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DEPARTMENT OF GEOSPATIAL AND SPACE TECHNOLOGY

USING GIS IN URBAN STORM WATER MANAGEMENT:

A CASE STUDY OF SOUTH C ESTATE, NAIROBI.

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ABSTRACT

With the growth of towns, storm water management has become more and more challenging especially in the urban areas of developing countries. This is characterized by urban explosion over a short period of time giving rise to unplanned urban development patterns, inadequate provision of storm water infrastructure amidst the rapidly increasing developments. This therefore constitutes major obstacles for effective urban storm water drainage.

Storm water infrastructure in Nairobi is facing increasingly heavy strain and increasingly frequent failure from storm water and this is mostly evident during the heavy rains. Due to poor storm water drainage systems, roads in Nairobi have been facing flooding issues over the years which not only inflict economic loss but also threaten public health caused by storm water pollution.

This study focused on storm water drainage in South C Estate in Nairobi. South C is one of the areas that suffer every time it rains, roads in this area are very quickly flooded becoming impassable and houses become flooded causing property loss and damage. The existing storm water infrastructure was investigated using GIS and the role of the surrounding community to this problem was also examined.

GPS data collection and field verification was used to establish the status of the existing storm water drainage. Secondary data was used to support the primary data collected. ArcGIS software was used to carry out data analysis. Comparative analysis was carried out using this software. Hydraulic analysis of the study area was also carried in order to understand the interaction of natural topography with the storm water drainage infrastructure.

The aim of this study was to encourage the Nairobi County Council to implement GIS systems as a monitoring and decision-making tool to improve storm water management in Nairobi and other Counties. This study would also assist in education of the public on Best Management Practices for storm water management.

DECLARATION

I, Lorraine Phoebe Odhiambo, hereby declare that this research project is my original work. To the best of my knowledge, the work presented here has not been presented for a proposal in any other university.

Lorraine Phoebe Odhiambo   ..…………………….   ……………………….
           Name   Signature   Date

This project has been submitted for review with my approval as university supervisor.

Dr.-Ing. David N. Siriba   …………………………   ………………………
           Name   Signature   Date

ACKNOWLEDGEMENT

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LIST OF ACRONYMS

BMPs – Best Management Practices

GIS – Geographical Information Systems

GPS – Global Positioning Systems

IHDP – International Human Dimensions Programme

NCC – Nairobi City Council

US EPA – The United States Environmental Protection Agency

WMO – World Meteorological Organization

CHAPTER 1: INTRODUCTION

1.1 Background

The current storm water infrastructure in Nairobi is increasingly experiencing heavy strain and frequent failure. Impervious land surfaces in urban areas are one of the major causes of flooding. Urban areas are mainly characterized by built up surfaces and structures that are often impervious and do not allow water to infiltrate through. These impervious surfaces include buildings, roads, sidewalks, driveways, parking lots, etc. Since water cannot infiltrate into the ground in these urban impervious surfaces, it runs across the surface when it rains and as the surfaces become larger and steeper the speed and quantity of runoff increases. Roads in most parts of Nairobi are often the casualties during the heavy rains as they are often flooded as a result of excessive run off. The results of storm water remaining unmanaged are impassable roads, increased traffic, damage of the roads and vehicles causing increase in maintenance costs, public health risks.

South C is a large residential and commercial area located in Nairobi's South Lands area (Figure 1). It is bordered to the East by South B Estate, Langata Estate to the west and the Nairobi National Park to the South. South C is one of the areas that suffer every time it rains, roads in this area are very quickly flooded and become impassable. To top it up is the impact on the roads as some are often washed off and new potholes emerge, even on recently re-carpeted roads. South C residents will also attest to the peculiar phenomenon where it floods in the estate despite no rain falling in the area. Run-off water from Langata, Karen and Ngong finds its way to South C and the National Park causing floods in this flood plain. Indeed, South C has earned the infamous 'South Sea' tag due to the frequent floods.

The study therefore involved seeking to evaluate the current urban storm water drainage system and as a basis to offer solutions using GIS to improve storm water management in urban roads. This would in turn reduce the risks involved with flooding such as economic loss, infrastructure damage, public health due to degraded water quality and degraded natural resource environments.
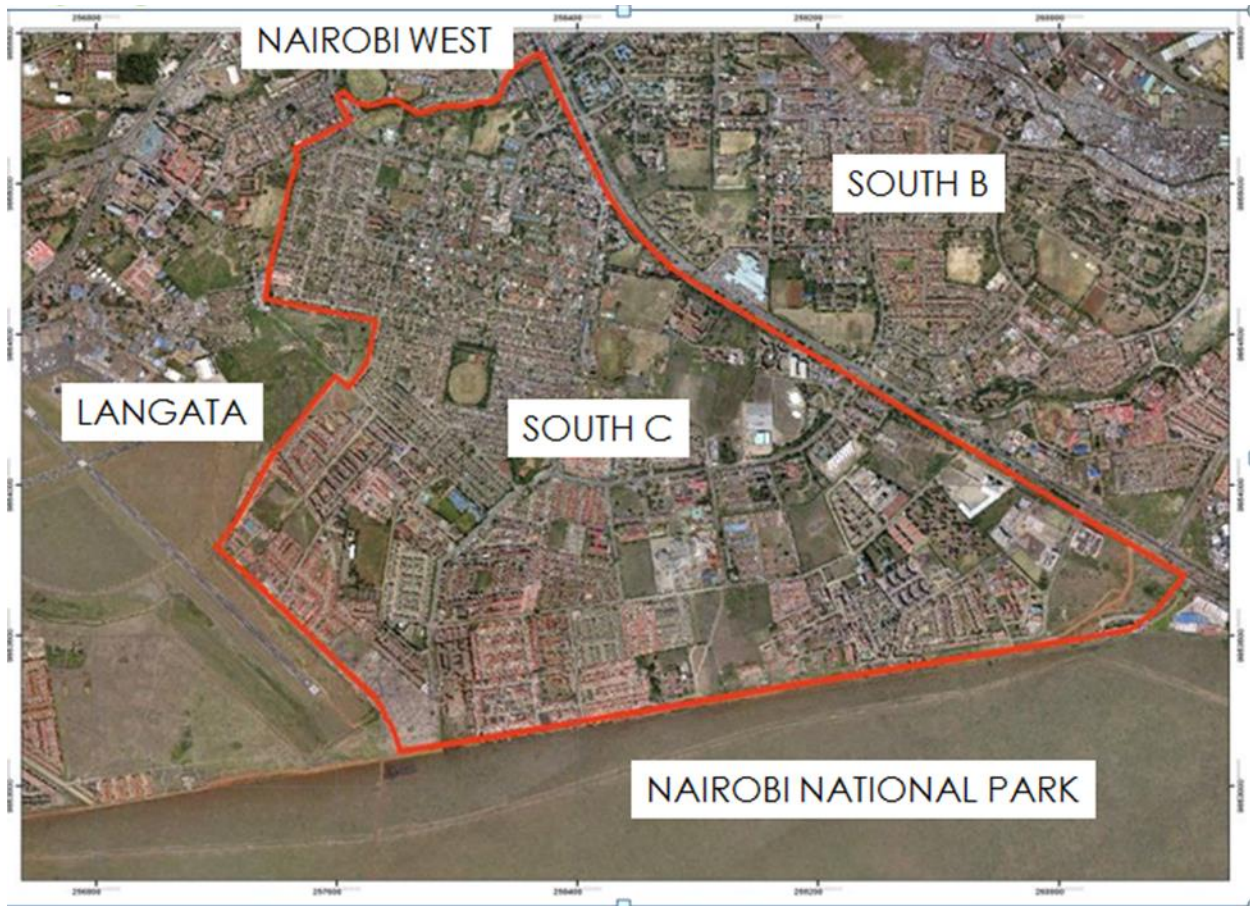
Figure 1: Orthophoto of South C area (Source: KURA).

1.2 Problem Statement

With the growth of towns, storm water management has become more and more challenging especially in developing countries. This is characterized by urban explosion over a short period of time giving rise to unplanned urban development patterns, inadequate provision of storm water infrastructure amidst the rapidly increasing developments. This therefore constitutes major obstacles for effective urban storm water drainage. Technical data available at the Nairobi County Council (NCC) is in many instances out-dated despite the ever-increasing demands of the urban population and this makes it difficult to manage the development and maintenance of the storm water system properly resulting in problematic situations that remain unimproved.

Most of the storm water drainage systems in Nairobi use the open channels to discharge storm water. These channels are prone to solid waste dumping from the surrounding community and deposition of solid waste in these channels by storm water runoff especially when it is in excess.

This solid waste usually ends up blocking and clogging drainage channels and culverts, which in turn cause flooding posing a health risk to the public. This problem is mostly common in areas where there is inadequate refuse or solid waste collection service.

Over time there has been an increase in developments in urban areas without much upgrading of the existing drainage systems, this causes a strain on the current systems thus limiting their capacity to handle storm water. This may be as a result of shallow drains that are not able to carry all the storm water flowing and undersized culverts that restrict the natural storm water, flow causing overflow of the storm water. There is also the issue of draining storm water into the existing sewer system. In many parts of Nairobi, the storm water and sewer lines run concurrently i.e. there are points where the storm water joins the sewer line. This causes a problem during heavy rains because when the sewer system is filled beyond capacity it eventually overflows onto roads causing further flooding and also serious environmental hazards to the immediate community.

1.3   Objectives

The overall objective of the project is to assess the current storm water system as a basis for understanding trends for storm water drainage in South C area.

Specific objectives of the study are:

- To evaluate the surface cover in the Nairobi South C area and its effect on storm water drainage.
- To determine the natural flow direction and accumulation points of storm water in the study area.
- To identify the inefficiencies within the storm water drainage in the study area.

1.4   Justification for the Study

Like in many developing cities, rains in Nairobi are associated with floods. During the heavy rainy season, flooding may be experienced in many parts of the city. This is largely due to lack of adequate drainage infrastructure during road construction and maintenance, newly built up areas that block natural water flows and often times choking of drainage channels with debris and other solid waste such as garbage. In many developing cities, the risks that flooding pose are taken lightly. Only after the heavy rains is there talk of something that should be done.

Preventative management is still yet to be considered as a solution to this problem, hence the timely need for this study.

The expected benefits of an efficient storm water management system include: reduced traffic jams during heavy rains, reduced flooding, reduced private and public property damage, reduced maintenance costs for roads and vehicles, reduced health risks.

This research would also be useful to organizations such as Nairobi County Council, Ministry of Infrastructure in an effort to implement GIS systems that would assist in monitoring and decision making.

1.5 Scope of work

The project was accomplished by reviewing all available aerial photos and plan drawings for details of the existing storm water infrastructure to create an inventory of existing infrastructure e.g. catch basins, open drains and culverts, analysing the topographical map of the study area, performing fieldwork to collect Global Positioning System (GPS) data to verify the existing positions and levels of the existing infrastructure. Creating thematic maps showing different data e.g. soils, impervious and non-impervious areas, flow accumulation maps.

The study involved analysis of the storm water infrastructure and recommendations for best management practices that could be employed by Nairobi County Council. Due to time limits of the project, the study focused on the Nairobi South C estate area.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

Storm water is water runoff that is generated when precipitation from rain and/or snow melt events flow out over land or impervious surfaces and does not percolate into the ground. As the runoff flows over the land or impervious surfaces (paved streets, parking lots and building rooftops), it accumulates debris, chemicals sediment or other pollutants that could adversely affect water quality if the runoff is discharged untreated (US EPA, 2015). Storm water management is a term used to describe the mechanisms for controlling and treating storm water in urban areas (Porsce, 2013). This management can be both qualitative and quantitative.

In urbanized regions, impervious land surfaces are one of the major causes of flooding and pollution. The infiltration capability in urbanized areas is lower than pervious areas such as forested watersheds and humid rural basins so it generates storm water runoff in form of Hortonian flow (Figure 2). Hortonian flow also known as infiltration-excess runoff is a dominant flow type on urbanized land such as paved areas where infiltration capacity is low. It is generated when rainfall intensity is greater than the infiltration capacity into the soil. Instead of soaking into the solid and becoming subsurface flow, rainfall is diverted to Hortonian flow on impermeable areas which can cause flooding, erosion and water pollution because of its high velocity compared to other runoff (James, 2012). The consequences of greater Hortonian flow is increased flooding, impaired water quality and degraded aquatic environments.

2.2 Impacts of Development & Urbanization

The growth of Nairobi's suburbs has profoundly altered natural drainage systems and the water resources. Urbanization changes not only the physical, but also the chemical and biological conditions of the waterways. When land is developed, the hydrology or the natural cycle of water is disrupted and altered. Clearing removes the vegetation that intercepts, slows and returns the rainfall to the air through evaporation and transpiration. Grading flattens hilly terrain and fills in natural depressions that slow and provide temporary storage for rainfall.

Rainfall that once seeped into the ground now runs off the surface. The addition of buildings, roadways, parking lots and other surfaces that are impervious to rainfall further reduces infiltration and increases runoff. Depending on the magnitude of changes to the land surfaces, the total runoff volume can increase dramatically. These changes not only increase the total volume of runoff but also accelerate the rate at which runoff flows across the land. The effect is further exacerbated by drainage systems such as gutters, storm sewer and lined channels that are designed to quickly carry runoff to rivers.
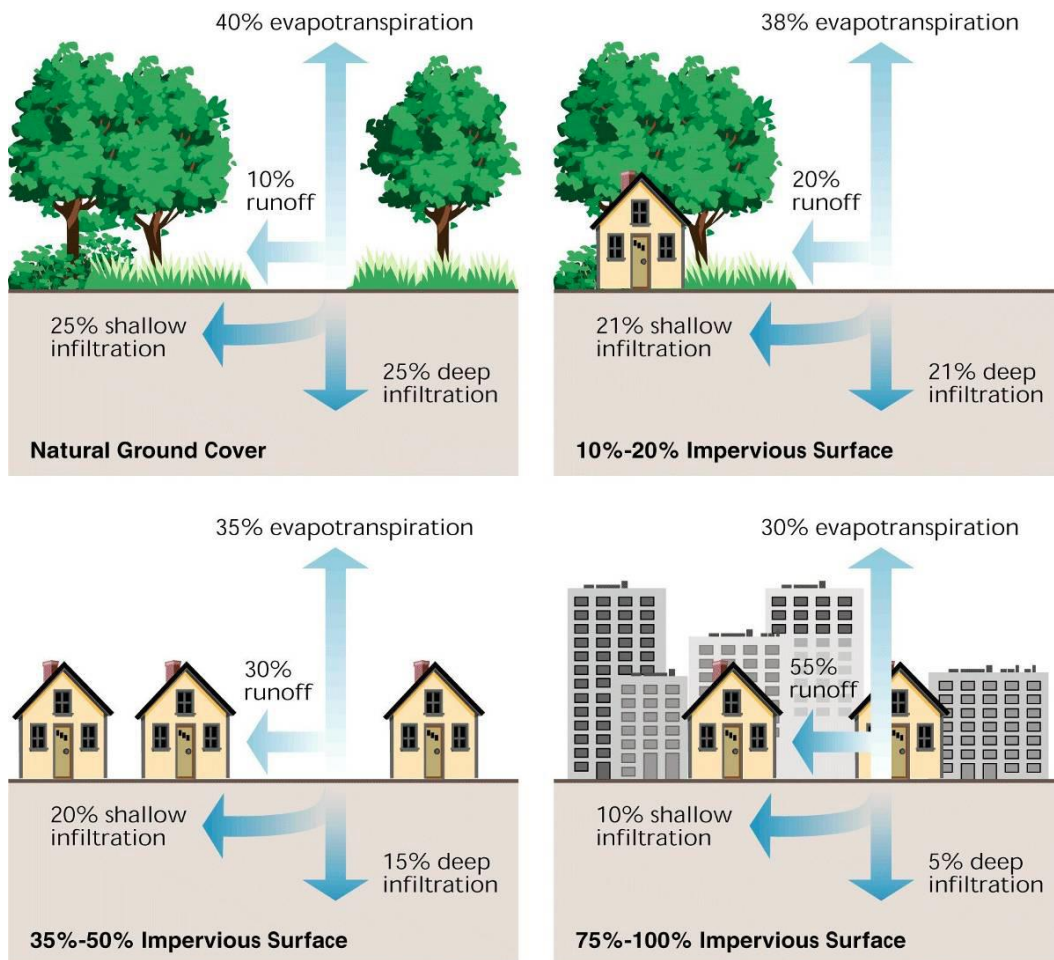
Figure 2: The infuence of urbanization on different components of the water cycle

(Source: WMO, 2008)

Development and impervious surfaces also reduce the amount of water that's infiltrated into the soil and groundwater thus reducing the amount of water that can recharge aquifers and feed stream flow during periods of dry weather. Development and urbanization affect not only the quantity of storm water runoff but also its quality. Development increases both the concentration

and types of pollutants carried by runoff. As it runs over rooftops, lawns, parking lots and industrial sites, storm water picks up and transports a variety of contaminants and pollutants to downstream water bodies.

2.3 Problems Associated with Urban Storm water

2.3.1 Urban Flooding

According to the World Meteorological Organization report on Urban Flood Risk Management (2008), floods result from a combination of meteorological and hydrological extremes. In most cases floods are additionally influenced by human factors which tend to aggravate flood hazards by accentuating flood peaks. Thus flood hazards in built environments have to be seen as the consequence of natural and man-made factors as shown in Table 1.

Meteorological Factors	Hydrological factors	Human factors aggravating natural flood hazards
- Rainfall - Cyclonic storms - Small-scale storms - Temperature - Snowfall and snowmelt	- Soil moisture level - Groundwater level prior to storm - Natural surface infiltration rate - Presence of impervious cover - Channel cross-sectional shape and roughness - Presence or absence of over bank flow, channel network - Synchronization of run-offs from various parts of watershed - High tide impeding drainage	- Land-use changes (e.g. surface sealing due to urbanization, deforestation) increase run-off and may be sedimentation - Occupation of the flood plain obstructing flows - Inefficiency or non-maintenance of infrastructure - Too efficient drainage of upstream areas increases flood peaks - Climate change affects magnitude and frequency of precipitations and floods - Urban microclimate may enforce precipitation events

Table 1: Factors contributing to flooding (Source: WMO, 2008)

The storm run-off system has two purposes:

1) The control of storm water runoff to prevent or minimize damage to property and physical injury and loss of life which may occur during or after a very infrequent unusual storm.
2) The control of storm water to eliminate or minimize inconvenience or disruption of activity as a result of runoff from more frequently occurring, less significant storms.

The straightening and lining of channels, the construction of roads, curbs and storm water inlets; sewer and other underground conduits; culverts and other means of controlling runoff; result in improved 'hydraulic efficiency' of the local drainage network. In other words the time required for surface runoff to reach a water channel is reduced. Unless the drainage network is specifically designed to counteract this increase in rate of runoff from the watershed, the result is likely to be an increase in flood peaks. Thus flooding will happen more quickly and usually to greater depths than before urban development occurred. Around 20-25% of all economic losses resulting from flooding occur in areas not designated as flood plains but as a consequence of urban drainage.

2.3.2 Impacts of Urban flooding

Urban floods have large impacts particularly in terms of economic losses both direct and indirect. Flood risks are a function of exposure of the people and the economic activities along with the vulnerability of social and economic fabric (WMO, 2008). As such the impact of such floods on the lives and livelihoods of people, a function of their vulnerability, needs to be understood.

a) Exposure

Exposure refers exclusively to the question of whether or not people or properties are in range of flood waters. One of the major factors for the rise in urban flood damages is simply the increasing number of people and properties that are physically exposed to floods in cities. The fast and unplanned growth of cities results in a larger number of people living in areas potentially liable to flooding.

Cities in many developing countries are growing rapidly. Unprecedented migration from rural

areas to cities has led to uncontrolled urban sprawl with increasing human settlements, industrial growth and infrastructure development in hazard areas such as riversides, wetlands, land below the river, sea or reservoir level or even inside dried up river beds - areas where floods will occur sooner or later. Often, urban growth that expands over some of the floodways, reducing the area into which floods can naturally overflow. Thanks to economic development, assets are growing even faster than population (IHDP, 2005). With the progress of the societies therein, the value of the assets that are now concentrated in such areas has gone unchecked and unabated. The human settlements and infrastructure behind such embankments assume the area to be free from flood risks grossly ignoring the residual risks that are associated with any flood protection scheme. The infrastructure such as underground transportation systems, multi layered basements used for storage and the telecommunication networks that have indirect impacts on the economies have spiralled over the past few decades. The cities and urban population, particularly in developed countries, protected from floods with structural measures such as flood detention dams and levees have over the years intensified their economic activities in such areas.

However, urban growth need not necessarily lead to the intensification of risks if it takes into account the flood risks in the land use planning processes. The decisive factor is whether urban growth factors flood risks in the development process or not. Many a times, the commitment to flood risk sensitive urban planning depends strongly on the flood frequency. After years or decades without major flood events it becomes more and more difficult to maintain the flood awareness of both people and authorities. This is particularly the case with urban settlements allowed to develop behind the flood levees. Unfortunately, many urbanization processes take place either without any planning or with plans that ignore or underestimate flood risks. Often the construction and land use regulations, the underlying legal basis, as well as a set of concrete plans do exist but are not enforced.

b) Vulnerability

Vulnerability is the most crucial component of risk in that it determines whether or not exposure to a hazard constitutes a risk that may actually result in a disaster. If the potential exposure to floods becomes reality, i.e. when flood waters physically encroach on people and infrastructure, then the vulnerability of people and infrastructure is decisive for the degree of harm and damage. The World Meteorological Organisation distinguishes three types of vulnerability:

- Physical vulnerability of people and infrastructure;

- Unfavourable organizational and economic conditions; and

- Attitudes and motivations.

These vulnerabilities are discussed below in the urban context in order to address them to avoid a flooding event turning into disaster both at societal level as well as at individual level.

i) Physical vulnerability of people and infrastructure

Urban development inherently creates larger risks, but those in higher income groups are able to avoid or bear such risks while those with low incomes cope with them to their detriment. There is a clear socio-spatial segregation with reference to the hazard exposure of settlement locations. Since urbanization is essentially the increase of population density, space gets rare and expensive. Consequently those who cannot afford to purchase or to rent space in secure environments are forced to move to cheaper places. Such locations may be found at the outskirts of town or in areas inside town where the wealthier do not want to live, e.g. because these areas are prone to floods or other hazards. Given the fact that the livelihood of the urban poor often depends on the proximity to informal economies in the central areas of big cities, many prefer to inhabit hazard areas inside town. Two more factors aggravate this spatial marginalization. On one hand hazard prone areas are often not privately owned, and thus informal dwellers are less likely to get displaced. On the other hand, however, many urban poor are migrants from rural areas who are not familiar with the respective hazards and therefore tend to underestimate the risk of living in such exposed areas.

The physical vulnerability of urban populations tends to increase as a result of the dense concentration of potentially dangerous infrastructure and substances in urban areas (bridges, solid and liquid waste, chemicals, electric facilities etc.). Existence of health threatening infrastructure such as sewage treatment plants (usually located at very low spots), waste dumps or dangerous industries at such locations increase additionally the risk of secondary hazards and damages. Special attention in the context of human settlement locations has to be paid to socio-economic factors.

ii) Unfavourable organizational and economic conditions

Informal settlement dwellers are unable to act effectively together. As such they face difficulties in getting support from government and make use of institutional mechanism to the betterment of their conditions. The lack of organizational structures may lead to chaotic circumstances in times of stress whereas the existence of formal or informal organizations or institutions may constitute a stabilizing factor.

In any case mutual support among community members is crucial for coping with stress situations. Such informal social networks are often the only "insurance" of the poor and are particularly important if official support is weak. Unfortunately it belongs to the characteristics of urban poverty that social networks tend to be weaker in cities than in villages. Livelihoods of people living in informal settlements, is dependent on their daily earning capacities, which is severely effected by flooding. On the other hand, those who have regular source of livelihood, their income is not disrupted by floods. Economic vulnerability prevails obviously among those households who lack financial resources and those who cannot afford or are reluctant to purchase flood insurances.

iii) Attitudes and motivations

Reluctance towards flood preparedness and mitigation measures may be the result of lacking hazard knowledge or of fatalistic attitudes. Moreover, dependence on too much external support can reduce the individual responsibility to deal with problems in a proactive manner.

Like exposure, vulnerabilities should not be considered merely as given unsafe conditions but as the result of different processes, which finally make people and their belongings more or less susceptible to the impact of hazards. Among the root causes of these processes, socio-economic factors are the driving forces, including access to or exclusion from education, medical facilities, economic opportunities, political participation and the use of natural resources. Those entitlements usually depend on the socio-cultural background of people in terms of class, ethnic origin, gender and religion. In the case of a hazardous event, access to such entitlements enable "… a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard" (Wisner B., et al 2004) Such capacities are also referred to as resilience, the opposite of vulnerability.

2.3.3 Urban Flood Damages

The impacts of urban floods can be:

- Physical

- Economic, and

- Environmental

In addition to the exposure and vulnerability, discussed in previous sections, the magnitude of the damage depends on the flood type (especially in terms of depth, flow velocity, water quality, duration and sediment load). While in rural areas the damages due to floods are mostly direct in terms of loss of agricultural production, the damages in urban context are more complex (Figure 3 and 4).

It is important to understand the construct of likely flood damages in a given situation in order to take preventive actions to mitigate these likely damages. Both direct and indirect primary potential losses can be prevented through better land use planning, which also impact the potential secondary losses. Better flood emergency response mechanisms help reduce potential secondary losses.

Figure 3: Damaged boundary wall as a result of floods in Midlands Estate, South C. (Source: Daily Nation, 18th October 2014)

Figure 4: Impassable roads caused by floods after heavy rains.
(Source: Daily Nation 18th October 2014)

WMO categorizes damage due to floods as:

a) Direct losses - Losses resulting from direct contact with flood water, to buildings and infrastructure

b) Indirect losses - Losses resulting from the event but not from its direct impact, for example, transport disruption, business losses that cannot be made up, losses of family income.

In both loss categories, there are two clear sub-categories of loss:

i) Tangible losses - Loss of things that have a monetary (replacement) value, for example, buildings, livestock and infrastructure.

ii) Intangible losses - Loss of things that cannot be bought and sold, for example, lives and injuries, heritage items, memorabilia.

Figure 5 provides an overview of typical flood losses and distinguishes between primary, secondary and tertiary loss categories.

	TANGIBLE DIRECT LOSSES	TANGIBLE INDIRECT LOSSES	INTANGIBLE HUMAN AND OTHER LOSSES
PRIMARY	Damage to: • Buildings (e.g. houses) • Contents of buildings • Infrastructure (e.g. roads, bridges) • Crops and animals	Loss of, or disruption, to: • Agricultural production • Industrial production • Communications (e.g. road, rail and telecommunications) • Health care and education services • Utility supplies (e.g. electricity)	• Loss of life • Physical injury • Loss of heritage or archaeological site
SECONDARY	• Flood causes fire and fire damage • Salt in seawater contaminants land and reduces crop yields • Flood cuts electricity supply, damaging susceptible machines and computer runs	• Lost value added in industry • Increased traffic congestion and costs • Disruption of flow of employees to work causing "knock-on" effects • Contamination of water supplies • Food and other shortages • Increased costs of emergency services • Loss of income • Increased household costs	• Increased stress • Physical and psychological trauma • Increase in flood-related suicides • Increase in water-borne diseases • Increase in ill health • Increase in post-flood visits to doctors • Hastened and/or increased mortality
TERTIARY	• Enhanced rate of property deterioration and decay • Long-term rot and damp • Structures are weakened, making them more damage prone in subsequent floods	• Some businesses are bankrupt • Loss of exports • Reduced national gross domestic product	• Homelessness • Loss of livelihoods • Total loss of possessions (i.e. uninsured) • Blighted families • Lost communities where communities are broken

Figure 5: Categorization of Flood losses (Source: Parker, 2000)

2.3.4 Storm Water Pollution

According to the US EPA (2015), the storm water problem has two main components: the increased volume and rate of runoff from impervious surfaces and the concentration of pollutants in the runoff. In addition to chemical pollutants in the storm water, the physical aspects related to urban runoff, such as erosion and scour, can significantly affect a receiving water's fish population and associated habitat. Alteration in hydraulic characteristics of streams receiving

runoff include higher peak flow rates, increased frequency and duration of bank full and sub-bank full flows, increased occurrences of downstream flooding and reduced base flow levels.

The US Environmental Protection Agency (2015) recommends an approach that integrates the control of storm water peak flows and the protection of natural channels to sustain the physical and chemical properties of aquatic habitats. Storm water can pick up debris, chemicals, dirt and other pollutants and flow into a storm sewer system or directly to a water body such as a lake, stream, river, wetland or coastal water. In many cases storm water that enters into a storm sewer system is discharged untreated into water bodies we use for recreation, fishing and even drinking water.

EPA identifies different types of storm water pollution:
- Litter such as cigarette butts, cans, paper or plastic bags
- Natural pollution from leaves, garden clippings and animal droppings (Figure 6).
- Chemical pollution from detergents, fertilizers and industrial chemical waste (Figure 7).
- Sediment pollution such as soil erosion and runoff from building sites and unsealed roads.

Figure 6: Debris blocking a storm water inlet drain
(Source: Author)

Figure 7: Unknown foam from the Nairobi River flows on Mabathi Road, Nairobi after heavy rains.
(Source: Author)

Together these pollutants and the increased velocity and volume of runoff cause dramatic changes in hydrology and water quality that result in a variety of problems. These include increased flooding, stream channel degradation, habitat loss, changes in water temp, contamination of water resources and increased erosion and sedimentation. These changes affect ecosystem functions, biological diversity, public health recreation, economic activity and general community well-being.

2.3.5   Effects of Storm water Pollution

Polluted storm water runoff can have many adverse effects on plants, fish, animals and people.

i) Sediment can cloud the water and make it difficult or impossible for aquatic plants to grow. Sediment can also choke and destroy aquatic habitats.

ii) Excess nutrients can cause algae blooms. When algae dies, they can sink to the bottom and decompose in a process that removes oxygen from the water. Fish and other aquatic organisms cannot exist in water with low dissolved oxygen levels.

iii) Bacteria and other pathogens can wash into swimming areas and create health hazards often making beach closures necessary.

iv) Debris such as plastic bags, six-pack rings, bottles, and cigarette butts - washed into water bodies can choke, suffocate, or disable aquatic life like ducks, fish, turtles, and birds.

v) Household hazardous wastes like insecticides, pesticides, paint, solvents, used motor oil, and other auto fluids can poison aquatic life. Land animals and people can become sick from eating diseased fish and shellfish or ingesting polluted water.

vi) Polluted storm water often affects drinking water sources. This, in turn, can affect human health and increase drinking water treatment costs.

The US EPA (2015) now considers pollution from all diffuse sources, including urban storm water pollution to be the most important sources of contamination in a country's waters. The main reason urban storm water remains such an important contributor to water pollution is the fact that unlike sewage, storm water is not usually treated before it enters water bodies. It flows directly from our streets and gutters into our rivers and other water bodies.

2.4   GIS Applications in Storm Water Management

Rusko, Chovanec, & Roskova (2010) describe GIS as a computer-based tool for collecting, storing, transforming, retrieving and displaying spatial data from the real GIS world. GIS provides facilities for Data capture, Data management, data manipulation, analysis and presentation of geographical data. They further suggest that GIS is not simply a system for making maps, a GIS is an analysis tool as well. The geographical or spatial data represent phenomena from the real world in terms of their position with respect to a known coordinate system, their attributes that are unrelated to position (non-spatial data such as color, pH, incidence of pollution) and their spatial interrelations with each other.

GIS occurs in almost every industry. It is used for education land management, natural resource management, environmental and aeronautical applications (ESRI, 2003). GIS are powerful and cost effective tools for designing intelligent maps for water, wastewater and storm water systems. Effective storm water management requires the linking of specialized computer models to the GIS as well as integration of engineering, environmental and socio-economic objectives into storm water management.

Most of the physical, social and economic problems associated with storm water are attributable to unwise land use, insufficient attention to land drainage in urban planning and ineffective updating of existing storm water control systems. Implementing a comprehensive storm water plan throughout the watershed to prevent the adverse effects of storm water both at a particular site and anywhere downstream where the potential for harm can be reasonably identified can serve as an effective solution to storm water management (Poertner, 1988).

GIS can be useful to a community in a wide variety of storm water-related applications (Atlanta Regional Commission, 2001):

i) Mapping of surface features, land uses, soils, rainfall amounts, watershed boundaries, slopes, land cover, etc.

ii) Manage a storm water system inventory and information about facility conditions, storm sewer networks, maintenance scheduling, and problem areas.

iii) Automate certain tasks such as measuring the areas of subwatersheds, plotting floodplain boundaries, or assessing storm water utility fees.

iv) Evaluate water quality impacts and answer cause and effect questions, such as the relationship between various land uses and in-stream pollution monitoring results.

v) "What if" analyses can be undertaken with GIS. For example, various land use scenarios and their impacts on pollution or flooding can be tried in various combinations to determine the best management solutions or to determine the outcome of current decisions. When tied to hydrology, hydraulics and/or water quality models this type of analysis becomes a powerful tool to assess the impacts of new development on downstream properties.

vi) GIS databases can provide staff, elected officials, and citizens with immediate answers and ready information. For example, inventory, complaints and other information about storm water infrastructure (including pictures) can be placed in a database tied to geographic location.

vii) Complex problems or changes over time, such as water quality improvements, can be easily visualized in maps and graphs generated by GIS systems.

viii) GIS maps can be used to educate or convince citizens and political leadership concerning a course of action or the project viability.

GIS is intended to be a means of improving everyday life. Geographical information attaches a variety of qualities and characteristics to geographical locations but integrating all kinds of information and applications with a geographical component into one manageable system (Rusko, Chovanec, & Roskova, 2010). Therefore a benefit of GIS applications is the ability to integrate and analyse all spatial data to support a decision making process. The integration capability of GIS technology empowers organizations to make better and informed decisions based on all relevant factors.

2.5 Best Management Practices in Storm Water Management

According to the US EPA, Best Management Practices (BMPs) are known as activities or structural improvements that help reduce the quantity and improve the quality of storm water runoff. BMPs include treatment requirements, operating procedures and practices to control site runoff, spillage or leaks, sludge or waste disposal, or drainage from raw material storage. The US EPA proposes several site design and drainage Best Management Practices for urban developments that mostly apply to residential, commercial and industrial developments. These practices are effective in reducing the quantity and improving the quality of storm water runoff. They include:

- Green roofs,
- Rainwater collection tanks
- Permeable paving
- Vegetation filter strips to slow down the rate of runoff movement
- Bio filtration cells such as Rain gardens
- Green Drainage swales
- Naturalized detention basins
- Inlet protection devices

Figure 8: Green roofs to reduce the volume of storm water runoff
(Source: Chicago's Water Agenda, 2003)

Figure 9: Rainwater storage tanks to store rainwater for reuse
(Source: Chicago's Water Agenda, 2003)

Other BMPs implemented for management of storm water pollution include:

- Public Education and Outreach on Storm water Impacts

- Public involvement and Participation in activities such as Environmental cleanups

- Illicit Discharge Detection and Elimination through education, training and enforcement

- Construction site storm water runoff controls

- Post-Construction storm water management in New Development and Redevelopment.

- Pollution Prevention/Good housekeeping for County council operators

CHAPTER 3: MATERIALS AND METHODS

The research methods employed during this study encompass data collection, interpretation and analysis of the data collected. This type of research included field surveys and fact-finding enquiries of the state of storm water management as it currently exists. The main purpose of this process is to assess the current state of the storm water drainage system in Nairobi South C Estate and thereafter suggest solutions that can be employed for use in this area to reduce the negative impacts of storm water especially during the rainy season.

3.1   Data

This study largely relied on publicly available spatial datasets. Data collected for the purpose of this study was as follows:

3.1.1   Spatial Data

In this study, efforts were made to obtain and use the GIS databases that already existed and were relevant to the project. A wide variety of information and GIS data layers were obtained from a number of sources listed below:

- Roads shapefiles were obtained from the Kenyan Urban Roads Authority (KURA).

- Sewerline and Manhole shapefiles were obtained from the Nairobi Water and Sewerage Company

- Soils and Rivers shapefiles were obtained from the ILRI website

- Topographic Maps were obtained from the Survey of Kenya

After obtaining the data from different sources, there was need to ensure that all the data is converted to the same projection to avoid major errors during data analysis.

Primary data were also collected through discussions with relevant personnel within the above named organisations.

3.1.2 Orthophotos

Orthophotos are aerial images that have been orthorectified to geometrically correspond with a map. Orthophotos of the South C area was obtained from KURA. The imagery was taken in July 2014 and had a terrain resolution of 2.5m.

3.1.3 Weather Observation Data

The average annual rainfall in Nairobi is about 900 mm, but the actual amount in any one year may vary from less than 500 mm to more than 1500 mm. As already mentioned, there are two rainy seasons, from mid-March to the end of May (the so-called "Long Rains"), and from mid-October to mid-December (the "Short Rains"). The dates on which these rainy seasons start and end are very variable; in fact the beginning and end of a wet season are seldom, if ever, well defined. These seasons coincide approximately with the time of changeover of the monsoon currents which affect Eastern Africa, the South-West Monsoon becoming established in April, and north-east monsoon in November.
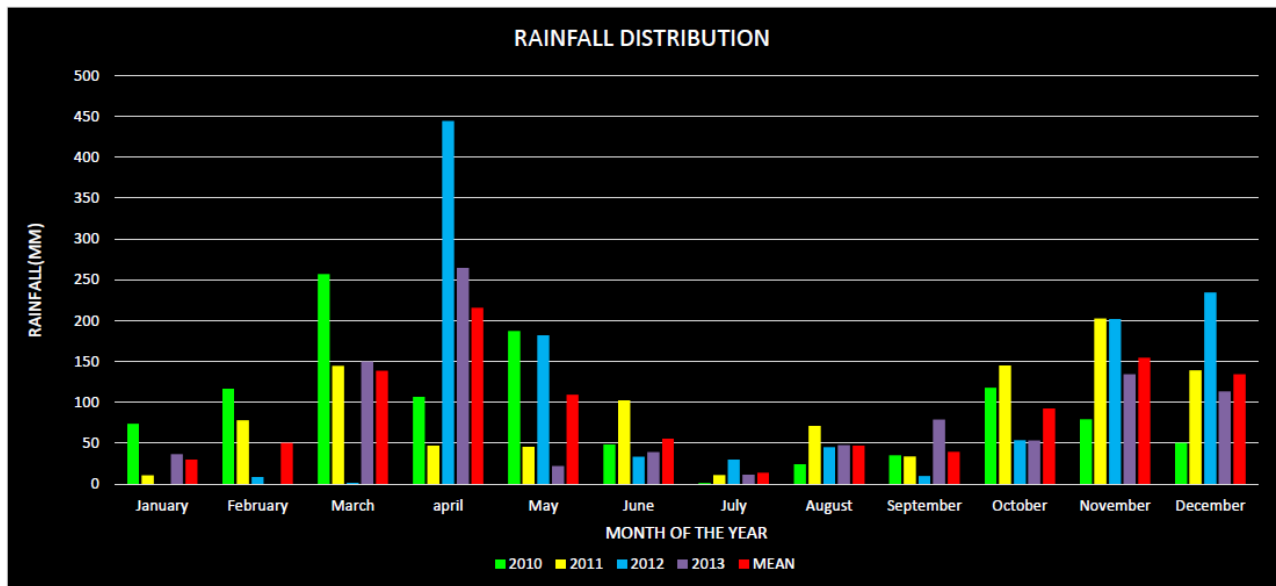

Figure 10: Rainfall statistics 2010-2013 (Source: Kenya Meteorological Department)

3.2   Software

Accessibility of existing GIS database and ease of integrating information from existing sources were the main criteria used in the selection of software for this study. ArcGIS 10.1 software with ArcHydro Tools 2.0 for ArcGIS was selected for data processing, analysis and presentation of the various aspects of the project.

3.3   Hardware

3.3.1   Handheld GPS Receiver

The Navigation Satellite Timing and Ranging Global Positioning System (NAVSTAR GPS), simply known as GPS is a satellite-based radio-navigation system that is capable of providing extremely accurate 24-hour, 3-dimensional (latitude, longitude, and elevation) location data (Wells, 1987). GPS currently uses a collection of 24 satellites positioned in orbit to allow a person who has the equipment to automatically have their position triangulated to determine their location. GPS now comes in instruments that can be hand-held, and can be connected to a PC to allow automatic downloading of data.

A handheld GPS receiver, Garmin GPS 60cs, was obtained from the Department of Geospatial and Space Technology, University of Nairobi, for data collection. Because it was not possible to obtain storm water infrastructure plans from the Nairobi County Council as a result of fire damages which had destroyed this information, there was need to collect the data from field survey. Due to good weather conditions at the time of data collection, the accuracy of the GPS ranged between +/- 2 meters and +/-3 meters. Locations of culverts, storm channels as well as underground drainage were collected.

The collected data was then downloaded to a laptop using MapSource software and saved in a format compatable for use in ArcGIS environment.

3.3.2   Digital Camera

An 8 megapixel camera was used to take digital images of some study areas e.g images of the condition of the storm water system. The images were downloaded to a laptop and some selected images are included in this project.

3.4 Methodology Flowchart

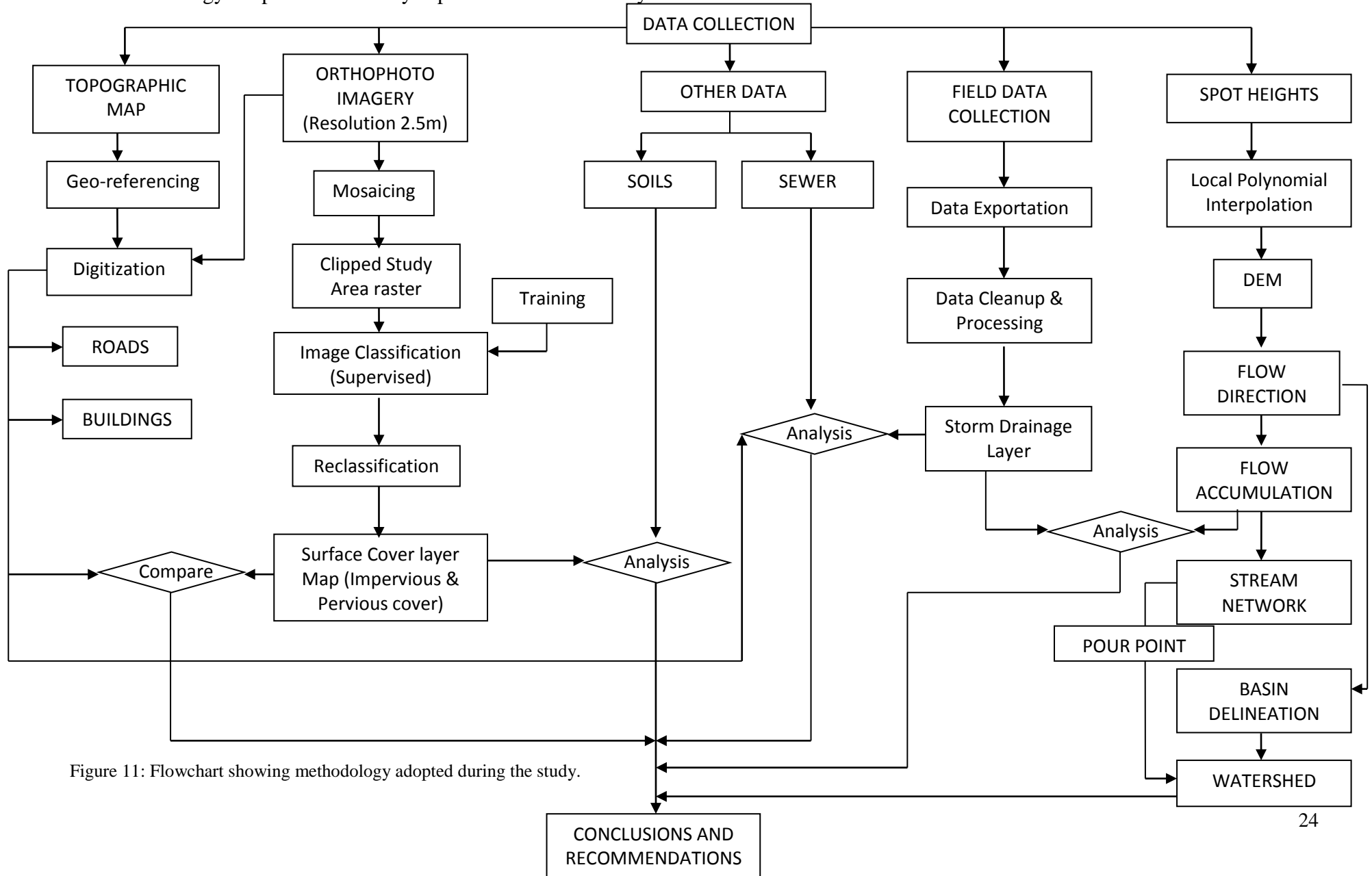The methodology adopted in this study is presented schematically in the flowchart below.

Figure 11: Flowchart showing methodology adopted during the study.

3.5   Methods

Based on the digital analysis of the orthophoto in conjunction with other ground survey, the thematic maps and relevant information related to the research area was integrated with GIS using ArcGIS 10.1 software for comparison and analysis.

3.5.1   Topographic Map

The topographical map used for this study was obtained from the Survey of Kenya as images in jpg format. The study area map was covered in four sheets i.e. 37-III-EG-89-1, 37-III-EG-89-2, 37-III-EG-89-3 and 37-III-EG-89-4. The map scale chosen for this project was 1:2500 which was found to be appropriate due to the level of detail available on the map and less generalization of features. These aspects would prove to be useful during the process of digitization of certain features on the map. The images were first georeferenced in ArcGIS and thereafter digitization of buildings and roads was carried out using ArcGIS 10.1 software.

i)   Georeferencing

The primary tool used for this exercise was the *Georeferencing* toolbar. The map was georeferenced using the coordinates indicated at the corners the map. The intersection points of the map corners were used as control points and the X and Y coordinates input to correspond with the coordinates on the map. This process of adding control points was done for all four corners of the map. The georeferenced image was then rectified and saved.
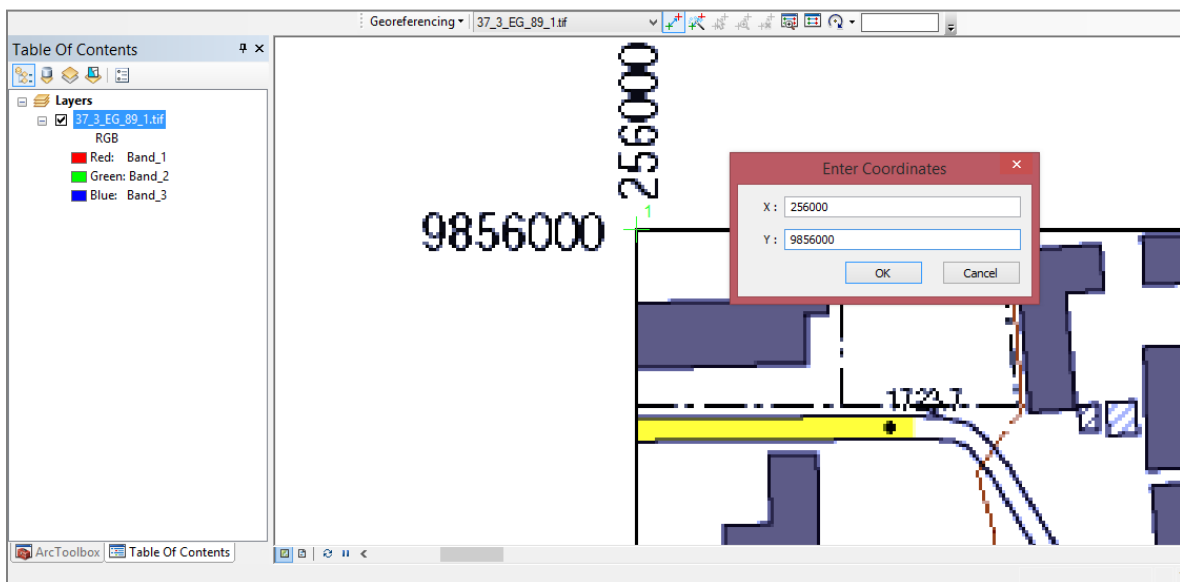

Figure 12: Georeferencing using the map coordinates

ii) Digitization

A new polygon shapefile was created for 'Buildings' and the feature type set to polygon. Another polyline shapefile was also created for 'Roads' and the feature type set to polyline. The spatial reference used was imported from the map image so that the shapefiles and map images had the same spatial reference for ease of digitization. The created shapefiles were added into the ArcMap environment as layers.

The *Start Editing* tool was activated from the *Editor* toolbar, Buildings was selected as the layer to be edited. *Create Features* command was selected from the Editor toolbar, the Buildings layer was again selected and the *Polygon* selected as the Construction tool to be used to outline the buildings from the map image (Figure 13). Once all the buildings were digitized, edits were saved and the *Stop Editing* command was used to stop all editing of the layers. The same process described above was also used for roads but in this case, *Line* was used as the Construction tool to be used for digitization.
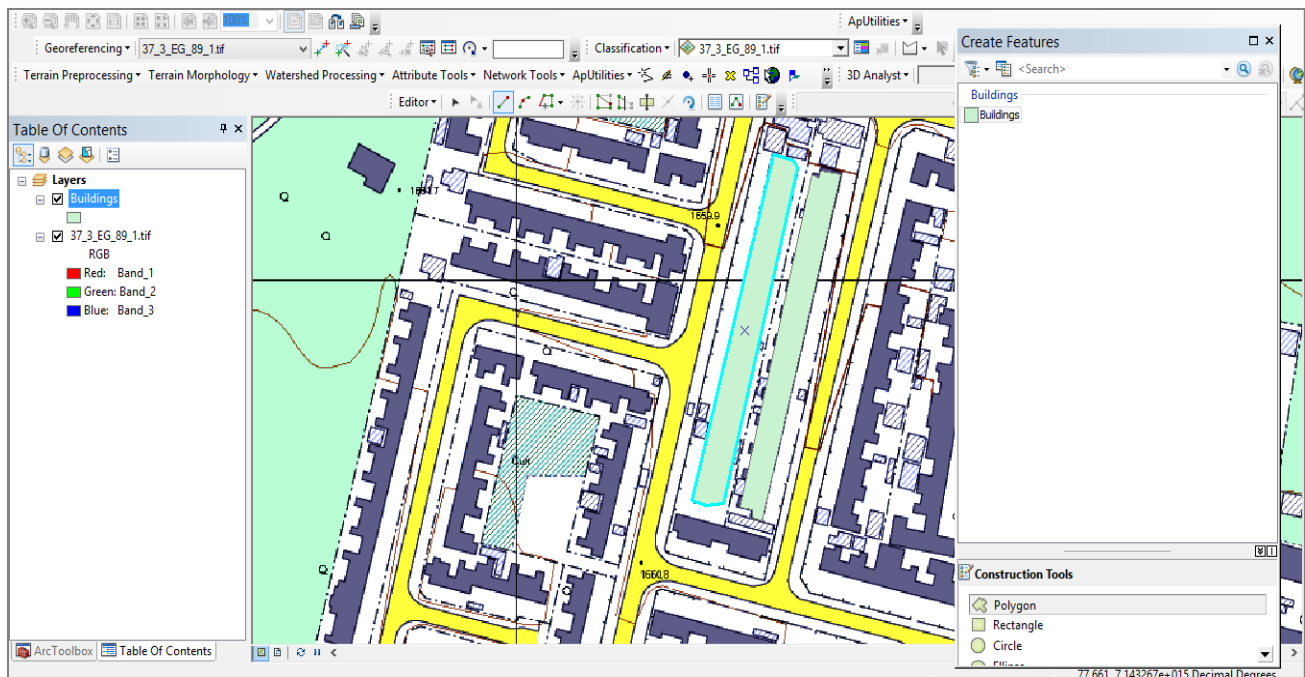

Figure 13: Digitization exercise in Arcmap

3.5.2 Orthophoto Imagery

The orthophoto imagery obtained for the study had a resolution of 2.5m. Although this was a highly complex image due to its high resolution, it was nonetheless used because it was the only

up-to-date image available for the study area that was offered free-of-charge for academic purposes. The imagery had to go through a series of processes in order to use for data analysis.

i) Mosaicing

The orthophoto obtained was provided as a collection of separate rasters of the Southern part of Nairobi. The rasters of the study area were identified and selected for use in data analysis. Since the study area rasters were separate, there was need to combine the images in order to form one complete raster. It would be easier to use one complete raster for analysis as opposed using several images for the same analysis. This process was carried out using the *Mosaic to New Raster* tool in *Data Management* tools in ArcToolbox shown in Figure 14.
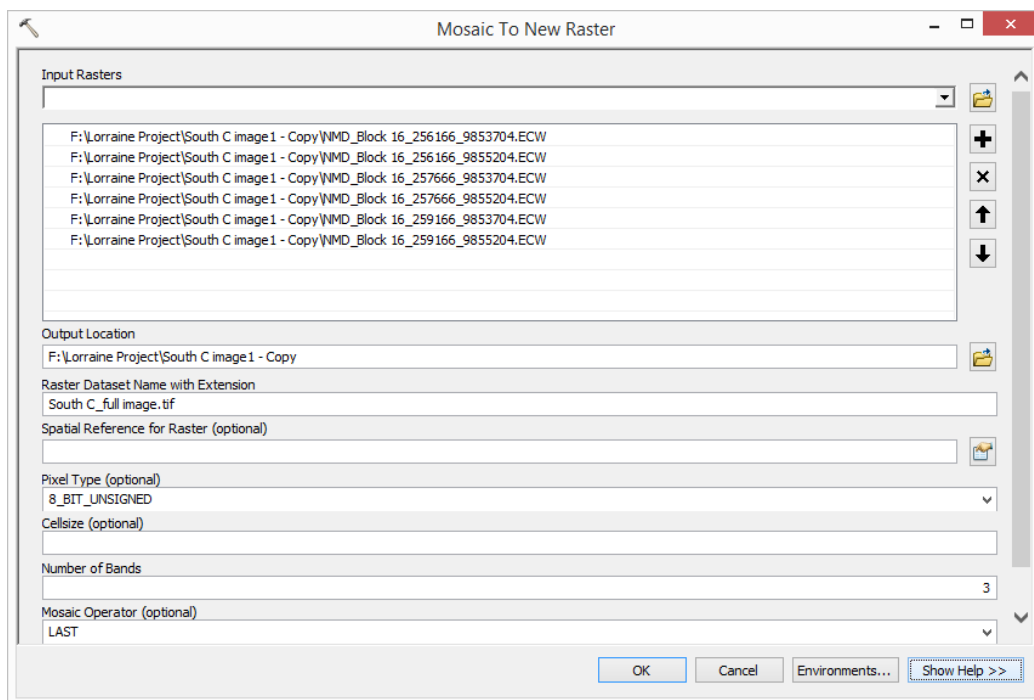

Figure 14: Mosaic to New Raster tool

The resulting image was then clipped (Figure 15) and used for digitization of features such as buildings as well as some editing some of the roads which were missing from the roads shapefile created from the topographic maps. It was also used for image classification to create a surface cover thematic map of impervious and pervious areas for the study area.
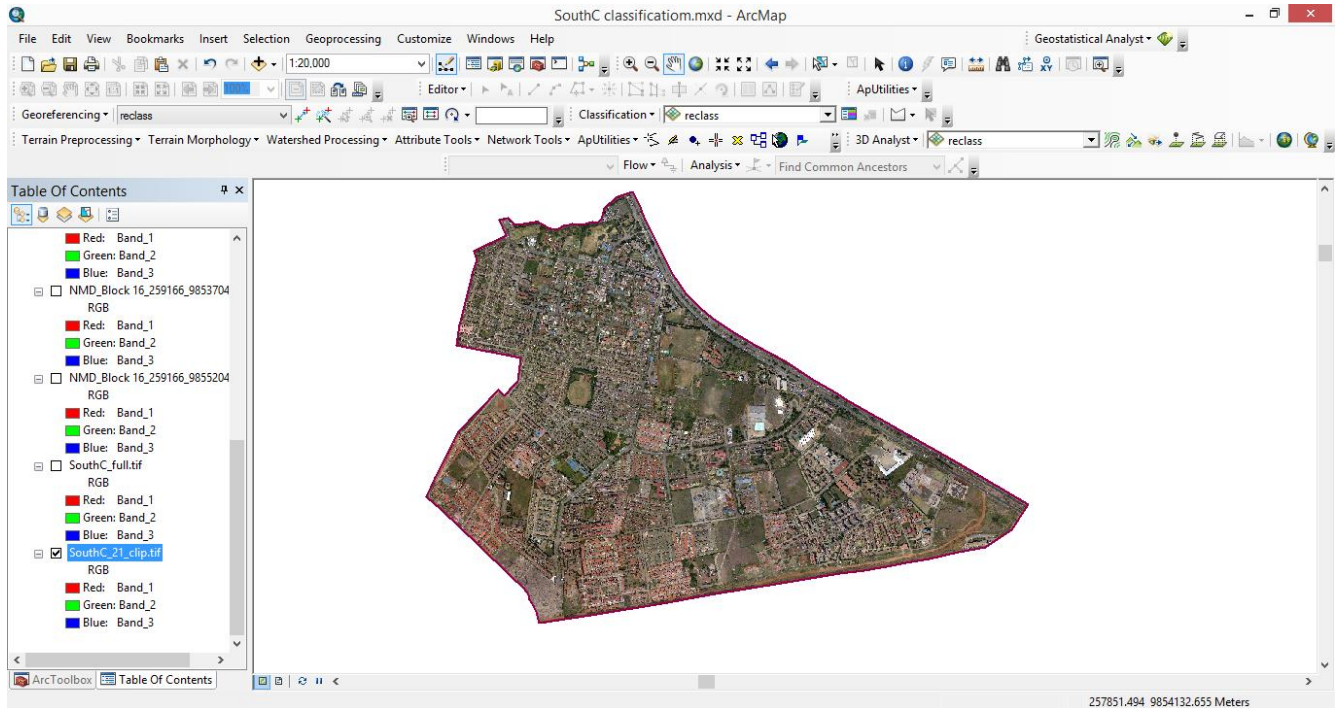
Figure 15: Clipped raster of the Study area after mosaicing.

ii)   Image Classification

Image classification refers to the task of extracting information classes from a multiband raster image. The resulting raster from image classification can be used to create thematic maps. For this study the interest was in creating a surface cover map in order to determine the amount of impervious surfaces vs. pervious surfaces.

Training samples were identified and these would act as a guide for the ArcGIS 10.1 software to know which pixel values belong in which class. Four main classes were identified on the image i.e. open spaces, built-up areas, tarmac roads, murram roads. It was however noted that within some classes, for example the Built-up areas class, there were different colours for the rooftops. Therefore it was necessary to identify each rootfop with different pixel values separately. Same case occurred with the open spaces where we had open spaces with grass and other open spaces with grass. The total number of training areas created for this study was 19 in total coded to the landcover classes previously mentioned as shown in Figure 16.

Figure 16: Training area samples used for classification.

A signature file of the training samples with a *.gsg* extension, was created and saved. This file was used during the process of classification.

The supervised classification technique selected for this study was the Maximum Likelihood Classification. This was because this technique works best if there is availability of ground truth information which was the case in this study. It is also a widely used technique as a result of better classification accuracy as compared to other supervised classification techniques.

A new classified raster *Supclss_clip* (Figure 17) was created and it was noted that the number of training areas created were the same as the number of classes the new raster had despite the difference in colour. As a result of the number of classes, it was then necessary to reclassify the them and reduce them to only two classes i.e. Pervious surfaces which would include the open

spaces and murram roads and Impervious surfaces which would include built-up areas and tarmac roads.
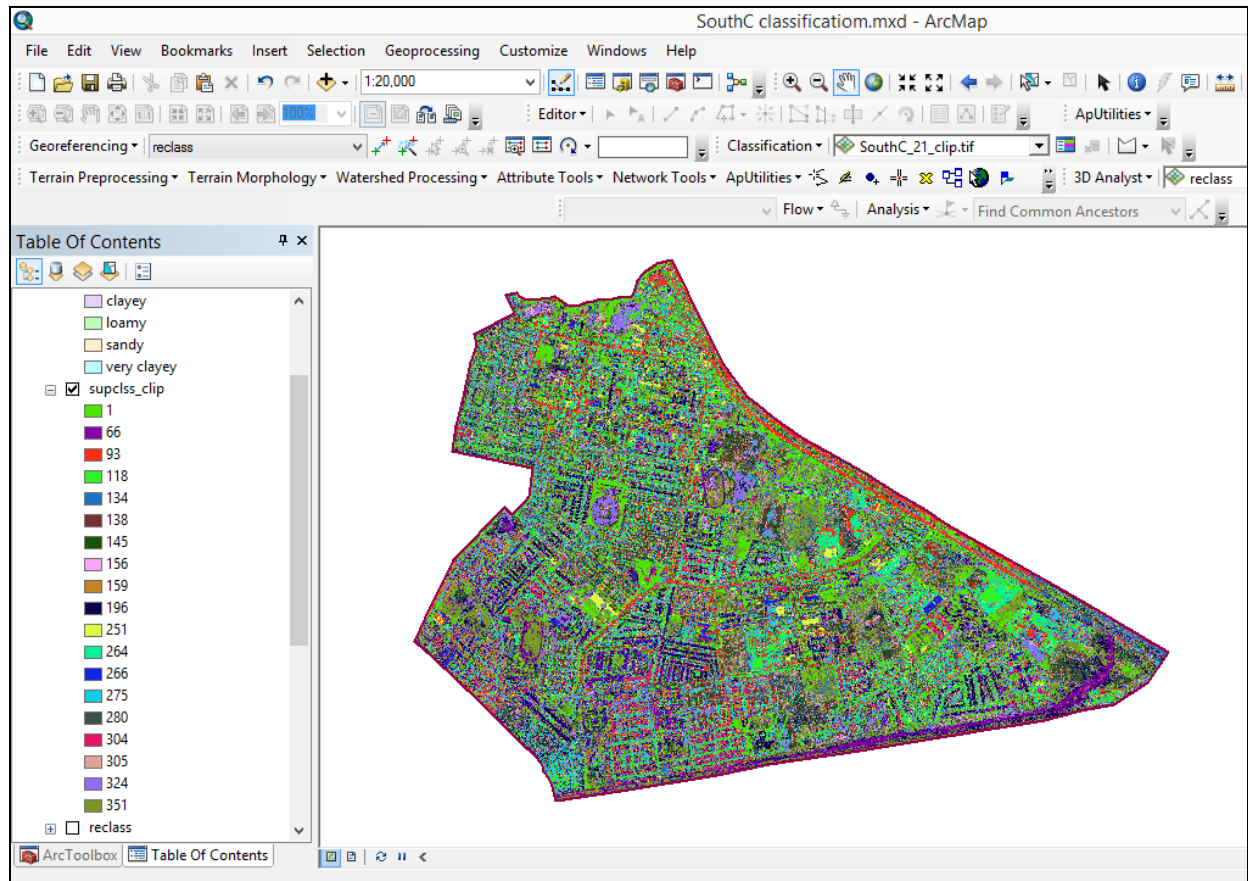

Figure 17: Supervised image classification with 19 classes.

The *Reclassify* sub-menu tool found in the *Spatial Analyst* tools was used with the input raster being the classified raster *Supclss_clip* with the 19 classes. New values were then assigned according to the value of the two classes we are interested in i.e. 1 representing Impervious surfaces and 2 representing Pervious surfaces. This was done for all the 19 values as shown in Figure 18. The new reclassified raster with only two classes specified i.e. impervious surfaces and pervious surfaces, was then subjected to further analysis.
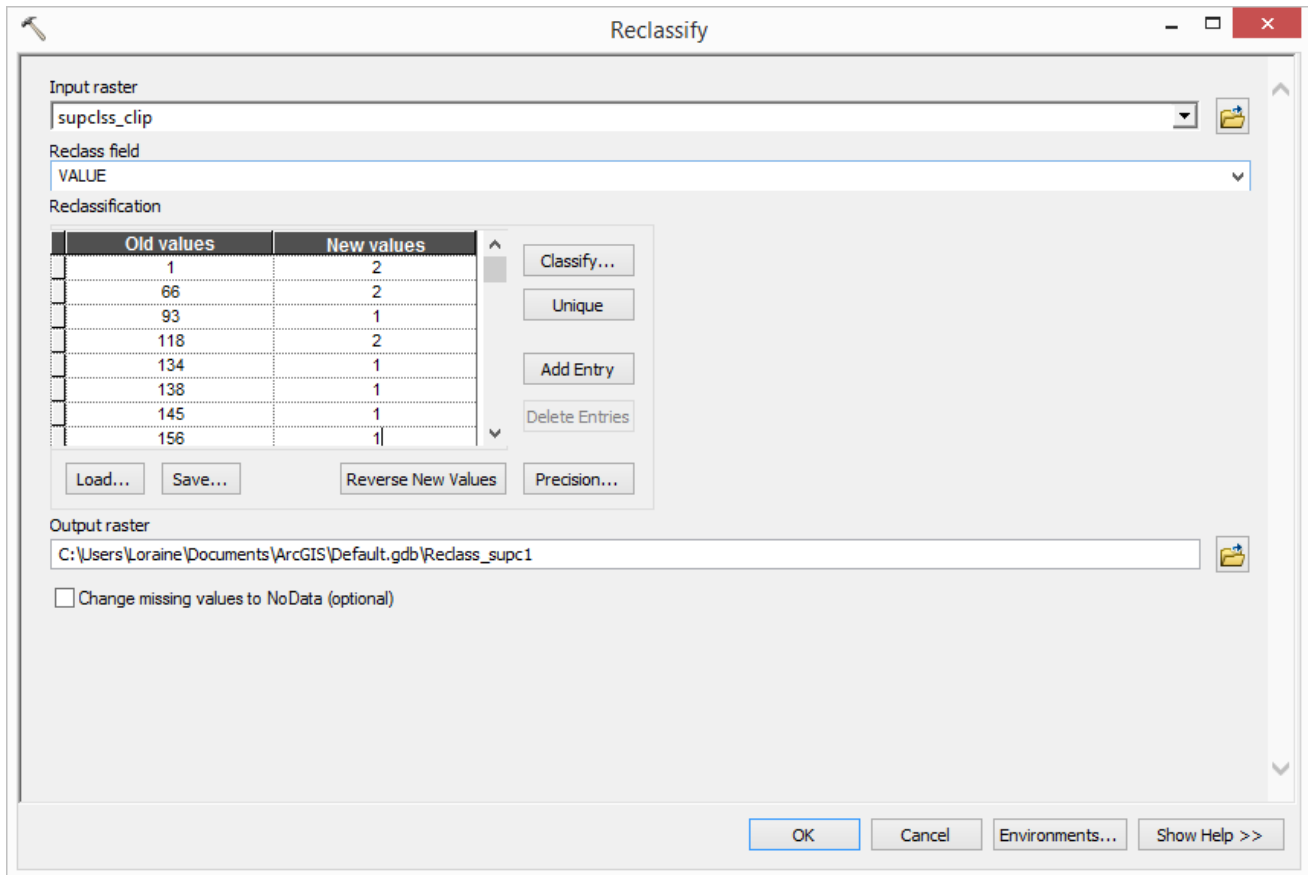
Figure 18: Reclassify Arcmap interface used to perform reclassification of the supervised classification raster

3.5.3 Field Collection Data

Due to the lack of storm water infrastructure plans at the Nairobi County Council, there was need to carry out a field survey in order to collect location data of the storm water drainage infrastructure. The field survey was carried out using a handheld GPS receiver, Garmin 60cs. All GPS points were coded during the survey to represent various features in the storm water drainage system: 1- Outfalls, 2-Driveway culverts, 3-Culverts across the road, 4-Open road drains, 5-Piped road drains, 7-Drain from plots, 8-Underground drains, 9-Start or End of drain, 10-Storm water Manholes.

The data from the GPS device was then exported from the device to a PC using Map Source software. The data was saved as a *.shp* file in order to use the data in the ArcGIS environment. Feature identity information was then added into the attribute table using the codes used during the field study, the condition of the storm water drainage features was also coded as follows: A-Good condition, B-Bad condition, C-Pinched points. Any erroneous points were eliminated from the attribute table shown in Figure 19.

FID	Shape *	type	ident	Latitude	Longitude	y_proj	x_proj	altitude	Point_ID	Condition
0	Point	WAYPOIN	065	-1.309585	36.822278	9855145.993828	257678.278934	1699.48	1	B
1	Point	WAYPOIN	066	-1.309716	36.822276	9855131.521135	257678.011525	1700.44	1	B
2	Point	WAYPOIN	067	-1.311031	36.82244	9854986.042461	257696.408795	1689.63	4	A
3	Point	WAYPOIN	068	-1.311137	36.822488	9854974.300397	257701.831171	1688.91	4	A
4	Point	WAYPOIN	069	-1.311185	36.822504	9854969.054326	257703.599266	1687.23	2	A
5	Point	WAYPOIN	070	-1.311236	36.822528	9854963.3456	257706.291665	1686.03	2	A
6	Point	WAYPOIN	071	-1.311568	36.822706	9854926.722615	257726.115235	1686.51	2	A
7	Point	WAYPOIN	072	-1.311632	36.822742	9854919.550095	257730.11533	1687.47	2	A
8	Point	WAYPOIN	073	-1.311664	36.822753	9854916.028107	257731.359468	1686.51	3	A
9	Point	WAYPOIN	074	-1.311781	36.822814	9854903.165449	257738.182533	1684.58	4	B
10	Point	WAYPOIN	075	-1.311932	36.822893	9854886.401361	257746.959218	1683.62	2	C
11	Point	WAYPOIN	076	-1.312032	36.822952	9854875.420563	257753.566008	1685.3	2	C
12	Point	WAYPOIN	077	-1.312098	36.822991	9854868.025773	257757.883466	1683.38	4	B
13	Point	WAYPOIN	078	-1.312271	36.823171	9854849.009328	257777.981049	1684.58	4	B
14	Point	WAYPOIN	079	-1.312329	36.823247	9854842.563844	257786.412877	1684.34	4	B
15	Point	WAYPOIN	080	-1.312473	36.823597	9854826.688152	257825.384853	1681.94	4	B
16	Point	WAYPOIN	081	-1.312582	36.824103	9854814.61038	257881.747095	1680.98	4	B
17	Point	WAYPOIN	082	-1.312595	36.824135	9854813.167095	257885.266277	1680.02	2	C
18	Point	WAYPOIN	083	-1.312603	36.824179	9854812.355509	257890.18462	1680.5	2	C
19	Point	WAYPOIN	084	-1.312646	36.824309	9854807.611975	257904.689504	1680.74	4	B
20	Point	WAYPOIN	085	-1.312687	36.824472	9854803.075517	257922.76824	1682.66	4	B
21	Point	WAYPOIN	086	-1.312707	36.824596	9854800.843979	257936.664426	1682.9	2	C
22	Point	WAYPOIN	087	-1.312727	36.82467	9854798.616611	257944.803235	1683.86	2	C
23	Point	WAYPOIN	088	-1.312738	36.824704	9854797.479638	257948.611487	1683.62	4	B
24	Point	WAYPOIN	089	-1.312815	36.824948	9854788.973635	257975.782271	1685.54	4	B
25	Point	WAYPOIN	090	-1.312843	36.825054	9854785.850169	257987.561015	1685.78	2	C
26	Point	WAYPOIN	091	-1.312851	36.825115	9854784.993942	257994.438966	1686.51	2	C
27	Point	WAYPOIN	092	-1.312866	36.825167	9854783.292953	258000.141931	1687.47	4	B
28	Point	WAYPOIN	093	-1.312921	36.825425	9854777.245376	258028.952857	1687.95	4	B

Table — Field_points

|◄ ◄   8 ► ►| (0 out of 751 Selected)

Field points

Figure 19: Attribute table for field points data

3.5.4   Spot Heights

Spot heights were obtained from the Survey of Kenya. Local Polynomial Interpolation (Figure 20) in the *Interpolation* toolset of *Geostatistical Analyst* tools was used to create a Digital Elevation Model (DEM) that would form the basis for further hydraulic analysis as described in Chapter 4.
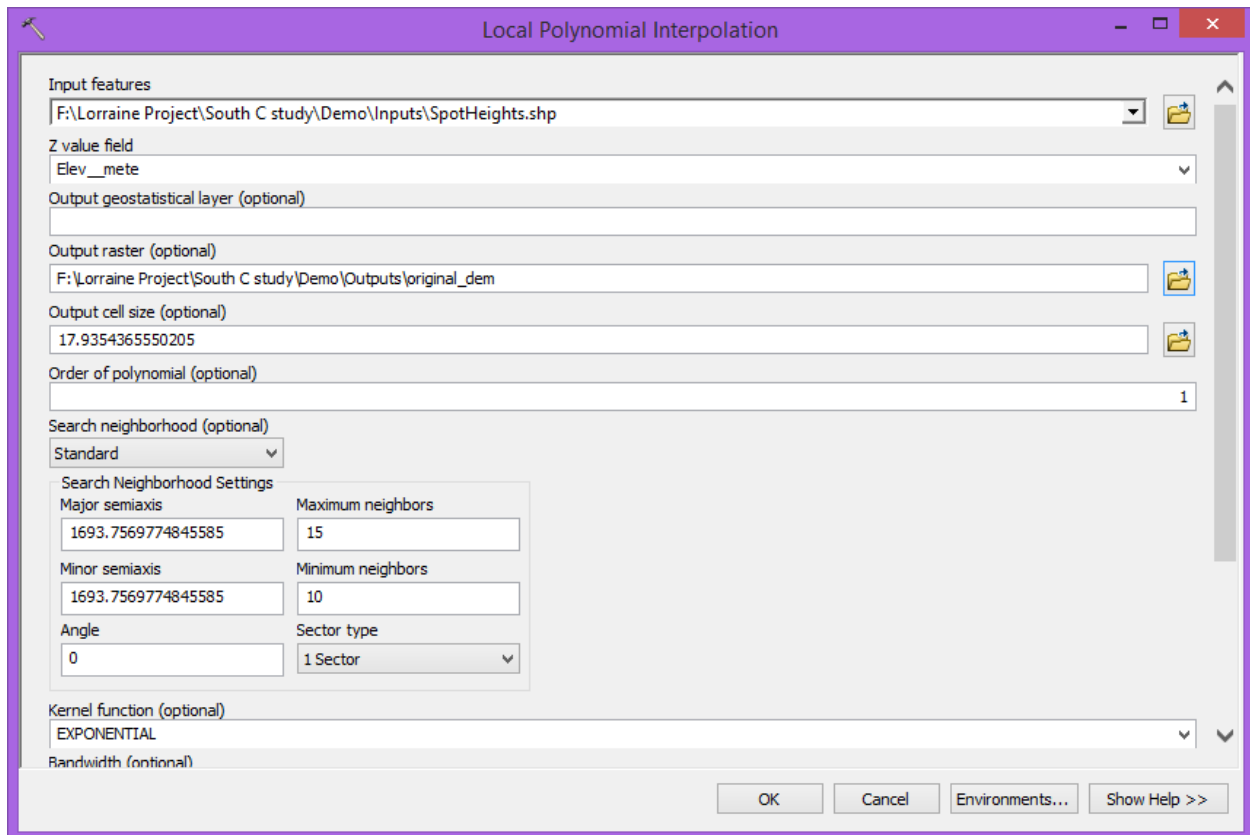
Figure 20: Local Polynomial Interpolation Arcmap interface used to create the Digital Elevation Model

Local polynomial interpolation was selected because it is a technique that is sensitive to the neighborhood distance. It also provides two measures of accuracy that are not available for the other deterministic interpolation methods offered in ArcGIS Geostatistical Analyst.

- Prediction standard errors indicate the uncertainty associated with the value predicted for each location.
- Spatial condition number is a measure of how stable or unstable the solution of the prediction equations is for a specific location. If the condition number is large, a small change in the matrix coefficients results in a large change in the solution vector (regression coefficients). The spatial condition number surface shows variation in the numerical model stability and provides additional information on the prediction uncertainty since the prediction standard error surface is created assuming that the model is correct.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Study Area

The study area selected for this project study is known as Nairobi South C area (Figure 21). It lies in the Southern area of the County Council of Nairobi. It consists of both residential and commercial areas. South C is one of the areas in Nairobi that suffers greatly during heavy rains. Analysis was carried out on the topographical conditions of the study area in order to better understand its relationship with storm water. Storm water infrastructure was also analyzed in order to establish the current situation of the system.
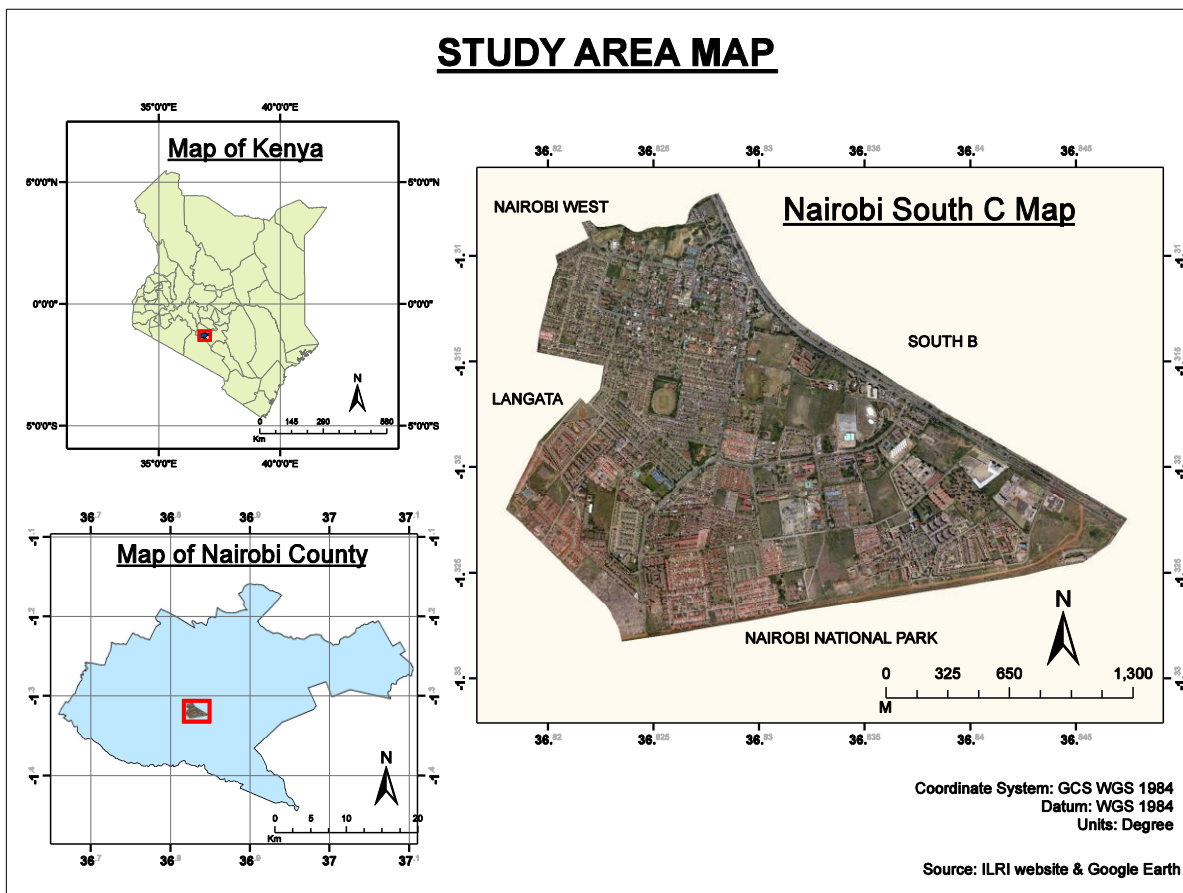

Figure 21: Study area map - Nairobi South C

4.2 Impervious vs. Pervious Surfaces

From the Literature review in Chapter 2, impervious surfaces are areas that do not allow water to infiltrate into the ground while pervious surfaces are areas that allow water to infiltrate into the ground. In order to better understand South C area's storm water runoff, an impervious layer was developed using ArcGIS and the percentage area determined as described in the previous chapter.
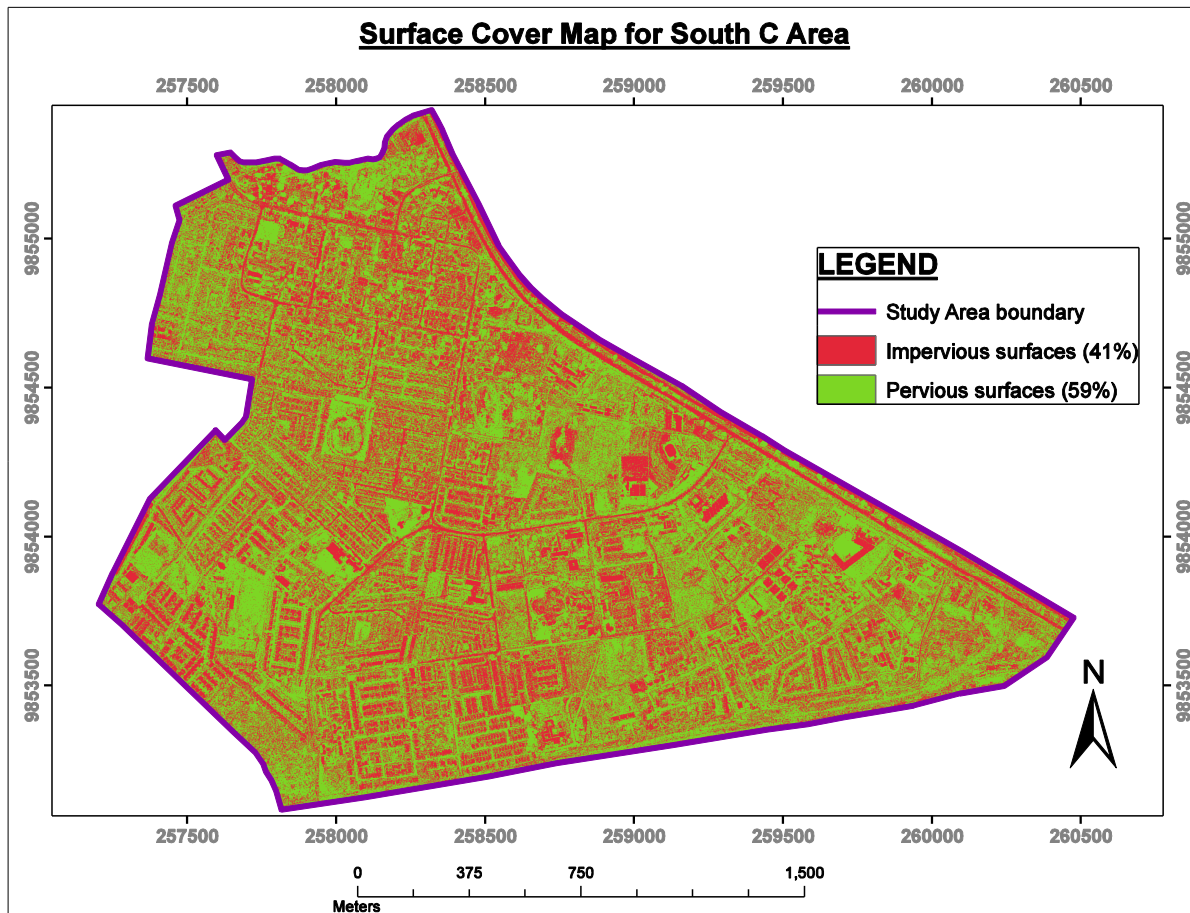

Figure 22: Surface cover map of the study area

The final map after reclassification shown in Figure 22, consists of red areas indicating all the impervious surfaces including the tarmac roads, sidewalks, rooftops and parking lots. 41 % of South C Area is composed of impervious surface while 59% of the study area is composed of pervious surfaces. High percentage of connected impervious surfaces contributes to high peak flows and storm water runoff volumes. These areas covered by impervious surfaces diminish the

areas where that rainfall is able to infiltrate into the soil thereby increasing storm water volumes and increasing pollutant loading into receiving water bodies.
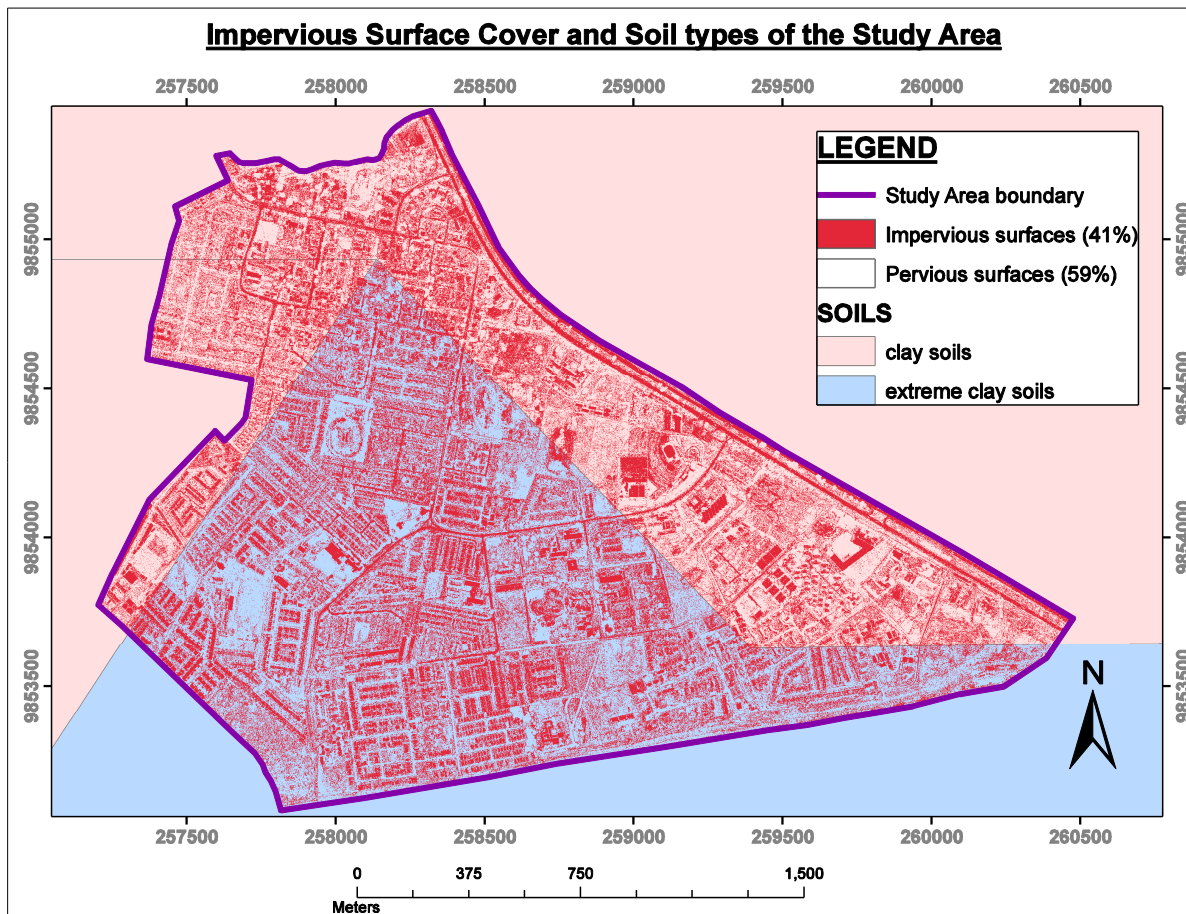

Figure 23: Impervious surface cover with soil types

Figure 23 is an overlay map of impervious layer with soil type layer. The soil types within the study area range between poorly draining soils to very poor draining soils. From the map it was noted that South C area predominantly consists of extreme clay soil, this means drainage is very poor hence presence of high levels of water runoff and low levels of infiltration. This means that though the pervious surfaces cover 59% of the study area, it is more likely to have rain water flow over the surfaces and does not get absorbed into the soil due to the soil types found there. This further explains the high water runoff during rain events.

4.3 Storm Water Drainage Analysis

4.3.1 Existing Storm water Drainage Flow

South C area has 2 major outfalls, one at Nairobi West joining Ngong River (A) and one opposite the Red Cross (B) that eventually ends up at Ngong River. Minor outfalls are located near Kenol along Muhoho Avenue (C) and near the Southern Bypass (D). In Figure 24, the blue arrows indicate the direction of flow of runoff within the storm water drainage system. This storm water drainage leads runoff to the outfalls, all of which end up at different sections of the Ngong River. Most of the storm water runoff within the study area is conveyed into the storm water drainage channels or runs over surfaces and is transported directly to the outfalls without use of a detention pond or a treatment system. This has a direct impact on the quality of storm water runoff that ends up in the Ngong River.
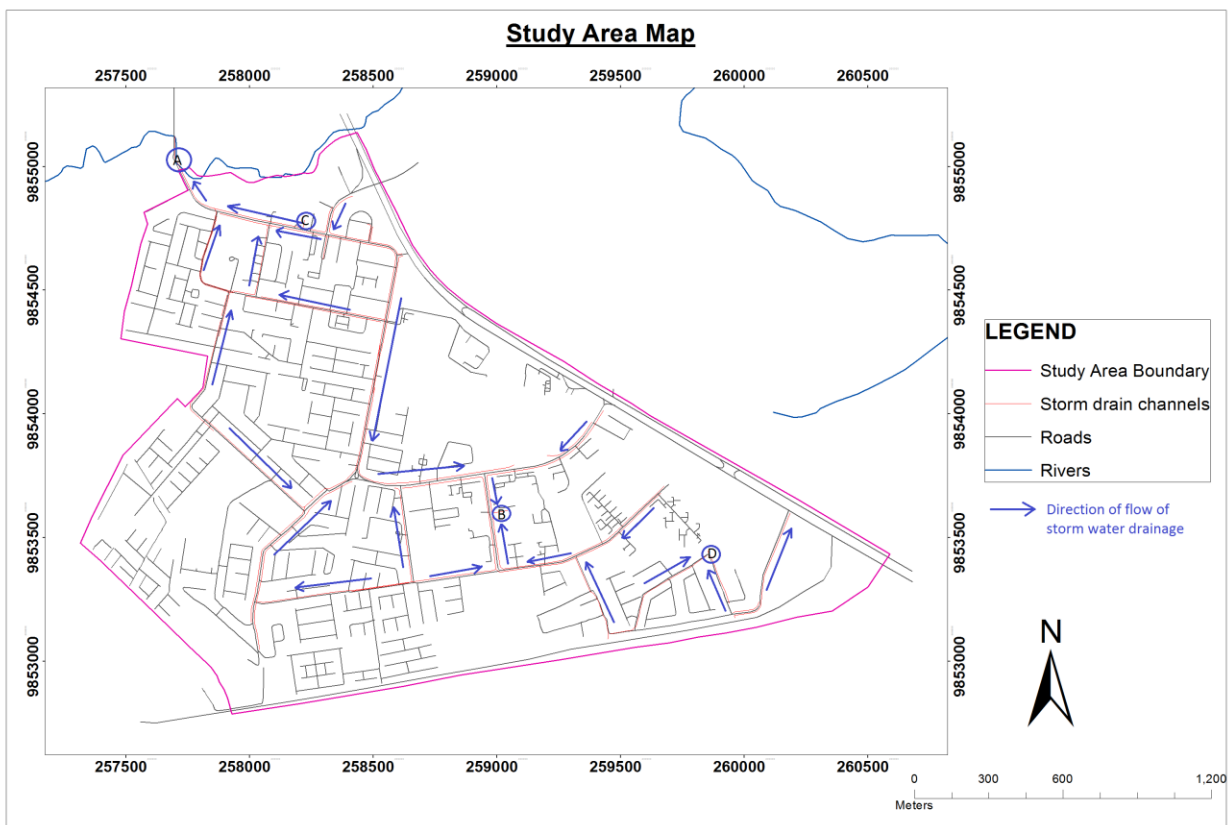

Figure 24: Storm water drainage flow within South C

4.3.2 Existing Condition of Storm Water Drainage Infrastructure

From the field survey conducted during data collection, it was noted that majority of storm water infrastructure was surface drainage consisting of open channel drains. Many of the channels were in poor condition, presence of small size culverts, clogged with debris or heavily silted thus preventing efficient movement of water (Figure 25).

It was also noted that there were also some underground drainage systems along some roads. However it was noted that most of the underground drainage within the older roads of South C area such as Ole Shapara Avenue and Muhoho Avenue were blocked and therefore not in use. Those along the newer roads were noted to still be in good condition.

(a)   (b)   (c)

(d)   (e)   (f)

Figure 25: Existing conditions of storm water drainage infrastructure in South C.

(a) Main outfall at Nairobi West (b) Dilapidated drainage channels (c) Small size culverts causing pinch points in the drainage system (d) Solid waste within the drainage channels. (e) Natural drainage channel increasing the rate of siltation within the drainage system. (f) Blocked underground drains with solid waste.
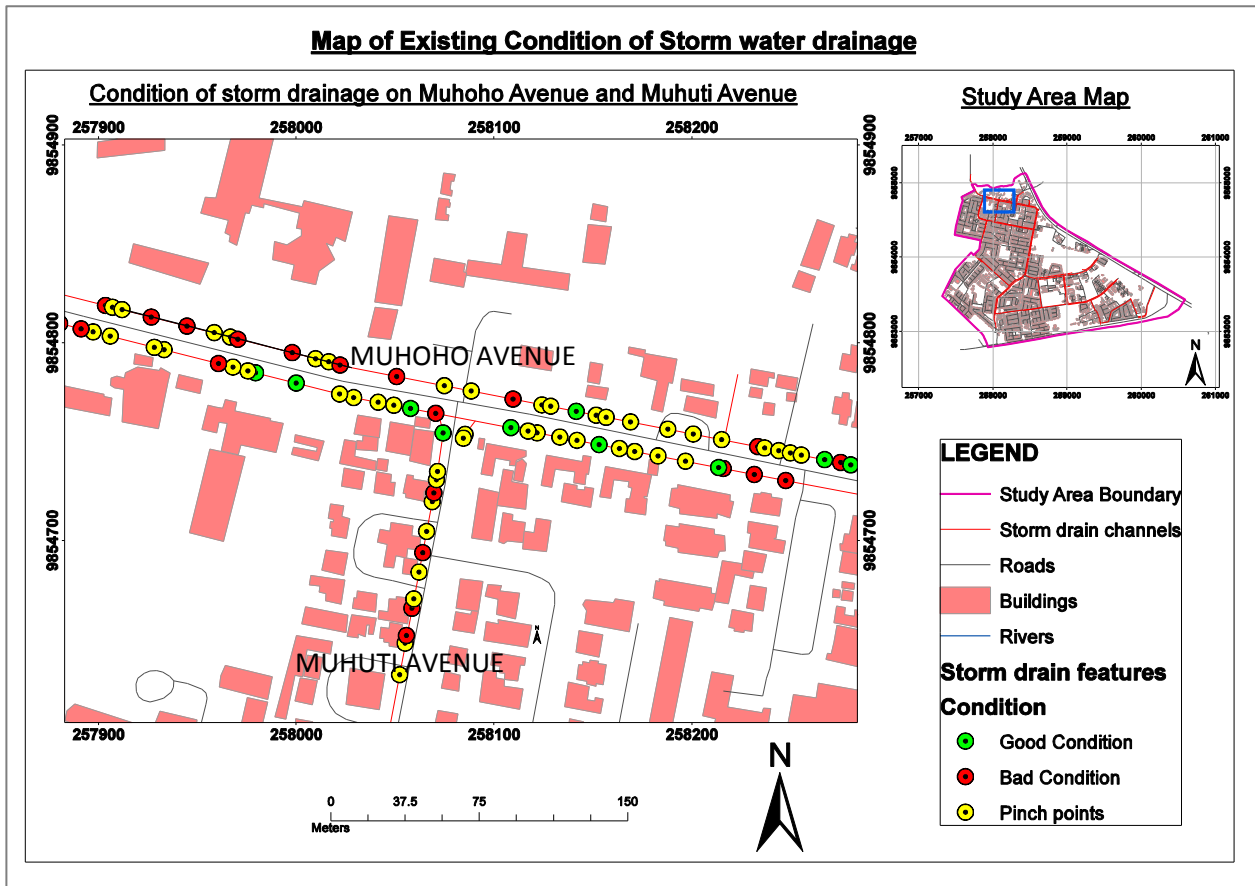
Figure 26: Condition of Storm water drainage

Displayed on the Figure 26 is the condition of storm water drainage along Muhoho Avenue. The conditions vary from green/good to red/bad condition. The green represents good condition, yellow – pinch point culverts that need to be upgraded (Figure 27-a), red - poor condition and are at risk of flood due to blockage from solid waste or debris (Figure 27-b). These culverts should be serviced first in the event of a storm.

Figure 27: Pinch point (a) and Drain channel in poor condition (b)

4.3.3 Natural Topography vs. Storm Water Drainage Topography

South C is a relatively flat area and drainage slopes are also not steep but instead more gradual. When intense rain events occur, these storm drain slopes reduce the velocity of the water thereby increasing the time of concentration. This increase in time of concentration causes storm water volumes to accumulate over a shorter period of time which can cause localized flooding especially in low points of the drainage system within the study area.

Various profile sections were then selected from certain areas of the study area shown in Figure 28. These sections were selected because they are areas that are most affected by localized flooding. The sections were taken in order to understand the effect of the manmade storm water drainage topography on occurrences of localized flooding within the study area and compare this with the natural topography of these particular areas. This exercise would assist in proving whether there are any conflicts or inconsistencies between the natural topography and the manmade storm water drain topography.
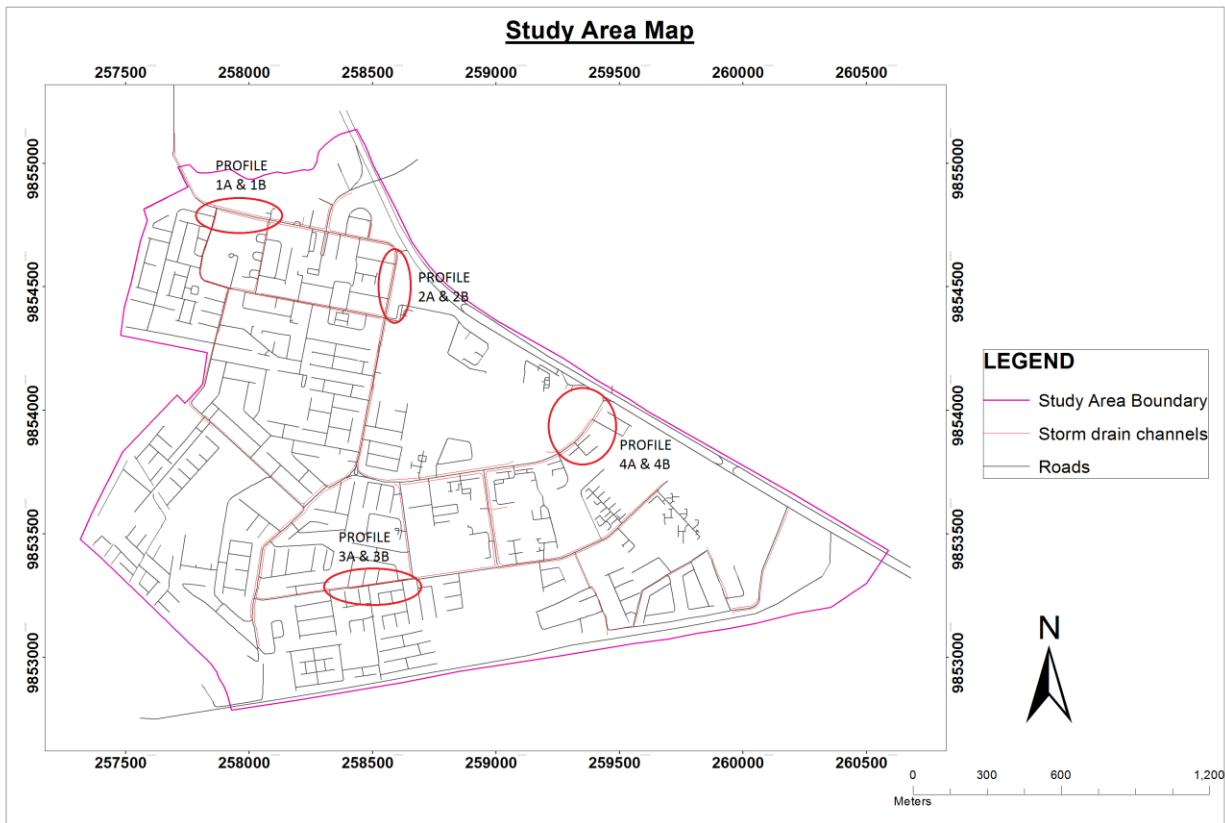

Figure 28: Map showing where profile sections were taken

Profiles of both the natural topography and the storm drain topography were compared in various parts of the study area as indicated by the various profiles shown in various graphs.
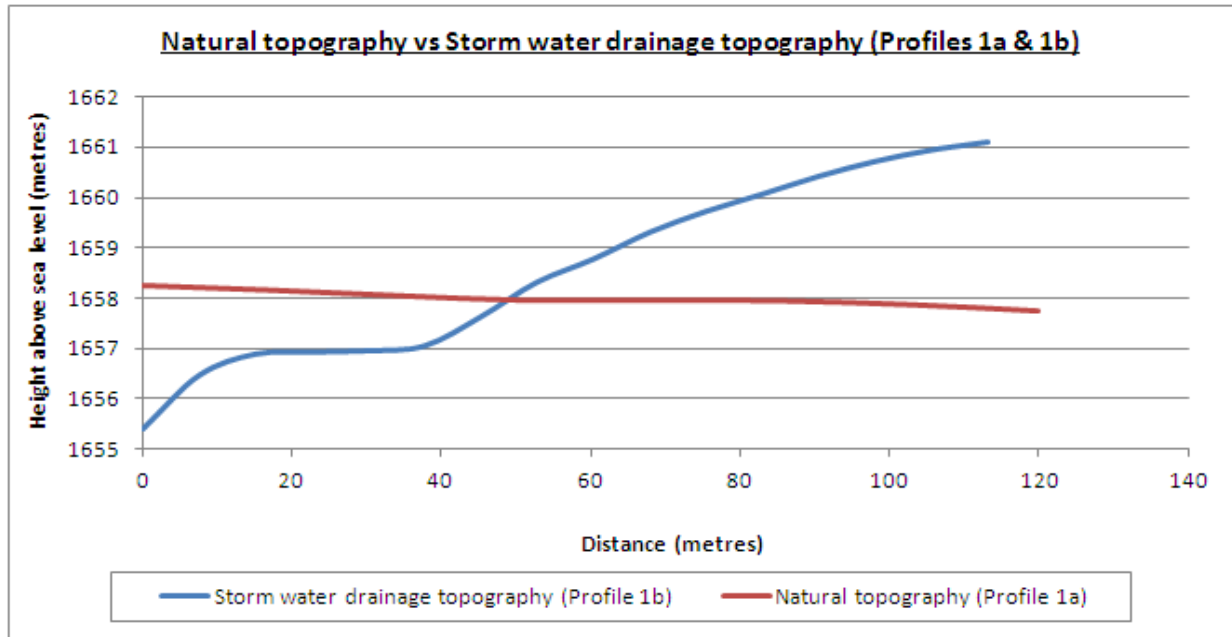

Figure 29: Profiles 1a & 1b

Profile 1a shown in red is the natural topography of the section which shows the general direction of the natural slope. Profile 1b shown in blue shows the storm drainage topography of the same section. It was noticed on Figure 29, that the slope of storm drainage topography was in the opposite direction to the natural topography. Storm drainage in this area was generally directed towards one of the major outfalls of South C which is located at Nairobi West.

The same situation occurs in Profile 2a and 2b, and Profiles 4a and 4b, as shown in Figure 30 and 31 respectively, where the storm water drainage topography is directed in the opposite direction to the natural topography. In profile 2b, it is seen on the slope profile that there is a low point which could also be a potential site for localized flooding.
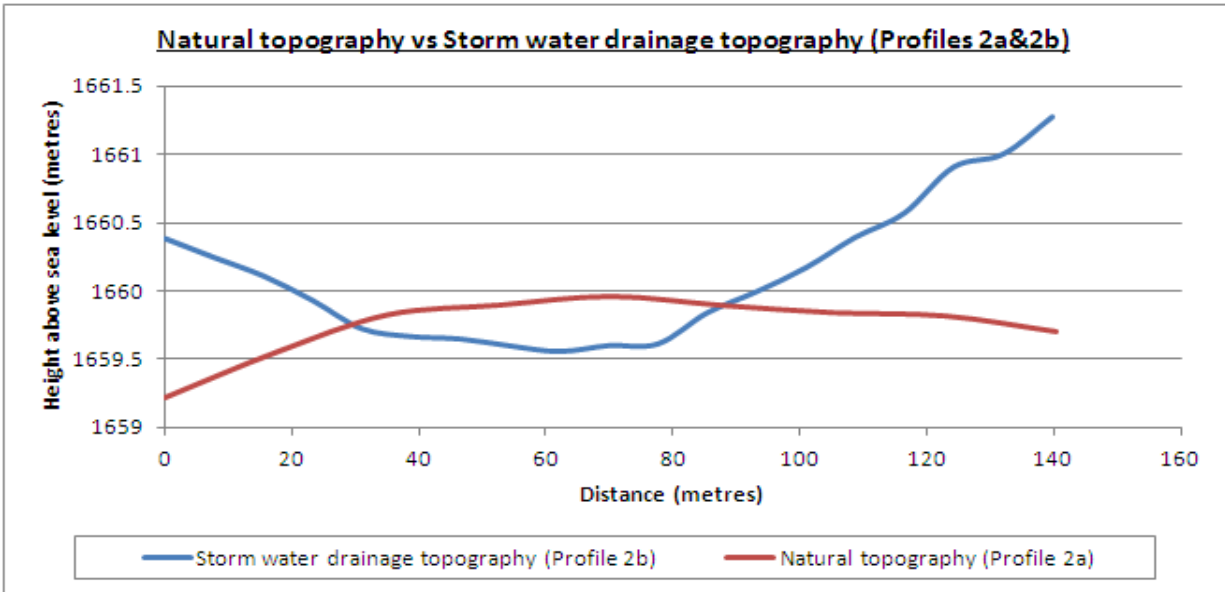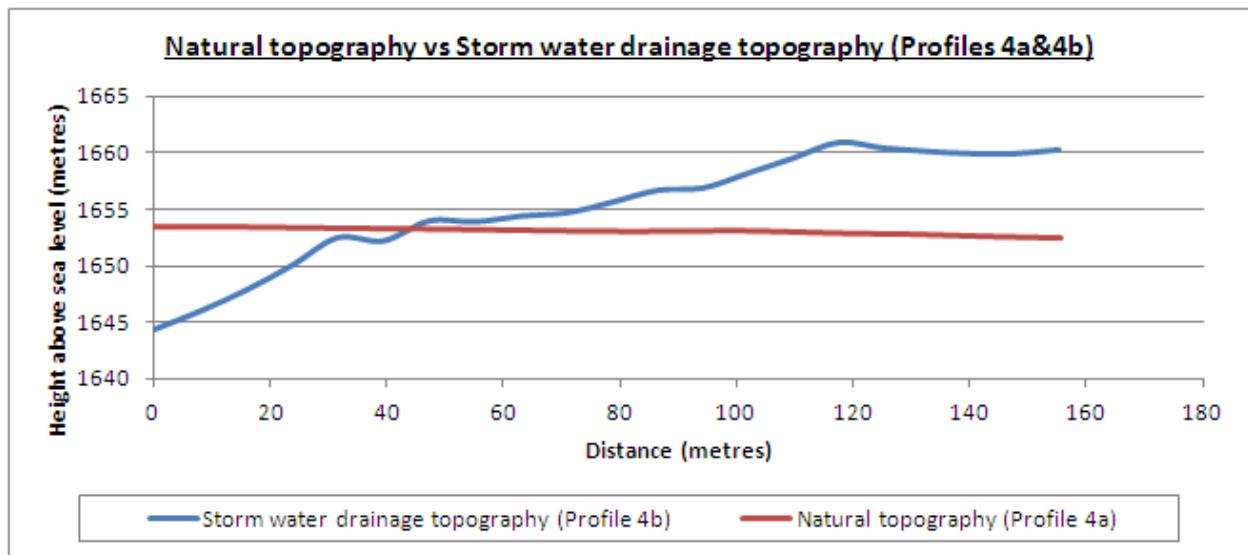
Figure 30: Profiles 2a & 2b

Figure 31: Profiles 3a & 3b

In the final profile selected, Profiles 3a and 3b, the slope direction of natural topography was in the same direction as the storm water drainage topography as shown in Figure 32. It was also noted that the storm drain topography is steeper than that of natural topography.
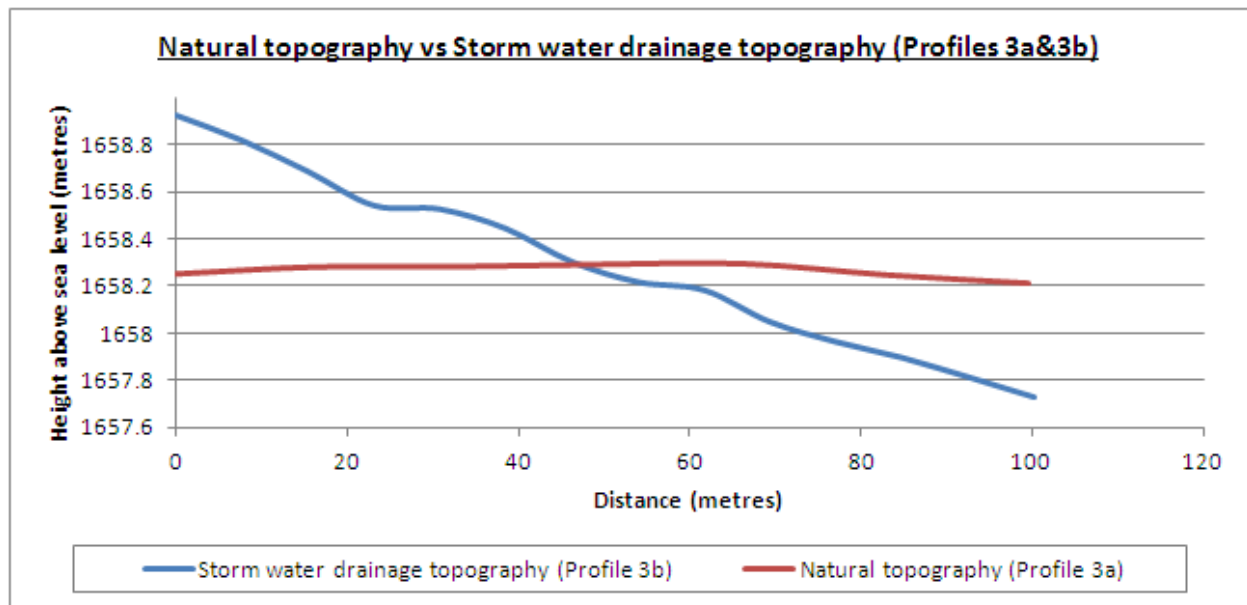
Figure 32: Profiles 4a & 4b

Generally it was noted that the storm drainage topography slopes for all four sections taken, were steeper than those of the natural topography. Whereas steeper slopes would transport storm water faster, they would also increase storm water runoff volumes. Moreover in cases where there would be an obstruction within the storm drainage infrastructure such as debris, siltation, pinch points or dramatic reduction of slope from steep to gentle, this would cause runoff speeds to slow down giving rise to flooding.

4.3.4   Sewer Lines vs. Storm Water Drainage

During the course of this study, there was need to establish whether there are areas of combined sewer and storm drainage. Such combined systems are known to increase the occurrence of flooding due to overflow during heavy rains. The sewer line layer for the study area was then overlaid onto the storm water drainage layer and analysis was done using ArcGIS 10 software (Figure 33). This was done in order to determine whether there were any areas of combined sewer and storm water drainage which would be a serious cause of flooding and degraded water quality posing health risks for the surrounding neighbourhood in case of overflow. From the field survey and data analysis using GIS software, it was confirmed that there are no areas of combined sewer and storm drainage in South C area. However it was noted that since the sewer lines and manholes run along the roads, these manholes would likely get filled up with storm water during heavy rains adding to the flooding occurrences caused by overflow of the sewer.
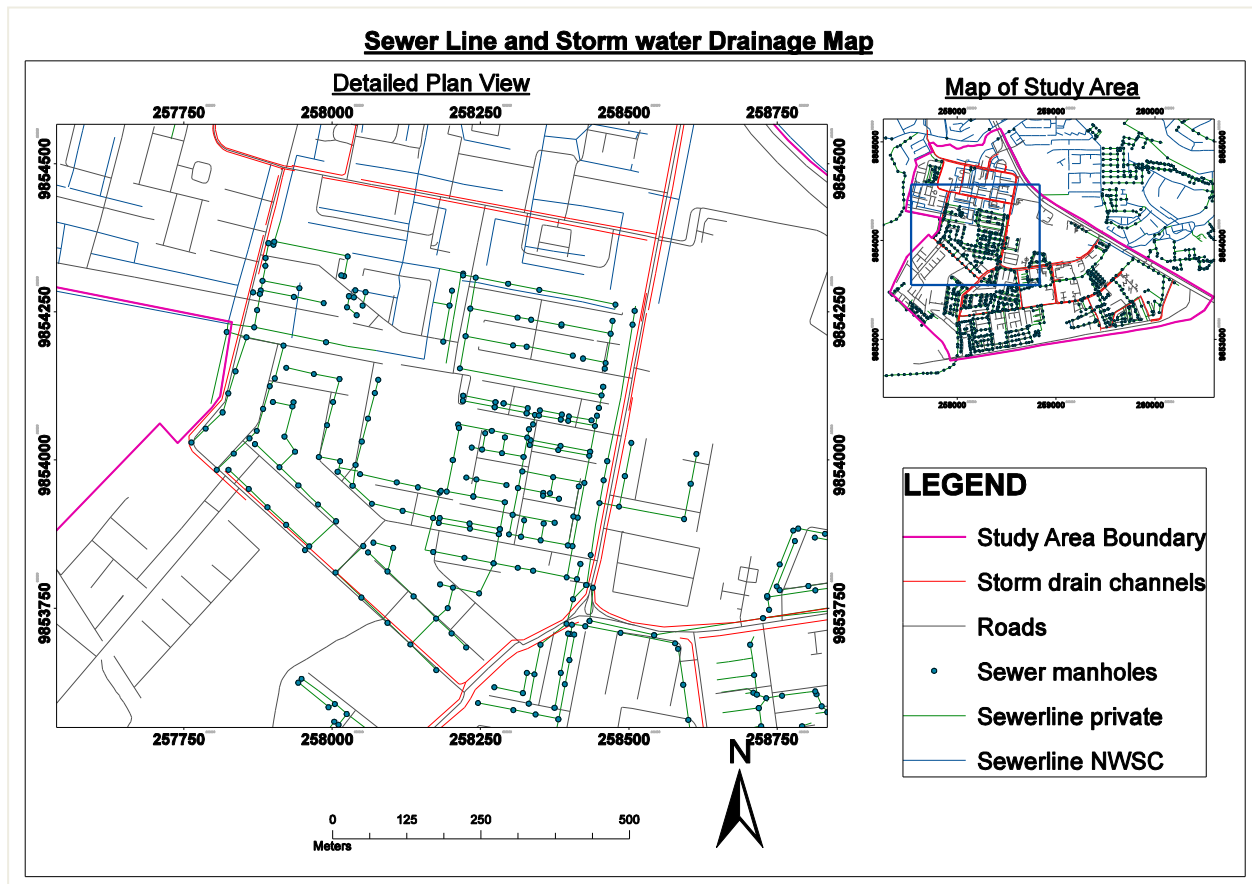
Figure 33: Sewer line and storm water drainage map

4.4 Hydrology Analysis

There was need to conduct a hydrology analysis of the South C area so as to understand how the natural topography interacts with the existing storm water drainage. An ArcGIS extension known as ArcHydro tools and Hydrology in Spatial Analyst tools were used during this process of Hydrology Analysis.

4.4.1 DEM Generation

The Digital Elevation Model generated from spot heights as described in Chaper 3 was used during this process of analysis. The DEM included the study area and extended beyond the study area revealing an area with gentle slope ranging from 1633.21 – 1731.65 m. Within the study area the range is between 1648 – 1663 m.

Inconsistencies in the DEM often times cause sinks. Sinks in the DEM data can be sample errors in the data, due to a typo, a place where the scale of the data does not adequately represent an existing elevation or some other source. The Fill tool was used on the DEM to provide a smoother surface that modifies the elevation value to eliminate elevation inconsistencies in the DEM that may affect subsequent results of the hydraulic analysis and allow for further analysis to be carried out. The resulting map was as shown in Figure 34.
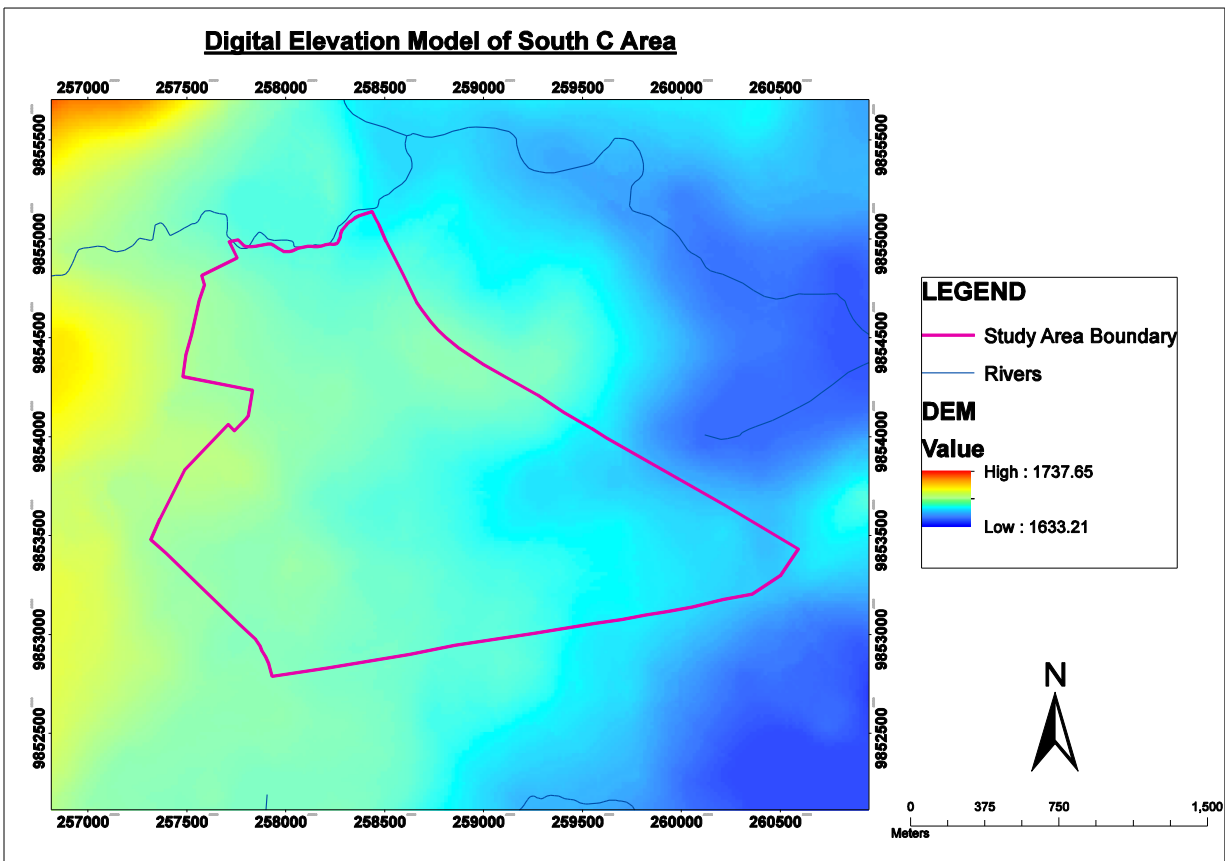

Figure 34: Depressionless digital elevation model of study area

4.4.2 Flow Analysis

i) Flow direction

A flow direction grid assigns a value to each cell to indicate the direction of flow –that is, the direction that water will flow from that particular cell based on the underlying topography of the landscape. The *Flow Direction* tool was used to create a flow direction raster grid. The filled

DEM (with no sinks) was used as the input surface raster. The result shown in Figure 35 is a map of the output raster that shows the direction of flow out of each cell.
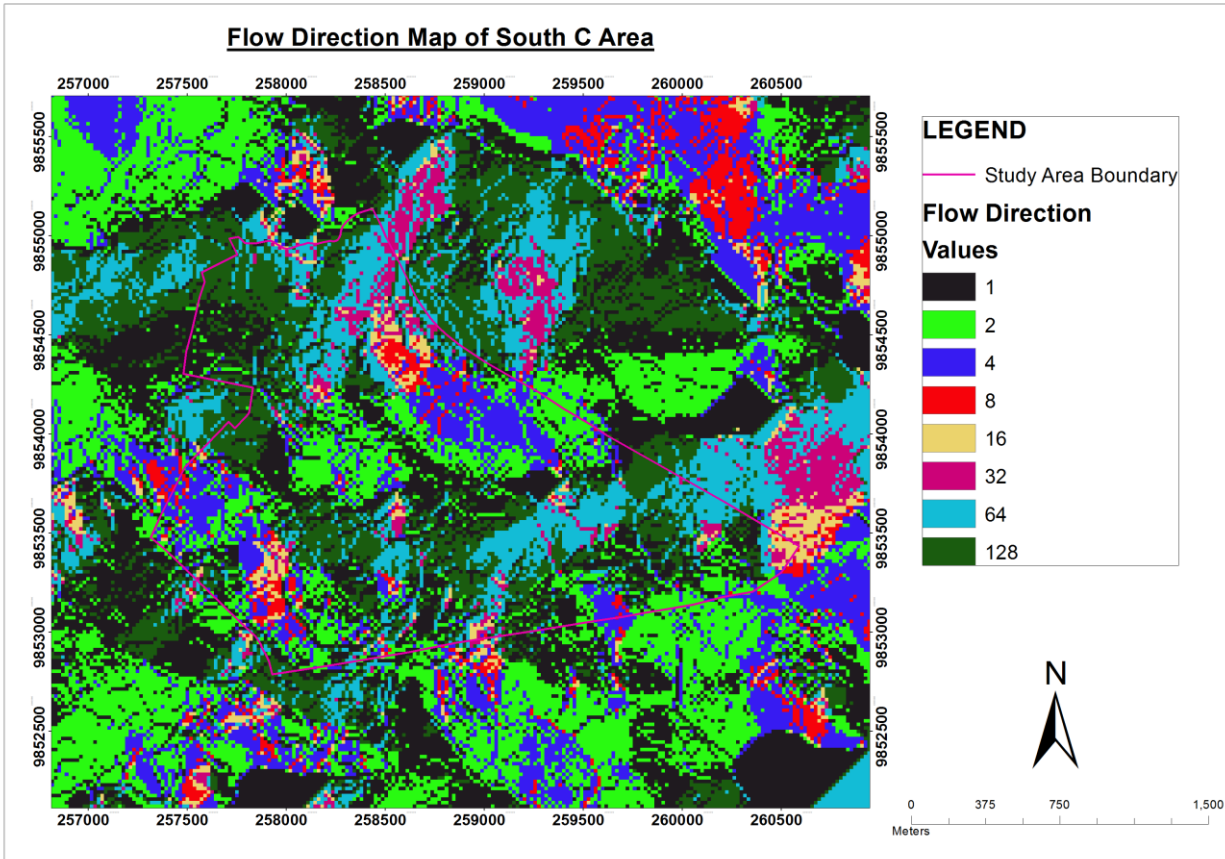

Figure 35: Flow direction map

The areas of each value shown in the flow direction raster represent areas of similar aspect. Figures 36 and 37 give us a better understanding of how the values are set. For every 3x3 cell neighbourhood, the grid processor finds the lowest neighbouring cell from the centre. Each number in the matrix shown in Figure 36 corresponds to a flow direction –that is, if the centre cell flows due north, its value will be 64 (Figure 37); if it flows northeast, its value will be 128, etc. These numbers have no numeric meaning –they are simply codes that define a specific directional value, and are determined using the elevation values from the underlying DEM.
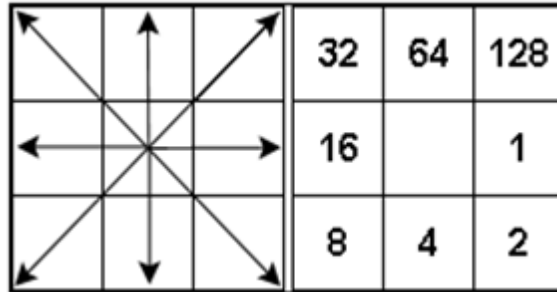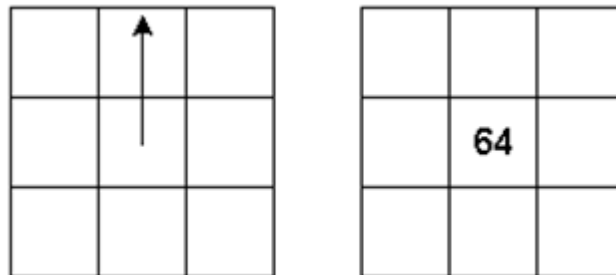
Figure 36: Flow direction matrix

Figure 37: Flow direction is north, cell is coded 64

Although this grid was not used for analysis directly, it was a crucial step in hydrological modeling, as the direction of flow would determine the ultimate destination of the water flowing across the surface of the land. The flow direction grid was used to create other layers which were used for analysis such as the Flow Accumulation layer.

ii) Flow Accumulation

Flow accumulation for the study area was carried out in order to understand the direction of flow of drainage within the study area. The *Flow Accumulation* tool calculates the flow into each cell by identifying the upstream cells that flow into each downslope cell. In other words, each cell's flow accumulation value is determined by the number of upstream cells flowing into it based on landscape topography.

The flow direction raster created in the previous section was used as the input and the resulting map is the flow accumulation map of the Study area and its surroundings. From the flow accumulation map created, it is evident that the cells with higher flow accumulation values are located in areas of lower elevation such as valleys or drainage channels when water flows naturally as it is following the landscape.

The existing storm drainage and roads layers were then overlaid onto the flow accumulation raster as shown in Figure 38. From this it was possible to establish drainage channels that were likely to receive high water flow accumulation.
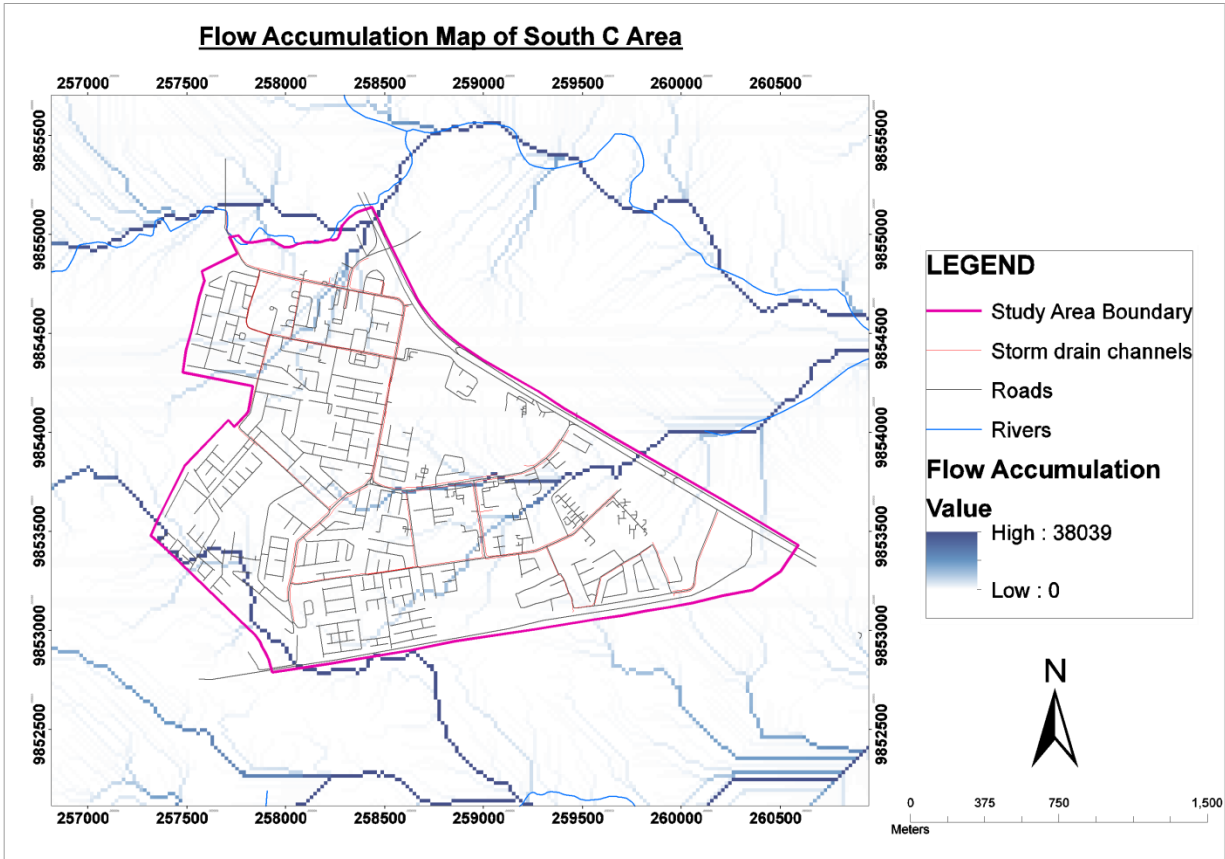

Figure 38: Flow accumulation map overlaid with storm drainage and roads layers

4.4.3   Stream Network

Stream definition tool in ArcHydro toolbox was used to create a stream grid which would determine the actual stream channels from the flow accumulation grid. The flow accumulation grid was used as the input. The resulting stream grid raster was then converted to vector format in order to make it easier to symbolize the data using the *Raster to Polygon* conversion tool in the *Conversation* toolbox. A polyline layer of the stream network was then created.

Rivers layer was overlaid onto the stream polyline layer to establish whether the streams correlate with rivers. The resulting map in Figure 39 showed that the streams and rivers layer correlate with one another.
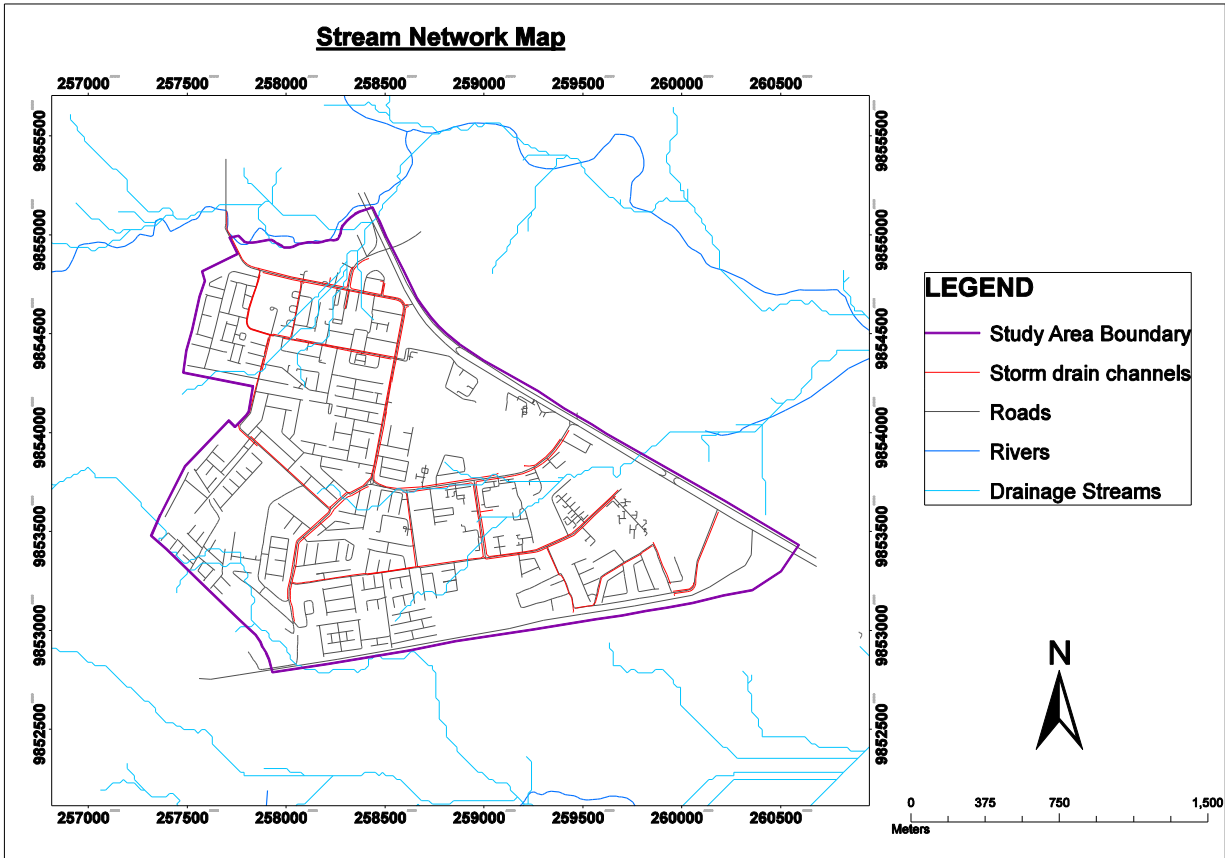
Figure 39: Stream network map

4.4.4 Basin Delineation

Drainage basins for the South C area were then delineated using the *Basin* tool in the *Hydrology* toolset with Flow direction raster as the input. From the raster generated it is possible to establish which drainage basins lie within the South C study area.

From the analysis it is noted that there are 2 drainage basins which fall within the study area indicated in blue and yellow shown in Figure 40. The majority of the study area drains into one drainage basin (in blue) and another smaller portion drains into another drainage basin (in yellow). From the image we can conclude that the major drainage basin indicated in blue, drains into the Ngong River.
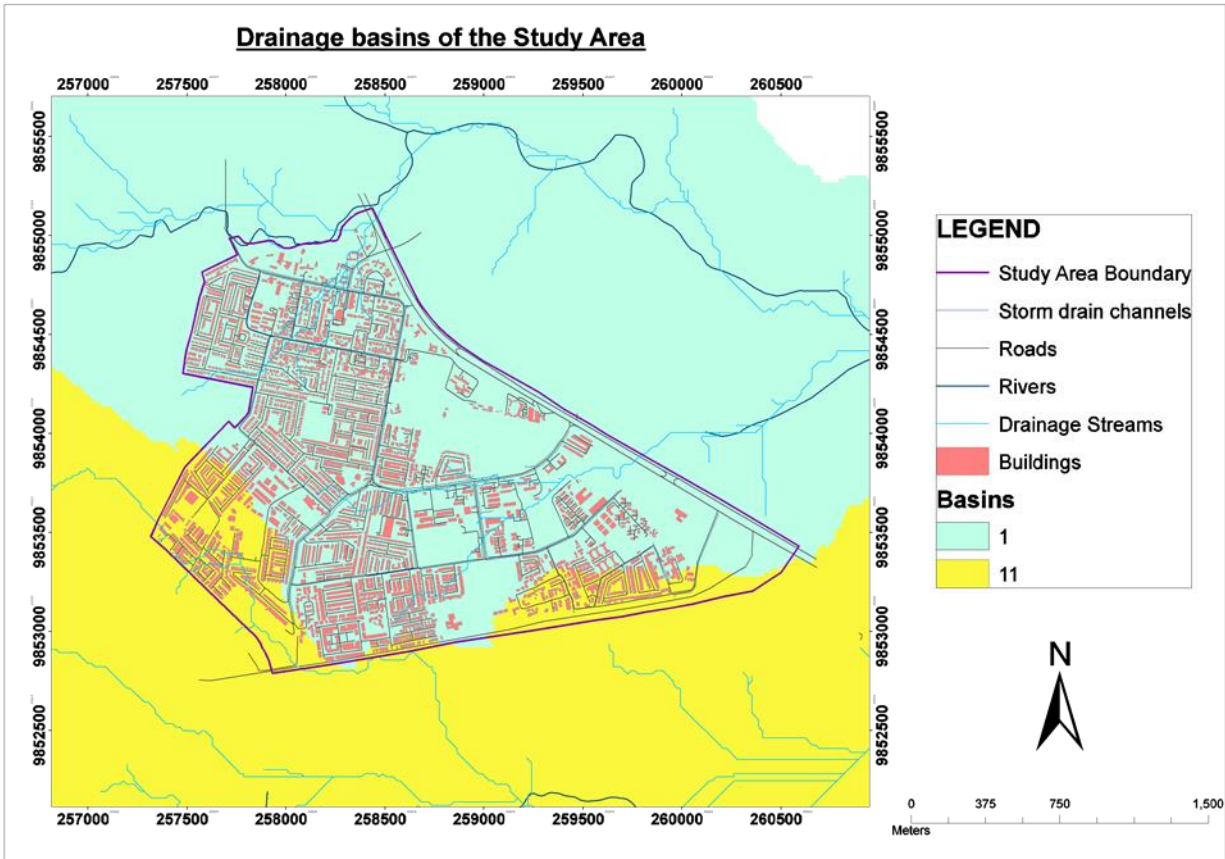
Figure 40: Drainage basin map

4.4.5 Watershed Delineation

Watershed delineation was then carried out for the study area. A watershed is the upslope area that contributes flow to a common outlet. The outlet, or pour point, is the point on the surface at which water flows out of an area. It is the lowest point along the boundary of a watershed. Pour point placement is an important step in the process of watershed delineation because it is used to calculate the total contributing water flow to that given point. Since there was no file containing location of the pour points for this study, it was necessary to create the pour points manually. Three points were selected at the points of highest flow accumulation corresponding with the outfalls of the Study area.

Watershed tool was used to generate watershed delineation with flow direction raster and pour point data as the inputs. The map generated appeared as shown in Figure 41.
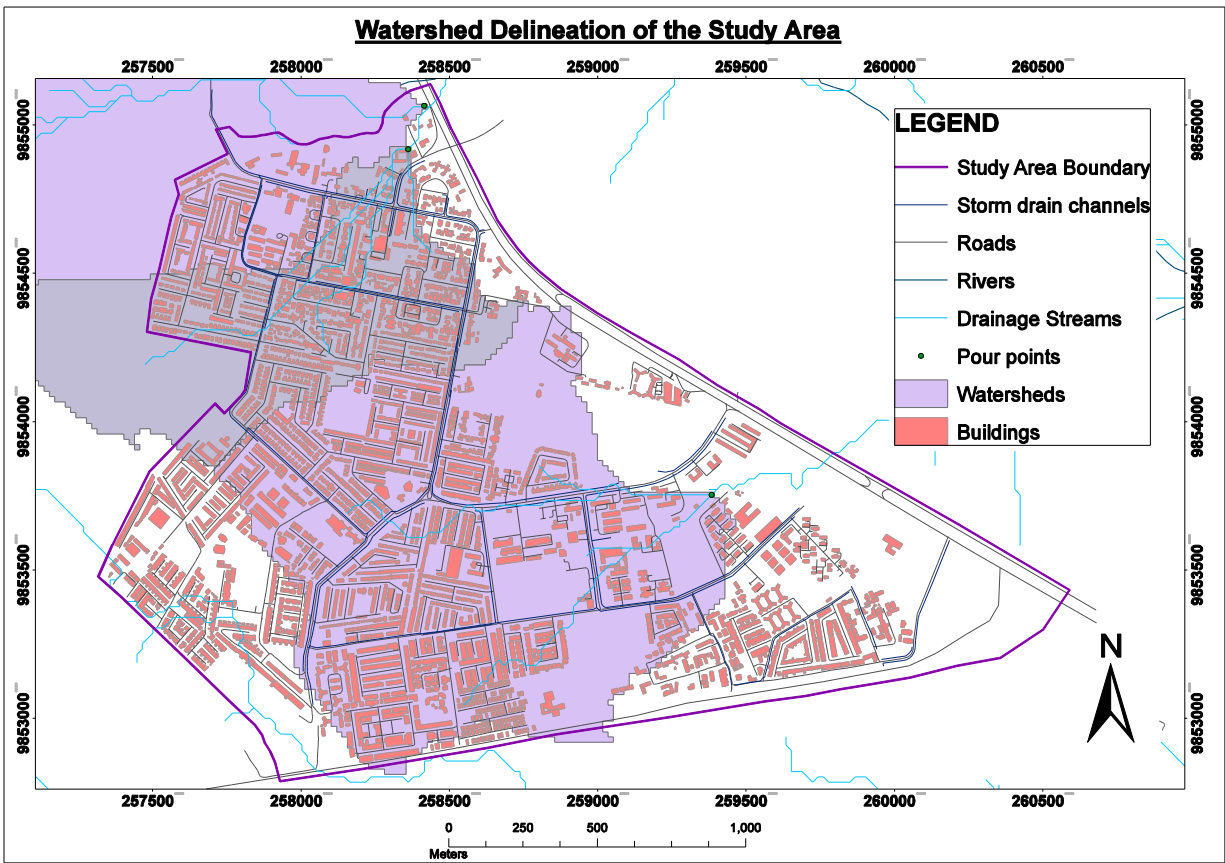
Figure 41: Watershed delineation for the study area

It is therefore possible to determine the total upslope area contributing to the outfalls and establish whether these outfalls can withstand the amount of water flowing out into them. The location of these watersheds should inform local authorities on prioritization of features within the storm water system that need to be dealt with in the short term and those that can be dealt with in the long term.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The overall objective of this project was to assess the current storm water system as a basis for analysis of storm water drainage in South C area. The purpose of the research was to highlight to the Nairobi County Council the storm water inefficiencies that they can improve on or eliminate in order to better manage the City's storm water challenges. The study analysed the potential for storm water runoff for South C area using various methodologies.

The study area's surface cover areas were analysed using remote sensing techniques. The results showed that 41% of South C is covered by impervious surfaces and 59% is covered by pervious surfaces which mainly consist of clay and extreme clay soils. The combination of mostly non-porous clay soils and intense urban infrastructure resulting in impervious surfaces, creates a serious need for better monitoring technology and methodologies to combat storm water runoff that results in flooding.

The natural topography and the existing storm drain topography were analysed individually and comparatively. Field collected data was useful in providing location data for the features of the storm water drainage infrastructure. The condition of the existing drainage system was found to be in moderate to poor condition. This was as a result of solid waste dumping; out-dated drainage system which consisted of small size pipes and drains that clearly could be able to carry the growing capacities of storm water runoff. It was found that in some areas of South C, the direction of slope of the storm water drainage system was in the opposite direction to the natural topography which can create conflict. In other areas, though the storm water drain flow was in the same direction as the natural topography, most drains had steeper gradients than the natural topography. This situation would likely cause increased speeds of runoff and in case of any occurrence such as blockage or reduced gradient, localized flooding would likely occur.

The sewer system was also analysed together with storm water drainage system. Although it had earlier been assumed that there were areas of combined sewer and storm drains in South C, the field survey carried out during data collection verified that there were no areas where sewer and storm drainage combined. It was however noted that the levels of the manholes in some areas

were low and thus rising volumes of storm water seeped into the manholes and caused overflow of the sewer system.

Hydrology Analysis was carried out using spot heights for the study areas as the basic input for further analysis. The analysis revealed the trends of storm water runoff within and immediately around the study area. The analysis gave a better understanding of the inefficiencies of the storm water drainage system with regard to the natural topography. From the maps generated, it was established that majority of the South C area fell within a drainage basin that drains into the Ngong River. The watersheds generated for the study area showed that not only are upslope areas within the study area responsible for contributing to water flow to common outlets/ outfalls but also upslope areas from outside of the study area contributed to these same outlets/ outfalls. This could easily result in increased storm water runoff volumes leading to increased incidences of flooding.

5.2 Limitations of the Study

There were some limitations encountered during the project that are highlighted below:

i) Information about the storm water drainage infrastructure is unavailable at the Nairobi County Council due to a fire outbreak which destroyed most of the files and there was no backup for the data as it was all in hardcopy format. This information is vital to any storm water modeling and analysis. Therefore, any study that would need to be carried out would require field data collection which can be very time consuming and expensive depending on the scale of the project study area.

ii) There is no existing storm water guideline document that would act as a guideline for current and future designs of storm water drainage systems. Currently, the storm water drainage design is handled by the Department of Roads, Public Works and Infrastructure at the Nairobi County Council. Although this department only deals with the design of specific storm drains for roads to be constructed and not the whole system in general.

iii) Image Classification of the study area using the orthophotos was difficult due to the heterogeneity of the pixels within the image. Many features such as roof tops and open spaces had different colors and therefore there was need to create different training

samples for the various rooftop colors in order to carry out the process of image classification. A lot of time was taken to carry out this process of classification which had to be repeated several times in order to come up with the most accurate classification result. This proved to be a very time-consuming process.

iv) Cost of acquiring the orthphotos from vendors was quite expensive and the Nairobi County Council does not have aerial images of Nairobi that are publicly available. Due to the cost of an orthophoto, the author had to work with the image that was availed from the Kenya Urban Roads Authority free-of-charge for academic purposes.

5.3 Recommendations

From the study, the following recommendations are made:

i) There is need to develop a storm water database that gives a full inventory of the infrastructure. This would enable stakeholders such as the Nairobi County Council and other Environmental organizations to keep track of the conditions of the storm water infrastructure and on what needs to be maintained, repaired or upgraded.

ii) There is need to develop a storm water guideline document that would deal with all issues related to storm water. This document can be adopted by different counties within the Country to guide future development of storm water drainage systems as well as monitoring of the systems relevant for each particular county.

iii) There is need to employ best management practices in a bid to enhance storm water management. Maintenance strategies such as regular clean-ups of drains and fixing of destroyed drains would go a long way in managing the situation. Developing policies that encourage the public to care for their surroundings though public awareness outreach programs to educate the public on storm water management.

The research can be taken a step further by using runoff volumes collected as input to create flood hazard maps for the study area and other areas of Nairobi. Surface runoff volumes can also be used to study and calculate outfall capacities and determine whether the current outfall capacities are adequate for the storm water volumes and what can be done in a case where they are not adequate.

While this topic is not new, it is far from expended. This study has added to the understanding of current situation of storm water management and exposed the opportunity for further development.

REFERENCES

1) Atlanta Regional Commission. (2001). *Georgia Storwmwater Management Manual.* Atlanta: Atlanta Regional Commission.

2) ESRI. (2003). GIS Standards and Interoperbility. *Arc News*, Vol 25. No. 1.

3) IHDP. (2005). *Science Plan-Urbanization and Global Envirnmental Change IHDP Report No. 15.* IHDP.

4) James, A. (2012). *Watersheds & Water Resources.* Unpublished.

5) Kothari, R. (2004). *Research Methodology: Methods and Techniques.* New Delhi: Wiley and Eastern Ltd.

6) Parker, D. (2000). *Floods, Volume I & II.* Routledge.

7) Poertner, H. (1988). *Storm water Management in the United States.* Illinois: Bolingbrook.

8) Porsce, C. (2013). Storm water Governance and Future cities. *Journal of Water*, 29-52.

9) Rusko, M., Chovanec, R., & Roskova, D. (2010). *An Overview of Geographic Information System and Its role and Applicability in Environmental Monitoring and Process Modeling.* Bratislava: Slovak University of Technology.

10) US EPA. (2015, January 21). *Storm water Homepage.* Retrieved January 31, 2015, from United States Environmental Protection Agency: http://www.water.epa.gov/polwaste/npdes/storm water/

11) Wisner B., e. a. (2004). *At Risk Natural Hazards People's vulnerabilities and disasters.* Routledge.

12) WMO. (2008, March). Urban Flood Risk Management: A Tool for Integrated Flood Management. *APFM Technical Document No. 11, Flood Management Tools Series*.