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Mauritania and Senegal coastal area urbanization, ground water flood risk in Nouakchott and Land use / land cover change in Mbour area

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Abstract

Urbanization has increased significantly in Mauritania and Senegal during the last decades since the countries gained independence. In both countries most of the important cities are located in their coastal area. Cities inherited from the colonial period expand both in size and inhabitants. The total urbanised surface has increased at a rate of 300- 400 % in 30 years. The development of cities impacts the coastal environments, particularly the ground water flow in the city of Nouakchott in Mauritania during the rainy season and the land cover and land use in the city of Mbour, located in the coastal area called Petite Côte in Senegal. This study used GIS and RS techniques to map the expansion of urban area over the Mauritania and Senegal coastline and measure the rate of expansion during the last decades. A linear regression analysis revealed a strong relationship between the urban area expansion and population growth in both countries' capitals. In Dakar, the capital of Senegal, the urbanised area increase rate is estimated at 291 % between 1978 and 2002. The correlation has a R^2 –value of 0.94 that indicate a strong relationship between the two variables. Using the same techniques, the environmental impacts of urbanization was evaluated. Classification and reclassification of Nouakchott elevation identified suitable and unsuitable areas and this data was used to estimate the extent of built-up construction in low-lying areas that may be influenced by ground water flooding during the rainy season. These surfaces represent 13.66% of the urbanised area in 2008 with a population of 112 964 inhabitants. To evaluate the change in land cover/land use in Mbour area located on Petite Côte (Senegal), Landsat 5 TM anniversary images of 17th October 1984 and 22nd October 2009 were used. Supervised classification method was used after defining training sites. Image classification was done using maximum likelihood classification. Post classification was used to evaluate the changes. The rates of changes were calculated. The results show that urban area, rain fed cropland, mosaic cropland vegetation and sparse vegetation increased at a rate of 490.04%, 27.02%, 30.21%, and 23.17 % respectively. Open shrubland decreased by an estimated of 85.69%. Landsat NDVI statistics showed no significant change in greenness but changed vegetation patterns were detected by visual analysis. NOAAH/AVHRR time series and rainfall data were extracted and analysed. The correlation analysis indicated a strong relationship between NDVI and rainfall data in Mbour area. The LU/LC map was compared to Landsat NDVI and NOAAH/AVHRR time series and rainfall data by visual analysis. The results indicated that urbanization had effect on LU/LC in the Mbour area and that the degree of greenness was more a function of rainfall. The change in Landsat NDVI pattern is related to land use change.

Key words: urban area expansion, coastal area, population, ground water flood, land cover/land use, Normalized Difference Vegetation Index, Geographical Information System, Remote Sensing.

Sammanfattning

Urbaniseringen har ökat betydligt i Mauretanien och Senegal under de senaste decennierna sedan länderna blev självständiga. I båda länderna är de viktigaste städerna lokaliserade längs med kusten. Städer som grundats under kolonialtiden växer både i storlek och invånarantal. Totalt har de exploaterade områdena ökat med 300-400% under de senaste 30 åren. Städerna expansion påverkar kustområdena, speciellt grundvattenflödet under regnsäsongen i staden Nouakchott i Mauretanien och markanvändningen i staden Mbour som ligger i ett kustområde kallat Petite Côte i Senegal. Denna studie använder GIS- och fjärranalysmetoder för att kartlägga städernas utbredning längs Mauretaniens och Senegals kuster och städernas tillväxthastighet under de senaste decennierna. En linjär regressions analys visar en stark relation mellan utbredningen av städerna och befolkningstillväxt i de bägge ländernas huvudstäder. I Dakar, Senegals huvudstad, har de urbana områdena ökat med 291 % mellan åren 1978 och 2002. Korrelationen har ett R^2 värde på 0,94 vilket visar ett starkt samband mellan de båda variablerna. Med hjälp av samma metoder utvärderades urbaniseringens påverkan på miljön. Genom klassificering och omklassificering av höjddata från Nouakchott identifierades lämpliga och olämpliga områden och dessa data användes sedan för att göra en uppskattning av hur stor del av staden som återfinns i låglänta områden och därmed riskerar att drabbas av översvämning då grundvattnet stiger under regnsäsongen. Dessa områden står för 13.66% av stadens areal och hade 112 964 invånare 2008. För att utvärdera förändringar markanvändning/ marktäcke kring Mbour och Petite Côte användes Landsat 5 TM anniversary images från 17 oktober 1984 och 22 oktober 2009. Efter att kontrollpunkter (training sites) definierats användes övervakad klassificering (supervised classification). Bildklassificeringen gjordes med hjälp av maximala sannolikhets-metoden (maximum likelihood) och de slutliga kartorna hade en noggrannhet på 54 % (1984) och 60 % (2009). Efter-klassificering gjordes för att utvärdera och kvantifiera förändringar. Resultatet visar att uppbyggda områden, jordbruksområden, mosaikartad jordbruksvegetation och gles vegetation ökat med respektive 490,04%, 27,02%, 30,21%, och 23,17 %. Buskvegetationen har minskat med uppskattningsvis 85.69%. Landsats NDVI statistik visade ingen signifikant skillnad i grönhet, men genom en visuell analys kunde ändrade vegetationsmönster ses. NOAAH/AVHRR tidsserier och nederbördsdata extraherades och analyserades. En korrelationsanalys visade ett starkt samband mellan NDVI och nederbörd kring Mbour. Markanvändning/marktäcke-kartan jämfördes visuellt med NDVI och NOAAH/AVHRR tidsserierna och nederbördsdata. Resultatet visar att urbaniseringen påverkade markanvändningen/marktäcket kring Mbour medan grönheten främst är en funktion av nederbörd. Förändringar i Landsats NDVI mönster är relaterade till förändrad markanvändning.

Nyckelord: urbanisering, kustområde, befolkning, grundvattenöversvämning, marktäcke/ markanvändning, Normalized Difference Vegetation Index, Geografisk Informations System, fjärrnalays

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List of abbreviation

ANSD: Agence National de la Statistique et de la Demographie

APFM: Associated Programme on Flood Management

AVHRR: Advanced Very High Resolution Radiometer

GIS: Geographical Information System

GDEM: Global Digitalization Elevation Model

GPHC: General Population and Housing Census

IRD: Institut de Recherche et de Developpement

KOMPSAT: Korea Multi Purpose Satellite

LC: Land Cover

LU: Land Use

NASA: National Aeronautics and Space Administration

NDVI: Normalized Difference Vegetation Index

NIR: Near Infra Red

NOAA: National Oceanic and Atmospheric Administration

ONS: Office National de la Statistique

R: Red

RS: Remote Sensing

SPOT: Satellite pour l'Observation de la Terre

SRTM: Shuttle Radar Topographic Mission

TGAE: Télédetection et Géomatique appliqué á l'Environment

UN: United Nation

UVSQ: Université de Versailles Saint Quetin

VI: Vegetation Indices

CHAPTER 1: INTRODUCTION

1.1. Background

Urbanization is the process in which an increasing proportion of an entire population lives in cities and the suburbs of cities. The twentieth century is seen as the period of the rapid urbanization of the world's population (UN, 2005).Estimates show an increase in urban population from about 220 million in 1900 to 732 million in 1950, with an estimated 3.2 billion in 2005(UN, 2005). According to the UN (2007) the year 2008 has earmarked the colonization of the world's urban centres by half of the world's population. Both the 2005 and 2007 projects report a population increase of 5 billion (roughly 60%) by 2030. This being more pronounced in Africa and Asia. In Africa for instance the most dramatic urban transformation occurred between the years 1950 and 1960 **(**Arnaud, 1993). During this period of urbanization, urban development focused on the erection of many administrative centers based on some ports cities; some industrial and populated areas in most cases utilizing the urban structures left by the colonial administrators.

In West Africa, urbanization has been the most spectacular change in recent decades after population growth. Between 1950 and 1975, the region experienced a phase of intense urbanization, resulting from a strong rural-urban drift with a sustained natural growth of 2.7% per year **(**Arnaud, 1993). Accordingly, Arnaud (1993**)** estimates that within the region, almost 50 % of countries population lives in urban areas in 1992against 20% in 1960. This growth in urban population was more pronounced in coastal countries which had coastal lowlands conducive to urban expansion. In West Africa this coastal zone extends from Mauritania's sandy desert, to the coastal and lagoon barrier beaches of the Gulf of Guinea through the islands and estuaries upon 4400 km. This region is strategically important in terms of development having the highest concentration of economic activities, administrative, industrial and commercial centers.

Mauritania and Senegal as countries boarded by the coastline have experienced both an increase in urban population and coastal city size. Population dynamics have also changed. Between 1960 and 1970, however, prevailing drought conditions, disrupted the nomadic lifestyle and forced rural inhabitants towards the cities, characterized by movements from the rural continental interior to the coast regions (Ould Sidi Cheikh et al, 2007). Since then the country has been experiencing rapid urbanization and population increase (Ould Sidi Cheikh et al, 2007). Today, Mauritania's coast is inhabited by over a third of the country‘s population (Mint Snih, 2007). In the former French colony of Senegal the cities of Dakar and St Louis serve as examples of the rapid urbanization that has come to characterize the urban expansion through the exploitation of the coastal lowlands of Western Africa. The high rate of urbanization through the high incidence of occupation of the coastal zone in Mauritania and Senegal is clearly observable in their respective capital Nouakchott and Dakar. Clearly this rapid urbanization has severe environmental impacts through the modification of land use and land cover (LU/LC), altering natural systems and increasing the risks of environmental hazards like flooding in the region. To quantify urbanization and some of its impacts on environment, remote sensing and GIS techniques were used in this study.

1.2. Remote Sensing and GIS

Remote Sensing (RS) and Geographical Information System (GIS) represent a powerful geospatial tools for coastal area management (Mumby et al, 1995). RS is defined as both the science and art of obtain information about an object, area or a phenomenon, and its analysis thereof, without being in contact with it (Lillesand et al, 2004). Remote sensing is a scientific set of tools that can be used to measure a monitor phenomenon and activities on Earth (Jensen, 2000). RS detects records and analyse sun energy radiated by ground or atmosphere (Lillesand et al, 2004). Generally two processes are involved in remote sensing; the first involves the acquisition of data and the second involving the analysis of the acquired data (Lillesand et al, 2004). The first process uses sensors that emit electromagnetic energy to record energy reflected by the land surface and atmosphere. In the second process, the pictorial and digital images are then analysed with a computer. The information extracted by remote sensing techniques is converted in data format usable in GIS. Most of the databases used in GIS are extracted from an analysis of RS data (Jensen, 2000). GIS is a system of hardware, software and procedures used to manipulate and analyse geographical data. It‘s provide an analyse results in supports like a map that permit to improve the planning and the management of resources (Goodchild et al. 1990). GIS data is represented in vector or raster format with different extension. Raster and vector data can be merged overlay and applied in modelling to make an analysis.

1.3. Thesis outline

Thesis is divided in two parts with a total of 8 chapters. The first part beginning with chapter 1 and ending with chapter 4 contains the introduction, the study area, the data used, the background of the study and the methodology used shall be discussed. The second part of the work contains 4 chapters that present the results, the analysis, the discussion and the conclusion.

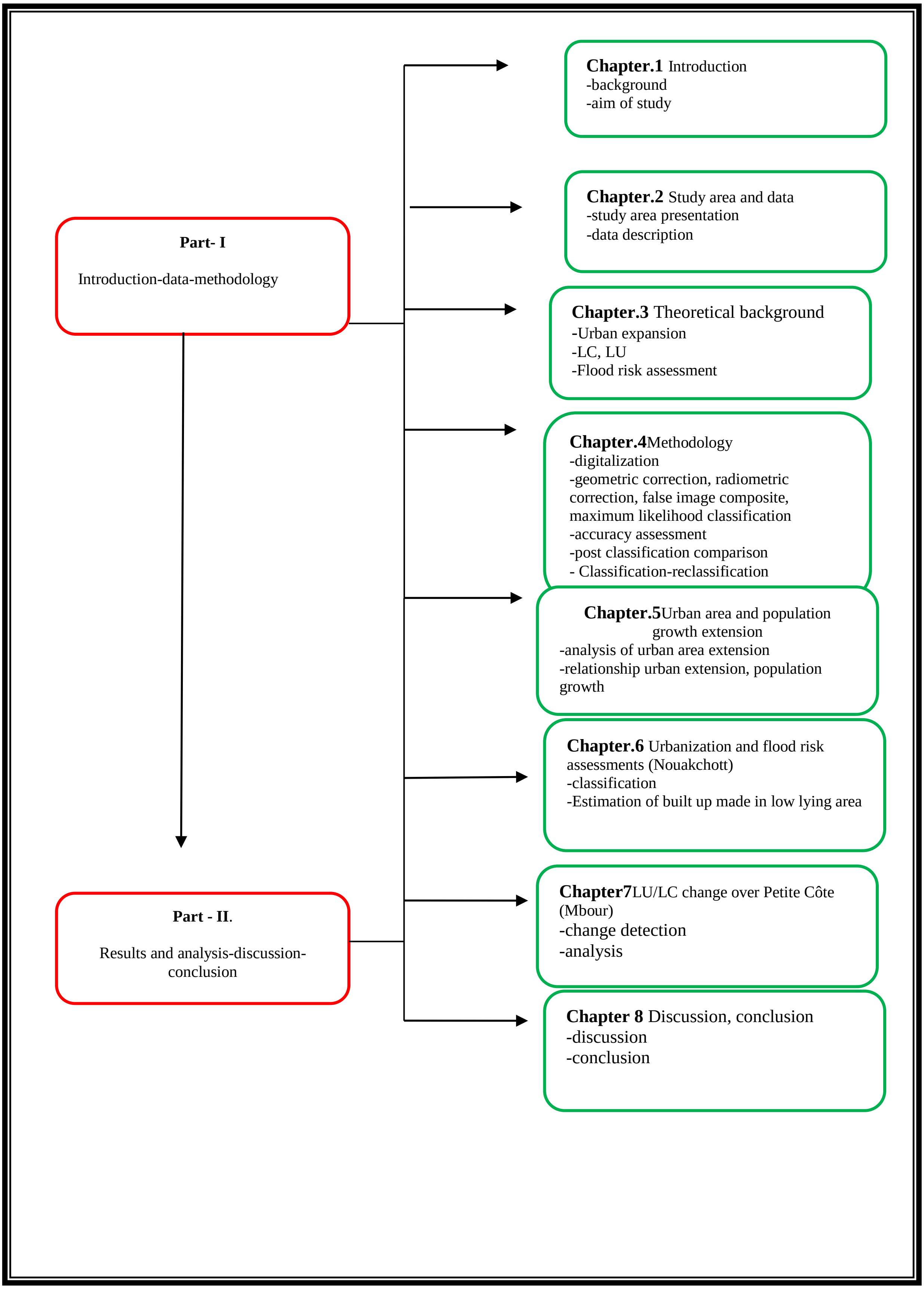


Figure.1. Flow diagram of thesis outline

1.4. Urban area expansion

Rapid urbanization is a modern day reality in Western African countries, particularly as it concerns Mauritania and Senegal. This urbanization is concentrated on a small portion of the country relative to their vast expanse of territorial land. Mauritania has a surface land area of 1030700 km^2 of which 70% is desert. According to a World Bank estimates Mauritania had a population of 3 290 690 in 2009 and a rate of urbanization of 50% in 2008. Neighboring Senegal covers an area of 197 000 km2 with 700 km of coastline as in Mauritania. In 2010, country population was estimated to 12 179 400 inhabitants with the urbanization rate of 46, 2% (ANSD, 2011).

Urbanization in both countries as is the case with all the other Western African countries, is characterized by high population growth, the spatial expansion of cities and the imbalance between the populations living in the interior/ in inland locations and those living within the coastal zone. In both countries, the major cities, namely, Nouakchott and Nouadhibou in Mauritania; Dakar, Saint Louis, and Mbour in Senegal are all located within the coastal zone and it is in these cities that urban expansion is the greatest.

The rapid urbanization experienced in both countries is the result of the natural growth of the population, the concentration of economic activities in the coastal zone and the massive rural-urban migration arising from inhospitable and poor living conditions in the rural interior. The promise of a better life, access to government services and the chance to make use of available opportunities drive rural dwellers to the city. As a consequence the coastal zone is heavily exploited as population density increases. Dakar, the capital of Senegal covers only 0.3% of the country's area yet it is home to 25% of the country population (ANSD, 2006).

The coastal zone is strategic for the development of important economic activities (transport, tourism, agriculture, oil extraction, fisheries, sand exploitation and salt extraction). These economic activities require construction and installation of facilities leading to a spatial extension of the city. The employment created by the economic activities is one reason for the population migration to the coastal zone. Dakar city extension for instance is the direct consequence of the high concentration of economic activities. In 1999, Senegal had 1 105 industrial companies, 991 of which were located in the Dakar region, representing 90% of the industrial fabric of Senegal (Ndiaye, 2008). Mauritania's capital, Nouakchott serves as both the administrative and economic centre of the country. It comes as no surprise then, that it is the most densely populated, accounting for a nearly a quarter of the country's population (ONS, 2000).

1.5. Flood risk due to urban expansion in coastal area

Floods result from a combination of hydrological, meteorological and human factors. It is one of the environmental changes due to urbanisation. The unforeseen rural-urban migration due to drought induces uncontrolled spatial extension of urban area. Construction is made in hazard prone areas such as riversides, converted wetlands, and land below the river, sea or reservoir level or even inside dried up river beds, in areas where the risks of flooding is relatively high (APFM, 2008).In Nouakchott for example, the urban area extends toward the low lying, flood prone area. The occupation of flood plain by built up construction in low-lying area is obstructing water flow and leading flood (APFM, 2008).

1.6. Urbanization - land cover/ land use change

Remote Sensing provides a powerful tool for land cover change study in urban areas and the quantification of forest lost or agricultural land estimation (DiGirolamo, 2006).The rate of land cover change can be estimated through the use of Remote Sensing data (Li et al, 2004). Demographic growth causes city expansion by increasing the number and extent of built up area. This extension is accompanied by landscape transformation. Land cover modification resulting from population growth, reduces natural vegetation cover in countries throughout the world (Nicolson, 1987). Land cover and agricultural fields are modified through infrastructural development either for human habitation or for economics activities. Infrastructural development, like the construction of motorways, airfields, and buildings changes the physical appearance of the coastline. Furthermore infrastructural development for tourism in the coastal zone modifies the landscape and alters the physical processes at work in the coastal zone.

The impacts of these activities on environment are as follows:

Land cover, land use change,
Degradation of the coastal area because of coastal sand exploitation,
Degradation of natural resources due to land covers change,
Coastal erosion, fragility of the dunes that promotes flood risk, supply, electricity,
Development of informal settlements (slums) with the servicing (water wastewater collection) poses serious problems to the authorities,
Risks of flooding during raining season,
Pollution of grounds water and sea water,
Relief modification by an abuse use of the sand dunes in the house construction.

The listed environmental changes raise a number of questions for research:
How did the spatial occupation of Mauritania and Senegal's coastal areas by the cities occur?
Is there a relationship between urban area expansion and population growth?
What are the impacts of urbanisation in flood risk assessment?
Is there a significant land cover and land use change due to urban expansion and its population growth?

From these questions, derives the following objectives:

1.7. Aim of study

The primary objective of this study is to investigate the effect of urbanization in the Senegal and Mauritania coastal area. The following specific objectives will then be investigated:

Estimating and analysing built up area extension caused urbanization in the Mauritania and Senegalese coastal cities.

Measuring environment impacts (flood risk assessment for Nouakchott in Mauritania followed by LU/LC changes in the region of Mbour in Senegal) caused by urbanisation in the coastal area.

CHAPTER 2: STUDY AREA AND DATA

This section describes the physical and human aspects of study area. It also provides an overview of data used in this study. This study is based on the coastal zones of the Western African countries of Mauritania and Senegal. The major cities are located within a buffer area of 30 km stretching from the Atlantic Ocean toward the continental interior, henceforth called the coastal zone. The strong demographic and economic pressures generated in this fragile area of these Sahel countries and the residual environment impacts they induce is the reason for the choice of study site.

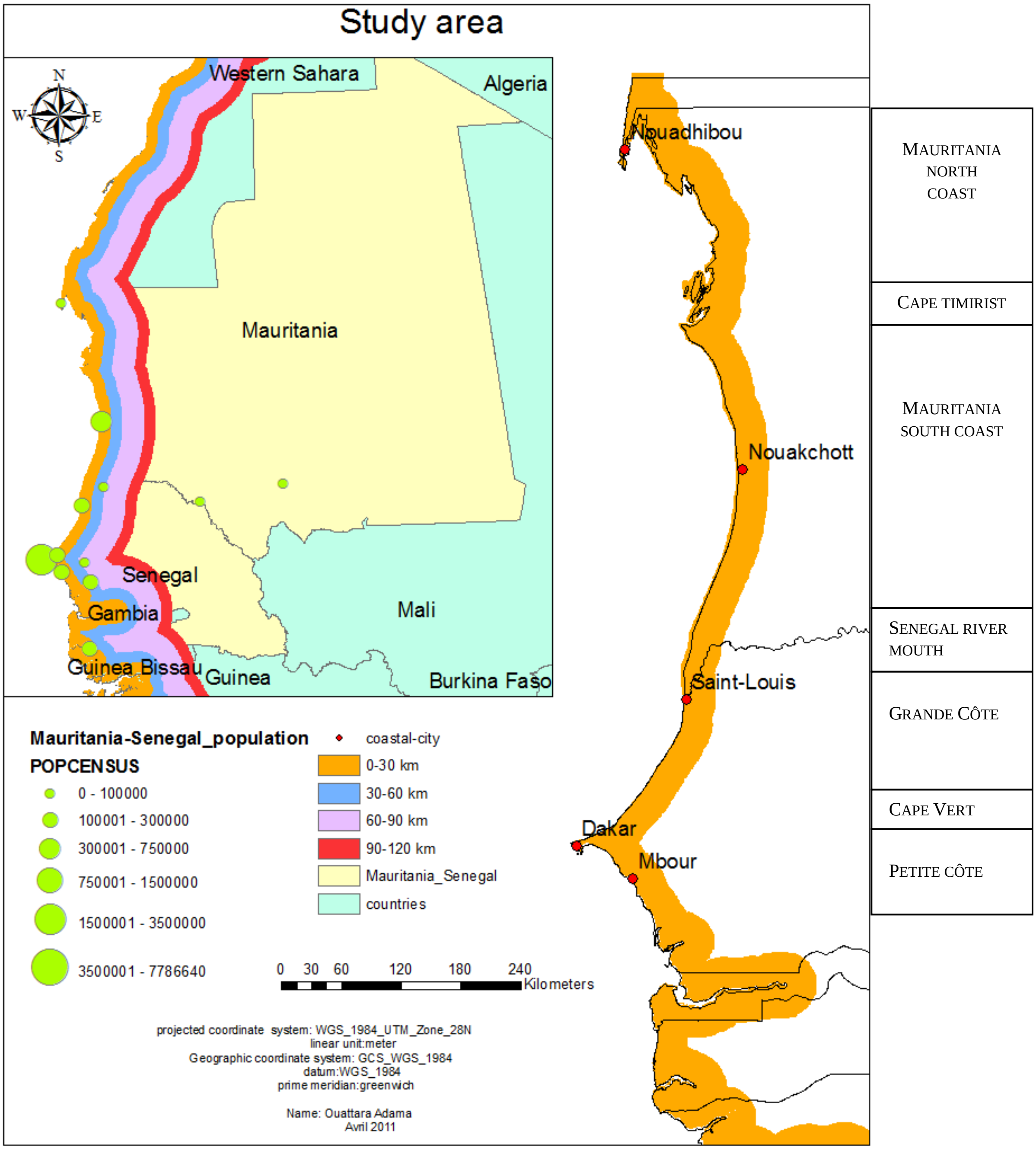


Figure 2. Location of Study area

2.1. Physical aspect

The coastal area of Mauritania and Senegal is occupied by the countries major cities and its economic activities. Nouadhibou cities and Nouakchott in Mauritania and those of Saint Louis, Mbour, and Dakar in Senegal extend over the coastal zone of the two countries bounded by Atlantic Ocean in the East and the West by the continent land. These built up area are built on a fragile environment.

2.1.1. Location

Mauritania is located between the 15^{th}- 27^{th} degrees North latitudes and the 5^{th} - 17^{th} degrees west longitudes with an area of 1030 700 km^2. The country is bounded on the west by the Atlantic Ocean, east and southeast by Mali, on the north by Algeria, northwest by Western Sahara and south by Senegal. The Senegal River that originates from Fouta Djallon in Guinea forms a natural boundary with Senegal.

Senegal covers an area of 196 722 km^2. Senegalese territory is between 12◦ 8 and 16◦ 41 of north latitude and from 11◦ 21 to 17◦ 32 of west longitude. Dakar is the westernmost city in all Africa. Senegal is also bounded by the Atlantic Ocean to the west, Mauritania in the north, Mali in the east and Guinea and Guinea Bissau in the south and almost contains Gambia's area. The coastal area in both countries lies along the western border with the Atlantic Ocean.

2.1.2. Coastal area description

There is no one definition of the coastal area. US Coastal Zone Management Act (1972) defines the coastal zone as a group of the coastal waters and the adjacent shore lands strongly influenced by each land in proximity to the shoreline coastal states. The World Bank (1996) defines the coastal zone as the interface where the land meets the ocean, encompassing shoreline environments as well as adjacent water. According to the South Africa's Integrated Coastal Management Act (2008) the coastal zone includes coastal waters and the Exclusive Economic Zone (EEZ). For the purpose of this project, the coastal area is by definition the territory located at the edge of the sea and at low altitude and that directly contributes to the marine economy (port activities, fisheries, tourism).
The coastline of the two countries is estimated to be 723 km for Mauritania and 700 km for Senegal respectively. Geomorphologically, the coastal area of Mauritania has two large natural entities separated by Cape Timirist.

The northern stretch of coastline is characterized by a succession of bays, rocky headlands, islands and islets, some in the form of rocky precipices (Cap Peninsula, Cap Blanc, Cap Tafarit, Cap Tagarit) reaching heights of up to 20 m. This morphology extends well into the land, emerging as sandstone hills (5 to 10 m height) in the regions of Nouadhibou.

Compared to the north, the south stretch of coastline is altitudinally lower. From Cape Timirist to Senegal River mouth, the coastline stretches for about 350 km (Marico, 2006). It is sandy, straight and consists of active dunes more or less stabilized by vegetation. It is limited in its south part near Senegal by the tongue of Barbary that deviate toward the South and South West direction of the Senegal River over a distance of about 20 km at its mouth. The width of the barrier beach at this point varies from tens to several kilometres with some altitudes exceeding 10 m (Marico, 2006). The succession of dunes in the coastline isolates the marshlands and hypersaline lagoons whose heights is less than that of sea.

The Senegalese coast stretches from Saint Louis to Cap Roxo. Most of it is sandy. It is divided into three entities: Cape Vert peninsula, Grande Côte and Petite Côte.

The Peninsula of Cape Vert separates the Grande Côte in the north region and the Petite Côte in the south. It represents the most occidental area of the Africa continent. Dakar is located within this region. Although its coast is essentially rocky; beaches and cliffs exist between Cape Fann and Cape Manuel.

The Grande Côte in the north of Dakar is covered by sand. Behind it, lies the Niayes region (zone consisting of dunes and depression suitable for vegetables crops) on a narrow strip of 180 km and a width varying between 25 and 30 km. The region extends from Senegal River mouth to the peninsula of Cape Vert. It covers Senegal River delta and the tongue of Barbary, which separates the Senegal River from the ocean. Compared to the southern stretch, this part of Senegalese coast is less urbanized. St Louis is the most important city.

The Petite Côte in the south is an important geographical and economic region, being the largest for traditional fishing activities in M’bour and Joal. The region extends from the peninsula of Cape Vert to Sine Saloum. The coastline is sandy and characterized by the successive processes of erosion and accumulation.

The coastline is bounded by the continental shelf whose width doesn’t exceed 100 km.

2.1.3. Climate

The Saharan climate in the north of Mauritania and the Sahel climate in the south of Mauritania and Senegal area characterize our study area. The aridity typifies the general climatic conditions of the region. Essentially the annual climate of the region can be distinctively divided into two seasons. The rainy season which falls within July and October is ushered in by the northeast winter winds and southwest summer winds while the hot dry “harmattan” wind dominate the dry season between November and June. Total annual precipitation diminishes from the south of Senegal to the North of Mauritania. In the south of Senegal, rainfalls reach 1500 mm. In Dakar region annual rainfall is about 600 mm whereas in the farther north of Mauritania it barely exceeds 335 mm, almost half the value for the Dakar region. The Atlantic Ocean by producing cold air influences the coastal area climate. Interior temperatures are generally higher than that of the coast.

2.1.4. Vegetation

Owing to its aridity rainfall is the main climatic driver of Mauritania's vegetation. Vegetation exists in some special places like the massif escarpments and some oasis in the Sahara part. The coastal area composed by salt land is cover by many sebkhas (mangrove vegetation).Senegal vegetation can be divided into five broad categories. In the north along Senegal River and some part of coastline where swamps exist, mangrove is the dominant vegetation. Under the Senegal River's wetland in the north, the savannah Acacia covers the region. The middle part of the country is the area of tall grass savannah and the shrub. Deciduous forest and the evergreen broadleaf forest characterize the south.

2.2. Socio economic characteristic of the coastal area

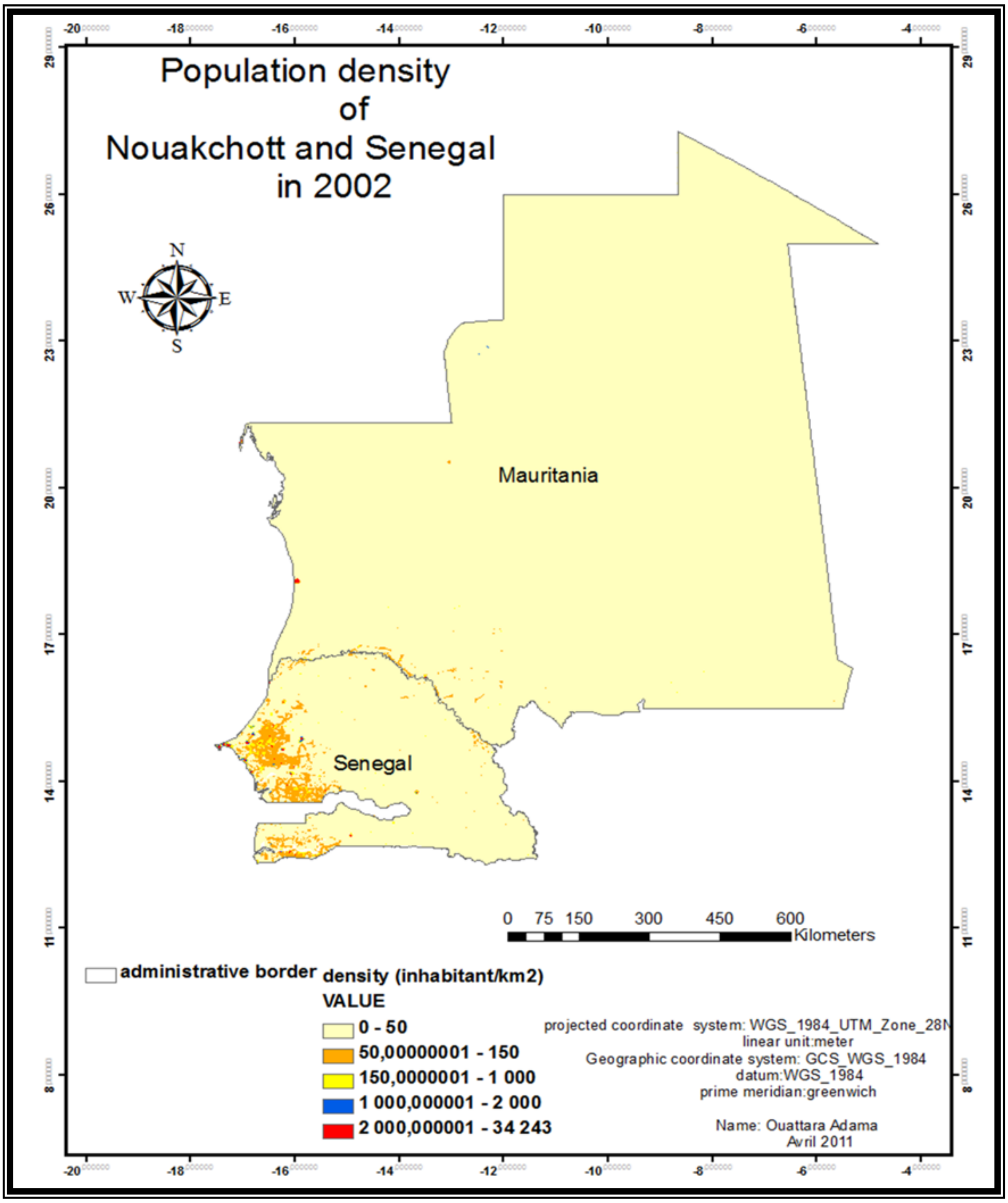
2.2.1. Demography

Mauritania is located between black Africa and the Maghreb giving the country a rich cultural and historical heritage. Islam is the most important religion and the foundation and the cement of the unity in Mauritania and Senegal. In both countries the African and the Arabic make up the population. Africans are the predominant group in Senegal while the Arabic make up the majority of the population in Mauritania.

In 2008 Mauritania population was estimated at around 3 200 600 inhabitants, 41% of which were urban population (Africa Statistical Yearbooks, 2009). Its population density is one of the lowest in the world (2 people per square kilometre). The country has experienced and is experiencing a relatively progressive rate of urbanization. As a consequence nearly half of the country population lives in the coastal cities of Nouakchott and Nouadhibou.

Senegal had a population of approximately 12,179 400 inhabitants in 2010 with an average density of 60 inhabitants per square kilometre, unevenly distributed over the entire country (GPHC, 2002). Its coastal zone is the most populated, developed and urbanized. In 1994, the World Bank estimated that 54% of the country's population lived within a 60 km buffer from the coastline (World Bank, 1996). Dakar, costal city have the greatest density, averaging 4500 inhabitants per km ^{2} **(**Mbow et al).

In both countries Population, a large proportion of the population are young. In Mauritania 46% of the population are below 15 years old, while in Senegal approximately 54.9% are below 20 years of age (GPHC, 2002). It could thus be concluded that both countries have a youthful population, majority of which are in the child-bearing age category. The social changes inherent in these countries partly are a function of the environment. Prevailing droughts conditions contribute to the modification of traditional productions system and speed up urbanization. The population will continue to increase in the coastal cities in the future and in various ways impact the coastal zone.



2.2.2. Economy activity

Mauritania's economy is heavily dominated by mining and fishing, which alone provides the bulk of export earnings of the country. These activities are developing along the coast and attract rural populations. Mauritania coastal waters are among the richest fishing area in the world. A well-developed traditional economy involving agriculture and livestock rearing is concentrated along the Senegal River basin area. Most of the country's population still operate on this traditional economy.

Senegal is a very poor country in terms of natural resources. The bulk of its economy is based on fishing and tourism. More than half of the population are employed in the Agriculture sector. Agriculture depends on rainfall variation and the price of agricultural products on international market. The Industrial sector which includes food processing, cement and textiles is not so developed in Senegal. Most of the companies are run by French businessman. Like Mauritania, the coastal area of Senegal plays a vital role in the development of country's economy by supporting infrastructural development

2.3. Data

Data for this study has been collected from different sources. Some of was supplied by the supervisor and some have been downloaded from FAO GeoNetwork, from USGS website (satellite image), and from kursdata.

2.3.1. Received data

Table 1 below presents the data supplied by the supervisor. The vector data were produced in 2007 and 2008 and are derived from satellite images (Landsat, SPOT and KOMPSAT) and aerial photography. Field assessment was also conducted to validate vector data extracted from satellite imagery. The Landsat images were provided by NASA, the SPOT image by IRD and KOMPSAT image by ADS. They were developed for the conservation program of coastal environments supervised by NASA and IUCN (International Union of Conservation of Nature).As part of the program a comparative study between the urbanization process in India, the Baltic States and West Africa countries. The supervisor Sebastién GADAL (personal communication) was responsible of the Urbanization project within the program.

Table.1. Data received

Countries	Folder	data	format	Geographic coordinate system	Projected coordinate system
Senegal	GIS Dakar - 1988	-industrial zone -road -urban	Map info format (DAT; TAB extension)	GCS-WGS 1984	WGS-1984-UTM-ZONE 28N
Senegal	GIS Dakar - 2002	-industrial zone -road -urban -stadium -park -harbor -airport	MAP info format (DAT; TAB extension	GCS-WGS 1984	WGS-1984-UTM-ZONE 28N
Mauritania	GIS Nouakchott-1988	-road -airport -harbor -residential housing -dense housing -diffuse housing -park -green space -agriculture field -shantytown	MAP info format (DAT; TAB extension)	GCS-WGS 1984	WGS-1984-UTM-ZONE 28N
Mauritania	GIS Nouakchott-2001	-road -harbor -airport -ocean -residential housing -dense housing -diffuse housing -park -green space -agriculture field -shantytown	MAP info format (DAT; TAB extension	GCS-WGS 1984	WGS-1984-UTM-ZONE 28N
		-Spot image of 2001	Tiff- image	GCS-WGS 1984	WGS-1984-UTM-ZONE 28N
Senegal and Mauritania	Urban shape file	-urban 1954 -urban 1978 -urban 1988 -urban 1989 -urban 1996 -urban 1997 -urban 1999 -urban 2001 -urban 2002 -urban 2004 -urban 2006 -urban 2007	Shape file	GCS-WGS 1984	WGS-1984-UTM-ZONE 28N

2.3.2. Data from FAO GeoNetwork

FAO GeoNetwork portal is an open source website. Interactive maps, GIS datasets, satellite image in different formats are available through descriptive metadata from a variety of data providers. The purpose of FAO GeoNetwork portal is to facilitate and to promote the sharing and the access of spatial data and geographic information between the organisations and the users of spatial data.

Table.2. Data from FAO GeoNetwork portal

data	format	date	Geographic coordinate system	Projective coordinate system
World coastal buffer	raster grid	2003	GCS-WGS 1984	No defined
City location and population in Africa	raster and shapefile format	2008	GCS-WGS 1984	No defined
Africa national boundaries	raster and shapefile format	2000	GCS-WGS 1984	No defined
World population density persons/sqr km	raster grid	2007	GCS-WGS 1984	No defined
LU/LC map(Senegal)	shapefile format	2009	GCS-WGS 1984	No defined

2.3.3. Population data

The ANSD of Senegal website, the Africa Statistical Yearbooks of 2009, the ONS of Senegal, the city population website are the different sources from where population data have been extracted.

2.3.4. Data from USGS server

United State Geological Server is a Center for Earth Resources Observation and Science. It provides impartial information on the health of our ecosystems and environment, information about land cover and land use change and the impacts of climate change. Further provides data (satellite imagery, aerial photographs, and maps) in different formats to improve knowledge and education about the world. The table below presents the data satellite images downloaded from the server.

Table .3.Data from USGS server

	Area	Path/row	Acquisition date	Spatial resolution	bands
Landsat TM5	Mbour	205/50	17 October 1984	30*30 m	1, 3, 3, 4, 5, 7
Landsat TM5	Mbour	205/50	22 October 2009	30*30 m	1, 3, 3, 4, 5, 7,
Landsat TM5	Nouadhibou	206/46	12 January 1985	30*30 m	1, 3, 3, 4, 5, 7,
Landsat TM5	Nouadhibou	206/46	15 December 2000	30*30 m	1, 3, 3, 4, 5, 7,
Landsat TM5	Saint Louis	205/49	22 October 2009	30*30 m	1, 3, 3, 4, 5, 7,

Landsat TM5 is the fifth satellite of the Landsat program that was launched on March 1, 1984. It's composed by seven spectral bands included a thermal band (band 6):
Band 1 Visible (0.45 – 0.52 µm)
Band 2 Visible (0.52 – 0.60 µm)
Band 3 Visible (0.63 – 0.69 µm)
Band 4 Near-Infrared (0.76 – 0.90 µm)
Band 5 Near-Infrared (1.55 – 1.75 µm)
Band 6 Thermal (10.40 – 12.50 µm) 120 m
Band 7 Mid-Infrared (2.08 – 2.35 µm)

2.3.5. Data from kursdata: NGEN08 Course Materials, Lund University
Kursdata is an access data folder of the Physical Geography and Ecosystem Analysis department of Lund University. NOOA satellites time series NDVI data at 8*8 km was acquired from GIMMS for the Sahel region have been obtain from there. NDVI data for the Mbour area was extracted for the period 1984-2002. Rainfall data was extracted from Global Historical Climatology Network for the closest meteorological stations

2.3.6. ASTER GDEM data

The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) were developed jointly by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA).From there Nouakchott elevation data has been extracted. ASTER instrument was built by METI and launched onboard NASA's Terra spacecraft in December 1999. The elevation postings in the ASTER GDEM are at 1 arc second, or approximately 30 m. The ASTER GDEM Characteristics**:**

Tile Size 3601 x 3601 (1°-by-1°),
Posting interval 1 arc-second,
Geographic coordinates, Geographic latitude and longitude,
DEM output format GeoTIFF, signed 16 bits, and 1m/DN,
Referenced to the WGS84/EGM96 geoid,

Special DN values -9999 for void pixels, and 0 for sea water body, Coverage North 83°to south 83°;22,600 tiles for Version 1.

CHAPTER 3: THEORETICAL BACKGROUND

3.1. Urban expansion

Urbanization is generally associated with a gradual reallocation of labour from agriculture to industry, as experienced during the 19 th century (Bairoch, 1985). Beauchemin et al (2004) define urban expansion as a process of accumulation of people, buildings and capital in one place while Bassam et al (2007) describe it as a set of elements that comprise built up area (buildings, roads, industries, business areas, parks) and natural elements such us water, land cover (vegetation) and soil that has a direct interaction with the activity of the urban population. The urban expansion process induces socio economic transformation in the areas surrounding the city. It results in the concentration of population in an area and affects natural vegetation cover in most countries throughout the world (Nicolson, 1987). Kalnay and Cai (2003) asserted that the land cover transformation through urbanization can alter the local climate both in urban and surrounding areas. With Mauritania and Senegal the urban expansion is the result of the rural-urban migration and the natural growth of population than the industry development. The rapid rate of urban growth induces a modification of urban and sub-urban environments (Binns et al. 2003).

3.2. Ground water flood risk assessment due to Nouakchott urban expansion

Cobby et al, (2009) define as flooding caused by the emergence of water originating from subsurface permeable strata. Flooding in the city of Nouakchott is a real environmental problem. Flooding leads to outbreaks and increases the incidence of diseases such as malaria and cholera (Cissé, 2006). Several factors can be responsible of occasional, total or partial risk of flooding in Nouakchott city (Ould Sidi Cheikh et al, 2007). According to Who (2005), flooding in Nouakchott city occurs simultaneously with heavy rainfall events during the rainy season. Factors including topography, complex geology and the degree of artificial influence in the subsurface controlled (Cobby, D. et al.2009) Nouakchott groundwater.The risk of flooding is particularly high in those parts of the city currently being used for building construction (Ould Sidi Cheikh et al, 2007). Ould Sidi Cheikh et al, (2007) note that several neighborhoods in the city of Nouakchott are built on sites unsuitable for human habitation. Building construction is carried out in low pressure areas where the water table intersects the ground during the raining season. The lack of corridors for rainwater evacuation leads to a stagnation of water during the rainy season (Semega, 2006).

3.3. Land cover, Land use change

The topic of land transformation is divided in two broad categories, those involving land use change and those involving land cover change (Turner et Meyer, 1991). Land use is the human employment of the land (cultivation, pasture, settlement, recreation…) while land cover concerns the physical state of the land (Meyer and al, 1994). Contemporary human activity is the driving force behind land cover change for societal or individual needs such us agriculture (Turner et al, 1990; Ojimma et al, 1994; Walker et al, 1999; Cassman et al, 2005).

The knowledge of land cover and land use is essential for planning and monitoring of natural resources (Zhu, 1997). Satellite remote sensing hence provides a powerful tool for acquiring and developing information about land cover at local, regional or global scales (Csaplovics, 1998; Foody, 2002). It is particularly well-suited for land cover change studies in urban areas.

3.4. Normalized Difference Vegetation Index (NDVI)

NDVI is that part of VI that uses the red and the infra-red regions of the electromagnetic spectrum to measure biomass and vegetation health (Campbell, 1996). NDVI is the most used of vegetation indices to assess seasonal vegetation changes, and it serves as an indicator of environment quality (Hollen, 1986). NDVI is expressed by the formula below (Hollen, 1986):

$$\mathbf{NDVI} = \frac{\textbf{Near infrared - visible red}}{\textbf{Visible red + near infrared}}$$

The higher the NDVI value in an area is an indication of the high probability that the area develop green healthy vegetation (Gibsonet al, 2000). Its use in the early Landsat MSS reveals its efficiency in vegetation greenness study (Tucker 1979). The technique has been employed for other remotely sensed data (Fung T et al, 1999). Landsat thematic Mapper bands 3 and 4, NOAA AVHR channels 1 and 2 and SPOT bands 2 and 3 are the most used in vegetation indices study like NDVI (Gibson Paul et al, 2000).It has been proven to effectively map temporal variation in vegetation patterns (Eidenshink, 1992) at large scales (Townshend et al. 1991, 1994) using the NOAA AVHRR (Gutman, 1991). Lyon et al (1997) using Landsat MSS images proved that NDVI was a better measure for vegetation pattern change detection compared to other vegetation indices. Lo and Faber (1997) demonstrated the inherent qualities of NDVI for urban area land use study and also its correlation to socio-economic data.

3.5. Change detection

Change study provides the avenue for improving our understanding about natural or human processes on landscape (Jensen John R, 2000). Knowledge about the temporal change allows us to model what happened in the past and what can happen in the future (Lunetta et Elvidge, 1998). Satellite datas provide records of environmental change that reflect the natural cycles but are often caused by human activity (Gibson Paul et al, 2000).Land cover change detection in urban area is linked to forest conversion and agricultural land transformation to make space for commercial and residential building (DiGirolamo, 2006). Change detection necessitates the use of multi temporal image to detect the change between dates of imagery (Lillesand et al, 2004). Lillesand et al (2004) describes several ways for change detection analysis; such as, post classification comparison, classification of multi temporal data sets, principal components analysis, temporal image differencing, and temporal image rationing.

Two kinds of mathematical operation (addition and subtraction) are used to produce a change detection image. The rationing change detection requires high accuracies to ensure that the pixels match (Gibson et al, 2000). Change detection study requires anniversary images (same calendar date) because the detection is based on the spectral reflectance of image, the illumination angle and the Sun-Earth distance which vary throughout the year. The use of anniversary images minimizes sun angle and seasonal difference (Lillesand et al, 2004).

3.6. Supervised classification

Image supervised classification involves the selection of spectral classes that represent patterns of land cover feature and can be recognize by the analyst (Lathrop, 2009).The supervised classification process proceeds in 4 steps: select training fields, editing/evaluating signatures, classifying image, and evaluating the classification. The classification stage represents the heart of the supervised classification process and it involves evaluating the spectral pattern of the image in the computer after identification of each pixel by using predefined decision rules (Lillesand et al, 2004). During this process, image pixels or spectral patterns are classified into categories.

3.7. Accuracy assessment

The accuracy assessment is elaborated to test the quality of the map produced**.** The map produced has to be compared with a reference data that can be spatial resolution imagery (with visual interpretation) or ground truth: GPS fields or an existing GIS map (Lathrop, 2009). It allows the error matrix production where the following accuracy can be determinate:

The overall accuracy or total accuracy is calculated by dividing the total number of correctly classified pixels by the total number of reference pixels.
The producer accuracy is calculated by dividing the number of correctly classified pixels in each class divided by the number of pixels in that class in the ground truth data.
The user accuracy is calculated from number of correct sample points in a class divided by number of that class in the map. It reveals the probability of an unknown point on the map of being correctly mapped.
The kappa value for random agreement is 0. The highest value is 1 and the lowest is -1. A value of 1 indicated that the map and the validation data have exactly the same attributes and a value of -1 means the map is poor than what is expecting by chance.

3.8. Linear regression

Linear regression is a statistical measure for determining the types of relationship that exist between two sets of data (x and y). The existence of relationship between the two variables gives a straight line. This relationship is known as having a linear correlation and follows the equation of straight line $y = mx + b$. Like all forms of regression, linear regression focuses on the conditional probability of y given x, It means the x value is function of y value.

The determination of the correlation coefficient r, gives a measure of the relationship between two variables. If $r^2 = 1$, it means there is an exact linear relationship between the variables. The linear relationship is excellent when the r^2 value is closed to 1. If the r^2 value is far away from 1 the predictions based on the linear relationship, $y = mx + b$, is less reliable.

CHAPTER 4: METHODOLY

The methods described here are those employed for processing the data for the final outputs. It concerns the satellite image and the auxiliary data transformation that is needed and performed in order to have the maps, the satellite images and aerial photographs in compatible format and in the same geographic coordinate and projection system. The figure 4 below is a flow chart describing the different steps adopted in this thesis. Ancillary vector data contained Nouakchott GIS, Dakar GIS, and city location and population data.

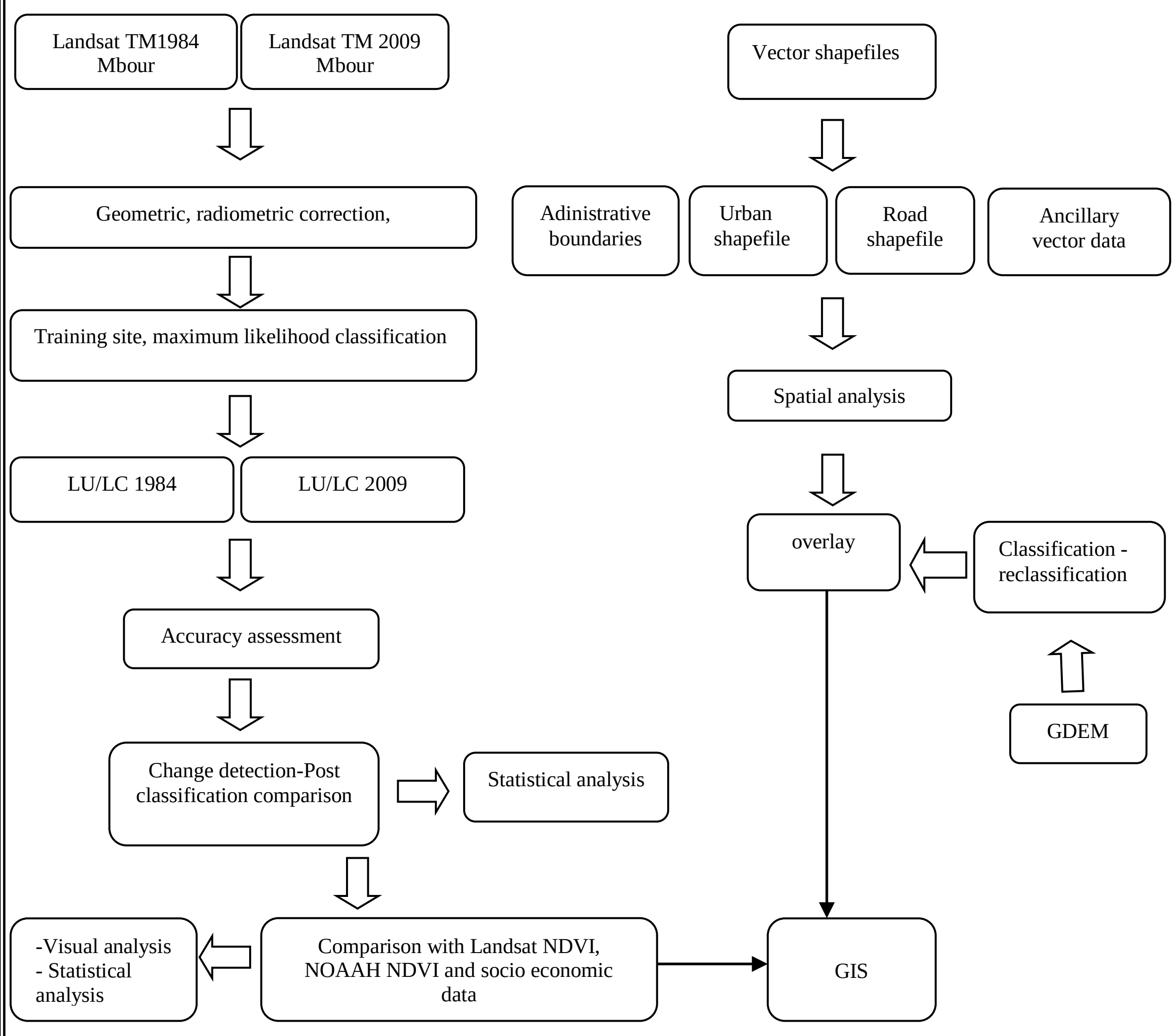


Figure .4. Methodology overview

4.1.1. Data and pre-processing:

A vectorisation was done specifically for Nouadhibou region and Saint Louis to complete the vector data received. Landsat TM images of 1985 and 2000 were used for Nouadhibou and 2009 image for Saint Louis. An image composite was made and the spatial component of urban extension was delaminated through the tracking of built up area.
The vector data received (GIS Dakar and GIS Nouakchott) were converted from Map Info format to ArcGis format. All the geographical data were transformed in the same geographic coordinates system GCS-WGS 1984 and projection system WGS-1984-UTM-ZONE 28N.

4.1.2. Creation of urban extension map

The expansion map of the 5 coastal cities (Nouadhibou, Nouakchott, Saint Louis, Dakar and Mbour) was produced based on the vector data received, the downloaded vector data and the vectorisation data done specifically for Nouadhibou (1985 and 2000) and Saint Louis (2009).
Arc map tools were used to estimate cities area and linear regression was used to evaluate the relationship between urban area expansion and population growth.

4.2. Flooding area estimation

One main data source was used for the based cartography, GDEM which is elevation data. GDEM tiles data were converted to new raster and then mosaic. Nouakchott area was clipped and the urbanised area in 2008 was delimitated by digitalisation and then extracted. The slope map, the elevation map, and the map of its urban area expansion in low lying area were produced for analysis. The area below 3 meters was considered like unsuitable for the built up construction because of its action on ground water flow during the raining season. The estimation of built up constructed in low lying area was done by overlaying the elevation data and the urban vector data of 1998, 2000 and 2008.The urbanized area in low lying area was represented in 3D by using ENVI 4.7. Population living in low lying area which is considering unsuitable and responsible of ground water flood was estimated by using population density of 2008.

4.3. Landsat Image pre-processing for LU/LC study

To make possible the comparison of satellite image of Mbour area, image pre-processing is done (geometric, radiometric correction) by using remote sensing techniques.

4.3.1. Geometric correction

Geometric correction is necessary for relating terrain surface information to ground coordinates by removing distortions from sensor geometry. Most of the distortion is due to earth rotation (Gibson et al, 2000). Two kinds of distortions exist; the predictable one is applicable in all images while the non-systematic distortions apply to individual images by mathematical process (Gibson et al, 2000).

USGS provides Landsat images that have already been orthorectified and corrected to the right coordinate system. The Landsat data that covers the study area has the coordinate system of WGS-1984-UTM-ZONE 28N that correspond to the right coordinate system.

4.3.2. Radiometric correction

Detecting and characterizing landscape change by using multi temporal satellite imagery requires atmospheric correction of image to be used. The radiometric correction is performed in two steps, the absolute calibration at the receiving stations and relative calibration (Pilesjö, 1992).

The radiance and the reflectance information derived from Landsat bands make comparison between images possible. The image DN value was converted to radiance and then to spectral reflectance through equation 1 and 2 by using “image calculator” in Idrisi.

DN to radiance (equation 1)

$$\boxed{L(i) = (DN / DNmax) \times (Lmax - Lmin) + Lmin}$$

Where

$L_{(i)}$ = radiance (mW/cm2/sr/µm)
DN = the specific digital number from the scene in a given band
DN_{max}= maximum digital number for a given sensor
L_{min}= the sensors minimum brightness
L_{max}= the sensors maximum brightnes
Lmin, Lmax are from Table 4

Table.4. Landsat TM and ETM spectral reflectance specifications

Band	Band width (µm)	Lmin	Lmax	DNmax	Esun
TM 1	0.45 - 0.52	-0.15	15.21	255	195.8
TM 2	0.52 - 0.60	-0.28	29.68	255	182.8
TM 3	0.63 - 0.69	-0.12	20.43	255	155.7
TM 4	0.76 - 0.90	0.15	20.62	255	104.7
TM 5	1.55 - 1.75	-0.037	2.719	255	21.93
TM 6	10.4-12.5	0.1238	1.560	255	n/a
TM 7	2.08 - 2.35	-0.015	1.438	255	7.452

Source: (Markham and Barker, 1986)

- Radiance to spectral reflectance (equation 2). Reflectance provides a measure that makes the images comparable (Gibson Paul et al 2000).

$$\boxed{\mathbf{p p\lambda = \frac{p^{*}\ Li^{*}d2}{Esun\ ^{*}\cos(\Theta)}}}$$

Wehre

ρpλ = Unitless effective at-satellite reflectance
Li = Spectral radiance (mW/(cm2 srµm)) from Equation 4.2
d = Earth-sun distance in astronomical units
p = pi
Esun = Mean solar exoatmospheric spectral irradiance in mW/(cm2 µm) (see Table 4.1)
Θ= Solar zenith angle
Esun values are from Table 4

4.4. Image classification

Supervised classification and maximum likelihood classifier have been used to detect the different land cover types. False colour composite image was generated by merging Landsat band 2, band 3 and band 4. Training site of the study area based on the false colour composite image was developed for the detection of the different land cover classes. Twelve training sites were defined (no data, rainfed cropland, mosaic vegetation, mosaic cropland vegetation, open broadleaf deciduous, mosaic forest shrub land, open shrub land, open grassland, sparse vegetation, urban area, bare land and water bodies). Maximum likelihood classification was applied for the classification step by using equal prior probabilities for each class signature.

4.5. Accuracy assessment

Accuracy assessment was used to evaluate and estimate the precision of the map. It follows the classification in order to evaluate the quality of the classification. This process will tell the analyst the accuracy of the map produced. To determine the accuracy an Error Matrix was generated and used to validate the relationship between reference data and classified map by a category comparison (Lillesand et al, 2004).
Senegal LU/LC map has been used for accuracy assessment. This reference map was downloaded fromFAO GeoNetwork portal. Itderived from the original raster based Globcover regional (Africa) archive and has been published on May 2009.The LU/LC shapefile vector data is cut and convert in raster format according to our study area in Arc map, then exported in Idrisi for accuracy assessment. From the error matrix produced which show the frequency

of pixels in each category the overall accuracy, user accuracy, producer accuracy and the kappa value were estimated.

4.6. Post classification comparison

The Post-Classification Comparison Change Detection involves classifying the rectified images from two time periods separately, and defining the value of each class in the classification. Afterwards, the classified images from the two periods were compared and analyzed to outline the change-detecting matrix by using an algorithm, and finally construct the change map (Lillesand et al, 2004). Anniversary or near-anniversary satellite image is important. It permits to reduce variation in sun angle, phenological state and soil condition (Minnesota, 1999). Two images were used; the first from 17 October 1984 and the second from 22 October 2009. The month of October marks the end of the rainy season in Senegal. At this time of the year, vegetation is still green.The errors of each initial classification are considered in the change detection process (Lillesand et al, 2004).
This method has been used to get statistical values of each land cover classes for the two time periods (1984 and 2009). The comparison of the statistics indicated the change.

4.7. NDVI (Normalized Difference Vegetation Index)

Landsat bands 3 and 4 were used to obtain NDVI map and statistics for the two time periods. The statistics was analysed and changes in pixel value was detected and recorded. Visual analysis was then used to detect changes in NDVI pattern. NDVI statistics, NDVI pattern analysis, NOAAH/AVHRR time series NDVI, rainfall and socio economic data were incorporated in the analysis to explain the change.
The methodology described was used to analyse urban area expansion within the coastal buffer of 30 km from the sea whose economy is directly or indirectly related to the ocean.

4.8. Visual analysis

Visual analysis involves the examination of images and the detection of interesting patterns, followed by its spatial description and relationships that exist (Philipson, 1997). The visual analysis of image is based on the location, the size, the shape, the shadow, the tone/colour, the texture, and the elevation (Jensen, 2000). This method was used to detect pattern in changes in NDVI and also analyse the urban area expansion.

The data and methodology are used to estimate urban area extension over Mauritania and Senegal coastal area, then to analyse environment impacts. The urban expansion environment impacts study will be based on a flood risk in Nouakchott and the change in LC/LU over Petite Côte that covers Mbour area in Senegal.

CHAPTER 5: URBAN AREA AND POPULATION GROWTH EXTENSION OVER NNOUAKCHOTT AND SENEGAL

Using GIS software and different vector layers, urban area was estimated at different dates.

5.1. Nouadhibou

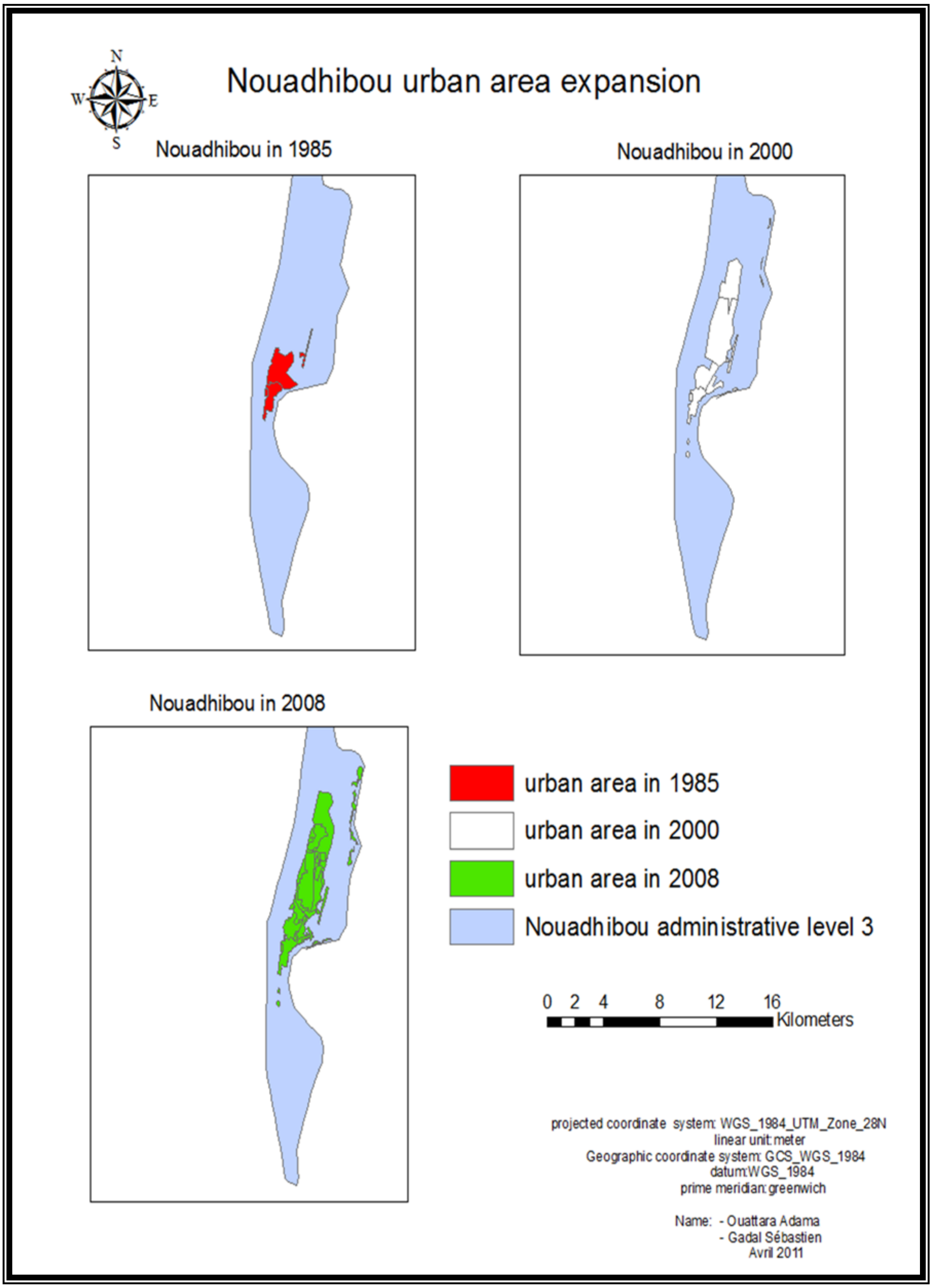


Figure .5. Nouadhibou urbanisation

Table .5. Urban expansion corresponding to the population growth in Nouadhibou

Nouadhibou			
year	1985	2000	2008
Population	63 030	79 516	118 200
Area(km2)	4.90	13.05	16.10

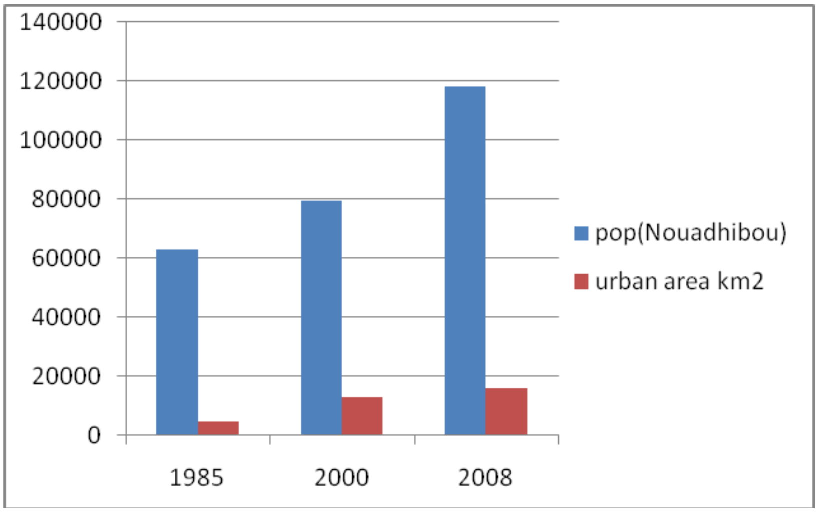


Figure 6. **Figure.6.** Nouadhibou urban area expansion and its population growth

The figure 5 above shows the extent of Nouadhibous urban area growth from 1985 to 2007. Table 5 shows the result of urban area extension with the corresponding population. The trend of these changes is visible in figure6. Table 5 denotes a significant increase in both Nouadhibous urban area and population. The urban area increased from 4, 90km ^{2} to 16, 10 km ^{2} during the time period 1985 to 2008. During the same time period population showed an increase from 63 030 to 118 200 inhabitants.

Two large urban expansions periods were observed during the time frame 1985-2008. The first expansion took place between 1985 and 2000 with an estimated to 8.15 km ^{2} which corresponds to a growth of 166.32% over a 15 years period. The second period of expansion happened between 2000 and 2008 with estimated 3.05 km ^{2} which represents a growth rate of 22.59% over 8 years.

During these 2 periods the population growth is estimated to 26.15% for the first period (1985-2000) and 48.64% for the second period (2000-2008). For the entire period, from 1985 to 2008, the increase in urban area was estimated to be 228.15 % with population growth of 87.52%. Urban expansion in Nouadhibou follows one major axis, .i.e. from the south toward the north direction of the coastal area.

5.2. Nouakchott

Figure 7 shows the degree of urban spatial extension in Nouakchott. The urban area extension and its corresponding population growth are given in table 6 below and figure 8 below.

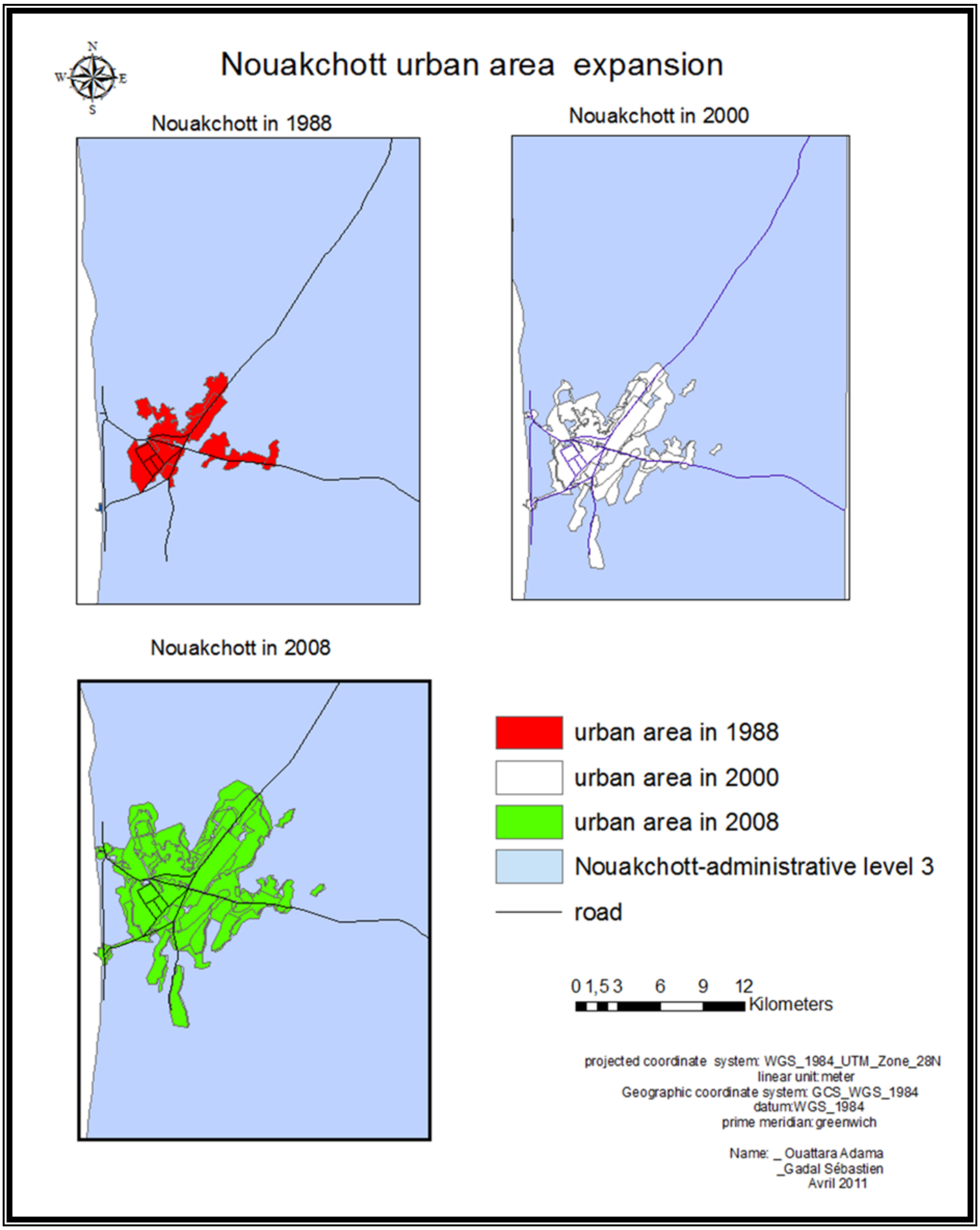


Figure .7. Nouakchott urbanisation

Table .6. Urban expansion corresponding to the population growth in Nouakchott

Nouakchott			
year	1988	2000	2008
Population	393 325	558 195	846 900
Area(km^2)	37.42	83.84	92.97

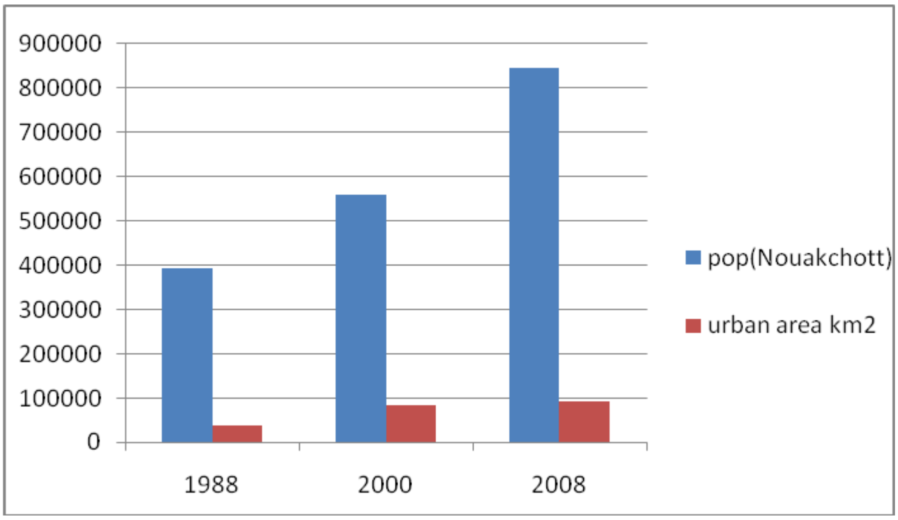


Figure8: Nouakchott urban area expansion and its population growth

Nouakchott urban area had extended by 55.55 km^2 between 1988 and 2008 at an annual extension rate of 2.77 km^2 per year corresponding to a population growth of 22 679 new residents per year.

Two large urban extensions were observed. Between 1988 and 2000 the city had extended by 46.42 km^2, with an annual growth rate of 3.86 km^2 and a rate of expansion of 124.05 %.

Between 2000 and 2008 the city's area had increased from 83.84 km2 to 92.97 km^2 with an annual increment of 1.14 km^2 per year and a growth rate of 10, 88%.The first urban expansion and population growth between 1988 and 2000 have been attributed to the prevalent drought conditions in the surrounding rural areas. The second expansion was primarily the outcome of the natural growth of population.

For the entire period, from 1988 to 2008, the urban area expanded at a rate of 148 % and the population increased by 115.31 %.

Nouakchott's growth was more concentrated in the urban core in 1988 and oriented toward three main directions. The first expansion was towards the coastline. The second axis is toward the north and the third toward the south along the main road.

5.3. Saint Louis “Grande Côte”

Figure 9 below shows the urban area extension in Saint Louis from 1989 to 2009. Table 7 and Figure 10 indicate the urban area increase and its corresponding population.

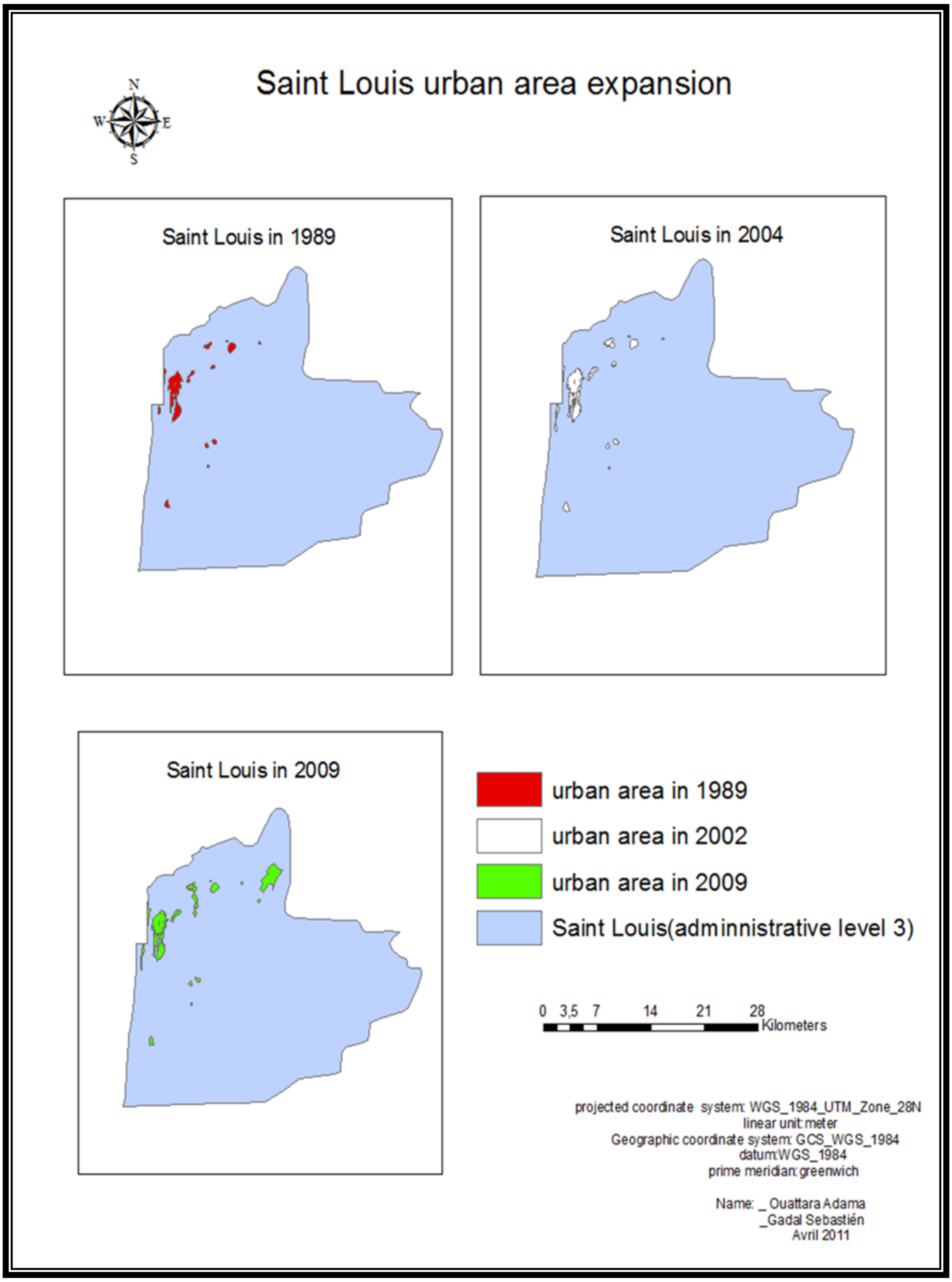


Figure 9. Saint Louis urbanisation

Table .7. Urban expansion corresponding to the population growth in Saint Louis

St Louis			
Year	1989	2002	2009
Population	76 751	153 503	199 400
Area(km^2)	9.20	14.92	19,92

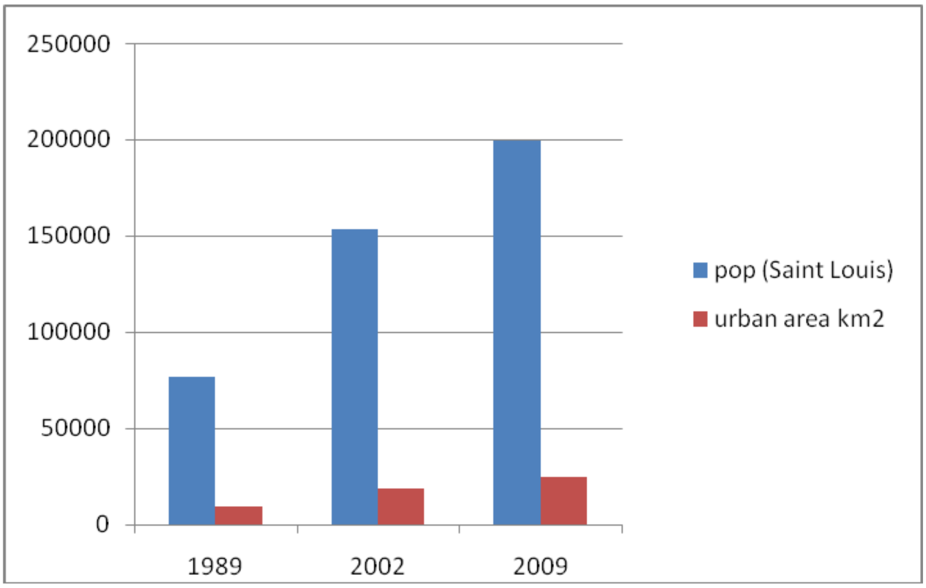


Figure.10. Saint Louis urban area expansion and its population growth

Saint Louis urban expansion is presented between 1989 and 2009. Urban area expansion was 9.20 km^2 in 1989, 14.92km^2 in 2002 and 19, 92km^2 in 2009. The city had expanded at an annual growth rate of 0.51km^2 per year with a corresponding population of 5840 inhabitants for the time period between 1989 and 2009. Two large urban extensions periods were observed. The first expansion was estimated to 9.72 km^2, which corresponds to a growth rate of 105% between 1989 and 2002. The second extension period represents 5km^2 and correspond to an expansion rate of 33, 51% over a7years period from 2002 to 2009.
The city of Saint Louis expanded at a rate of 116, 5% during 1988 and 2009 with a population growth rate of 159.80 % for the same period. In 1989 settlements were scattered in the Eastern part of the city, spilling over to the south and the north. The core of St Louis is the most urbanized zone. The port is located west of the city.

5.4. Dakar

Figure11 below shows Dakar’s urban space extension between 1978 and 2002. Table 8 displays the statistics for the city’s expansion, in terms of area and population, this being represented graphically in figure12 below.

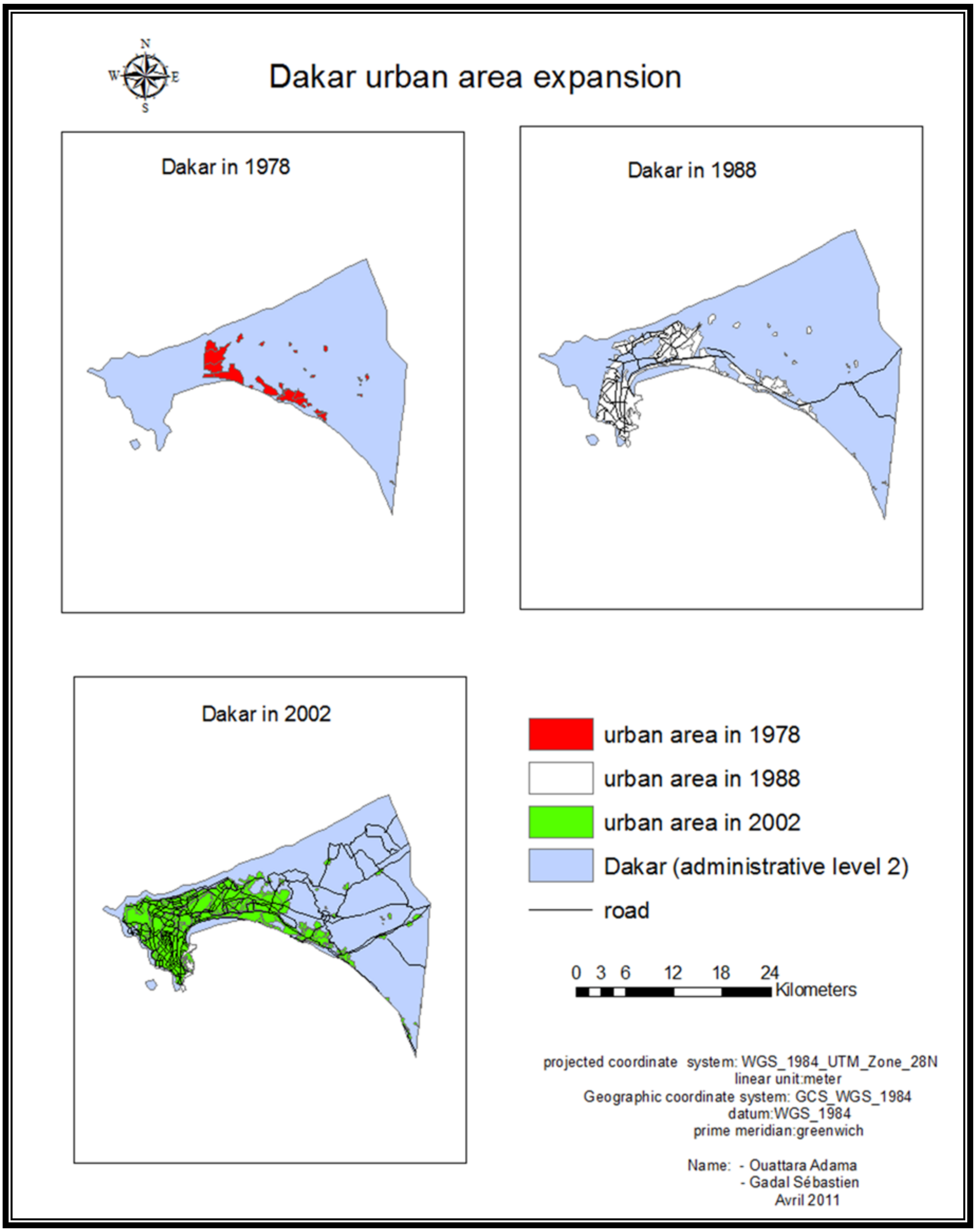


Figure.11. Dakar urbanisation

Table. 8. Urban expansion corresponding to the population growth in Dakar

Dakar			
Year	1978	1988	2002
Population	941 000	1 375070	1 983 093
Area(km2)	30.41	93.40	118.9

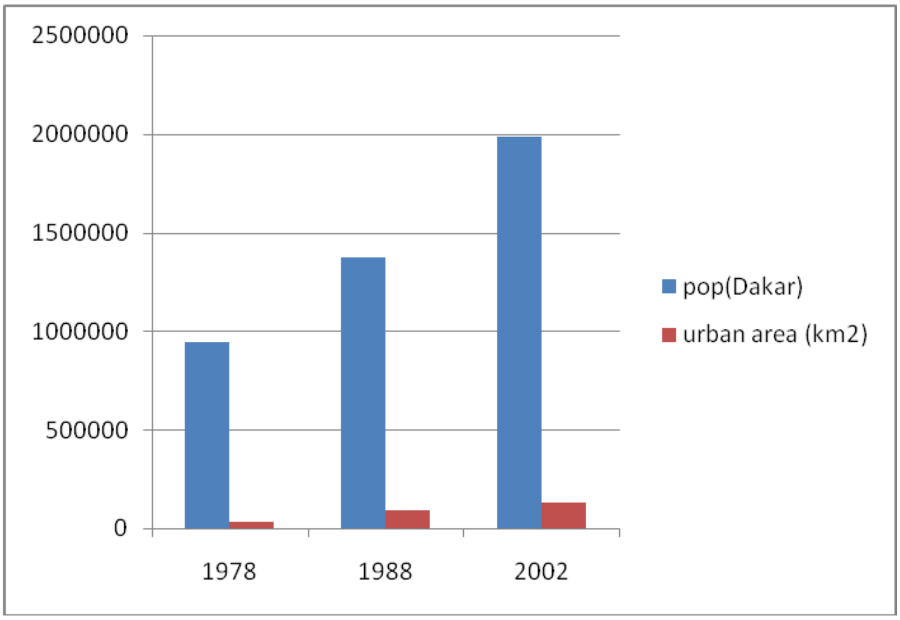


Figure .12.Dakar urban area expansion and its population growth

Spatial extension of Dakar's urban area is divided into 2 periods like the others cities. During a 10 year period, between 1978 and 1988, the urban area expanded by approximately 62.99 km^2, followed by a 14 year period from 1988 to 2002 by approximately 39.09 km^2. The annual growth rate during these two periods was 6.2km2/year, and 2.7km^2/ year. The corresponding annual population growth rate was 46.12% and 44.21%.From 1978 to 2002, the urban area expanded at the rate of 291 %, which meant that the urban area increased three times more than it had 24 years ago. Population increased at the rate of 110.74%. Dakar was composed of a few districts located within the central part. Between 1978 and 2002, the city expanded westward towards the, covering the entire west coast of Dakar (CapeVert). The city spatial extension trend reveals one major axis from east to west toward the coastline. The spatial distribution of settlement shows a concentration in the west coast of Dakar. The trend reveals the concentration of built up areas on Dakar's coastline.

5.5.Mbour “Petite Côte”

Figure13below shows the spatial extension of Mbour urban area over the time period 1978-2002. The urban area statistic and population data changes are represented in the figure14and the table 9.

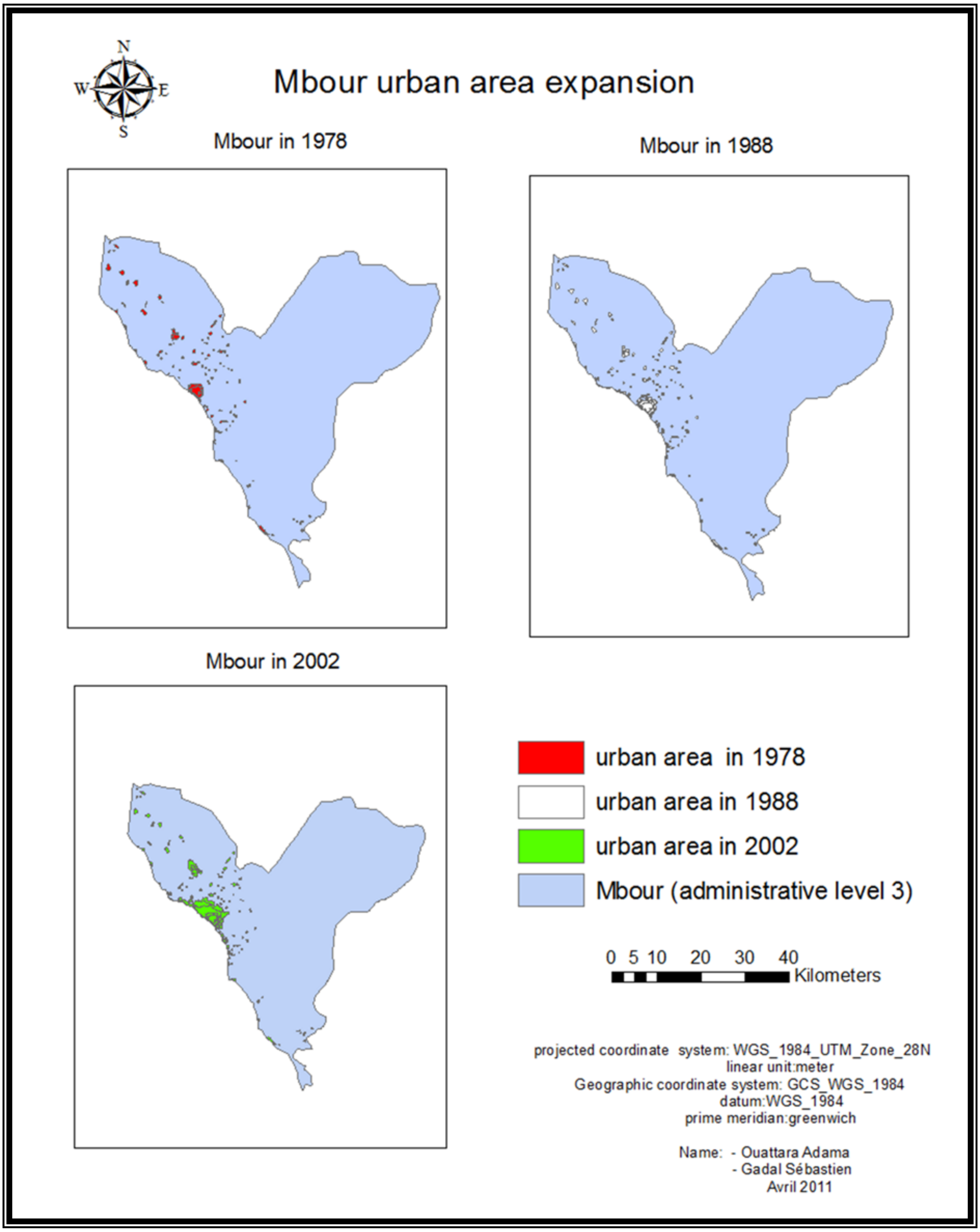


Figure.13. Mbour urbanisation

Table9. Mbourmurban area expansion and its population growth

Mbour			
Year	1978	1988	2002
Population(thousand)	36 900	76 751	153 503
Area(km2)	22.42	34.94	73.91

Table 9.Urban expansion corresponding to the population growth in Mbour

Mbour			
Year	1978	1988	2002
Population	36 900	76 751	153 503
Area(km2)	22,42	34,94	73,91

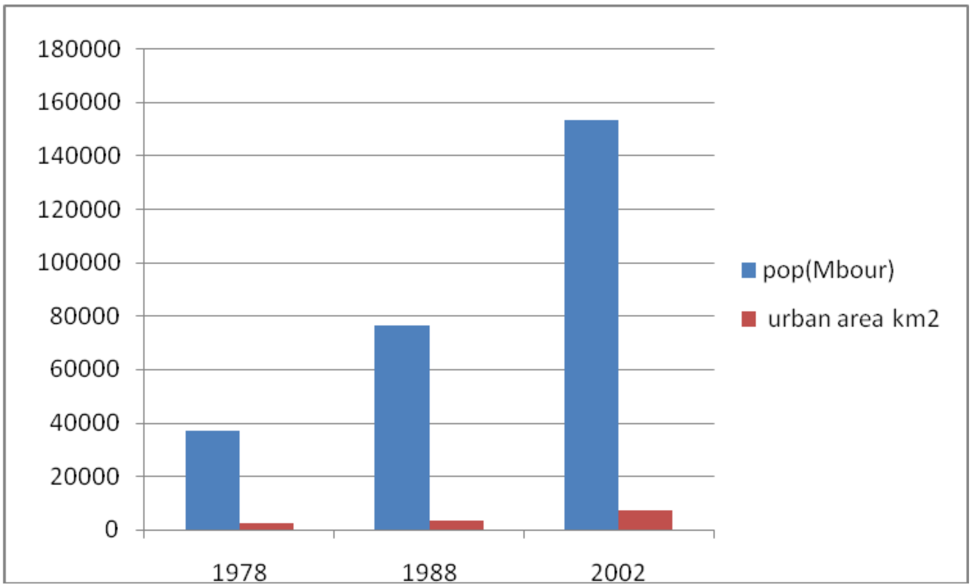


Figure 14.Mbour urban area expansion and its population growth

In 1978, very little constructions took place along the Mbour coastal area. The settlements were primarily set up by the fishing and farming community. Urban expansion was divided between 2 time periods. The first urban expansion is from 1978 to 1988 with an urban expansion rate of 55, 84% and a corresponding population growth rate of 107.99%. Between 1988 and 2002, the built up area increased at the rate of 111.53% against a population growth of 100%. The urban expansion between 1978 and 2002 is estimated at 229% with a corresponding population growth rate of 319%.

The built up is spatially distributed along the coastline and decreases towards the inland. Inland settlements are more spread out than those within the coastal area. From 1988 to 2002, the urbanisation was mostly concentrated over Mbour city and also in the coastal zone. The general analysis of Mbour city extension shows the concentration of settlement in the city area and its development toward the coastal area while the inland settlement remains almost intact.

5.6. Relationship urban area increase and its population growth

A linear regression analysis between urban area expansion and population growth was realised for Nouakchott and Dakar.

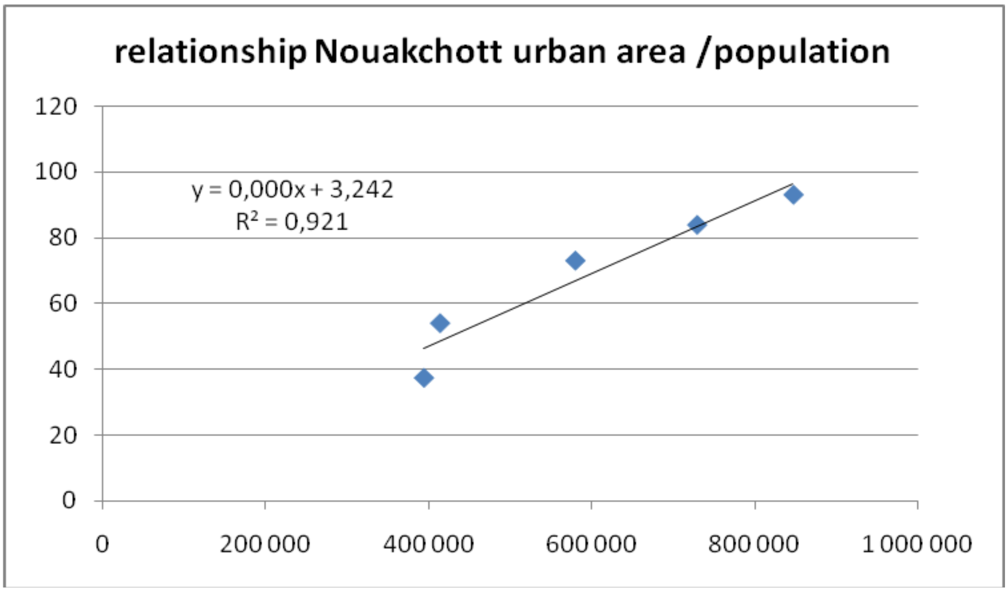


Figure 15. Relationship between Nouakchott urban area increase and its population growth

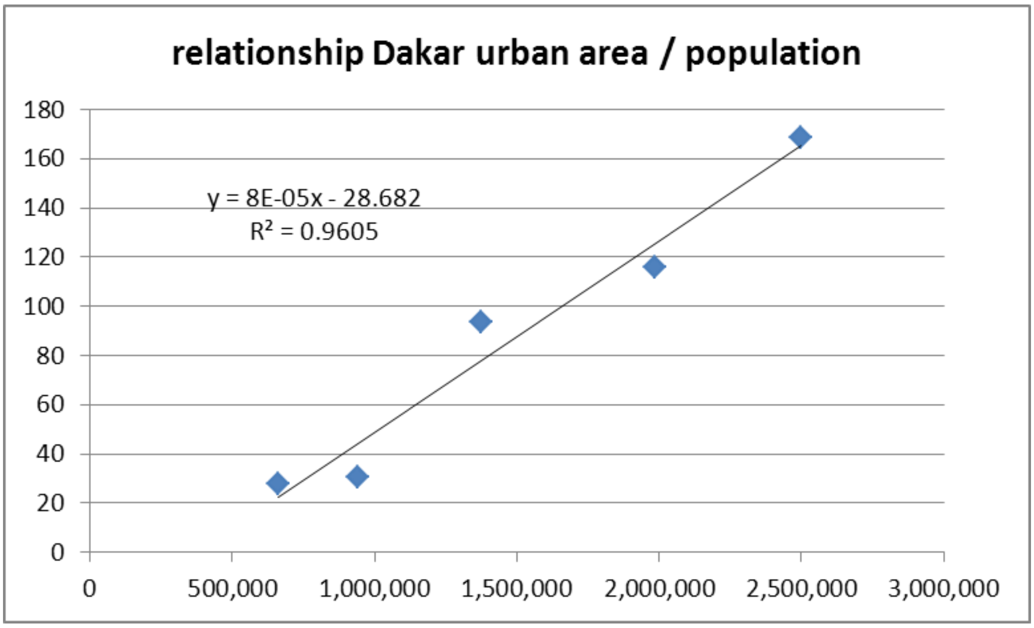


Figure16 .Relationship between Dakar urban area increase and its population growth

The linear regression shows an excellent relationship between urban area developments and population growth in Nouakchott and Dakar with respectively a R^2 value of 0, 92 and 0, 96.That result denotes that the urban area expansion is the result of population growth.

The rapid population growth and the concentration of economic activities in Mauritania and Senegal's coastline have lead in most cases to the expansion of the cities along the coastal area. The urban area shows one major axis from east towards west, which is the coastal area near the coastline and two medium axes toward the north or the south direction. In all the coastal cities, urban area expands with an increase in urban population. The linear regression analysis between the urban area extension and the population growth showed an excellent relationship between the two variables. The excellent relationship means the urban area increase is the result of the population growth in Nouakchott and Dakar. Population growth and city extension put pressures on the physical environment resulting in the physical alteration of the environment, giving rise as a consequence to human-induced environmental hazards.

CHAPITER6: URBANISATION AND FLOOD RISK ASSESSMENT IN NOUAKCHOTT

This analysis is a flood risk assessment that explores the relationship between ground water flooding and urbanization in Nouakchott.The elevation has an importance when building construction is making because of the deph of ground water table. To evaluate urbanised area susceptible of ground water flooding during raining season, the analysis is done through the following images

6.1. Nouakchott elevation

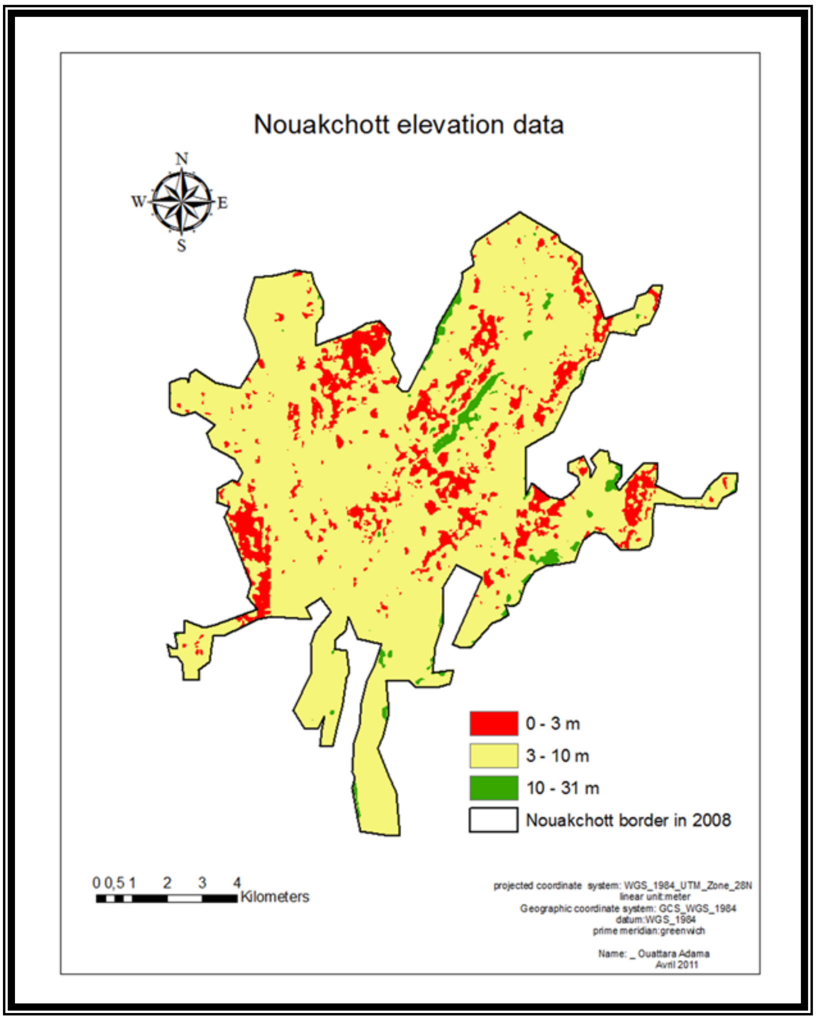


Figure.17. Nouakchott elevation

Nouakchott city is located in an area where heights range between 0 and 31 meters above sea level. The elevation was subdivided in 3 main classes. Elevations areas less than 3 meters were assigned as the most favourable from a flood susceptibility point of view and heights above 3 meters were assigned as the least favourable .

6.2. Nouakchott slope

The slope map was prepared in degree based on using the DEM of the study area. Knowledge about slope is an important factor to identify city areas susceptible of rain infiltration due to low slope.

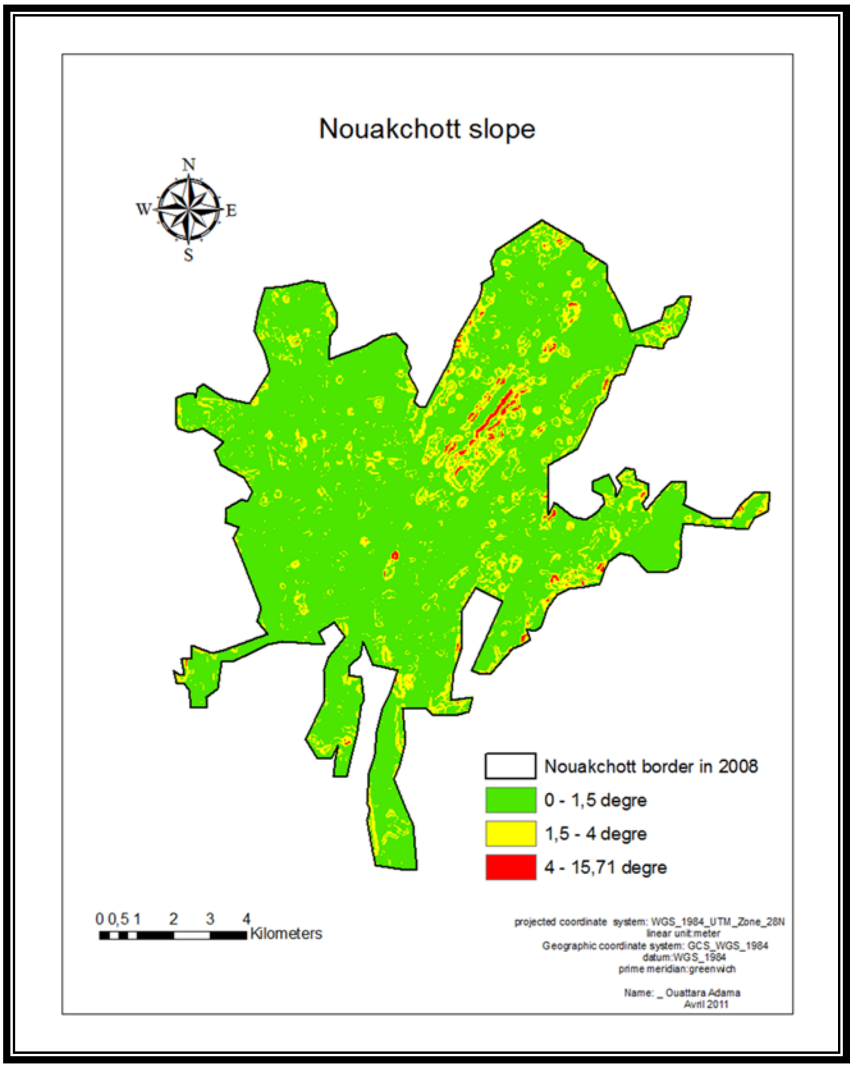


Figure.18. Nouakchott slope

The result reveals that the slope is between 0 and 15, 71 degree. The general slope is less than 1, 5 degree and represent 85, 17% of Nouakchott area that issusceptible of rain infiltration. The flattest of area indicated by the lowest slope indicated that main surface runoff water is maintained and favor infiltration that contributed to ground water.

6.3. Estimation of buildings constructed in low-lying area (less than 3 meters)

The estimation of buildings constructed in low lying area (unsuitable for buildings construction because of its depth) responsible of ground water flooding was done by overlaying the elevation data and the urban vector data of 1998, 2000 and 2008. Urban areas elevations less than 3 meters were estimated.

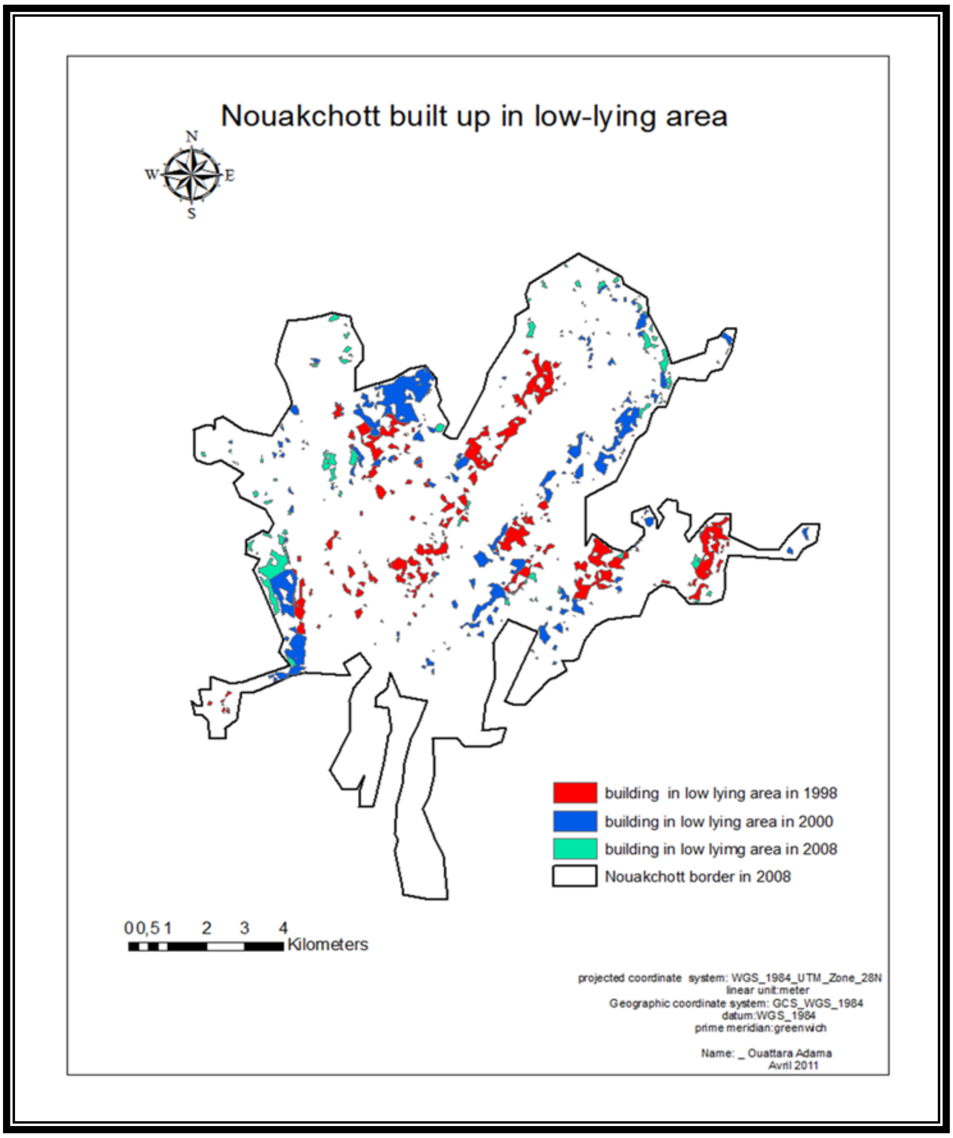


Figure.19. Nouakchott built up in low lying area

Table.10. Building constructed in low lying area

year	Building in Low-lying urban area (km^2)
1988	5,3
2000	5,4
2008	1,7
Sum	12,4 km^2

6.4. Nouakchott built up constructed in low-lying area in 3D presentation

The 3D presentation provides a good picture of the location of building constructed in low lying areas. They are represented by the black polygon on the image. They are more located in the North, the south and the west of Nouakchott. The extension is more pronounced in the south toward the Ocean and in the north direction.

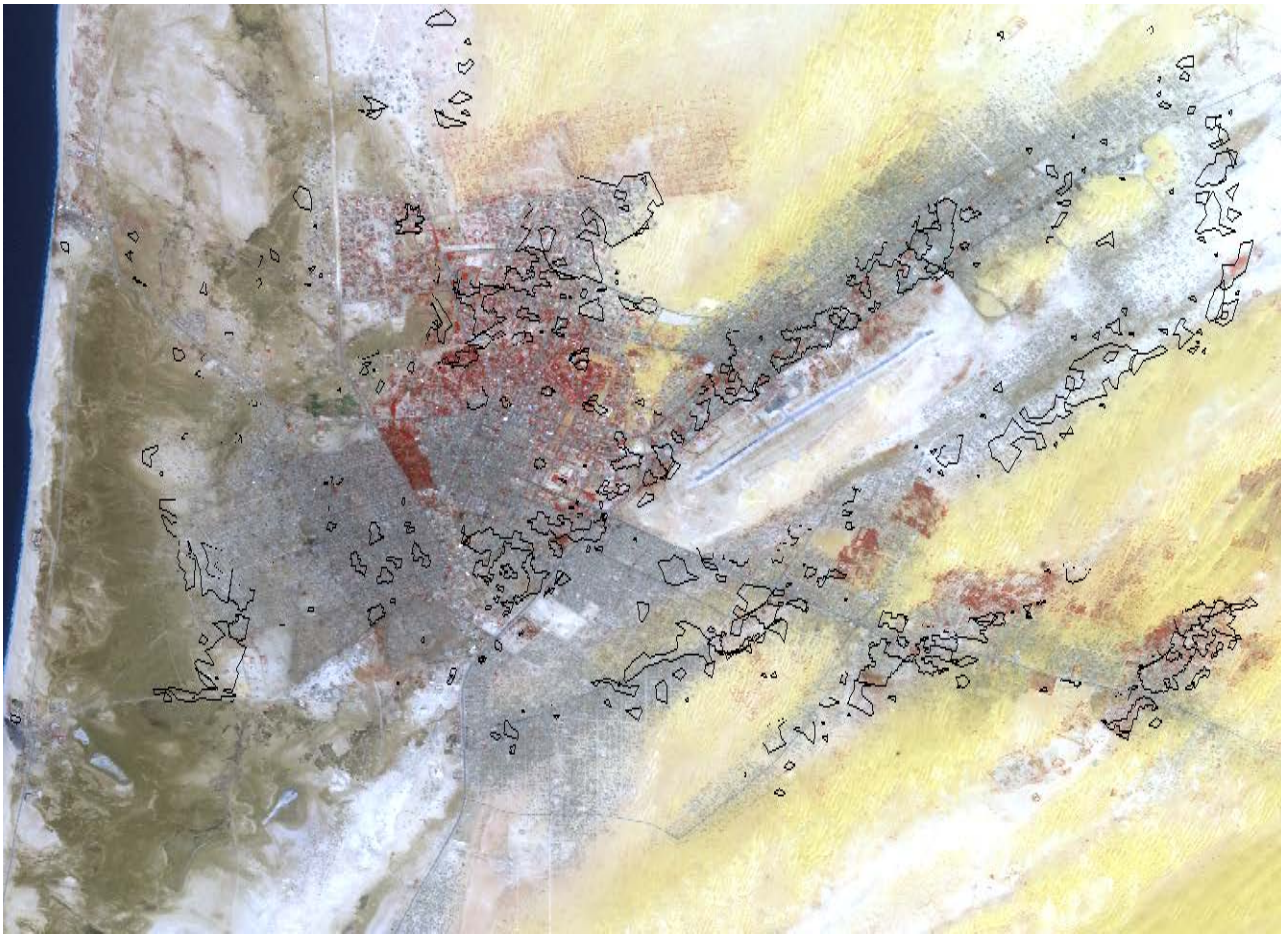


Figure.20. GDEM merged with a colour composite generated from spot image of 2002

6.5. Estimation of population living in low lying area

The population density of Nouakchott was used to estimate the population living in unsuitable area exposed to ground water flood. In 2008, population density was estimated at 9110 inhabitants per square kilometre. Approximately 112 964inhabitants of Nouakchott lived within the flood prone regions.

CHAPTER7: Land cover/Land use change in Mbour coastal area over Petite Côte

The Mbour area is one part of Senegal that has experienced rapid population growth and built up area extension during the last decades. Population growth and human activities affect the land cover and the land use of area. The result of change detection was obtained through the analysis of land cover classification, Landsat NDVI and NOAH/AVHRR time series NDVI data, in relation to the socio-economic data of the region.

7.1. Land use/land cover map

A total of 12 land cover classes was identified and developed for the region: no data, rainfed cropland, mosaic vegetation, mosaic cropland vegetation, open broadleaf deciduous, mosaic forest shrub land, open shrub land, open grassland, sparse vegetation, urban area, bare land and water bodies. The result of LU/LC classification is shown in figure 21 and 22.

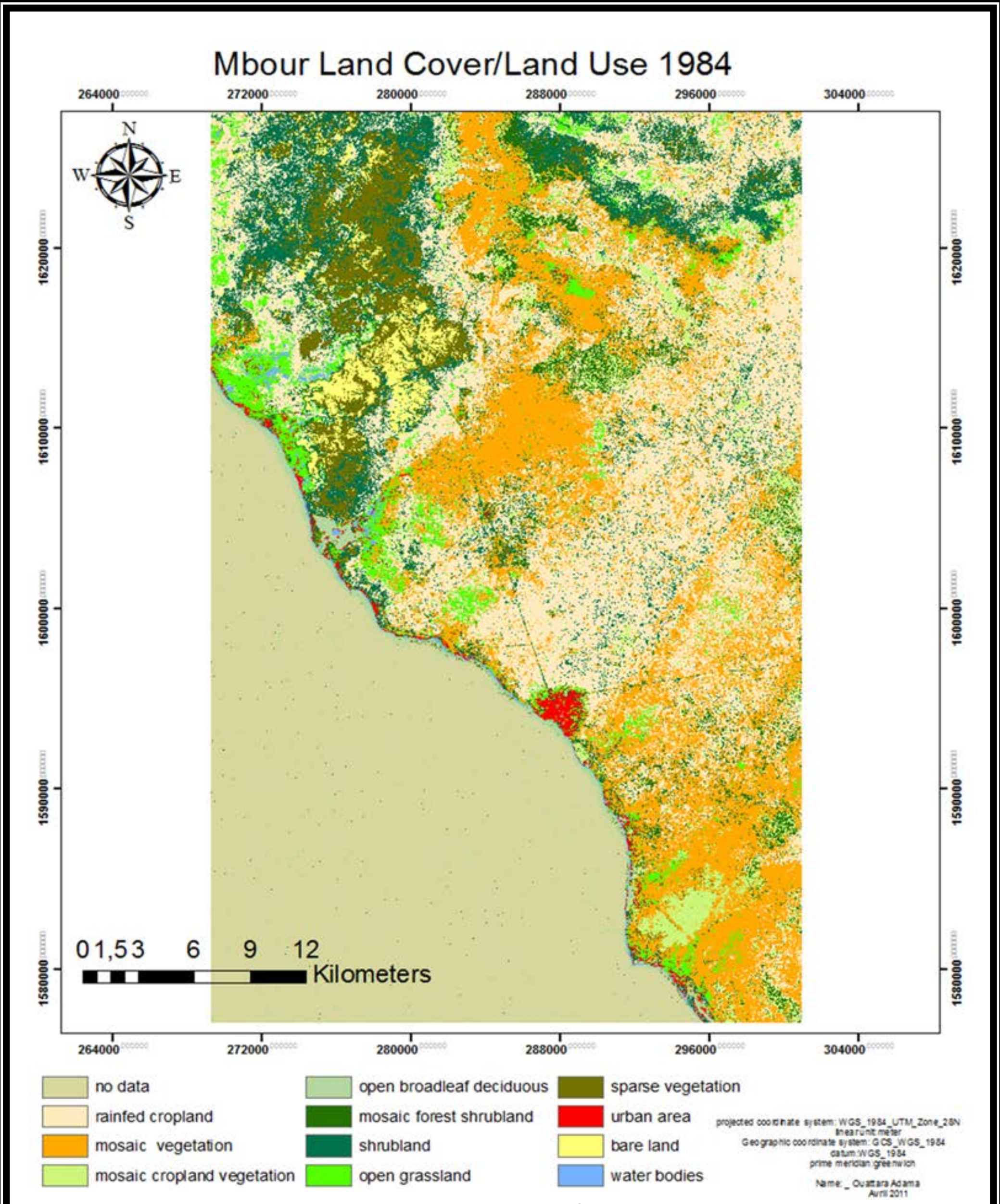


Figure.21. Mbour land use, land cover classification 1984

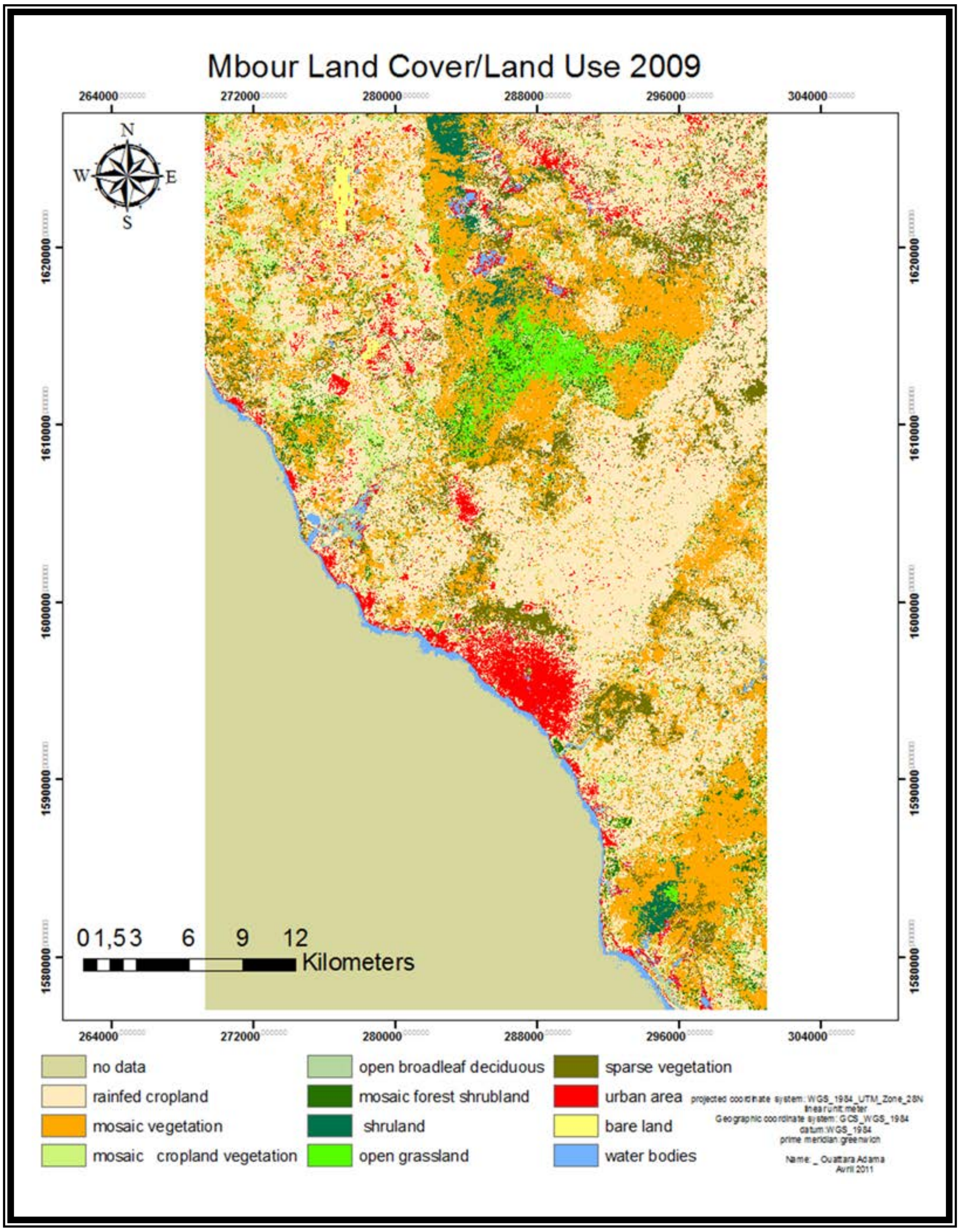


Figure.22. Mbour land use, land cover classification 2009

7.2. Classification accuracy assessment

It has not been possible to evaluate the accuracy of the produced map by the lack of field data and the reference map of Mbour area for the two times periods.

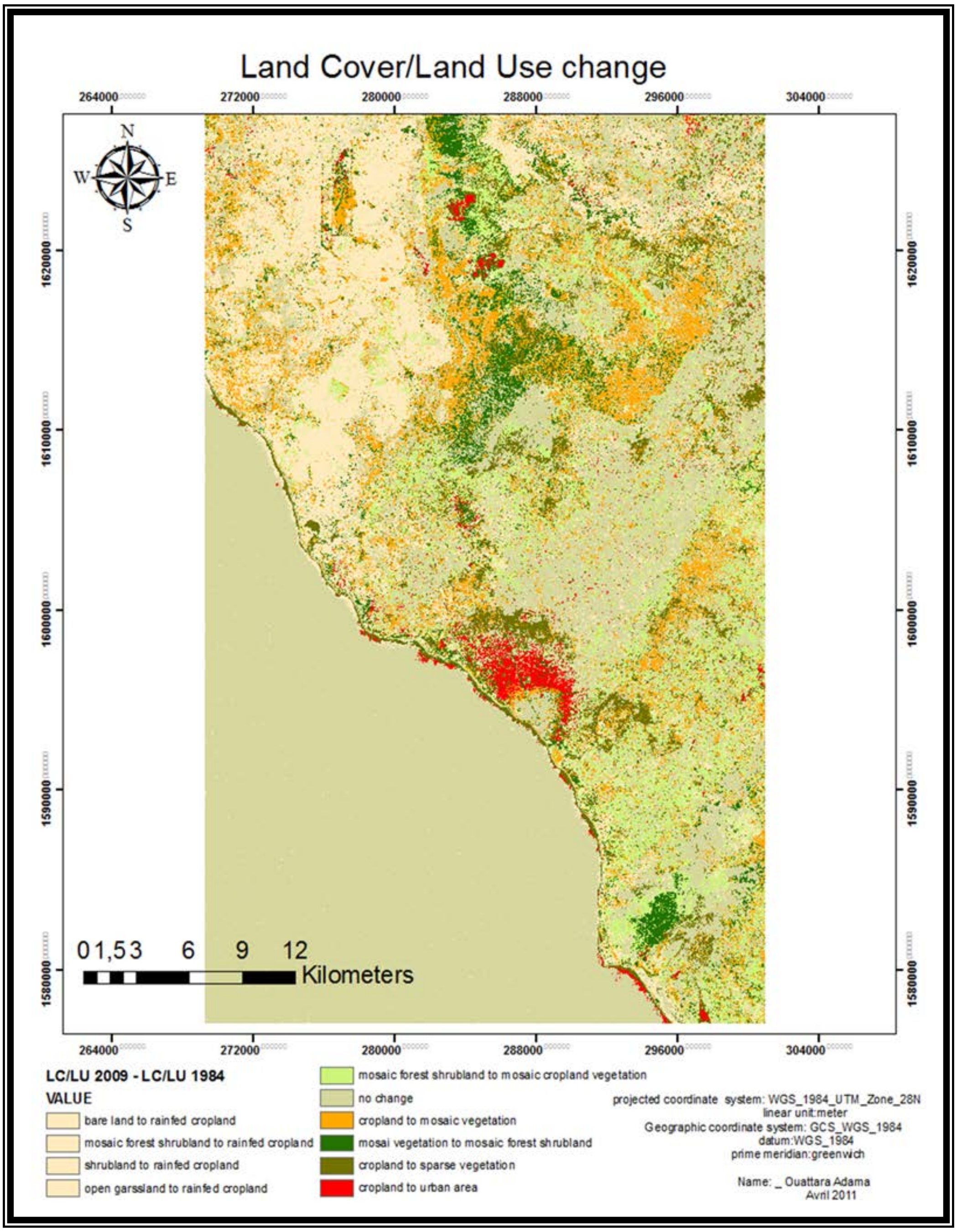
7.3. Post classification comparison

Land cover change was analysed based on post classification comparison method. The comparison is based on thematic information extracted from time series satellite imagery. Change is analysed from the statistics table. The bare chart show the change within the land cover classes during the study period.

The result of change statistics was derived from a pixel based post classification scheme for 12 classes and evaluated in percentage. The analysis reveals an important increase of the built up area (490, 04 %) followed by water bodies (147, 12%), mosaic cropland vegetation (30, 21%), rainfed cropland (27, 02%), sparse vegetation (23, 17%) and others. The decrease in land covers concerned open shrubland (85, 69%), bare land (80, 32%), open grassland (72, 03%), open broadleaf deciduous (70, 58%). The land use in Mbour area recorded significant increase between 1984 and 2009 while the vegetation cover is declining. The more significant change concerns built up area mainly due to population increase and economy development. Results show the conversion of open shrubland and open grassland in cultivated area. The decrease in bare land and an increase in forest induce increase in greenness cover in some places. Figure 23 below shows the result of subtracting the two images (2009-1984) revealing the changes that have taken place. The North West part of Mbour area and the area surrounding city are more affected by change. Cropland surrounding the urban area in 1984 is converted in built up area in 2009.These sites appeared severely desiccated in 2009 as compared to 1984.

Table .12. Land cover statistics

Land Use/land Cover	1984	2009	1984%	2009%	2009-1984	% change detection 2009-1984	remark
no data	554281	560481	30,99	31,33	6200	1,12	increase
rainfed cropland	454149	576879	25,39	32,25	122730	27,02	increase
mosaic vegetation	315064	308929	17,61	17,27	-6135	-1,95	decrease
mosaic cropland-vegetation	47790	62230	2,67	3,48	14440	30,21	increase
open broadleaf deciduous	18199	5355	1,02	0,30	-12844	-70,58	decrease
mosaic forest shrubland	39893	40488	2,23	2,26	595	1,49	increase
open shrubland	157624	22563	8,81	1,26	-135061	- 85,69	decrease
open grassland	67017	18744	3,75	1,05	- 48273	-72,03	decrease
sparse vegetation	81348	100198	4,55	5,60	18850	23,17	increase
urban area	11243	66340	0,63	3,71	55097	490,04	increase
bare land	34175	6727	1,91	0,38	-27448	-80,32	decrease
water bodies	8081	19970	0,45	1,12	11889	147,12	increase
total	1788864	1788904	100	100			


Land Cover/Land Use change
264000
272000
280000
288000
296000
304000
1620000
1610000
1600000
1590000
1580000
N
S
W
E
0 1,5 3 6 9 12
Kilometers
LC/LU 2009 - LC/LU 1984
VALUE
bare land to rainfed cropland
mosaic forest shrubland to rainfed cropland
shrubland to rainfed cropland
open garssland to rainfed cropland
mosaic forest shrubland to mosaic cropland vegetation
no change
cropland to mosaic vegetation
mosai vegetation to mosaic forest shrubland
cropland to sparse vegetation
cropland to urban area
projected coordinate system: WGS_1984_UTM_Zone_28N
linear unit:meter
Geographic coordinate system: GCS_WGS_1984
datum:WGS_1984
prime meridian:greenwich
Name: _ Ouattara Adama
Avril 2011

7.4. NDVI comparison (images and statistics)

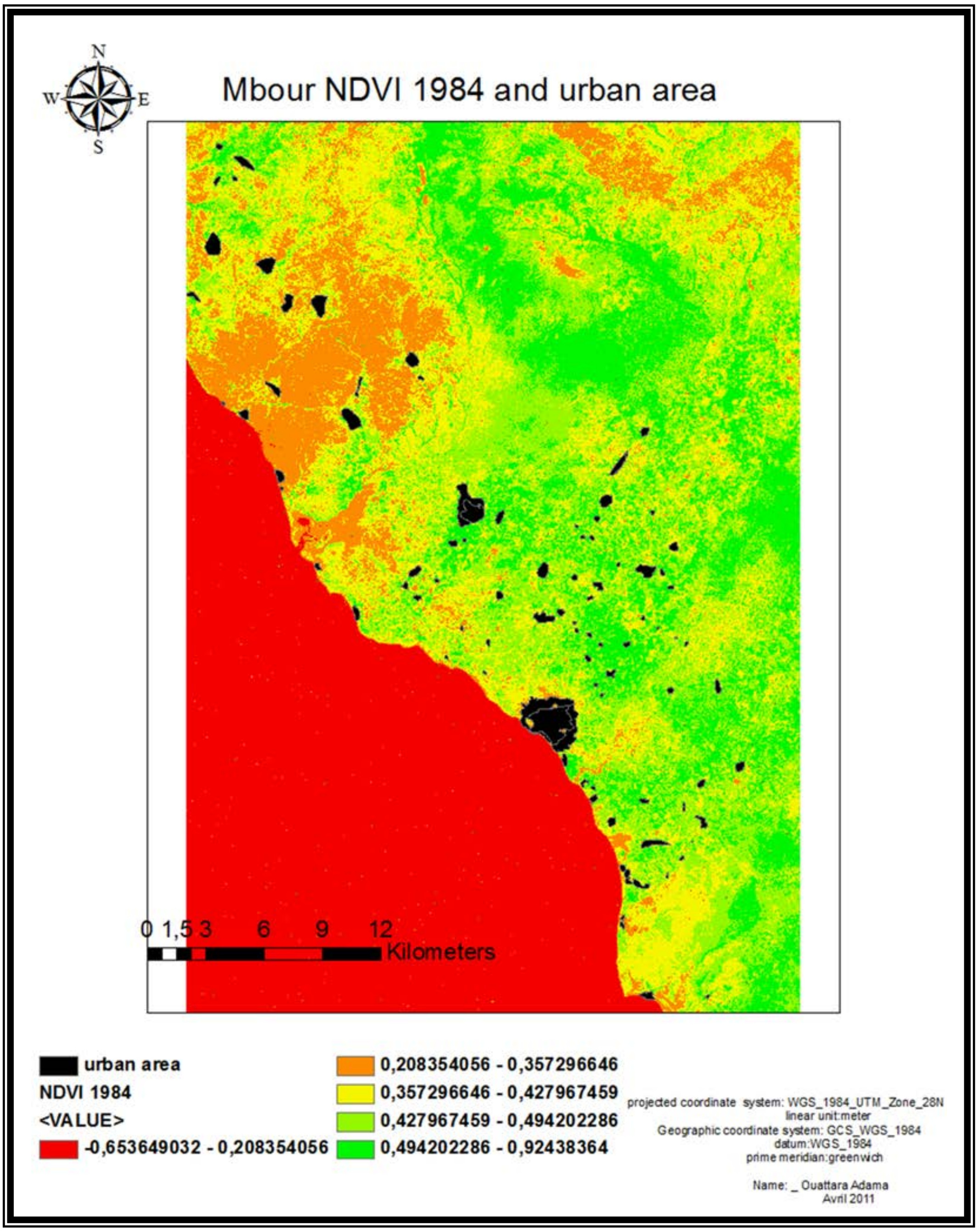


Figure.24. NDVI 1984

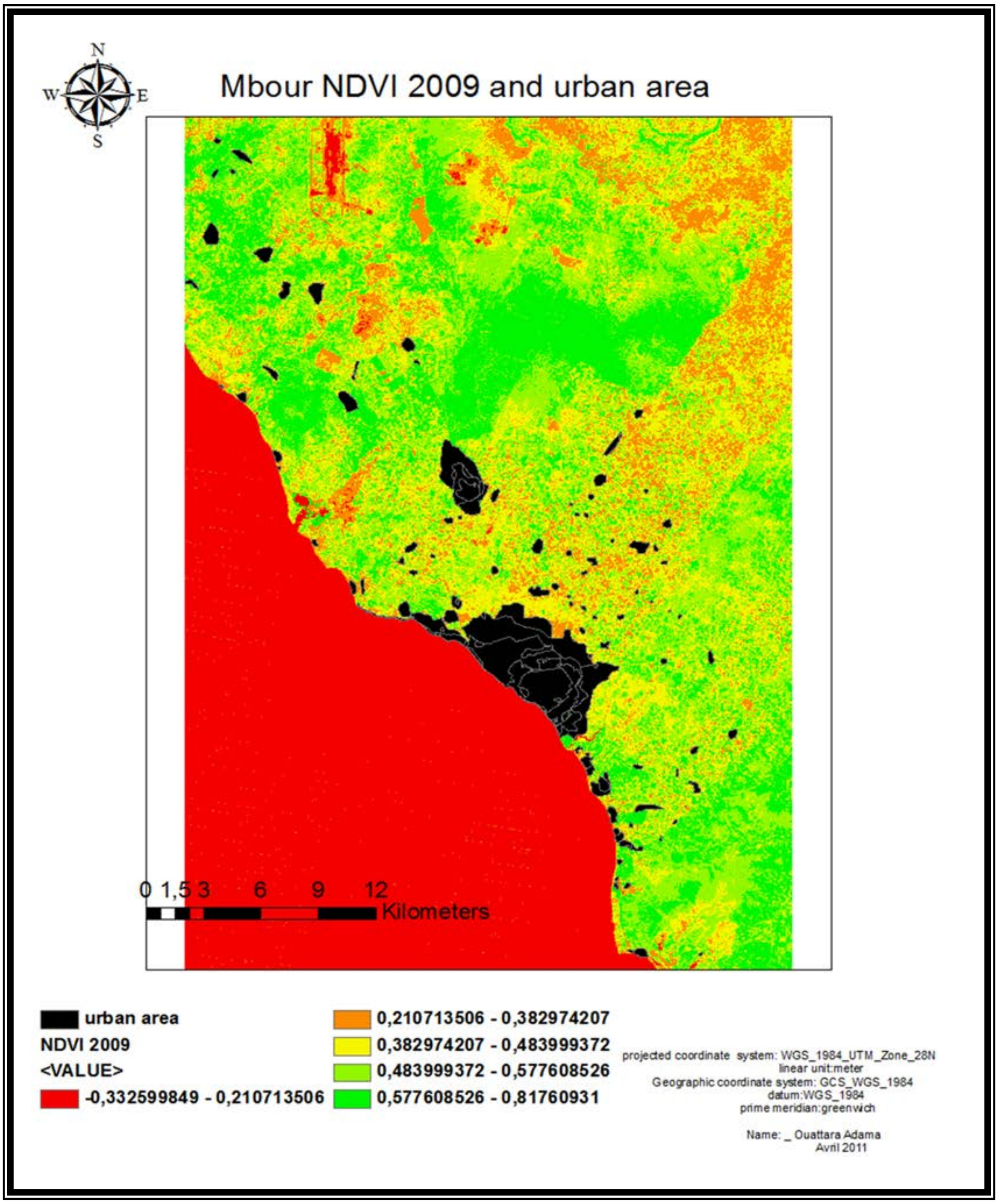


Figure. 25. NDVI 2009

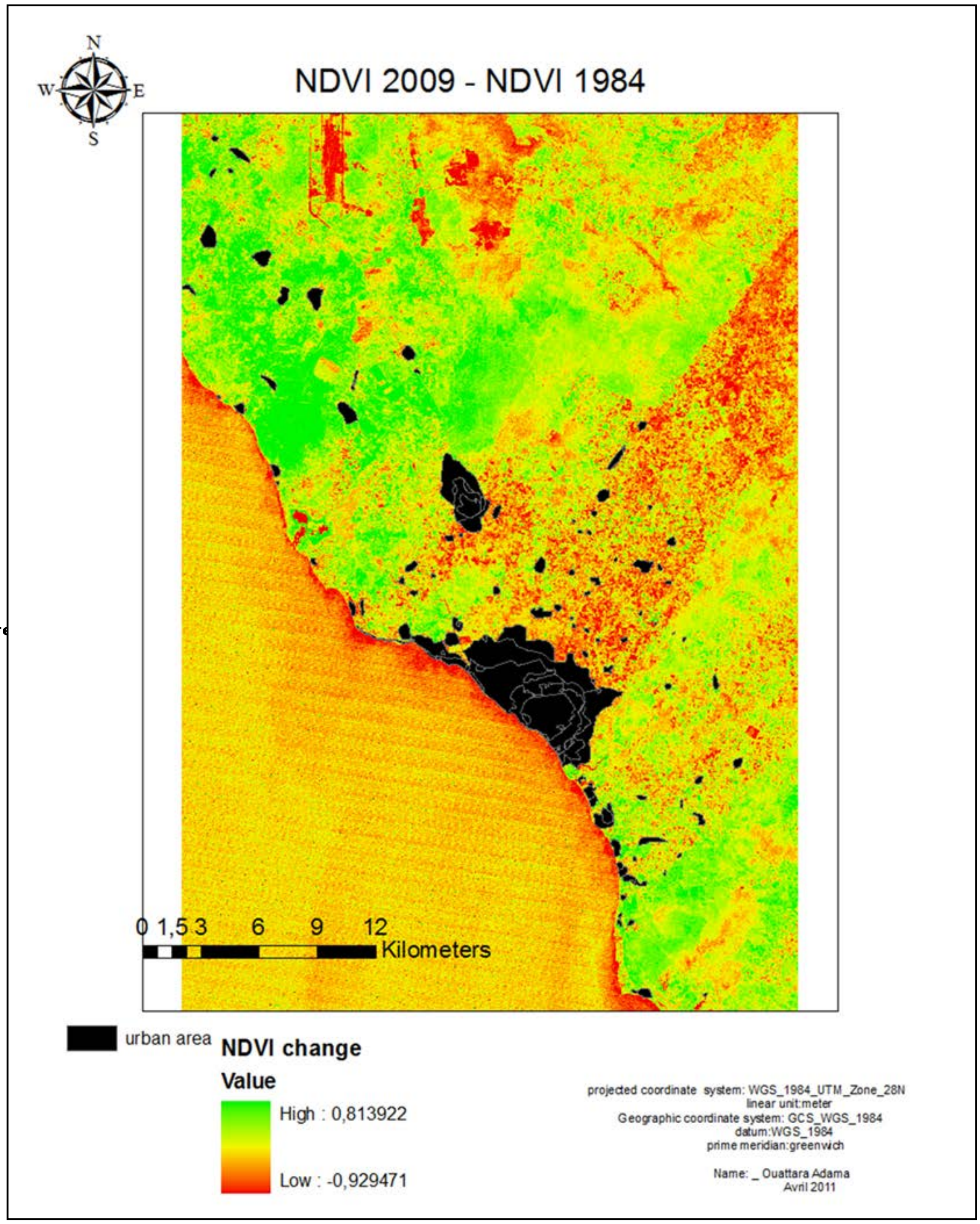
The statistics is based on the NDVI pixels value extracted from NDVI image above.

The calculation of Normalized Difference Vegetation Indices value reveals no significant change. The vegetation change based on NDVI statistics reveals almost equal amounts of greenness in 1984 and 2009 although the urban area and the population increase.

NDVI structure analysis reveals change in pattern of greenness. In 1984, the area covered by NDVI low values was concentrated in the Northwest part of Mbour. Highest NDVI values were registered for Mbour city and those areas immediately outside the city. By 2009; however the pattern had been reversed. The Northwest gain greenness while Mbour city area and surrounding loses vegetation covers. The NDVI analysis showed no significant change in the degree of greenness in Mbour area but rather a change in the pattern of greenness. This change in pattern is directly linked to human modification of the environment. Activities such as farming contribute to the modification of land cover and land use in areas surrounding the city.

Table.13. NDVI statistics

NDVI	NDVI84	NDVI2009	1984%	2009%	Percentage change (2009-1984)	Remark
LOW VALUE	570685	575 855	31,90	32,19	0,91	increase
WEAK NEGATIVE VALUE	171701	183 228	9,60	10,24	6,71	increase
MEDIUM VALUE	367 781	351 138	20,56	19,63	- 4,53	decrease
WEAK POSITIVE	405 845	400 177	22,69	22,37	-1,40	decrease
HIGH VALUE	272 841	278 466	15,25	15,57	2,06	increase
TOTAL	1788853	1 788 864				



Figur

7.5. NOAAH /AVHRR NDVI and rainfall data analysis

The histograms represent the NDVI value and the curb shows the variation of the rainfall data in MBOUR area. The data only covers the time period from 1984 to 2000.

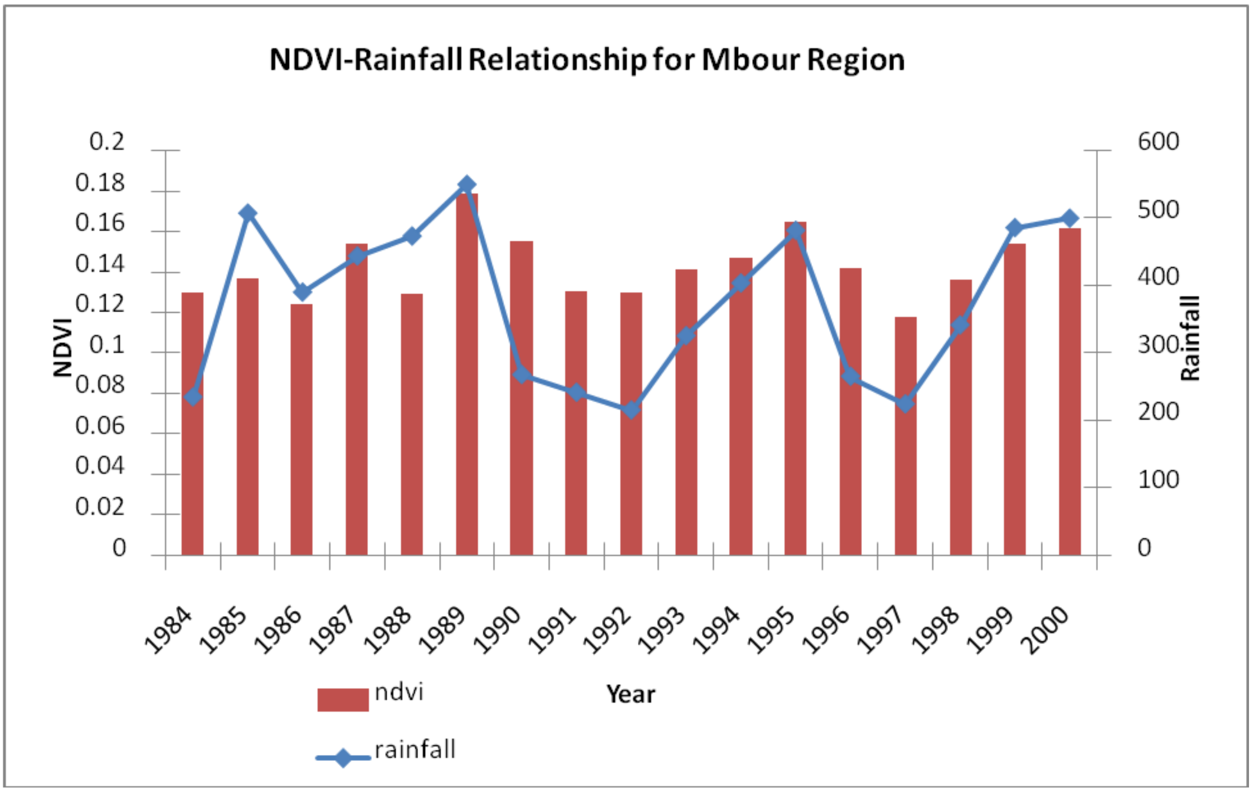


Figure.27. NDVI and rainfall variation

The visual analysis of NDVI and rainfall show that the two variables follow more or less the same trend from 1984 to 2000. The decreases in rainfall value result in the lower NDVI values while an increase in rainfall value is also follow by the increase in NDVI values. Rainfall and NDVI values have a positive link in this area. Rainfall may be the main factor driving the NDVI in the Mbour coastal area.

Mbours land cover change from 1984 to land use in 2009. The important change that did occur was concerned urban area (increase of 490, 04%), mosaic cropland vegetation (increase of 30, 21%), open shrubland (decrease of 85, 69%), and open grassland (decrease of 72, 03%). The statistics of landsat NDVI did not show any significant change. The value of the change between NDVI classes for the time period (2009-1984) is less than 7% but the change in pattern is important. The analysis of NOAHH/AVHRR images and rainfall data indicate the link between NDVI and rainfall data in Mbour area. Both the urban area and population are increasing.

CHAPTER8: DISCUSSION AND CONCLUSION

8.1. Urban expansion

The urban expansion and the population growth in Mauritania and Senegal coastal area were analysed. The results reveal an excellent relationship between the two variables. Urban area expansion is the consequence of immigration and natural growth of population. It is interesting to note that urbanization is not new to the African continent and to West Africa in particular. After independence in the 1960s, there was rapid urbanization fuelled by both anthropogenic factors life characterized by rapid industrialization acting as the pull factors and the natural factors (Sahel drought) which force people from the rural interior. Change in urbanization rate has been attributed to changes in the economy. Before colonisation the economy of the city was based on agriculture, livestock husbandry, fisheries and trade. The introduction of new financial systems altered the social organization. People moved to the cities, which had developed/adopted the capitalist economy. The urban expansion in both countries can be divided into three periods. During the 1970s, urban growth was primarily the outcome of the Saharan droughts. During this period of expansion Nouakchott became a city of climatic refugees (Université de Rouen et al, 1999; Encyclopedia, 2000). The second period of rapid growth happened in the 1980s. The inhabitants of small cities and the nomads immigrated to the coastal cities in search of better job opportunities (Frérot, 1998). The third expansion happened towards the end of the 1990s. This growth was the direct result of national immigration and the natural growth of existing population.

The high rate of urbanization combined with urban economic and social demands presents a challenge for the city and its space management like housing, transportations, education, garbage collection and planning. It increases the need for efficiency in municipal service delivery and elasticity in infrastructure capacity and further exacerbates unemployment and underemployment in cities (Bairoch, 1985; Todaro, 1997). Also it involves a potential decrease of agricultural output due to the loss of its more innovative and stronger members (Beauchemin et al, 2004). The rapid urbanization due to migration involves the difficulty in organizing space and represents one of the primary factors of uncontrolled urban area expansion. From the opposite point of view, urbanization in West Africa cities is seen as a means of relieving human pressure on natural resources (Arnaud, 1998). In the same way Beauchemin and al, (2004), think that urbanization stimulates agriculture production and represents a potential market for economy development. City planning which fails to take into account many parameters like the natural drainage system, the variations in the landscape, would invariably result in unwarranted circumstances.

8.2. Flood risk disasters in Nouakchott

The city of Nouakchott is exposed to a great risk of flooding. Its location and proximity to the Atlantic Ocean makes it vulnerable to coastal inundation and rain generated flooding. The expansion of built up in low lying area is the consequence of increase in population. Although rainfall in Mauritania has increased over the past few years (Ould Sidi Cheikh et al, 2007) since the long dry period experienced by the Sahel area between 1960-1990 (Heumann et al.2007) built up are still increasing in high risk areas. The unsuitable urban area exposed to rain flood was estimated to 12,4 km^2 in this study representing roughly 13,66% of the urbanised surface. The estimation is less than the result found by Ould Sidi Cheikh and al (2007) which approximated the rain flood area to 15% of urbanised area. The difference can be explained by the methodology use to estimate the unsuitable surface and its definition.Ould Sidi Cheikh and al, (2007) delaminated flood risk area based on the topographic map, SPOT satellite image and a radar image of Nouakchott.

A part from rainfall generated flood, rising sea level as a consequence of climate change will further exacerbate problems on the low lying coastal zone. Ericson and al, (2006) estimated a rise in sea level of a few inches (14-80cm) by 2050 due to thermal expansion and melting glaciers in Greenland and Antarctica. Rising sea level and coastal erosion will severely affect Nouakchott because its core is located in low coastal zone less than 10 metres above sea level. Sand exploitation for building construction contributes also to the degradation of the littoral zone. Furthermore Nouakchott is exposed to the risk of tropical storms, which could generate considerable waves (Ould Sidi Cheikh et al, 2007).

The methodology used to estimate the urban area susceptible to ground water flood in this study is simple. It focused only on the analysis of elevation data overlay with urban area. The advantage to have more data will allow use of multi criteria decision analysis to short-list a number of alternatives for analysisor to determine acceptable and unacceptable alternatives (Malczewski, 1999).

8.3. Land cover/land use

The result of LC/LU over the Mbour region revealed that Mbour area land cover in 1984 altered to land use in 2009. Major changes in LC/LU caused by urban expansion are not obvious at this scale on the map probably because the analysis used the entire area of Petite Côte for change detection. LU/LC map of 2009 has recorded an expansion of cropland in its North West part. The change detection map gave us an overview of this transformation. This modification can be explained by the presence of human settlement in the area that contributes to the transformation of land cover. The cropland replaced bare land, open grassland and open shrubland.

The highest amount of achievement is based on open shrubland to rainfed cropland what demonstrate the anthropogenic action on land cover. The decrease in open broadleaf deciduous is the second main change in rainfed cropland. Rainfed cropland expansion in 2009 can be the result of rainfall resumption after 1990. Bare land is being converted into rainfed cropland (land use) in 2009. Sahel experienced a long dry spell characterized by decrease in rainfall from the early 1960 to mid-1990 (Heumann et al.2007). Population growth in the area has obviously increased the demand on farm production.

The increase in urban area (490, 04%) is mainly due to change around Mbour city that concerns rainfed cropland to built up area expansion. Rainfed cropland is being cleared and replaced for the development of urban infrastructure. The increase of sparse vegetation around

Mbour city in 2009 could be related to the heavy exploitation of the natural environment through human activities.

8.4. NDVI

The NDVI change detection is easy to implement and interpret but it can not provide complete matrices of changes direction (Gong et al. 1992). Landsat NDVI statistics results reveal no significant change in Mbour area over the period 1984-2009. NOAAH /AVHRR NDVI and rainfall data used in this study show the link and the slow increase of the two variables over the period 1984-2000. Lebel et Ali (2009), prove that Sahel rainfall analysis on interval covering 1970-1989 and 1990-2007 is characterized by increasing rainfall especially in its central part. Fensholt R et al. (2010) confirm that the raise of rainfall and greenness has characterized the Sahelian zone over the period 1996-2007 although this region experienced a decrease in rainfall from the early 1960 to mid-1990 (Heumann, et al.2007).

NDVI Statistics result: Many reasons can explain the non-significant NDVI statistics change in Mbour area. It may be caused by anthropogenic factors on the environment or natural factors. The increase in population and urban area that affect the vegetation cover by land use change and firewood exploitation. The phenological change related to climatic factors (temperature, rainfall), illumination difference, and the change of atmospheric condition between the times periods affect the NDVI. The result is also influenced by the differential vegetation responses to climate conditions such as responsiveness to precipitation or limitations from high temperatures (Diallo et al. 2009). The last reason for no significant change in NDVI statistics can be related to Landsat data quality for NDVI study.

NDVI pattern result: The visual analysis of pattern in area of positive NDVI change located in the North West part of Mbour indicated a transition from open to shrubland and bare land to rainfed cropland. Area of low NDVI is also cover by rainfed cropland in 2009. Some plausible explanation could be land management, the type of cultivated crop, the crop density, the temporal growing pattern or the difference in the amount of agricultural fields cover by crop.

8.5. Limitations of the study

The limitation of this study:

NOOAH/AVHRR time series NDVI and rainfall data (1984-2000) did not cover the entire study period (1984-2009).
The shapefile vector data used for urban area expansion analysis is from different years and does not permit the study of urban extension over the coastal area at the same time period.
The lack of satellite image high resolution to complete urban vector data. Instead Landsat images were used
The map produced did not have field data or a reference map for accuracy assessment.
The lack of Nouakchott ground water data for a good estimation of urban area responsible of ground water flood.
The lack of urban area value to estimate the relationship between the urban area expansion and population growth in all the cities.

CONCLUSION.

In this study remote sensing and GIS techniques were used first to estimate urban area expansion in the 5 coastal cities (Nouadhibou, Nouakchott, Saint Louis, Dakar and Mbour) then to evaluate the urban area susceptible of ground water flooding due to city expansion in Nouakchott (Mauritania) and finally analyse LU/LC change in Mbour area (Senegal).

Digitalisation of urban area by using temporal satellite images and produce a map permit to follow the temporal change in urban extension. It’s easy to understand area change especially with satellites high images resolution.

The classification of GDEM data to evaluate the urban area susceptible of ground water flood is really simple. It should be improved in future studies.

The use of multi temporal LU/LC, NDVI and socio economic data (demography) greatly aided the analysis of change.

From the results of this study it can be concluded that:

Urban area is increasing in the 5 coastal cities of West Africa. Population growth is one of the most important factors responsible of this phenomenon. Within 30 years the urban area had increased by three to fourfold. Dakar in Senegal provides a perfect illustration of this rapid increase in urban area. The rate of urbanization was estimated to be 291% between 1978 and 2002.City expansion follows the direction North or South along the Atlantic Ocean.

The rapid urbanisation of Nouakchott involves building construction in low lying area and increase the risk of ground water flood. Future planning should avoid unsuitable area.

Population and urban area increase on Petite Côte (Mbour) bearing on the amount of greenness in Petite Côte area, whose impacts were observable in the pattern of land use. Land cover in 1984 is converted in land use in 2009. The cropland area surrounding Mbour city and along the coastline changed in urban area in 2009 Changes in NDVI pattern is the result of anthropogenic activities such as agriculture, and over grazing by both domesticated and wild herbivorous animals. As urbanization increased.

The approach adopted in this study demonstrated the potential of GIS and Remote Sensing to measure changes in the features of the physical and cultural landscape, in this case urban area expansion and in so doing detect and highlight the environmental impacts of such changes.
To have a deep understanding of urbanisation impacts in Senegal and Mauritania coastal cities, this work should be improve

REFERENCES

ACKERMANN, Gabriela et al. 2003**: Analysis of built-up areas extension on the Petite Côte region (Senegal) by remote sensing**, European Journal of Geography, N^{o}.249, 15P.

Africa Statistical Yearbooks, 2009: **Mauritania, social and demographic indicators**, 6p.

APAN, A. et al.2005: **Image analysis technique for assessing landscape structural change: a case study of the Lockyer valley catchment, Queensland** in Göttinger Geographische Abhandlungen, vol 113, 6p.

ARNAUD, M. 1993: **Urbanisation en Afrique de l'ouest, mécanismes et logiques.**

ASSOCIATED PROGRAMME ON FLOOD MANAGEMENT, 2008: **Urban Flood Risk Management – A Tool for Integrated Flood Management**, version 1, world meteorological organization, 44 p.

BAIROCH, P**.** ***1985:*** **De Jericho a Mexico: Villes et economie dans l'histoire** . Paris: Gallimard.

BAODANG, Ma. et al.2009: **Analysis to Shenyang Urban Expansion by Using Multi-source Remote Sensing Images,** Urban Remote Sensing Joint Event, 5p.

BEAUCHEMIN, Criset al. 2004: **Migration and Urbanization in Francophone West Africa: An Overview of the Recent Empirical Evidence,** in urban studies Vol 41 N^{o} 11, pp 2245-2272, Carfax publishing.

BHATTACHARYAH, P. K et al**.** 2005**: Change detection of eastern coastal zone of India using satellite remote sensing and GIS,** Göttinger Geographische Abhandlungen, vol 113, 6p.

BINNS, J. A., et al. 2003:'**Water, Land and Health in Urban and Peri –Urban Food Production: A Case of Kano, Nigeria**'.

CAPO, Armelle. 2008: **Urbanisation et risques naturels: Cas de la ville de Cotonou en République du Bénin,** mémoire de travail de fin d'étude, ESGT, 58 p.

CISSE H., 2006: **Les maladies hivernales**. Nouakchott info quotidien, 1034, 25 juillet, page17.

COBBY, D. et al.2009: **Ground water flood risk management: advances towards meeting the requirements of the EU floods directive** in Journal of Flood Risk Management N^{o} 2 pp111–119.

CHIRISA, Innocent.2008: **Population growth and rapid urbanization in Africa: implications for sustainability,** journal of sustainable development in Africa, Vol 10,N^{o}2. 34p.

COPPIN, P.R et al. 1996: **Change Detection in Forest Ecosystems with Remote Sensing Digital Imagery,** in Remote Sensing Reviews N^{o} 13 pp.207-234.

CSAPLOVICS, E. 1998: **High Resolution space imagery for regional environmental monitoring —** status quo and future trends. International Archives of Photogrammetry and Remote Sensing, 32(7), 211-216.

DEER, Peter.1995: **Digital changes detection in remote sensing**, Information Technology Division, Electronics and Surveillance Research Laboratory, DSTO-TR-0169, 53 p.

DIALLO, Ngagne: **Diachronic study on the urban growth of Dakar year 1988, 1998, 2007,** Cadastre of Senegal, Republic of Senegal.

DIALLO, Yacouba et al. 2009: **Assessment of Land Use Cover Changes Using Ndvi and Dem in Puer and Simao Counties, Yunnan Province, China,** world rural observation, N^{o} 2,11p.

DIOP, Aminata. 2006 : **Dynamique de l'occupation du sol dans les niayes de la région de Dakar de 1954 à 2003: exemples de la grande niaye de pikine et de la niaye de yembeul** , UniversitéCheikh Anta Diop de Dakar, 61P.

DIOP, N.I et al: 2002: **Senegal national report, phase 1: integrated problem analysis, Development and Protection of the coastal and Marine Environment in Sub-Saharan Africa**, Global Environment Facility, 86 p.

DIOP, M.C. 2001: **Les politiques sociales en Afrique de l'Ouest: Quels changements depuis le Sommet de Copenhague? , Synthèse des études de cas (Bénin, Burkina Faso, Côte d'Ivoire, Mali, Sénégal), politique sociale et développement**, Document du programme N^{o} 5, Institut de recherche des Nations Unies pour le développement social.

DIGIROLAMO, Paul Alrik. 2006: "**A Comparison of Change Detection Methods in an Urban Environment Using LANDSAT TM and ETM+, Satellite Imagery: A Multi-Temporal, Multi-Spectral Analysis of Gwinnett County, GA 1991-2000",** Anthropology Theses, Georgia State University, 136 p.

DIREN /INEA, 2002: **Caractéristiques environnementales et fonctionnelles du littoral,** diagnostic environnemental - Mission Littoral 48P

DORIER, Apprill E et al. 2004: **Les nouvelles échelles de l'urbain en Afrique : métropolisation et nouvelles dynamiques territorials sur le littoral béninois**, in vingtième siècle, dossier Ghorra édition N^{o} 81, pp 41-54.

EKLUNDH, Lars. et al. 2003: **Vegetation index trends for the African Sahel 1982-1999**, Geophysical Research Letters, Vol. 30, N^{o}8, pp. 131-134.

EKLUNDH, Lars. et al**. Analysing vegetation changes in the Sahel using sensor data from Landsat and NOAA**, Department of Physical Geography and Ecosystem Analysis, Lund University, 4p.

FAYE, Cissé S et al.2008: **Impact of land use on ground water quality in the thiaroye unsewered suburb (Dakar Senegal): Remote Sensing and GIS approach**, International Symposium "Coupling Sustainable and Groundwater Protection", **Centre de Suivi Ecologique Dakar.**

FENSHOLT R et al.2010: **Analysis of trends in the Sahelian 'rain-use efficiency' using GIMMS NDVI, RFE and GPCP rainfall data,** in Remote Sensing of EnvironmentN^{o}115 pp 438–451.

FOODY, G M. 2002: **Status of Land Cover Classification Accuracy Assessment**, Remote Sensing of Environment, 80:185-201

FREROT, A.M. et al, 1998: **Du parcours à la ville : L'imprévu, Espace et Société en Mauritanie**, URBAMA, Fascicule de Recherche nº33,Tours, France.

FUNG, T et al. 1999: **Environmental quality and its changes, an analysis using NDVI,** Department of Geography, in. journal of remote sensing, Vol. 21, N°5, pp. 1011 –1024.

GADAL, Sebastién.2010: **Visualizing the World**, Paris: S.A.P.I.E.N.S.

GADAL, Sebastién, S.2007. **Construction d'un SIG pour le suivi de l'urbanisation littorale en Afrique de l'ouest**, DVD- SIG

GADAL, Sebastién.2007: D**ynamiques de peuplements et urbanisation: Casablanca**, Les villes aux défis du développement durable: quelle maîtrise de l'étalement urbain et les ségrégations associées? Université du Mans –CNRS.

GADAL, Sebastién.2007: **Pertinence de la géomatique pour la prévention et la gestion des risqué naturels** , in Géographes et assureurs face aux risqué naturels, Editions MAIF, Niort, pp. 192-220.

GADAL, Sebastién. 2006. **Urbanisation et métropolisations littorales et développement en Afrique de l'ouest. Rapport d'étude pour le Bilan Prospectif**, PRCM.

GADAL, Sebastién. 2006: **Urban multi-level geographical information satellite generation", in GIS for sustainable development**, Campagna M. (Ed.), Taylor & Francis, London, pp. 313-328.

GIBSON, Paul et al. 2000: **Introductory Remote Sensing, digital image processing and application**, published by Routledge 249p

GOODCHILD, M.F., and al, 1990: **NCGIA Core Curriculum in GIS**. National Center for Geographic Information and Analysis, University of California, Santa Barbara CA.

GOURMELON, Françoise et al. 2006: Contraintes d'utilisation des technologies de l'information géographique pour la gestion intégrée des zones côtières en Afrique, in *la revue électronique en sciences de l'environnement*, Volume 7 N° 3, 25p.

HARA, Charles G.2003: **Multi temporal Land Use and Land Cover Classification of Urbanized Areas within Sensitive Coastal Environments,** in IEEE Transactions on Geosciences and remote sensing, vol.41, N° 9, 10 p.

HEUMANN, B.W et al.2007: **AVHRR derived phenological change in the Sahel and Soudan, Africa, 1982–2005** in Remote Sensing of Environment N° 108 pp 385–392.

HOLBEN, B. N. 1986: **Characteristics of maximum-value composite images from temporal AVHRR data**. International Journal of Remote Sensing, 7, 1417−1434.

IAGU, 2007: **Géo Ville Région de Dakar,** résumé du rapport, 27 p.

ICOMOS, 2000**: Island of Saint-Louis (Ile de Saint-Louis)**, N° 956, 12P.

IFATIMEHIN, O. O. and al. 2006: **An Analysis of Urban Expansion and Loss of Vegetation Cover in Lokoja, Using GIS Techniques,** in the Zaria Geographer Vol 17, N°.1, pp.28-36.

JAGER, Jean Claude. 1998 : **Urbanisation du littorale méditerranéen**, ministère de l'Equipement, du Transport et du Logement, les Editions de la DGUHC, 148 p

JENSEN, John R. 2000: **Remote sensing of the environment and earth resources perspective**, Keith C. Clarke editor, 544p.

JENSEN, J.R. and TOLL, D.R. 1982: **Detecting residential land use development at the urban fringe**, Photogrammetric Engineering and Remote Sensing, Vol.48, p.629-643, 1982

KALNAY Eugenia et CAI Ming 2003: **Impact of urbanization and land-use change on climate**, University of Maryland, College Park, Maryland 20770-2425, USA

KOMAC, B et al. 2008: **Influence of spreading urbanization in flood areas on flood damage in Slovenia**, IOP Conf. Series: Earth and Environmental Science, N^{o}4, 10p**.**

LAMBINE, E.F et al. 2006: **Land use and Land Cover Change, Local Process and Global Impacts**, The IGBP series, 222p.

LATHROP, R 2009: **Image classification**, ERDAS Field Guide Ed. Ch 6:234-260

LILLESAND, T. M et al, 2004: **Remote Sensing and Image Interpretation**, 5th edition, John Wiley and Son, Inc, New York, 763p.

LI, J. et al. 2004: **Evaluation of land performance in Senegal using multi-temporal NDVI and rainfall series**, in Arid Environment N^{o} 59 pp. 463-480, Elsevier.

LO, C.P. and Faber, B.J. 1997:'**Integration of Landsat Thematic Mapper and census data for quality of life assessment**', Remote Sensing of Environment **62**, 143–157.

LUNETTA, S. Ross. et al.2006: **Land-cover change detection using multi-temporal MODIS NDVI data**, in Remote Sensing of environment N^{o}105 pp. 142-154, Elsevier.

MARICO, Demba. 2009: **L'urbanisation accélérée du cordon littoral, un danger latent**, Université de Nouakchott, 2p.

MARICO, Demba et al. 2009: **Préservation des defenses naturelles du littoral mauritanien: démarche de l'Observatoire du Littoral autour du cordon dunaire,** Université de Nouakchott, 7p.

MARTIN, Mac et al. 2007: **Remote Sensing analysis of urban expansion in Birmigham, Albama: 1988-2004**, N^{o}30, in Papers of the Applied Geography Conferences pp 147-156.

MBOW Cheikh, DIOP Aminata, DIAW Tahirou: **Flood risk and land occupation in Dakar outskirts. Does climate variability reveal inconsistent urban management?**
ISE/ Laboratoire d'Enseignement et de Recherche en Géomatique Ecole Supérieure Polytechnique, Université Cheikh Anta Diop de Dakar-Sénégal

MEYER, William. B et al. 1994: **Change in Land Use and Land Cove**r, A Global Perspectives, 508p.

Ministère de l Economie et des Finances, 2006: **Senegal-Troisième Recensement Genéral de la Population et de l Habitat 2002**, agence national de la statistique et de la demographie 125p.

Ministère de l'Environnement et de la Protection de la Nature du Sénégal, **Rapport national sur l'état de l'environnement marin et côtier.** 70p.

Ministère de la santé et des affaires sociales de la république islamique de la Mauritanie, 1996:**profil sanitaire**, 20 p

MINT, Sneih. K. 2007 : **Dynamique urbaine à Nouakchott (Mauritanie) : évolution spatiale des dépressions salées (sebkha)**, Université cheikh Anta Diop de Dakar, 41 p.

MORAWITZ, DANA. F et al. 2006: **Using NDVI to assess vegetative land cover change in Central Puget Sound in Environment Monitoring and Assessment**, in Environment monitoring and Assessment pp. 85-106.

MUMBY, P.J., and al, 1995: **Geographic Information Systems: a tool for integrated coastal zone management in Belize**. Coastal Management, **23**, 111–121.

NJOH, Ambe.2003 : **Urbanization and development in sub-Saharan Africa, in** Cities, Vol. 20, N° 3, pp. 167–174.

ORSTOM, 1985 : **Villes secondaires et développement régional au Sénégal**, Convention ORSTOM/ ACA/C CE, 71 p.

OULD SIDI CHEIKH, M.H et al. 2007 : **flood risks in the city of Nouakchott (Mauritania),** in Geo-Eco-Trop pp 19-42.

PILESJO, P. 1992: "**GIS and Remote Sensing for Soil Erosion Studies in Semi-arid Environments**," Meddelanden från Lunds Universitet, Avhandlingar 114, University of Lund.

QUENSIERE, J et al. **Gestion intégrée et développement durable des zones côtières ouest africaine,** l'expérience et le projet de la chaire de l'UCAD, 13 p.

ROBIN, Marc et al. 2005: **La télédétection et les SIG dans les espaces côtiers**, in Norois N° 196, pp. 11-21.

ROCHETTE, J. 2010: **Coastal zone definition and geographic coverage of the ICZM Protocol issues,** 2nd Ad hoc Legal and Technical Working Group meeting on the ICZM Protocol, 18 p.

SALEH, Bassam et al. 2007: **Study of Urban Expansion in Jordanian Cities Using GIS and Remote Sensing,** in International Journal of Applied Science and Engineering, Vol 5,N°1, pp41-52.

SONG, Conghe et al. 2001**: Classification and Change Detection Using Landsat TM Data: When and How to Correct Atmospheric Effects?** In Remote Sensing of Environment, Vol 1,15p.

TURNER, B. L., and W. B. Meyer. 1991**: Land use and land cover in global environmental change: considerations for study**. International Social Science Journal 130:669-679.

Université de Rouen et Université de Nouakchott, 1999: **Atlas migrations et gestion du territoire**, République islamique de Mauritanie, Coopération francaise CAMPUS, 1999

WU, Weicheng et al. 2003: **Application of Remote Sensing to the Urban Expansion Analysis for Nouakchott Mauritania**, Geocarto International, Vol 18, N° 1, 8 p.

ZAVOIANU, F. et al. 2001: **Study and accuracy assessment of remote sensing data for environmental change detection in Romanian coastal zone of the black sea**, Faculty of Geodesy, Technical University of Civil Engineering Bucharest, Romania, 6p

ZHU, A X. 1997: **Measuring uncertainty in class assignment for natural resource maps under fuzzy logic**. Photogrammetric Engineering and Remote Sensing, 63 (10), 1195-1202

ONLINE REFERENCES

http://edcsns17.cr.usgs.gov/NewEarthExplorer/

http://phoenix.phys.clemson.edu/tutorials/excel/regression.html

http://www.citypopulation.de/Africa.html

http://www.geom.unimelb.edu.au/gisweb/GISModule/GISTheory.htm

http://www.crssa.rutgers.edu/courses/remsens/rem_cpe_1/remsensing7_files/frame.htm

http://www.gdem.aster.ersdac.or.jp

http://www.citypopulation.de

http://www.census.gov/ipc/www/idb/informationGateway.php

APPENDIX

Appendix 1: Linear regression table

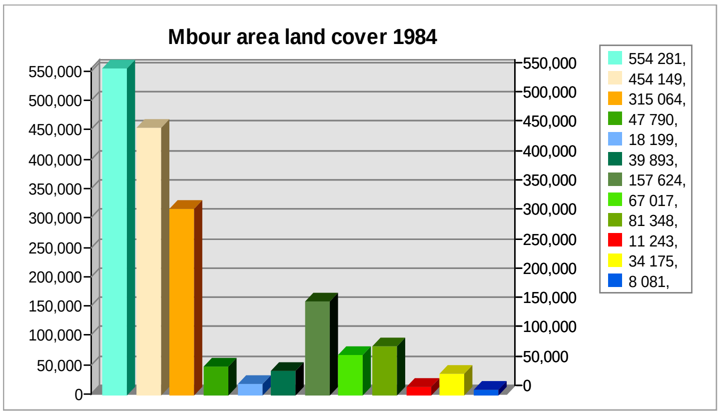
Dakar					
Year	1966	1978	1988	2002	2006
Population	659 675	941 000	1 375070	1 983 093	2 496 244
Area(km2)	28,09*	30.41	93.40	115.9	168.80*

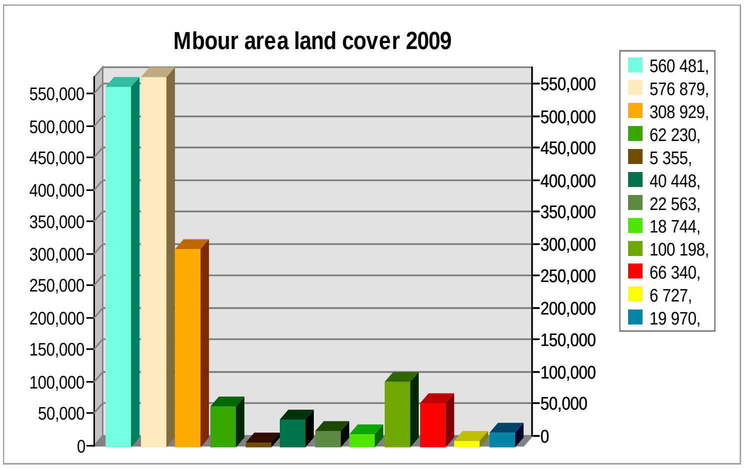
* Source: FAYE, CisséS.and al.2008:

Nouakchott					
year	1988	1989	1995	2000	2008
Population	393 325	413 100	579 130	728 635	846 900
Area(km^2)	37.42	54*	73*	83.84	92.97

*Source: WU, Weicheng and al. 2003
Population data 2000, source: ONS

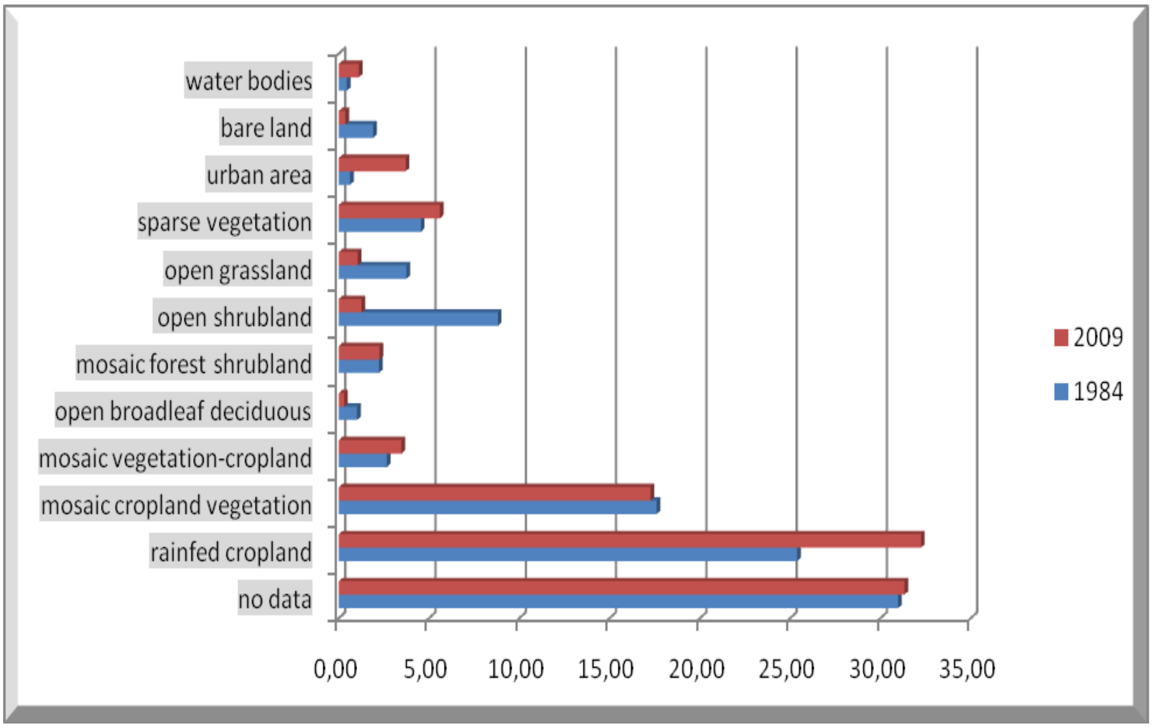
Appendix 2: LU/LC histogamms



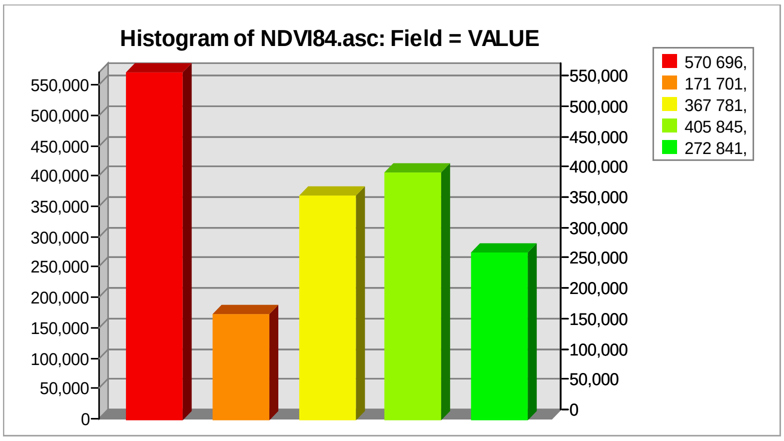


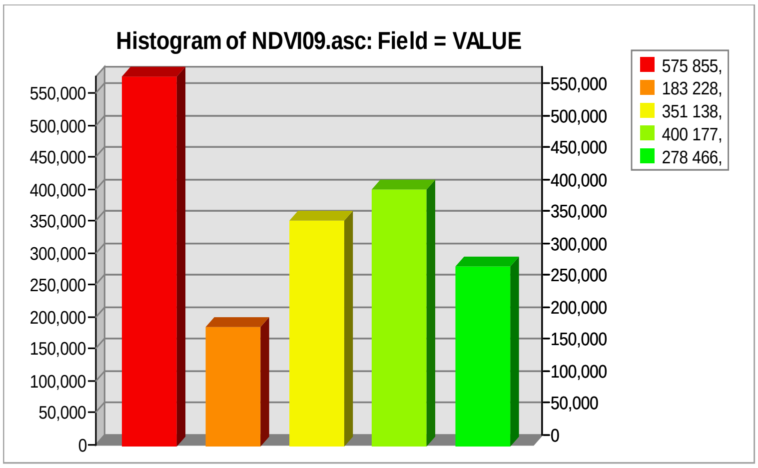
LU/LC 1984 and 2009: histograms and statistics

Appendix 3: Land cover graph comparison 1984-2009



Appendix 4: NDVI graph





Appendix 5: NOAAH/AVHRR NDVI and rainfall data for Mbour area

year	ndvi	rainfall
1984	0,12980311	234,4
1985	0,13646867	506,4
1986	0,12414756	389,5
1987	0,15348133	443
1988	0,12918556	472,6
1989	0,17846933	549
1990	0,15483911	267,4
1991	0,130568	241,2
1992	0,129728	215
1993	0,14118489	325
1994	0,14671467	403
1995	0,16432067	481
1996	0,14162956	265
1997	0,11755533	224
1998	0,13634556	341
1999	0,15358022	485
2000	0,161184	499

Data source: kursdata, NGEN08 Course Materials, Lund University

Institutionen för naturgeografi och ekosystemvetenskap, Lunds Universitet.

Student examensarbete (Seminarieuppsatser). Uppsatserna finns tillgängliga på institutionens geobibliotek, Sölvegatan 12, 223 62 LUND. Serien startade 1985. Hela listan och själva uppsatserna är även tillgängliga på LUP student papers (www.nateko.lu.se/masterthesis) och via Geobiblioteket (www.geobib.lu.se)

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