitan Assembly
TIR	Thermal Infrared
TM	Thematic Mapper
TMC	Takoradi Market Circle
TOA	Top of the Atmosphere
UHI	Urban Heat Island
UN	United Nations
UNFCCC	United Nations Framework of the Convention on Climate Change
USGS	United States Geological Survey

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Urbanization is defined as the movement of people from communities concerned chiefly or solely with agriculture, to other communities generally larger, whose activities are primarily centred in government, trade, manufacture, or allied interests (Trusilova, 2006). In other words, urbanisation comes with a corresponding increase in population. Urbanization is one of the most evident examples of human modification of the Earth. The urban land cover accounts for less than 2% of the Earth's land area, but this proportion is growing rapidly as more cities expand into natural ecosystems and agricultural areas (Trusilova, 2006). The intensive urbanization of the industrial nations which occurred in the past is currently under way in today's developing countries. Although the rate of urbanization in the developing world is proceeding at a fairly comparable rate as that of the industrial nations in the heyday of their rapid urbanisation, the rate of population growth of cities in developing countries as distinct from urbanization is rather unprecedented (Songsore, 2003; Davis, 1967; Satterthwaite, 1996; Preston, 1979). In 2008, for the first time in history, more than half of the world's population (3.3 billion people) was living in urban areas. This is projected to increase to some 5 billion by 2030 (UNFPA, 2007; UN-HABITAT, 2008). Over 80% of this growth will accrue to Asia and Africa, with most of the rest to Latin America (Martine *et al.*, 2008).

Much of this urban population is concentrated in Asia and Latin America which have a good number of mega-cities which are increasingly integrated into functional networks of economic linkages with global or core cities (Martine *et al.*, 2008).

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Between 2000 and 2030 whiles Asia's urban population of 1.36 billion will double to about 2.64 billion, that of Africa which is far smaller will more than double from 294 million to 742 million if the impact of HIV/AIDS can be held in check. At this rate, by 2030 seven out of every ten urban inhabitants of the globe will be from Asia and Africa (Martine *et al.*, 2008). By 2050, Asia will host 63% of the global urban population, or 3.3 billion people; Africa will have an urban population of 1.2 billion, or nearly a quarter of the world's urban population. Altogether, 95% of the world's urban population growth over the next four decades will be absorbed by cities in developing countries (UN-HABITAT, 2008).

Africa is currently rated among the least urbanized regions of the world and has hardly any of its mega-cities although its process of urbanization is very rapid (UNCHS-Habitat, 1996). As a result, Africa is only in the early phases of its urban transition. With a 3.3% growth rate per year between 2000 and 2005, the rate of change of Africa's urban population is currently the highest in the world. With growth rates of 4.02% and 4.05% respectively, the West and Central Africa, and East Africa regions are the fastest growing regions in Africa (UN-HABITAT, 2008). The percentage share of the total population which is urban in West Africa of 41.75 in 2007 is well above the average of 38.70 for the continent whiles that of East Africa of 20.48 makes the region the least urbanized in Africa (UN-HABITAT, 2008).

It is, however, the belief that Africa, with its relatively rapid rate of urbanization, will in future also be part of what Toynbee has called the 'world city' or 'ecumenopolis' according to Doxiadis with the majority of the world's population then living in a network of urban centers (Songsore, 2000). Whereas in 1995 only about 35 per cent of all Africans were urban dwellers as shown in Table 2-1, it is projected that by 2030 Africa may reach the milestone of half of its population living in urban

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settlements (UN-HABITAT, 2008). Africa's urbanization is approaching a demographic inflection point as a result of the projected sharp rise in the urban population (Kessides, 2006).

Africa presents a particularly poignant example of the problems involved, as it has the fastest population and urban growth in the world as well as the lowest economic development and growth and many of the poorest countries, especially in Tropical Africa (Clarke, 1993). The driving forces behind the rapid urbanization in Africa today are a combination of rural-urban migration and natural increase within towns and cities themselves. This rural-urban drift gives rise to a corresponding change in land use since vegetative and agricultural land will have to be converted into other uses to accommodate the population increase.

Consistent with observed trends in the rest of Africa, Ghana's population is becoming increasingly urbanized. The census or statistical definition of an urban centre in Ghana is any settlement with a population of 5,000 or more persons. Currently five out of every ten Ghanaians live in a city or town of more than 5,000 people (GSS, 2012). If current trends continue, by the year 2020 more than half of all Ghanaians will live in urban areas (Nabila, 1988). Whereas only 9.4% of the total population lived in urban settlements in 1931, this population shifted to 13.9% in 1948, 23% in 1960, 28.9% in 1970, 31.3% in 1984 and 43.9% in 2000 (Nabila, 1988). According to the 2010 housing and population census report, 50.9% of the country's population are urban dwellers. To put it differently, by 1984, the number of urban settlements had increased nearly nine fold from 41 in 1948 to 364 in 2000 whilst the associated population increased nearly fifteen fold from 570,597 persons in 1948 to 8,278,636 persons in 2000. In terms of comparison by administrative region within Ghana, the greatest contrast is between the Greater Accra Region and

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the Ashanti Region on the one hand and the other regions on the other. The Greater Accra region is the most urbanized with as much as 90.5% of its total population living in urban centres. This is followed by Ashanti Region with 60.6% of the population living in urban settlements dominated by Kumasi, the second largest metropolitan agglomeration after the Greater Accra Metropolitan Area. All other regions had urbanization levels that fell below the national average of 50.9%. The Brong Ahafo, Central, Western and Eastern regions are the next batch of regions with between 47.1% to 42.4% of their populations living in urban areas. The least urbanized regions lie in the poorest regions in Ghana, namely Upper West (16.3%) and Upper East (21.0%) regions (GSS, 2012).

Sekondi-Takoradi, a coastal city in the Western Region of Ghana has been experiencing a considerable increase in its population over the years. The population of the metropolis between 1960 and 1980 grew rapidly from 152,607 to 249,371, at a growth rate of 3.5% per annum. As at 2000, the population of the metropolis stood at 359,363. The metropolis happens to be the regional capital of the Western Region and the third most urbanised city in Ghana after Accra and Kumasi. As a result of the increase in the population, there is a considerable change in the land cover and the land use of the metropolis. Vegetative land is being converted to other uses associated with urbanisation and industrialisation. The metropolis is also a major industrial centre for the country, with the first harbour of the country. Thus a number of industrial activities occur in the metropolis. The recent oil discovery has also added to the complex land use changes that are occurring in the district.

The conversion of land associated with agriculture and vegetation to those associated with population growth, urbanisation and industrialisation give rise to a considerable environmental problem such as changes in the air temperature, changes in

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precipitation, changes in the sunshine hours and land degradation. This seems to be exactly what is occurring in Sekondi-Takoradi, therefore, there should be a growing concern on how to deal with these urbanisation problems.

The growing incidence of global environmental degradation, especially the depletion of protective atmospheric ozone layer, rising levels of global temperatures, and loss of biodiversity, have attracted the attention of decision makers worldwide for quite sometime. A series of global environmental conferences in the 1970s, 1980s, and through to the 1990s which culminated in the United Nations Framework of the Convention on Climate Change (UNFCCC) in 1992 and Kyoto Protocol in 1997, sparked frenzy discussions about global environmental integrity (Manu *et al.*, 2006). While human impact on the environment has intensified, considerable attention has been directed towards the search for a means to reduce emissions caused by greenhouse gases like carbon dioxide (CO_2). In the process, the question of climate change and global warming continues to draw substantial interests from researchers. It is evident from recent studies that most cities around the globe have witnessed an increase in urban temperatures as urbanisation of cities increases. The results of urban expansion are increases in number of buildings, extensive road networks, and other paved surfaces. Urban areas generally have higher solar radiation absorption, greater thermal capacity and heat is stored during the day and released by night (Weng, 2001). Built-up or urban areas tend to have relatively higher temperatures compared to those of non-urban areas. This thermal difference, combined with heat generated through urban houses, burning of fossil fuel in automobiles, and industry contribute to the development of “urban heat islands” (UHI). The difference in urban and rural areas according to Mather (1986) is generally less than 1^{o}C but it could be higher depending on other topographical and meteorological conditions. Several studies have demonstrated the potential for human activities to strongly influence

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urban atmosphere through the establishment of UHI (Oke, 1997; Magee *et. al.*, 1999). The use of remote sensing and GIS have been proven as an effective technique of assessing urban growth in terms of its location, trend, amount and rate as well as the effect it poses on their environmental elements such as climate. However in order to use remote sensing and GIS for such purpose, it is very imperative to determine the specific methods or techniques that would be used since the results that would be obtained is dependent on the methods adopted.

1.2 STATEMENT OF PROBLEM

Urban growth, both in population and in area extent, transforms the landscape from natural cover types to increasingly impervious urban land. The result of this change can have significant effects on local weather and climate (Landsberg, 1981). One of the most familiar is the urban heat island (UHI) phenomenon that shows that temperatures in urban areas are a few degrees higher than in surrounding non-urbanised areas. The occurrence of UHI makes urban areas hotter or warmer than surrounding rural areas. By covering agricultural lands and forests with buildings, roads and other impervious surfaces, urban areas generally have higher solar radiation absorption, and a greater thermal capacity and conductivity, so that heat is stored during the day and released by night (Weng, 2001). Therefore, urban areas tend to experience a relatively higher temperature compared with the surrounding rural areas. This thermal difference, in conjunction with waste heat released from urban houses, transportation and industry, contribute to the development of UHI.

In Ghana, land use and land cover pattern have experienced fundamental change due to accelerated economic development. Urban growth has increased, and extreme stress to the environment is occurring. This is particularly true in the industrial city of

Sekondi-Takoradi, where massive virgin forests and agricultural lands are disappearing, being converted to urban or associated uses. The population of the Sekondi-Takoradi Metropolis has been increasing over the years, industrial and commercial activities are also increasing. Land which was initially covered with vegetation is now being covered with reflective impervious structure such as road and building. To add to the above, as a result of the lack of appropriate land use planning and measures for sustainable development, widespread land use changes in the form of urban growth has been creating severe environmental consequences such as increase in temperature and changes in precipitation. There is therefore the need to evaluate the impact of land use changes (urban expansion).

The integration of remote sensing and Geographic Information Systems (GIS) has been widely applied and recognized as powerful and effective tools in detecting urban land use and land cover changes (Ehlers *et al.*, 1990). Satellite remote sensing collects multispectral, multiresolution and multitemporal data, and turns them into information valuable for understanding and monitoring urban land processes and for building urban land cover datasets. GIS technology provides a flexible environment for entering, analysing and displaying digital data from various sources necessary for urban feature identification, change detection and database development. These make remote sensing and GIS more useful tools for land use land cover and change detection projects (Weng, 2001).

The study aims at using Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM+) to analyse urban growth patterns in the Sekondi-Takoradi Metropolis and further evaluate the impact of urban growth on surface temperature.

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1.3 RESEARCH OBJECTIVES AND QUESTIONS

1.3.1 Main Objective

The main objective of the study was to evaluate the effect of urbanisation on surface temperature for the Sekondi-Takoradi Metropolis using Remote Sensing and GIS approach, in order to address the following research questions.

i. Is the land cover and land use in Sekondi-Takoradi undergoing any changes?

ii. What is the extent of urban expansion in Sekondi-Takoradi?

iii. Does urban expansion have any effect on changes in surface temperature?

1.3.2 Specific Objectives

The specific objectives were to

i. Creation of subset from the images for the extraction of the study area.

ii. Measurement of GPS coordinate for classifying (supervised) the subset images.

iii. Determine land-cover-land-use and change detection for Sekondi-Takoradi.

The following were done to evaluate urban growth pattern in Sekondi-Takoradi.

iv. Extraction of urban areas from the two classified land cover images.

v. Determination of urban expanded areas using image differencing technique.

vi. Determine the relation between density of urban expansion and distance to major road using correlation analysis.

The following were done to assess the impact of urban growth on surface temperature.

vii. Conversion of digital numbers to spectral radiance for bands 3, 4 and 6.

viii. Conversion of spectral radiance to spectral reflectance for bands 3, 4 and 6

ix. Conversion of spectral radiance to LST in degree kelvin and subsequently to degree celsuis for band 6.

x. Determination of NDVI from spectral reflectance for band 3 and 4

xi. Determine the relationship between LST and NDVI using correlation analysis.

CHAPTER TWO

LITERATURE REVIEW

2.1 URBANISATION AND URBAN GROWTH

Urbanisation can be defined as the shift from a rural to an urban society and involves an increase in the number of people in urban areas during a particular year. Even though urbanisation is measured in relative terms, it, however, refers to a complex process of social transformation. It is arguably the most significant demographic trend to emerge over the twentieth and twenty-first centuries and there is generally a growing concern about the rate of urbanisation. Urbanisation is the outcome of social, economic and political developments that lead to urban concentration and growth of large cities as well as changes in land use and transformation from rural to metropolitan pattern of organization and governance.

Urbanisation is occurring at a faster rate in both the developed and developing countries. However, speedy urbanisation, particularly the growth of large cities, and the associated problems of unemployment, climate change, poverty, inadequate health, poor sanitation, urban slums and environmental degradation pose a formidable challenge in many developing countries. According to Agotti (1993) and UNFPA (1993), more than half of the world's 6.6 billion people live in urban areas, crowded into 3% of the earth's land area.

2.1.1 Driving Forces of Urbanisation and Urban Growth

The rate as well as the level of urbanisation and urban growth varies from country to country. The mechanisms for urbanisation may also differ from one region to the other. However, urbanisation occurs in five main principal ways namely:

- Natural increase by urban dwellers,

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- International immigration to cities,
- Internal rural-to-urban migration,
- Reclassification
- Metropolitanisation.

Natural increase basically refers to excess of births over deaths in an area. Its impact on urbanisation comes chiefly through rural-urban differences in these two vital forces (Drescher and Iaquinta, 2002). Historically, when the now industrialised nations were urbanising, death rates in cities were higher than in rural areas. This relationship was reversed with improvements in sanitation, communication and transportation. In the modern era improvements in the ability to resist death passed largely from the industrialised world to the developing countries, and the diffusion of death control spread from cities to the countryside. Thus, for the past several decades throughout most of the world, death rates in cities have been lower than in rural areas.

International migration involves the movement of individuals across national boundaries. Most international migrants wind up in urban areas, causing an increase in the urban population.

Internal rural-to-urban migration has always been a significant contributor to the existence and persistence of urban populations. As a result of unemployment and lack of resources and infrastructure in rural areas, rural folks migrate to urban centre to take opportunity of the facilities that abound in these urban centres.

Reclassification or in-place urbanisation occurs when a particular location reaches the administratively defined threshold to be defined as urban. It depends both on underlying demographic processes and on administrative-political definition

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(Drescher and Iaquinta, 2002). Unlike births, deaths, and migration which accrue on a largely individual basis, reclassification affects urbanization in an aggregated fashion. A particular place increases in population until it reaches a given administratively defined threshold. At this point all of its residents are reclassified from rural to urban at one time. Reclassification is most likely to occur in places with a perceived economic advantage and the capacity to absorb non-agricultural labour. In some cases reclassification occurs as a direct result of annexation of areas that are distinctly non-urban. Thus, by administratively incorporating residents with non-urban lifestyles into the political jurisdiction, all of the residents become "urban" (Drescher and Iaquinta, 2002).

Metropolitanisation exerts its influence through a process of dominance whereby rural and periurban areas are either absorbed into the city itself or brought significantly within its sphere of daily activities. This has become a dramatic component of urbanisation since the middle of the twentieth century in the developed countries and is increasing rapidly in most developing countries like Ghana (Drescher and Iaquinta, 2002).

2.1.2 The Extent of Urbanisation

The level of urbanisation is increasing almost everywhere in the world today (Drescher and Iaquinta, 2002). Nonetheless, there remain significant regional differences in both the level and rate of urbanisation. The impacts are felt at all levels of the urban hierarchy from the growth in the number of mega cities to rapid population increases in small towns and medium sized cities (Drescher and Iaquinta, 2002).

The developing world has been predominantly rural but is quickly becoming urban. In 1950 only 18% of people in developing countries lived in cities. In 2000 the

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proportion was 40%. By 2030 the developing world will be 56% urban. While the developed world is more urban, 76% urban in 2000, developing countries have much faster urban population growth, estimated 2.3% annually, which far exceeds the developed world's urban growth rate of 0.4% (Drescher and Iaquinta, 2002). According to Table 2-1, with the exception of Southern Africa and South-central Asia, the rate of urbanisation throughout the world will slow down between 2000 and 2030. Yet paradoxical as it may seem, in every region urbanization has increased since 1950 and is estimated to continue increasing through 2030. The population in urban areas of the less developed regions will likely rise from 1.9 billion in 2000 to 3.9 billion in 2030. These areas will absorb most of the overall population increase expected during 2000 and 2030. Because the more developed regions and Latin America are already highly urbanised, their urban populations are expected to increase only slowly, passing from 0.9 billion in 2000 to 1 billion in 2030. During 2000 and 2030, the world's urban population will grow at an average annual rate of 1.8%, nearly double the rate expected for the total population of the world (1% per year). At that rate of growth, the world's urban population will double in 38 years. Growth will be particularly rapid in the urban areas of less developed regions, averaging 2.3% per year during 2000-2030, consistent with a doubling time of 30 years. In contrast, the rural population of the less developed regions is expected to grow very slowly, at just 0.1% per year during 2000-2030 (Drescher and Iaquinta, 2002).

Table 2-1 Various Indicators of Urbanization for the Regions of the World

	Urban population (millions)			*Percentage urban*			*Urban growth rate (percentage)*		*Growth rate of the total population (percentage)*		*Urbanization rate (percentage)*	
Major area, region	*1950*	*2000*	*2030*	*1950*	*2000*	*2030*	*1950-2000*	*2000-2030*	*1950-2000*	*2000-2030*	*1950-2000*	*2000-2030*
Africa												
Eastern Africa	3	65	205	5.3	26.1	44.1	5.88	3.86	2.68	2.11	3.21	1.75
Middle Africa	4	34	109	14.2	35.4	53.2	4.41	3.90	2.58	2.54	1.83	1.35
Northern Africa	13	88	174	24.7	50.8	66.2	3.80	2.27	2.36	1.38	1.44	0.89
Southern Africa	6	23	36	38.2	48.1	62.0	2.66	1.57	2.20	0.72	0.46	0.84
Western Africa	6	88	242	10.2	39.8	58.2	5.31	3.36	2.58	2.09	2.73	1.27
Asia												
Eastern Asia	121	572	933	18.0	38.5	54.6	3.11	1.63	1.59	0.47	1.52	1.16
South-Central Asia	83	455	1 027	16.6	30.6	47.9	3.41	2.71	2.19	1.21	1.22	1.50
South-Eastern Asia	27	193	397	14.8	37.2	55.9	3.94	2.41	2.09	1.05	1.84	1.36
Western Asia	13	132	248	26.7	70.2	79.1	4.57	2.10	2.64	1.70	1.93	0.40
Europe												
Eastern Europe	86	219	226	39.3	71.2	80.1	1.86	0.11	0.67	-0.29	1.19	0.39
Northern Europe	57	79	84	72.7	83.8	88.4	0.66	0.21	0.38	0.03	0.28	0.18
Southern Europe	48	96	101	44.2	66.4	76.3	1.37	0.16	0.56	-0.30	0.82	0.46
Western Europe	96	151	160	67.9	82.6	87.8	0.92	0.19	0.53	-0.02	0.39	0.21
Latin America and the Caribbean												
Caribbean	6	24	36	35.4	63.0	73.3	2.76	1.33	1.61	0.82	1.15	0.51
Central America	15	91	150	39.8	67.2	75.9	3.65	1.66	2.59	1.26	1.05	0.40
South America	48	276	419	42.8	79.8	87.3	3.48	1.39	2.24	1.09	1.24	0.30
Northern America	110	239	314	63.9	77.2	84.4	1.56	0.91	1.18	0.61	0.38	0.30
Oceania												
Australia/New Zealand	7.6	19.3	25.4	74.6	84.9	88.7	1.88	0.91	1.62	0.76	0.26	0.15

(Source: UNCHS-Habitat (1996))

2.2 LAND USE AND LAND COVER (LULC) CHANGE

Although the term land-cover and land-use (LULC) are often used interchangeably, their actual meanings are quite distinct. Land-cover refers to the surface cover on the ground, whether vegetation, urban infrastructure, water, or bare soil. Identifying, delineating and mapping land-cover is important for global monitoring studies, resource management and planning activities (CCRS, 2004). Identification of land-cover establishes the baseline from which monitoring activities (change detection) can be performed and provides the ground cover information for baseline thematic maps.

Land-use refers to the purpose the land serves, for example, recreation, wildlife habitat, or agriculture. Land use applications involve both baseline mapping and subsequent monitoring, since timely information is required to know what current quantity of land is in what type of use and to identify the land use changes from year

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to year. This knowledge will help develop strategies to balance conservation, conflicting uses, and developmental pressures. Issues driving land use studies include the removal or disturbance of productive land, urban encroachment, and depletion of forests. It is important to distinguish this difference between land cover and land use, and the information that can be ascertained from each (CCRS, 2004). The properties measured with remote sensing techniques relate to land cover, from which land use can be inferred, particularly with ancillary data or a priori knowledge (CCRS, 2004).

LULC studies are multidisciplinary in nature, and thus the participants involved in such work are numerous and varied, ranging from international wildlife and conservation foundations, to government researchers. Regional government agencies have an operational need for land cover inventory and land use monitoring, as it is within their mandate to manage the natural resources of their respective regions. In addition to facilitating sustainable management of the land, LULC information may be used for planning, monitoring and evaluation of development or industrial activity. Detection of long term changes in land cover may reveal a response to a shift in local or regional climatic conditions, which is the basis of terrestrial global monitoring. (CCRS, 2004).

2.2.1 Urban Land Use and Land Cover Classification

Urban LULC datasets are very important sources for many applications, such as socioeconomic studies, urban management and planning, and urban environmental evaluation. The increasing population and economic growth have resulted in rapid urban expansion in the past decades. Therefore, timely and accurate mapping of urban LULC is often required. Although many approaches for remote sensing image classification have been developed (Weng and Lo, 2001), urban LULC classification is still a challenge because of the complex urban landscape and limitations in remote

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sensing data. Because of the confusion of spectral signatures in some land cover types, such as between impervious surface and soil and between low-density residential area and forest, ancillary data have become an important source for improving urban LULC classification accuracy (Weng, 2010). However, in urban areas, the separation of different densities of residential areas, the distinction between residential areas and forest or grass, and the separation of commercial/industrial areas from residential areas are important. Census data, such as those on housing density distribution, are closely related to urban LULC patterns (Weng, 2010).

2.2.2 Effect of Land Use and Land Cover Changes

Changes in LULC date to prehistory, and are the direct and indirect consequence of human actions to secure essential resources (Ellis, 2007). The effects of land cover change can either be positive or negative and on the balance, the effects are most tilted to the negative side in tropical forest areas. Furthermore, the consequences of land cover change can be permanent or reversible depending on the type and cause of change which may have short or long term impacts on the earth's environment. Land cover change, the causes and their consequences, are observed simultaneously around the world today. Ellis (2007) groups the consequences of land-cover change into biodiversity change, climate change, pollution and other impacts.

In addition to global-scale climatic drivers, land-cover change has the potential to be a highly important driver of climate change at regional scales (Feddema *et al.*, 2005). Global warming which is driven by the release of greenhouse gases to the atmosphere is caused by (amongst others) changes in land cover. Land cover change due to deforestation and tillage of soil are responsible for accelerating the release of carbon dioxide into the atmosphere which results in global warming. On the contrary, the release of sulphur dioxide, and particles from biomass combustion

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associated with agriculture and human settlement are believed to cause regional and global cooling by the reflection of sunlight from particulates and aerosols, which has an effect on the cloud cover. Land-cover changes that alter the reflection of sunlight from land surfaces are also another major driver of global climate change (Ellis, 2007).

2.2.3 Land Cover Changes in Ghana and Sekondi-Takoradi

Ghana like most developing countries depends heavily on the exploitation of their natural resources for sustainable development. Dickson and Benneh (1995) categorised Ghana's vegetation into four main classes namely the coastal bush and grassland, forest, mangrove and savannah vegetation. These classes differ in terms of flora, fauna and mineral resources.

The forest plays an important role in the nation's economy. The forestry sector provides 43% of the Gross Domestic Product, 50% of export earnings and 70% of employment (Agyarko, 2001). Kufuor (2000) reported that the structural adjustment program, which was prescribed for the country by the World Bank in the 1980s, encouraged the expansion of timber companies and increased timber exploitation to raise foreign exchange earnings to service Ghana's debt. This led to the increase in the felling of tree for export and subsequently changed the LULC of certain places.

Deforestation is considered the dominant driving force of Ghana's land cover change. Since independence, the structure and composition of Ghana's land cover has witnessed a rapid change due to natural and human activities such as lumbering, clearing of land for agriculture purposes, firewood collection, flooding, bushfires, mining and urbanisation (Adu-Poku, 2010). Since independence the annual rate of the forest loss has been alarming. Its reductions have averaged around 220 – 650 km^2 annually with depletion rates of 2%. Estimates put Ghana's forest area at the turn of

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the 20th century around 82,000 km^2 but as of 2007. It had sharply declined to 16,000 km^2. Ghana can only boast of 25% of her original size of forest cover (Dogbevi, 2010).

The city of Sekondi-Takoradi, the third most urbanised city in Ghana has undergone changes in her land cover coupled with environmental challenges due to the rapid urbanisation occurring in the city. Being the first harbour city of Ghana, the city accommodates some of the country's industries. In recent times, there have been serious land use changes as a result of the current exploration and exploitation of oil along the coastal areas of the metropolis.

The population of the Sekondi-Takoradi in the year 1970 was estimated at 135,760, this figure increased to 272,150 in 1984 and sharply increased to 369,166 by the year 2000 (GSS, 2002), at an annual growth rate of 3.5 % which was higher than the national figure of 2.7%. The 2010 population and housing census recorded a value of 559,548 as the population of the entire metropolis. With regards to the increase in population growth, the metropolis has witnessed pressure on her land cover which has resulted in many environmental problems some of which this research aims at investigating. Activities such as farming, firewood collection, construction of buildings and logging of timber have altered the natural vegetation cover.

2.3 URBANISATION, LULC AND LAND SURFACE TEMPERATURE DYNAMICS

Urban development and sprawl drastically alter the biophysical environment. The most significant is the replacement of soil and vegetation with impervious urban materials, such as concrete, asphalt, and buildings, which affect the albedo and runoff characteristics of the land surface, thus significantly impacting the local and

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regional land-atmosphere energy exchange processes (Lo and Quattrochi, 2003). A most current noticeable phenomenon that has arisen as a result of city expansion is that urban climates are more polluted and warmer than the surrounding rural areas (Lo and Quattrochi, 2003). This phenomenon is as a result of the low values of albedo, vegetative cover, and moisture availability coupled with the presence of high levels of anthropogenic heating. These have given rise to the UHI phenomenon effect (Lo and Quattrochi, 2003). Thus, urban areas generally tend to act as islands of elevated temperature relative to the natural areas surrounding them (Sailor, 1995). The higher temperatures in the cities as a result of UHI have an adverse effect on air quality because ground level ozone is produced from volatile organic compounds (VOCs) in the presence of nitrogen oxides (NO_x) and sunlight by a complex set of chemical reactions. (Cardelino and Chameides, 1990). VOC and NO_x are emitted from motor vehicles, power plants, and other sources of combustion involving fossil fuel. Ground level ozone is a public health hazard that can cause respiratory and cardiovascular illness. Additionally, the UHI is seen as a possible contributor to increased instances of human mortality during high heat events (Lo and Quattrochi, 2003).

2.3.1 Relationship between LULC and Land Surface Temperature

When changes occur in LULC over a period of time as a result of depletion of vegetative cover and its replacement with surface such as residential and commercial buildings, highways and parking lots, it consequently change the characteristics of the moisture, albedo and temperature (Betts, 1999). Thus, changes in LULC results in a corresponding alteration in the temperature of that area. These land surface temperature changes tends to enhance the temperature contrast between urban areas and their surrounding rural areas.

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A vital human impact on atmospheric temperature changes and trends is extensive LULC changes. Various studies using both observed and modelled data have documented these impacts. Chase *et al*. (2000), Kalnay and Cai (2003), Trenberth (2004), Feddema *et al*. (2005), Christy *et al*. (2006), Mahmood *et al*. (2006) and Ezber *et al*. (2007) all demonstrated that there is a corresponding change in surface temperature if land-use also changes.

2.3.2 Thermal Characteristics of Urban Areas

The influence of human on climate changes is predominantly significant in urban areas. This is as a result of the kind of structure located in urban areas. Urban areas are mostly covered with impervious surface such as pavements (sidewalk, driveways, roads and parking lots) that are covered with impassable materials like asphalt, stone, brick, concrete and rooftop. Such a surface has the ability to collect heat in their dense mass so that when heat is released it raises air temperature as well as increase energy consumption in buildings. Urbanisation alters the thermal properties of the land, changes the energy budget at the ground surface, changes the surrounding atmospheric circulation characteristics, generates a great amount of anthropogenic waste heat, and leads to a series of changes in the urban environmental system. Those effects mostly originate near the ground surface resulting in surface temperature anomalies. The anomalous urban ground surface temperature will unavoidably propagate upward into the atmosphere (Huang *et al*., 2008).

2.4 URBANISATION AND LAND SURFACE TEMPERATURE - THE ROLE OF REMOTE SENSING AND GIS

Remote sensing and GIS play significant roles in understand the trends and dynamics of land use changes, urbanisation and land surface temperature. Remote sensing is

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the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analysing, and applying that information (CCRS, 2004). Thus remote sensing can be applied to inaccessible areas and regions that inhibit the use of conversional surveys. In much of remote sensing, the process involves an interaction between incident radiation and the targets of interest.

Traditional survey and mapping approaches do not offer the necessary information in a timely and cost-effective manner. Remotely-sensed data, with their advantages in spectral, spatial, and temporal resolution, have demonstrated their usefulness in provision of information about the physical characteristics of urban areas; including size, shape, and rates of change, and have been used widely for mapping and monitoring of urban biophysical features (Haack *et al.*, 1997; Jensen and Cowen, 1999).

Geographic Information System (GIS) technology offers a flexible environment for entering, analysing, and displaying digital data from various sources that are necessary for urban feature identification, change detection and database development. The integration of remote sensing and GIS technologies has been applied widely and has been recognized as an effective tool in urban-related research (Weng, 2010).

2.4.1 Image Classification

Image classification uses spectral information represented by digital numbers in one or more spectral bands and attempts to classify each individual pixel based on the spectral information. The objective is to assign all pixels in the image to particular

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classes or themes (e.g., water, forest, residential, commercial, etc.) and to generate a thematic "map" (Weng, 2010).

The image analyst decides on the type of classification approach to adopt and decides between using spectral classes or information classes. Generally there are two types of classification approaches, namely, *supervised* and *unsupervised* classification.

A supervised classification is based on detection algorithms using pixels from known reference samples, usually located within a scene, as a basis for comparison to other pixels from objects in the same scene. For example, if the analyst knows one specific area is a gravel road, then all other areas with the same detection algorithm will also be a gravel road. Therefore, in supervised classification, the analyst usually starts with known information classes that are then used to define representative spectral classes that closely match the reference samples. Unsupervised classification is basically the opposite of supervised classification. Pixels in an image are grouped into spectral classes based solely on the information in the data compared to signature libraries or other known information classes.

2.4.2 Estimation of Land Surface Temperature (LST)

Various algorithms have been developed for converting Thermal Infrared (TIR) measurements into surface kinetic temperatures. (Weng, 2010). Satellite TIR sensors measure top of the atmosphere (TOA) radiances, from which brightness temperatures (also known as blackbody temperatures) can be derived using Plank's law (Dash *et al*., 2002).

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There also exists an algorithm which converts digital number to spectral radiance. From the spectral radiance obtained, temperature in degree kelvin can be obtained which can then be converted to degree Celsius. (Weng *et al*., 2003).

TIR data have been widely used to retrieve LST (Quattrochi *et al.*, 1997; Weng *et al.*, 2004). A series of satellite and airborne sensors have been developed to collect TIR data from the earth surface, such as HCMM, Landsat TM/ETM+, AVHRR, MODIS, ASTER and TIMS. In addition to LST measurement, these TIR sensors may also be utilised to obtain emissivity data of different surfaces with varied resolutions and accuracies. LST and emissivity data are used in urban climate and environmental studies, mainly for analysing LST patterns and its relationship with surface characteristics. (Quattrochi *et al.*, 1997).

In thermal remote sensing studies, much emphasis has been placed on using the NDVI as the major indicator of urban climate. For example, Gallo *et al*. (1993) assessed the influence of the urban environment on observed minimum air temperatures by analyzing urban–rural differences for NDVI and surface temperatures. Lo *et al*. (1997) studied changes in the thermal responses of urban land cover types between day and night and examined the relation between land cover radiance and vegetation amount using NDVI derived from Advanced Thermal and Land Applications Sensor (ATLAS) data. Gallo and Owen (1999) evaluated seasonal trends in temperature and NDVI and found that differences in NDVI and satellite-based surface temperature accounted for 40% of the variation in urban–rural temperature differences. The NDVI–temperature relationship has also been utilized in various studies to derive or evaluate two variables, fractional vegetation cover and surface soil water content for climate modeling (Carlson *et al.*, 1977; Gillies and Carlson, 1995; Goward *et al*., 2002).

CHAPTER THREE

MATERIALS AND METHODS

3.1 STUDY AREA

3.1.1 Location

Sekondi-Takoradi metropolitan area is located between Latitude 4° 52' 30'' N and 5° 04' 00'' N and Longitudes 1° 37' 00'' W and 1° 52' 30''W. Bounded to the north of the metropolis is the Mpohor Wassa District, the south by the Gulf of Guinea, the West by the Ahanta West District and the East by Shama District. The metropolis happens to be the smallest district in the region with a land area of 385 km^2. However, it is the most populated district. The metropolis is strategically located in the south-western part of the country, about 242 km to the west of Accra the capital city and approximately 280 km from the La Côte d'Ivoire in the west. Figure 3-1 is a map of the study area.

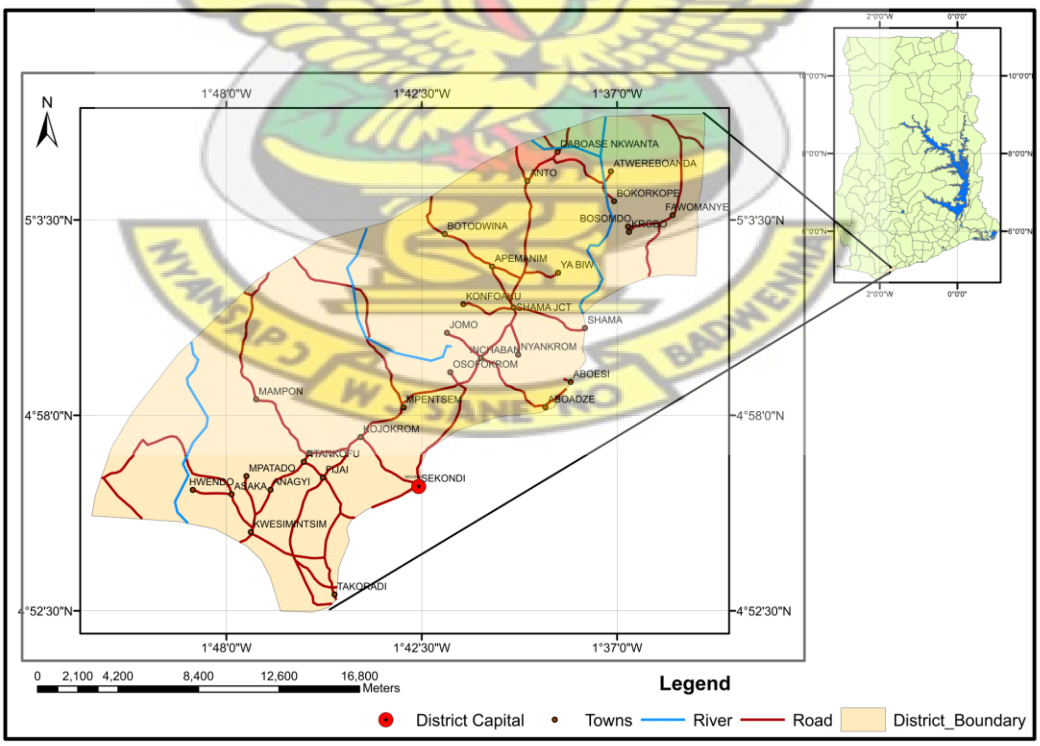

Figure 3-1 Map of Ghana Showing the Study Area

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3.1.2 Climate

The Metropolis lies within the South-Western Equatorial Zone. It therefore has fairly uniform temperature, ranging between 22 ^{o}C in August and 30 ^{o}C in March. In recent, times, however, the maximum temperature for the metropolis is said to be increasing throughout the year. It has a mean annual rainfall of 2,350 mm. It experiences heavy rainfall in May and June with the minor rainfall occurring between September and October. Sunshine duration for most part of the year averages 7 hours per day. Relative humidity is generally high throughout the year between 50% and 70% in the dry season and 75% and 85% in the wet season. (STMA, 2012)

3.1.3 Land Use/ Land Cover and Vegetation

The metropolis has an equatorial type of climate. Vegetation is mainly woodland in the northern and central parts, while thickets are intermingled with tall grass species along the coast, especially in areas where there are no permanent crops. The land cover of the metropolis can broadly be categorised into five types, namely, moderately closed tree canopy with herb and bush cover, moderately dense herb or bush with scattered trees, mosaic of thickets and grass with or without scattered trees, planted cover and settlements. (STMA, 2012). Some few years back, the moderately dense herb or bush with scattered trees covered about 70% of the entire land for the metropolis; however, as a result of urbanisation and increased industrialisation most of these areas are now being replaced with settlement (STMA, 2012). Figure 3-2 is a land cover map of the study area.

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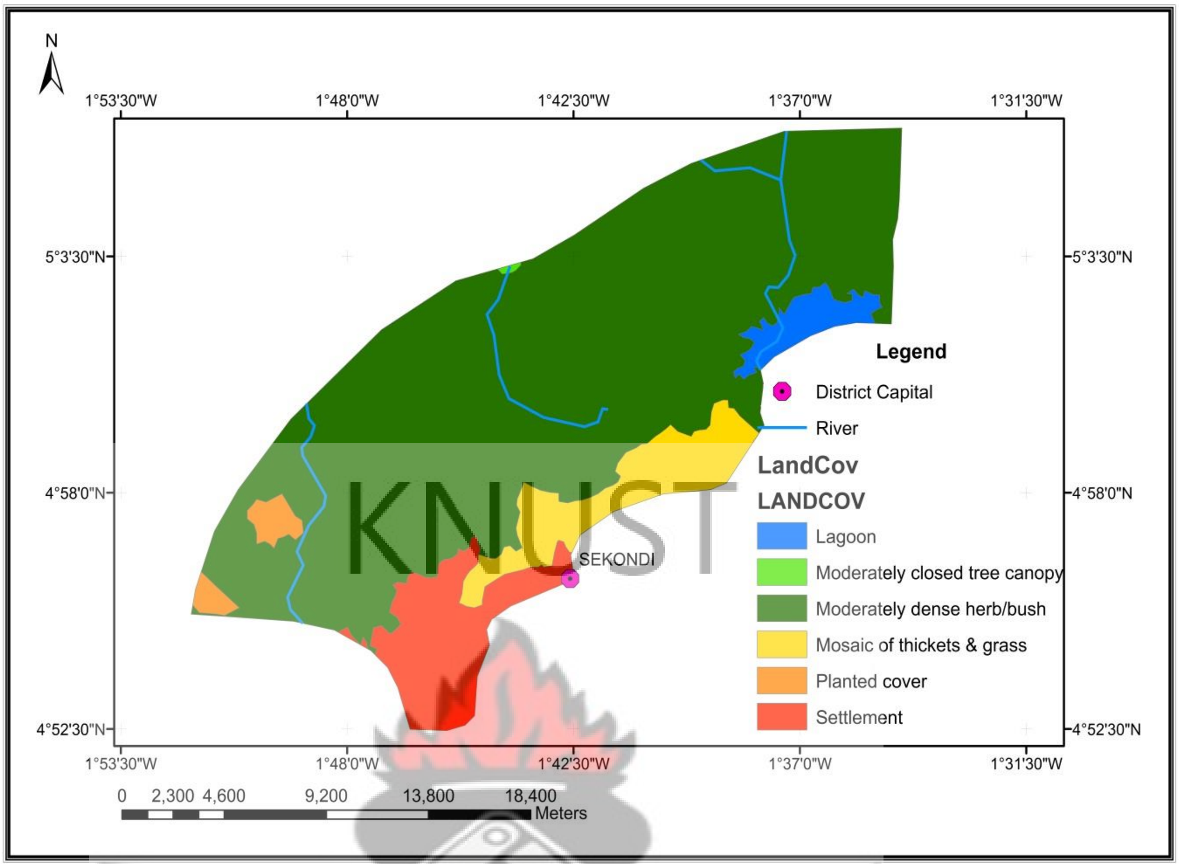

Figure 3-2 Land-cover Map of the Study Area

3.2 MATERIALS

Table 3.1 shows the various data types that were used during the study. These data types have been grouped into two, namely, remote sensing (RS) data and reference data. The study was based on the use of a time series of satellite Landsat images – Thematic Mapper (TM) and Enhanced Thematic Mapper Plus (ETM+) as remote sensing data acquired in the years 1991 and 2008. The satellite images were downloaded from the U.S. Geological Survey (USGS) database based on the availability and suitability due to cloud cover (the acceptable cloud cover should not be more than 10%). Among the reference data used are topographical maps, aerial photographs and land cover of the study area. Also geographic data (GPS points)

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were collected for all the various land cover types; these were used as the training data during the classification.

Table 3-1 Data Types Used for the Study

RS Data	Date Acquired	Resolution	Source
Landsat TM	01/01/1991	30 m	USGS EROS Centre
Landsat ETM+	01/02/2008	30 m	USGS EROS Centre
Reference Data	**Date Acquired**	**Scale**	**Source**
Topographic Map	1992	1:50,000	Survey Department, Ghana
Aerial Photograph	2003	1:250, 000	Survey Department, Ghana
Land cover map	1992	1:50,000	Forestry Department, Ghana
GPS Points	2012	300 points	Field Mapping

3.2.1 Reference Data

A topographical map for the study acquired from the Survey and Mapping Department was used to perform geometric correction of the satellite image. The GPS points picked during the field work and the land cover maps acquired were used during the image classification. It is also worth noting that temperature data was also acquired from the Ghana Metrological Service to assist in assessing the temperature trend in the study area.

3.2.2 Landsat Image

The images used for the study were downloaded from the USGS database with 194/56 as the path/row scene. As shown in Table 3-1, one of the images used was a Landsat TM image acquired on 1st January, 1991 whiles the other was a Landsat ETM+ image obtained on 1st February, 2008. Figure 3-3 shows the Landsat images that were used for the study. Two Landsat images were used for the study as a result of lack of required data. Apart from these two images, all the other images available did not meet the minimum 10% cloud cover; most of them had a cloud cover of more than 40%. The initial intention of this research was to use 3 images, however, because of the constraints on the other images especially the cloud cover, only 2 images were finally chosen.

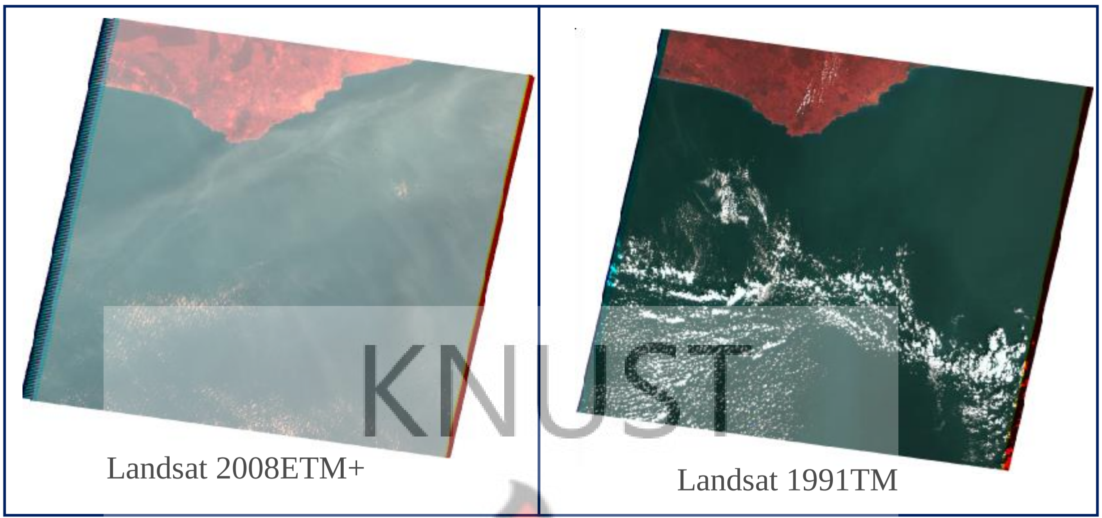

Figure 3-3 Landsat Imagery Used for the Study

3.2.3 Software Used

This research used ERDAS Imagine 9.2 and Envi 4.7 for the image processing including pre-processing, image classification, accuracy assessment, production of a change map and image transformation. ArcGIS 10.0 was used to generate the output maps and also used to carry out all the GIS analysis that were done. The 2008 image had strips of lines at the western and eastern side as a result of an error in the sensors. There was therefore the need to remove these strips using Frame_and_Fill_win32 software.

3.3 METHODS

Assessment of urban growth and its effect on surface temperature is a complex process involving several activities. Such research involves the processing of multi-temporal images to obtain essential, precise and accurate information on the changes that the earth’s environment is undergoing. The methodologies adopted in the

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research are divided into four main categories namely: Image Pre-processing, Image Classification, Urban Expansion Detection and Analysis and Urban Expansion Impact Analysis. Figure 3-4 is a flow chart summarising the methodologies that were used during the execution of the work.

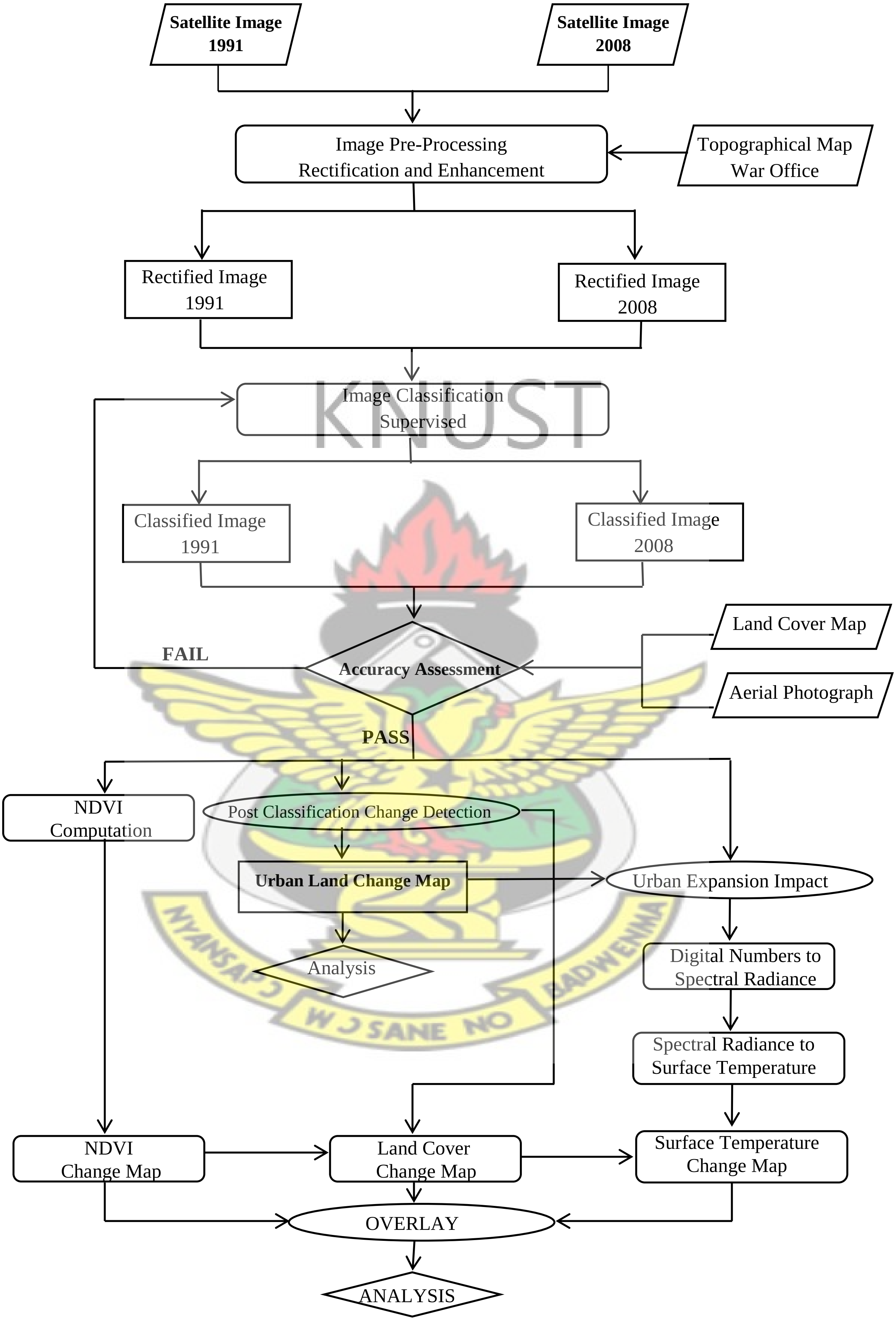

Figure 3-4 Flowchart Summarizing the Project Methodology

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3.3.1 Pre-processing

To achieve accurate change detection, multi-temporal images must be pre-processed both geometrically and radiometrically to correct errors arising from imaging sensors, atmospheric effect and earth's curvature. Pre-processing operations, sometimes referred to as image restoration and rectification, are intended to correct for sensor and platform specific radiometric and geometric distortions of data.

Sections 3.3.1.1 to 3.3.1.4 show the pre-processing that was performed during the study prior to image classification and analysis.

3.3.1.1 Geometric Correction

Accurate and precise registration of multi-temporal image is extreme important in change detection studies. This is because a misregistered image will lead to the production of wrong change detection and vice versa. Therefore, the integrity of change detection depends on the accuracy of the image rectification. Image registration can only be done when the individual bands of satellite images are combined into a single image. Thus with the aid of the Layer Stack tool in the Utility toolbar of ERDAS Imagine, the separate bands (bands 4, 3, 2 which clearly showed the various cover types and produced the maximum information) of all the two images (1999TM and 2008ETM+) were combined into a single image. The original unrectified satellite images obtained were in Global Coordinate System, UTM WGS 84. There was therefore the need to re-project it unto a common coordinate so that the area of interest (study area) could be selected. Thus all the resultant stacked images were re-projected onto the Ghana Datum, War Office whose projection is based on the Transverse Mercator Projection. Appendix A shows the parameter of the War Office Datum.

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A total of 25 ground control point (GCP), which were road intersections were used to register or georeference the 2008ETM+ image, since this was the most recent image. The georeference image produced a root mean square value of 0.17 which was accepted because it was within half of a pixel (Jianya *et al*., 2008). The Nearest Neighbour Re-sampling technique which has the merit of keeping the original pixel values of the original image used during the rectification. The rectified 2008 ETM+ image was used to georeference the 1999 TM image. After rectifying all three bands, they were finally resampled to a 30 m X 30 m pixel resolution to assist in further accurate image analysis of the datasets.

3.3.1.2 Radiometric Correction

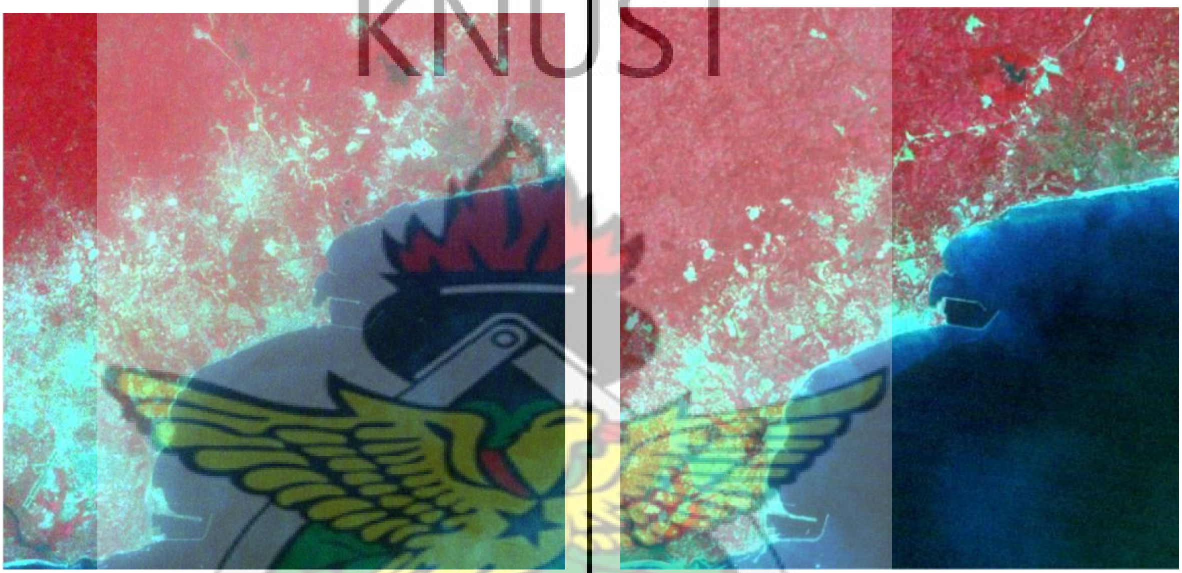
Inconsistencies between the pixel values recorded by sensors and the spectral reflectance and spectral radiation brightness of the object can be removed or reduced by using radiometric correction techniques (Jianya *et al*., 2008). In this particular study no radiometric correction was done, because the datasets obtained were already corrected to some extent by the USGS. Radiometric correction often becomes unnecessary with regards to change detection methods based on feature or object comparison (Jianya *et al*., 2008).

3.3.1.3 Generating subsets

Using the subset tool in the Data Preparation toolbar of ERDAS Imagine, subsets were generated for the two images in order to extract the study area for consideration. There are two main techniques in generating subset using ERDAS Imagine; that is using either an area of interest (AOI) tool or by specifying the rectangular area extent. The AOI tool was used in creating the subsets. Four corner coordinates were used to extract the study area. Table 3-2 shows the four corner rectangular coordinates that were used to generate the subset, whiles Figure 3-5 shows the subset images that were generated.

Table 3-2 Rectangular Coordinates of the Study Area

Description	Easting (ft)	Northing (ft)
Upper Left	614803.53	123734.13
Upper Right	664016.13	123734.13
Lower Left	614803.53	74521.53
Lower Right	664016.13	74521.53



Subset 2008ETM+ Subset 1991TM

Figure 3-5 Subset Image showing only the Study Area

3.3.1.4 Image Enhancement

In order to improve the visual interpretation of the images, which is extremely important, all the individual subset images were subjected to image enhancement. Among all the image enhancement techniques that are available, the Histogram Equalised Stretch (HES) technique was chosen to enhance the images. Using this technique, digital values were plotted as a histogram to show the frequencies of occurrence of each of the digital values. More display values or range was assigned to the frequently occurring portion of the histogram (and stretched within that range)

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while less range was assigned to the less occurring portion. In doing this, details in frequently occurring values were enhanced relative to those of the original image.

3.3.2 Image Classification Scheme

3.3.2.1 Supervised Image Classification

Supervised classification was used to classify the individual images into the various land cover classes. Training samples for all the various land cover types or information classes were obtained from an aerial photograph, a land cover map and the GPS coordinates that were picked during the field navigation. Using the AOI tool in ERDAS imagine, training sites were digitised for urban land cover, non-urban land cover and water on the 2008 image. These three training sites which represented the three cover types used in this study were named and saved in the Signature Editor in the Classifier Tool of ERDAS imagine. The generated training sites were then assessed using a feature space to determine the distribution of the individual pixels in the image. This process was repeated for the 1991 image.

After the generation of signatures, the next stage of the classification process was the classification stage itself. Using the Supervised Classification tool in ERDAS imagine as well the signatures that were saved, the 1991 and the 2008 unclassified images were then classified into three cover types. The parametric rule used in the classification was the Maximum Likelihood Algorithm (MLA). The MLA classified the images according to the covariance and variance of the spectral response patterns of a pixel. With the help of Anderson Classification System, the individual images were classified into three main distinct land cover classes namely; urban/built-up, non-urban (consisting of barren land, forestland, farmland) and water (consisting of reservoir, wetland, rivers, streams and the sea). Table 3-3 is a description of the various land cover classes.

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Table 3-3 Description of the Land Cover Classification System Used in the Study

Main Cover Class	Sub Cover Class	Description
URBAN	Urban/Built-up	This comprises of areas of intensive use with much of the land covered by structures. Included in this category are cities, towns, villages, highways and transportation, power, and communications facilities.
WATER	Water and Wetland	This consists of areas persistently covered with water; provided that if linear they are at least 200m width. This category includes; streams and canals, lakes, reservoirs, bays and Estuaries
NON-URBAN	Barren land	Barren Land is land of limited ability to support life and in which less than one-third of the area has vegetation or other cover.
	Agricultural land	Agricultural Land may be defined broadly as land used primarily for production of food and fibre. This category includes; Cropland and Pasture, Ornamental Horticultural Areas.
	Forestland	Forest Lands have a tree-crown areal density (crown closure percentage) of 10% or more, are stocked with trees capable of producing timber or other wood products, and exert an influence on the climate or water regime. Forestlands include Deciduous, Evergreen and Mixed Forestlands.

(Source: Anderson Classification System, 1980)

3.3.2.2 Accuracy Assessment

After completion of the classification exercise it was necessary to assess the accuracy of the results obtained. This would allow a degree of confidence to be attached to the results and will serve to indicate whether the analyses of the objectives have been achieved (Richards and Xiuping, 2006). It is in this regard that the accuracy of all the land cover maps generated from the individual images was assessed.

In this research, the reference data used to assess the accuracy of the classification were extracted from an aerial photograph and a topographical map. In assessing the accuracy of the 1991 classified image, hundred randomly generated points were extracted from the 1992 topographical map and land cover map using the Accuracy Assessment tool in ERDAS imagine. In assessing the 2008 classified image hundred

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randomly generated points were extracted from 2003 aerial photograph. During the accuracy assessment, the overall accuracy as well as the Kappa statistic was also computed for both the 2008 and the 1991 classified image.

3.3.3 Post Classification Change Detection

Change Detection studies have various meanings to diverse users (Singh, 1989) nonetheless, the commonest understanding of Change Detection applications is the fact that it has the ability to provide information on changes in terms of the trend, spatial distribution and extent of change. As one of the objectives of this research was to quantify the land cover changes (urban expansion) that have occurred within the study area, a Post-Classification approach to Change Detection was employed. To easily facilitate this analysis, Envi 4.1 software was used. Since Envi does not support Tag Image File Format (TIFF) (.tif), there was the need to export all the classified images into Erdas Imagine Image format (.img) or Envi (.hdr) which Envi recognises.

3.3.3.1 Cross Classification

The Matrix module embedded in Erdas Imagine and the Compute Difference Map/Change Detection Statistic also embedded in Envi give information on the frequencies with which each land cover classes remained either changed or unchanged to one of the other classes, using two thematic maps of different dates. The Matrix Module in Erdas Imagine was used to investigate the land cover changes that have occurred in the study area. Transition contingency matrix was also generated to test the independence or association that existed between the land cover classes in the different years.

A cross-tabulation (matrix) was generated from the thematic maps (classified image) 1991 – 2008 using the Matrix module in the Erdas imagine software and the Change

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Detection module in Envi. The elements in the off-diagonal of the contingency matrix represent land cover classes that have changed whiles the elements in the diagonal shows unchanged land cover classes.. The column element **j** represents land cover class in the earlier (initial year) date and the row element **i** represents land cover class in the later date (final year).

3.3.4 Urban Expansion Analysis

In order to analyse the rate, nature and location of the urban land change, there was the need to obtain an image of urban/built-up land from each of the original classified images. The Extract by Attribute Tool in the Spatial Analyst Toolbox of ArcGIS was used to extract an image of urban land from 1991 and 2008 classified images. The extracted images were converted to Erdas Imagine (.img) format. In order to obtain the urban expansion image, the 1991 urban/built-up land image and the 2008 urban/built-up land image were overlaid and then recoded. The matrix module embedded in Erdas Imagine was then used to generate an urban change image from the two urban/built-up images.

Several factors come into play into assessing and analysing the trend and patterns of urban change in the Sekondi-Takoradi Metropolis. Among such factors is proximity to a major road. To assist in analysing the patterns of urban expansion, the urban expansion image was converted to a vector form in a GIS environment; the vector form of the urban expansion feature was then overlaid with several geographically referenced features such as the boundary of the metropolis, some major urban centres and major roads in the metropolis.

Urban expansion process usually shows a relationship with distance from certain geographic features such as road. Using the buffer function in GIS, ten buffers with a width of 400 m cumulatively were created around a major road in the metropolis.

The major road chosen is the main Takoradi-Accra road. Each of the buffers created were then overlaid with the urban expansion feature to compute the amount of urban expansion in each buffer or zone. To also calculate the amount of land in each buffer, each of the created buffers were overlaid with the land use land cover change map. In order to construct a distance decay function of urban expansion, the density of urban expansion in each buffer zone was computed using the formula below.

$$\text{Density of Urban Expansion} = \frac{\text{Amt. of Urban Expasion in each Buffer Zone}}{\text{Total Amt. of Land in each Buffer Zone}}$$

To determine whether a relationship exist between the amount of urban expansion and the distance to a major road as well as the density of urban expansion and distance to a major road, a distance decay function was constructed. This distance decay assisted in analysing the pattern of urban expansion in the metropolis.

3.3.4.1 Relationship between Density of Urban Expansion and Distance to Major Road

To investigate the relationship between the density of urban expansion and distance to a major road, Pearson Correlation Analysis was employed. This was done to determine the pattern of the urban growth in relation to the available social amenities such as schools, hospitals and recreation facilities. The Pearson Coefficient of Correlation was determined for the ten buffer zones that were created using the formula below:

$$r = \frac{\sum XY - \frac{\sum X \sum Y}{n}}{\sqrt{\sum X^2 - \frac{(\sum X)^2}{n}}\sqrt{\sum Y^2 - \frac{(\sum Y)^2}{n}}}, where$$

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r = Pearson Coefficient of Correlation

X = Independent Variables (Distance to Major Road)

Y = Dependent Variable (Density of Urban Expansion)

n = Number of Observations (Number of buffer Zones, 10)

To test the significance of the Coefficient of Correlation, r the *student t-test* for Pearson's r was applied. Like any other hypothesis test a comparison was made between the *observe t* ($t_{ob.}$) and the *critical t* ($t_{crit.}$) at a 5% level of significance. The approach use is as shown below:

H_o: r = 0

H_a: r ≠ 0

$t_{crit.}$ (α = 0.05 df = n-2 = 8) = 1.860

Rejection Rule Using 0.05 level of significance and 8 degree of freedom

Reject Ho, if $t_{ob} > 1.860$

$$t_{ob.} = r\sqrt{\frac{n-2}{1-r^2}}$$

$$t_{ob.} = 0.9702\sqrt{\frac{10-2}{1-0.9702^2}}$$

$$t_{ob.} = 11.325$$

Since $t_{ob} > 1.860$ that is 11.325 > 1.860 the null hypothesis (H_o) was rejected and concluded the correlation is statistically significant.

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3.3.5 Analysis of Urbanisation Expansion Impact

Urban expansion normally causes drastic changes of the surface of the earth, since natural vegetation is removed and replaced with non-transpiring non-evaporating structures and surfaces such as concrete, asphalt and metal. Such modifications will definitely lead to a redistribution of incoming solar radiation and subsequently induce the rural-urban contrast in air temperature and surface radiance (Weng, 2001).

Given the relationship that exist between the texture of land cover and surface radiant temperature, the effect of urban development on surface temperature for the Sekondi-Takoradi Metropolis was evaluated.

3.3.5.1 Determination of Radiant Temperature (T_b), NDVI from TM and EMT+

To determine the surface temperature change from 1991 to 2008, surface radiant temperature (T_b) were derived from the radiometrically corrected TM and EMT+ thermal infrared data (band 6). The radiometrically and geometrically corrected images resulted in digital numbers (DN) images which are measures of at-satellite radiance. Using the Modeler tool in ERDAS Imagine, a model was created to transform the DNs into surface temperature values using several equations. The DNs in each of the bands were converted first to at-satellite radiance using the following equation:

L_{λ} = Grescale x QCAL + Brescale OR

L_{λ} = LMIN+ (LMAX-LMIN) x DN/ 255, where

Grescale = Rescaled gain

Brescale = Rescaled bias

L_{λ} = Spectral Radiance

QCAL = the quantized calibrated pixel in DN

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LMIN = Spectral Radiance of DN value 1

LMAX = Spectral Radiance of DN value 255

The radiance values from TM band 6 and ETM+ band 61 and 62 were transformed to radiant surface temperature values in kelvin using the following equation:

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

T_b = Surface Temperature in Kelvin

K_1 = Calibration Constant 1 (607.76 for TM and 666.09 for ETM+)

K_2 = Calibration Constant 2 (1260.56 for TM and 1282.71 for ETM+)

The Surface temperature in kelvin was finally converted to surface temperature in degree Celsius (T_c) using the following equation

$$T_c = T_b - 273$$

In order to examine the relationship that exists between the LULC types and the energy response of the earth surface as measured by the T_c, the T_c images in 1991 and 2008 were overlaid with the classified land cover images of corresponding years. Since NDVI (Weng, 2001; Xian and Mike, 2004) is a good indicator surface radiant temperature, a NDVI image was computed for the 1991 and 2008 images. Reflectance value from visible band (P_3) and near-infrared band (P_4) of the images were used to compute NDVI values according to the following equation:

$$NDVI = \frac{P_4 - P_3}{P_4 + P_3}$$

To facilitate easily visualization of the interaction among the land use land cover, T_b and NDVI, the resultant NDVI image was overlaid with the T_b image for each year.

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Using the concept of image differencing, an image of surface radiant temperature change and NDVI change between 1991 and 2008 was produced. The surface temperature change map, the NDVI change map and the LULC change map were all overlaid to analyse how all these changes have interacted with each other.

CHAPTER FOUR

RESULTS

4.1 RESULTS OF CLASSIFICATION AND ACCURACY ASSESSMENT

The classification scheme (supervised classification) that was used in this project resulted in two land cover maps from the two multi-temporal images, which are the 1991TM and the 2008ETM+. The land cover maps that were obtained from the 1991TM and the 2008EMT+ images are shown in Figure 4-1 and 4-2 respectively.

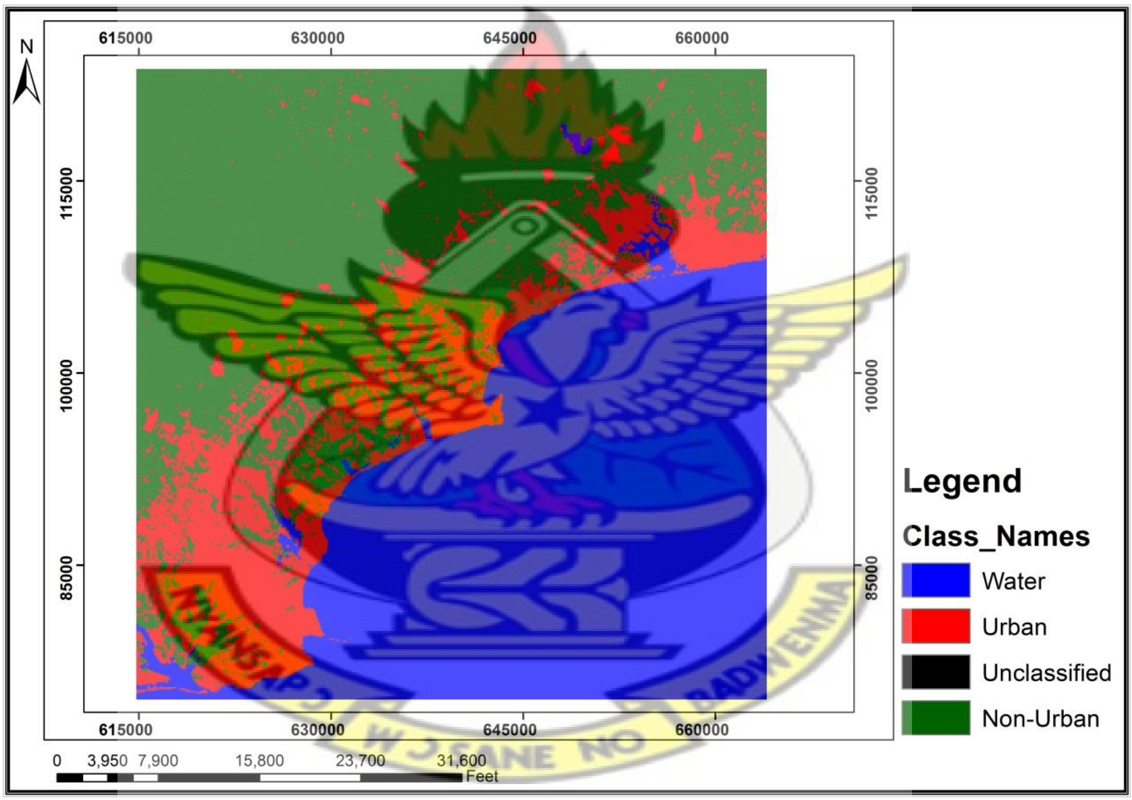

Figure 4-1 The Classified Land Cover Map of the 1991TM Images

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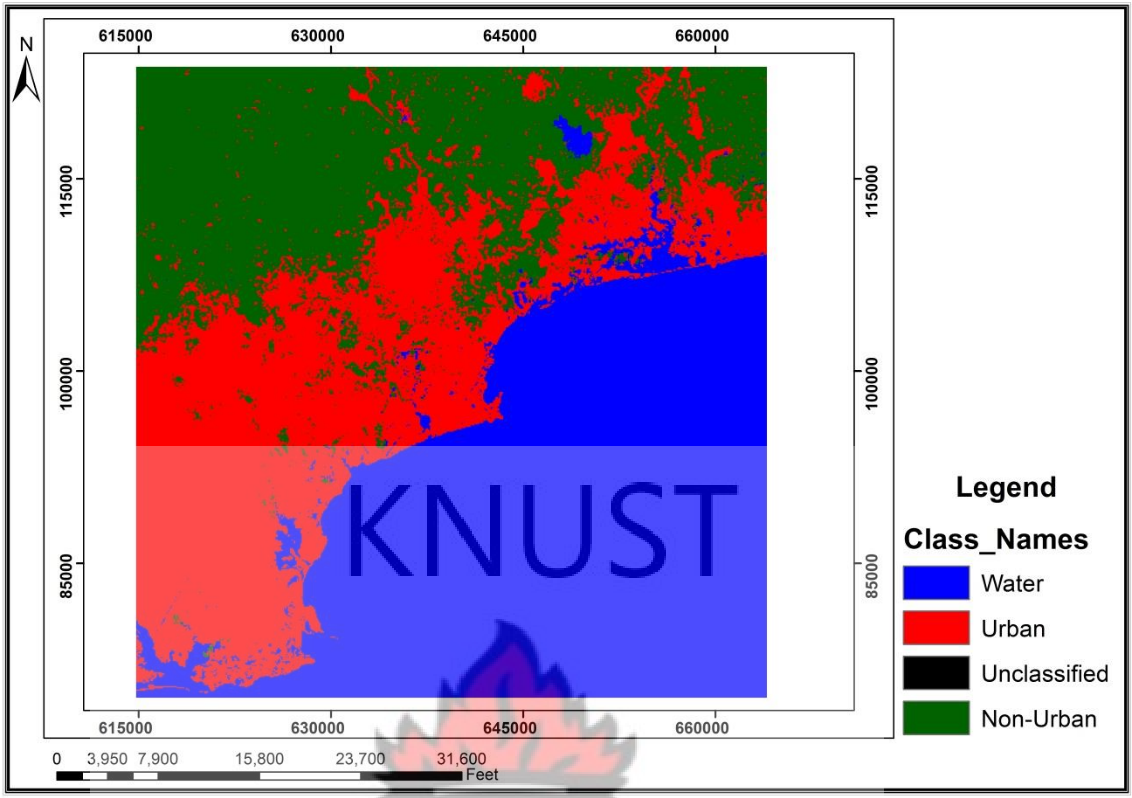

Figure 4-2 The Classified Land Cover Map of the 2008ETM+ Image

Careful observation and examination of the two land cover maps revealed that the study area lies along the coast of the Gulf of Guinea and almost all the urban and built-up areas are concentrated along the coast. From the land cover maps, it could be observed that about 90% of the urban and built-up areas lie about 2 km from the coast while the remaining 10% are small villages and hamlet scattered in the non-urban areas, mainly in places with some amount of vegetation cover. Most of the non- urban lands lie on the northern part of the study area with few of them located within some urban centres. Apart from the Gulf of Guinea, the Inchaban Head Water Works and the Whin River are some of the water bodies in the land cover maps.

From the aerial photograph, the topographical map and the land use map, hundred items of reference data were chosen to perform the accuracy assessment on both the 1991 and the 2008 land cover maps. Appendix B1 and B2 show the resultant error

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matrix. The overall accuracy for the 1991 land cover map was determined to be 86.00% whiles that of the 2008 land cover map was also determined to be 82.00%. The Kappa indices for the 1991 and the 2008 maps were 0.7890 and 0.7299 respectively. These data are sufficient for urban growth detection because the results of the accuracy assessment are reasonably high.

4.2 EXTENT OF LAND COVER CATEGORIES

Table 4-1 shows the area extent of the individual land cover categories in hectares (ha) as well as the percentages they occupy, Figure 4-3 is also a graphical representation of the extent of area of the individual land cover types depicting the trend of the three land cover changes in 1991 and 2008.

Table 4-1 Land Cover Types with their Corresponding Area

Land Cover Class	1991		2008	
	Area (ha)	**Area (%)**	**Area (ha)**	**Area (%)**
Non-Urban	9369.27	41.61	5924.77	26.31
Urban	3925.09	17.43	7024.69	31.20
Water	9221.66	40.96	9566.56	42.49
Total Area	**22516.02**	**100.00**	**22516.02**	**100**

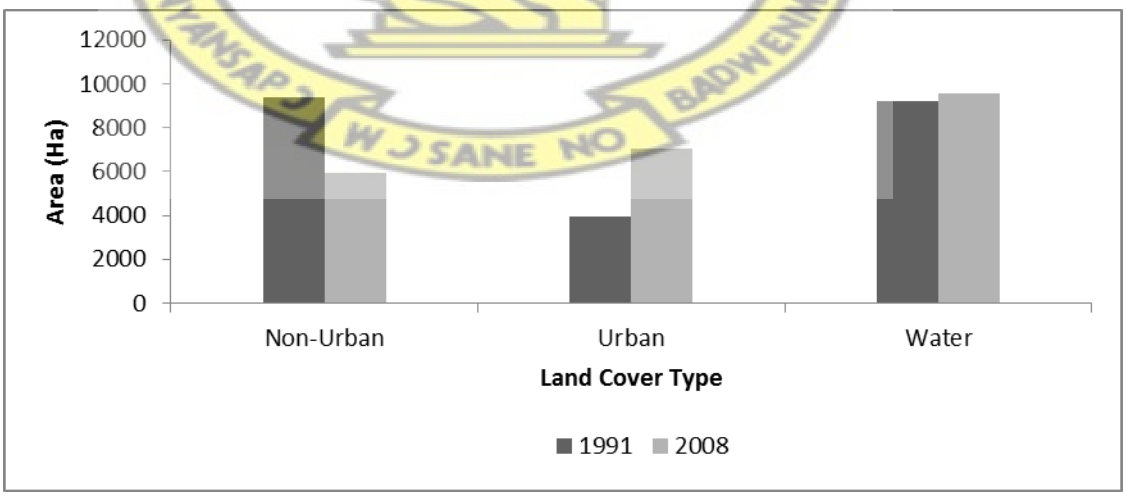

Figure 4-3 Graphical Representation of the Extent of Area Occupied by the Land Cover Types

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Table 4-1 shows that in 1991 Non-Urban land were the dominant land cover type in the study area, covering an area of 9369.27 ha (41.46%). However, in 2008 non-urban land had decreased to 5924.77 ha. The table also shows that, in 1991, urban land was the least of the three land cover types covering an area of 3925.09 ha. This increased to 7024.69 ha (78.97%) in 2008. The total area covered with water also increased from 9221.66 ha (40.96%) in 1991 to 9566.56 ha (42.49) in 2008.

It can be observed from Table 4-1 and Figure 4-3 that all the three land cover categories have undergone major changes. However, of all these changes, the prominent and significant of them is the increase in urban/built-up land which has increase over 78% over the past 17 years (from 1991 to 2008).

4.3 RESULT OF CROSS CLASSIFICATION/TABULATION

The change map and the transition matrix generated provide an explanation on the cross correlation that exist between the land cover transition. Table 4-2 depicts the transition area matrix that was generated after running the Change Detection Module in Envi. From the Table, it could be noted that the columns represent the land cover classes of the earlier date (1991) and the rows represent that of the later date (2008).

The diagonal elements of the matrix represent the land cover classes that have remained unchanged, whiles the off-diagonal elements (both below and above) represent the number of cells that have changed existing land cover class in earlier date to other new land cover class in later date. It can be observed from the table that 5747.92 ha, 3463.80 ha and 9169.12 ha of non-urban land, urban land and water, respectively remained unchanged, which meant 18380.84 ha (81.63%) land cover area remained unchanged within the 1991-2008 period. Therefore, it can be inferred that the amount of change for the 1991-2008 period was 18.37%. In Table 4-2, the

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image difference represents the difference that exists between a land cover class in the earlier date and its corresponding class in the latter date. It can therefore be observed that there was a decrease of 3444.48 ha in non-urban land, and increase of 3099.57 ha and 344.90 ha in urban land and water, respectively. It can be concluded that the greatest difference that occurred within the period was a reduction in non-urban land. Figure 4-4 is a change map that shows the locational or spatial distribution of the land cover change that has occurred between the three individual cover classes

Table 4-2 Land Cover Change Matrix 1991-2008 (ha)

		1991				
	Class	Unclassified	Non-Urban	Urban	Water	2008 Total
2008	Unclassified	0	0	0	0	0
	Non-Urban	0	5747.92	175.26	1.59	5924.77
	Urban	0	3509.94	3463.80	50.95	7024.69
	Water	0	111.41	286.03	9169.12	9566.56
	1991 Total	0	9369.27	3925.09	9221.66	---
	Class Changes	0	3621.35	461.29	52.54	---
	Image Difference	0	-3444.48	3099.57	344.90	---

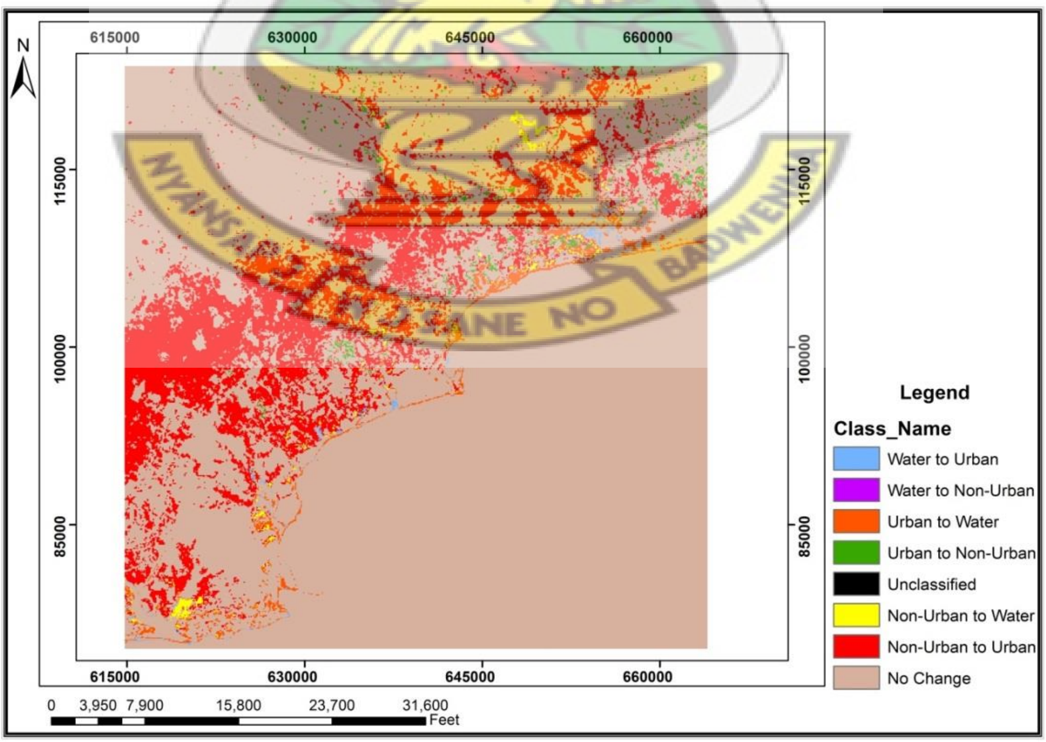

Figure 4-4 Change Map Showing Land Cover Transition

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From Figure 4-4 it is easy to observe that a lot of the changes that occurred (about 90%) within the 17 year period was between non-urban and urban cover classes. There was also a significant change between non-urban cover class and water cover class.

4.4 RESULT OF URBAN EXPANSION ANALYSIS

To facilitate easy analysis of rate, nature, location and trend of urban expansion, an image of urban/built-up cover class was extracted from both classified images. Figure 4-5 and 4-6 shows the image of urban/built-up covers class for 1991 and 2008 respectively.

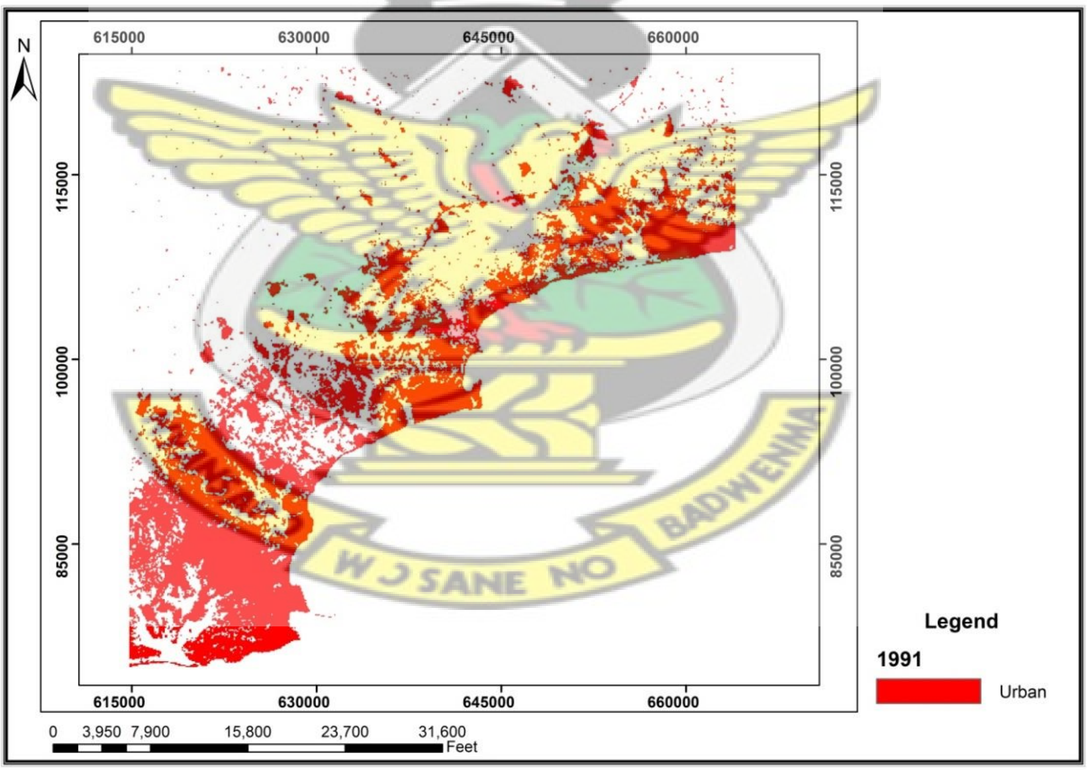

Figure 4-5 Map of 1991 Urban/Built-up Land

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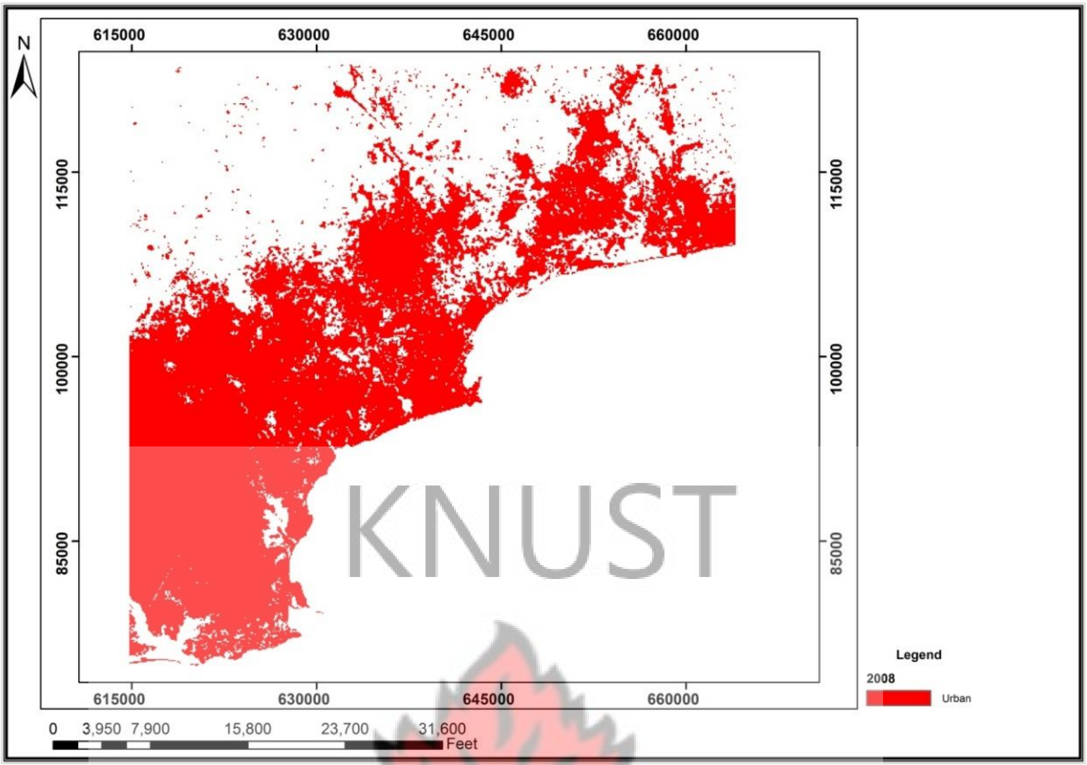

Figure 4-6 Map of 2008 Urban/Built-up Land

The two images show that there has been a considerable amount of change in urban/built-up land from 1991 to 2008. Most of the change is concentrated at the northern part of the Central Business District (that is, Market Circle).

The overlay of the 1991 and 2008 urban land images further indicates that there has been a considerable increased or expansion in urban/built-up land. Figure 4-7 indicates the spatial occurrence and area extent of urban expansion that has occurred within the Sekondi-Takoradi Metropolis over the 17 year period.

The study area was divided into four zones, namely Takoradi, Sekondi, Effia-Kwesimintsim and Essikado-Keten; the urban expansion image and an image of the four zones were overlaid. Figure 4-8 shows the spatial occurrence and area extent of urban expansion that has occurred in each of the four zones. Table 4-3 also shows the area extent of urbanisation that has occurred in each of the zones both in hectares and percentage.

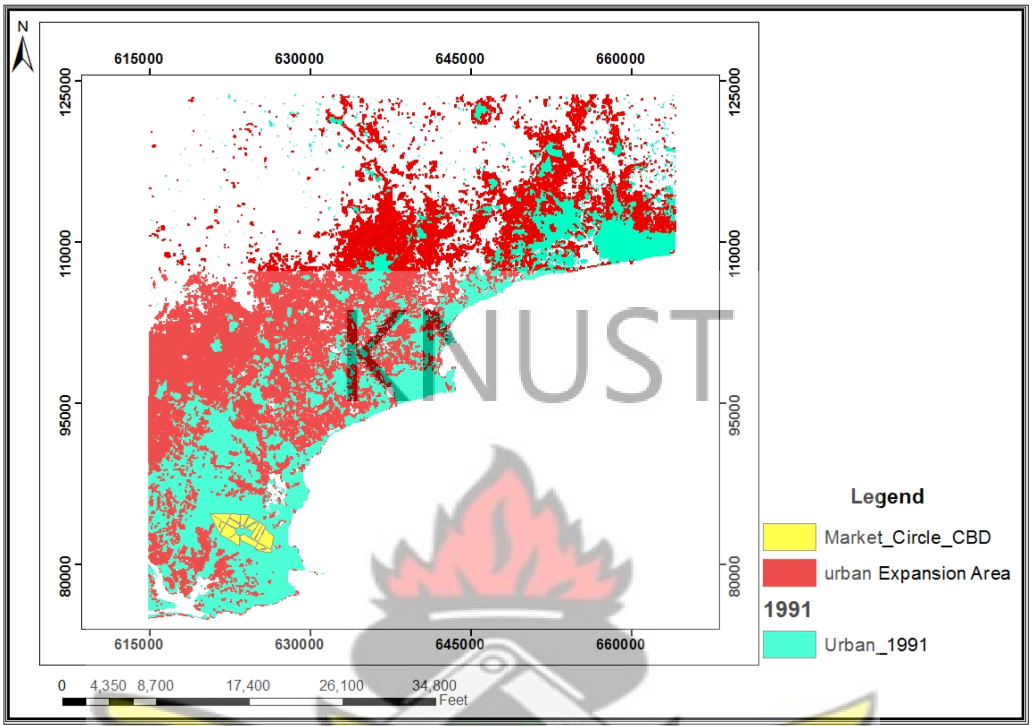

Figure 4-7 Map of Urban Expansion

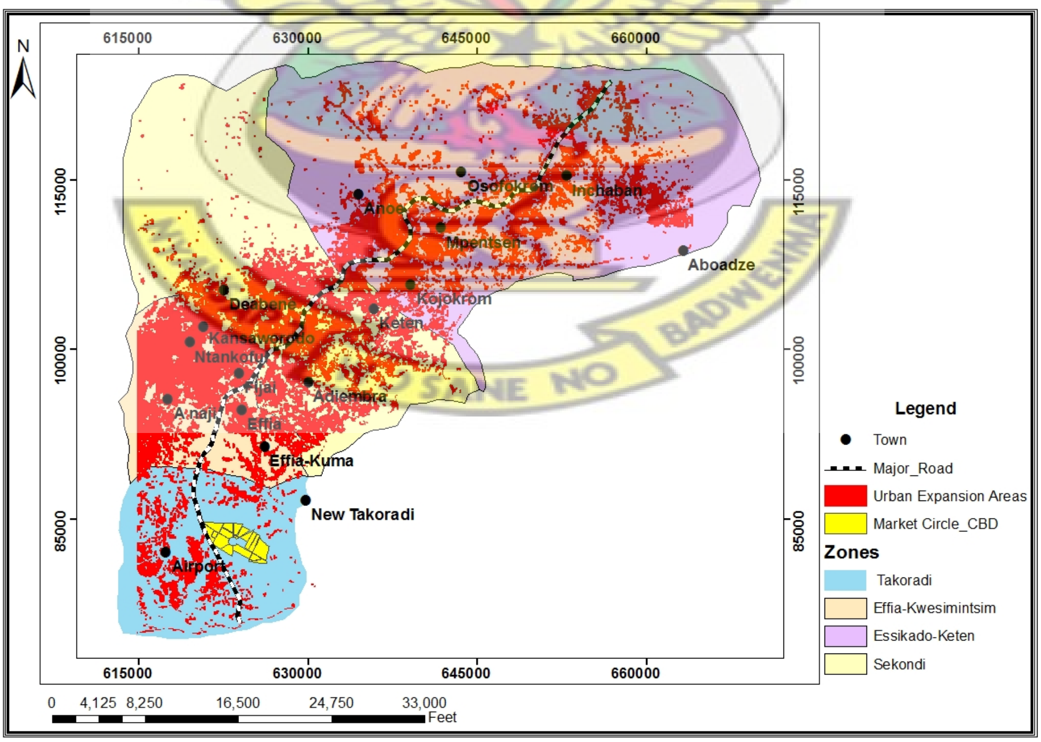

Figure 4-8 Map of Urban Expansion in Each Zone

Table 4-3 Amount of Urban Expansion in Each Zone

Name of Zone	Area of Urban Expansion (ha)	Percentage of Urban Expansion
Takoradi	137.22	6.69
Effia-Kwesimintsim	831.46	47.76
Sekondi	919.91	19.85
Essikado-Keten	1211.00	17.29

From Table 4-3 it can be seen that in absolute term, the greatest urban expansion occurred in the Essikado-Keten Zone (1211.00 ha) followed by the Sekondi Zone (919.91 ha), whiles the least urban expansion occurred in the Takoradi Zone (137.22 ha) followed by the Effia-Kwesimintsim Zone (831.46 ha). However, in terms of percentage, the Effia-Kwesimintsim Zone (47.76%) recorded the greatest urban expansion followed by the Sekondi Zone (19.85%).

Further urban expansion analysis in the Sekondi-Takoradi Metropolis during the 17 year period (1991 to 2008) was carried out by constructing a distance decay curve from a major road. This was necessary because it assisted in establishing the pattern and trend of urban expansion in relation to the available social amenities. Figure 4-9 is a map showing the ten buffer zones that was used to plot the distance decay curve. Table 4-4 shows the density of urban expansion in each of the buffer zone.

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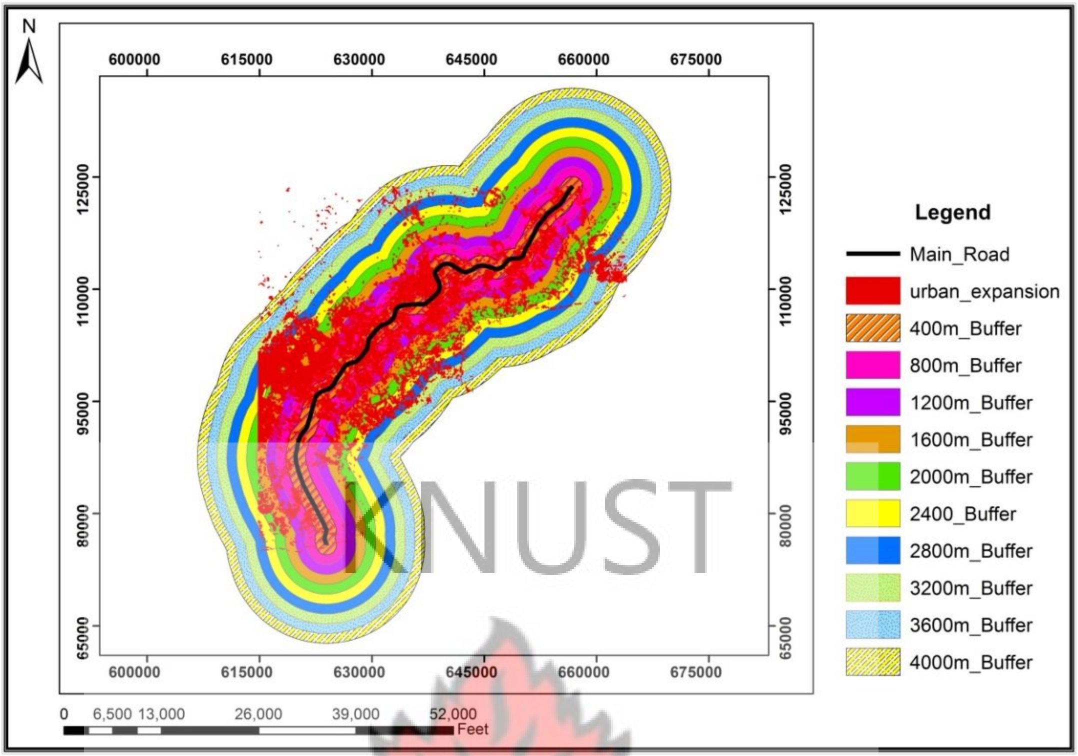

Figure 4-9 Map of Urban Expansion in Ten Buffer Zones

Table 4-4 Density of Urban Expansion in Each Buffer Zone

Buffer Zone (m)	Density of Urban Expansion
400	0.386
800	0.412
1200	0.346
1600	0.304
2000	0.285
2400	0.267
2800	0.212
3200	0.120
3600	0.074
4000	0.071

Figure 4-10 is the density decay curve that was plot from Table 4-4

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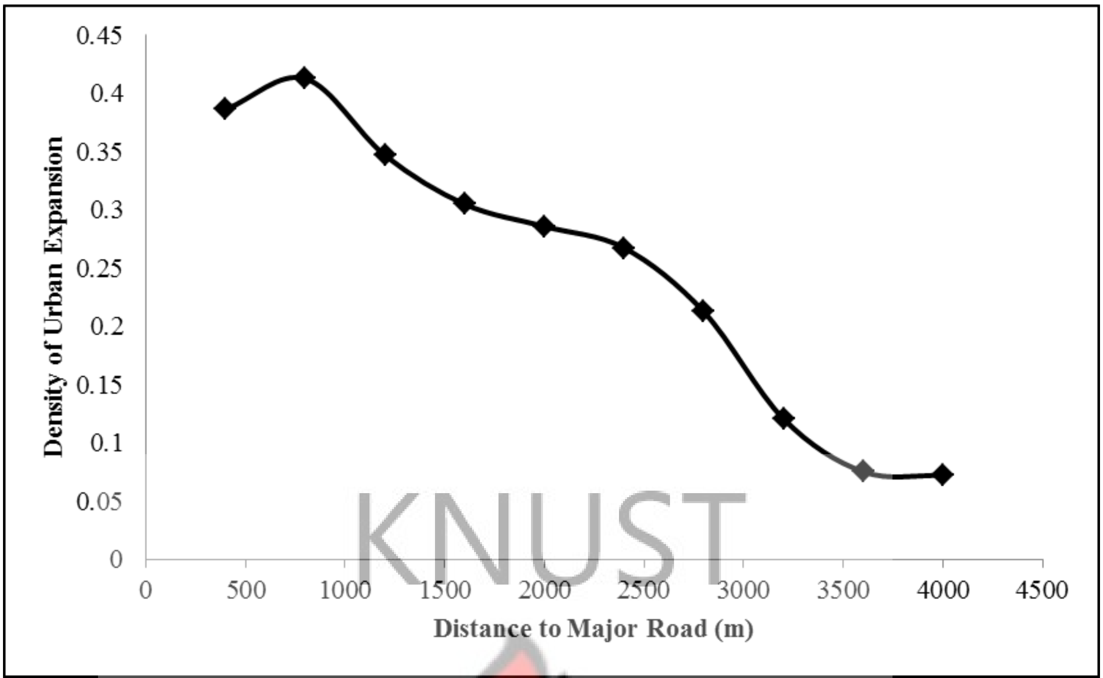

Figure 4-10 Density Decay Curve of Urban Expansion

Table 4-4 as well as the density decay curve (Figure 4-10) indicates that there is a relationship between the density of urban expansion and distance to a major road; the density of urban expansion decreased as distance away from a major road increased. In order to test this relationship, Pearson Correlation was applied on the density of urban expansion and distance to a major road. The Coefficient of Correlation that was obtained was -0.9758 depicting that there is a strong negative correlation between the density of urban expansion and distance to a major road. To test the significance of the coefficient of correlation, *r*, the student *t-test* for Pearson's r was applied. The t_{crit} value at 0.05 level of significance obtained was 1.860 and the t_{ob} value obtained was 11.325. These values led to the rejection of the stated null hypothesis showing the correlation is statistically significant. It can also be seen in Figure 4-10 that most of the urban expansion (about 75%) has occurred within a distance of 2 km from a major road. This rapid expansion has occurred along the main Takoradi-Sekondi-Accra road where individuals seek land for housing and industrial purposes. From the distance decay a relationship was established between

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the distance to a major road (X) and the density of urban expansion (Y) expressed mathematically as:

$$Y = 0.6459e^{-0.0004x}$$

4.5 RESULTS OF ANALYSIS OF URBAN EXPANSION IMPACT

4.1.5. Thermal Signature of Land Cover Types

To understand the effect or impact of land use/land cover on surface radiant temperature, there is the need to first study and understand the characteristics of the thermal signature of each land cover type. Figure 4-11 and 4-12 shows the average surface radiant temperature by the three land cover types in 1991 and 2008 respectively.

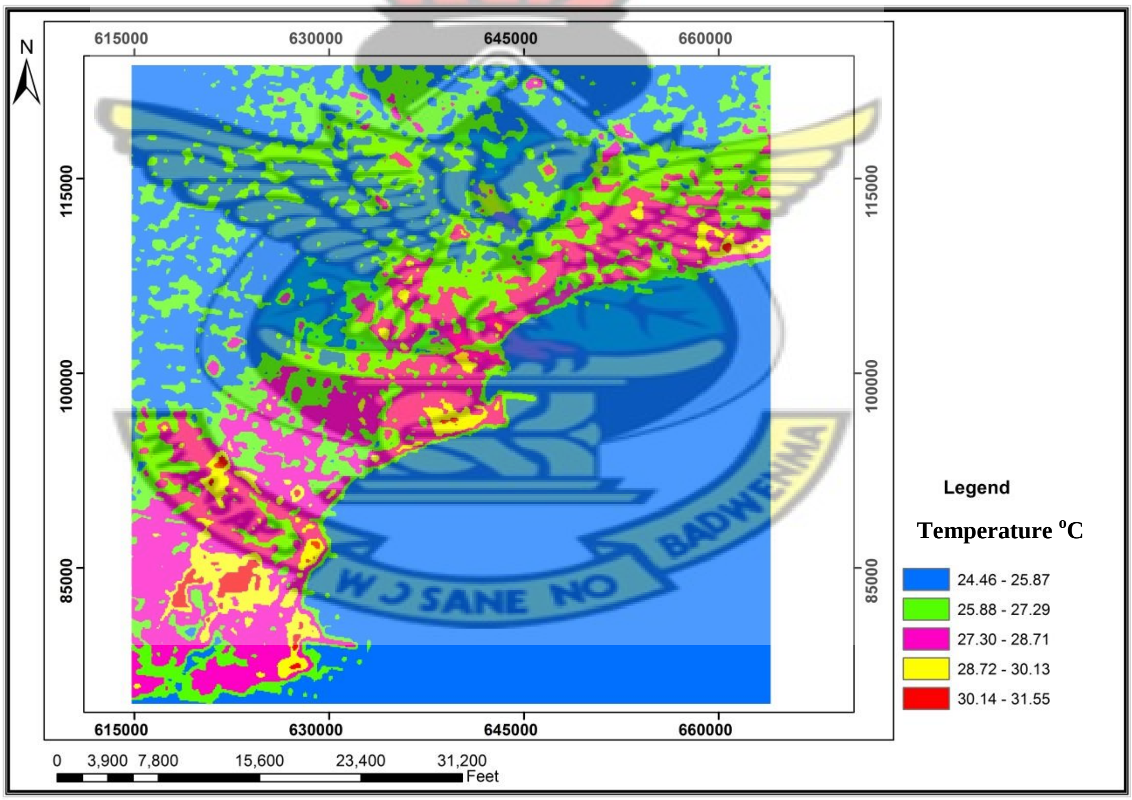

Figure 4-11 Map of Surface Radiant Temperature for 1991

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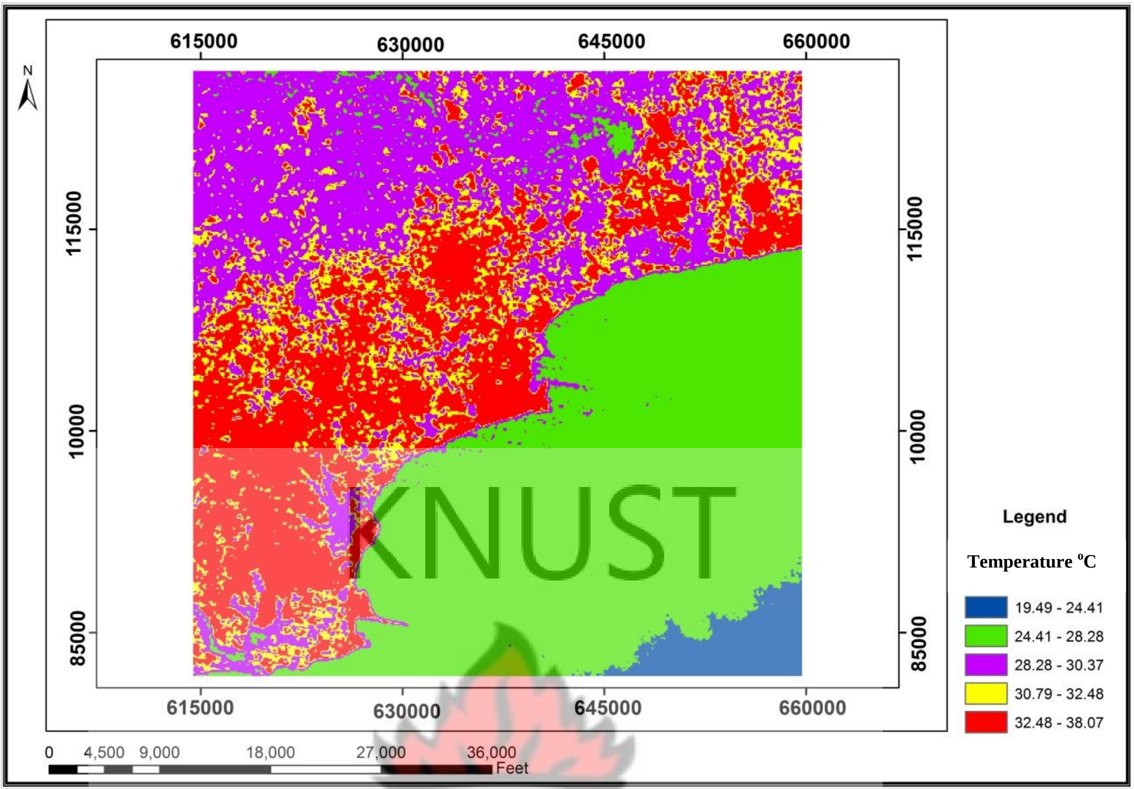

Figure 4-12 Map of Surface Radiant Temperature for 2008

The average surface radiant temperature values for each of the three land cover types in 1991 and 2008 is summarised in Table 4-5.

Table 4-5 Average Surface Temperature in Degree Celsius

land Cover	Mean Temperature ± SD	
	1991	**2008**
Urban/Built-up	29.63 ± 0.70	33.93 ± 0.72
Non-Urban	26.24 ± 0.84	29.44 ± 1.11
Water	25.54 ± 0.44	25.79 ± 1.98

The highest surface radiant temperature values in both years were recorded in urban/built-up areas (29.63 °C in 1991 and 33.93 °C in 2008), whiles the lowest surface radiant temperature for both years were recorded in water bodies (25.54 °C in 1991 and 25.79 °C in 2008). From the table, it can also be observed that all three land cover types have experience significant increase in surface temperature.

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4.5.2 Surface Temperature Change in the Sekondi-Takoradi Metropolis

The temperature changes in the four zones of the metropolis were assessed to determine where the highest and lowest temperature values were recorded. This was very important because it assisted in determining the effect of urbanisation on surface radiant temperature and also easily explained the concept of the Urban Heat Island. Figure 4-13 and Figure 4-14 show the temperature range in some selected urbanised centers in the metropolis.

Using the concept of image differencing, a change image of surface radiant temperature was obtained and then overlaid with the urban expansion image. Subsequent analysis was carried out in the GIS environment. Figure 4-15 shows the temperature increase areas. To augment and check the satellite temperature, minimum and maximum temperature for the years 1991 and 2008 were also collected from the Ghana Meteorological Agency (GMA). The collected temperature values are shown in Appendix C. The trends of temperature change for the two years were also plotted and investigated. The result of this is shown in Appendix D. The GMA temperature values show that there has been an increase in temperature in the metropolis. For instance, the average monthly daytime (maximum) temperature for 1991 as collected by the GMA is 30.02 °C whiles that of 2008 is 30.83 °C, showing an increase of 0.81°C. From the GMA data the average monthly nighttime (minimum) temperature for 1991 is 26.63 °C whiles that of 2008 is 27.21 °C, showing an increase of 0.58 °C. The annual average daytime and nighttime temperatures series were also characterised by substantial increased warming trend during the study period (Appendix E). The averaged quadruple-decade climate data of the metropolis indicates that, the annual monthly daytime temperature has a 0.2 °C per-decade increasing trend whiles that of the nighttime has a 0.3 °C per-decade increasing trend.

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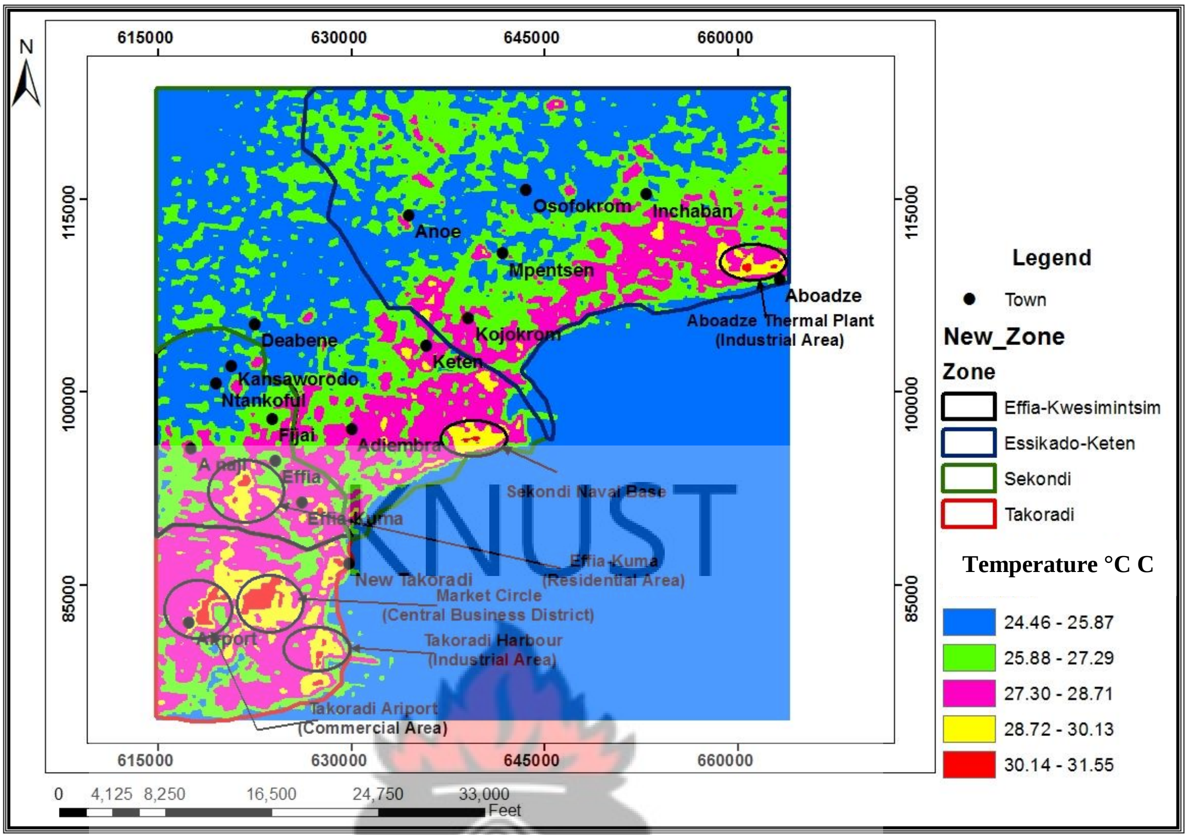

Figure 4-13 Map of Radiant Temperature for Some Selected Urbanised Centres for 1991

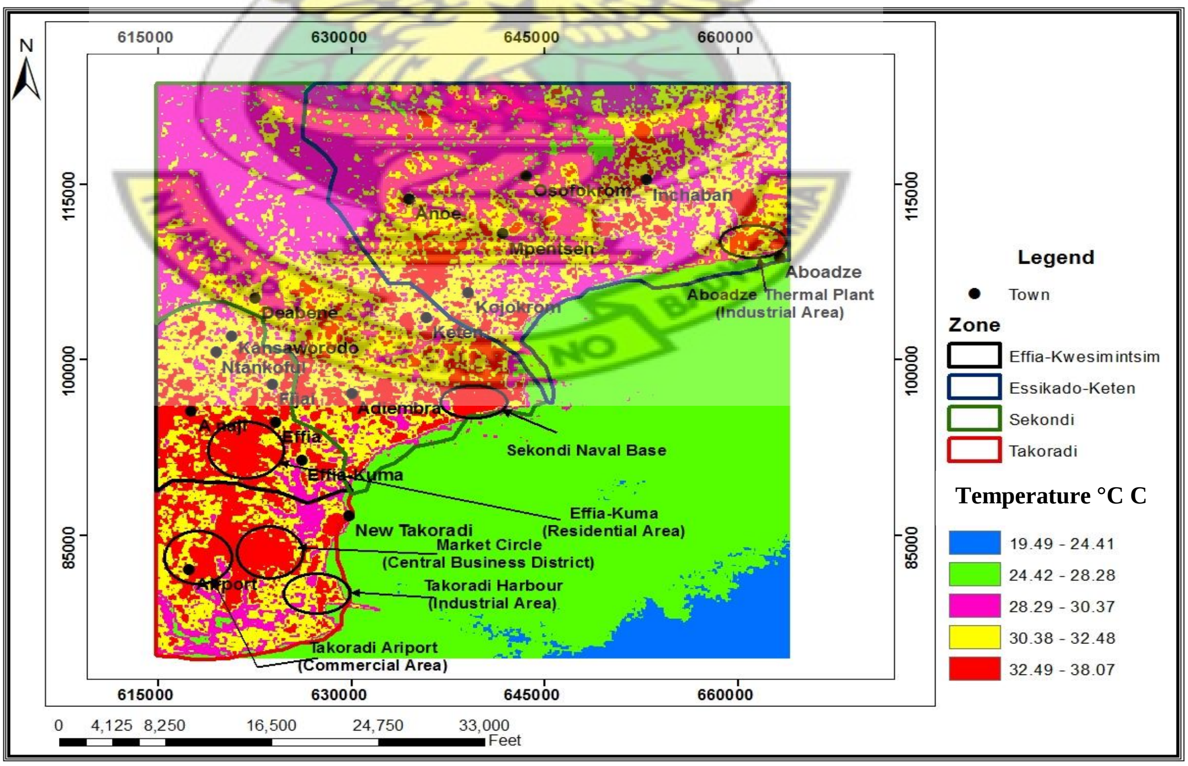

Figure 4-14 Map of Radiant Temperature for Some Selected Urbanised Centres for 2008

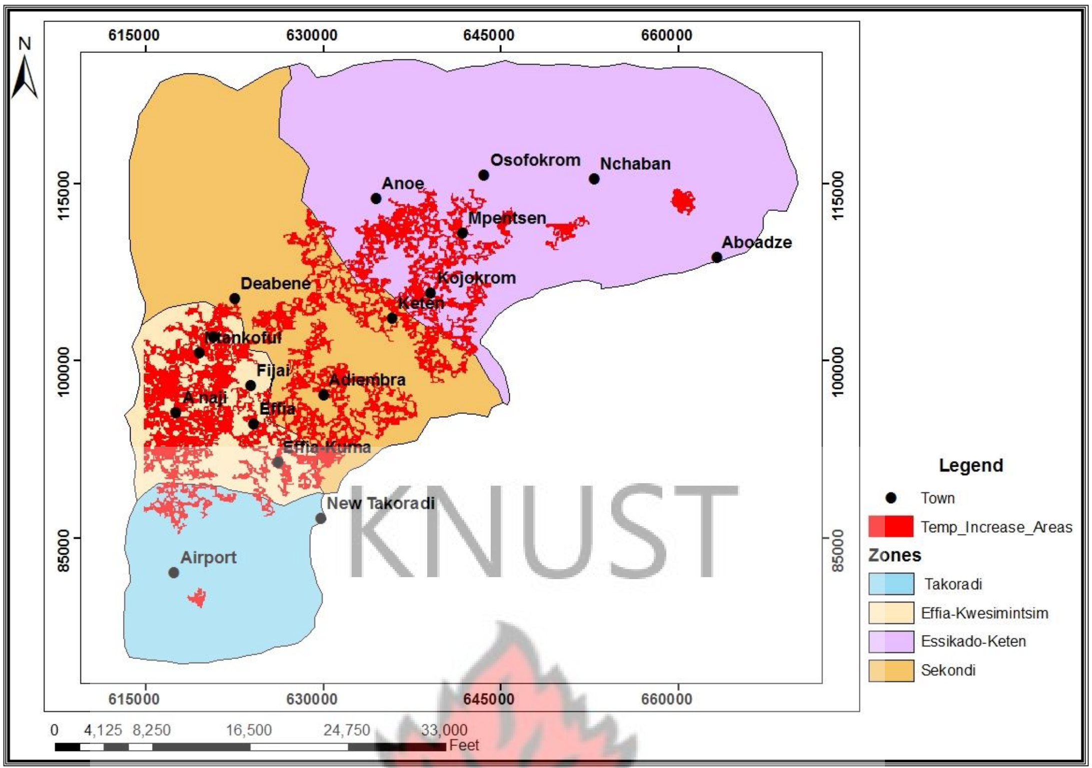

Figure 4-15 Map of Temperature Rise Areas

From Figure 4-13 and 4-14, it can be deduced that the highest surface radiant temperature values were recorded in the heavily urbanised centers of the metropolis such as the Takoradi Market Circle, Takoradi Airport, Takoradi Harbour, Effia-Kuma and the Aboadze Thermal Plant areas. Majority of the highest temperature was recorded in the Takoradi Market Circle (TMC) which happens to be the Central Business District (CBD) of the Metropolis. Critically examining the surface radiant temperature, higher temperature values were also recorded in some peri-urban centers such as Anaji, Kojokrom and Inchaban. Lower temperature values were also recorded in rural areas such as Osofokrom and Anoe.

4.5.3 Normalised Difference Vegetation Index (NDVI)

Figures 4-16 and 4-17 is a map that shows the NDVI values for the 1991 and 2008 images respectively.

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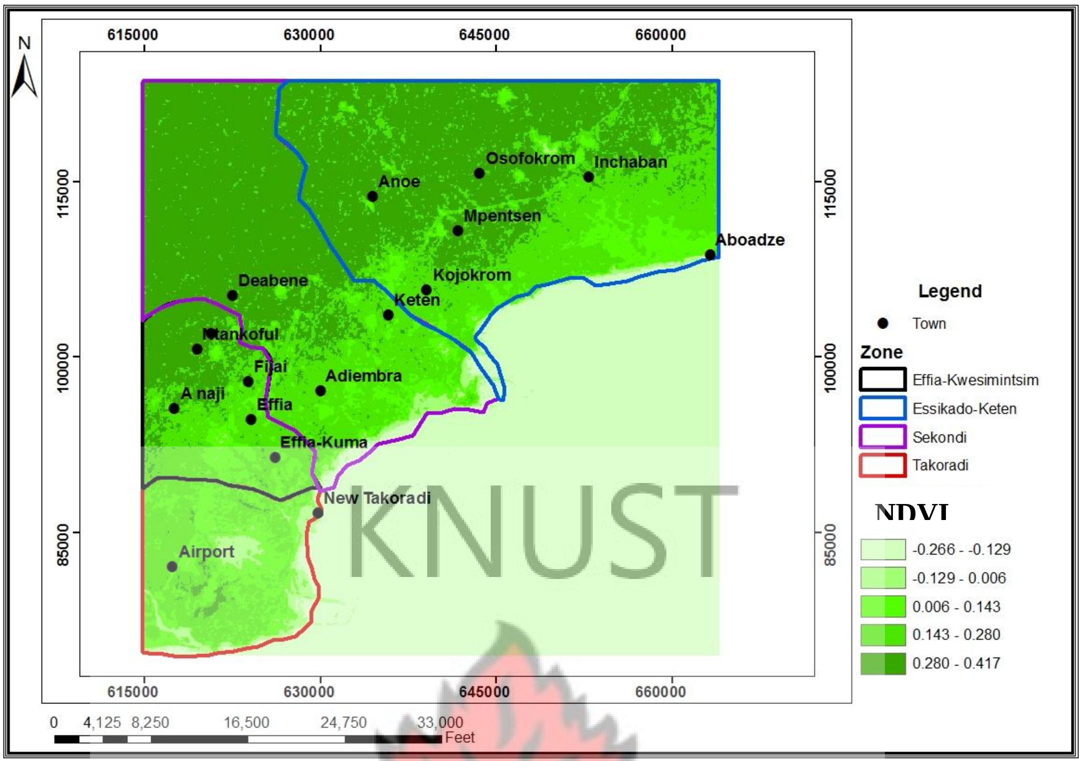

Figure 4-16 Map of NDVI for 1991

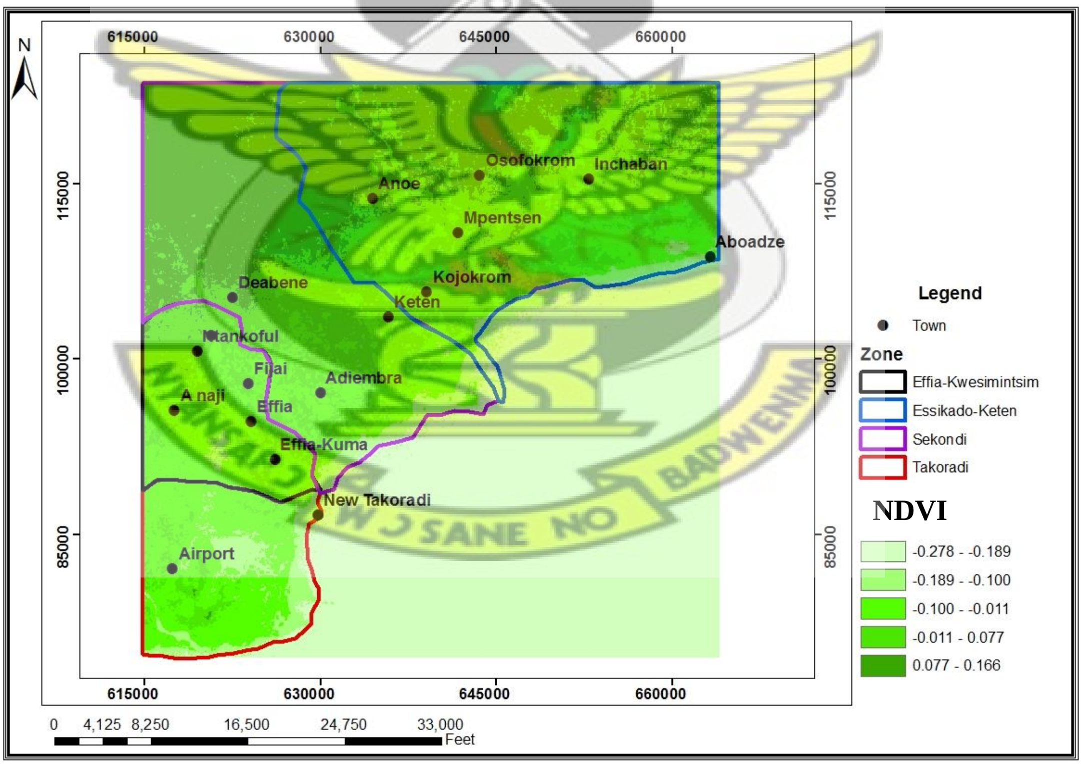

Figure 4-17 Map of NDVI for 2008

It is evident from both maps that the lowest values of NDVI were recorded in water followed by urban areas. From the figures again, it can be deduced that there have

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been a decrease of biomass in the areas with the highest measure of greenness. From the 1991 NDVI map, the highest NDVI values covered about 50% (11258.01 ha) of the study area. However, from the 2008 NDVI map, the highest NDVI values covers about 24% (5471.39 ha) of the study area. Not only has there been a reduction in the size of the areas with the highest vegetation but there has also been a progressive decrease in the measure of the greenness at such areas. For instance places like Ntankoful and Deabene had NDVI values between 0.280 and 0.417 in 1991, however, in 2008, the NDVI values for these same location ranges between -0.011 to 0.077. From the 1991 NDVI map, the NDVI values ranged between -0.266 and 0.417 whiles those from the 2008 NDVI map ranged between -0.278 and 0.166.

4.5.4 Relationship between NDVI and Radiant Surface Temperature

It is well known that NDVI negatively correlate with radiant surface temperature. Therefore the relationship between radiant surface temperature and NDVI for each of the land cover types was investigated using correlation analysis. Table 4-6 shows the Pearson's Correlation Coefficient between NDVI and average surface temperature in degree Celsius by land cover types.

Table 4-6 Pearson's Correlation Coefficient between NDVI and Surface Temperature in Degree Celsius by Land Cover Type (Significant at 5% Level)

Land Cover	1991	2008
Non-Urban	-0.969	-0.698
Urban	-0.924	-0.964
Water	-0.486	-0.257

Using the one tail student *t-test*, the significance of each correlation coefficient was determined at a 0.005 level of significance. It can be observed in Tables 4-6 that there is a negative correlation between NDVI and surface temperature for all the three land cover types. This implies that, the higher the biomass a land cover has, the lower the radiant surface temperature. As a result of this relationship between NDVI and surface temperature, changes in land use land cover indirectly impact on surface temperature through NDVI. It is therefore of no doubt that small NDVI values and high surface temperature values can be seen to occur in urban areas and especially at places where there have been significant urban expansion. The highest negative correlation for both years was found in urban/built-up land, whilst the smallest for both years was found in water.

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CHAPTER FIVE

DISCUSSION

5.1 CLASSIFICATION AND ACCURACY ASSESSMENT

The errors due to change detection can be classified into errors due to the following: reference data, post-processing, pre-processing and classification (Shao, 2006). In view of these errors, it is extremely important to assess the accuracy of the classification implemented in this study. Although there are several accuracy assessment methods or techniques, the most widely used technique is the error matrix of classification (Lillesand and Kiefer, 2008; Foody, 2002).

The overall accuracy for the 1991 land cover map was determined to be 86.0% whiles that of the 2008 land cover map was determined to be 82.0%. It is clear that the 1991 data has met the minimum requirement of 85% as determined by the USGS classification scheme (Anderson *et al.*, 1976). The 2008 data however fell short of this 85% minimum standard mark and this can be attributed to the fact that referenced data used for the accuracy assessment were obtained from a 2003 aerial photograph of the area and field survey that was carried out in 2012 during the field mapping stage of the study. According to Lillesand and Kiefer (2008), the quality of the reference data and training sample plays a very essential role in determining the success of the accuracy assessment as well as improving the accuracy of the classification. A field interview with some of the inhabitants of some selected communities in the study area revealed that, part of the metropolis which have beenn classified as flooded land (Wetland close to Poase New Takoradi, areas around the Whin River close to the Takoradi Airforce Base and Wetland close to Aboadze Thermal Plant), experienced successive flooding in the years 2006, 2007 and 2008.

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This flooding subsequently led to changes in land cover and land use in such areas and may have affected the accuracy assessment especially that of the 2008 data.

Kappa statistics measures the agreement between the classified image and the reference data or training samples. The overall kappa statistics for the 1991 and the 2008 land cover maps were 0.7890 and 0.7299, respectively. The computation of the kappa statistics do not only consider the diagonal elements but also considers all the other elements in the error matrix (Foody, 2002). According to Lillesand and Kiefer (2008), kappa statistic appears to be lower because the technique of its computation has the effect of taking into account change agreement in the classification as well. It is found therefore that, the overall kappa statistics for both years are lower than the overall classification accuracy. The kappa statistics for the 2008 data is lower than that of the 1991 data as a result of the reasons given above.

5.2 LAND COVER CHANGE DETECTION ANALYSIS IN SEKONDI-TAKORADI

In this study, in order to analyse the land cover changes that have taken place within the 17 year period (1991-2008), post-classification change detection was used. The advantage of this is that, it is able to provide thorough and in-depth information on the changes of one land cover type with other land cover types in terms of the location of the change, the extend of the change and the amount of the change.

Within the 17 year period, the land cover in the Sekondi-Takoradi Metropolis had undergone rapid changes due to increase in human population, industrialisation of the city and increase in other human activities such as construction of residential facilities. Results of the study indicate that, changes in land cover have occurred all

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over the study area with majority of the changes concentrated around urban/built-up areas. The total land covered with water from 9221.66 ha or 40.96% in 1991 to 9566.56 ha or 42.49% in 2008. This increase could be due to an error in the classification of the 2008 image. However, it is worthy to mention that, within the period there was a major expansion work at the Inchaban Head Waters Works which is the sole producer of potable water for the whole of the metropolis. Apart from this expansion work, flooding also occurred in the years 2006, 2007 and 2008 at some places designated as flood-prone areas such as the Wetland close to New Takoradi, areas around the Whin River close to the Takoradi Airforce Base and Wetland close to Aboadze Thermal Plant. Notable among this is the flooding of the Whin River which overflowed its banks and covered several hectares of land classified as non-urban. Much of such lands were being used as subsistence farmland. Apart from these, the interaction of the sea with land could have also caused an increase in the area of water bodies. Results of the study indicate that, there have been significant changes in land cover along the coast. This means that places which initially (1991) were bare lands are now (2008) being covered with sea water.

It can be deduced from the land cover change matrix generated that, 18380.84 ha (81.63%) of the total land cover remained unchanged, leaving 18.37% of the total land cover to be subjected to change at an annual land cover change rate of 1.07%. This annual rate of change seems to be a bit smaller and insignificant. The reason being that about 40% of the study area is covered with the ocean (Gulf of Guinea). Therefore in order to appreciate the land cover changes that has taken place, it would be expedient to subtract the area of the ocean from the total land cover since the ocean would not be subject to any changes. Upon doing this, it was realised that out of the 13346.9 ha representing the total land cover (exclusive of the ocean), 4135.18

ha representing 30.98% remained unchanged, meaning 9211.72 ha representing 69.01% of the land cover was subjected to change. This means that the study area experienced an annual rate of land cover change of 4.06% within the seventeen year period (1991-2008).

Critically examining the transition matrix that was generated it could be realised that the highest change that occurred was between non-urban and urban lands. A total of 3509.94 ha (Table 4-2) was the change that occurred between non-urban and urban land. This means that a total of 3509.94 ha of non-urban land was lost to urban/built-up land. This gives an indication of urban expansion. Further analysis of the changes that have occurred between non-urban and urban lands shows that over the 17 year period, there has been an annual loss of 5.88% of non-urban land, representing an annual loss of 206.47 ha. This rate of change is a significant indicator of urban expansion.

The factors that affect LULC changes are diverse and can generally be grouped into biophysical and anthropogenic (Turner *et al.*, 1993). The biophysical factors includes flooding, drought, bushfire, whiles the anthropogenic factors includes deforestation, urbanisation and increase in population. Among the biophysical factors, flooding is seen to be the main factor which affected the land cover changes in the study area. As stated earlier on, the study area lies along the coast of the Gulf of Guinea, and in 2006, 2007, 2008 successive flooding of some wetlands and floodplains contributed to a rise in the area being covered with water.

Although population growth has been found not to be the cause of environmental change in some developing countries of the tropics (Boserup 1981; Ehrlich and Ehrlich, 1990), other studies have positively correlated population growth to deforestation (Allen and Barnes, 1985) and increased exploitation of land resources,

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particularly in developing countries (Cheng, 1999). Population growth, therefore, is still widely recognized as a key determinant of environmental change, especially in developing countries (Cheng, 1999). The population of Sekondi-Takoradi has been increasing since 1970 at an annual rate of 3.5%. This increase in population may have contributed to loss of non-urban to urban/built-up land over the past year.

5.3 ANALYSIS OF URBAN EXPANSION IN SEKONDI-TAKORADI

Within the 17 year period urban expansion (urbanisation) was identified as one of the major forces responsible for the alteration of the land cover in the study area. The population of the metropolis as at 1970 was 135,760; however, this population grew to 272,150 in 1984. According to the 2000 Population and Housing Census the population of the metropolis was recorded to be 369,166 (GSS, 2000), whiles the results for the 2010 Population and Housing Census recorded a value of 559, 548 as the population of the entire metropolis (GSS, 2012). It can therefore be deduced from the figures that between 2000 and 2010, the population of the metropolis had almost doubled. Such an increase in the population could be due to rural-urban migration. According to the GSS (2012), about 69% of the metropolis' population was urban whiles the remaining 31% was rural as at the year 2000. However there has been a tremendous increase in urban population from 246,169 in the year 2000 to 402,874 in the year 2010.

Sekondi-Takoradi is the third largest city in Ghana after Accra and Kumasi and one of the most industrialised cities in Ghana. The city has a lot of commercial and industrial activities taking place due to the Port/Harbour and therefore many people both within and outside the metropolis migrate to the major urban areas like Takoradi and Sekondi to take advantage of the economic activities. Sekondi-Takoradi is the major economic city in the whole of the Western Region and therefore many people from various parts of the region travel to this place for various economic reasons. An increase in human population subsequently must result in an increase in infrastructure and amenities to accommodate the added population. The effect of population increase and urbanisation can clearly be seen in the sharp increase in urban or built-up areas between the period of 1991 and 2008. The study revealed that, the urban or built-up land as at 1991 was 3925.09 ha and increased to 7024.69 ha at 2008. This represents an increase of 78.97% in urban or built-up land over the seventeen year period; an annual change of 4.65% in urban or built-up land.

Another effect of the increase in population of the metropolis was the lateral expansion of urban infrastructure, especially for office and residential accommodation. (Attua and Fisher, 2011). With reference to the Accra Metropolitan Area (AMA) Attua and Fisher (2011), observed that demand for and access to land for residential purposes were the major drivers for the spatial growth of the city. Lateral expansion of residential and office accommodation is the status quo in most urban communities of Ghana, accounting largely for sprawl infrastructure development, often at the expense of other land uses.

As indicated in the analysis, The Takoradi Zone recorded the least urban expansion both in absolute and percentage terms; this is because this zone has no land for further expansion as they have expanded fully in the past. Again, almost all the commercial and industrial areas are concentrated in the Takoradi Zone, contributing to its lowest rate of urban expansion. Results of the study also indicate that, the location of urban expansion is greatest close to the Takoradi Zone and reduces as one moves away from that zone. This is so because most of the social amenities and resources (hospitals, schools, markets and recreation centres) are located within

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Takoradi Zone and therefore developers would like to take advantage of these resources, hence leading to the concentration of urban expansion closer to the Takoradi Zone. The study further demonstrated that, horizontal urban growth increased greatly over the study period, specifically in peri-urban areas such as Anaji, Deabene and Ntankoful. The result showed an expansion and merging of the physical boundary boundaries of Takoradi with those of adjoining towns such as Effia-Kuma, Anaji, Ntankoful and Kansaworodo, forming a single built-up conurbation. (Attua and Fisher, 2011). Future urban agriculture and biodiversity could be jeopardized, as more potential arable lands comprising woodland and cropland were converted to near-permanent physical urban housing (Attua and Fisher, 2011). Lands in peri-urban areas in particular could already be described as land tenure ‘‘hot spots’’ because they are characterized by rising demand for residential land as found in the AMA of Ghana (Attua and Fisher, 2011).

The combined use of remote sensing and GIS also allows for an examination of the location and trend of the urban expansion (Weng, 2001). Employing this integrated approach in the study revealed that urban expansion was uneven in different parts of the metropolis and that there is also a negative correlation between the density of urban expansion and distance to a major road. Further away a major road is, the lesser the density of urban expansion. Much of the urban expansion (about 75%) was concentrated within a radius of 2 km from a major road. This pattern or trend is because many of the metropolis infrastructures such as hospitals, schools and recreational centres are all located in close proximity to the major road, and therefore many developers would like to site their development near a major road to take advantages of these facilities. Again as a result of easy accessibility to developing site, many developers also make the choice of siting their development close to the

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major road. The Effia-Kwesimintsim zone experienced the highest urban expansion within the 17 year period. This is because Effia-Kwesimintsim is the closest to Takoradi and in time past had a vast land for further development and urban expansion. Over the past 17 years most of the lands in this zone which were mainly farmlands have been converted to either residential, commercial or industrials areas; with the greater part being commercial areas. Such changes in land use (from non-urban to urban) can be observed mostly in areas such as Anaji, Deabene, Ntankoful and Kansaworodo which were predominately rural in the early 1980s, but now have seen rapid urban expansion over the past 17 years. These communities currently have little or no vegetation cover. About 17 years ago, however, they were very green. These changes are anticipated to be very fast in recent time and in the future especially with the discovery and exploitation of oil at the Jubilee Field. The current oil exploitation in the Western Region has caused tremendous increase in the economic activities of the metropolis. Several companies have migrated to the metropolis to take advantage of this; and led to an increase in urban growth in the metropolis.

5.4 ANALYSIS OF URBAN EXPANSION IMPACT IN SEKONDI-TAKORADI

With the integrated approach of remote sensing and GIS, the effect or impact of urban expansion on surface temperature was examined (Weng, 2001). From both images, it can be observed that the highest surface temperatures were recorded in urban/built-up areas such as the TMC, Takoradi Harbour Area, Takoradi Airport and Aboabze Thermal Plant. This is because urban/built-up areas are predominately composed of materials and structures which are mostly non-transpiring and non-

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evaporating. These materials tend to absorb more of the heat energy from the sun in their dense mass. When the heat is release mainly at night, it raises the air temperature as well as increase the consumption of energy in buildings. The standard deviations of the surface temperatures for both years are also small in urban/built-up areas for both years (±0.70 for 1991 and ±0.72 for 2008). This is an indication that urban areas do not experience a wide change in surface radiant temperature (Weng, 2001). Urban areas are generally composed of surfaces which are rough and dry, as natural vegetated surfaces are replaced with buildings and paved street. These changes affect the rate of absorption of solar radiation. Solar radiation is therefore hindered from penetrating through such surfaces because of their imperviousness (Xian and Mike, 2004).

Impervious surfaces are mainly constructed surfaces such as rooftops, sidewalks, roads, and parking lots, covered by impenetrable materials such as asphalt, concrete, and stone (Kent *et al.*, 2002). These materials effectively seal surfaces, prevent heat from penetrating, repel water and prevent precipitation and melt water from infiltrating soils (Kent *et al.*, 2002). As a result of these properties of impervious surface, much of the incoming solar energy that could have been employed to evaporate water is instead transformed into sensible heat. This effectively raises the temperatures of these surfaces and of the overlying atmosphere (Kent *et al.*, 2002). In addition to this, impervious surfaces act like rocky desert surfaces in that they tend to have high thermal conductivities and heat storage capacities in comparison to vegetated pervious surfaces (Kent *et al.*, 2002). The differences in the thermal characteristics of surface materials that overlie urban areas versus those that overlie natural pervious areas have profound implications on microclimates. Human activities in most urban areas also produce emission of heat which causes an increase

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in the surface temperature of such areas. It is therefore of no doubt why high temperature was recorded in urban/built-up areas for both years (29.63 °C for 1991 and 33.93 °C for 2008).

5.4.1 Surface Radiant Temperature Change in the Sekondi-Takoradi Metropolis

The highest average surface temperatures (29.63 °C for 1991 and 33.93 °C for 2008) were recorded in the Takoradi Market Circle (TMC) areas. The TMC which is in the Central Business District (CDB) is the busiest commercial area not only in the metropolis but also in the whole of the Western Region. The area also is the most urbanised area in the whole of the region which mainly is composed of impervious surfaces such as walkways, parking lots and paved roads. The impervious structures collect solar heat in their dense mass and when the collected heat is released mainly at night, it raises the air temperature. This explains the highest temperature values that were recorded in the CBD in both years.

The Takoradi Airport area also recorded higher surface temperature for both years. These high temperature values at the airport could be due to the asphaltic nature of the runway. Except some few areas which are covered with vegetation, the airport area is paved with concrete and bricks and these are the areas where the high temperature values were recorded. These surfaces are highly impermeable so that heat from the sun is collected and prevented from penetrating through them. The heat collected is then released which increases the temperature of the surfaces. Effia-Kuma, a densely populated area also recorded a significantly high temperature values. This is a residential area where the buildings are closely packed. The buildings are roofed with corrugated iron roofing sheets with higher solar radiation absorption and a greater thermal capacity and conductivity. The Effia-Kuma area has

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virtually no vegetation cover and is a very dry urban area. These could be responsible for the higher temperature values recorded in this residential area.

The major industrial area in the metropolis is the Takoradi Harbour area; it is therefore not surprising that high temperature values were recorded there. The Harbour is much paved consisting of bricks and concrete. There is a good road network in the area which is mainly asphalt. As stated earlier on, this is an area which has been zoned as a heavy industrial area, and therefore houses most of the industries in the metropolis. Notable among these industries are Ghacem; a cement producing company and Takoradi Flour Mills; a flour producing company. Both companies together with other companies have their factories and plant located within the Harbour industrial area. Apart from the heat these industries release during the processes, the plant and its accessories are themselves having higher solar radiation absorption and a greater thermal capacity and conductivity. A number of concrete made warehouses and storage silos are also located within the industrial area. All these impervious surfaces together with the heat released during industrial operations could be responsible for the high temperature values in the Takoradi Harbour. Among the high temperature areas is the Aboadze Thermal Plant. Even though areas around the thermal plant recorded low temperature values, the thermal plant area itself recorded a high temperature. This is as a result of the structures or surface located within the thermal plant areas. Most of the structures are impervious with high thermal radiation absorption. These impervious surfaces together with the heat released from the plant would be responsible for the high temperature.

To further analyse the impact of urban expansion on surface temperature, the metropolis was divided into four zones, namely, Takoradi, Sekondi, Effia-Kwesimintsim and Essikado-Keten. This was done to determine the temperature

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changes in each of these zone and also to establish the impact of urbanisation on surface temperature. Among these four zones, the Effia-Kwesimintsim zone experienced the greatest change in surface temperature. This zone also happens to be the zone which has experienced the highest urban expansion. It is therefore indicative that in the past, the zone was predominantly non-urban composed of high vegetation cover. However, in recent time, the rich vegetation of the zone have been removed being replaced with non-evaporating non-transpiring impervious surface such as concrete buildings, asphalt roads, corrugated iron roofing sheets and paved surfaces. This rapid urbanisation could be responsible for the change in surface temperature. The average surface temperature from the 1991 data was 28.15 ^{o}C whiles that from the 2008 data was 31.65 ^{o}C, a change of 3.5 ^{o}C. In 1991, the Effia-Kwesimintsim was predominantly non-urban having high amount of vegetation cover, however in the year 2008 the zone had been transformed into one which is predominately urban. Also urban expansion which occurred in the zone over the 17 year period was 47.76%, highest among all the other zones. It is therefore found to have the highest change in surface temperature among the zones over the 17 year period.

A comparison of the satellite temperatures and the GMA temperatures confirms that there has been an increase in temperature in the study area over the past 17 years. Generally, the temperatures as recorded by the GMA are lower than the satellite temperatures. This is because the satellite measure the land surface temperature which is the temperature of a surface as one would fell whiles the GMA measure the ambient air temperature which is the temperature of the surrounding atmosphere. Generally land surface temperature is higher than ambient temperature. It is however worth to note that despite the changes in the satellite temperature and the GMA temperature, they are show an increase in temperature over the past 17 year. The

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long term effect of this temperature increase (UHI) could potentially modify the general climate condition of the metropolis. Several factors could possibly have caused the increase in both average nighttime and daytime temperatures; however, the major factor could be anthropogenic land-use changes as shown earlier on (Manu *et al.,* 2006). The metropolis is experiencing tremendous urbanisation with associated population increase. This rapid urban growth could have contributed to the development of UHI with simultaneous increase in both daytime and nighttime temperatures at virtually equal rate. The effect of urban growth is also expressed in the increase in nighttime temperatures. This means that the heat capture, absorbed and stored temporally by impervious surfaces are released at time, hence causing an increase in the nighttime temperature. This is consistent with a research carried out by Manu *et al.* (2006), who observed that the nighttime temperatures of Accra and Kumasi have been increasing. According to their research, the effect of urbanisation and urban heat intensities were expressed in nighttime temperature, it is therefore of no doubt that, the rate of increase of per-decade temperature trend was higher for nighttime temperature that for daytime temperature.

5.4.2 Relationship between NDVI and Surface Temperature in Sekondi-Takoradi

NDVI measure the greenness of the environment and the amount of biomass or vegetation. A higher NDVI gives an indication of a higher degree of greenness and healthy vegetation (Curran, 1980). According to Xian and Mike (2004), NDVI is a good indicator of surface temperature, and thus NDVI correlate negatively with surface temperature. Results of the study indicate that, higher NDVI values were recorded in non-urban areas which had low surface temperature values, whiles lower NDVI values were recorded in urban areas which had high surface temperature values. The results of the study further show an inverse correlation between land

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surface temperature and NDVI for all the land cover classes. The strongest of this relationship was observed in urban/built-up areas (0.924 for 1991 and -0.964 for 2008). This means that the amount of vegetation available in an area influences the area's surface temperature. The gradual decrease in NDVI in the metropolis also indicates that the biomass or vegetation of the metropolis is gradually decreasing. Since NDVI is measure of biomass, it gives an indication of urbanisation therefore assisting to analyse the effect of urban expansion on surface temperature.

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CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The study used the integration of remote sensing and GIS to analyse urban land expansion in terms of the amount of expansion, the location of expansion and the rate of expansion that has taken place in the Sekondi-Takoradi Metropolis between the period of 1991 and 2008. This integration of remote sensing and GIS provided an effective and efficient approach to identify urban expansion and also to investigate and assess the impact of urban expansion on surface temperature. The study has revealed that, the study area has experienced extensive land cover changes with an annual rate of land cover change of 4.06%. From the study it was realised that, for the past 17 years, the Sekondi-Takoradi metropolis has seen dramatic urban expansion and this subsequently has resulted in the loss of non-urban lands such as farmland and forestland, hence altering the characteristics of the land surface in the metropolis. The coupling of digital image classification in remote sensing and GIS has also proven to be an efficient and effective way of obtaining information on the location, trend and amount of urban land expansion.

The rapid urban expansion in the metropolis could be attributed to the accelerated economic growth and increase in human population over the last two decades. The urban land in the metropolis increased from 3925.09 ha in 1991 to 7024.69 ha in 2008. The rate of urban expansion in the study area was observed to be 4.65% per year. Although, urban growth/expansion was random in all directions, majority of the urban expansion occurred in the south-western part of the metropolis. The study also revealed that about 75% expansion was concentrated within 2 km from the main

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Takoradi-Accra road. Most of the urban expansion also occurred in communities close to the city of Takoradi, notable among them being the Effia-Kwesimintsim Zone (47.76%) which experienced the highest urban expansion among all the four zones that was chosen.

The effect of urban expansion on surface temperature was also investigated. The result of the analysis of the surface temperature in terms of land cover classification showed that urban land had the highest surface temperature values with the lowest vegetation cover ratio. The result of the study also showed that urban development had increased surface radiant temperature in the study area by 4.3^{o}C in the urban expanded area. Result of correlation analysis between the extracted surface temperature and NDVI showed a negative correlation with the highest value in absolute terms being observed in urban/built areas. In addition, the study shows that the change of surface temperature is dependent on NDVI and surface cover. The result further showed that urban land expansion or development causes an increase in surface temperature. The changes in LULC has a tremendous impact on other environmental elements and thus, the direct impact of urban LULC on one environmental element can indirectly impact on other environmental element such as climate.

The temperature values obtained in this study may be a little bit higher than as they were; this is because the roughness of the land surface which has an effect on surface temperature was not taken into account. Research has shown that to effectively measure surface temperature, an analysis of the significance of the nature of the land surface and its roughness on emissivity should be taken into account and incorporated. Thus emissivity values for the various land use land cover should be obtained and incorporated into the computation of the surface temperature. The study

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further shows that the statistical analysis of vegetation index (NDVI) and thermal signature each provides independent information which can be used to analyse the urban environment.

Finally the integration of GIS and remote sensing has therefore demonstrated their effective and efficient approach of analysing and monitoring urban expansion patterns and assessing its impact on surface temperature. Biophysical measurement such as biomass and surface temperature can be obtained from Landsat TM and ETM+ images. The study also showed that environmental effect of land use/land cover change can be mapped and modelled using the integrated technique of GIS and remote sensing. The methodology adopted in this study present an alternative to the traditional empirical analysis using in situ data for environmental studies.

6.2 RECOMMENDATIONS

The following recommendations are being made;

i. Further studies should be done with a more recent image to determine the current land use land cover status of the metropolis as well as to determine the current trend and rate of urbanisation. Subsequently the effect or impact of urbanisation should be assessed using a more current image to assist in determining the current trend and extent of urban heat island in the metropolis. To add to the above, levels of gaseous emissions which potentially affect temperature should be monitored.

ii. Again the urban warming occurring in the metropolis should be mitigated for. The following mitigation measures are suggested.

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- Encourage the use of building materials that will minimise absorption of heat; such as encourage the use of cool mainly reflective roofing materials and the use of cool pavements.
- Promote and increase tree planting and vegetative cover.
- Promote and encourage the creation of green roofs also known as eco-roofs or rooftop gardens.
- City planners would also develop and implement programmes directed toward education the general public on the effects of the urban heat islands phenomenon.
- Anthropogenic sources of heat generation such as industrialisation, burning of fossil fuel and extensive exhaust emissions from vehicles should be monitored and policies should be implemented to streamline such activities.

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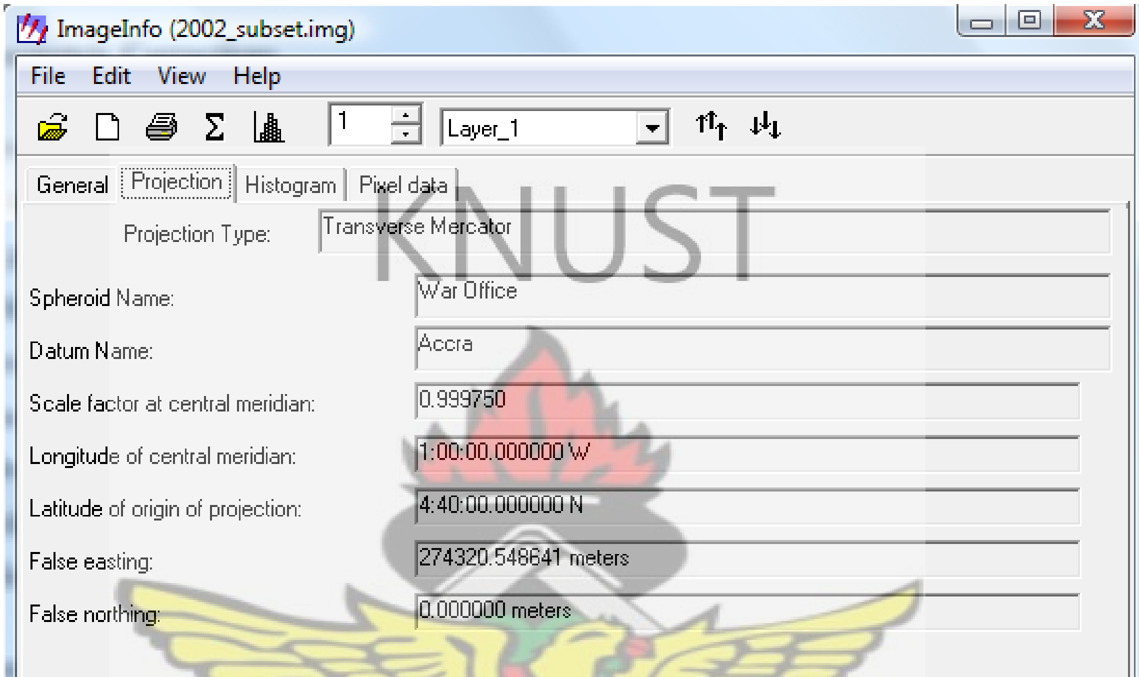
APPENDICES

APPENDIX A : PARAMETERS OF THE WAR OFFICE GHANA DATUM



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APPENDIX B1: ERROR MATRIX OF THE 1991 LULC MAP

	Reference Data									
Classified Data	UC	NU	UB	WA	RT	CT	NC	PA (%)	UA (%)	Kappa
UC	0	0	0	0	0	0	0	---	---	----
NU	0	27	4	2	33	35	27	81.82	81.82	0.7286
UB	0	4	21	1	26	26	21	80.77	80.77	0.7401
WA	0	0	1	38	41	39	38	92.68	97.44	0.9565
Column Total	**0**	**31**	**26**	**41**	**100**	**100**	**86**			

Overall Classification Accuracy = 86.00 %
Overall Kappa Statistics = 0.7890

UC = Unclassified, NU = Non-Urban, UB = Urban, WA = Water, RT = Reference Total, CT = Classified Total, NC = Number Correct, PA = Producer's Accuracy, UA = User's Accuracy

APPENDIX B2: ERROR MATRIX OF THE 2008 LULC MAP

	Reference Data									
Classified Data	UC	NU	UB	WA	RT	CT	NC	PA (%)	UA (%)	Kappa
UC	0	0	0	0	0	0	0	---	---	0.000
NU	0	25	5	1	32	31	25	78.13	80.65	0.7154
UB	0	5	27	2	35	34	27	77.14	79.41	0.6833
WA	0	2	3	30	33	35	30	90.91	85.71	0.7868
Column Total	**0**	**32**	**35**	**33**	**100**	**100**	**82**			

Overall Classification Accuracy = 82.00 %
Overall Kappa Statistics = 0.7299

UC = Unclassified, NU = Non-Urban, UB = Urban, WA = Water, RT = Reference Total, CT = Classified Total, NC = Number Correct, PA = Producer's Accuracy, UA = User's Accuracy

APPENDIX C1: 1991 AND 2008 MAXIMUM TEMPERATURE FOR THE STUDY AREA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	31.56	31.58	31.91	30.77	30.84	30.06	28.55	27.17	28.47	28.56	30.11	30.66
2008	31.34	32.44	32.55	31.83	31.39	30.08	29.26	28.58	29.02	30.51	31.21	31.81

(Source: Ghana Meteorological Agency)

APPENDIX C2: 1991 AND 2008 MINIMUM TEMPERATURE FOR THE STUDY AREA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	23.28	24.02	24.28	23.59	23.83	23.92	22.46	22.16	23.11	22.26	22.89	23.15
2008	21.23	24.26	24.28	24.53	24.10	23.83	23.33	22.61	23.09	23.84	24.03	23.96

(Source: Ghana Meteorological Agency)

APPENDIX C3: 1991 AND 2008 AVERAGE TEMPERATURE FOR THE STUDY AREA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1991	27.42	27.80	28.10	27.18	27.33	26.99	25.51	24.67	25.79	25.41	26.50	26.90
2008	26.28	28.35	28.42	28.18	27.75	26.96	26.30	25.60	26.06	27.17	27.62	27.89

(Source: Ghana Meteorological Agency)

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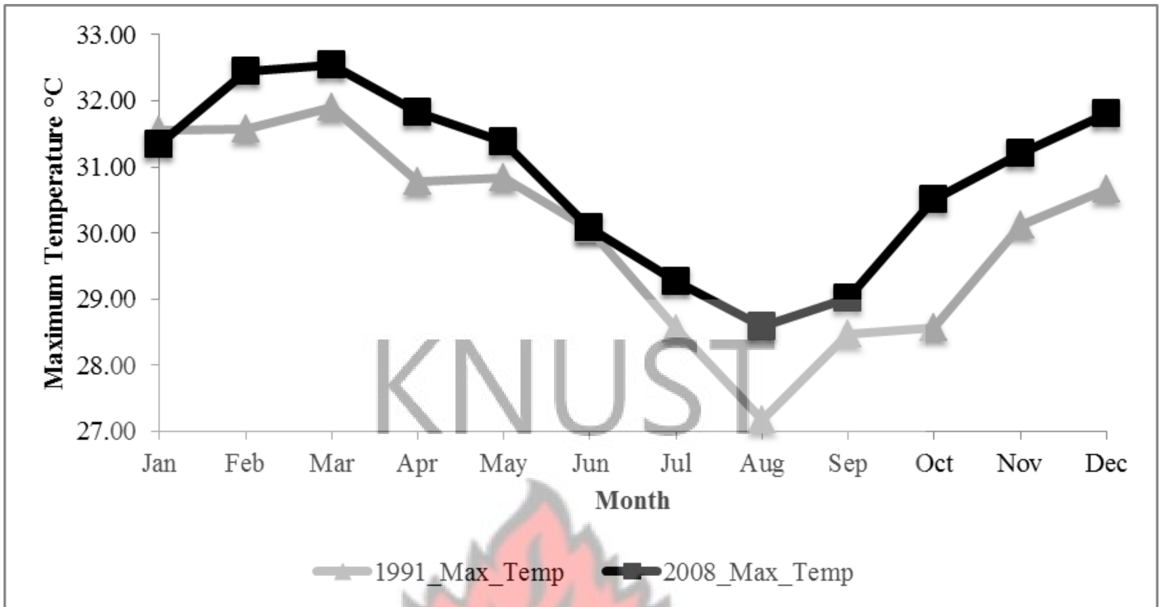
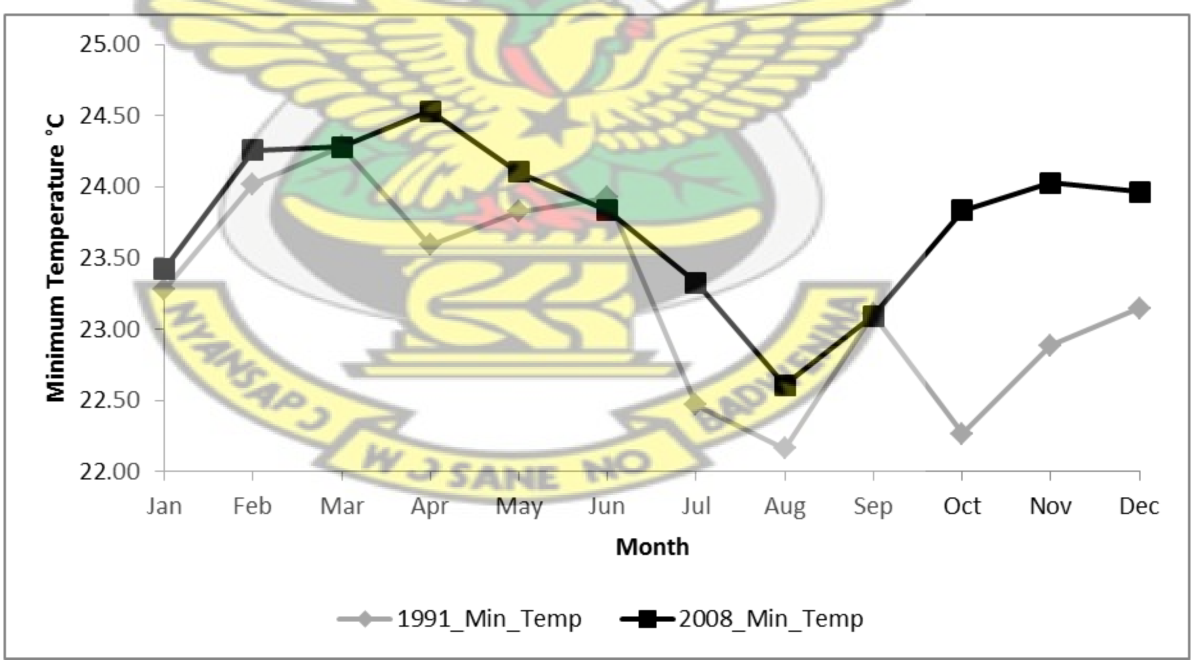
APPENDIX D1: TREND OF MAXIMUM TEMPERATURE FOR 1991 AND 2008



APPENDIX D2: TREND OF MINIMUM TEMPERATURE FOR 1991 AND 2008



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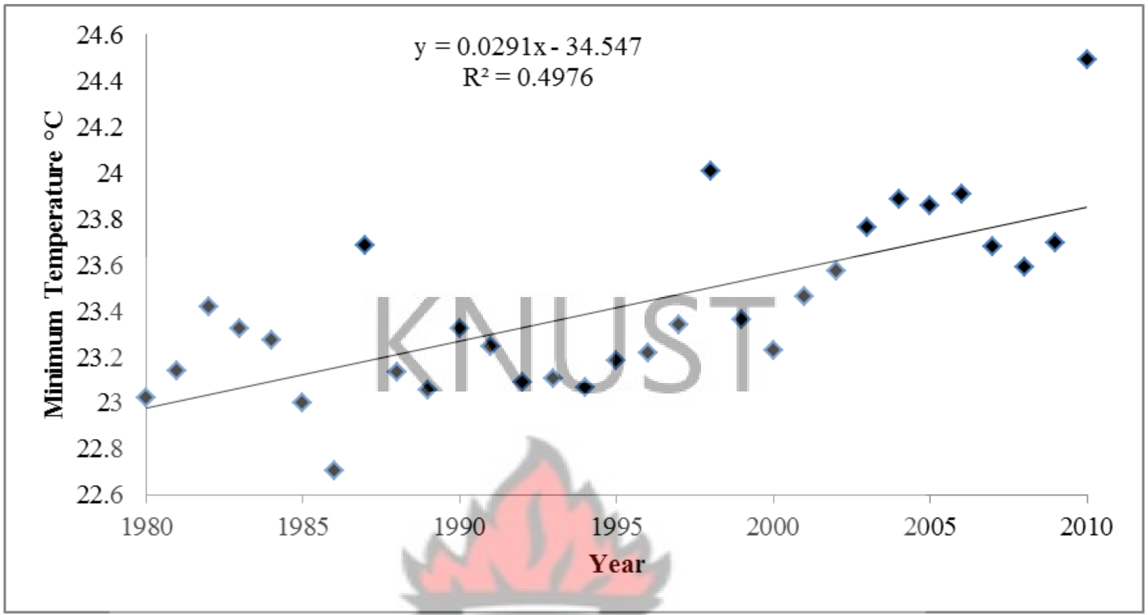
APPENDIX E1: AVERAGE OF MONTHLY MINIMUM TEMPERATURE FOR THE METROPOLIS



APPENDIX E2: AVERAGE OF MONTHLY MAXIMUM TEMPERATURE FOR THE METROPOLIS