ASSESSING THE IMPACT OF DENSIFICATION ON URBAN RUNOFF IN KAMPALA

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March, 2014

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ABSTRACT

Increasing urban building densities is one of the widely adopted concepts of cities compaction promoted as a counter measure to the challenges of urbanization. The recently prepared Physical Development Plan for Kampala (2012), for instance, proposes to increase building densities across all residential neighbourhoods in the city. But what impacts do such planning policies have on the urban environment? This study therefore assessed the impacts of such densification policies on urban hydrology, by quantitatively relating densification to surface runoff in one of the residential neighbourhoods in Kampala called Lubia. This study area was selected for the mere fact that it is one of the residential neighbourhoods earmarked by the newly prepared physical development plan for densification.

The objectives of this study were as follows; (i) To compare the current densification practices against the proposed densification policies of Lubia neighbourhood; (ii) To estimate the current level of surface water runoff generated from Lubia neighbourhood; (iii) To investigate the impact of the proposed neighbourhood densities on urban runoff and flood hazard; and finally (iv) To suggest possible improvements on the proposed policies on densification, that would help reduce urban runoff in the study area.

These objectives were achieved through a set of methods comprised of field survey, literature review, GIS operations and modelling techniques. Field survey techniques were the initial stages which firstly, sought to understand the study area, appreciate people's opinions on the existing densification practices, proposed densification policies and their experiences with surface runoff and flooding. To acquire this information, interviews were carried out with key informants through interview schedules and open discussions; interviews were also carried out with Lubia residents through questionnaires. Other methods used to collect data were observation, photography, field measurements and mapping. Literature review was also an important methodology for this study; firstly to compare the study with other hydrological modelling studies and their impacts to the urban environmental and secondly to have a deeper insight of the densification policies that were proposed for the neighbourhood. GIS applications and Modelling techniques (using PCRaster) were used to quantitatively relate densification to urban runoff.

Estimation of surface runoff generated in the neighbourhood was done under three densification approaches; base scenario (current scenario), horizontal densification (trend scenario) and vertical densification. Base scenario generated 48% runoff from the total rainfall; horizontal densification generated 51% of runoff; however, three sub scenarios were further experimented under horizontal densification by increasing the spatial coverage of bare soil. The three scenarios generated percentile runoff of 54%, 57% and 60%, respectively. Vertical densification was experimented through three sub scenarios; built-up area remained the same for the three sub scenarios but variations were done for vegetation and bare soil covers. The percentile runoff generated under this scenario was 24 %(vegetated land cover for the non-built areas); 37% (non-built areas were partly bare and partly vegetated) and 89% (bare soil cover for the non-built areas).

In conclusion, the methodology used in this study was considered a success in line with other hydrological studies that been done in other parts of the world. The results of runoff generation favoured vertical densification to horizontal densification; as long as due consideration is also given to spatial coverage of other land cover classes (bare and vegetation). However, this is not practical at least in the near future, due to financial and logistical limitations. The obvious option therefore would be the prevailing horizontal densification; and in view of this consideration, a detailed development plan for the neighbourhood should be prepared; but with a principal consideration of runoff and flooding reduction strategies. Vertical densification on the other hand, would be the best option to be considered in the long term, considering the glaring challenges of urbanization; as it is, urban runoff and flooding are already hot issues in the neighbourhood and in the entire city of Kampala.

Key Words: compact cities, urban planning policies, densification, surface (urban) runoff.

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God Bless You All.
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ACRONYMS

DEM: Digital Elevation Model

FAR: Floor Area Ratio

GIS: Geo-Information Science

IFM: Integrated Flood Modelling

ITC: International Institute of Geo-information Science and Earth Observation

LDD: Local Drain Direction

KCCA: Kampala Capital City Authority

KDMP: Kampala Drainage Master Plan

KPDP: Kampala Physical Development Plan

SPSS: Statistical Package for Social Scientists

1. INTRODUCTION

1.1. Background to Research Problem

Over the past few decades, the concept of compact cities has emerged as a key issue in urban policy debates. Although different various countries apply different forms and notions of the concept, it has widely been adopted as a planning tool, and is promoted in managing urban sprawl by maximizing the utilization of land while at the same time, ensuring that existing infrastructures and services operate in an efficient manner.

The definition of compact cities varies across authors, with several of them using density as a measure of urban compactness. Gordon and Richardson (1997) define compact cities as high density or monocentric development; Ewing (1997) looks at city compactness through the lenses of concentration of employment, housing and diversity of land uses. Chhetri et al. (2013), broadly conceptualizes compact cities as a policy goal for controlling and regulating urban sprawl by promoting a relatively high-density, mixed land-use city structure supported by a more efficient public transport system and increased opportunities for walking and cycling. Chhetri et al. (2013), further bring in the concepts such as intensification, consolidation and densification; infill development and redevelopment; more intensive use of urban land; sub-divisions and conversions of existing development; re-zoning and greater mixing of land uses; greater dwelling density and re-urbanization; and higher degrees of accessibility, to further explain the concept of compactness of cities.

The impacts of compaction of urban areas and cities are wide and varied across the globe. Although not 100 percent fully guaranteed, some of the positive impacts of compacting cities include: containment of urban expansion, better access to services, reduced car dependency and improved efficiency in urban infrastructure and services (Burton, 2000; Ng, 2010). However, there may also be downsides to compact cities which include: depletion of open spaces, overcrowding, microclimate, inflated housing market, increased health risks and extreme weather conditions such as floods and storms (Burton, 2000; Ng, 2010). These downsides of compact cities counteract the benefits for its adoption as a sustainable urban policy option.

1.2. Research Problem

The tension between the up and down sides of compactness also reveals themselves in Kampala, Uganda's capital. Compact city policies have recently been promoted as counter measures to the challenges that have come with this high rate of urbanization. For instance, the recently prepared physical development plan for Kampala advocates for increased building densities across all residential neighborhoods of the city, as a means to control sprawl and allow for efficient transportation systems. But what impacts do such planning policies have on the urban environment, on surface runoff and the possibility of floods?

This research explored the impacts of such planning policies (urban densification), on urban run-off in Kampala. Surface (urban) runoff in itself it is not really a hazard unless the amount and timing are such that it can be considered a "flash flood". However, as asserted by Pauleit et al. (2005), such information would essentially be vital for a better understanding of the sustainability of urban development processes. Flooding for one is already a hot issue in Kampala and is bound to increase even more as a result of increase in the percentage of urban land covered by impervious/sealed surfaces. Therefore this research attempted to quantitatively relate two variables; densification and urban run-off in order to estimate the amounts of surface runoff generated from the study area.

1.3. Research Objectives and Research Questions

The main objective of this research was to assess the impacts of the proposed urban densification policies on Urban Runoff in Kampala. The specific objectives were as follows:

1. **To compare the current densification practices against the proposed densification policies of Lubia neighbourhood**
   Research Questions
   i.) What are the existing densification policies or practices (types and nature) in Lubia neighbourhood?
   ii.) How are these policies implemented (actual situation on the ground)?
   iii.) What are the proposed densifications polices (types and nature) for Lubia neighbourhood?

2. **To estimate the current level of surface water runoff generated from Lubia neighbourhood**
   Research Questions
   i.) What are the factors of estimating surface water runoff?
   ii.) How much runoff is generated from Lubia neighbourhood?
   iii.) Where are the points of generation and accumulation?
   iv.) Does the runoff contribute to flood hazard in Lubia?
   v.) What is the nature of flooding in Lubia Neighbourhood?

3. **To investigate the impact of the proposed neighbourhood densities on urban runoff**
   Research Questions
   i.) What are the implications of the proposed densities on the form and structure of Lubia?
   ii.) How do these policies relate to land cover change?
   iii.) What is the potential impact of the proposed densities on runoff and flooding possibility?

4. **To suggest possible improvements on the proposed policies on densification, that would help reduce urban runoff in the study area**
   i. What possible improvements could be suggested over the proposed densification policies to mitigate urban run-off and in Lubia?

1.4. Research Motivation

The study area, Kampala City, continues to experience unprecedented urban growth and expansion; with an urbanization growth rate of 4.7%. This rate is expected to continue with prediction that by the year 2050, 64% of population in the developing countries will be living in urban areas (United Nations Department of Economic and Social Affairs, 2011). As such, the landscape of cities and urban areas continues to evolve with a continued adoption of more compact urban forms. Kampala city is no exception to these phenomena. The increased rate of urbanization in Kampala has necessitated city planners to device ways that would accommodate the changes brought in by city expansion and population growth; city compaction, through densification of developments has been one such proposed method. Despite adoption of city compaction methods, there is need for the policy enforcers to be aware of the downsides of adopting such development policies.

There is limited research that has been done in Kampala City on empirical relationship between the increase in developments density to urban run-off and flooding possibility. This research will therefore be vital for the city of Kampala and an important addition to social science. This was achieved through a research methodology that modelled surface runoff generation against various urban densification approaches.

1.5. Hypothesis

The hypothesis for this research was that the proposed densification policies on residential neighborhoods in Kampala would impact negatively on urban runoff and potential of flood occurrence.

1.6. Thesis Outline

This thesis was be organized in six chapters as follows:

Chapter one: *Introduction*-This chapter introduced and grounded this research; the chapter discussed the background to the research problem, the research problem, research objectives, research questions, hypothesis, and research motivation.

Chapter two: *Densification and the urban environment*-This chapter focused on relevant literature, concepts and theories relating to densification and urban hydrology, as well as similar studies and methods that informed this research, theoretical background and conceptual framework.

Chapter three: *Background to the Study Area*: this chapter discussed and delineated the study area as well as its physical and climatic conditions.

Chapter four: *Research Methodology*-This chapter detailed out the methodology used to undertake this research. This includes the methods and tools used for collecting data, for data processing, data analysis and presentation of results.

Chapter five: *Results*-This chapter discussed the findings of this research in relation to the research objectives.

Chapter Six: *Conclusions and Recommendations*: This chapter highlighted the conclusions and recommendations of this research, based on the study findings, as well as proposed areas for further research.

2. DENSIFICATION AND THE URBAN ENVIRONMENT

2.1. Introduction

This section addresses the main concepts and theories that were useful for this research, namely urbanization, densifications, the concept of compact cities, surface water runoff, flooding and urban drainage systems.

2.2. Urbanization and its impacts to the Urban Environment

One of the recent thrusts in hydrologic modelling is the assessment of the effects of land use and land cover changes on water resources and floods (Yang et al., 2012), which are essential not only for planning but also for early flood warning. Urbanization (with a current growth rate of approximately 1.9%) is one of the phenomena that drives land use (pattern) change, and according to the United Nations Department of Economic and Social Affairs (2011), more than half of the world's population lives in urban areas; Kampala the study area has an urbanization growth rate of 4.7%, against the Country's 5.74% and the world's 1.9%. Urbanization results in to physical growth and expansion of cities and urban areas, and even conversion of suburban concentration into cities; according to Angel et al. (2011), the on-going rate of urbanization trend has a major impact on the extent and growth of urban areas worldwide. The increasing global rate of urbanization has continued to create new challenges and new opportunities for managing cities (Wagner & Breil, 2013). One of the major challenges associated with urbanization is worsening physical, social and environmental conditions in the urban environment (Kong et al., 2012); for instance, increased rate of concretization of cities, which results to increased urban run offs and flood occurrences. With urban land development, impermeable land surfaces enlarge rapidly, the capability of rainfall detention declines sharply and runoff coefficient increases(Shi et al., 2007). According to Du et al. (2012), urbanization affects hydrological processes within watersheds by altering surface infiltration characteristics, thereby increasing storm flow volumes, peak discharges, frequency of floods, and surface runoff. In response to the challenges of diminishing urban space, brought about by the increasing urbanization rate, planners and urban managers have resorted to policy measures that would maximize the use of urban space. City compaction is one such policy measure that is being adopted.

There has been numerous efforts that have been made by researchers to simulate, assess and predict the effects of urbanization and their consequent hydrological responses in catchments. Tung and Mays (1981), for instance, developed a non-linear hydrological system-state variable model to simulate urban rainfall–runoff, and examined the variation of each parameter for different levels of urbanization. Arnold and Gibbons (1996), in their research 'impervious surface coverage', measured impervious surface coverage as a quantifiable environmental indicator that correlates to urbanization, seeking to understand surface water runoff problems. S. J. Cheng and Wang (2002), focussed on defining the degree of change in a runoff hydrograph for urbanizing basin in Taiwan's Wu-Tu watershed. Weng (2001), integrated remote sensing and GIS to relate urban growth studies and hydrological modelling in Zhujiang Delta of southern China; according to their results, in areas which experienced more urban growth produced increased annual surface runoff, and highly urbanized areas as well, were more vulnerable to flooding. In 2013, (Dams et al.), described a methodology that estimated the changes in impervious surface fraction from remote sensing data for hydrological modelling; according to their results, most urbanization occurred as a result of densification of the existing urban areas. They conclusively equate the increase of urban surface runoff between the years to the increase in impervious surfaces. This research is a further contribution to science and to what that has already been done by these authors; by assessing the impact of densification on urban runoff in Kampala using GIS applications and modelling tools, and Remote Sensing tools.

2.3. The Concept of Compact Cities

The concept of compact cities has been widely adopted as a planning tool in developed countries (Chhetri et al., 2013), and is now fast rapidly finding its way into the developing countries. The single largest cause of compacting cities and urban areas is urbanization, which has significant influence on land use and land use changes, the general economic as well as environmental issues (Verbeiren et al., 2013). Thus, compactness has been seen as a mechanism of regulating and controlling urban sprawl.

Placing this research in context, several researchers have investigated on the compact city concept. For instance, in their paper 'Mapping urban residential density patterns: Compact city model in Melbourne, Australia', Chhetri et al. (2013), discussed the realization of the density aspect of compact city policy implemented in Melbourne 2030 Plan. In this study, it was found that the policy of densification in pursuit of a more compact city produced mixed/different results; and as part of their conclusions, they proposed that there is need to accurately measure the concepts and outcomes of policy change with regards to densification as it had potential effects to the society and the environment. Gordon and Richardson (1997), evaluated whether or not the promotion of compact cities was a worthwhile planning goal, of which they refute citing reasons such loss of prime agricultural lands, pressures on residential density preferences, costs and benefits of suburbanization, impact on social equity and impacts of telecommunications on development densities. Lanzendorf (2001), assessed the relationship between compact cities and sustainable development, from the perspective of policies and plans, where he acknowledges the inevitability of policy formulation and the existence of complex relationships between compact cities and sustainable urban form; he as well underscores the impacts of higher density developments on living and on the environmental conditions. Therefore, the concept of compacting cities is not new; it has been researched and advocated for, for many years; however, there have been limited empirical research on the downsides of this concept, and more so, as a policy tool for urban planning.

2.4. Densification

2.4.1. Introduction

Rapid urbanization since 1950 has exerted tremendous pressure on urban development in many cities and has been confronted with the scarce supply of land in urban areas(Edward, 2010). Land is always a scarce resource in urban development; high building density, by providing more built-up space on individual sites, can maximize the utilization of the scarce urban land.

Densification is one of the aspects defining city compactness, and for many years it has been used as a way to establish building density norms for achieving sustainable urban forms. It is justified by planners and urban managers as a response to urban growth(Kyttä et al., 2013); urban growth leads to sprawl and densification of built up area (Loibl & Toetzer, 2003). It is a key concept in planning as it helps to describe, to control and to predict the use of land (Boyko & Cooper, 2011). There exists multiple and varied definitions and measures of densification. The Spatial Planning and Urban Design Department of Cape Town (2009), defined densification (and for the purposes of this research) as 'The increased use of space both horizontally and vertically within existing areas/ properties and new developments accompanied by an increased number of units and/or population thresholds'. As such, the horizontal and vertical forms of densification revolve around intensification and consolidation of urban developments through redevelopment, infilling and new developments.

Attitudes towards densification are diverse; whereas some people acknowledge its advantages and advocate for urban compaction, others criticize the associated drawbacks and argue strongly against it. V. Cheng (2010), for instance, asserted that densification helped to reduce the pressure of developing on open spaces and avails more land for communal facilities and services to improve the quality of urban living. Other advantages of densification, as planning policy tool, advanced by various authors include managing the effects of urbanization and urban sprawl by ensuring optimal and efficient use of land and infrastructure facilities thereby making the city or urban area more equitable; supporting development of viable public systems; improving housing patterns and choice of housing types; promoting economic opportunities and support of service provision; and reducing consumption of valuable /non-renewable resources. However, some people argue that the opposite is also true. Vertical densification, for instance, results to massive high-rise buildings, crammed into small sites, and this can conversely result in very little open space and a congested cityscape (V. Cheng, 2010). Another major potential downside associated with densification (particularly horizontal densification) is increase of impervious or sealed surfaces, ultimately leading to increased surface runoff and therefore increasing the chances of flood occurrences. In cities where flooding is already a major issue, such as Kampala, densification policies must address such issues explicitly.

2.4.2. Understanding Densities...

2.4.2.1. Introduction

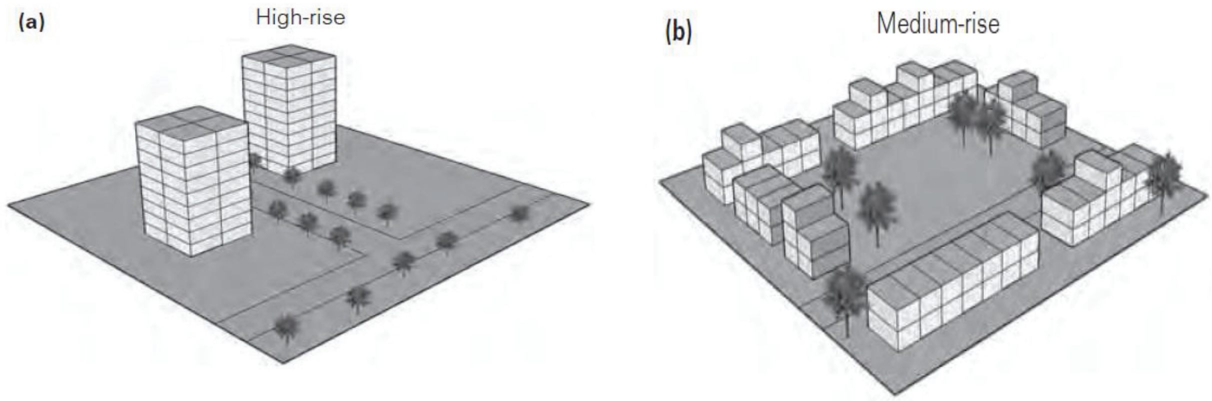
Understanding the measures of densification is important for this study; densification is a process of increasing densities; thus density is a measure of densification. The definition of density is complex and multifaceted, determined by various and or the context it applies. In planning for instance, density is a physical and numerical measure of the concentration of people or physical structures within a given geographical unit; thus, broadly divided into building density and people density (V. Cheng, 2010). This study will limit the density measurement to the physical aspect (physical structures) within a (lubia) neighbourhood, defined by measures described in the next section.

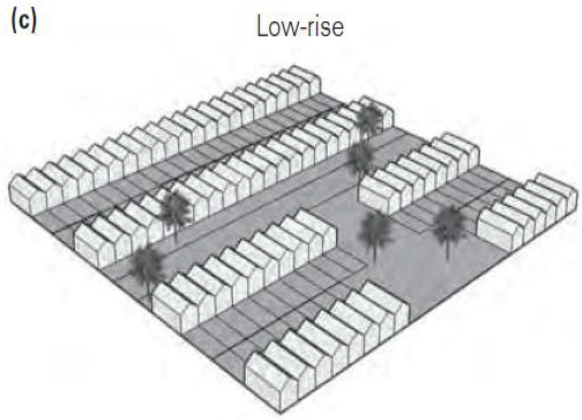
2.4.2.2. Calculating Physical Densities

This section highlights measures of density (that define the densification process) and are important for this research from a micro scale (plot/parcel) to a macro scale (neighbourhood). These are described as follows;

i.) Building Density and Urban/Neighbourhood Morphology

Building densities has intricate relationship with urban morphology, for instance in shaping the urban form. Urban developments of the same density can however exhibit very different urban forms, as demonstrated in the figure 2.1 below.





Same density in different layouts: (a) multi-storey towers; (b) medium-rise buildings in central courtyard form; (c) parallel rows of single-storey houses.

Even though, increased building densities decrease site coverages

Figure 2.1: Building Density and Urban/Neighbourhood Morphology

Source: Adopted from Understanding Density and High Density by Vicky Cheng, 2010 (pg. 10)

ii.) *Impervious surface parcel coverage*

This refers to the area of ground floor building footprint including paved car parks, pavements, paths, decks and other buildings divided by the plot /parcel area(Boyko & Cooper, 2011).

iii.) *Site coverage*

Site coverage also called building site coverage or coverage ratio refers to the ratio of building footprint coverage in relation to its site/plot area (Ng, 2010). Open space ratio, an inverse of site coverage, refers to the amount of open space available on a development site. Figures 2.2 and 2.3 below represents different site/plot coverages adopted from V. Cheng (2010).

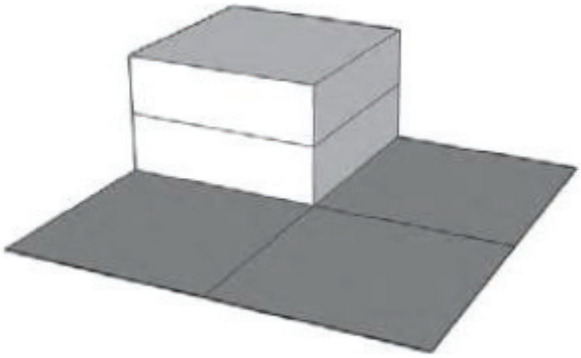


Figure 2.2: 25% Site/Plot Coverage

Figure 2.3: 50% Site/Plot Coverage

Source: Adopted from Understanding Density and High Density by Vicky Cheng, 2010 (Pg.6)

iv.) Plot ratio

Plot ratio, also called floor area ratio (FAR), refers to the ratio of total gross floor area of a development to its plot area. Boyko and Cooper (2011), defines the term as built floor area (on all floors) divided by the parcel/plot area. This takes into account the entire area within the perimeter of the exterior walls of the building. Just like site coverage, plot ratios are extensively adopted as a standard indicator in land use zoning and development control in planning practice. Figures 2.4 and 2.5 below demonstrates different plot ratios adopted from V. Cheng (2010).

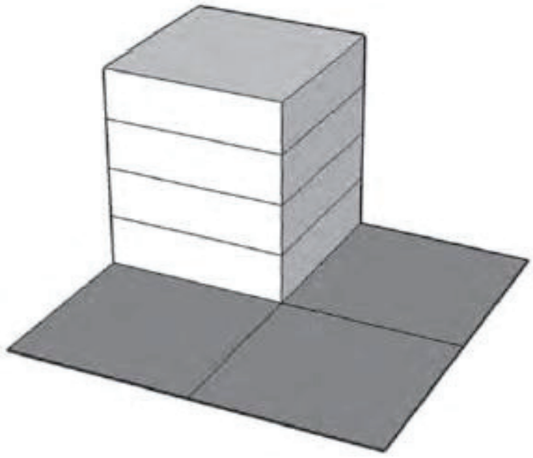


Figure 2.4: Plot Ratio (1)

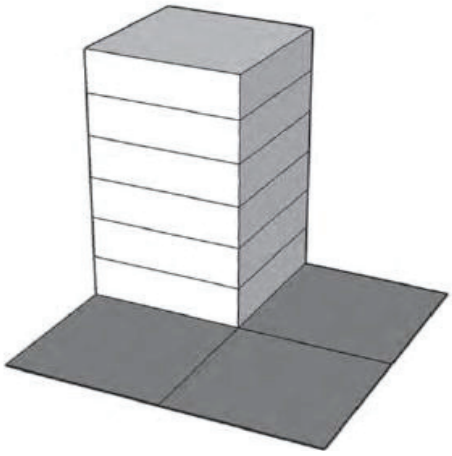


Figure 2.5: Plot Ratio (2)

Source: Adopted from Understanding Density and High Density by Vicky Cheng, 2010 (pg. 5)

From these two examples from V. Cheng (2010), the first building structure has a random plot ratio of 1, while the second structure has a plot ratio of 1.5; increase in the number of floors subsequently increases the total floor area, thereby increasing the plot ratio.

v.) *Gross dwelling units*

The number of dwelling units per unit of land calculated in a designated area, on the basis of specific land use, for instance residential, industry, commerce, etc.

vi.) *Dwelling unit density*

Number of dwelling units per unit area of land.

2.5. Densification, Urban Runoff and Flooding

Densification is a response to urban growth; increase in urbanization (urban growth) changes urban landscapes; increasing the percentage of urban land covered by impervious/sealed surface. Verbeiren et al. (2013), defines sealed/impervious surfaces as surfaces which limit infiltration of precipitation forcing this water to runoff often faster than it would naturally do. Increase in sealed (impervious) surfaces, limits infiltration (Jennings & Jarnagin, 2002) resulting in generation of urban runoff. According to Arnold and Gibbons (1996), the measures of imperviousness can be determined by land use, function(s) of each land use and their relative impact on surface runoff; thus, the percentage of land covered by impervious surfaces varies with land use. Urban watersheds, according to Sheng and Wilson (2009), lose an average of 90% of the storm rainfall to runoff, whereas the non-urban forested watersheds retain 25% of the rainfall.

The diagram below shows the rates of infiltration based on different levels of surface imperviousness by Arnold and Gibbons (2009).

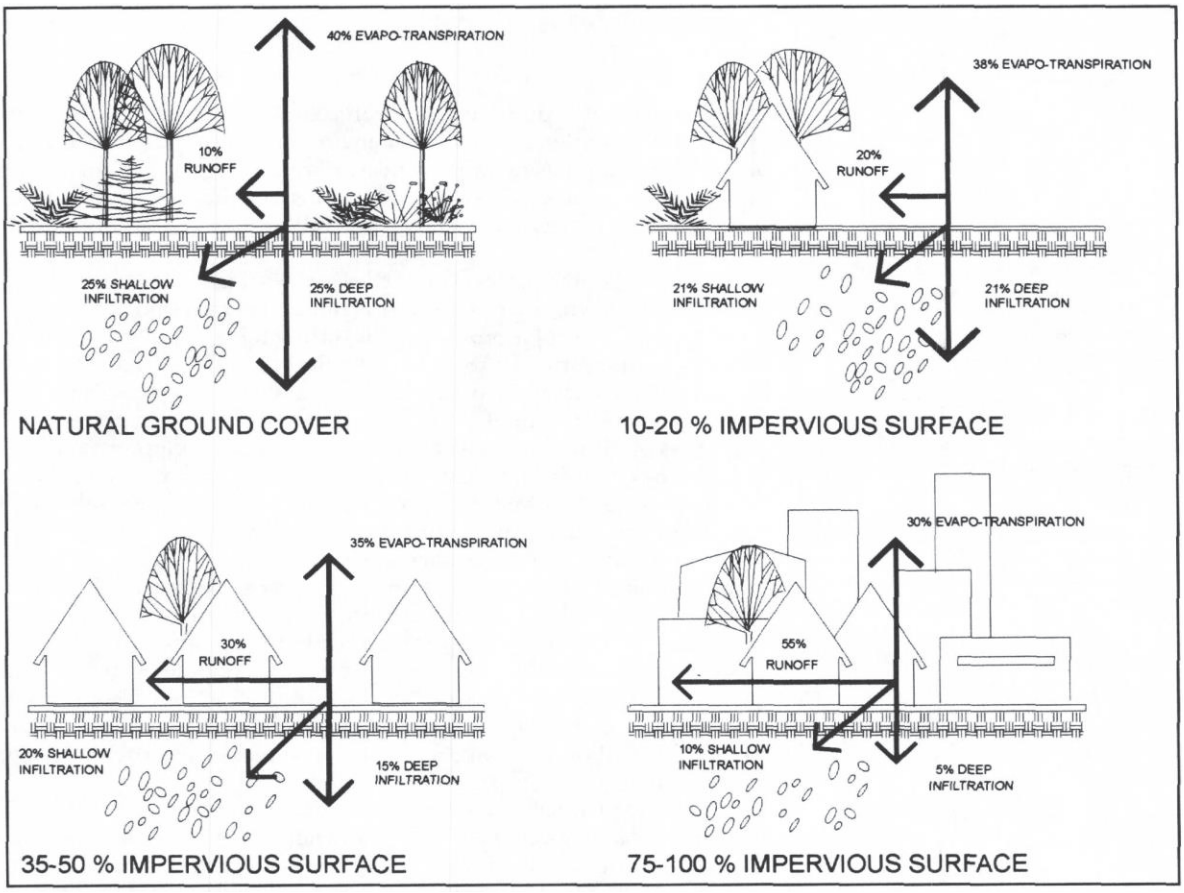


Figure 2.6: Infiltration Rates by Impervious Surface Coverage

Source: from Impervious surface coverage by Arnold and Gibbons (1996)-pg. 244.

Floods are natural hazards caused by natural factors such as heavy rainfall and high tides; or by a combination of natural and human factors, such as urbanization, improper land use, and deforestation (Tingsanchali, 2012). Floods occur when a watercourse is unable to convey the quantity of runoff flowing downstream (Lin, 2012). As much as flooding might be a natural process, it is also largely influenced by land use changes, which alters the natural processes Lin (2012). As the number and susceptibility of urban developments increases, flooding increasingly becomes a natural hazard; and according to Tingsanchali (2012), the key aspects of hazards severity are flood magnitudes, such as flood depths, velocity and duration. Impacts due to flooding are significant in terms of loss of life, property damage, contamination of water supplies, loss of crops, social dislocation and temporary homelessness (Lin, 2012).

Flood risk is the probability of loss as a consequence of flood occurrence. Barredo and Engelen (2010), evaluated flood risk on the basis of three factors, which included hazard, exposure and vulnerability; any increase in these three factors leads to increase in the risk. Exposure could be defined by the (anthropogenic) factors that contribute to flood risk; for instance, urbanization and land use changes and natural factors such as extreme precipitation. Vulnerability is defined as the susceptibility level of a community or exposed structures to the impact of hazard determined by physical, social, economic, and environmental factors (Barredo & Engelen, 2010; Tingsanchali, 2012). In many parts of the world, flood risks have continued to grow with increase and expansion of urban developments, this is a result of increasing flood hazards, vulnerability and exposure of urban communities.

2.6. Urban Drainage Systems

Urban drainage systems are networks that transport urban waste water and rainwater to various terminals (Cembrano et al., 2004); they assist in draining the urban environment. Urban drainage systems are an important component in modelling surface runoff and floods. According to Schmitt et al. (2004), surface runoff and flooding may occur at different stages of hydraulic surcharge, depending on the general drainage design characteristics, the drainage system of the area, and the specific local constraints of an area. Cembrano et al. (2004), further asserts that in many cities where urban growth is fast occurring and with frequent stormy rains, the sewer systems are unable to carry the rain water and the wastewater to the treatments, and as a result surface overflows and flooding occurs.

Urban drainage systems can be categorized into single drainage areas, distinct surface drainage component, surface area, and closed underground sewers (Schmitt et al., 2004). The single drainage areas, which include roofs, streets, parking lots and yards, transform rainfall into effective runoff, based on surface characteristics; for instance slope of an area, land cover properties and surface area. The distinct surface drainage components, for instance street gutters, direct surface runoff to underground sewer system through inlets. Surface area, according to Schmitt et al. (2004), refers to the area where runoff may occur in case of flooding, for instance roads, while closed underground sewers form the drainage networks. (Smith (2006)), categorizes urban storm water drainage systems into surface (major) systems, which comprises of streets, ditches, and the various natural and artificial channels, and secondly, subsurface storm sewer network (minor system).

2.7. Conceptual Framework

This section describes the main concepts of this research and their relationships. The first concept of this research is urbanization/urban development. Cities and urban areas continue to grow and expand globe wide; as such, they influence the types and nature of planning policies. The planning policies adopted are in support of compaction of cities and urban areas, to accommodate the growing urban populations as well as make the best use of limited resources and facilities in urban space. Such policies for instance include densification of developments (taking the forms of vertical and horizontal expansions) achieved through infilling practices, new developments, redevelopments etc. The increase in use of urban space through compaction (densification) leads to increase in sealed/impervious surfaces and change in hydrological characteristics of an area; this situation however, may come with its downsides, such as increase in urban runoff and flooding. The interrelationships of these concepts formed the motivation for this research, in assessing the empirical impact of densification of urban space on urban runoff g. These concepts are schematically presented in figure 2.7 below.

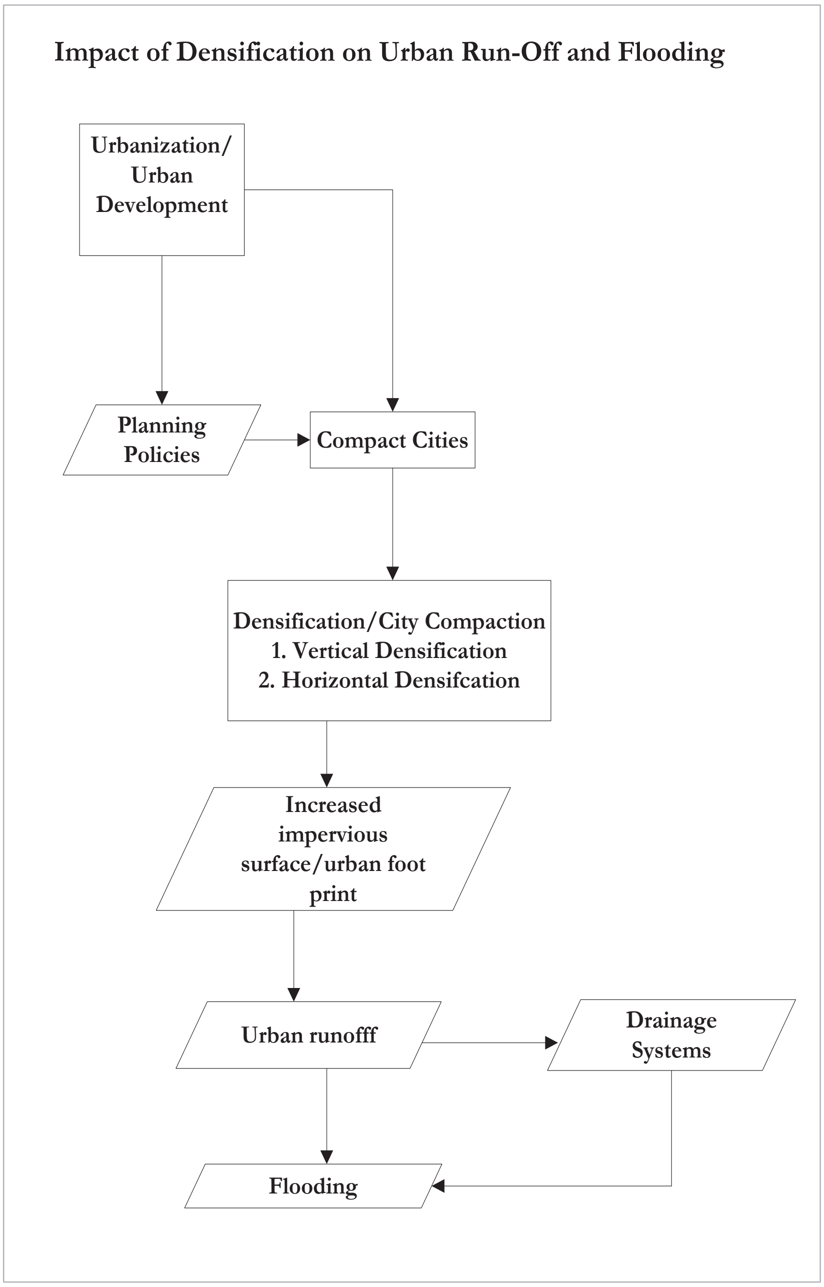


Figure 2.7: Conceptual Framework

Source: Author, 2014

3. BACKGROUND TO STUDY AREA

3.1. Location of the Study Area

Figure 3.1: Regional Context of Kampala City

Kampala City is the largest City and Capital of Uganda. It is located at 00 19' North and 32^0 35' East, 45km north of the Equator and on the Northern shores of Lake Victoria (figure 3.1). The city is approximately 190km². It has five administrative divisions, namely; Central Division, Kawempe Division, Makindye Division, Nakawa Division and Rubaga Division (figure 3.2 below).

The study area is Lubia Parish, located in Rubaga Division in Kampala City (figure 3.2 below). It falls within the inner city residential zone demarcated as one of the fastest growing precincts in Kampala. Lubia Parish has nine villages including Namung'oona 1 and 2, Lubya, Lugala, Lusaze, Masanafu Bukuluki, Masanafu Kinoonya, Nabulagala, and Mapeera (figure 3.1 below).

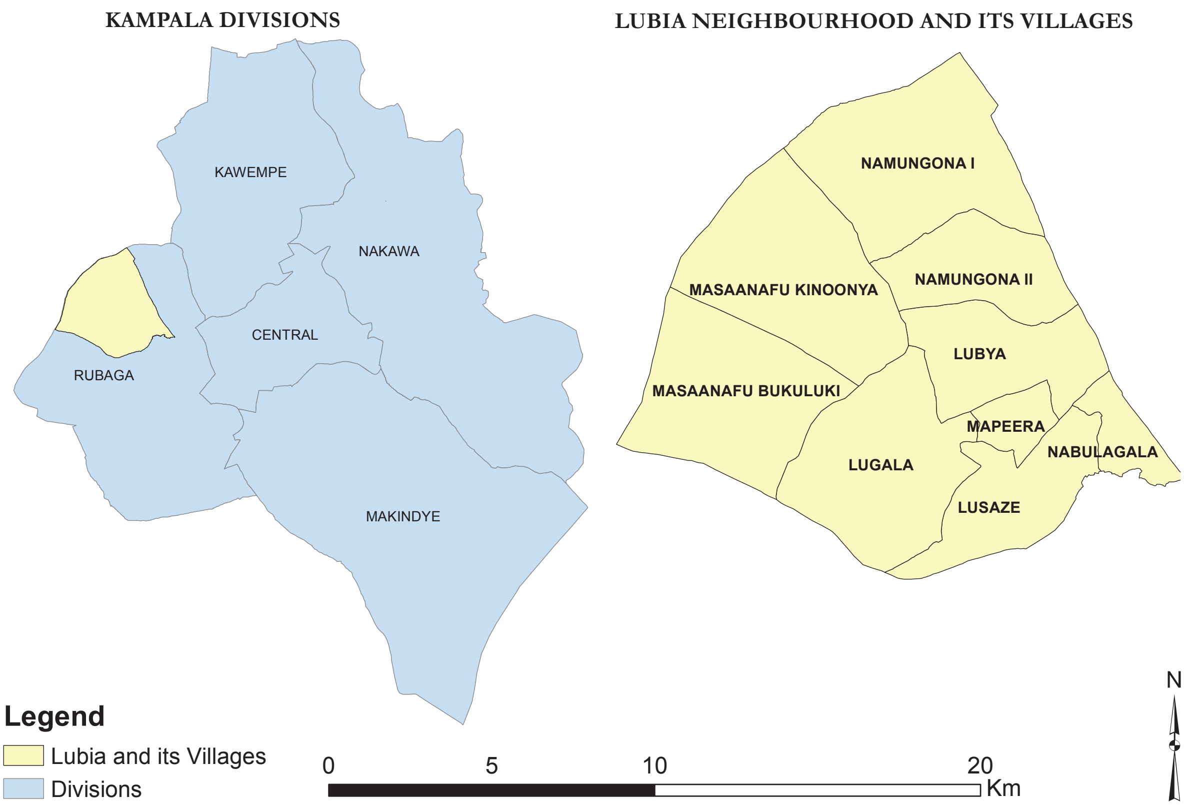
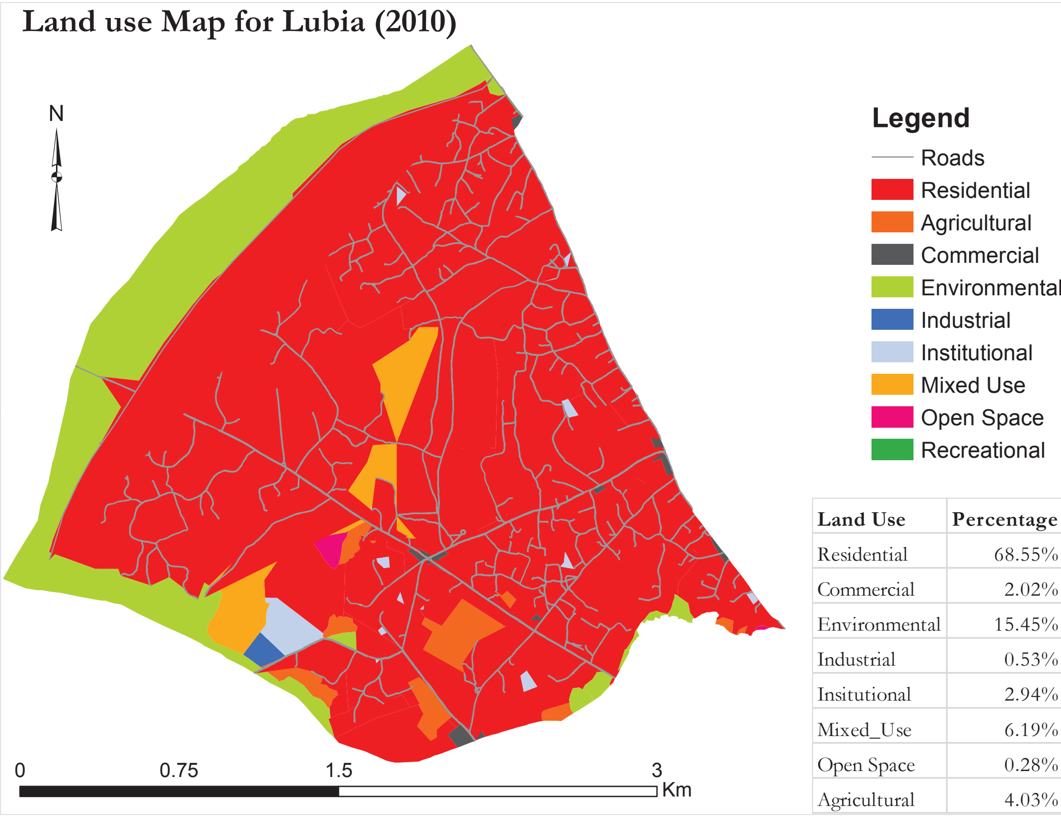


Figure 3.2: Location of the Study Area
Source: KCCA, 2010

3.2. Land use Profile

The study area is largely a residential neighbourhood, with the area demarcated for residential land use occupying approximately 68.5% of the total area (figure 3.3). The environmental land use (which includes wetlands and swampy areas) is also relatively large accounting for 15.45% of the total area, followed by mixed uses at 6.19%. Figure 3.3 below is a land use map of the study area and an inset table showing percentage area coverages of each land use.



Land Use	Percentage
Residential	68.55%
Commercial	2.02%
Environmental	15.45%
Industrial	0.53%
Insitutional	2.94%
Mixed_Use	6.19%
Open Space	0.28%
Agricultural	4.03%

Figure 3.3: Land Use Map for Lubia Neighbourhood
Source: KCCA, 2010 Land Use Map

3.3. Rainfall and Temperature Patterns

Precipitation is fairly reliable in Uganda; with distribution classified into low (under 1000 mm per annum-26% of land area); moderate precipitation under which Kampala falls (between 1000 mm to 1750 mm per annum-70% of land area); and high (over 1750 mm per annum-4% of land area). Kampala generally has convective rainfall patterns; characterized by high intensity rainfall within a short period of time. The main rainfall season in Kampala is between March and May, while the driest season is from December to February. Figure 3.4 below shows the rainfall pattern of Kampala, with rainfall measurements collected between May 2012 and April 2013, obtained from the report on Integrated Flood Management Project in Kampala by (Sliuzas et al. (2013)). Based on figure 3.4, it is safe to say that Kampala receives rainfall throughout the year even during the driest seasons; for instance, the highest rainfall was registered in December, despite the month being one of the driest months (figure 3.4). Based on this study, flooding was reported between April and June and between November and February. Generally, the temperatures of Uganda show little variation throughout the year, stretching between 25°C to 31°C in most areas.

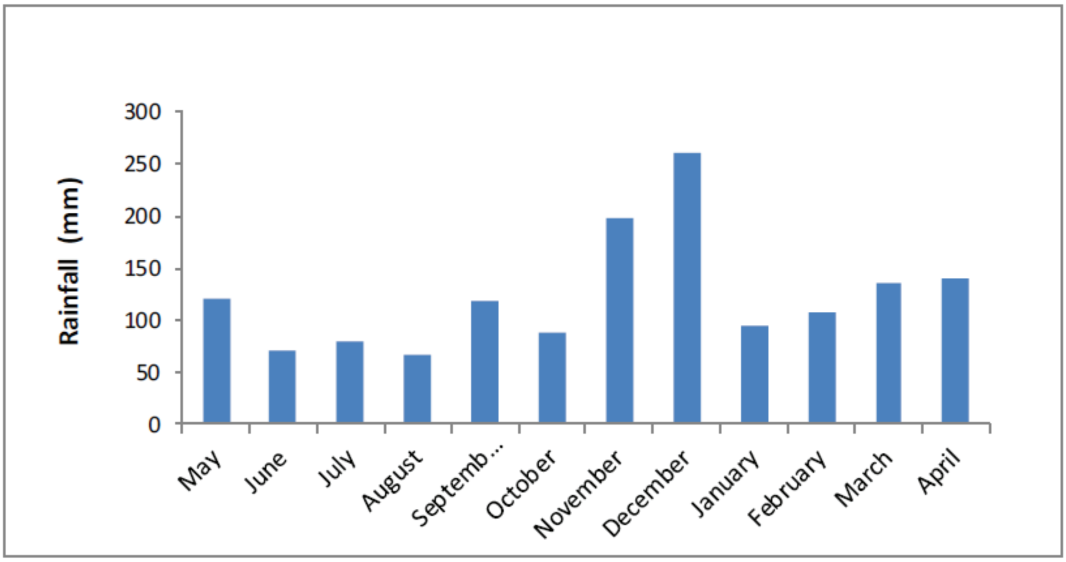


Figure 3.4: Average Monthly Rainfall between 2012-2013
Source: Report on Integrated Flood Management in Kampala (Sliuzas et al., 2013)

3.4. Topography

Kampala's topography is characterized by hills and water logged valleys. There are approximately 30 hills within the central zone of the city. The hills are quite significant in forming the city's landscape and the inner structure. The topography also defines the city's functionality; it determines the distribution of land uses as well as accessibility in the city. The hilltops are particularly important because they offer great potential for development, they are touristic sites as well as recreational areas. Figure 3.5 below represents an image of Kampala's topographic terrain.

Based on topography, Uganda is divided into four relief regions, namely: areas above 2000 meters which covers approximately 2% of total land area; areas between 1500 to 2000 m which covers about 5%; areas between 900 to 1500 meters covering approximately 84% and areas below 900 meters, which cover about 9% of the land area (Mwebaze)

Figure 3.5: Topography of Kampala
Source: Obtained from Kampala Physical Development Plan (2012), page 68

The slope gradient of the study area (calculated from data obtained from KCCA in 2010) ranges between 0-89 percent as shown in figure 3.6.

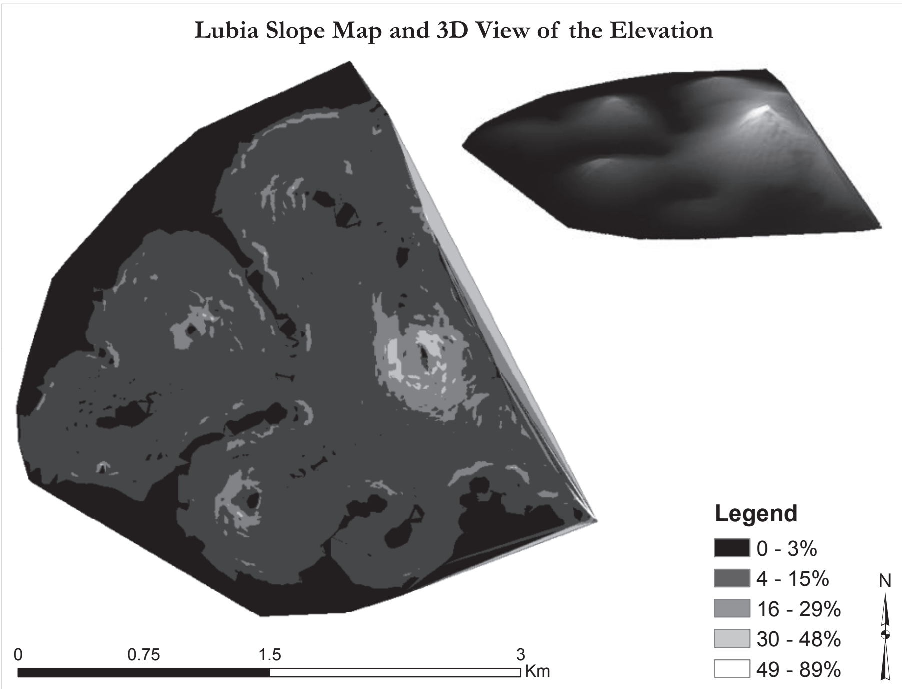


Figure 3.6: Slope gradient and 3D Elevation View
Derived from KCCA Topography Data, 2010

4. RESEARCH METHODOLOGY

4.1. Introduction

The research methodology involved three main phases; (i) Data Collection phase (ii) Data Analysis, and Data Pre-processing & Modelling phase; and (iii) Results and Discussion phase.

Both primary and secondary data was collected; on (i) types and nature of existing developments and proposed densification policies (ii) residents' experiences with surface runoff and flooding (iii) drainage system characteristics, and (iv) on factors for estimating urban runoff generated; which were defined by land cover properties, types and nature of developments, soil data, rainfall data, and DEM characteristics of the Lubia neighbourhood.

The second phase was done in three parts; first was data pre-processing, which involved preparation of both spatial and non-spatial data prior to data analysis. Data analysis was the second step in the second phase; spatial data analysis (done in ArcGIS) involved analysis of land cover properties, existing land uses, topographical data and drainage patterns; non-spatial data analysis on the other hand, which essentially represented people's views on densification practices and surface runoff and flooding experiences, as collected through questionnaires and interviews was done in SPSS (non-spatial data analysis was important for this study especially to comprehend the views of the people in the study area which would then complement results obtained from modelling) . The third step in the second phase was runoff modelling and this was done under three scenarios using PCRaster software.

The last phase was results and discussion; the first step in this phase was comparative analysis of the existing densification practices and the proposed densification policies-this was to establish the types and nature of the densification practice in the study area, which as well informed discussion on surface runoff modelling. The drainage system is considered an important component of hydraulic modelling; and the results of data collected from the field on drainage patterns were also discussed, however due to limitations of spatial data, this data was not included in the modelling part. The third step in this phase was analysis and discussion of results generated from runoff modelling. The results obtained were informative in proposing recommendations that responded to the fourth objective of this study.

The following diagram (figure 4.1) is a schematic representation of the research methodology.

Research Methodology

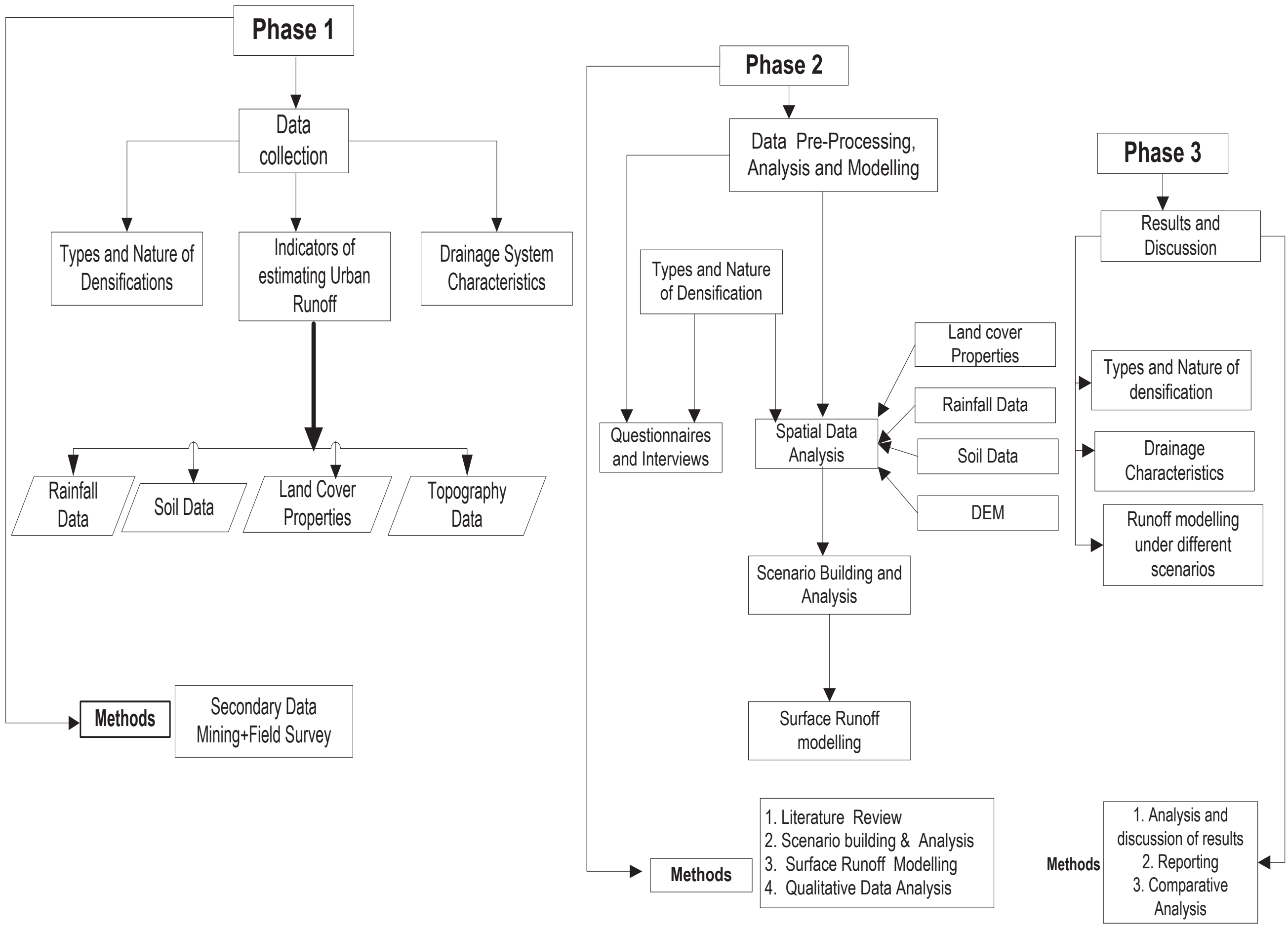


Figure 4.1: Research Methodology

4.2. Data collection

Data collection exercise was undertaken for a period of three weeks between 29th Septemebr to 18th of October, 2013. The main source of data for this research was secondary sources, which were essentially useful for acquisition of spatial data. Primary data was considered a useful supplement to spatial data in understanding the views and perceptions of the residents in regard to existing developments and the proposed densification policies and their experiences with surface runoff and flooding; and for that reason, a few random interviews (60 in number), were conducted. Key informants including KCCA planners and the chief engineer were interviewed to further give more insight on the technical planning and design aspects of densification. Field observation formed an important data collection method, as well as photography and taking measurements (of the drainage channels). The data collection process is summarised in table 4.1 below.

Table 4.1: Data Collection Methodology

Data Needs	Data Source	Data Collection Method
Existing Densification Polices	Primary Data	▪ Questionnaires- Lubia Residents; ▪ Interviews-Key informants from KCCA; ▪ Observations& Photography
	Secondary Data	▪ KPDP, 2012
Proposed Densification Polices	Primary Data	▪ Questionnaires- Lubia Residents ▪ Interviews-Key informants from KCCA;
	Secondary Data	▪ KPDP, 2012
Sources and Sinks of Urban Runoff (and Flooding)	Primary Data	▪ Questionnaires- Lubia Residents ▪ Observations and Photography
Rainfall Data	Secondary Data	▪ Obtained from rainfall measurements taken at Makerere University (from IFM project)
Land cover data	Secondary Data	▪ Derived from 2010 satellite Imagery provided by ITC
Development/Built up structure	Secondary Data	▪ Building footprint derived from Kampala Land use map 2010 data provided by KCCA
Soil infiltration properties	Secondary Data	▪ Data obtained from Mhonda's Thesis (2013)
Drainage systems	Secondary Data	▪ KCCA/ITC-Drainage Channels, Drainage basins, catchment characteristics
	Primary Sources	▪ Measurements of drainage channels ▪ Interviews-Lubia Residents ▪ Observations& Photography
Topographic Data	Secondary Sources	▪ Digital Elevation modelling (DEM)-processed at 2m resolution (topographic data obtained from KCCA)

4.3. Data Preparation and Analysis

Data preparation and analysis was done in two main phases; spatial data preparation and analysis and non-spatial data preparation and analysis.

Non spatial data preparation and analysis was for data collected through questionnaires and interviews. Data collected through questionnaires (60 in number) was prepared and analysed through SPSS. This included such data as average plot sizes in the neighbourhood; percentage of built up area per plot; types of land cover of the unbuilt area within plots; types and nature of densification being experienced; types and nature of land cover changes in the neighbourhood and their supposed impacts; experiences with surface runoff and flooding, and their relationship with densification practices and measures being undertaken to mitigate against surface runoff generation and potential for flooding. Data collected from interviews (especially from key informants) was transcribed and included in the report. Inputs from data collected from observations and photography were also integrated in the report. Apart from data collected in the field, non-spatial data collected from secondary sources was also prepared, analysed and included in the report and in the modelling process- this included soil data, rainfall data and data on the proposed densification policies.

Spatial data preparation and analysis, was done in ArcGIS, using spatial analyst tools, conversion tools, data management tools, fields, and 3D analyst tools. The following activities were executed;

i.) Preparation and analysis of land cover maps. This was done into four land cover classes; (i) Built-up (ii) Vegetation (iii) Bare Soil and (iv) Tarmac. Essentially, Built-up land cover and Tarmac form the impervious layer that basically inhibits natural surface water infiltration, but they varied in infiltration characteristics.
ii.) Preparation of Digital elevation model from existing topographic maps (2010)
iii.) Analysis of existing land use data (2010)
iv.) Preparation and analysis of drainage measurements obtained from the field

Spatial data preparation and analysis culminated in preparation of a geo-database of the required data for surface runoff modelling.

4.4. Factors of Estimating Surface Water Runoff

Factors of estimating surface water runoff for this study were limited to; soil data, rainfall data, topographical data and land cover properties.

4.4.1. Soil Types and Infiltration Characteristics

Soil moisture variations and all processes related to the soil layers strongly depend on the soil properties. These processes are infiltration, evapotranspiration, percolation, and groundwater flow. The texture and structure of the soil are the main characteristics that determine the soil hydraulic properties (porosity, field capacity, wilting point and hydraulic conductivity). For hydrological purposes, soils can be classified according to their texture class, as shown in figure 4.2 below. Figure 4.3 on the other hand shows a general water balance framework of a catchment which would for instance constitute a canopy (interception), soil layer, etc., as in the case of the study area.

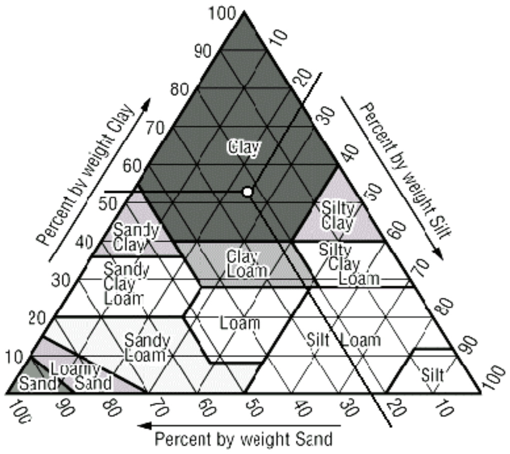


Figure 4.2: Soil Classification

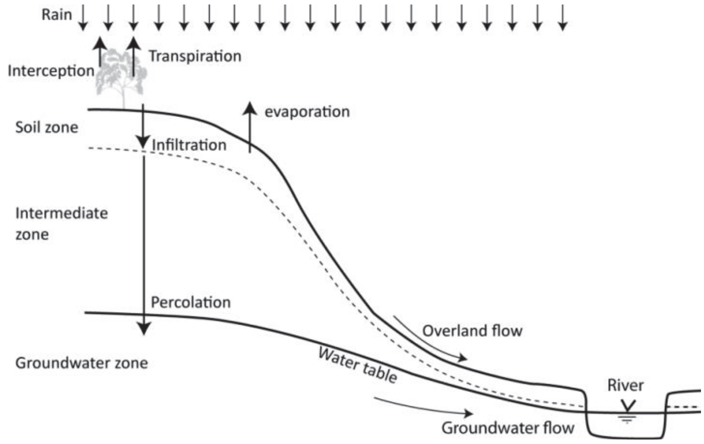


Figure 4.3: Schematic drawing of a general water balance framework

Source: obtained from Spatial Modelling of Natural Hazard Processes Pg. 27 & Pg. 9 resepectively ((Jetten et al., 2011)

Kampala Soils are classified as Ferralsols. In the context of surface runoff modelling, the following soil infiltration measures were used;

i.) **Ksat:** Which is the saturated hydraulic conductivity in mm/h of the surface layer

ii.) **Interception canopy storage** (mm) for the various land covers. This was an important infiltration characteristic to determine how much rainfall would reach the soil after interception.

Data on soil hydraulic conductivity was obtained from Mhonda's study on flash flood risk reduction strategies in built-up environment in Kampala done in 2013 for 29 soil samples for five land cover classes (table 4.2 below); while data on interception canopy storage was obtained from de Jong and Jetten (2007) study on estimating spatial patterns of rainfall interception from remotely sensed vegetation indices and spectral mixture analysis.

Table 4.2: Soil Hydraulic Conductivity for Various land Cover classes

Land Cover	**Minimum**	**Maximum**	**Mean**	**Median**	**Std**	**N**
Upland Vegetated	0	104.43	20.98	5.17	32.81	14
Lowland Vegetated	0.29	1.97	1.07	1.76	23.28	4
Bare Soil	0.39	6.06	3.34	11.5	2.35	4
Earth Road	1.4	4.97	2.5	1.78	1.47	6
Earth Drainage	1.79	2.29	2.04	2.04	0.36	3

Source: Evaluating Flash Flood Risk Reduction Strategies in Built-up Environment in Kampala (Mhonda, 2013)

4.4.2. Rainfall Data

This study used a one-time rainfall event to model surface runoff generation; this was obtained from rainfall data collected at Makerere University, between May 2012 and October 2012. The 25th June 2012 rainfall event was done in 10 minutes time series for 110 minutes; within which the highest rainfall of 66.2 mm was registered.

Climate predictions from Uganda in terms of rainfall are very uncertain. It can therefore not be predicted whether heavy rainfall events would continue to occur. On a 1:10 year's rainfall record, for instance, KMDP recorded 100 mm of rainfall on a single day.

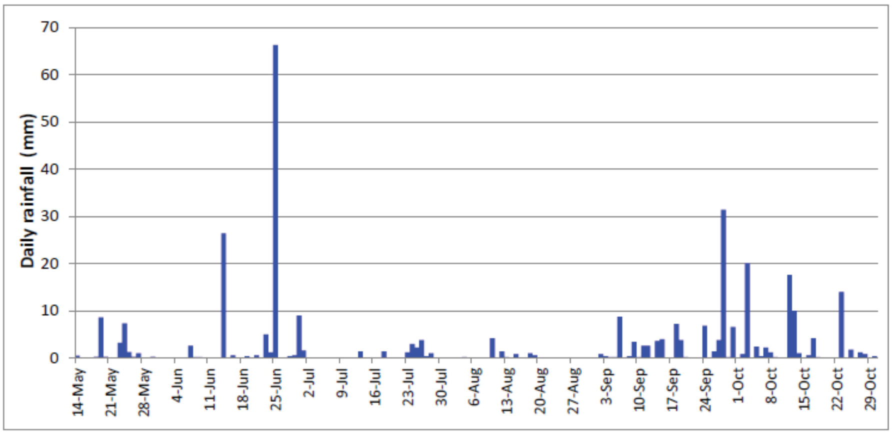


Figure 4.2. Daily rainfall pattern form May 14th to October31st

Figure 4.4: Daily Monthly Rainfall Pattern of Kampala from May 14th to October 31st
Source: Integrated Flood Modelling Study (Sliuzas et al., 2013)

4.4.3. Digital Elevation Model

A digital elevation model was generated from topographic data (2010) obtained from KCCA (figure 4.5 below). The DEM was processed at 5m resolution. The DEM was not exactly the same size as the study area coverage; this was attributed to processing error of the topographic data at the edges of the study area map; however, the modification was quite insignificant and did not affect the results of the study.

Based on the DEM, the highest elevation of the study area is 1286 m above sea level, while the lowest is 1160 m.

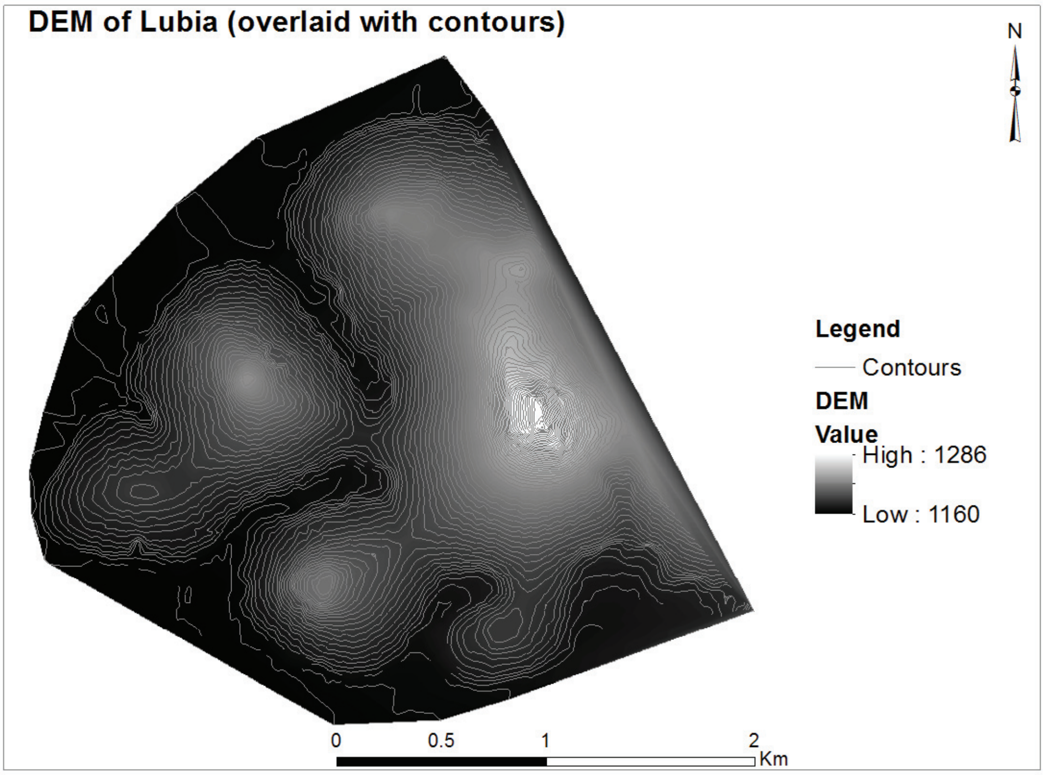


Figure 4.5: DEM of the Study Area Lubia
Source: KCCA topographic data (2010)

4.4.4. Land Cover Properties

Generally, hydrological models describe land-use properties using a limited number of uniform urban land-use classes(Dams et al., 2013). However, urban land-use is characterized by a large heterogeneity of surface cover types including buildings, roads, gardens, parks, etc., causing a strong variation of imperviousness within the urban area (Ackerman and Stein, 2008).

Initial land cover properties for the study area were derived from the 0.5 m resolution Geo Eye satellite imagery (2010) using ArcGIS 10.2, which was classified into four themes that were important for modelling surface runoff. These were vegetation cover, built-up, tarmac and bare soil. The satellite imagery was classified using unsupervised image classification method and maximum likelihood classifier. The image was classified at a spatial resolution of 1.5 m; the spectral resolution constituted only three bands of the visible spectrum.

Based on the land cover map for 2010 (figure 4.6 below), the percentile coverage of the different classified covers was as follows;

Land Cover Class	Percentage Coverage
Built-up	14.62%
Vegetation	51.99%
Bare Soil	25.2%
Tarmac	8.19%

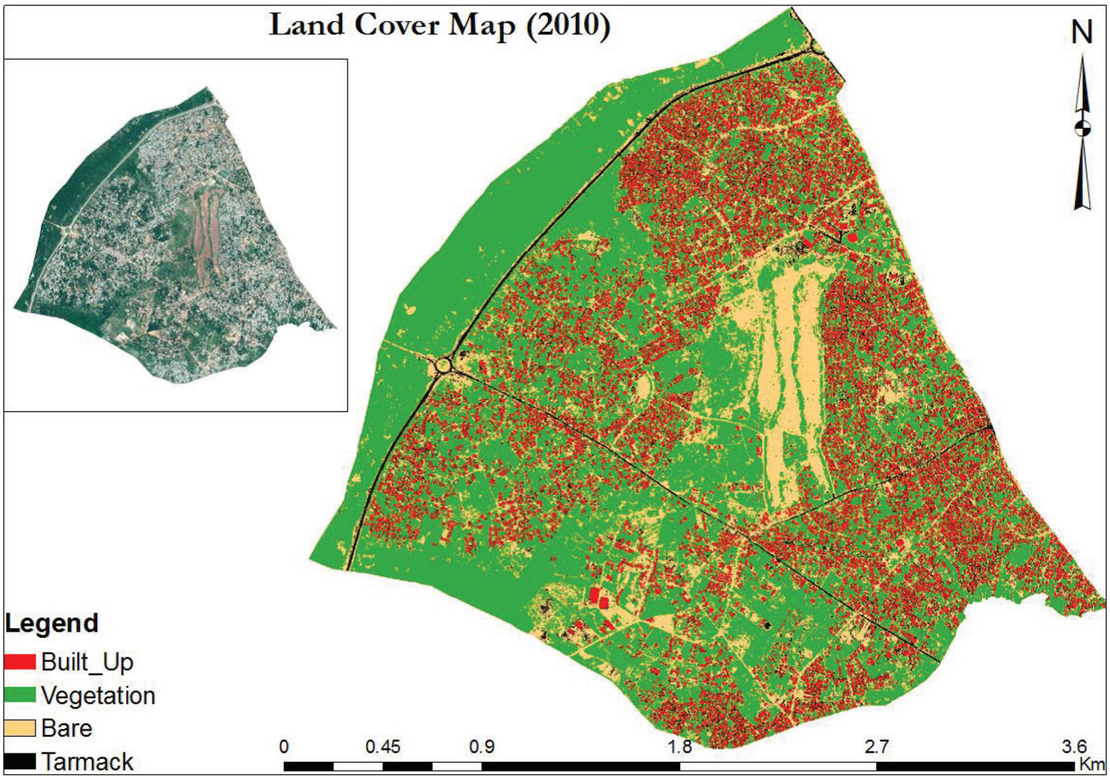


Figure 4.6: Land Cover Map-Lubia Neighbourhood

4.5. Estimating (Modelling) Surface Runoff under Different Scenarios

4.5.1. Part 1: Scenario Building of the Various Densification Approaches

Estimating surface runoff was done in three different densification approaches; Base scenario (existing scenario), under horizontal densification (trend scenario) and thirdly under vertical densification. Horizontal and vertical densification resulted to modification of the original land cover properties and this influenced the land coverages of the other land cover classes (bare soil, vegetation and tarmac). Figure 4.7 below is a summary of the process used in estimating surface runoff generated under the three scenarios.

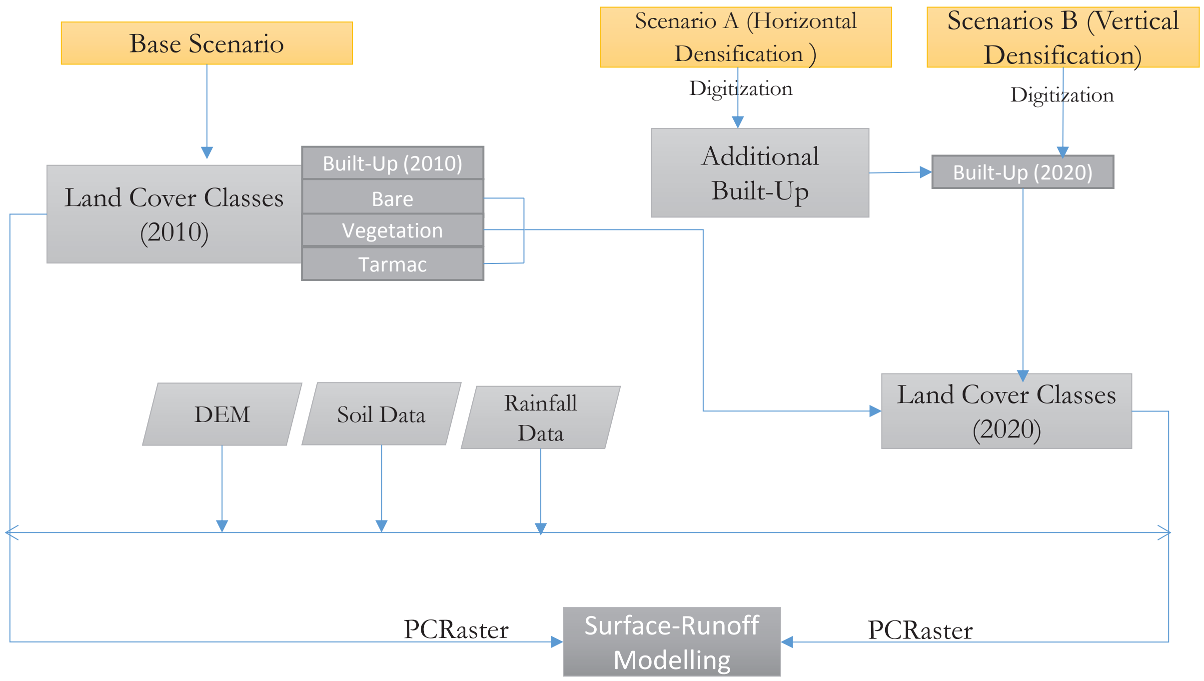


Figure 4.7: Summary Process of Estimating Surface Runoff under Different Scenarios

4.5.1.1. Base Scenario

This scenario attempted to estimate surface water runoff currently being generated in the neighbourhood, based on the classified image of 2010. The model inputs included: land cover map 2010 (built-up area, vegetation cover, Tarmac and bare soil), DEM, Rainfall data and soil data. This scenario acted as a base scenario; upon which the following two scenarios (based on horizontal and vertical densification) were compared.

4.5.1.2. Scenario A: Business as Usual

This scenario attempted to estimate the amount of surface water runoff that would be generated in the next 10 years, by disregarding or rather assuming that there was no planning and policy intervention in the study area. With such assumption, the current trend of development which was in the form of horizontal densification and characterized by haphazard, uncontrolled and uncoordinated developments was set to continue. Based on household survey undertaken in this study, the main forms of horizontal densification in the neighbourhood were infilling/new developments rated at 31.6%; subdivisions or shrinking of plot sizes at 26.6%; increase in plot coverages at 20.9%; increase in plot ratios at 5.1% and redevelopments at 15.8%. But due to lack of access to cadastral information, horizontal densification scenario (for this study) was developed on the assumption that densification would take place through infilling and/or new developments. Other assumptions for this scenario were that:

- The neighbourhood would continue being a home to the low income bracket for the next ten years, and therefore the types and nature of housing developments would remain the same
- There would be minimal or no change to the average building size (average roof area)
- The existing roads remain the same
- Household size (3.9) remained the same for the next ten years; for this research, the household size of the neighbourhood was obtained from Uganda Central Bureau of Statists (2010).
- The neighbourhood was largely residential with percentile coverage of 68.55% based on the land use map 2010; however, this study disregarded the other land use functions and instead adopted the residential function at 100%.
- The existing drainage channels did not play any role in modelling runoff for this study; instead PCRaster created (spatial) local drainage directions (ldd) based on the DEM; the ldd defines the path of flow and accumulates water through the set of cells.

Methodology

The spatial dataset used to estimate the number of built up structures in the year 2010, was in form of polygons digitized from the 2010 Geo Eye satellite imagery. The built up structures were inclusive of both temporary and permanent buildings as both types are considered infiltration interceptors for surface runoff modelling. This was the first step for this scenario.

The second step was to calculate how many more structures were likely to be added in the neighbourhood by the year 2020. Despite that there may be many variables that would determine the type and nature of densification, given by literature (including economic development and land availability), the control variable adopted for this study, to determine how many more houses or structures would be constructed for the next ten years-starting from the year 2010-was population (growth). It was therefore needed to calculate the neighbourhood population for 2010, which would then be projected to the year 2020.

Lubia Popn 2010=Ave.HH size*No. of Households/Structures (2010)

The number of households/structures in the neighbourhood based on the 2010 data was 14475; at an average household size for urban areas of 3.9 and sustaining the average population growth rate as an 3.2% (according to Uganda Bureau of Statistics (2010), Lubia registered a population increase/ households(structures) increase of 37.02%. Table 4.3 below shows the predicted population of the neighbourhood for the year 2020 and the additional number of structures likely to be constructed.

Add. Res. Structures 2020=Res Structures 2020 - Res. Structures 2010

Where:

Res. Structures 2010=Total Count of 2010 digitized Structures
Res. Structures 2020= Ave. HH Size * (Projected Population 2020-Population 2010)

Table 4.3: Estimating Additional Number of Residential Structures by 2020

No.of Households (2010)	HH Size	Estd. Popn 2010	Population Growth rate (PA)	Projected Popn 2020	Projected No. of Households 2020	Add. Households 2020
14478	3.9	56464,2	3.2	77369.56	19838.35	5360.35

The third step for this scenario involved digitization of the additional structures; this would then be joined with the 2010 built-up layer to form a new layer of built-up structures for 2020. Digitization of new structures was done based on the neighbourhood rule; new structures are more likely to be built next to existing structures. Although areas under the residential function were densely built compared to the other land use functions (according to land use map and built-up layer 2010), the unoccupied areas under the residential function, were the most obvious targets for addition of the new structures-people are more likely to build in open/unoccupied areas next to where other people are. Digitization on the rest of the land use functions was limited next to the areas where development was already occurring and in the same proportion.

The shape and size of the new structures was guided by the neighbouring structures; this was done to try as much to maintain the average structure size (70.68 m^2), according to the built-up layer (2010).

4.5.1.3. Scenario B: Vertical Densification

Vertical densification was the third development scenario considered for this research in estimating the amount of surface runoff that would be generated in this neighbourhood.

Vertical densification in this research assumed a complete redevelopment approach of the neighbourhood-with consideration of a single land use function-residential land use. The Redevelopment approach was guided by the building standards and guidelines stipulated in the National Physical Planning Standards and Guidelines for Kampala (2011).

Assumptions

The assumptions under for scenario include:

- The neighbourhood constituted both low income bracket (75%) and medium income bracket (25%)
- Household size (3.9) remained the same for the next ten years; for this research, the household size of the neighbourhood was obtained from Uganda Central Bureau of Statists (2010).
- The redevelopment was considered only for residential use; however, existing environmental, institutional and recreational land uses were preserved.
- All residential units were based on 3 levels high-rise design (residential flats)
- For runoff modelling, the unbuilt area for this model was assumed to be vegetation cover and/or bare soil in varied proportions.
- The existing drainage channels did not play any role in modelling runoff for this study; instead PCRaster created (spatial) local drainage directions (ldd) based on the DEM and the roads layer; the ldd defined the path of flow and accumulated water through the set of cells.

Methodology

In estimating the amount of surface runoff produced, one of the most important modelling variables as earlier mentioned is estimating the surface area covered by impermeable material; and in this scenario represented by the built-up area, tarmac roads and paved areas that may be associated with buildings (i.e. for car parking, walking or as terrace spaces. Therefore, based on a redevelopment concept, the first step involved designing a neighbourhood on the assumption that all the existing buildings in the area have been demolished. Some of the existing major roads were maintained in order to simplify the re-design process.

I. *Estimating the number of residential units required and total space coverage*

Just like the preceding discussion on Scenario A, the number of residential units required for vertical densification was determined based on the projected population of the neighbourhood for the next ten (10) years (Table 4.2 baove). Using the same variable essentially facilitated comparison between the various scenarios. As earlier calculated in scenario A, the total number of units/structures required by the year 2020 was 19838 (Table 4.2 above).

The size of the residential units was guided by the building standards and guidelines stipulated in the National Physical Planning Standards and Guidelines for Kampala (2011). Considering that the neighbourhood is largely a low income neighbourhood, this scenario experimented with two types of densifications: high density developments and medium density developments. However, data on the spatial distribution of income levels is limited, therefore this study assumed a ratio of 3:1 in favour of high density developments; this is based on the fact that the area is largely a low income area from observations made during field survey and from literature review.

As shown in table 4.4 below, the minimum plot area requirements for medium density was 600 sq. metres and 200 sq. m for the high density developments. The building regulations further require that at least one parking space per dwelling is provided for medium density residential developments, and at least 2 parking spaces per dwelling in housing estates, as shown in the table 4.5 below.

Table 4.4: Building Standards and Guidelines

	Medium Density	**High Density Detached**	**High Density Semi-Detached**
Plot Area (Sq. M)	600 – 1,000	300 – 600	200 – 300
Minimum Plot Width (m)	20 m	12 m	12 m
Minimum Plot Length (m)	30 m	25 m	25 m
Maximum Plot coverage	40%	40%	50%
Minimum Building Lines			
(a). Front	6	3	3
(b). Side	2	2	2
(c). Rear	8	2	2

Source: National Physical Planning Standards Guidelines for Uganda (2011)

Table 4.5: Parking Requirements for Housing Estates

Dwelling Units	**No. Of Parking Spaces Required**
Flats with 2+ bedrooms	2 per unit
Flats with 1 bedroom only	2 per unit
Visitor parking provision	1 space per 5 units
Medium Density Residential flat building	1 space for each unit plus 1 for each 5 x 2 bedroom unit plus 1 for each 2 x 3 bedroom units

Source: National Physical Planning Standards Guidelines for Uganda (2011)

a) High Density Dwellings

In the proposed ratio of 3:1, high density dwellings constituted 14879 of the total 19838 units. Minimum plot area for these developments was 300 sq. m and the maximum 600 sq. m.

Area covered by one unit (One dwelling) =Plot coverage=40%

Design Considerations

Design consideration for high density dwellings were as follows;

- For surface runoff modelling, the design would only consider plot coverage (which was 40% of plot area)
- Plot sizes differed in sizes and may consist more than one residential building

- Every building had four levels/floors
- No considerations for parking space for the high density developments

Number of Buildings required =Number of high density dwellings/4
=14879/4=3720

Based on the least provision for a plot size of (300 sq. m), and assuming that this plot would host a single dwelling, then the size of the dwelling would be 120 sq. m (40% of 600); this was however considered quite large for high density residential dwellings, considering the current average size of a building was approximately 70 sq. m. Therefore this study downscaled it and considered a standard average size of 100 sq. m per dwelling. The total amount of space that was required for high density dwellings was:

100 sq. m *3720=372000 sq. m

b) Medium Density Dwellings

Medium density dwellings constituted 4959 of the total 19838 units. Minimum plot area for these developments was 600 sq. m and a maximum of 1000 sq. m and a plot coverage of 40%.

Area covered by one unit (one dwelling) =Plot coverage=40%

Design Considerations

Design proposals for medium density dwellings were as follows;

- For surface runoff modelling, the design only considered the plot coverage (which is 40% of plot area)
- Plot sizes differed in sizes and may consist more than one residential dwelling
- Every building had four levels/floors- the first level (ground floor) was considered as parking area for this design

Number of Buildings required =Number of medium density dwellings/3
=4959/3=1653

Based on the least provision for a plot size of (600 sq. m), and assuming that this plot would host a single dwelling, then the size of the dwelling would be 240 sq. m (40% of 600); this was however considered way too large for a single dwelling, considering the current average size of a building is 70 sq. m. Therefore this study, considered a standard average size of 120 sq. m per dwelling.

Therefore the total amount of space required for medium density dwellings was:

120 sq. m *1653=198360 sq. m

Figure 4.8 below is an illustration showing the proposed residential standards per unit for the medium and high density residential units.

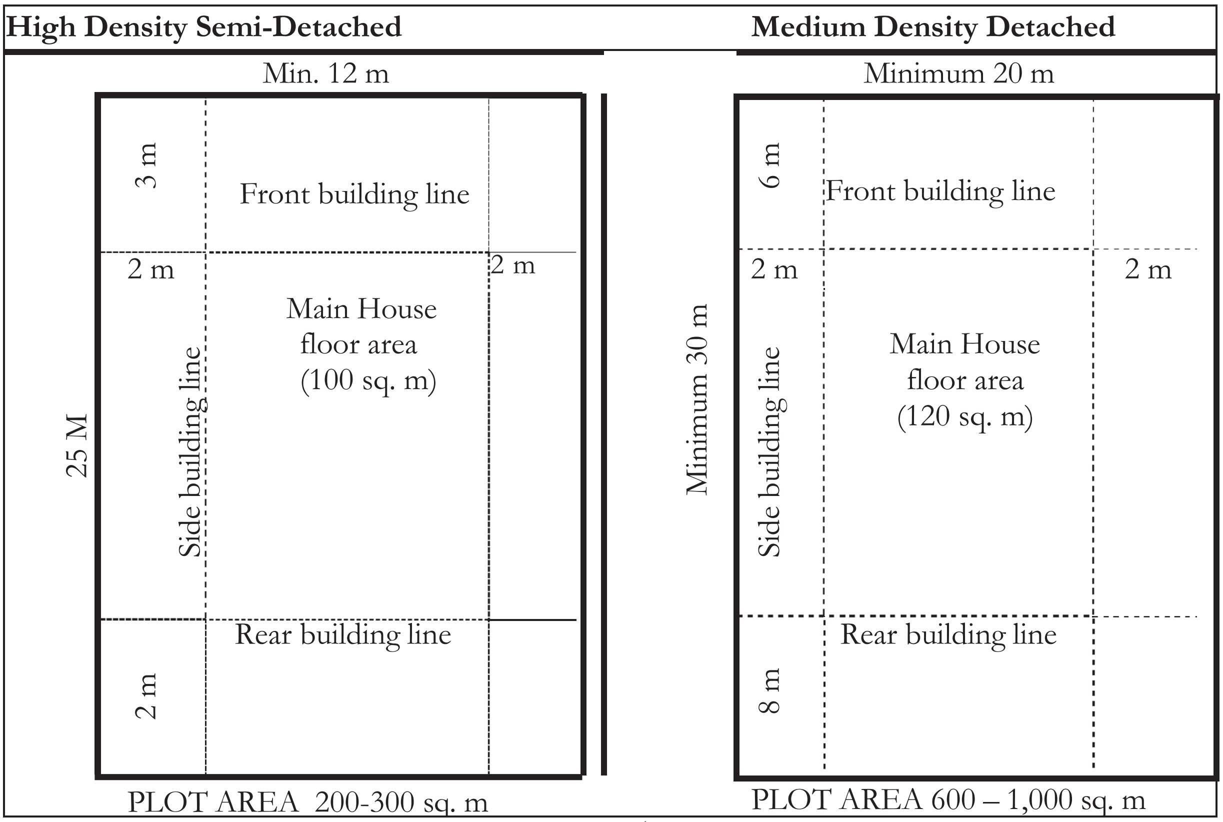


Figure 4.8: Proposed Residential Standards per dwelling (unit/structure)
Modified from National Physical Planning Standards Guidelines for Uganda (2011)

II. *Neighbourhood Design*

Vertical densification, as earlier discussed constituted integration of planning policies and standards for the new residential developments and this therefore necessitated a neighbourhood design that would accommodate the estimated number of housing units. The following steps were involved in designing the neighbourhood;

i.) Determining suitable areas for the residential development
ii.) Spatial design of the neighbourhood
iii.) Digitization

a) Determining Suitable Areas for New Developments

Prior to digitization of the new developments, suitable areas for development were selected using spatial analyst tools in ArcGIS. The following process was undertaken;

i.) First, residential, commercial, agricultural, open spaces and mixed-use land use functions were selected from the existing land use map (2010); this formed the suitable areas for development. The environmental areas were basically wetlands and therefore unsuitable for development; recreation, institutional and industrial areas were best reserved as they were to supplement the new residential developments.
ii.) A slope map was thereafter prepared and a slope analysis performed. Areas with medium slope ranging between 3-15% (referencing the National Physical Planning Standards Guidelines for Uganda) were selected, which formed areas with suitable slope for development (Figure 4.9).

iii.) The suitable areas selected from the land use map were overlaid with the slope map of suitable (medium) slope to form the final map of suitable areas for the new residential development (Figure 4.9). However, some of the areas cut out were pretty much small and insignificant and were therefore overlooked during digitization.

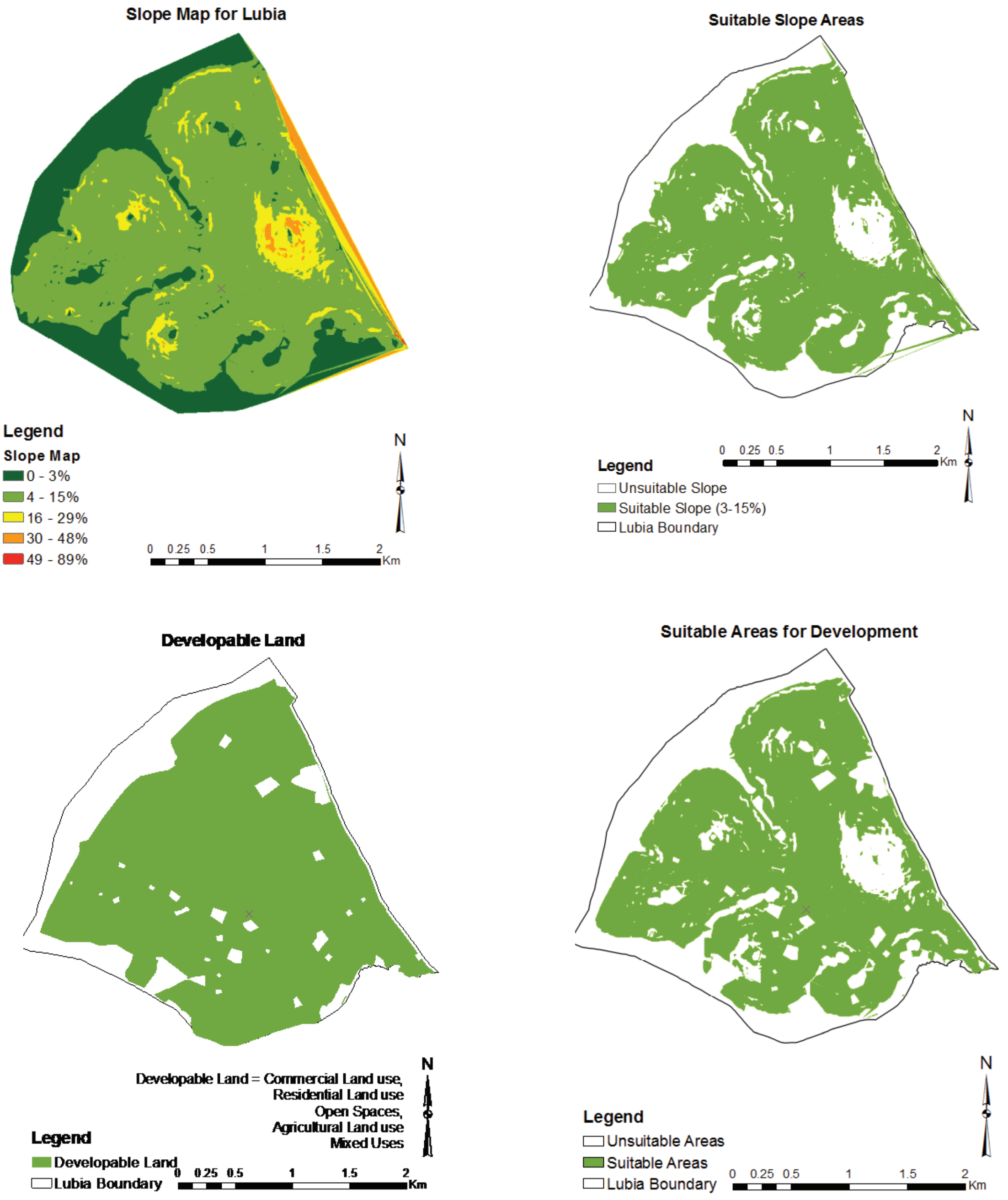


Figure 4.9: Determining Suitable Areas for New Developments

NB: As shown by the maps on figure 4.9 above, some of the areas cut out were pretty much small and insignificant and were therefore overlooked during digitization.

b) Spatial design of the neighbourhood

Neighbourhood design was done on the land deemed suitable for development as discussed in the preceding section. Three main land use functions were considered at this stage; the transportation system (represented by primary and secondary roads), the drainage system and the residential plots. The layout of the design was largely dependent on the topography of the neighbourhood, which essentially guided the orientation of the plots, roads and drainage channels.

Neighbourhood design was initiated by sketching which was done intensively and repeatedly before the final design was arrived at. The first step was to sketch the new roads, which were oriented to the contours. This would then facilitate the sketching and orientation of the drainage channels and the residential plots, which were aligned to the roads (figure 4.10 below).

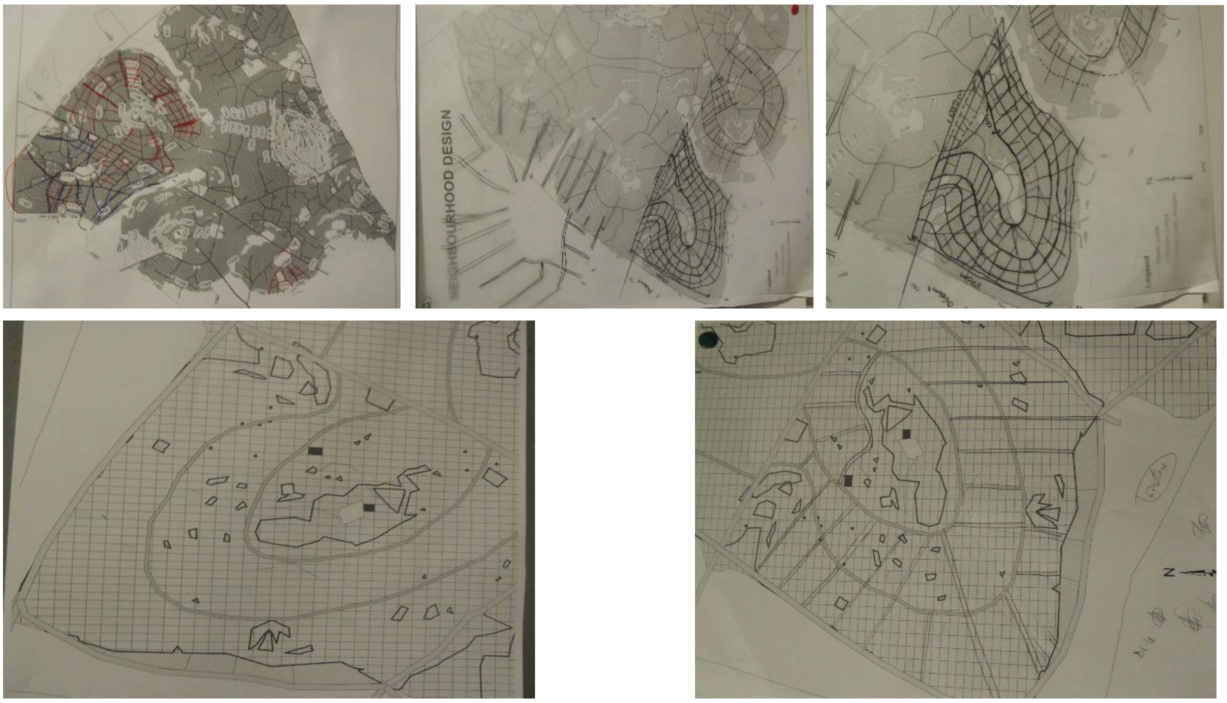


Figure 4.10: Design Sketches

c) Digitization

Digitization commenced after the desired neighbourhood design was achieved. Informed by the existing residential patters, the medium density dwellings were digitized in three neighbouring villages (Masaanafu Bukuluki; Masaanafu Kinoonya and Lugala); while high density developments were digitized onto the other 6 villages Lubya, Lusaze, Mapeera, Nabulagala, Namung'oona 1 and Namung'oona II.

Digitization was done in form of plots; however, only 40% (plot coverage), which represented building/roof area per plot, was used for surface area modelling

The plots were digitized in various sizes ranging between 4446 sq. m to 40296 sq. m. Based on the earlier calculated dwelling size, the total area coverage of all plots digitized was calculated as follows;

High Density Dwellings:

40% (built-up area) =372000 sq. m

100%=Total area of all plots= (100%*372000 sq. m) /40 =930,000 sq. m

Medium Density Dwellings;

40% (built-up area) =198360 sq. m

100%=Total area of all plots= (100%*198360 sq. m) /40 =495900 sq. m

Figure 4.11 below is a snap shot of Plot Areas and Plot Coverages of the digitized plots.

Table

New_MediumDensity_plots

OBJECTID *	SHAPE *	SHAPE_Length	SHAPE_Area	Built_Up_Cover
114	Polygon	178.76	1377.1	551
120	Polygon	242.44	1905.92	762
82	Polygon	215.06	2429.53	972
113	Polygon	273.82	4609.9	1844
111	Polygon	347	5419.94	2168
86	Polygon	344.72	5466.76	2187
79	Polygon	344.22	5476.43	2191
115	Polygon	330.53	5683.6	2273
112	Polygon	335.69	5973.67	2389
119	Polygon	367.76	6495.02	2598
76	Polygon	374.41	6504.42	2602
70	Polygon	421.87	6520.21	2608
118	Polygon	380.96	6706.77	2683
71	Polygon	344.36	6799.94	2720
75	Polygon	364.64	6850.09	2740
83	Polygon	373.58	7048.92	2820
85	Polygon	418.09	7078.58	2831
77	Polygon	409.48	7299.36	2920
116	Polygon	402.41	7770.68	3108
110	Polygon	433.25	7855.25	3142
117	Polygon	417.7	8037.87	3215
80	Polygon	416.75	8315.53	3326
103	Polygon	422.82	10200.23	4080
109	Polygon	483.35	10436.98	4175
97	Polygon	427.95	10644.7	4258
99	Polygon	450.09	11129.67	4452
106	Polygon	523.85	11361.5	4545
96	Polygon	446.54	11476.28	4591
104	Polygon	490.1	11548.31	4619
88	Polygon	483.23	11594.44	4638
87	Polygon	465.06	12439.63	4976

Figure 4.11: Snapshot showing Plot Areas and Plot Coverages of the digitized plots

III. *Calculating the built up cover from the digitized plots for Surface Runoff Modelling*

Calculating the built up area from the digitized plots was essential for part 2 of this study (surface runoff modelling). Built-up area was the total sum of the area covered by the dwellings; for both medium and high density dwellings, plot coverage (which was 40%) for both cases was used to calculate the built up area per each digitized plot.

4.5.2. Part 2: Modelling Surface Runoff under the Three Scenarios in PCRaster

4.5.2.1. Introduction

Surface runoff, or overland flow, is the water that does not infiltrate into the soil, but flows over the surface to the stream channel during and immediately after a rainfall event (Jetten et al., 2011). In itself it is not really a hazard unless the amount and timing are such that it can be considered a "flash flood", which have to be modelled in very short time steps (Jetten et al., 2011). There are two types of overland flow: saturation excess overland flow and 'Hortonian' overland flow. *Saturation excess overland flow* occurs when the soil storage is exceeded and no more rainfall can be absorbed and often occurs after a series of wet days. *Hortonian overland flow occurs* when the rainfall intensity is higher than the infiltration rate of the soil and this instigates for detailed information about the rainfall event.

Surface runoff modelling for this study was done using GIS operations-PCRaster-a spatial dynamic modelling tool that uses dynamic modelling language. It consists of two main programs: **pcrcalc** which is used for GIS operations with maps and tables to execute the model and **aguila,** which is used for visualisation. Dynamic Modelling language follows the same approach as Map Analysis Package (MAP) in the sense that it provides a set of generic operators, which can be used as primitives for the models.

PCRaster is *command-line* based program as opposed to menu based and the syntax always used is as follows:

Pcrcalc result = operation (arguments)

The main concept in PCRaster is discretization of landscape in space, resulting in cells of information. Each cell contains attributes that basically define its properties, but can also receive and transmit information to and from the neighbouring cells. GIS operations or operations used in modelling induce change in the properties of these cells. Figure 4.12 below shows the relations between attributes within a grid cell and lateral directions with neighbouring cells; figure 4.13 is a simplified representation showing how different layers of information combine into one set of information per grid cell.

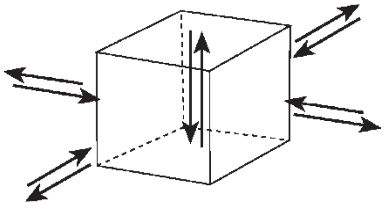


Figure 4.12: Relations between attributes within the cell and in lateral directions with neighbouring cells
Source: obtained from obtained from lisem website, http://itc.blogs.nl/lisem

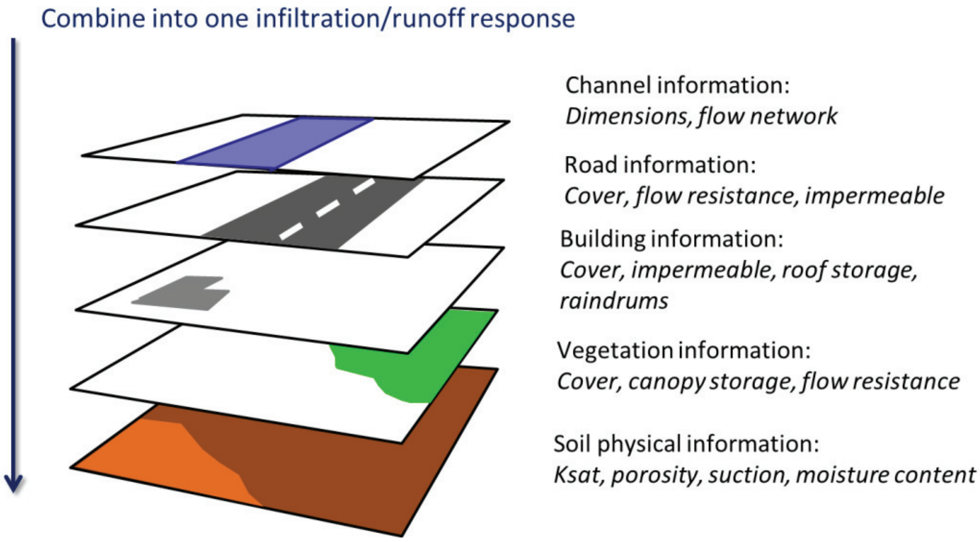


Figure 4.13: Different information layers combined into one set of information per grid cell.
Vegetation and buildings information is given as a fraction per cell while roads and channels as width in m. The soil layer forms the base layer.

Source: obtained from obtained from lisem website, http://itc.blogs.nl/lisem

4.5.2.2. Estimating Surface Runoff

The infiltration capacity is ksat (mm/h) multiplied by the duration of the event which is 2 hours, and 20 minutes extra is taken for the runoff process which continues for a short while after the rainfall stops. Dt is set at 140 minutes = 2.33 hours$I_c = ksat*dt$

Surface runoff is generated from the infiltration per grid cell, and accumulates that runoff towards the outlet. A first estimate is to simply subtract the infiltration from the effective rainfall Pe (mm), which is the rainfall decreased with the interception storage (mm) by houses and vegetation:
Pe = P - interception storage:

$$\mathrm{RO\ (RunOff) = Pe(Effective\ Rainfall) - I_c(Infiltration\ Capacity)}$$ (Source: Jetten et al., 2011)

Using an example given by (Jetten et al., 2011); with the provision that when Pe = 0, runoff RO = 0. However, this only calculates how much water is available for runoff *per grid cell*, but that water does not yet flow to the stream channel. It still has to be 'routed' to the outlet (using an accuflux operation). Also, when runoff water flows over cells that still have infiltration capacity, further infiltration will take place. With an accuflux the subtraction is done *before* the accumulation, not *during* the accumulation. PCRaster has a special version of accuflux that can handle this: "accuthresholdflux". This operation accumulates the effective rainfall over the surface subtracting for each gridcell the infiltration capacity. The formulae (i) and (ii) summarizes the process of calculating surface runoff using PCRaster.

i.) runoff = **accuthresholdflux**(LDD, Pe, Ic);

ii.) Where Infilcap is the maximum possible infiltration. In order to calculate what actually infiltrates into the soil the inverse command is used:

Infil = **accuthresholdstate** (LDD, Pe, Infilcap)

4.5.2.3. Modelling Surface Runoff for Lubia Neighbourhood under the Three Scenarios

The first scenario to be modelled was base scenario. This scenario attempted to estimate surface runoff generated in the neighbourhood based on the classified image of 2010 under the four land cover classes; built-up layer, vegetation cover, bare soil and tarmac. Other model inputs for this scenario included existing roads, DEM, Rainfall data and soil data as shown in tables 4.2 and 4.3. Figure 4.15 below is a simplified flowchart of the process that was used for hydrological modelling (for all the three scenarios) with the main variables that were used as inputs.

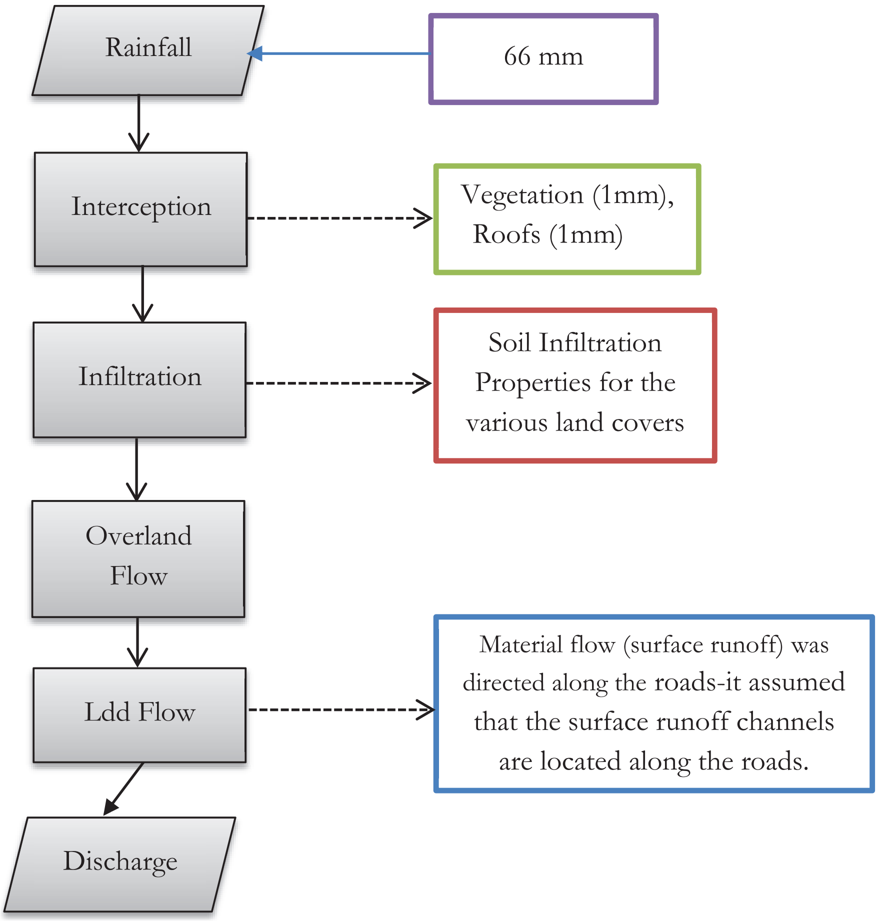


Figure 4.14: Simplified flowchart of hydrological modelling with PCRaster

The second scenario to be modelled was Scenario A (horizontal densification). This was based on a trend assumption of the base scenario. The model inputs (Tables 4.7 and 4.8) for this scenario were similar to the base scenario; but with additional built up structures which took preference of a grid cell over the other classes (bare soil, vegetation, tarmac) in the event that two land covers overlaid. Some assumptions were also made for this scenario to create some sub scenarios; it was assumed that bare land would also increase with increase in built-up cover; therefore the following command was used to adjust bare land;

LU = if(LU eq 2 and uniform(1) gt 0.7 and windowmaximum(house, 15) eq 1, 3, LU);
This command was used to change part of vegetation cover to bare land for sub scenario A; the command is a random uniform generator that says If a grassed grid cell has an adjacent grid cell that has a house (in a 3 x 3 cell window), there is a 30% chance it is converted to bare soil. The same was done for other sub scenarios, this time assuming a value of 0.5 (meaning a 50% chance of conversion); and 0.2 value (implying an 80% chance for conversion).

Scenario B (vertical densification) formed the third and final scenario. This scenario was based on a redevelopment approach, where planning standards and regulations informed the redevelopment of this scenario (as further elaborated in the previous section under vertical densification). The model inputs included digitized plots (from which plot coverage was calculated in PCRaster), new roads layer, vegetation cover, tarmac and bare soil (Tables 4.7 and 4.8). Several sub scenarios could be generated under scenario B, but this study limited to the following sub-scenarios;

- i.) Runoff generated with assumption that all the non-built area was covered by vegetation
- ii.) Runoff generated with assumption that all the non-built area was covered by bare soil
- iii.) Runoff generated with assumption that all the non-built area was covered partly by vegetation and partly by bare soil. For this assumption, the proportions assumed for the vegetation and bare land covers were as for the original land cover classes (under scenario 0) only that priority was given to Scenario B in case of conflicts between cells.

Modelling process

The model inputs were first pre-processed in ArcGIS 10.2.1 and exported to PCRaster in ASCII file format. In PCRaster, the ASCII tables were converted to PCRaster maps and further processed for runoff modelling. The basic maps exported from ArcGIS and the table of soil properties created in PCRaster formed the basic data for runoff modelling; all the other maps were generated from this data. Tables 4.7 and 4.8 show a list of maps that were generated for runoff modelling and their description. The scripts used to generate the maps in PCRaster environment are attached in Appendix 1, 2 and 3.

DEM Data

The DEM, as input data was basically used for two purposes; firstly, it was used as elevation map which is an important input for runoff modelling; and as such, it formed the base (mask) upon which the other input maps were aligned; secondly it was used to create local drain maps which basically show the flow direction of material (surface runoff in this case) as shown by figure below 4.16.

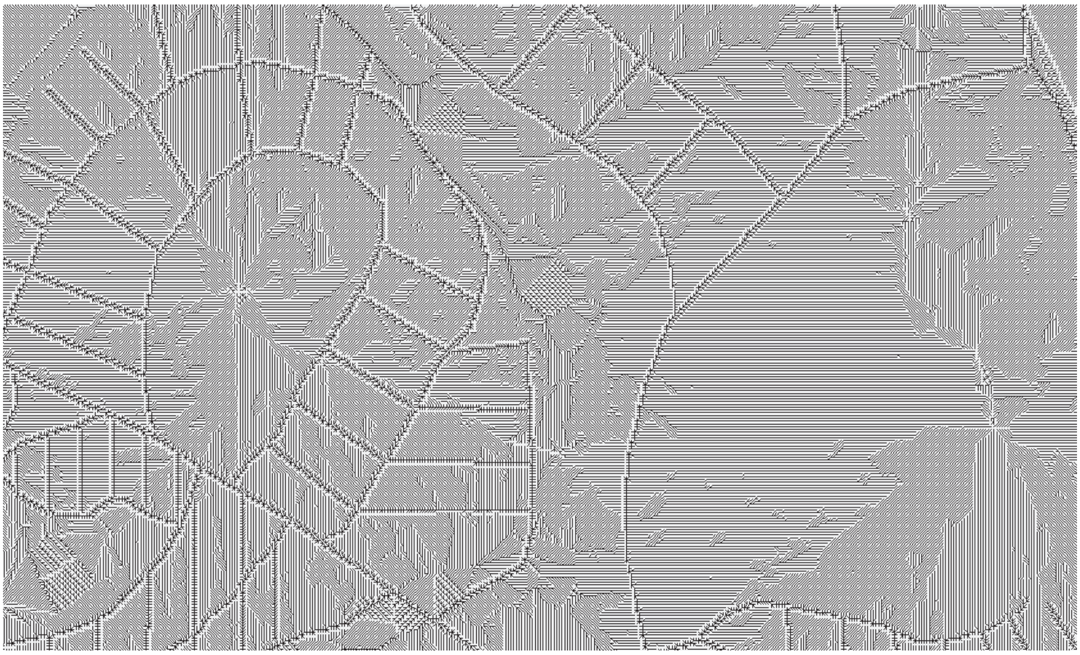


Figure 4.15: Snapshot of local drain directions for Scenario B created from DEM and Roads Layer in PCRASter

Rainfall Data

For the three scenarios, rainfall data was a scalar value of 66 mm. This was a value recorded on 20th June 2012 by a recently undertaken study of Integrated Flood Modelling undertaken in Kampala in 2012-2013; there was as well, significant flooding witnessed on this day. This rainfall event was a 1:2 year event and was registered for a time period of 110 minutes; but for runoff modelling, runoff is assumed to remain active shortly after active downpour; therefore 140 minutes was used to run the model instead. The commands used in PCRaster for rainfall calculations were as follows;

p = scalar(66); # mm: this is a scalar value showing rainfall amount used in the model

rainm3=maptotal(p*mask)/1000*cellarea(); this command was used to calculate the total amount of rainfall accumulated in all the cells

report rainm3new.map = rainm3; this commands instructs the PCRaster to report or give rainfall results (rainm3) based on the model input

Soil Data

Soil infiltration characteristics were simplified to average saturated hydraulic conductivity Ksat (mm/hr) and interception canopy storage (mm). Ksat and interception maps generated for the modelling process was informed by infiltration table 4.6, which shows the infiltration characteristics of the various land cover classes.

Table 4.6: Infiltration Table

No	Land Cover	Average saturated hydraulic conductivity (mm/h)	Interception canopy storage (mm)
1	Built_Up	0	1
2	Vegetation Cover	25	1
3	Bare Soil	5	0
4	Tarmac	0	0

The average saturated hydraulic conductivity values were obtained from a study on flash flood risk reduction strategies in built-up environment in Kampala, conducted by Mhonda (2013); while the interception canopy storage values were obtained from de Jong and Jetten (2007) study on estimating spatial patterns of rainfall interception from remotely sensed vegetation indices and spectral mixture analysis. Ksat calculations produced for the various scenarios were as follows;

Scenario 0 and Scenario A (Horizontal Densification):
report ksat = lookupscalar(lu_tbl, 1, lu)*140/60 this command was instructed PCRaster to report ksat value/map based on the infiltration table column 1(land units/classes) and for 140 minutes (converted into hours)

Scenario B (Vertical Densification):

ksatgras = scalar(25*140/60)*mask; # basic infil of veg area	This command was for the first sub scenario under scenario B; assuming the rest of non-built area was fully vegetated
ksatbare = if(LU2010 eq 3, 5*140/60, 0)*mask;	This command was for the second sub scenario under scenario B; assuming the rest of non-built area was bare soil
ksat = if(LU2010 eq 3, ksatbare, ksatgras);	This command was for the third sub scenario under scenario B; assuming the rest of non-built area was partly bare and partly vegetated
ksat = if(lu eq 1, ksatgras*0.4, ksat); #house	This command calculated infiltration with assumption that 40% of class cover 1 (plots) was built-up, while the rest of the neighbourhood was vegetation (grass)

Interception was based on the second column of the infiltration table, which had values for interception canopy storage (mm) for the various land covers. The commands used to calculate interception for all the three scenarios were as follows;
report intercep = lookupscalar(lu_tbl, 2, lu)
report intcm3.map=intercep/1000*cellarea(); this command was for showing total amount of interception per cell in cubic meters

The following are a few selected commands that were used to produce final results of the runoff model;

report runoff = accuthresholdflux(LDD, pnet, ksat)/1000*cellarea(); #m3 - This command generated maps and values of total runoff accumulated in all cells and per cell in cubic mm based on local drain direction, net rainfall and ksat.

report sink = accuthresholdstate(LDD, pnet, ksat)/1000*cellarea(); - This command was used to show the total sum of infiltration per cell and in all cells in cubic meters based on local drain direction, net rainfall and ksat.

report rof = runoff-upstream(LDD, runoff)/(p); - This command was used to produce maps showing total net value of runoff accumulated per cells and the sum of all cells in cubic meters by subtracting runoff generated upstream.

rainm3=maptotal(p*mask)/1000*cellarea(); - This command was used to show total amount rain accumulated in all the cells

report avgro.map=mapmaximum(runoff)/rainm3; -This command was used to calculate average runoff produced

(where pnet = rainfall (p)-interception); LDD was Local drainage network)

Tables 4.7 and 4.8 below are a list of maps and their description used in the runoff model for the study area.

Table 4.7: PCRaster-Basic Input Maps (Data)

Scenario Name	ASCII File Name	Description	Map Name in PCRaster
Scenario 0 (Base Scenario)	Landcover_2010_5m.txt	This was land cover map 2010 prepared in ArcGIS (Consisting of four classes (Built-up layer, Vegetation Cover, Bare Soil &Tarmac)	lu2010.map
	dem_5m.txt	Digital Elevation Model prepared in ArcGIS	dem5m.map
	roads_lubia_raster2.txt	Roads currently existing in the neighborhood prepared in ArcGIS	lubiaroads.map
Scenario A (Horizontal Densification)	Scenarioa.txt	Built-up layer for 2020 prepared in ArcGIS	landcover2020.map
	dem_5m.txt	Digital Elevation Model prepared in ArcGIS	dem5m.map
	roads_lubia_raster2.txt	Roads currently existing in the neighborhood prepared in ArcGIS	lubiaroads.map
Scenario B (Vertical Densification)	reclass_newplots.txt	Plots digitized in ArcGIS	newclas.map
	reclass_newroads.txt	Newroads digitized in ArcGIS	lubiaroads.map
	dem_5m.txt	Digital Elevation Model prepared in ArcGIS	dem5m.map

Table 4.8: Model Inputs (2): New Data (Maps and Tables) prepared in PC Raster

Map/Table Name in PCRaster	**Description**
mask.map	Generated from DEM; basically forming the base of the processing extent of the other maps.
idd.map	This is a local drain direction map generated from the digital elevation model and basically shows the flow direction of material (surface runoff in this case).
ldd2010.map (Base Scenario)	This are local drain direction maps; this maps were generated from a combination of the digital elevation model and the roads data, and basically shows the flow direction of material (surface runoff in this case).
ldd2010new.map (Scenario B)	
ldd2010neww.map(Scenario A)	
lu2010.map	This was a PCRaster version of the original land cover map (2010) imported from ArcGIS (Figure 4.18 below)
lunew.map (Scenario B)	This was a new land use map for Scenario B with three land cover classes; this was the base map used for scenario B (figure 4.17 below), and was further modified for the sub scenarios.
luneww.map (Scenario A)	This map was a combination of built up cover from Scenario A imported from ArcGIS and three land cover classes (Bare, Tarmac and vegetation) from the original Land cover map (2010)-(figure 4.16 below)
infil.tbl (Soil Data)	Table showing saturated hydraulic conductivity of the various land cover classes
P=Scalar(Rain data)	Rainfall data used for this study was a scalar value of 66 mm
pit map	Map showing pit areas of material (surface runoff) based on ldd
cell.map	Map/value of total number of cells
Ksat.map (Base Scenario)	Maps showing the saturated hydraulic conductivity and the interception canopy storage of the various land cover classes
Ksatnew.map (Scenario B)	
ksatneww.map (Scenario A)	
ro.map (Base Scenario)	Maps showing total Runoff generated in all cells and per cell in cubic meters as well as runoff patterns
ronew.map (Scenario B)	
roneww.map (Scenario A)	
rof.map (Base Scenario)	Maps showing total net value of runoff accumulated per cells and the sum of all cells in cubic meters by subtracting runoff generated upstream.
rofnew.map (Scenario B)	
rofneww.map (Scenario A)	
runoffm3.map (Base Scenario)	Maps/values of maximum amount of runoff generated in all cells
runoffm3neww.map (Scenario A)	
runoffm3new.map (Scenario B)	
sink.map (Base Scenario)	Maps showing the sum of infiltration
sinknew.map (Scenario B)	
sinkneww.map (Scenario A)	
avgro.map (Base Scenario)	Maps showing total average rainfall (of the entire neighbourhood) in percentage
avgronew.map (Scenario B)	
avgroneww.map (Scenario A)	
rainm3.map (Base Scenario)	Maps/values of total amount of rainfall accumulated from all the cells (entire neighbourhood)
rainm3new.map (Scenario B)	
rainm3neww.map (Scenario A)	
intercep.map (Base Scenario)	Maps showing interception values per land cover
intercepnew.map (Scenario B)	
intercepneww.map (Scenario A)	
intcm3.map	Map showing total interception in cubic meters per cell

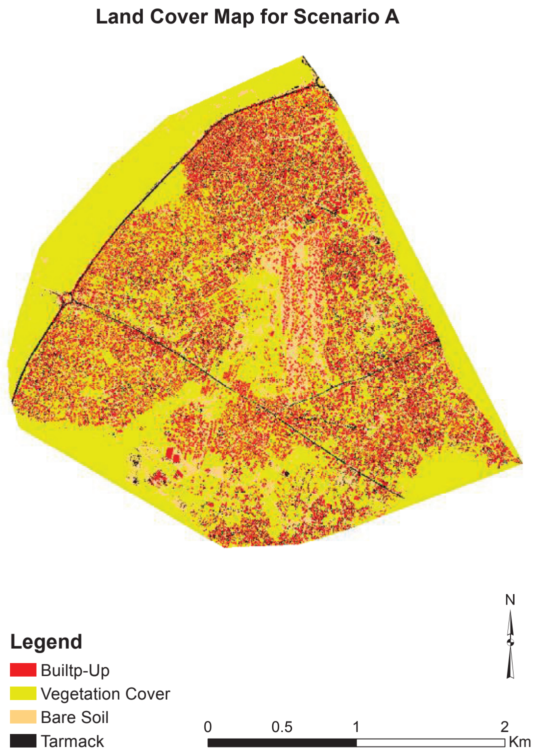


Figure 4.17: Land cover Map for Scenario A

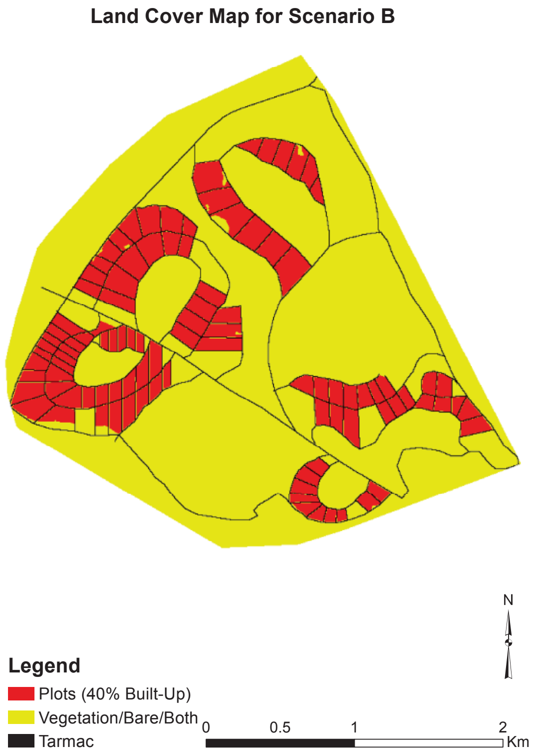


Figure 4.16: Land Cover Map for Scenario B

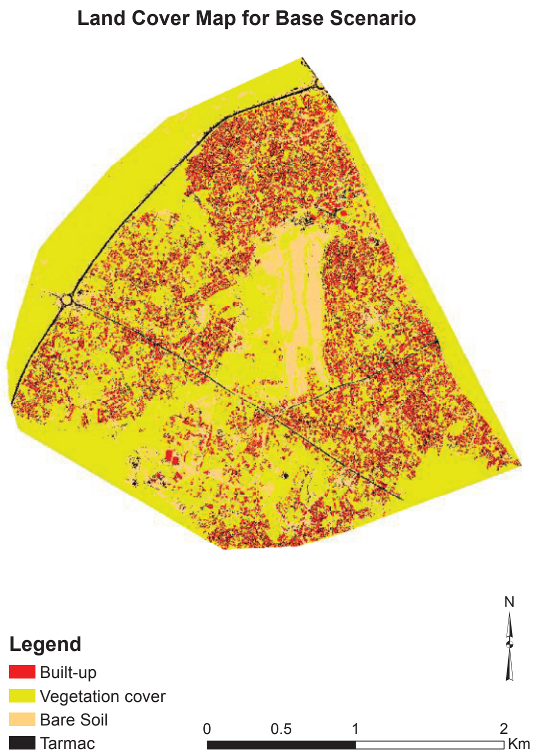


Figure 4.18: Land use Map for Base Scenario

The figures above (4.16 and 4.17) show the base land cover maps prepared in PCRaster for Scenario A and Scenario B respectively. However the land cover properties for both maps were modified for the various sub scenarios modelled under each of the two scenarios; essentially, land coverage of bare land and vegetation was modified for the various sub scenarios; the built-up cover however remained the same in both cases for all the sub scenarios.

Figure 4.18 shows the land cover map that was prepared in PCRaster and used to model surface runoff under base scenario.

5. IMPLICATIONS OF DENSIFICATION ON SURFACE RUNOFF

This chapter presents and discusses the results of the assessed impact of densification on surface runoff and in Kampala. It starts by presenting and discussing a comparative analysis between the existing densification practices and the proposed densification policies. The characteristics of the existing drainage system are also presented and discussed. The results of the densification approaches explored for surface runoff modelling and the implications of such approaches are also herein reported and reflected. The chapter concludes by assessing the impacts of these densification approaches on surface runoff; the assessment was done under three scenarios; Base Scenario, Horizontal Densification (with no planning or policy intervention) and Vertical Densification (with planning intervention).

5.1. Existing Densification Practices

This study sought to examine the existing densification practices in Lubia Neighbourhood. This was crucial for understanding the existing densification practices, which then gave an insight to the scenarios against which generation of surface runoff would be estimated and projected.

From field survey, the study area was largely a single-dwelling residential neighbourhood-with mostly one level developments. The area depicted an informal characteristic where most of the developments (both the old and new) were haphazard and unplanned (figure 5.2)-this was probably due to the fact that the neighbourhood (just like the rest of the residential neighbourhoods in Kampala), lacked a detailed development area plan as highlighted by the key informants. The Kampala land use map for 2010 acquired from KCCA further confirmed this informality as shown in the building foot print on figure 5.1 below.

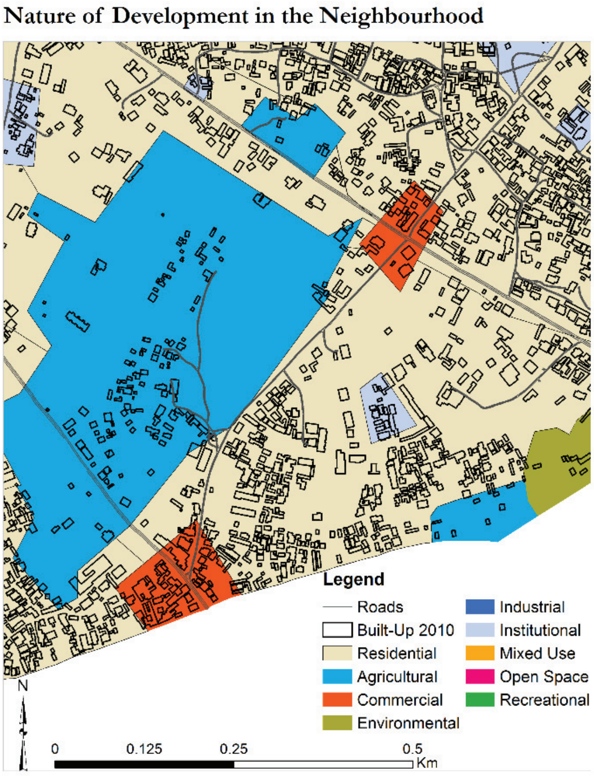


Figure 5.1: Building Footprint of Lubia Neighbourhood

Figure 5.2: Photo showing the type and nature of developments in Lubia Neighbourhood
Source: Field Survey, 2013

From interviews with the area residents and field observations, horizontal densifications was the dominant type of development that was on-going in most parts of the neighbourhood that were undeveloped, for instance in Namung'oona II village (photo-figure 5.3 below).

Figure 5.3: New Developments (Infilling) in the study area
Source: Field Survey, 2013

There were also some few existing vertical developments in the neighbourhood; there was for instance a relatively large and well planned housing estate belonging to the National Housing Cooperation (figure 5.4 below). Some few vertical developments were also scarcely spotted (figure 5.5 below).

Figure 5.4: National Housing Cooperation housing estate

Figure 5.5: A photo showing vertical development in the neighbourhood

NB: These were however very rare developments in the neighbourhood and were hardly spotted.

This study also collected information on the existing plot sizes in the study area; this information was expected to guide the new neighbourhood design; however, due to lack of cadastral data, this information was not incorporated, but maybe helpful for a further study.

Based on the data collected from field survey, 83.3% of the sampled respondents had their plots measuring below 500 m² as shown in figure 5.6 below.

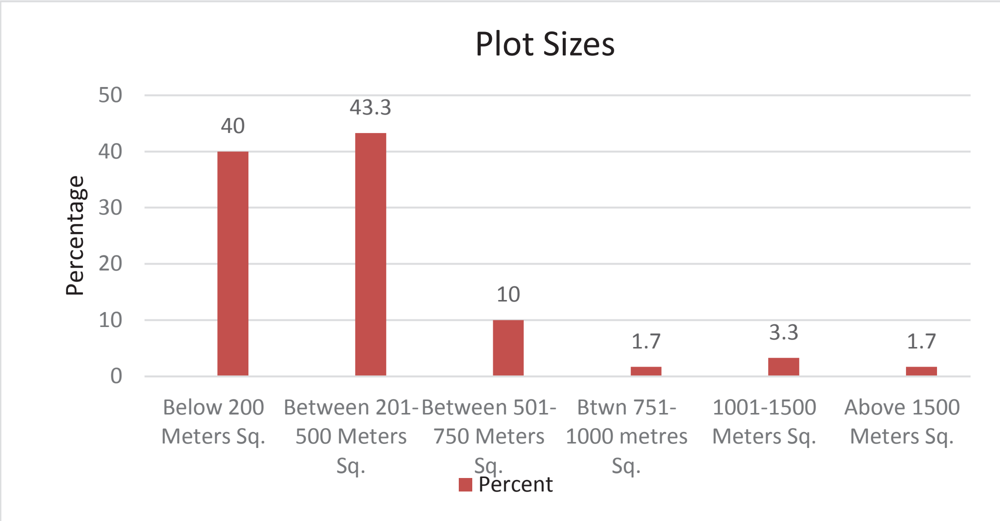


Figure 5.6: Current Plot Sizes in Lubia Neighbourhood
Source: Field Survey, 2013 (N=60)

5.2. Proposed Densification Policies

In the recently prepared Physical Development Plan (2012) for the city of Kampala, densification of existing built areas was one of the development targets and policy measures proposed as an intervention approach. This, according to the development plan, would help to constrain the scale of the built up area, ensuring that future development occurs at the requisite density.

Kampala Physical Development Plan proposes fundamental shift in housing typologies and increase in densities in the selected neighbourhoods in the following ways:

- By subdivision and/or addition of residential units on the plot;
- Redevelopment and/or upgrade (rehabilitation, extension, addition of second and third floors).
- New Developments with the new proposed densities
- Where relevant upgrading infrastructure (sewage, roads, lighting, etc.)
- Where possible block or neighbourhood scale intervention for upgrade and redevelopment

Lubia Parish is one of the neighbourhoods proposed for densification intervention measures, including infilling, new developments, and redevelopments through increase in plot ratios and plot coverages. It is also one of the areas demarcated for development of new residential areas within the greater Kampala Metropolitan Areas. The development plan characterises Lubia as a low density area with between 50-100 Households per Ha, with estimated gross density of 17% (2011), gross built area capacity of 90% and a growth potential of 433%.

Table 5.1 below shows the densities and intervention approaches proposed for residential developments within, inner city frame in which Lubia Parish falls.

Table 5.1: Proposed Densities and Intervention Approaches for the Inner City Frame

Location/Land Use	Estimated Gross Density 2011	Gross Built Area Capacity	Indicative Nett Development Rights	Intervention Approach
Apartments	16%	100%	150%	Upgrade Densification
High Income	20%	50%	75%	Infill Densification
Middle Income	25%	70%	105%	Upgrade Densification
Low income	22%	100%	150%	Upgrade Densification

Source: Kampala Structure Plan, 2012

It was important to comprehend development practices in the study area to be able to relate it to surface water generation and probability of flooding; 80% of the residents interviewed said they would embrace the proposed densification policies, quoting reasons such as decrease in runoff and/or flooding generation; enhanced neighbourhood appearance; it would lead to relocation from swampy areas to better places or higher grounds; reduction in overcrowding; and preservation of green spaces.

If the proposed densification policies were to be adopted, it would probably necessitate a complete transformation of the development and densification patterns of the neighbourhood, replacing the existing housing types with apartments and houses based on income variations. Although no evidence is given, the plan suggests that the neighbourhood would have a growth potential of 433% against the current 17% based on the gross built up area.

5.3. The Drainage System

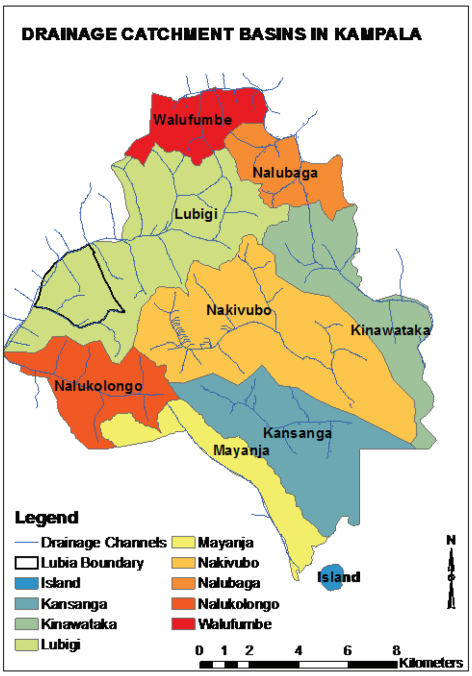


Figure 5.7: Drainage Catchment Basins
Source: KCCA, 2010

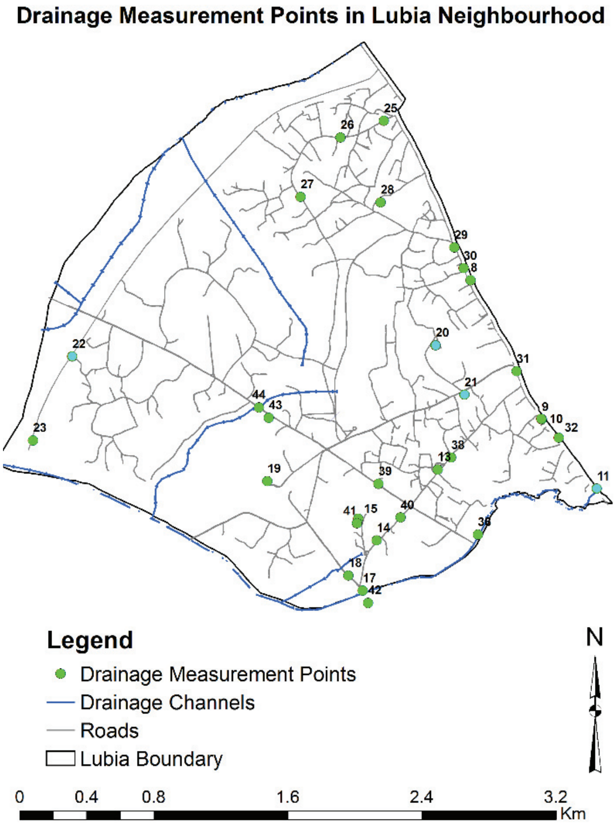
The study area is located within Lubigi Catchment area, (figure 5.7). The study area is drained by three major channels (along the northern bypass, along Sentema Road and along Masiro Road).

According to Kampala Physical Development Plan (2012), drainage systems should be aligned with the urban growth model for KCCA and GKMA, to ensure that there is adequate provision of drainage systems for all segments of the population. In addition, densification policies should be followed so as to achieve economies in provision of the infrastructure.

Drainage Measurements

The study area had manmade drainage channels, largely located along the major roads, along access roads and at plot levels. A sample of 44 points of drainage measurements- (depths and top widths) as well as their spatial references, was taken across the drainage channels to ascertain their capacities in the face of proposed densifications (figure 5.8 below). All these channels varied in sizes, types and conditions and were mostly disjointed. Drainage channels at plot levels were fairly well maintained, as compared to the public channels. As shown by the photos taken during field survey and from field observations, most drainage channels were partially blocked by garbage deposits (a condition definitely limiting the smooth flow of water). 20% of the respondents interviewed quoted poor drainage system as the main cause of surface water generation and flooding. This was a rampant behaviour across the neighbourhood; there were however noticeable cleaning efforts by the community, in some parts.

For lack of spatial data on drainage channels for the study area, this information was not used in modelling surface runoff, however it may provide information on the nature of drainage channels in the study area for a further study. Instead, the modelling application that was used created local drain directions (LDD), done along the roads, with the assumption that the drainage channels would be aligned along the roads.



Point 21-Drainage channel located in Lugala Village. The width of the channel measured approximately 168 cm.

Drainage channel passing through Masanafu village-Spatial location is shown by **Point 22** on the map. Although the drainage channel was fairly big, parts of it were had garbage deposits that definitely hindered the smooth flow of waste water

Smaller Drainage Channels connecting at plot level at point 20 in Lubia village

This was presumably the longest and widest drainage channel cutting across the study area. This photo was taken at location **Point 11,** with a width measurement of 3.8 m and a depth of 6m. This measurements however varied at various points/locations of the channel

Figure 5.8: Drainage measurement points and photos showing the conditions of the drainage channels
Source: Field Survey, 2013

5.4. Densification Approaches for Surface Runoff Modelling

Base scenario

This formed the first scenario for assessing surface runoff generated from the study area. The assessment was done based on the classified image 2010. Based on the 2010 classified data (figure 4.6), the built-up area accounted for 14.62%; vegetation cover for 51.99%; Bare soil for 25.2% while tarmac accounted for 8.19%. The average structure size using 2010 data was 70.68 sq. m, with 62% of the buildings below 70 sq. m.

Scenario-A (Horizontal Densification)

Horizontal densification as described in the methodology section was based on the assumption that the trend of the existing densification practices (as in the base scenario) would continue. Based on the field survey conducted for this study, the main forms of horizontal densification in the neighbourhood (confirmed by 93.3% of the interviewees) were infilling/new developments rated at 31.6%; subdivisions or shrinking of plot sizes at 26.6%; increase in plot coverages at 20.9%; increase in plot ratios at 5.1% and redevelopments at 15.8%. Due to lack of access to cadastral information and for the sake of this study, horizontal densification was presumed to continue through infilling and/or new developments.

This scenario saw an increase of buildings by 37%, from the current 14478 (2010) to 19838 (2020). The average unit/structure size for this densification approach was 70.99 sq. m, which is pretty close to the current average building size based on 2010 data.

This densification trend was indiscriminate to other land use functions; for instance, encroachment on roads reserves, wetlands and in very high and very low slopes seemed to be taking shape. Settling in environmentally fragile areas could have detrimental results, for instance, as found out in the field survey, people settling in the in very low slope and wetlands were experiencing flooding. Figure 5.9 below shows the existing and additional residential structures under horizontal densification.

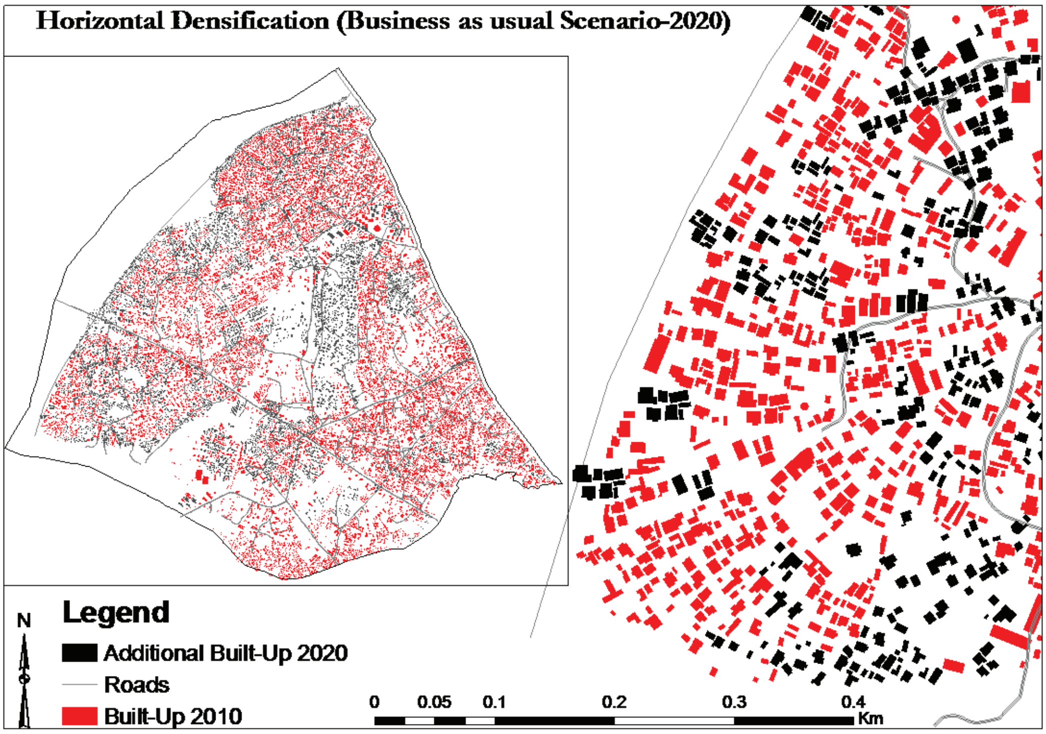


Figure 5.9: Scenario A (Business as Usual) _Horizontal Densification

Scenario-B (Vertical Densification)

Vertical Densification was one of the development intervention approaches proposed by the Kampala Physical Development Plan. 15.8% of the respondents interviewed alleged that vertical densification was already being experienced in some parts of the neighbourhood. The physical planner of Rubaga division further asserted that this was one of the long term development approaches proposed for this neighbourhood.

Vertical densification for this study was done based on a redevelopment approach, guided by the building standards and guidelines stipulated in the national physical planning standards and guidelines for Uganda (2011). The number of housing units required under this development approach by the year 2020 was 19838 similar to horizontal densification; divided to high density developments and medium density developments in the ratio of 3:1. Suitable areas for development were determined based on the existing land use map and slope map. Areas currently under environmental, institutional, industrial and recreation land use functions were unsuitable for the new developments, as well as very low slope below 3% and steep slope above 15%.

Three land use functions were considered for this scenario; residential land use, access roads and drainage channels. Secondary access roads had a buffer of 8 m and 15 m for primary access roads; drainage channels had a width of 1.5 m. Digitization of residential units was done in form of plots, instead of individual buildings with each plot aligned to the roads. Due to lack of cadastral data, digitization was done in various sizes ranging from 4446 sq. m to 40296 sq. Each plot would afterwards be subjected to appropriate subdivision, guided by design considerations discussed in the methodology section under vertical densification and any other relevant additional subdivision provisions in Kampala. As such, additional roads and drainage channels would be introduced as appropriate; the national physical planning standards and guidelines for Uganda stipulate that every plot should have vehicular access. Further stipulation from the standards and guidelines manual require that, every 60 houses are provided with a secondary access road, and a primary access road for every 120 houses. The neighbourhood design has taken this specification into consideration. Figure 5.10 shows the neighbourhood design for vertical densification.

Vertical densification reduced the total built-up area from the current 14.62 (based on 2010 data) to 8.29%. The average building size assumed for high density developments was 100 sq.m and 120 sq.m for medium density developments. Comparing to the current average building size of 70 sq.m (based on 2010 data), this scenario would certainly improve the average living conditions of the residents by increasing the average dwelling size.

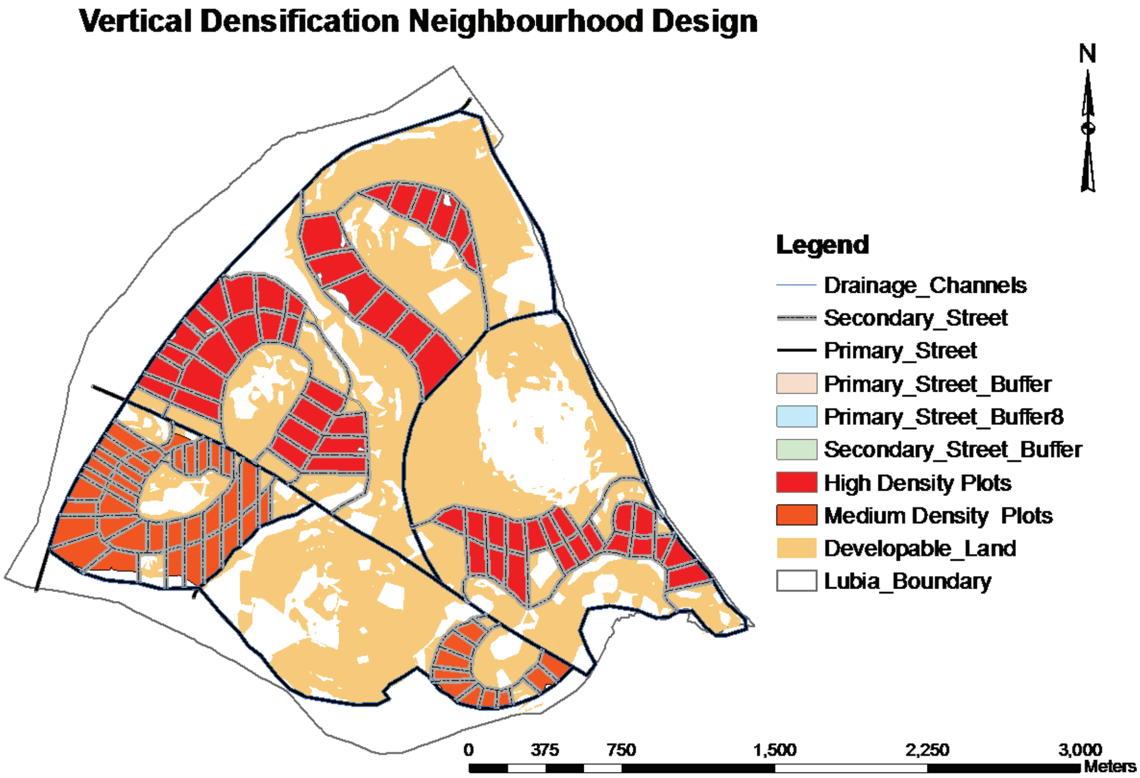


Figure 5.10: Neighbourhood Design under Vertical Densification

5.5. Implications of Densification Approaches

i.) Implications to the Form and Structure of the Neighbourhood

This research also deliberated on what would be the implications of the proposed densification approaches to the form and structure of the neighbourhood. Horizontal densification was developed on the basis of a trend scenario; implying that the existing development practices would continue. Therefore the following situations are likely to occur with this trend;

- Continuance of haphazard and uncontrolled developments will continue
- People are likely to continue developing on environmentally fragile areas (including wetlands and steep slopes) and on vegetated lands; and this would in turn increase generation of surface runoff and flooding potential
- Development on undeveloped land; leading to increase in the surface area covered by impermeable surface and this would increase generation of surface runoff
- The indiscriminate garbage disposal into the drainage channels would continue

Figures 11, 12 and 13 below shows the current types and nature of developments and development practices in the study area that are likely to continue if the current trend of horizontal densification persists.

Figure 5.11: New Developments occurring in environmentally fragile areas - Swampy Areas
Source: Field Survey, 2013

Figure 5.12: Informal Settlements in Swampy Areas and close to the drainage channels in Kosovo, Lusaze village. According to the residents interviewed, their housing units flooded whenever it rained.
Source: Field Survey, 2013

Figure 5.13: Developments on steep slopes in Lubia Village
Source: Field Survey, 2013

On the other hand, vertical densification (which would incorporate planning) would improve the appearance and form of the neighbourhood and the developments would be restricted to suitable lands. This would in turn reduce the amount of surface runoff generation and reduce flooding possibility.

ii.) Implications to Land Cover Change

Based on Land Cover Map 2010 (figure 4.6), the built-up area covered a percentage of 14.62%; vegetation 51.99%; bare soil 25.2% and Tarmac cover 8.19%. Horizontal densification approach increased the built up cover to 21.16%; while vertical densification reduced the built-up cover to 8.26%. The increase of built up area automatically results to decrease in vegetation cover and bare soil. However, based on vertical densification, vegetation land cover and bare soil would be increased due to reduction of built up area; however, this may require a deliberate effort from the residents. This sub scenarios were tested against surface runoff generation in the following section.

A direct result of land cover change is alteration of hydrological balance; as the results of surface runoff generation indicated; horizontal densification increases surface water runoff, this is because part of the initially vegetated areas and bare soil are covered by impermeable land cover (built-up). Vertical densification on the other hand reduces the area covered by impermeable cover of built-up replacing it with vegetation and/or bare soil. This in turn reduced surface runoff generation.

To reinforce the preceding discussion, from the interviews undertaken in the study area, residents confirmed experiencing land cover changes (basically through conversion of non-built up to built-up) in the following ways (table 5.2);

Table 5.2: Types and Nature of Land Cover Change

Type and Nature of Land Cover Change	Responses	
	N	**Percent**
New developments in low lying areas (Downhill)	8	11.8%
Mushrooming (Congestion) of Developments	12	17.6%
Encroachment onto Swampy Areas	9	13.2%
Building in Open Spaces	31	45.6%
Clearing Vegetation	6	8.8%
New developments on hills	2	2.9%
Total	68	100.0%

Source: Field Survey, 2013

5.6. Implication of Densification Approaches on Surface Runoff

Base scenario formed the first scenario for which surface runoff modelling was done; it essentially estimated the amount of surface runoff generated using 2010 classified data. The second scenario tested was horizontal densification (trend scenario) while vertical densification was the third scenario. According to the interviewed residents, 48.3% of them experienced surface runoff in their neighbourhood, 16.7% experienced flooding while 33.3% experienced both. 98.3% asserted that they experienced surface runoff whenever it rained. This section presents results of the estimates of surface runoff produced under three different densification scenarios.

i.) Saturated hydraulic Conductivity

Saturated hydraulic conductivity is one of hydraulic properties of soil and is important for surface runoff modelling. For this study, the saturated hydraulic conductivity (measured in mm/h) for the different land covers spread from 0 for the impermeable land covers (tarmac, built-up) to 58.3 (vegetation) with bare soil having a value of 11.7. This was the same for all the three scenarios. The calculation was based on 66 mm of rainfall active in for 140 minutes. This means that areas with impermeable land covers infiltrated no water while areas with permeable land covers (vegetation and bare) allowed infiltration in different proportions, based on their properties of hydraulic conductivity. Therefore impermeable land covers would be said to generate more runoff than the relatively permeable covers; until such a time that the maximum storage capacity for the soils is attained. This was one of the parameters used to calculate the amounts of runoff generated under the three scenarios.

Maps showing hydraulic conductivity properties of the various land covers (under the three scenarios) are shown by figure 5.4 below;

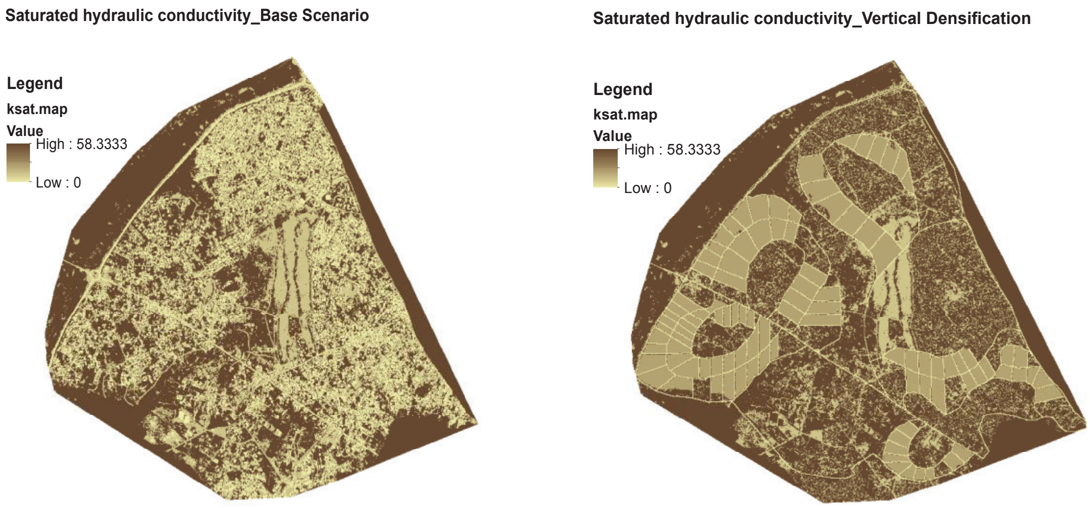


Figure 5.14: Saturated hydraulic Conductivity

ii.) Interception

Calculating interception was important for this study, to determine how much rainfall reaches the ground that would then be converted to runoff and infiltration. Normally, interception of rainfall is calculated for vegetation and built-up areas (house cover); built up areas had an interception value of 1mm, same as vegetation covers; bare soil and tarmac had 0 interception values-this was the case for all the three scenarios.

iii.) Surface Runoff Generated

The model used a number of parameters including land covers properties, land covers infiltration properties (determined by Ksat and interception), local drains direction networks, and rainfall data to produce maps and values of the surface runoff generated under the three scenarios. Rainfall amount remained the same for all the scenarios. Due to the variations in land cover properties, the amounts of runoff generated were pretty much different as well.

The first scenario to be modelled was base scenario; which generated a total amount of 228682 cubic meters of runoff. This was against 477056 meters cubic of rainfall accumulated from all the cells (neighbourhood). Therefore approximately 47.94% of the total rainfall was converted to runoff given the land cover properties of the Base Scenario. Figure 5.15 below shows surface water generation patterns under base scenario; the map has several channels with different colours based on the total amount of runoff in a particular channel. The highest amount of runoff is accumulated at the lowest point in the map.

With the same amount of rainfall, horizontal densification (trend scenario) generated a total of 240906 cubic meters of runoff. The average runoff generated for this scenario was 50.5%; the increase in surface runoff from the base scenario is associated with the change in land cover properties resulting from the increase in house cover; certainly, impermeable surface area is increased. However, the increase of runoff from base scenario was only by 2.55% implying that there is a relatively big impact played by other land covers; for instance for this scenario, the vegetated areas (and especially the wetlands at the edges of the neighbourhood remained untouched. This results prompted a further analysis for this scenario; where an assumption was made that there is likely to be more bare land (compacted land) with increase in house cover because this Scenario operates under the assumption that the trend of the base scenario will continue; implying a further unplanned development of the neighbourhood. Therefore, a uniform random generator command in PCRaster was used to generate new conditional maps; where if a grassed grid cell had an adjacent grid cell that had a house (in a 3 x 3 cell window), there is a 30%, 50%, or 80% chance it is converted to bare soil. Under these three sub scenarios, new runoff values were produced as shown in table 5.3 below. Figure 5.16 shows the surface runoff patterns generated under this scenario.

Table 5.3: Surface Runoff Generated under Scenario A

Scenario Name	Percentile Chance of Change from Vegetation to Bare	Unifom Random Generator Value	Percentage of Runoff Generated
ScenarioA (Original)	-	-	50.49%
ScenarioA (SubScenario 1)	30%	0.7	54.21%
ScenarioA (SubScenario 2)	50%	0.5	56.63%
ScenarioA (SubScenario 3)	80%	0.2	60.24%

The third scenario (vertical densification) was also interesting because sub scenarios were tested within this scenario. The first sub scenario was developed on the assumption that all the non-built areas were vegetated; such that the only areas that had built-up cover were 40% of each plot. This sub scenario generated a total amount of 117921 cubic meters of runoff (average runoff of approximately 24.72% of total rainfall). The second sub scenario which assumed that the non-built areas were partly vegetated and partly bare and generated runoff of 176779 cubic meters (an average runoff of approximately 37.06%); while the third sub scenario which assumed the non-built areas were purely bare soil generated 423216 cubic meters of runoff (an average runoff of approximately 88.71%)-summarized in table 5.4 below. Based on vertical densification, the importance of vegetation cover comes out as a strong factor to reduction of surface runoff; bare land on the other hand should evidently be avoided due to its huge impact of runoff generation. Figure 5.17 below shows surface water generation patterns under vertical scenario; the highest amount of runoff is accumulated over ldd channels and directed to the lowest point in the map.

The three scenarios compared the estimated amount of runoff generated under different land cover properties. Persistence of the current trend (as tested through horizontal densification) is not the best development approach because increase in surface area covered by impermeable area (built-up) subsequently increases runoff generation as shown by results of scenario 2. Given the model results, redevelopment option tested under scenario 3 (vertical densification), would be the best development option for the study area, but only if the vegetated option (sub scenario 1) for the non-built areas is adopted; as presented by the results of this scenario, bare soil generates a relatively high percentage of surface runoff and should therefore not be advanced; a mix of the two land covers would be preferred as an alternative to bare soil. Table 5.4 below is a summary of surface runoff model results.

Table 5.4: Summary of Model Results

Scenario	Perecentag e Built-up Coverage	Rainfall Amount used for the model (mm)	Total Rainfall Accumulated (cubic meters)	Total Runoff Accumulated (Cubic meters)	Average Runoff generated in Percentage
Base Scenario	14.92%	66	477056	228682	47.94%
Horizontal Scenario	21.16%	66	477056	240906	50.49%
Vertical Scenario					
Sun Scenario1	8.26%	66	477056	117921	24.72%
SubScenario 2		66	477056	176779	37.06%
Subscenario 3		66	477056	423216	88.71%

iv.) Surface Runoff Patterns

Based on the surface runoff maps produced by the models as displayed by figures 5.15, 5.16 and 5.17 below vegetated areas have lower values, suggesting that most of the runoff is absorbed, while the built up areas and bare land generate relatively more runoff. As shown by the figures, more runoff is also observed in low lying areas (base of the hills) and along the roads. Multiple runoff channels are seen to be draining the neighbourhood towards the edges (neighbourhood boundary); and at these points the runoff disappears (into these wetlands and vegetation). These runoff patterns are observed in all the three scenarios.

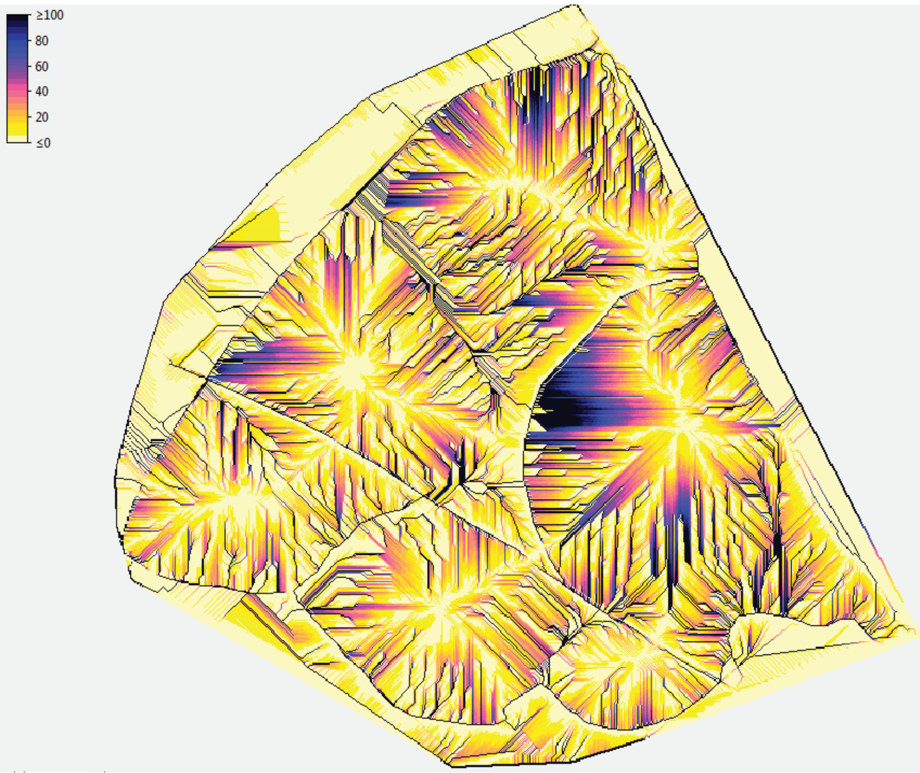
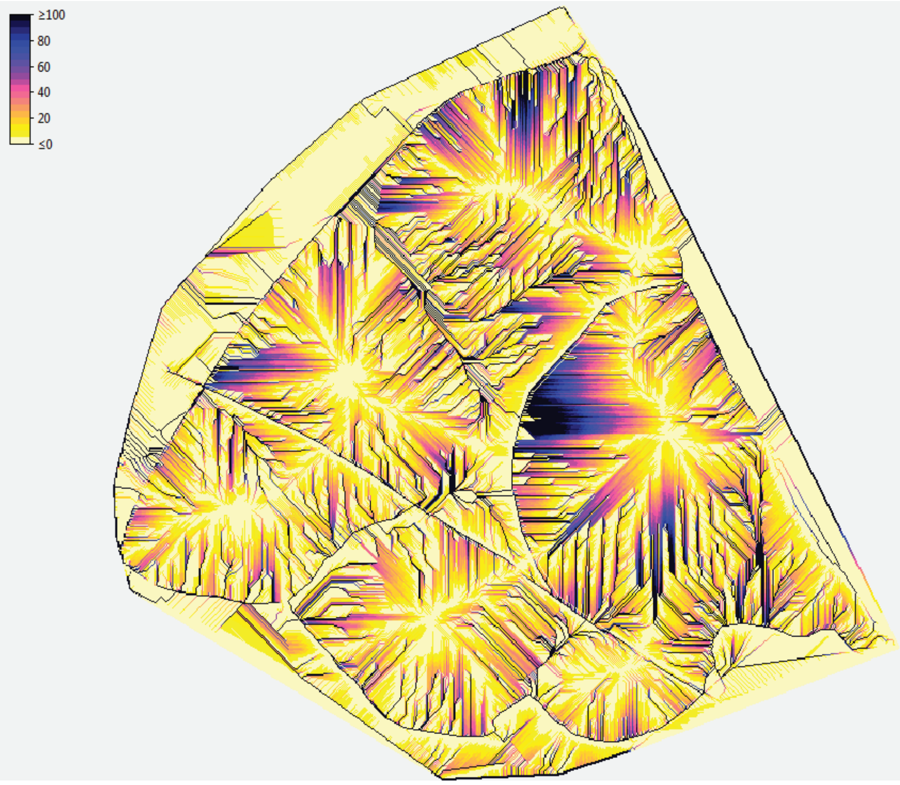


Figure 5.15: Runoff Patterns for Base Scenario

This map represents runoff patterns generated by the Base Scenario. The Local Drain Directions (LDD) were created along the roads-this study assumed that the drainage channels would run along the roads. The runoff pattern is cut at 100 cubic meters; as shown by the map, the LDD have more surface runoff more than 100 cubic meters as shown by the black colour, this is because they accumulate and direct runoff; some parts with bare soil also have high runoff values as shown by the black colours. Areas covered by vegetation and hill tops have lower runoff values as shown by light yellow colour, compared to areas covered by the house cover which have higher runoff values as shown by the darker shade of yellow and pink colours. The total runoff generated by this Scenario was 228682 cubic meters (50.49%).



The runoff pattern for Scenario A pretty much resembles that of Base Scenario; this is because the roads layer for both scenarios are the same, as well as patterns of other land covers. The total runoff generated by this Scenario was 240906 cubic meters (47.94%)

Figure 5.16: Runoff Patterns for Scenario A (Horizontal Densification)

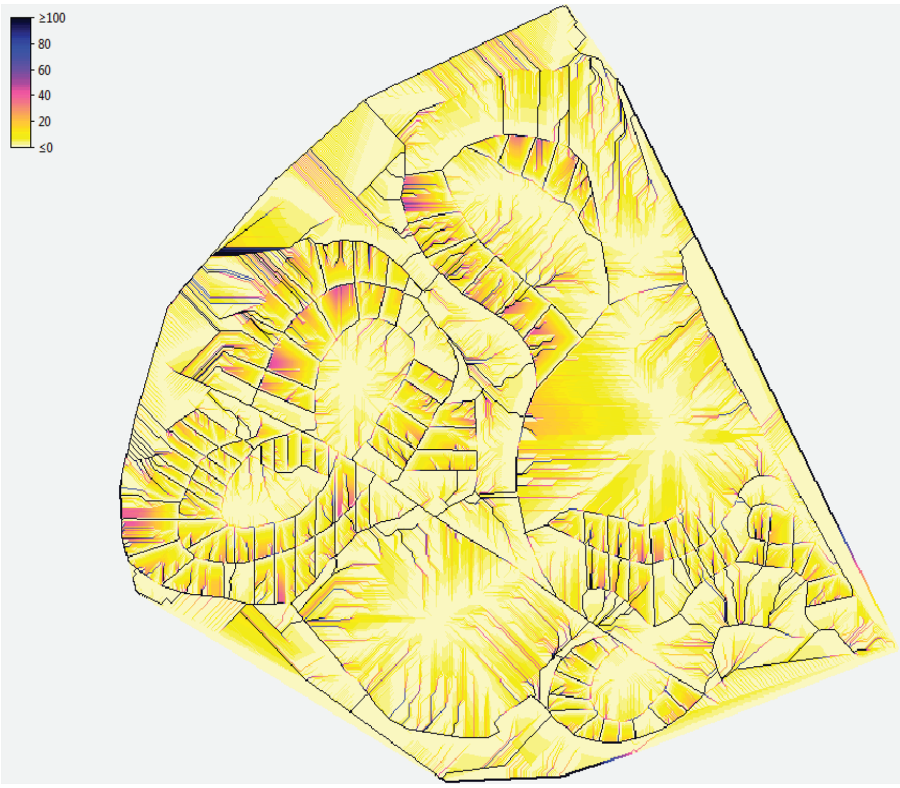


Figure 5.17: Runoff Patterns for Scenario B (Vertical Densification)-*Sub scenario 1*

The runoff pattern for Scenario B (Sub scenario 1) is different from the first 2 scenarios in terms of pattern and runoff intensity-even though the similarity is that LDD for this scenario was also created along the roads.

The runoff pattern is also cut at 100 cubic meters; as shown by the map, the LDD which accumulate and direct runoff have higher runoff values going beyond 100 cubic meters as shown by the black colour. Areas covered by vegetation and hill tops have lower runoff values as shown by light yellow colour compared to the areas with house cover which have a darker shade of yellow and pink colours. The total runoff generated by this Scenario was 117921 cubic meters (24.72%).

6. SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

6.1. Introduction

This study sought to assess the impact of densification on urban hydrology by relating development densities to surface runoff generation in Lubia neighbourhood, Kampala. The study was motivated by the recently prepared physical development plan for Kampala (2012) which advocates for increased building densities across all residential neighbourhood in an attempt to accommodate population outbursts brought about by urbanization.

The methods used in this study were a blend of field survey, literature review and GIS and modelling techniques. Field survey techniques were the initial stages which firstly, sought to understand the study area, appreciate people's opinions on densification practices and comprehend the densification practices currently being undertaken in the neighbourhood, as well as to understand people's experiences with surface runoff and flooding. To acquire this information, interviews were carried out with key informants through interview schedules and open discussions; interviews were also carried out with Lubia residents through questionnaires. Other methods used to collect data were observation, photography, field measurements and mapping. Literature review was also an important methodology for this study; firstly to compare the study with other hydrological modelling studies and their impacts to the urban environmental and secondly to have a deeper insight of the densification policies that were proposed for the neighbourhood by the physical development plan. GIS applications and Modelling techniques (using PCRaster) were the final methodology; and these were used to quantitatively relate densification to the urban runoff generated in the neighbourhood.

6.2. Objective 1: Comparison between current densification practices and the proposed densification policies

The recently prepared Physical Development Plan for Kampala (2012) proposes fundamental shift in housing typologies and increase in densities in the neighbourhood; this is to be achieved through land subdivisions and or additional of residential units on the plots; redevelopment and or upgrading; new developments with proposed new densities; and addition and or upgrading of infrastructure. The plan estimated the current (2011) gross density of the neighbourhood at 17%; and proposed a gross built capacity of 90% and a growth potential of 433%.

On the other hand, the densification practices in the neighbourhood were largely horizontal in nature, comprised of informal developments that were haphazardly built, unplanned and disorderly-this was the case for both old and new developments. This would probably be associated with the fact that the neighbourhood lacked a detailed development blue print just like most residential neighbourhoods in the city. According to the residents interviewed, the types and nature of developments comprised of infilling/new developments rated at 31.6%; subdivisions or shrinking of plot sizes at 26.6%; increase in plot coverages at 20.9%; increase in plot ratios at 5.1% and redevelopments at 15.8%. 40% of the interviewed residents had their plots measuring below 200 square meters, 43.3% between 200 to 500 square meters while the rest had their plots measuring above 500 square meters.

6.3. Objective 2: Estimating the levels of surface runoff generated by the current densification practices

The factors used to estimate surface runoff generation included land cover properties; topographical data; rainfall data; and soil data. Land cover properties were firstly generated from 2010 Geo Eye satellite imagery and were classified into built-up cover, bare soil, vegetation and tarmac. This land cover map (2010) was used to estimate surface runoff generated under the current densification practices-this formed the base scenario. Surface runoff generated under this scenario was 48% of the total rainfall. The main points of generation were the impermeable surfaces (built-up, tarmac and parts of bare soil); vegetated areas on the other hand absorbed most of the runoff. The main accumulation points were the lowest areas, including the base of the hills and along the local drainage directions (LDD) - which were aligned to the DEM and along the roads. Although it was not empirically proven in this study, interviews with the area residents revealed that most of the low lying areas, swampy areas and the informal settlements experienced flooding whenever it rained.

6.4. Objective 3: To investigate the impact of the proposed neighbourhood densities on urban runoff

Two densification approaches were experimented to respond to this objective. A trend scenario (under horizontal densification) was the first densification approach to be tested; this was under the assumption that there would be no planning intervention in the neighbourhood for a period of 10 years from the base scenario (2010). This scenario also represented some of the proposed densification policies; which propose to increase residential densities through infilling and subdivision and/or addition of residential units on the plot. Horizontal densification saw an increase of the buildings by 37% from the current 14478 (2010) to 19838 (2020)-increasing the percentage of the built-up cover from 14.62% (2010) to 21.16% (2020). The additional buildings were only based on population dynamics, as described in the methodology section.

The second scenario tested was vertical densification approach which incorporated planning intervention; this also responded to one of the proposed densification practices that suggests redevelopment through the new proposed densities. The same land cover classes were used for this scenario; however, since this was a redevelopment approach, the land covers were spatially different from the other two scenarios. Vertical densification reduced the built-up cover to 8.19%, implying a reduction of the impermeable land cover surface.

Modelling results based on horizontal densification registered an increase of surface runoff generated from 48% (2010) to 51%. A further analysis of this scenario was done by adjusting the coverage of bare soil; this was done on the assumption that house cover is more likely to be surrounded by bare soil than grass. Three sub scenarios were developed; where if a grassed grid cell had an adjacent grid cell that had a house (in a 3 x 3 cell window), there was a 30%, 50%, or 80% chance it is converted to bare soil respectively. The runoff generated under the three sub scenarios was 54%, 57% and 60%, respectively up from the original 51%. From this results, it can be concluded that the impact of vegetation land cover cannot be underestimated; even with the increase of the bare soil coverage, quite a significant amount of runoff is still absorbed by the surrounding vegetation (wetlands).

For vertical densification, three sub scenarios were modelled and they produced quite some interesting results. The first sub scenario assumed the rest of the unbuilt areas were covered by vegetation and generated 25% of surface runoff; the second sub scenario generated 37% of runoff on the assumption that the unbuilt areas were partly bare and partly vegetated (land cover properties (2010)); while the third sub scenario generated 89% of runoff on the assumption that the unbuilt areas were bare soil.

Although this study did not go a step further to model flooding, it's would be true to assert that substantial increase in surface runoff generated would increase the likelihood and extent of flooding; according to the household surveys conducted, 16.7% of 59 respondents experienced flooding in their homes, 29% experienced surface runoff while 33.3% experienced both flooding and surface runoff. The areas most affected were areas downhill, swampy areas and the informal settlements (Kosovo).

6.5. Objective 4: Possible improvements on the proposed densification policies that would help reduce urban runoff

Land cover properties largely influence hydrological balance; this has also been empirically proven in this research. Surface runoff in the study area may not be completely eradicated; however, based on this research the following proposals would help in reduction of surface runoff in the study area;

i.) It has been proven that horizontal densification increases the generation of surface runoff. However, one of the plan proposals is to increase housing densities through land subdivision and additional residential units per plot; based on this study, this would not be the best option for consideration because of its negative influence on the urban hydrology; from literature review and field survey, urban runoff and flooding are already hot issues in the neighbourhood and in the entire city of Kampala. Therefore adoption of runoff and flooding reduction strategies should be a principal consideration by the planners and city managers.

ii.) Vertical densification, which is also a proposal of the physical development plan proved to be a better option; however, due consideration should be given to the spatial coverage of other land cover classes. It is known and also proven by this study that vegetation is quite a substantive absorber of surface runoff, and would greatly help in its reduction as well as mitigate against flooding.

iii.) This study attempted to design a neighbourhood on vertical densification approach; several issues of importance such as the topography and environmental issues such wetlands and swamps were given due consideration; this study strongly suggests adoption of this approach in determining suitable areas for new developments. The topography of the study area, and for the entire city as well, is delimiting and largely influences the urban form. However, further interruption of the natural environment on very steep slopes and very low slopes as well, would impact negatively on the hydrological balancing-moderate slope (between 3-15%) is considered the best option for settlements. Settlement on wetlands and swampy areas is also highly discouraged due to the obvious repercussions of runoff and flooding, and interruption of the natural environment, that would otherwise act as sinks of urban runoff. The neighbourhood design under vertical densification approach also emphasized on the relatively obvious need to align the roads and the drainage channels along the contours; this would facilitate smooth flow of surface runoff in the channels and reduce construction costs.

iv.) Adoption of vertical densification approach as proven by the neighbourhood design developed in this study is highly recommend, at least in the long run; it does not only reduce generation of surface runoff but also makes best use of the limited urban space, improves the general appearance of the neighbourhood and improves the living conditions of the residents by improving their housing conditions.

6.6. General Conclusion

The hypothesis of this study assumed that the proposed densification policies on residential neighbourhoods in Kampala would have a negative impact on surface runoff and potential of flooding occurrence. In the event that these policies were implemented with consideration of both horizontal and vertical densification approaches, then the hypothesis would partly be true based on the results obtained for this study. First, modelling results based on horizontal densification registered an increase of surface runoff generated from 48% (2010) to 60% under the various sub scenarios. Vertical densification on the other hand had surface runoff reduced under the first two sub scenarios to 25% and 37% respectively, but increased the generation under the third sub scenario to 88.71%. Since the neighbourhood was not fully covered with built-up cover, and neither was the built-up cover evenly distributed, the other land cover classes also played a role in estimating the amount of surface runoff generated; and therefore the impact cannot entirely be pegged on the built-up cover.

In an attempt to assess the impact of surface water generation and densification, this study was a further corroboration to other authors that have established the relationship between building densities and surface runoff generation in other parts of the world. Although the first two sub scenarios under vertical densification gave better results, and would be the best densification options for consideration based on this study, the redevelopment approach would not be feasible, at least not in the near future. According to the division planner, redevelopment would require a huge amount of monetary resources currently not available. There will also be a need for a relocation and resettlement plan, which would ultimately take quite a lot of time and money. The obvious option therefore would be the prevailing horizontal densification; a detailed development plan for the neighbourhood should however be prepared. With the obvious negative correlation between densification and surface runoff accumulation, a primary consideration should be given to drainage infrastructure; encourage vegetation on the unbuilt areas, undertake relocation of people from swampy and very low lying areas and encourage rain harvesting especially by people residing on higher areas.

6.7. Reccommendations

This study considers the methodology applied a success; as results compared to other hydrological studies undertaken in other parts of the world and is highly recommended for similar studies.

Although the study classified the built-up cover in a highly generalised manner as an impermeable land cover and ultimately only considered the built up area, therefore giving the same infiltration value to all the buildings, it's also true that the type of roof materials and roof shapes would influence water retention and runoff characteristics. Flat roofs would for instance retain more water than sloping roofs; the same way tiled roof would retain more water than flat iron roof; and probably these considerations would give a deeper insight for a further study.

Secondly, the runoff percentages were averaged to the total area, regardless of the land cover properties; it would probably be a better study to limit the impact or rather surface water generated only to the areas covered by the plots. However, for comparison reasons to the other scenarios, it was important to consider the entire neighbourhood coverage.

Thirdly, the neighbourhood design would be improved with availability of cadastral and land tenure information, because this would give a relatively more accurate picture than the designed plots. Availability of cadastral information would further enable design of individual plots; and this would probably give more accurate results. This

Fourth, this study considered rainfall data of a one-time rainfall event; registered as the highest in a study conducted between 2012-2013; it's however possible that there would be instances that the rainfall would surpass this figure (the KDMP for instance registered the highest rainfall event in a 1: 10 years period of 101 mm of rainfall recorded in one day according to their data). It is also possible that surface runoff would be generated from much lower rainfall amounts; according to the area residents, 98.3% of them reported that they experienced runoff, flooding or both whenever it rained. However the difference in rainfall amounts would only vary the amount of surface runoff generated, but would not change the underlying concepts of the relationship between densification and surface runoff generation. It would however be important for surface runoff and flooding management systems, drainage infrastructure installation, and for early warning mechanisms.

Finally, it would be interesting to experiment the impact of artificial drainage channels especially so when considering the flooding aspect as well as their capacity to handle surface runoff under the different densification scenarios.

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APPENDIX 1: PCRASTER SCRIPT DATABASE FOR BASE SCENARIO

```
Binding

DEM = dem5m.map;
LDD = ldd2010.map;
LU = lu2010.map;
lu_tbl = infil.tbl;
roads=roadslubia.map;
runoff = ro.map;
sink=sink.map;
ksat=ksat.map;
intercep=intercep.map;
rof =rof.map;

areamap
DEM;

initial
mask = DEM/DEM;
cells=maptotal(DEM/DEM);
p = scalar(66); # mm

LU = if(roads eq 1 and LU ne 4, 3, LU);
lu = nominal(LU);
#lu = if(lu eq 3, 2, lu);

# rainfall lastsa 110 minutes and runoff is still active shortly after that
# LISEM run giver 140 minutes,

report ksat = lookupscalar(lu_tbl, 1, lu)*140/60; # value is in mm/h, active 140 min
report intercep = lookupscalar(lu_tbl, 2, lu);
report intcm3.map=intercep/1000*cellarea();

pnet=p-intercep;

report runoff = accuthresholdflux(LDD, pnet, ksat)/1000*cellarea(); #m3
report sink = accuthresholdstate(LDD, pnet, ksat)/1000*cellarea();
report rof = runoff-upstream(LDD, runoff)/(p);

rainm3=maptotal(p*mask)/1000*cellarea();
report rainm3.map = rainm3;
report avgro.map=mapmaximum(runoff)/rainm3;

report runoffm3.map=mapmaximum(runoff);
```

APPENDIX 2: PCRASTER SCRIPT DATABASE FOR SCENARIO A

```
Binding

DEM = dem5m.map;
LDD = lddnew.map;
LU2010 = lu2010.map;
lu_tbl = infil.tbl;
roads = roadslubia.map;
house=landcover2020.map;
runoff = roneww.map;
sink=sinkneww.map;
ksat=ksatneww.map;
intercep=intercepneww.map;
rof =rofneww.map;

areamap #[areamap...]
DEM;

initial
mask = DEM/DEM;
cells=maptotal(DEM/DEM);
p = scalar(66); # mm

LU = if (LU2010 eq 1, 3, LU2010)*mask; # lu 2010, houses replaced by bare soil

LU = if(LU eq 2 and uniform(1) gt 0 and window maximum(house,15) eq 1, 3,LU);
# new houses, because if the neighbourhood is unplanned there is lkely to be more bare soil than
vegetation
# if there is a house in a 3x3 window there is a XXX percent change of bare soil, compaction
# Uniform (1) gt 0.5 means if a random generator (uniform) produces a value higher than 0.5 = 50%
change of bare
# Uniform (1) gt 0.2 means if a random generator (uniform) produces a value higher than 0.2 = 80%
change of bare

LU = if(house eq 1, 1, LU); # 1 = house; 2 = rest
lu = nominal(LU);

report lunewwa.map = lu;

# rainfall lastsa 110 minutes and runoff is still active shortly after that
# LISEM run giver 140 minutes,

report ksat = lookupscalar(lu_tbl, 1, lu)*140/60; # value is in mm/h, active 140 min
report intercep = lookupscalar(lu_tbl, 2, lu);
report intcm3.map=intercep/1000*cellarea();

pnet=p-intercep;

report runoff = accuthresholdflux(LDD, pnet, ksat)/1000*cellarea(); #m3
report sink = accuthresholdstate(LDD, pnet, ksat)/1000*cellarea();
report rof = runoff-upstream(LDD, runoff)/(p);

rainm3=maptotal(p*mask)/1000*cellarea();
```

```
report rainm3neww.map = rainm3;
report avgroneww.map=mapmaximum(runoff)/rainm3;

report runoffm3neww.map=mapmaximum(runoff);
```

APPENDIX 3: PCRASTER SCRIPT DATABASE FOR SCENARIO B

```
binding
DEM = dem5m.map;
LDD = lddnew.map;
LU2010 = lu2010.map;
lu_tbl = infil.tbl;
roads = lubiaroads.map;
house=newclas.map;
runoff = ronew.map;
sink=sinknew.map;
ksat=ksatnew.map;
intercep=intercepnew.map;
rof =rofnew.map;

areamap
DEM;

initial
mask = DEM/DEM;
cells=maptotal(DEM/DEM);
p = scalar(66); # mm

LU = if(house eq 40, 1, 2)*mask;
LU = if(roads ne 0, 4, LU);
lu = nominal(LU);
report lunew.map = lu;

# rainfall lastsa 110 minutes and runoff is still active shortly after that
# LISEM run giver 140 minutes,

# ksat = lookupscalar(lu_tbl, 1, lu)*140/60; # value is in mm/h, active 140 min
ksatgras = scalar(25*140/60)*mask; # basic infil of veg area
ksatbare = if(LU2010 eq 3, 5*140/60, 0)*mask;

ksat = if(LU2010 eq 3, ksatbare, ksatgras); #baseline ksat, gras/bare soil

# ksat = ksatgras; #grass only
#ksat = ksatbare; #bare soil only, compacted

ksat = if(lu eq 1, ksatgras*0.4, ksat); #house
report ksat= if(lu eq 4,0,ksat); #roads

intercep = lookupscalar(lu_tbl, 2, lu);
report intercep = if (lu eq 1, intercep*0.4, intercep);

report intcm3.map=intercep/1000*cellarea();

pnet=p-intercep;

report runoff = accuthresholdflux(LDD, pnet, ksat)/1000*cellarea(); #m3
report sink = accuthresholdstate(LDD, pnet, ksat)/1000*cellarea();
report rof = runoff-upstream(LDD, runoff)/(p);
```

```
rainm3=maptotal(p*mask)/1000*cellarea();
report rainm3new.map = rainm3;
report avgronew.map=mapmaximum(runoff)/rainm3;

report runoffm3new.map=mapmaximum(runoff);
```

APPENDIX 3: HOUSEHOLD QUESTIONNAIRES AND KEY INFORMANTS INTERVIEW SCHEDULES

ITC, University of Twente

Assessing the Impact of Densification on Urban Runoff and Flooding in Kampala City

Village **Name**………………………………………………………………………………. **Location** ……………………………………………………………………………………………….

Research carried out in partial fulfilment of the requirements of Masters of Science Degree in GI Science and Earth Observation in Urban Planning and Management, University of Twente

Household Questionnaire

No.	Questions	Answers
1.	Development Status of the plot (Interviewer to validate with observation)	Size of the plot Percentage of Plot Ratio (gross floor area) Percentage of Built up Percentage non-built up/open space
2.	Land Cover in percentage	1. Percentage of Concrete/built up 2. Percentage of Open space/non built (specify type of land cover)
3.	How long have you lived in this neighbourhood?	1) Below 1 yr. 2) Between 1-2 years 3) 2-3 years 4) Above 3 years
4.	Have you been experiencing densification in this neighbourhood? (interviewer to explain meaning of densification)	1) Yes 2) No
5.	If yes in question 4 above, in what forms?	1) Increase in plot ratios 2) Increase in plot coverages 3) Decreasing plot sizes/subdivision 4) Infilling/New developments 5) Redevelopments
6.	Have you ever increased density of this plot? (for home owners) If yes, by how much?	1) Yes 2) No …………………………………………………………………………………… …………………………………………………………………………………… ……………………………
7.	Have you experienced increase in density in this plot? (for rentals) If yes, by how much?	1) Yes 2) No …………………………………………………………………………………… …………………………………………………………………………………… …………………………………………………………………………………… ………………………………………….

8.	How would you describe the type and nature of land cover change in this neighbourhood, and what has been its effect?	…………………………………………………………………… …………………………………………………………………… …………………………………………………………………… ……………………………………………
9.	Do you experience surface runoff or flooding in your house or in this neighbourhood?	1) Surface Runoff 2) Flooding
10.	How often do you experience surface runoff and/or flooding in this house/neighbourhood?	1) Surface runoff 2) Flooding
11.	If yes in question 9 above, how severe is it? (can give answers in terms of destructions experienced if any or level of water above the ground in m)	…………………………………………………………………… …………………………………………………………………… …………………………………………………………………… …………………………………………………………………… …………………………………………………………………… …………………………………………………………………
12.	How long does the surface runoff and/or flooding last?	1) Surface runoff 2) Flooding
13.	What do you think are the main causes of surface runoff and/or flooding?	…………………………………………………………………… …………………………………………………………………… …………………………………………………………………… …………………………………………………………………… …………………………………………………………
14.	Which areas are mostly affected in this (Lubia) neighbourhood?	
15.	Do you think there is any relationship between densification and surface runoff or flooding that is experienced in this neighbourhood?	1) Yes 2) No
16.	If yes in question 15 above, how would you describe it?	…………………………………………………………………… ……………………………………………………………………
17.	The newly prepared structure plan proposes densification intervention approach in this neighbourhood. Would you embrace it?	1) Yes 2) No
18.	What are your reasons for answer in question 17 above?	…………………………………………………………………… …………………………………………………………………… ……………………………………………………………………
19.	With the proposed densifications in this neighbourhood, what do you think would be the impact on surface runoff and flooding?	…………………………………………………………………… …………………………………………………………………… ……………………………………………………………………
20.	Do you feel safe from flooding and/or surface runoff in this neighbourhood?	1) Yes 2) No
21.	What is your reason for your answer in question 20 above?	…………………………………………………………………… …………………………………………………………………… ……………………………………………………………………
22.	In your opinion, what measures do you think should be taken to mitigate against flooding and surface runoff?	…………………………………………………………………… …………………………………………………………………… ……………………………………………………………………

THANK YOU FOR YOUR COOPERATION

ITC, University of Twente

Assessing the Impact of Densification on Urban runoff and Flooding in Kampala City

Research carried out in partial fulfilment of the requirements of Masters of Science Degree in GI Science and Earth Observation in Urban Planning and Management, University of Twente

Interview Schedule for Key Informants

1. In the newly prepared Structure Plan for Kampala; you have earmarked some areas for densification-Lubia Parish is one of the earmarked areas. What are the types and nature of this densification, considering it's largely an informal settlement? (Would you be having it documented?)

What forms do you expect densification to take? Do you expect a; large scale densification in which a whole neighbourhood is transformed or will it be a piece meal approach plot by plot?

2. Are you also considering any accompanying infrastructure? (Roads and drainage systems)?
   What forms will these be? Design type...

3. What are the current plot ratios and plot coverages allowable in Lubia Parish?

4. Do you follow up on implementation to ensure developers follow all the conditions of approval for their development? How do you do it?

5. Do you have surface runoff or flooding problems in Lubia, and which areas exactly? If yes, (i) for how long?
   (ii) What is the annual frequency?
   (iii) And just how severe is the surface runoff and or flooding?

6. Does this runoff (if any) contribute to flooding?

7. Do you expect the structural form of Lubia Parish would change with the proposed densification? If yes, how?

8. Do you anticipate that problems (surface runoff and flooding) would increase with the proposed increase in building densities? If yes, to what extent?

9. What mitigation measures are you putting in place or would you propose against possible surface runoff and or flooding?

For Key Informants in charge of Development Control

The following table shows the existing and proposed densities in the city. Kindly indicate for me:

I. Which city frame Lubia Parish belongs to
II. What is the meaning of:
   - Estimated Gross Density 2011
   - Gross Built Area Capacity
   - Indicative Nett Development Rights
III. Considering that Lubia Parish is largely informal, are the density proposals feasible and in what forms?

Location/Land Use	Estimated Gross Density 2011	Gross Built Area Capacity	Indicative Nett Development Rights	Intervention Approach
City Centre Frame				
Apartments	100%	120%	180%	Upgrade and Densification
High Income	21%	120%	180%	Densification
Middle Income	24%	100%	150%	Upgrade Densification New developments
Low income	21%	120%	180%	Redevelopment
Very Low Income	51%	120%	180%	Redevelopment
Inner City				
Apartments	16%	100%	150%	Upgrade Densification
High Income	20%	50%	75%	Infill Densification
Middle Income	25%	70%	105%	Upgrade Densification
Low income	22%	100%	150%	Upgrade Densification
Very Low Income	26%	70%	100%	Slum Avoidance Upgrading

APPENDIX 4: RESULTS OF ANALYSIS OF HOUSEHOLD INTERVIEWS

1. Frequencies of Village names where interviews were undertaken

Village Name	Frequency	Percent
Lugala	8	13.3
Masanafu Bukuluki	7	11.7
Masanafu Kinoonya	8	13.3
Lusaze	9	15.0
Namung'oona 1	7	11.7
Namung'oona 2	4	6.7
Nabulagala	6	10.0
Mapeera	6	10.0
Lubya	5	8.3
Total	60	100.0

2. Location of the Interviewee

	Frequency	Percent
Uphill	26	43.3
Downhill	34	56.7
Total	60	100.0

3. Percentage of Built-up area per plot

4. Percentage of Built-up area per plot	Frequency	Percent
between 20%-40%	4	6.7
between 40%-60%	16	26.7
between 60%-80%	17	28.3
ABove 80%	23	38.3
Total	60	100.0

5. How long have you lived in this neighborhood?

Duration lived in the Neighbourhood	Frequency	Percent
Below one year	5	8.3
between 1-2 years	7	11.7
2-3 years	11	18.3
Above 3 years	37	61.7
Total	60	100.0

6. Experiencing Densification in the neighborhood?

Experiencing Densification in the neighborhood	Frequency	Percent
Yes	56	93.3
No	3	5.0
NA	1	1.7
Total	60	100.0

7. Type of Land cover on the Unbuilt Area

Type of Land cover on the Unbuilt Area	Responses	
	N	Percent
Bare ground	44	53.7%
Grass	24	29.3%
Agriculture	6	7.3%
Trees/vegetation	7	8.5%
Concrete	1	1.2%
Total	82	100.0%

8. Type and Nature of Densification in Lubia

Type and Nature of Densification in Lubia		Responses	
		N	Percent
	Increase in plot ratios	8	5.6%
	Increase in plot coverages	37	25.7%
	Decreasing plot sizes/subdivision	41	28.5%
	Infilling/New developments	29	20.1%
	Redevelopments	22	15.3%
	No Answer	7	4.9%
Total		144	100.0%

9. Type and nature of land cover change

Type and nature of land cover change		Responses	
		N	Percent
	New developments in low lying areas (Downhill)	8	11.8%
	Mushrooming of Developments	12	17.6%
	Encroachment onto Swampy Areas	9	13.2%
	Conversion/building up of open spaces	31	45.6%
	Clearing Vegetation	6	8.8%
	New developments on hills	2	2.9%
Total		68	100.0%

10. Do you experience surface runoff or flooding in your house/neighborhood?

Do you experience surface runoff or flooding in your house/neighborhood?		Frequency	Percent
Valid	Surface runoff	29	48.3
	Flooding	10	16.7
	Both (Surface Runoff and Flooding)	20	33.3
	Total	59	98.3
Missing	NA	1	1.7
Total		60	100.0

11. Areas most affected by surface runoff/flooding in Lubia neigbourhood

		Frequency	Percent
Valid	Swampy areas	19	31.7
	Kosovo	6	10.0
	Areas Downhill	15	25.0
	masanafu	1	1.7
	All areas	1	1.7
	Hilly areas (of Lubya)	9	15.0
	No Answer	3	5.0
	Total	54	90.0
Missing	NA	6	10.0
Total		60	100.0

12. How often do experience surface runoff and or flooding in your house/neighborhood?

How often do experience surface runoff in your house/neighborhood?		Frequency	Percent
	Whenever it Rains	59	98.3
	No Answer	1	1.7
	Total	60	100.0

13. Embracing Densification intervention approach

Embracing Densification intervention approach		Frequency	Percent
Valid	Yes	48	80.0
	No	10	16.7
	Total	58	96.7
Missing	NA	2	3.3
Total		60	100.0

14. Do you feel safe from flooding and/or Surface Runoff this neighborhood?

		Frequency	Percent
	Yes	7	11.7
	No	53	88.3
	Total	60	100.0

15. Severity of surface runoff and Flooding

Severity of surface runoff and Flooding		Responses	
		N	Percent
	House gets flooded	21	28.4%
	Not so severe-clears in a few minutes	14	18.9%
	Destruction of Property	12	16.2%
	Destruction of Roads	18	24.3%
	Drainage channels overflow	7	9.5%
	Severe soil erosion	2	2.7%
Total		74	100.0%

16. How long does the surface runoff last?

How long Does the Surface runoff Last?		Responses	
		N	Percent
	below 30 minutes	24	37.5%
	30-60 minutes	3	4.7%
	1-3 Hrs	15	23.4%
	Upto 3-24 hours	3	4.7%
	1-2 days	2	3.1%
	More than 2 days	12	18.8%
	No Answer	5	7.8%
Total		64	100.0%

17. Main Causes of Surface Runoff and Flooding

Main Causes of Surface Runoff and Flooding		Responses	
		N	Percent
	Heavy Rainfall	40	32.3%
	Poor drainage system	37	29.8%
	Clearance of Vegetation	9	7.3%
	Poor planning	4	3.2%
	Building on hills	8	6.5%
	Encroachment onto Swampy Areas	11	8.9%
	Excessive land subdivision	1	0.8%
	Low capacity in water harvesting	2	1.6%
	New developments/Infilling	5	4.0%
	Hilly Topography	2	1.6%
	Poor roads	2	1.6%
	Clearing Vegetation	3	2.4%
Total		124	100.0%

18. Reasons for Embracing/not embracing Densification intervention approaches in this neighbourhood

Reasons for Embracing/not embracing Densification intervention approach in this neighbourhood		Responses	
		N	Percent
	There is a lot of soil erosion	5	8.2%
	Always flooding when it rains	4	6.6%
	Its better planning of the Neighborhood	32	52.5%
	It will lead to relocation to better places/higher grounds	2	3.3%
	Will reduce Overcrowding	2	3.3%
	Increase in informal structures leading to increased runoff and/or flooding	7	11.5%
	it would Preserve green spaces	1	1.6%
	No Answer	8	13.1%
Total		61	100.0%

19. With the proposed densifications in this neighbourhood, what do you think would be the impact on surface runoff and flooding?

Impact of Densification on Surface runoff and Flooding	Responses	
	N	Percent
Can reduce if well planned	34	50.7%
Better roads with good Drainage	3	4.5%
Preservation of green spaces	5	7.5%
Increased surface runoff/flloding	17	25.4%
No Answer	8	11.9%
Total	67	100.0%

20. Do you feel safe from flooding?

Do you feel safe from flooding?	Multi-Responses frequecies	
	N	Percent
House floods/sips in water whenever it rains	21	32.8%
Roads become impassable	18	28.1%
Destruction of Property by floods	9	14.1%
House/Resides upstream	4	6.3%
Densification leading to increased surface runoff and/flooding	4	6.3%
Poor drainage channels leading to generation of urban runoff and/or flooding	7	10.9%
A lot of Soil Erosion whenever it rains	1	1.6%
Total	64	100.0%

21. Measures that should be undertaken to mitigate against flooding and surface runoff?

Mitigation Measures	Multi-Responses frequecies	
	N	Percent
Improved Drainage System	47	44.3%
Relocation of People from the hilly areas	7	6.6%
Use barieers	5	4.7%
Planting Trees	4	3.8%
Preserving Open Spaces	2	1.9%
Relocation of people from Swampy Low lying areas/Reclaiming Swamps	12	11.3%
Better Housing	7	6.6%
Water Harvesting at (hill tops)	8	7.5%
Help with technical support to avert floods	4	3.8%
Flood warning Mechanisms	2	1.9%
Institute laws, policies and regulations on flood management	5	4.7%
Restrickting developments on wetlands	3	2.8%
Total	106	100.0%