RUNOFF GENERATION, IMPACTS AND MANAGEMENT PRACTICES IN AMALEMBA URBAN INFORMAL SETTLEMENT, KAKAMEGA MUNICIPALITY, KENYA

BY

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DECLARATION

Declaration by the Student

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DEDICATION

This work is dedicated to my daughters, Sandra A. Bright, Ruth G. Khayosa, sons Samir M. Fabregas, Junior K. Patrick, my wife Nancy Shipendi who encouraged me to complete my studies on time; Father Musonye John and Mother Mmbishi Adelaide who supported my education unconditionally. Above all to God *"He provides rain for the earth, he sends water {runoff} on the countryside."* Job 5:10

ABSTRACT

The study was carried out in Amalemba informal urban settlement within Kakamega municipality, Kenya. It concerned environmental impacts of uncontrolled runoff in the environmentally vulnerable low income settlement. Management of runoff is a significant component towards the sustainability of a sound urban environment infrastructure. Runoff management is imperative in urban informal settlements since it enhances a healthy surrounding. This study identified human and physical features that influence runoff generation, determined influence of rainfall on runoff discharge, influence of slope and ground cover on runoff discharge, effects of runoff; and investigated runoff management measures in Amalemba informal urban settlement. The study followed a quasi-experimental research design. Runoff discharge measurements, visual observations, photography, individual and focus group interviews were used to collect data. Runoff from bare ground, 50% grass cover and 100% grass cover were compared using thirty rainfall events during long rains in April/May 2020. Runoff volume was collected using the Gerlach trough setup, the precise volume of discharge was measured using a graduated one litre measuring cylinder. Data from interviews with respondents was analyzed according to themes while data from the Gerlach trough setup was analyzed using inferential statistics. The rainfall-runoff relationship for Amalemba informal urban settlement indicates a statistically positive significant correlation between daily rainfall and runoff volume with $r = 0.9822$ for 100% grass cover, for 50% grass cover $r = 0.9672$ and $r = 0.9934$ for bare ground respectively with p-value <0.0000001 for all the three surfaces. Bare ground coupled with steeper slope produced the highest runoff while the surface with 100% grass cover yielded the lowest runoff. The results show that vegetation cover is better at protection of the soil against erosion and reduction of runoff than bare ground. Runoff produced adverse effects such as flooding, mini landslides, soil erosion, and blockage of drains as a result of bad solid waste disposal mechanisms and destruction of shacks, farmland and roads. On-site and institutional practices complemented each other in management of runoff. This study emphasizes meaningful involvement and participation in management of runoff; adopting methodologies which withstand both social and human capabilities ranging from controlling and managing runoff to the effects of runoff in informal urban settlements. Runoff management at the catchment level, appropriate use of green infrastructure and the formulation of policies aimed at development of sustainable drainage systems in Amalemba informal urban settlement is of critical importance.

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ADB:	Asian Development Bank
CGK:	County Government of Kakamega
FAO:	Food and Agriculture Organization
FGDS:	Focus Group Discussions
GIS:	Geographic Information System
GOK:	Government of Kenya
KACWASCO:	Kakamega County Water and Sanitation Company Limited
KMWS:	Kakamega Meteorological Weather Station
LWU:	Lao Women Union
Mo ALF:	Ministry of Agriculture, Livestock and Fisheries
MOW:	Ministry of Works
NGOs:	Non-Governmental Organizations
SCS:	Soil Conservation Service
UN:	United Nations
UNESCO:	United Nations Educational, Scientific and Cultural Organization
USEPA:	United States Environmental Protection Agency
WHO:	World Health Organization

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God bless you all.

CHAPTER ONE

INTRODUCTION

1.1 Background to the Study

Urban areas have up to 90% hard surfaces (such as rooftops and pavements), where water collects and flows rapidly as urban runoff (Parris, 2016). Unfortunately, urban runoff is one of the major sources of water contamination. Water contamination by runoff is difficult to avoid since it is a non-point source of pollution. In this regard, non-point source pollution refers to pollution that is not identifiable by a single source and occurs at sites dispersed across the drainage basin. Such causes include deforestation, drainage, yards, sidewalks, highways, building sites, agricultural activities and parking lots (USEPA, 2017).

Runoff and drainage management is one of the basic, fundamental urban infrastructural systems. Any droplet of rainwater in the terrestrial coverage of the municipality ought to be disposed of safely. A failure to correctly dispose runoff causes a wide range of flood and environmental health problems, in particular when settlements are not lawfully planned or have not been sanctioned for development (Button and Muniz, 2010).

Informal settlements consist of residential buildings that have not officially been approved in 'planned' and 'unplanned' areas. It is characterized by poorly constructed homes or a lack of or insufficient social and infrastructure (Srivinas, 2005). Informal settlements exist in areas where residential buildings do not comply with the existing regulations (UN 2006). It is estimated that more than 60% of Africa's urban population lives in slums and informal settlements. With little attention to groundwater, the settlements grow into poor runoff and drainage systems in these regions. The location and physical appearance of these settlements exacerbate the problem. Numerous informal settlements are situated on steep slopes, lowlands, river banks, wetlands, that predispose these areas to hazards and disasters related to runoff (Schiariti, 2014).

Over the post-millennial era, informal settlements have increased the responsiveness of county and national governments in developing nations. This resulted in attempts to provide basic facilities and amenities (including runoff drainage) to informal settlements as relished in formal regions. Inhabitants and communal groups in informal settlements are also pursuing homegrown projects aimed at providing drainage infrastructure that can control runoff and its impacts (Corburn and Karanja, 2014).

Kakamega Municipality's activities have a definite, substantial and cumulative environmental effects. If the city grows, there is growing demand for water, urban pollution and waste. Not only does urban development cause shifts in land use, but the region's emerging issues with water supply and increased demand for people. To support the activities of the municipality an enormous amount of water is needed. The bigger the urban area, the more hydrological the acquisition of its water supply could have an impact. In addition, the market typically exceeds that of surface and groundwater (Nazire and Michihiro, 2016).

Kakamega Municipality's key attribute is that it has tougher surfaces than unpaved ones as well as roofs and pavement where water pools and flows easily. This has a negative effect on the runoff system hydraulic load rate (KACWASCO, 2018). As a result, with the inclusion of the paved field, the volume of infiltration is decreased and the quantity of flush increases. In view of these factors, urban activities impact the city and its ecosystem significantly through increased runoff and pollutant burdens. These effects create problems in relation with urban water supplies (USEPA, 2017).

1.2 Statement of the Problem

The effect of urbanization in the developing countries includes informal settlements. In Kenya, many people searching for new jobs in town areas illegally settled on abandoned, informal settlements. These settlements are very vulnerable to runoff effects for the Municipality of Kakamega due to their precarious position and characteristics. Some of the townships are built on volcanic loamy soils. The flooding of rainwater or percolating groundwater dissolves gradually the material of these soils, resulting in surface soil movements. An increased runoff as a result of high rainfall amount means that these poorly "infrastructured" settlements are more vulnerable. These potentially hazardous conditions require innovative solutions. Some of the innovative solutions may be a combination of structural and non-structural runoff management practices. This study explored runoff generation, impacts and management strategies in Amalemba informal urban settlement.

1.3 Main Objective

The main objective of this study was to assess urban runoff generation and management in Amalemba informal urban settlement.

1.3.1 Specific objectives

The study was guided by five specific objectives:

i. To identify human and physical features that influence runoff generation in Amalemba informal urban settlement.

ii. To determine the quantity runoff discharge in Amalemba informal urban settlement.

iii. To establish the effects of runoff on the environment in Amalemba informal urban settlement.

iv. To investigate on-site and institutional runoff management practices in Amalemba informal urban settlement.

1.4 Research Questions

i. What are the human and physical features that influence runoff generation in Amalemba informal urban settlement?

ii. What is the quantity of runoff discharge in Amalemba informal urban settlement?

iii. What are the effects of runoff on the environment in Amalemba informal urban settlement?

iv. What are the on-site and institutional runoff management practices in Amalemba informal urban settlement?

1.5 Justification

A wide area of informal settlements characterizes many towns of developing nations. Sometimes, these fail to comply with official planning codes, building regulations and construction laws, and are scarcely equipped with appropriate facilities and services because they are not formally recognized by local authorities. A significant amount of physical data is required to establish a drainage system, but in the informal urban settlement of Amalemba these data were scarce. Therefore, the provision of better runoff drainage systems is a major component of urban upgrade efforts in informal areas. It is imperative to have drainage systems suited to the requirements of residents in Amalemba informal urban settlement in order to improve their environmental conditions. This is because provision of adequate drainage in informal settlements has the objective of protecting life and property against flooding and erosion. It is a truism that informal urban areas with large volumes of generated runoff are unhealthy places for human habitation. The World Health Organization defined health as a state of complete physical, social and mental well-being and not merely the absence of diseases or infirmity (WHO, 2018). An informal settlement with large volumes of runoff that is capable of causing psychological stress to the residents is by implication, an unhealthy settlement. This adumbrated some structural and non-structural strategies for mitigating the effects of runoff on residents of Amalemba informal urban settlement and urban infrastructure. The study also focused on the way residents of the settlement can be integrated in managing the runoff sustainably. Policy makers may use the gaps identified to design policies that enhance runoff management within the informal settlements. This study therefore, will provide the baseline information on environmental development programs for Amalemba residents including infrastructure and the planning of the town. It will also come up with a database upon which the future challenges and changes on land use practices in Amalemba can be based. Findings of this research will be vital to schools that conduct educational projects that teach students how to manage runoff. In addition, the resultant runoff management practices can benefit the civil construction industry with regard to roads, bridges, residential estates, schools and service stations that have opportunities to control runoff onsite. Many institutions and residents in Amalemba informal urban settlement can implement community based practices that can reduce runoff discharge. The data gathered in the study may point towards means by which runoff and drainage management practices can be incorporated sustainably at institutional level.

This information will be useful to the water and environmental departments of the Kakamega County Government during planning.

1.6 Assumptions of the Study

The study was based on the following assumptions:

i. The relevant and updated records were available from the water and civil departments of Kakamega County Government.
ii. Urban centers have similar morphological features with those of the study area
iii. Morphological features influence runoff generation in informal urban settlements
iv. All the respondents would be co-operative in providing the required data.

1.7 Scope of the Study

The scope of the study was restricted to the study objectives listed earlier. It focused on identifying human and physical features that influence runoff, determining runoff discharge, establishing effects of runoff on the environment and investigating on-site and institutional runoff management practices in Amalemba urban informal settlement. The factors about runoff generation included; rainfall, soil type, vegetation cover, slope and catchment size. It however did not neglect the fundamental environmental challenges in the drainage network and management of runoff within the framework of informal urban settlements.

1.8 Limitations of the Study

The main limitation experienced in the course of carrying out this study was mistrust from the respondents on the purpose of the research. Others held the researcher was stand-in on behalf of the County Government department in charge of development control. Some residents were concerned that their constructions were going to be destroyed because of non-compliance. To address this problem, the researcher through the county works officer sought audience with opinion leaders and explained the purpose of the study to their satisfaction. In addition, the findings of this study in Amalemba informal urban settlement may not allow for generalizations to other informal settlements in the country because of their dissimilar structural characteristics.

CHAPTER TWO

LITERATURE REVIEW

2.1 The Concept of Runoff and its Problem in Urban Environment

During rain storms and other precipitation events, surfaces built from materials such as asphalt and concrete, along with rooftops, carry polluted runoff to drainage systems, instead of allowing the water to percolate through soil. This lowers the water table causing flooding because groundwater recharge is lessened since the amount of water that remains on the surface is greater. Most urban drainage systems discharge untreated runoff, to streams, rivers and bays. This excess water can also make its way into people's properties through basement backups and seepage through building walls and floors.

2.2 Human and Physical Features that Influence Runoff Generation

Rainfall is considered to be the key contributor to the production of surface runoff. There is also an important and special relationship between rainfall and surface runoff. By the fundamental theory of the hydrological cycle, as rain occurs, the first drops of water are intercepted by leaves and stems. When the soil surface is reached, the water will penetrate the soil until it reaches a stage where the precipitation level exceeds the penetration potential of the soil to produce runoff.

2.2.1 Nature of land use and land cover

Land use factors that influence runoff coefficient are a fraction of an area with impervious cover, such as streets, parking lots or houses, and the extent of the vegetative cover that intercepts surface runoff (Grant, 2010). Changing green field surfaces to impermeable concrete and tarmac raises the amount of runoff in a region (Schiariti, 2014).

2.2.1.1 Paved surfaces

Land use / land cover shifts associated with urbanization have hydrological implications. In urban areas, runoff is high since impermeable surfaces such as rooftops, paved roads and parking cover a wide area (Booth, 2006). During building, vegetation removal and compaction takes place; this decreases soil retention and erosion resistance (Zhang and Jason, 2015). Replacing surfaces that were formerly pervious with impervious ones alters the drainage channel and ultimately changes the physical characteristics of the runoff hydrograph (Goonetilleke and Thomas, 2005). Many asphalt surfaces and rooftops do not permit water to enter and instead funnel water into tempest and drainage channels. A precipitation generates much more runoff than before, and flow peaks are growing by 2 to over 10 (Roesner, 1999)

2.2.1.2 Agriculture

Agricultural land use can intercept precipitation and reduce runoff. However, intensive agriculture where irrigation may be used can cause water logged soils and therefore lead to increased runoff. Heavy use of agricultural machinery can compact the soil and reduce its infiltration capacity increasing the probability of runoff taking place (Parkinson, 2016).

2.2.1.3 Vegetation cover

Vegetation cover pattern and extent have significant implications on the soil's infiltration. A major factor influencing the development of runoffs is above ground vegetation cover. Vegetation cover redistributes rainfall into three components: canopy interception, stem flow and collapse, thereby decreasing runoff, restricting the occurrence of runoff.

As a result, shrubs are most effective in reducing runoff levels, followed by herbaceous plants and trees (Jia, 2015). A thick covering of vegetation protects the earth from the raindrop effect and decreases the crushing effect. Before hitting the field, the presence of leaves and stems allows rain to be captured; the result is that the flushing is decreased. Dense vegetation with a large surface area with hairy roots can absorb large amounts of water, resulting in lower runoff (Parkinson, 2016). The simulated runoff ratio rises by 0.15 to 0.44, while the annual flow rates are increased by 35% to 36% depending on the catchment area (Li and Madison 2007).

The root and organic matter system in the soil increase the porosity of the soil and thus allow more water to penetrate. Vegetation also delays surface flux, particularly on mild paths, allowing more time for water to infiltrate, thereby reducing runoff on such a surface (Donner, 2004). Plant cover is a key element in the generation of runoff and protection against soil loss. After the undergrowth is cleared by fire, there is a major change in the hydrological response in the catchment area, i.e. more runoff is created (Wittenberg and Shin, 2014).

Some studies have shown that there is a decline in discharge because of the rise in vegetation density in Mississippi (Donner, 2004). A study in Ashio catchment in Japan on areas which were used formerly for mining and manufacturing, significant floods from 1974 to 1998 and found that the peak runoff coefficient decreased from 0.59 to 0.38, resulting in a decline in rush volume (Kobatake, 2014). There is a general tendency to change the form of vegetation in several catchments of the Volta Basin (for example, from forests to grassland).

The long-term structural improvements on native grasslands have mainly been restricted to pore radii more than 3000μm, which mean that land usages have a higher impact on movement in water than on the soil sequence. The research study characterizes and confronts the characteristics of the finely textured soles on native grasslands, a freshly tilled cropland and a restorative grassland. This suggests that land cover alteration is a significant water-moving mechanism in fine-textured soils (Schwartz and Evett 2003). This is an important process. In conclusion, there is less runoff than bare soil in an areas densely covered with vegetation. The runoff coefficient values for different land uses are shown in Table 1.

Table 1: Runoff coefficient values for various land uses

Description of Area		**Runoff Coefficients**
Business: Downtown areas		0.70-0.95
Neighborhood areas		0.50-0.70
Residential:	Single-family areas	0.30-0.50
	Multi-units, detached	0.40-0.60
	Multi-units, attached	0.60-0.75
	Suburban	0.25-0.40
Residential ; (0.5ha (1.2 ac) lots or more		0.30-0.45
Apartment dwelling areas		0.50-0.70
Industrial:	Light areas	0.50-0.80
	Heavy areas	0.60-0.90
Parks, cemeteries		0.10-0.25
Playgrounds		0.20-0.40
Railroad yard areas		0.20-0.40
Unimproved areas		0.10-0.30

Source: Niagara Regional Planning Board, 2016

2.2.2 Soil type

The types of soils influence the amount of runoff generated. The infiltration capacity of soil depends on the soil texture and structure. Soil composed of a high percentage of sand allows water to infiltrate through it quite rapidly because it has large, well connected pore spaces. Therefore, they have a relatively low storm water runoff rate and runoff coefficient. Clay soils have low infiltration rates due to their smaller sized pore spaces. As a result, they have a relatively high storm water runoff rate and a relatively high runoff coefficient (Button and Muniz, 2010). Where there are very fine grained and clay-rich soils, water infiltrates more slowly than sandy soils that readily soak up water (Grant, 2010). Runoff production in highly organic soil found in marshy or damp regions is sporadic (Holden and Burt, 2003). In the absence of soil, little fractured bedrock is exposed, there is minimal soaking of water causing rapid runoff. Such sporadic runoff has little base flow contribution. Yannopoulos (2013) also investigated the effect of soil moisture content and its spatial variation on runoff yield and concluded that, runoff yield from the plot increases with increasing soil moisture.

Four soil community classifications have been established by the United States Soil Conservation Service (2011), which can be applied in the assessment of drainage area rush values. Determining the SCS soil group is appropriate for a specific soil can be based on the calculated minimum soil infiltration rate or on a description of the soil as shown in Table 2.

Table 2: Infiltration rates for SCS soil groups

Soil Group	Infiltration Rate	Soil Group Description
Group A	0.762 – 1.143 cm/hr.	Soils having a low runoff potential due to high infiltration rates. These soils consists primarily deep, well drained sands, deep loess and aggregated soils/gravels
Group B	0.381 – 0.762 cm/hr.	Soils having a moderately low runoff potential due to moderate infiltration rates. They consist primarily of moderately deep to well drained soils with moderately fine to moderately coarse textures: Shallow loess, sandy loam
Group C	0.127 – 0.381 cm/hr.	Soils having a moderately high runoff potential due to slow infiltration rates. They include, Clay loams; shallow sandy loam; soils low in organic content; soils usually high in clay
Group D	0 – 0.127 cm/hr.	Soils having a high runoff potential due to very slow infiltration rates. They consist soils that swell significantly when wet; heavy plastic clays; soils with permanently high water tables; shallow soils over nearly impervious parent material.

Source: USSCS, 2011

2.2.3 Catchment size and slope

Size of catchment may affect runoff generation in terms of the volume of runoff per unit area, the larger the size of the catchment area, the larger the time of concentration (Wemple and Jones, 2003). There is a positive relationship between runoff and gradient but moderated with presence of vegetation cover. Steep slopes produce more runoff than the lowland areas in drainage basins (Sharma and Vallabh, 2013). Water will briefly sink on gentle slopes and eventually penetrate, but water tends to descend faster on the mountainside. A watershed with a larger slope is usually higher than one with a smaller slope (Bengtson, 2011). Experimental rush plots have shown that steep slopes contain more runoff than those with moderate routes. Soils tend to be thinner in steep slopes. Thus, water tends to be drained more quickly in steep slopes than on gentle slopes when the rock is exposed (Grant, 2010)). A related rise in the runoff volume for plots is caused by a growing slope length (Ahmed and Kumar, 2013). In some cases, accumulation of coarse sediment at the base of steep slopes soak up runoff from the cliffs above, turning into subsurface flow (Dasch, 2003). The relationship between slope and runoff is illustrated in Table 3.

Table 3: Runoff coefficients for pervious surfaces and slope ranges

Slope	A	B	C	D
Flat (0-1%)	0.04-0.09	0.07-0.12	0.11-0.16	0.15-0.20
Moderate (2-6%)	0.09-0.14	0.12-0.17	0.16-0.21	0.20-0.25
Steep (over 6%)	0.13-0.18	0.18-0.24	0.23-0.31	0.28-0.38

Source: Niagara Regional Planning Board, 2016

2.3 Determination of Runoff Discharge

Runoff discharge refers to the horizontal water flow occurring at the surface, in rivers and streams. Some of the factors that affect discharge are rainfall intensity and duration, land use, vegetation, soil type, drainage area and slope (Button and Muniz, 2010). Water that originates from precipitation events and is not absorbed by the ground is referred to as runoff. Runoff generation at a catchment scale includes surface runoff defined as water flow over the land surface based on the differences on slope gradient (Madungwe and Sakuringwa, 2007).

WaterRich (2012) put forth the following equation for calculation of runoff discharge:

Runoff Discharge = Surface Area x Runoff Co-efficient x Rainfall Depth

In this method, runoff is calculated by multiplying the surface area by a co-efficient that estimates the conditions of the particular study area. This is then multiplied by depth of rainfall to obtain a volume of runoff. During calculation, the method assumes that rainfall depth comes in units of 1cm (WaterRich, 2012).

2.3.1 Rainfall and Runoff Discharge

The key contributor to surface runoff generation is known as rainfall. Rainfall and surface runoff therefore have a specific and important connection. The rate, length and distribution of precipitation characteristics directly influence the occurrence and volume of the runoff (Kure and Yuya, 2008). The first water drops are intercepted by the leaves and stems of plants by the fundamental theory of the hydrological cycle as the rain flows. The word interception storage is generally referred to. Once it hits the earth's surface, the water can penetrate the soil before the rainfall rate exceeds the soil's penetration potential (Davis and Andrew, 2015).

Overland flow, stream flow and channel flow are the flow processes. The overland flow is referred to as overland flow of infiltration / Horton overland flow or overland saturation flux (Dunne flow). The Horton overland flow is produced if the strength of the rainfall exceeds soil infiltration or by a saturation mechanism, where the soil is saturated by the perennial soil waters that rise on its surface. The flux on the overland is seen as the flux, creating then the flow of the slurry. Any of the rills are added or the stream flux is formed, which then converges into channel flow (Button and Muniz, 2010).

Sporadic floods occur if the volume of the runoff overflows the riverbanks (natural and man-created) or if the river overflows (Jia, 2015). The physical interpretation of the runoff is the proportion of the rainfall that becomes surface waterfall (Bengtson, 2011). As shown in Table 4, the value of the runoff coefficient for a particular drainage depends on the type of soil, land use and pitch.

Table 4: Runoff coefficients for different soil types and land use

Land Use/cover	Soil Group A	Soil Group B	Soil Group C	Soil Group D
100% Impervious (parking lots, rooftops, paved sidewalks)	0.98	0.98	0.98	0.98
Open space with grass cover <50%	0.68	0.79	0.86	0.89
Open space with grass cover 50% to 75%	0.49	0.69	0.79	0.84
Open space with grass cover >75%	0.39	0.61	0.74	0.80
Woods in fair hydrologic condition	0.36	0.60	0.73	0.79
Residential lot (1/4 acre)	0.61	0.75	0.83	0.87
Residential lot (1/2 acre)	0.54	0.70	0.80	0.85
Residential lot (1 acre)	0.51	0.68	0.79	0.84

Source: USDANR, 1986

2.4 Effects of Runoff in Informal Urban Settlements

Certain drainage installations are provided in informal settlements, but these are incomplete, dysfunctional, or damaged. Informal urban housing is designed without complying with the existing planning or building codes (Tayler, 2007). They are made from cheap scrap materials, which are readily available. These shacks trigger large quantities of runoff in the towns (Armitage, 2011). Infrastructure provision approaches to convectional settlements appear to be unsuitable, provided that the inconsistencies and unintended character of squatter settlements, defined by limited access routes, occupational risk areas and an insufficient description of public and private spaces, are not taken into consideration (Imparato and Ruster, 2003).

Rainfall absorbs waste from roadway surfaces, other catchment surfaces, storm drains and eventually transforms into urban wastewater (Adams and Fabian, 2000). Solids also come to runoff, causing destruction of natural habitat and water scales, through vehicle pollution, tyre pulls and engine wear, as well as pavement wearing (Walsh and Anthony 2005). In the informal settlements, there are usually no formal arrangements for runoff drainage (Winter and Kruger, 2008). Therefore, runoff is normally polluted by gray water that may contain high fecal bacterial burdens (Carden and Winter, 2007). For example, on highways, household and industrial chemical products, motor vehicles leave oil and waste on the pavement surfaces. They can also be collected. During stormy events, pollution streams in which urban flows are quickly washed away from the source of non-point contaminants (Armitage, 2011). Below are some effects of urban runoff:

2.4.1 Waterborne diseases

Approximately 99 million US people suffer from acute gastrointestinal disorders/illness. Around 40% of those diseases can be caused by infected drinking water (Delleur, 2003). The key sources of urban and suburban nitrogen may include fertilizer carried by storm water, vehicle exhaust, and septic systems. Nitrogen presents direct threats to health, and the risks of respiratory disorders including breathability increase from exposure to nitrate in drinking water. Roof, road and park runoffs can have substantial copper, zinc and plumage concentrations that have toxic effects in people and wildlife (Richards & Jackson, 2003).

2.4.2 Flooding

In most urban centers in Nigeria, the urban poor from informal settlements are the most hit whenever there is flooding. Their dwellings are built using substandard building materials and these substandard materials are easily swept away by flood water (Okoko, 2008). A household survey in Nyalenda informal urban settlement in

Kisumu revealed that less than 30% of households had access to usable road during the rainy season. Consequently, flooding was a serious problem in the settlement particularly during the long rains between March and June. Households also experienced flooding because there were few drainage channels. Naturally formed open gullies, as opposed to proper drainage channels often served as runoff drains (Karanja, 2010). Floods in Nyalenda informal settlement develop when fast moving storm water flows into the low-lying flat areas in Nyalenda informal settlement at high speed but the inadequate storm water infrastructure cannot clear all the storm water (Zablon, 2015).

2.4.3 Inurement

Informal inhabitants of the settlement are normally inured to flood activities. Studies at Indore, India have shown that inhabitants of the slum anticipate and see flooding as part of their lives (Stephens, C; Lewin, S, 2013). This is what Parkinson (2003) also shared. Residents perceive living on the edge of the floodplains as a source of jobs and established help for people living close to the surface (from the neighbors, the churches, welfare organizations, NGOs). In general, flooding is seen as a normal and seasonal phenomenon (Armitage, 2011). In East Java Informal Settlements in Indonesia, however, residents are worried about the risks flooding would cause to their livelihoods and health (Santosa, 2003).

2.5 Runoff Management in Informal Urban Settlements

New Jersey Runoff Best Management Practices Manual (GoNJ, 2016) defines runoff management as:

> Any structural or non-structural strategy, practice, technology, process, program, or other methods intended to control or reduce runoff and associated pollutants, or to induce or control the infiltration or

groundwater recharge of runoff or to eliminate illicit or illegal non-runoff discharges into runoff conveyances.

Runoff Management focuses on several environmental benefits including; reducing the risk and effects of flooding, enhancing the quality of runoff and creating additional water supplies to improve water availability (MOW, 2002). The relationship between the natural and constructed ecosystems is recognized as interconnected components of the same watershed (Backstrom and Viklander, 2000). The management of urban runoff is a knowledge used to understand, regulate and use water in its various forms within the hydrological cycle. Urban runoff control in areas with very strong human interaction with natural systems is applied. In urban areas, the hydrological phase takes place at a lower time and space level (Delleur, 2003).

2.5.1 Urban planning

The problem of runoff management is compounded by inappropriate urban planning and management, insufficient and under-implemented structures to regulate growth, and the proliferation of lower-income settlements with slight concern for drainage (Armitage, 2011). Low-income, informal settlements are not ideal for residential development. In general, they are unplanned and sporadic in their spatial configuration. The places where such results are: near lakes, wetlands, deep ground (High Water Tables, issues with flooding), floodplains, previous waste disposal areas and rail/road lines and steep slopes/hillsides. These sites are subject to erosion and flooding which needs a lot of attention to runoff management and drainage (Murray, 2008). Research into New Delhi's slum networking shows that slum networking connects slums and the natural waterway that affects the infrastructure and the environment. The slum matrix definition combines core services such as home-to-house water and underground waste water supply networks, storm drains, parks, landscape management as well as solid waste (Tripati and Jumani, 2001). Urban drainage systems cannot be built independently from their serving neighborhoods. The ties of the slum and natural drainage roads that affect urban infrastructure and the city environment are, for example, used by slum networking in India. This approach aims to solve flood problems for the whole town and also to provide services to urban residents in lowlands adjacent to natural waterways. This approach also aims to solve flood problems. Implementation may however be problematic because of inadequate solid waste management, and because slum residents may not be willing to invest in the household infrastructure to link with the urban waste drainage network (Jonathan, 2003). An analysis of the construction of an improved runoff management system in Nigeria shows the current status of the runoff collection network in the Federal University of Technology was not satisfactory since most roads and their sidewalk were not well maintained. Drainage channels were blocked by sewage and other wastes due to mismanagement of the drainage system (Adewumi and Ajibade, 2014).

2.5.2 Participation

Involvement as a social aspect is a significant factor in controlling runoff and enhancing drainage in informal low-income settlements. The role of a well-organized, mobilized society is crucial. In the preparation, implementation and maintenance processes, group approval, contribution, consensus and partnership are possible and indispensable. The case of urban environmental re-establishment in the Dominican Republic slum of Santo Domingo (Parkinson and Tayler, 2007) indicates opportunities in this regard. Volunteers and recruited members from the well-organized group carried out responsibilities such as clearance of waste piles, digging ditches, constructing cesspits and runoff drains.

In Lao, the Lao Women Union was active in project monitoring and encouraged drainage infrastructure maintenance activities. Runoff control for some residents, however, had low priority. Having collapsed frequently in communication and mis-confidence between occupants and local authorities' hindered physical growth in settlement (ADB, 2008). This was the result of a two-year survey of 39 low-income unsewered settlements, which is consistent with Carden et al. (2007). Education programs focused on settlement are of vital significance among other non-structural / operative steps for improving runoff quality in informal settlements (Owusu-Asante and Ndiritu, 2009).

Public engagement gives local authorities a chance to determine the communal viability of runoff and overflow response schemes in informal urban settlements. Experiences in high-income countries, such as the United States, show that urban runoff systems need public support and engagement to succeed; the effectiveness of runoff management initiatives needs strong incentive to take action (Jonathan, 2003).

A research on the climate change effect on the built environment of Nigeria has revealed that individual homeowners have an important role to play in reducing the risk of urban flooding in informal settlements while addressing infrastructural problems, by safeguarding their own houses and reducing their contributions of runoff into runoff systems (Okonkwo and Ezeabasili, 2013).

A major problem for runoff management is insufficient waste management within Kibera, an informal settlement within the capital of Kenya (Karanja, 2010). Runoff management actions in non-formal areas must also be combined with effective waste management methods in order to be efficient and sustainable (Olumuyiwa 2012). In its strategic plan (2017-2022), the Kakamega County Water Regulators (KACWASCO) found that the rivers in and around Kakamega Town were primarily captured by the traditional drainage scheme that caught water from impervious surfaces. The collected water was transported by open drains to the nearby Isiukhu River. These traditional structures were planned and installed many decades ago and are now insufficient and outdated. The area needed current water and sewer infrastructure, physical infrastructure in place to cope with increased demand by a surging population (KACWASCO, 2018).

2.6 Theoretical Framework

The definition of pool resources, according to Ostrom (2009), refers to natural and man-made installations that produce operational units over time. Runoff water is a case in point of a shared pool resource. The explanation is that a significant component of the water supply available in rural and urban settings offers extractive rights for owners with mutually shared environmental benefits. Consider in this case the hypothesis of a runoff infrastructure scheme that serves an informal urban catchment. User A from a certain informal settlement can use the settlement by allowing waste to spill or intentionally deposit materials which prevent the runoff system. He knows not that this act takes away user B from the flood mitigation operation of this flush infrastructure in another informal settlement. Thus, when it rains, the User A's house will become inundated. If the water runoff were to be collected, processed and reused, its contents will already be tainted by the actions of the first person. The concept emphasizes the place of the informal town settings in order to regulate the runoff in favor of its inhabitants (Ostrom, 2009) as the congruence of rules and regulations arising from the existing institutional conditions.

2.7 Conceptual Framework

A conceptual framework is ‘an alignment of key concepts of a study which helps to position it in the bigger research enterprise’ (Henning, 2004). Figure 1 presents the conceptual framework for this research.

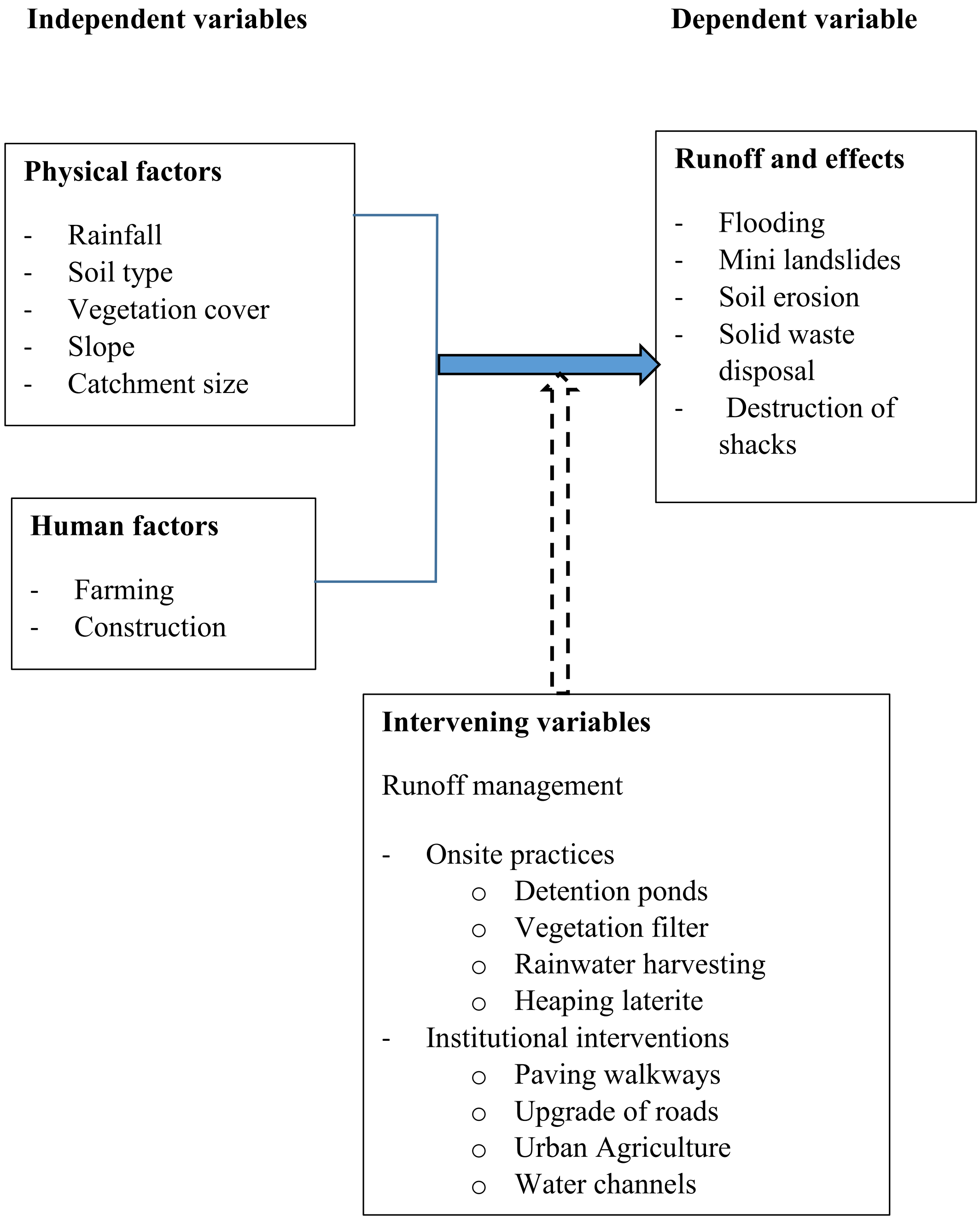

Figure 1: Conceptual framework for the study.

(Source: Author, 2020)

a) Independent variables

i) Rainfall is known as the main contributor to the generation of surface runoff. Rainfall characteristics such as intensity, duration and distribution have a direct bearing on the occurrence and volume of runoff.

ii) Soil composed of a high percentage of sand allows water to infiltrate through it quite rapidly due to its large, well connected pore spaces. The low infiltration rate in clay soils is due to their smaller sized pore spaces. As a result, clay soils fill rapidly and commonly generate runoff sooner that sandy soils (Ritter, 2006).

iii) Vegetation has a significant effect on the infiltration capacity of the soil. An area which is densely covered with vegetation produces less runoff than bare ground. Vegetation also retards the surface flow particularly on gentle slopes, giving the water more time to infiltrate and to evaporate (Kobatake, 2014).

iv) Steep slopes in the headwaters of drainage basins tend to generate more runoff than the lowland areas. Steep slopes yield more runoff than those with gentle slopes. Soils tend to be thinner on steep slopes, limiting storage of water (Wemple and Jones, 2003).

v) Size of catchment may affect runoff generation in terms of the volume of runoff per unit area. A larger catchment area requires a longer time of concentration (Ahmed and Kumar, 2013).

b) Intervening variable-Human activities

Modifications in the use of land and its cover related with development result in hydrological effects (Booth, 2006). When construction, takes place, vegetation is removed, the soil is compacted decreasing the capability of the soil to retain water and repel soil loss through erosion (Zhang and Jason, 2015). Replacing pervious surfaces with impervious surfaces and modifying natural or constructed drainages, changes the physical appearance of runoff hydrograph (Goonetilleke and Thomas, 2005). A given rainstorm produces significantly more runoff volume than before (Roesner, 1999).

c) Dependent variable-runoff discharge and its effects

Surface runoff is the flow of excess water that occurs when excess storm water flows over the earth's surface when the soil is soaked to full capacity, and rainfall is more than the soil can absorb it. Runoff has various effects on both human and physical environment.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This chapter presents the following aspects; study area, research design, target population and sample size, data collection, pilot study, data analysis and ethical considerations in research.

3.2 Study Area

The study area covered the Amalemba Informal Urban Settlement in Kakamega town, Kakamega County. Administratively; Kakamega County has 12 sub-counties with 60 wards. It has 24 divisions, 72 locations, and 233 sub locations. The county has 12 constituencies in total, namely Butere, Mumias East, Mumias West, Matungu, Khwisero, Shinyalu, Lurambi, Ikolomani, Lugari, Likuyani, Navakholo and Malava (GoK, 2019 c). Kakamega County covers an area of 3034 km^2. The County is located in Western part of Kenya, bordering Bungoma County to the north, Trans- Nzoia County to the north east, Uasin Gishu County and Nandi County to the east, Vihiga County to the south, Siaya County to the south west and Busia County to the west. It is bounded by longitude 34º42'E to 34º48'E and latitude 0°15'N to 0°20'N of the Equator (MoALF, 2017). Kakamega is a town in western Kenya lying about 30 km north of the equator. The town is the headquarters of Kakamega County with a population of 1,867,579 (GoK, 2019 c). The town is critical to the study because it is one of the key contributors of runoff that flows directly into Amalemba informal urban settlement. The average elevation of Kakamega is 1,535 m. The general topography of Kakamega town is characterized by undulating plains with occasional low hills jutting above and dissected by steep sided valleys that radiate to the south, west and east. These valleys form the main drainage of the area (KACWASCO, 2018). The geological formations of the area are typical of Kavirondian granites, Precambrian volcanic and sedimentary rocks (GoK, 2000 a).

The geographical location of Kakamega municipality is illustrated in Figure 2;

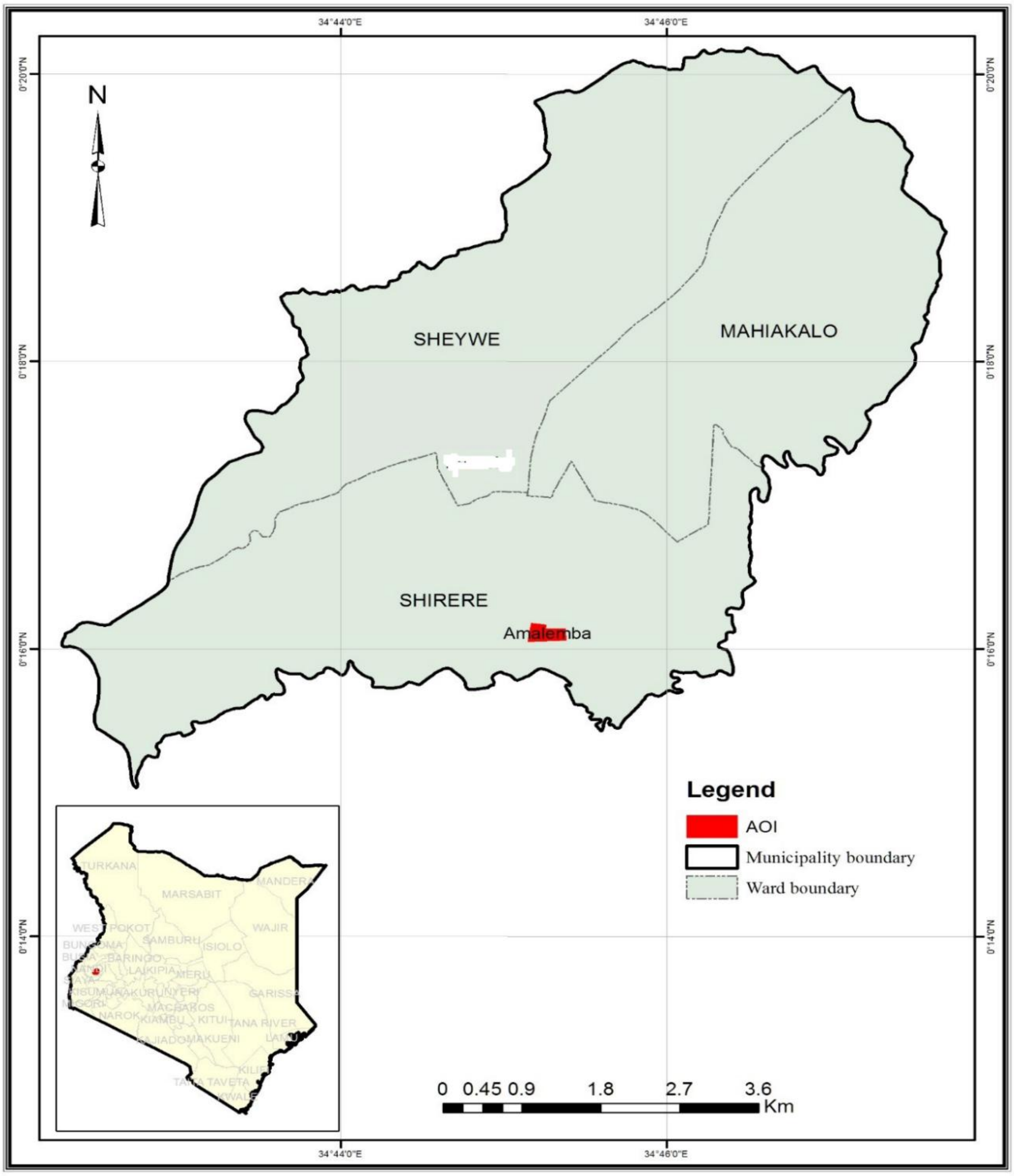

Figure 2: Geographical location of Kakamega Municipality

(Source: Landsat-June 2020)

The area of study is illustrated in Figures 3 and 4:

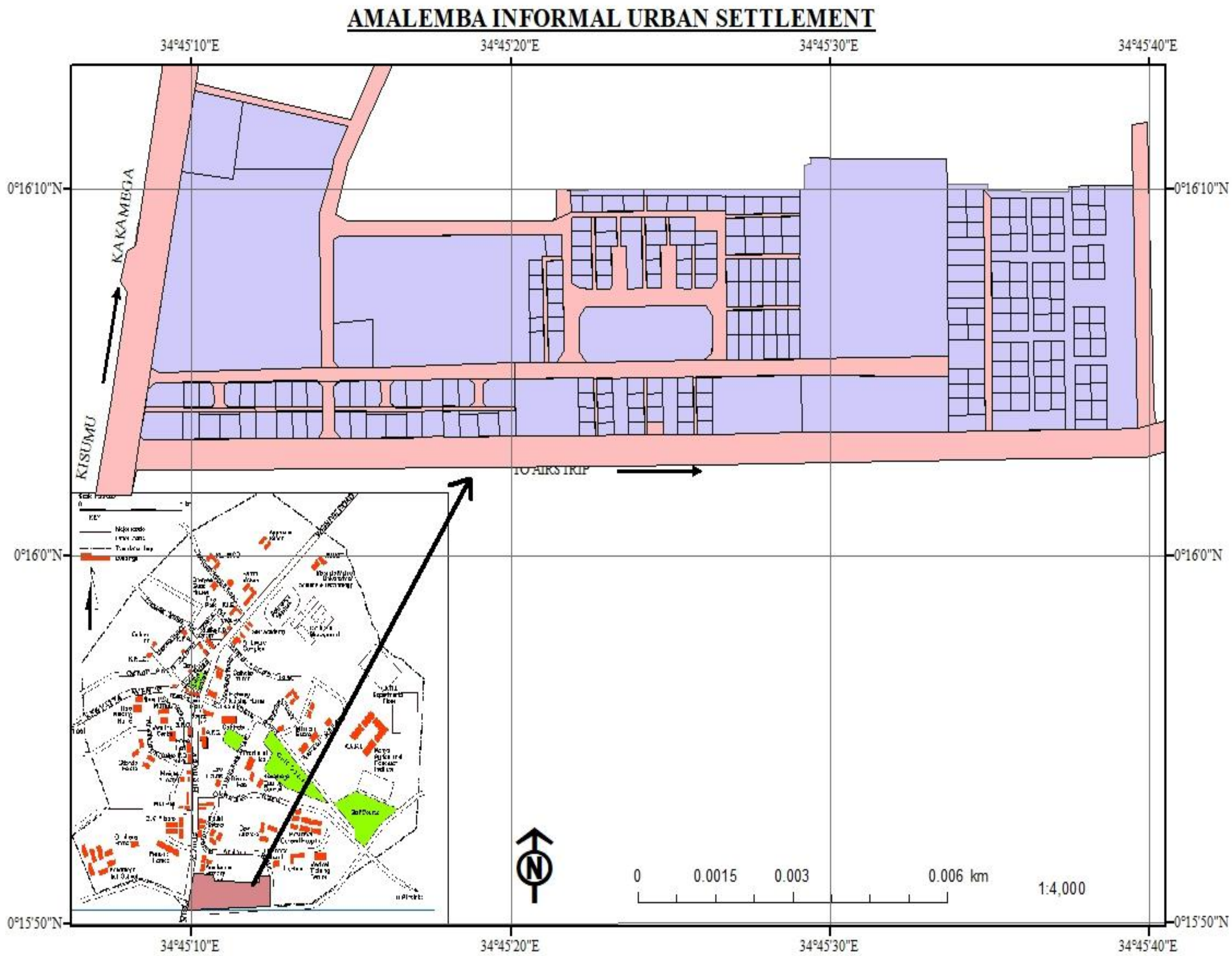

Figure 3: Location of Amalemba Informal Urban Settlement.

(Source: Landsat-June 2020)

3.2.1 Amalemba informal urban settlement

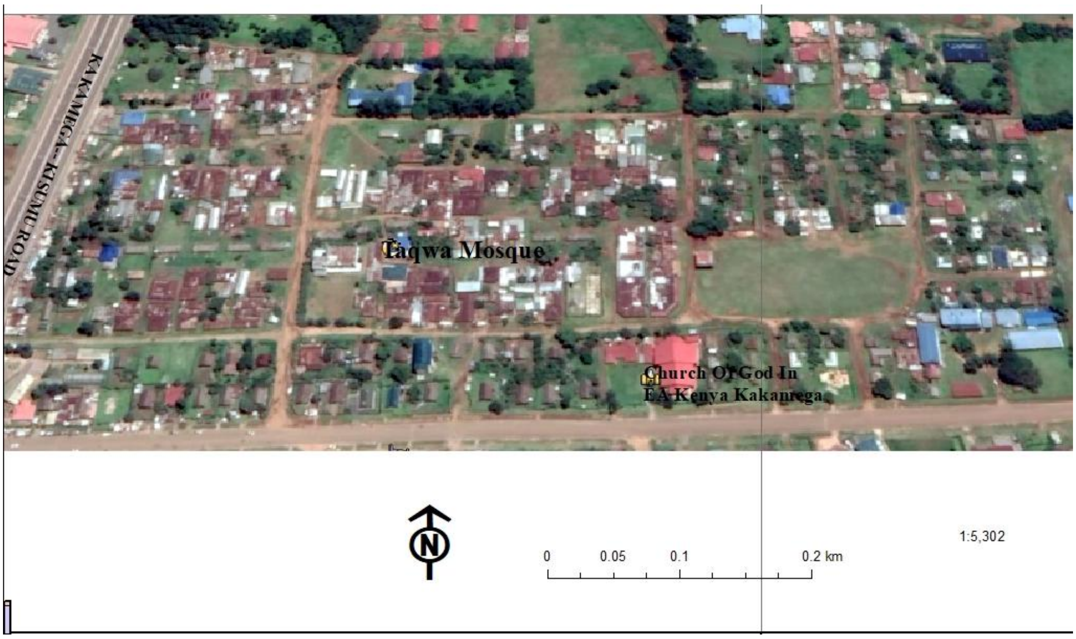

Figure 4: Satellite aerial image of Amalemba informal urban settlement

(Source: Landsat-June 2020)

3.2.1.1 Location

Amalemba informal urban settlement (Figure 4) is located in Shirere Ward situated to the South East of the old township boundary, about 3 km from the town center. It is bounded to the North by the former township boundary, to the West by the Kakamega-Mumias road, to the South by the Amalemba-Airstrip road. The informal settlement lies between the longitudes 34º45’8”E to 34º45’10”E and the latitudes 0°16’0”N to 0°16’15”N of the Equator. The informal urban settlement spans a 25 ha (0.25 km^2) portion of land between Amalemba Primary, Orthodox Church, Joy Supermarket and Taqwa Jamia Mosque. The settlement does not have any formal planning as a result of freehold tenure system. The informal settlement contains 122 households with a total population of 2596 as per the Kenya population and housing census (GoK, 2019 c). Majority of houses are of semi-permanent nature and shacks.

The informal settlement does not have a sewer line except one passing through it on the north eastern part but does not serve residents of the informal settlement.

3.2.1.2 Geology

The dominant soil in Amalemba informal urban settlement is deeply weathered, clay-loam that overlays the present sedimentary rocks. The soil is quite fertile, which explains why we have a high population density in Amalemba vis-à-vis the other adjoining areas. This soil can also support the growth of several crops for subsistence purposes. However, the soils are shallow and excessively drained and more vulnerable to erosion by runoff due to the misuse by the informal settlements.

3.2.1.3 Climate

The climate of Amalemba informal urban settlement is described in terms of precipitation and temperature. The area is characterized by very high amount of annual precipitation that ranges from 1200 mm – 2000 mm per year and which is bimodal as it occurs in two rainy seasons. The seasonal distribution shows a long period of rainfall in the months of April to June and the short period in October to December (KMWS, 2020). Consequently, Amalemba informal urban settlement receives runoff from various sources i.e. the Kakamega-Kisumu tarmac road, tarmac road from Kakamega County Referral Hospital that borders the area of study, from foot paths with undefined natural trenches within the settlement and from the iron roofed structures in the informal settlement. Mean maximum and minimum temperatures occur in April and October at 28ºC and 22ºC, respectively (MoALF, 2017).

3.2.1.4 Relief

The settlement is located at an average altitude of 1,500 - 1,700 m above mean sea level (Kuria and Mutange, 2010). The area has a very simple physiography. It lies on a shallow ridge that traverses the town in a north east/south west direction. The area gradually loses in gradient as one moves from the north to the south. The general topography of the area is generally dissected due to the shallow valleys formed by the effects of storm water from the township and can therefore be described as gentle undulating. The drainage pattern in the study area is of north-south direction, which explains why the current sewage treatment works are located near the study area. This has been due to advantage derived from the fall in gradient.

3.2.1.5 Land use

The immediate predominant land use of the study area is residential due to the short supply of houses in the town and the exorbitant rents charged. It is worth to note that these housing developments were carried out according to each developers wishes since there was no official guidance whatsoever in the form of a plan then. The dwelling units range from temporary mud-walled, semi-permanent with iron sheet roofing to very few permanent, brick or stone walled with iron sheet roofing. Most of the dwelling units are served with pit latrines except in cases of permanent houses which are connected to the sewer line that passes through the informal settlement. The roads in this settlement are mere footpaths that lead people into their respective shacks. During dry weather the paths are relatively passable but during rainy season the paths are rendered impassable. The other land use in the area is public purpose i.e. churches and a mosque which are found next to the residents’ houses. There is a sewer line to the extreme end of the informal settlement which often blocks spilling the wastes into the dwelling units.

3.3 Research Design

Quasi-experimental and survey research designs were both used for this study. A quasi-experimental study has the properties of both experimental and non-experimental studies (survey research); part of the study may be non-experimental (qualitative) and the other experimental (Ranjit, 2011). Survey research method was used to identify human and physical features that influence runoff generation, to establish effects of runoff and runoff management practices from the respondents' point of view in Amalemba informal urban settlement. The design was preferred for the study because of the need to have a holistic understanding of both technical and qualitative aspects with regard to runoff challenges and management practices in Amalemba informal urban settlement. Survey research design was also preferred for the study because it sought key informants and residents opinions on generation and management of runoff in Amalemba informal urban settlement. An experimental study was carried out in a natural environment to determine runoff discharge using the Gerlach trough setup within the informal settlements. The setup consisted of plot boundaries, soil and runoff collector at the end as illustrated in Plate 1, Plate 2 and Plate 3.

Plate 1: Plot A; Bare ground.

(Source: Author, 2020)

Plate 2: Plot B; 50% grass cover.

(Source: Author, 2020)

Plate 3: Plot C; 100% grass cover.

(Source: Author, 2020)

3.4 Target Population

The target population data for Amalemba informal urban settlement was sourced from the Kenya population and housing census, 2019. The study targeted the 122 households of Amalemba informal urban settlement with a total population of 2596 and a number of relevant professionals from the County Government who carried essential information on the problem of study drawn through purposive sampling.

3.5 Sample Size

The sample size for residents of Amalemba informal urban settlement was based on the total number of the 122 households, Kenya population and housing census (2019). According to Mugenda and Mugenda (1999) when the target population is less than 10,000 the following formula can be applied to determine the sample size.

$$n_f = \frac{n}{1+\frac{n}{N}}$$

Where:

n_f = desired sample size when the population is less than 10,000

n = desired sample size when the population is more than 10,000

N= the estimate of the population size (Mugenda and Mugenda, 1999)

Let population size be 'N'=122 households and sample size 'n'=100 households.

$$n_f = \frac{100}{1 + \frac{100}{122}} = 55 \text{ households}$$

The sample size used for residents of Amalemba informal urban settlement was 55 respondents (household heads) in addition to two key informants. Purposive sampling technique was used to select the Water Engineer and the County Engineer (Construction Works) due to their expert knowledge that could address methods and challenges of managing runoff. The choice of the sample size was influenced by the need to actually target those who had experienced the impacts of runoff in the area. The households were purposively selected based on the proximity and physical characteristics that were of interest to the study.

3.6 Data Collection

Two forms of data were collected in the study, primary data and secondary data. Diverse methods of data collection were employed at various stages of the study. These were within the confines of appropriate sampling techniques. In some cases, a single method of data collection was used while in others a combination of two or more techniques were necessary. The main techniques of data collection used were:

3.6.1 Primary data

Primary data was collected from the residents of Amalemba informal urban settlement, Water Engineer at the Ministry of water and County Engineer in charge of construction works at the Ministry of public works in the county. This was done with the help of questionnaires and interviews where residents and key informants were to give data based on the questions asked regarding runoff generation and management in Amalemba informal urban settlement.

Primary data for runoff from the three plots was collected on various dates from 10th April to 10th May 2020. At the end of rainfall on a given day, contents of the 20 litre container were allowed to settle until clear runoff water remained standing on the sludge. All runoff was then carefully siphoned into a bucket. The precise volume of water was measured using a graduated 1-litre measuring cylinder. The runoff volume was then recorded in the field note book. Table 11 shows the main characteristics of rainfall runoff observed and measured during each of the 30 events according to each type of plot and slope through April to May 2020.

3.6.2 Secondary data

Secondary data was collected from various sources including personal and institutional libraries, archives and information offices at the county level and internet services. The method provided factual and authoritative information on what other studies had done on generation and management of runoff in urban informal settlements. Secondary data on daily rainfall and temperature were collected from Kakamega Meteorological Weather Station. The secondary data was vital in analysis of rainfall trends over time with ease of re-checking for verification purposes.

3.7 Data Collection Instruments

The data for the study was collected using observation, interview schedules, photography, focus group discussion schedules and direct measurement.

3.7.1 Observation

Observation was used to obtain primary data from the sampled population on human and physical features that influence runoff generation, effects of runoff on the environment and on-site runoff management practices in Amalemba informal urban settlement. During field visits, a transect walk across Amalemba informal urban settlement was done. This provided primary information on the current runoff management and drainage systems in the informal settlement. A visual investigation of observable runoff patterns was done in the settlement during the walk. The field visit days were in the period marking onset of the long rains in March. Due to the first rains, challenges in drainage and management of runoff structures that had been constructed by the residents were observed.

3.7.2 Semi structured interviews

Semi structured interviews involve a series of open ended questions based on the topic areas the researcher wants to cover. Their open ended nature provides flexibility for the interviewer to probe the respondent's answers responses in detail (Kumar, 1999). In a semi structured interview, the interviewer poses questions from a pre-arranged list but allows the respondent to answer in his or her own words (PSI, 2010). A semi structured interview was employed in collecting qualitative in-depth data from the Water Engineer and Civil Engineer (Construction Works) in line with study objectives (Appendix V). The key informants were interviewed due to their position of management in Kakamega County and expert knowledge that could address features that influence runoff generation, effects of runoff on the environment and institutional runoff management practices in Amalemba informal urban settlement. Interview schedules were important because they helped in eliciting effective responses from the respondents particularly through observable non-verbal cues.

Some of the interview information was recorded and transcribed for analysis. The information collected formed part of primary data.

3.7.3 Questionnaires

A questionnaire is a form containing a set of questions, especially one addressed to a statistically significant number of subjects as a way of gathering information for a survey. A total of 55 questionnaires on effects of runoff and runoff management practices were designed and given out for filling by residents/households of Amalemba informal urban settlement (Appendix III). The questionnaires comprised closed and open ended questions. The main advantage of the instrument was that it allowed control by the researcher and enhanced focused responses to the research objectives hence relevancy of the data collected.

3.7.4 Focus group discussion schedule

Focus group discussions (FGDs) are a form of strategy in qualitative research in which a group of members sharing some characteristics discuss a topic of common interest. The method is suitable for large groups where it is difficult to collect data per individual (Ranjit, 2011). The focus groups were selected from Amalemba residents based on several factors; the longest stay in the area, i.e., 10 years, proximity to the drainage systems, formally built up areas, informal structures, bare ground, grassed surfaces and roads/paved areas. The cases aided the study to gain an in-depth understanding of runoff challenges, effects and on site management approaches (Appendix IV). Two focus groups were formed, one group from the upper area of the settlement and the other from the lower area of the informal settlement. Each of the two groups had six members. Through discussions the focus groups were able to draft sketches of the runoff infrastructure and also noted areas most affected by runoff events. Through the discussions the focus groups also explained the experiences of the informal settlement with regard to flooding.

3.7.5 Photography

Information about waste disposal in the field, storm drains, and structural measures of controlling runoff and associated impacts of the runoff was also captured using photography. Transect survey was conducted to obtain primary data on physical features that influenced runoff generation i.e. vegetation, land cover modifications and catchment size.

3.7.6 Carrying out experiments

Direct measurements of runoff were carried out in six established plots in Amalemba informal urban settlement depending on land gradient (slope), ground cover, soil type and land-use. The plots were two bare ground, two 50% grass cover and two 100% grass cover at 10% slope and 15% slope respectively. Measurements were used to obtain data on dimensions of drainage area, quantity of discharge and the slope of the plots. The tools utilized to obtain data on runoff are illustrated in Table 5.

Table 5: Tools for measurement of runoff discharge

	Tool	Quantity	Purpose
1.	Stop watch	1	Measure the duration of rainstorm
2.	Camera Sony W830	1	To capture land cover of plots
3.	Graduated measuring cylinder, 1000ml	1	Measurement of runoff
4.	Bevel	1	Determination of slope
5.	Levelling rods (2m length)	2	Determination of slope
6.	Gerlach trough set up	3	Collection of runoff
7.	Metal sheets (2mx0.8mx0.002m)	9	Plot boundaries to prevent splash or seepage from nearby areas
8.	Hoe & shovel	1	Making of earth banks around the plots

9.	Stainless tape measure (5m)	1	Measurement of length & width of the plots
10.	Sludge tank capacity 20 litres	1	Storage of runoff

Table 6 shows the types of data, period for which the data was collected, the category and sources of data.

Table 6: Data types, period, category & data sources

Data type	Period	Category	Data sources
Daily Rainfall	2020	Secondary	Kenya Meteorological Department
Soils data	2015- 2019	Secondary	Kakamega County Agriculture dept.
Land cover data	2019/2020	Primary	Satellite imagery
Slope data	2019/2020	Primary	Topographical map, Bevel, levelling rods(2m), stainless tape measure (5m)
Runoff data	2019/2020	Primary	Gerlach trough setup, plastic measuring cylinder capacity 1000ml
Drainage area (Plot size)	2019/2020	Primary	Stainless tape measure (5m)

Runoff collection;

Data for runoff discharge was collected for a period April 2020 to May 2020 during the long rains. The runoff setup used for the study was known as a Gerlach setup. The equipment was developed by Gerlach Morgan in 2005. It is used to collect runoff and sediment loss by utilizing simple metal gutters with a standard size of 0.5m long by 0.1m wide. About 2 or 3 troughs are grouped together across the slope (Ekwue and Samaroo, 2011). Advantages of using this method is that it is simple and cheap and ideal for sample measurements over large and small areas. The apparatus provides a reasonable assumption of erosion along both straight and curve slopes (Koster, 2013). In this study, the modified Gerlach set up consisted of plot boundaries, soil and runoff collector at the end of the plot, a hose pipe and a removable container with storage capacity of 20 litres. The runoff plot boundary was constructed to prevent water and soil from entering or leaving the plot. The boundary was constructed with 30 gauge galvanized sheet metal strips. The sheet metal dimensions were 2 m long by 1 m wide. The metal strips were held together by rebates to form water tight joints. The metal strips were then pushed into the ground to a depth of 15 cm. Finally, earth banks were packed against the outer sides of the metal strips to increase stability and prevent seepage. A runoff collector trough was made of 24 gauge galvanized sheet metal as illustrated in Plate

4.

Plate 4: Gerlach trough setup.

(Source: Author, 2020)

The collector was designed to reach across the entire 2 m width of the plot with a bottom slope of 5% to convey runoff to the tank by gravity. A sheet metal cover (1m by 0.3m) was placed on top of the collector trough to prevent rain from entering the system. A hose pipe of diameter 2.5cm (1 inch) was installed at the downslope side of the Gerlach trough to carry runoff and soil loss from the runoff collector outlet into the 20 litre collection container. The purpose of the 20 litre container was to store all the water and soil from the runoff plot. The storage capacity was set at 20 litres due to the size of the plots (1m by 2m). Measurements were taken after every rainfall event from April 2020 through May 2020. Runoff was quantified by measuring the water in a graduated measuring cylinder, (1000ml). Following each runoff measurement the collection buckets were emptied.

The data collection methods are summarized in the Table 7 below.

Table 7: Summary of data collection methods

Objective	**Data collection method**
1. Human and physical features that influence runoff	- Observation - Questionnaires - Satellite imagery
2. Rainfall and Runoff volume	- Documentary analysis - Experiment/measurements
3. Effects of runoff	- Observation - Questionnaires - Photography - Interviews/focus group discussion
4. Runoff management	- Observation - Questionnaires - Photography - Interviews/focus group discussion

3.8 Pilot Study

The pilot study was utilized to show weaknesses in the tools of research thereby making the necessary adjustments before the actual data collection procedure. These adjustments addressed the vague items identified by the respondents. Pilot studies help a researcher to reveal inadequacies in the workability of the tools (Yin, 2003). The pilot study was conducted in Amalemba settlement with respect to the qualitative and quantitative aspects of the study. The deficits in the procedures and tools of direct measurement were identified and addressed accordingly.

3.9 Data Analysis

In this study data was analyzed qualitatively and quantitatively. Thematic analysis was done on qualitative data collected from researcher's observation, interviews and FGDs. This process involved the following four steps; identification of the main themes, assigning codes to the main themes, classifying responses under the main themes followed by integrating themes and responses into the text of these findings. The results of the thematic analysis were reported in form of quotations, narrations and graphs. On the other hand, quantitative analysis included both descriptive and inferential statistical techniques. Descriptive statistics of variables complimented the use of frequencies, mean and percentages which were summarized and presented using tables, graphs and charts.

3.10 Ethical Considerations

In research, respondents participating in a study need to know its purpose and aims. The anonymity of the respondents should be protected and guaranteed by the study (Ranjit, 2011).

The ethical considerations observed included informed consent, voluntary participation and confidentiality. Informed consent and voluntary; the respondents were given a copy of the research clearance permit and the authorization letter from the County Commissioner, (Appendix A). During the interviews, delicate, personal interrogations were avoided. On anonymity, the interview schedules did not contain the identification details of the respondents. However, they were serialized to enable follow up on particular respondents when it was required. To maintain confidentiality, the raw data was exclusive to the researcher alone but was available to the supervisors on request.

CHAPTER FOUR

RESULTS

4.0 Introduction

This chapter gives a detailed account of the study findings in Amalemba informal urban settlement which are presented according to the set objectives. The main objective of this study was to assess urban runoff generation and management in Amalemba informal urban settlement. The chapter focuses on the results of the study as per the four specific objectives namely: to identify human and physical features that influence runoff generation, to determine runoff discharge, to establish the impacts of runoff on the environment and to investigate on-site and institutional runoff management practices. Some of the findings are presented in the form of tables, charts and graphs while others are given quantitatively in form of percentages.

4.1 Human and Physical Features that Influence Runoff Generation

4.1.1 Land cover in Amalemba catchment

The land use types for Amalemba informal urban settlement for the year 2020 were classified using a Digital Land Cover Classification System into six classes namely: trees, tarmac roads, grass cover, buildings, bare ground and all weather roads.

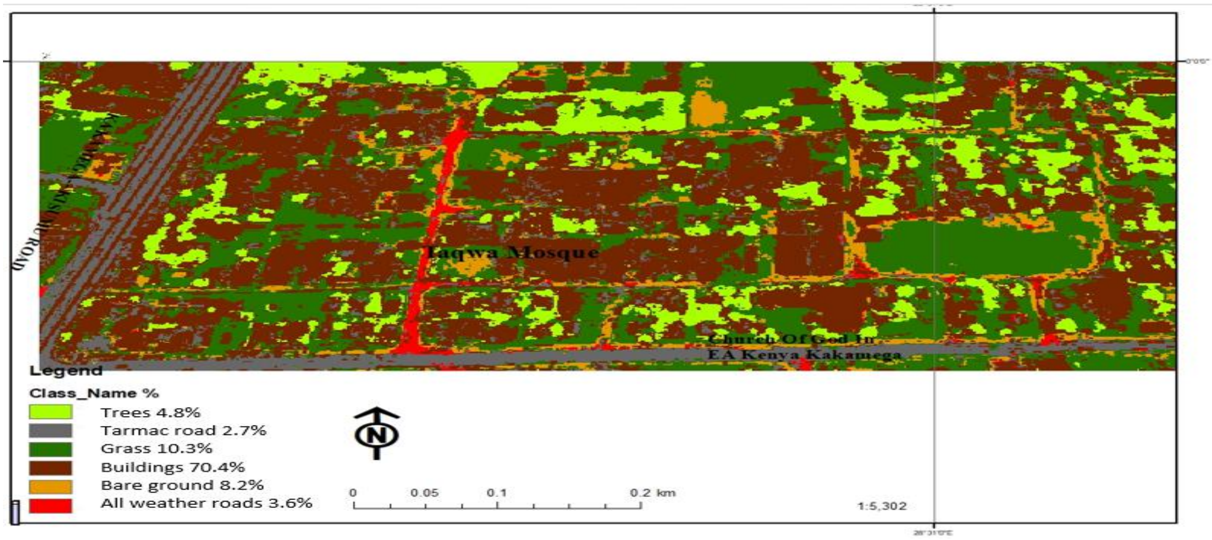

Figure 5: Land cover map of Amalemba informal urban settlement; a satellite image derived from Landsat-June 2020.

(Source: Landsat-June 2020)

Figure 5 shows the classified land use/cover map for 2020. The brown areas represented all kinds of buildings. The areas covered in light green represented trees while the green patches represented grasslands. The red colors were an indication of all-weather roads while grey areas were tarmac roads. Finally, the yellow tones indicated bare grounds. The findings are illustrated in Table 8 below.

Table 8: Land cover in Amalemba informal urban settlement

Class	Land cover/Use (%)
Buildings	70.4
Grasslands	10.3
Bare ground	8.2
Trees	4.8
All-weather roads	3.6
Tarmac roads	2.7
Total	**100**

The findings in Table 8 indicate that over 84.9 % of the Amalemba was comprised of built up area leaving a marginal 15.1% for runoff infiltration. Two thirds, (67%) of the respondents indicated that they had some form of natural vegetation close to their buildings/shacks. However, significance in controlling rainfall runoff was negligible as this vegetation was scanty. A third, (33%) of the respondents reported absence of vegetation close to their buildings. This increased surface water runoff, rate of runoff and reduced infiltration.

4.1.2 Soil characteristics in Amalemba informal urban settlement

The findings in Table 9 illustrate that the soil in Amalemba urban informal settlement had over 34% sand composition with silt and clay comprising 33% and 33% respectively (Rachilo and Michieka, 2013). The soil characteristics showed that the permeability of the soil in Amalemba informal urban settlement was moderately slow indicating a probability for high runoff rates.

Table 9: Soil characteristics in Amalemba (Rachilo & Michieka, 2013)

Parameter	Soil characteristic
Soil type	Eutric nitisol
Soil texture	Clay-loam
Sand	34%
Silt	33%
Clay	33%
Total	**100%**

The soil classification data for this study was then plotted in the soil textural classification triangular diagram as illustrated in Figure 6 affirming the classification of soil in Amalemba informal urban settlement as clay loam.

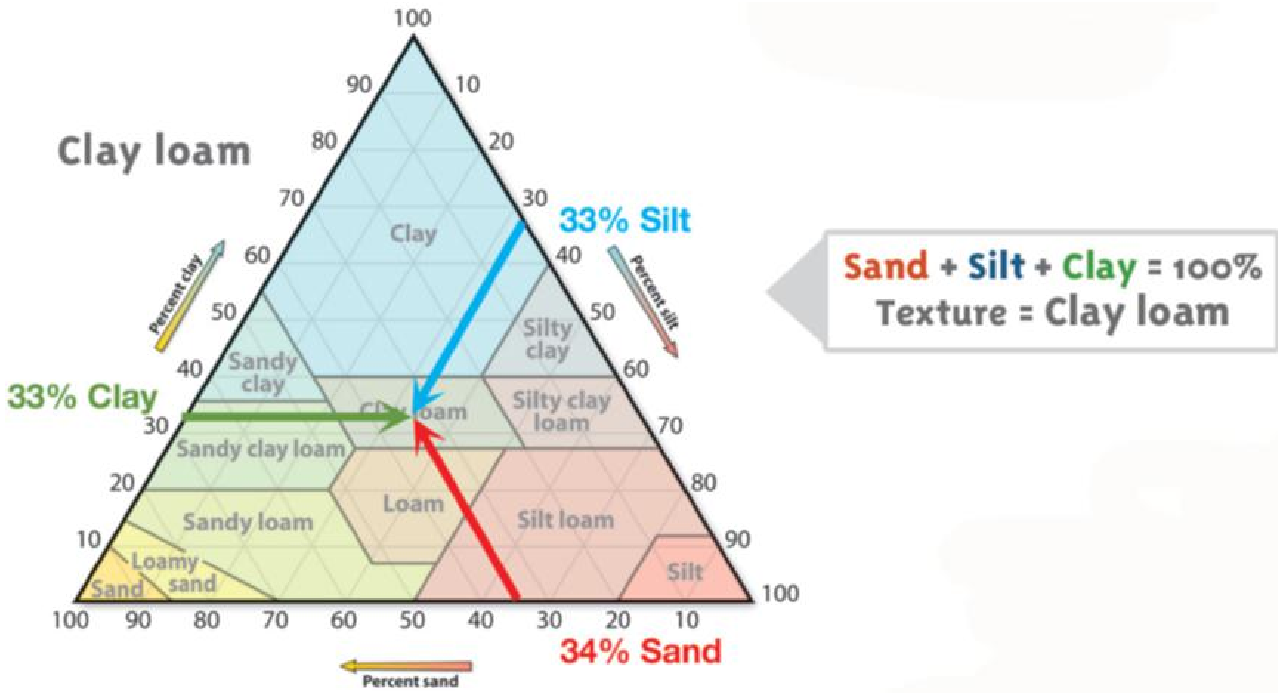

Figure 6: Soil textural classification triangle USDA, 2020.

(Source: Landsat-June 2020)

4.1.3 Slope characteristics of Amalemba informal urban settlement

The slope analysis was generated using computer software (Arc GIS) to indicate the ground elevation of the area. Amalemba informal urban settlement digitized contour map is illustrated in Figure 7.

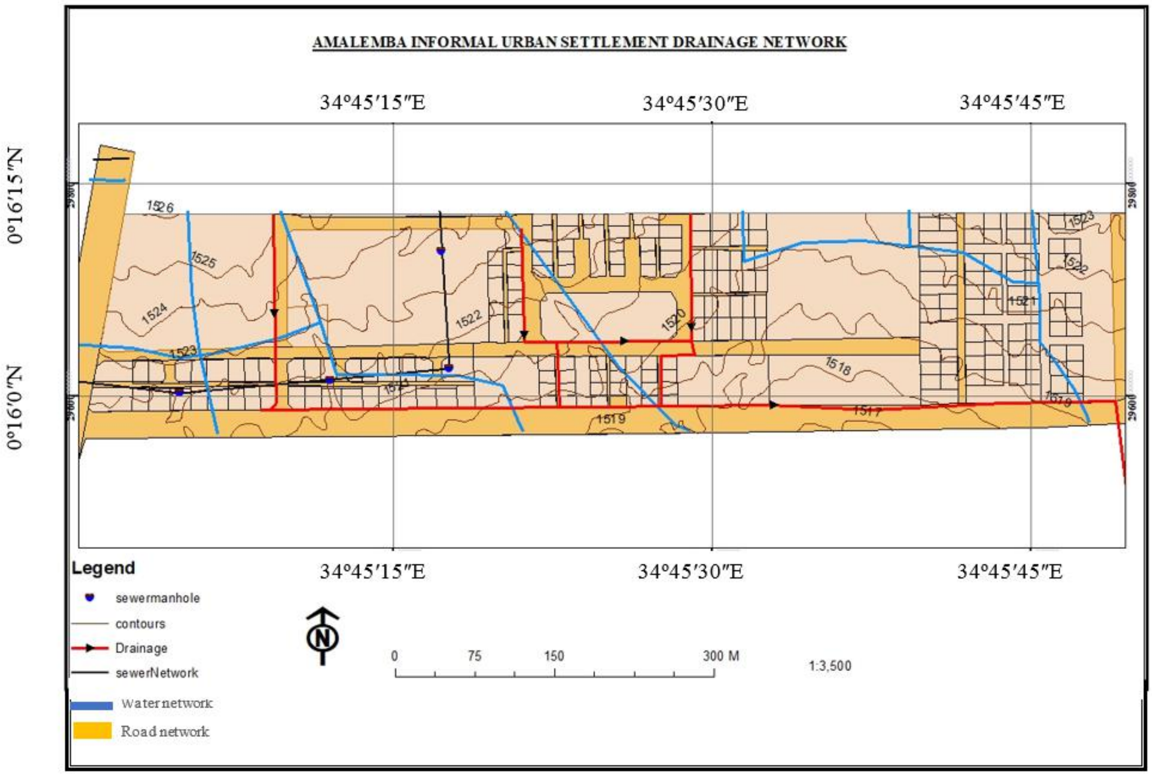

Figure 7: Digitized contour map of Amalemba informal urban settlement; a satellite image derived from Landsat-June 2020.

(Source: Landsat-June 2020)

The topography of the study area gradually increases in gradient as one moves from the north-west to the south-east of the settlement. High slopes on the north-western part of the study area may cause quick overland flow thus generation of more runoff and erosion. As a result, the general drainage pattern in the study area is of north-south direction. In the north-western area of the settlement, slopes are larger than the rest of the settlement. However, the area has a few isolated patches of raised ground to the west as illustrated by the contours; 1532 m to 1520 m above sea level to the west against 1524 m to 1517 m above sea level to the east. The general relief of Amalemba informal urban settlement is illustrated as a cross section in Figure 8.

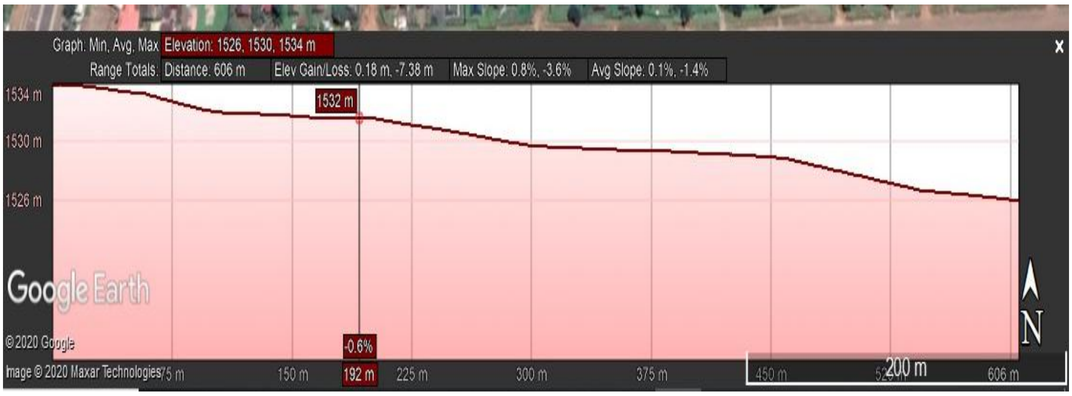

Figure 8: A cross section of Amalemba informal urban settlement; a satellite image derived from Landsat-June 2020.
(Source: Landsat-June 2020)

4.2 Determination of Runoff Discharge in Amalemba Informal Urban Settlement

4.2.1 Monthly rainfall data in Amalemba

Amalemba informal urban settlement being part of the modified equatorial climate of the Lake Victoria Basin receives an annual rainfall of between 1300 mm – 1800 mm (Kibuuka and Karuggah, 2009). Rainfall data from the Meteorological department gave the rainfall for Amalemba informal urban settlement for the period 2017 to 2019 as shown in Figure 9.

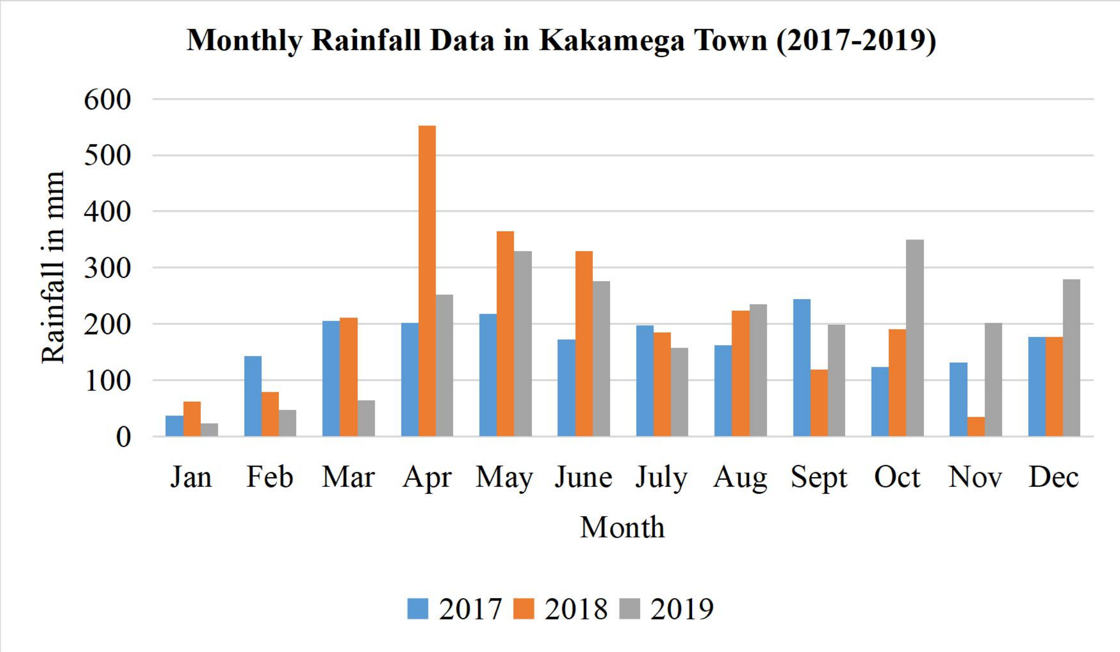

Figure 9: Monthly rainfall in Kakamega town (2017-2019).

(Source: GoK, 2020 d)

There are two heavy rain seasons during a year. These are the long rains season, April - June and the short rains season, October – December. The maximum amount of rainfall received over the long rains season, April to June was 553.5 mm in the period 2017 to 2019. The maximum monthly rainfall received over the short rain season, October to December in the period 2017 to 2019 was 349.5 mm. The average amount of rainfall received in the months of April, May and June was 335.9 mm, 303.6 mm and 241.3 mm respectively. During the short rains season, the months of October, November and December, Amalemba informal urban settlement received 221 mm, 122.5 mm and 211 mm of rainfall respectively. Amalemba informal urban settlement received an average amount of rainfall of 576.4 mm in the period between the two rain seasons (July, August and September). The average amount of rainfall received in January, February and March was 40.9 mm, 89.3 mm and 156.6 mm respectively. The total amount of rainfall received annually during the long rain season between April and June (2017 to 2019) was 2642.4 mm (average 880.8 mm) while the total amount of rainfall received over the short rain season October to December was 1663.6 mm (average 554.5 mm). The exact dates of the seasons differ every year but, the rain in the long rainy season was much heavier than that in the short rainy season. Amalemba informal urban settlement received the highest amount of rainfall in the month of April, average 335.9 mm. In the period 2017 to 2019, data from the Metrological Department showed that Amalemba informal urban settlement received an average of 2298.5 mm of rainfall annually. The mean monthly rainfall amount received in the period 1st January to 11th June 2020 is illustrated in Figure 10.

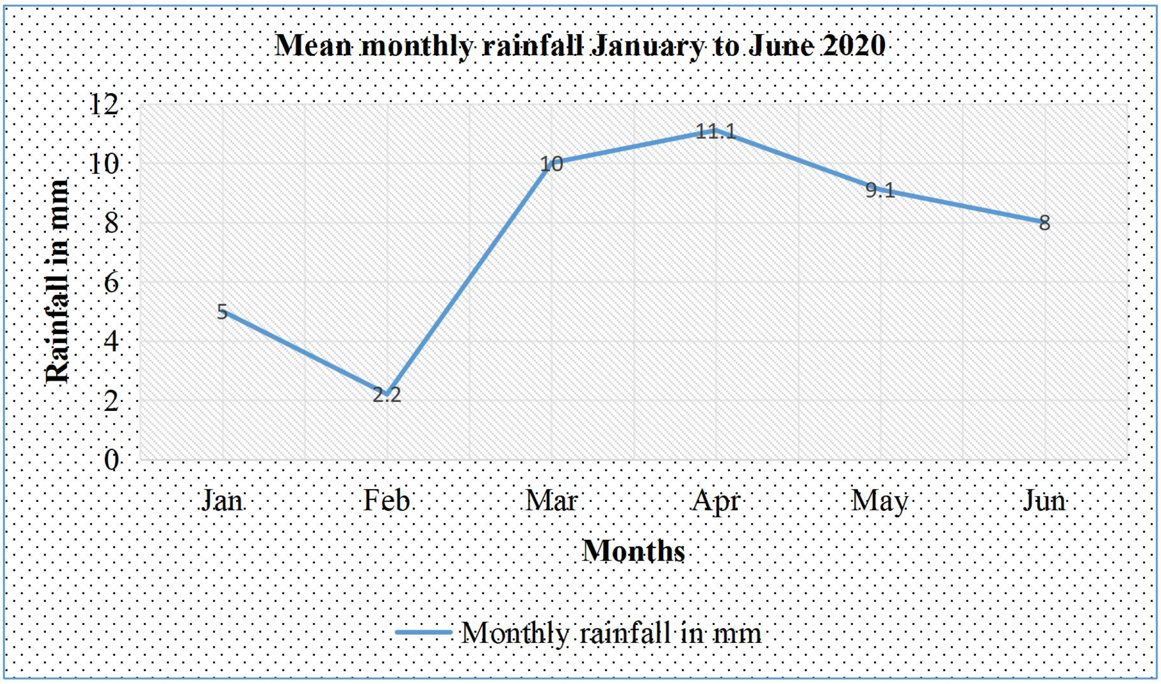

Figure 10: Mean monthly rainfall January to June 2020.

(Source: GoK, 2020 d).

According to the data from meteorological department, the amount of rainfall recorded between January 2020 and 11th June 2020 was 1157.6 mm. The highest amount of rainfall received was in April 333.3 mm (2020). The maximum amount of daily rainfall received in April was 47.8 mm on 25th followed by 44.4 mm on 22nd and

39.1 mm on 29th. The second highest amount of rainfall received was in May 273.5 mm (2020). The maximum amount of daily rainfall received in May was 50.3 mm on 3rd followed by 32.2 mm on 21st and 25.3 mm on 30th. The lowest amount of rainfall recorded was 61.9 mm in February 2020. Drawing comparisons between rainfall received in April-June 2017-2019 (Figure 13) and March-May 2020 (Figure 14), it was evident that high amount of rainfall was received during the months of April and May.

4.2.2 Rainfall and runoff discharge

Rainfall data was collected from Kakamega meteorological station to determine the relationship between amount of rainfall and runoff discharge. The data for daily rainfall and average runoff for each surface was plotted on a scatter plot from which a trend line was developed. Average runoff for each surface was obtained by summing runoff volume for the two slopes and then dividing by two. The rainfall-runoff relationship for Amalemba informal urban settlement indicates an approximate linear relationship between rainfall and runoff volume for the three plots. The results of the scatter plots are summarized in Figure 11.

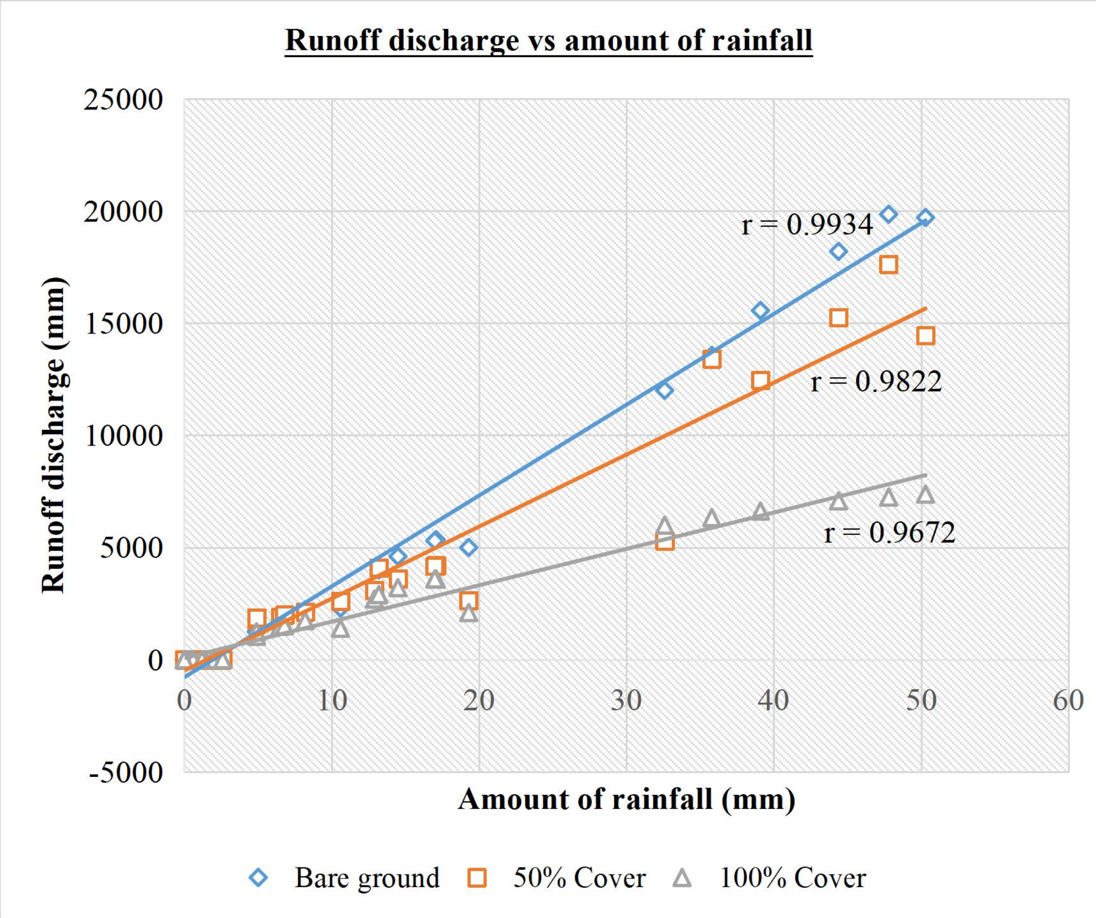

Figure 11: Daily rainfall vs average runoff

(Source: GoK, 2020 d).

The data on daily rainfall and runoff discharge volume for each plot was also analyzed using regression. The results presented in Table 10 show that all the three plots produced a p-value of less than 0.05 indicating a significant relationship between rainfall and runoff discharge.

Table 10: Correlation between rainfall and runoff discharge

Plot type	Pearson correlation, r	p-value	Confidence level	Alpha, α
Bare ground	0.9934	8.0×10^{-30}	95%	0.05
50% Grass cover	0.9822	2.2×10^{-22}	95%	0.05

100% Grass cover	0.9672	2.1×10^{-24}	95%	0.05

4.2.3 Measurement of runoff discharge

Table 11: Runoff volumes for various rainfall events at different slopes

		Runoff volume (mm^3)					
		Bare ground		**50% cover**		**100% cover**	
Date	**Rainfall (mm)**	**10% Slope**	**15% Slope**	**10% Slope**	**15% Slope**	**10% Slope**	**15% Slope**
10/04/2020	0.5	0	0	0	0	0	0
11/04/2020	0.4	0	0	0	0	0	0
12/04/2020	10.6	2300	3946	1730	3163	1400	2600
13/04/2020	19.3	5000	6920	2764	6082	2100	2650
14/04/2020	12.9	3000	4843	3000	3857	2700	3100
15/04/2020	0.6	0	0	0	0	0	0
16/04/2020	13.2	4000	5316	3720	4215	2900	4100
17/04/2020	32.6	10590	12339	8291	12113	6000	5300
18/04/2020	14.5	4603	5805	3709	4574	3211	3611
19/04/2020	4.9	1257	1637	1098	1226	1042	1776
20/04/2020	2.3	0	0	0	0	0	0
21/04/2020	0.6	0	0	0	0	0	0
22/04/2020	44.4	16193	17225	11638	15560	7077	7257
23/04/2020	1.4	0	0	0	0	0	0
24/04/2020	1.4	0	0	0	0	0	0
25/04/2020	47.8	16845	17650	12384	17621	7246	7620
26/04/2020	0.2	0	0	0	0	0	0
27/04/2020	1.9	0	0	0	0	0	0
28/04/2020	35.8	13557	14853	9542	11558	6330	7407
29/04/2020	39.1	15558	17130	10976	13780	6622	7464
30/04/2020	17.1	5344	6830	4396	5316	3590	4197
02/05/2020	4.9	1240	1694	1105	1236	1059	1876
03/05/2020	50.3	18340	19700	13854	19872	7377	7600
04/05/2020	6.5	1679	2332	1513	1848	1491	1897
05/05/2020	2.6	0	0	0	0	0	0
06/05/2020	8.2	2210	2719	1798	2188	1739	2135
07/05/2020	0.6	0	0	0	0	0	0
08/04/2020	17	5301	6530	4519	5694	3602	4167
09/04/2020	1.2	0	0	0	0	0	0
10/05/2020	6.8	1879	2342	1627	1541	1511	1997
Average	**13.3**	**4297**	**4994**	**3255**	**4381**	**2233**	**2558**

Table 11 shows the values of runoff volume for three different surfaces. Daily rainfall events exceeding 4.9 mm per day represented suitable events for generating surface runoff while rainfall events below 4.9 mm did not generate runoff from the three experimental plots. The number of rainfall events exceeding the 4.9 mm were measured for Amalemba informal urban settlement. The highest daily amount of rainfall received throughout the data collection period was on 3rd may 2020 (50.3 mm). This positively corresponded to the high runoff generated at the three plots in respect to the different slopes; 10% slope bare ground (18340 mm^3), 50% cover (13854 mm^3) and 100% cover (7377 mm^3) while at 15% slope bare ground (19700 mm^3), 50% cover (19872 mm^3) and 100% cover (7600 mm^3) respectively compared to the other dates.

4.2.4 Runoff with respect to slope and ground cover

Two parameters; slope and grass cover were found to influence runoff volume generated on bare surface, 50% grass covered surface and 100% grass covered surface. On average, runoff discharge was higher for bare ground compared to vegetated surface. The mean runoff volume for the steeper slope (15%) was in each case greater than the values for the gentle slope (10%) while higher precipitation levels generally caused more runoff across the three surfaces. Additionally, for 10% slope, bare ground generated 1.92 more runoff than 100% cover and 1.32 more runoff than 50% cover while the 50% cover plot generated 1.46 more runoff than 100% cover plot. A steeper slope (15%) produced higher average volume of runoff than a gentle slope (10%): on bare ground, the 15% slope produced 1.16 times more runoff volume, on 50% cover the steeper slope generated 1.34 times more. Similarly, on 100% cover, the

15% slope produced 1.15 times more runoff than the gentle slope as illustrated in Figures 12, 13 and 14.

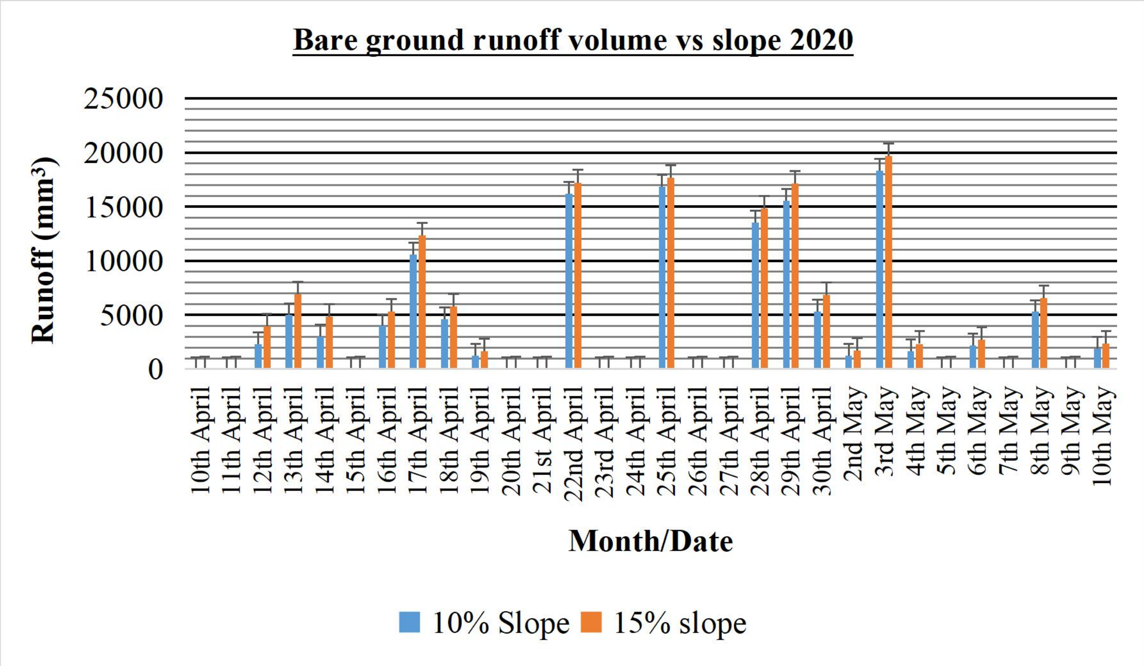

Figure 12: Runoff volume on bare ground at 10% and 15% slope.

(Source: GoK, 2020 d).

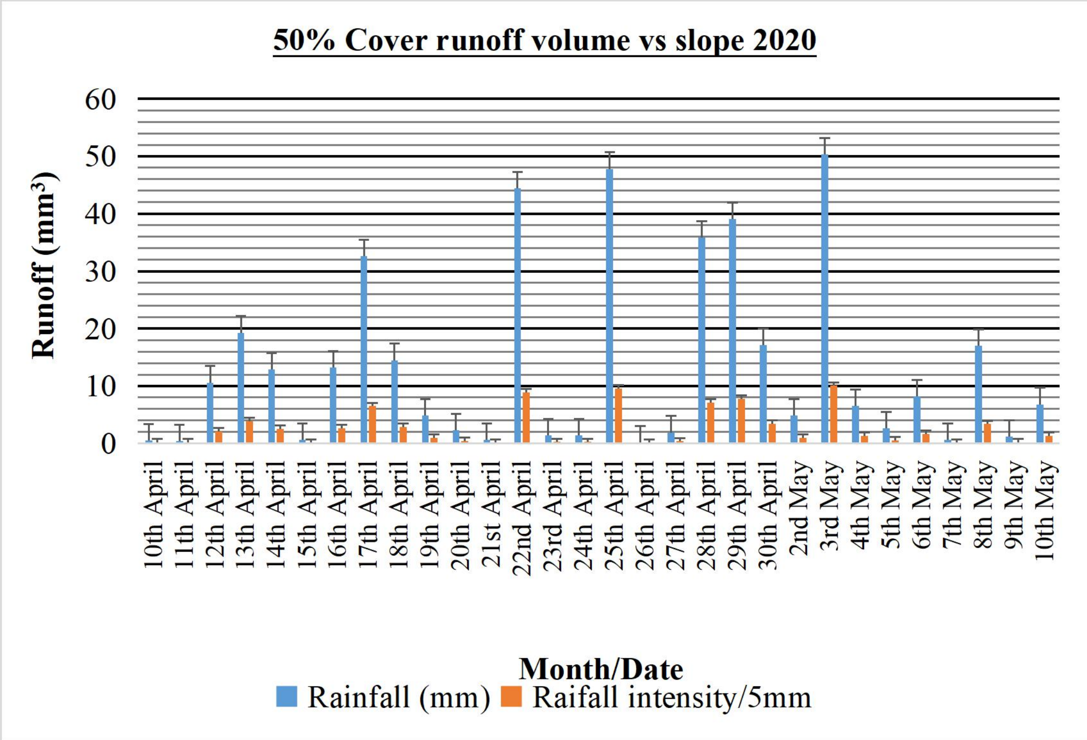

Figure 13: Runoff volume for 50% cover at 10% and 15% slope.

(Source: GoK, 2020 d)

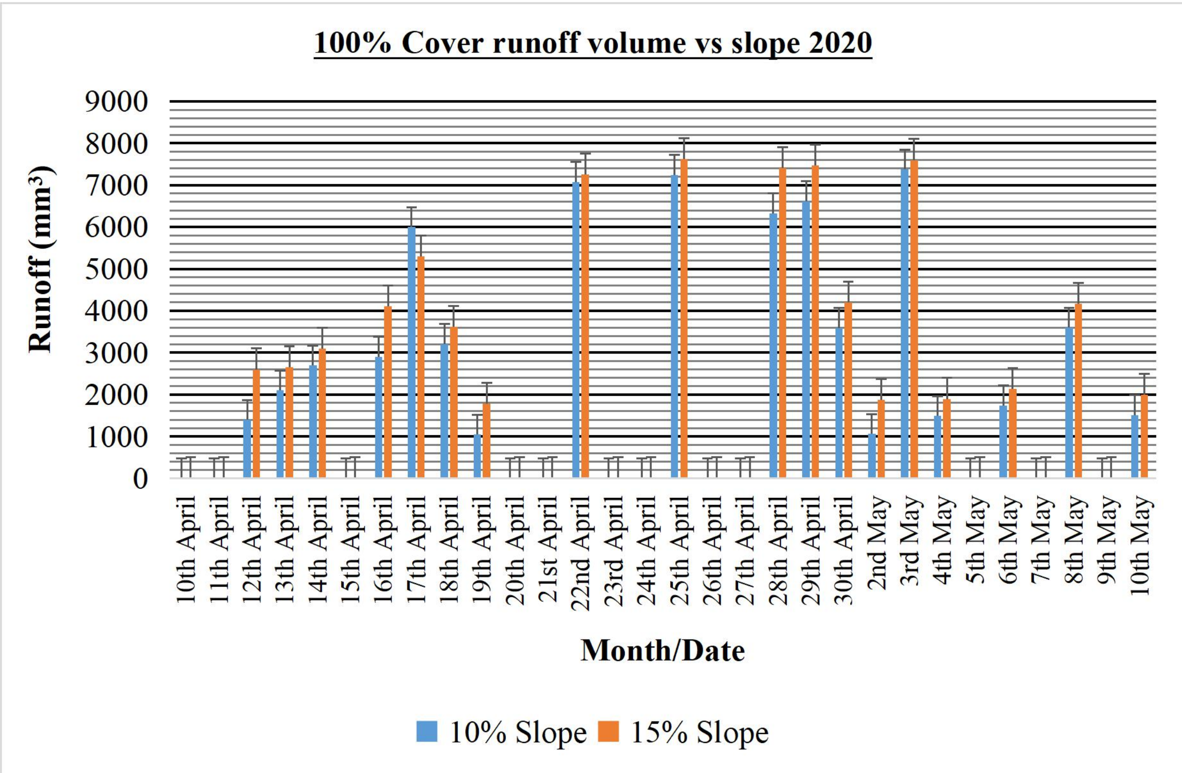

Figure 14: Runoff volume for 100% cover at 10% and 15% slope.

(Source: GoK, 2020 d)

4.3 Effects of Runoff in Amalemba Informal Urban Settlement

4.3.1 Flooding

The respondents concluded that the main cause of flooding was inadequate drainage control and management in the informal urban settlement of Amalemba. It has also been found from personal observations that drainage channels have not been supplied or they are blocked in most parts of the settlement. Blocking stopped water from the settlement from flowing into drainage channels. Of the 55 sampled respondents, 43 (78 percent) agreed that flood severity was consistently high and humiliating as it rained, with 8 (15 percent) undecided and 4 (7 percent) unsure about this problem. The results are shown in Figure 15.

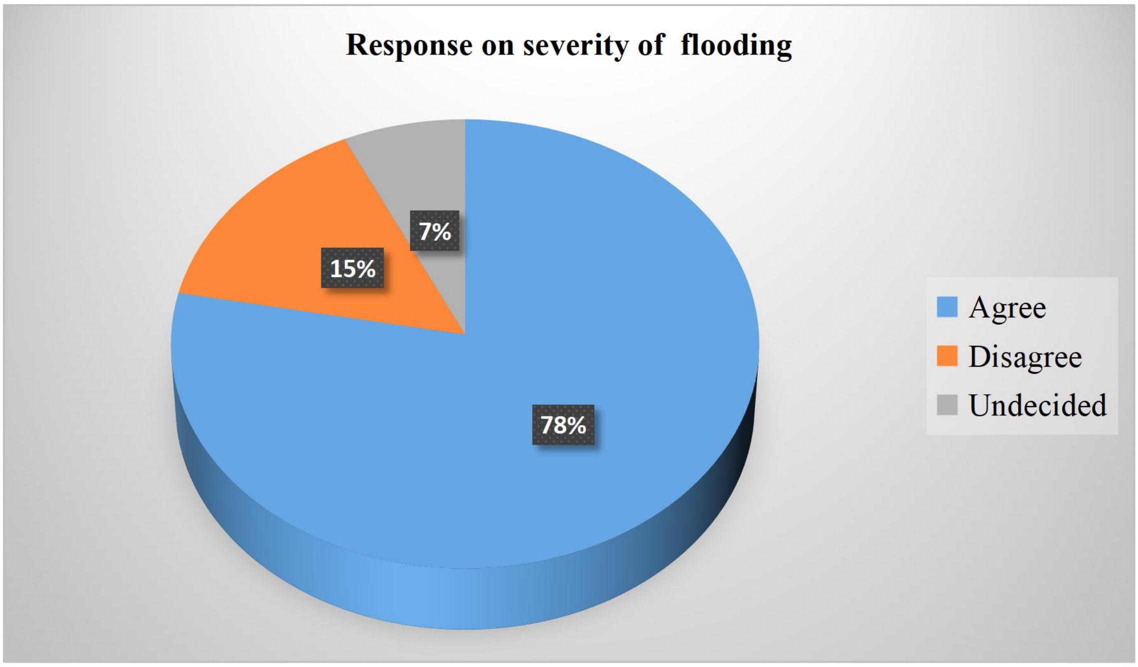

Figure 15: Perceptions on severity of floods to residents of Amalemba informal urban settlement due to blockage of drainages.

(Source: Author, 2020)

Flooding was one of the main threats to Amalemba residents residing in the lower region of the settlement. The impacts of flooding were great on the settlement due to the limited surface for water infiltration, the County Engineer observed:

> The informal settlement is surrounded by a high density of built up areas, (residential, pavements, parking lots, sidewalks) has reduced seepage areas and every time it rains it can kill. Runoff that flows into Amalemba (low point) comes from three main roundabouts in Kakamega Town which flows into the drainage that parallels the Kakamega-Kisumu main road (County Engineer, personal communication 2020).

Transportation was one of the infrastructure which was heavily impacted by the floods. Whenever floods occurred, traffic was affected and the roads were made impassable. The impact of the flood on the informal settlement transport facilities was agreed to by 52 (94.67 percent) of the respondents, 2 (3.66 percent) felt otherwise and 1 (1.67 percent) were undecided. The photograph shows the floods in the informal settlement in Plate 5.

Plate 5: A flooded road in Amalemba informal urban settlement disrupting transportation services.

(Source: Author, 2020)

Flooding in Amalemba informal urban settlement has caused structural damage to buildings. These include an absolute collapse of buildings as shown by Plate 6 and the display of foundations, humidity and confined water spaces. This problem persisted in the entire settlement. The respondents reported that they suffered a multitude of problems with their accommodation's structural fitness. 48 respondents (88%) all admitted that they had structural damage of some kind, e.g. partially crashed walls while 6 (10.33%) reported that the buildings were structurally damaged. There was no decision on the matter by one respondent (1.66%).

Plate 6: Structural damage to a house in the informal settlement due to flooding.

(Source: Author, 2020)

In an interview, one resident stated effects of flooding to the residents of Amalemba informal settlement as;

> …, destruction of houses (mostly mud walled), blocking of waterways, contamination of drinking water sources. The water becomes dirty and acquires a bad smell. Those who rely on piped water face the risk of waterborne diseases as the waste in runoff flows on top of the pipes, some of which are leaking.

> Open drainage channels are potential sources of infection and disease, especially to our children who play in them (Village elder, Personal communication 2020).

Loss of property and personal belongings during floods is associated with structural damage to houses. Around 14 (24.66%) reported losing their property because of runoff, while 40 (72.6%) said they never lost their personal property because of floods. There was no decision on the matter by 1 (2.74%) respondent.

Representatives reported that their workplace is continuously flooded and vulnerable to stress and depression. Floods also contributed to increased physical and emotional discomfort and vulnerability to psychiatric illnesses leading to anxiety, depression and apathy. Most of the respondents 52 (94%) agreed that living in a deteriorated environment made them suffer from stress, melancholy and shame, while 2 (4%) had no opinion on the matter, and 1 (2%) were undecided on the topic.

Physical disorder was a concern related to mental stress. It is understood that floods typically leave stagnant pools of water behind. This serves as breeding grounds for many mosquito species, and the people of Amalemba have known this fact. Around 38 (69%) of the respondents agreed to the high incidence of malaria in the surrounding area as a result of flooding, while 15 (28%) agreed and 2 (3%) were undecided on this problem. Information from Amalemba's informal health centers also revealed that most patients had amoeba, typhoid, cholera, bilharzia, malaria and dysentery (Ochunge and Inyanji, 2019).

The study also showed that very few residents of Amalemba informal urban settlements had lost livelihoods and their profits as a result of flooding. Around 3 respondents (6.33%) agreed that flooding led to damages to livelihoods and income loss, while 51 (92%) did not agree, whereas 1 (1.66%) were unsure. This is because people have mastered the technology to defend their wares against the ravages of rainfall over the years. Table 12 summarizes the consequences of floods.

Table 12: Perception of the impact of flooding by respondents

Variables attributes	Agree	Disagree	Unsure	Total
The amount of floods is excessive every time it rains	43 78%	8 15%	4 7%	55 100%
Transportation is disrupted	52 94.67%	2 3.66%	1 1.67%	55 100%
Physical damage to houses	48 88%	6 10.33%	1 1.67%	55 100%
Loss of properties and other household items	14 24.66%	40 72.6%	1 2.67%	55 100%
Stress from living in damp houses and in degraded environment	52 94%	2 4%	1 2%	55 100%
Incidence of diseases in the settlement	38 69%	15 28%	2 3%	55 100%
Loss of livelihoods and other means of income	3 6.33%	51 92%	1 1.67%	55 100%

4.3.2 Mini landslides

From focus group discussions and key informant interview of the Water Engineer, it was established that the risk level of mini landslides was very high over the months of March to May in the low lying areas of Amalemba informal urban settlement due to the intense rainfall over the long rain season as exemplified in Plate 7. It was also established that the risk level is lowest between January and February because of the small amount of rainfall received in the two months. In severe situations during the heavy rains (March-June), the runoff caused mini landslides. Mini landslides had adverse effects on human beings and their property. The movement of large amount of soil destroyed vegetation downhill and property.

Plate 7: Mini landslides behind Little Home Area at Amalemba.

(Source: Author, 2020)

4.3.3 Soil erosion

A transect walk in the north-south direction within the Amalemba informal urban settlement aided in collection of graphic evidence on soil erosion. Runoff caused soil erosion and swept away soils and dumped silt on neighboring farmlands which were unsuitable for plant growth. Eroded surfaces also had depressions which formed into pools of stagnant water that flooded on the gentler slopes/lower parts of the informal settlement. Plate 8 illustrates gully erosion caused by runoff in Amalemba informal urban settlement. The image shows substantial erosion of soil, formation of rills and gullies. Overall erosion had led to rills and gullies that were growing gradually head-wards towards built up areas.

Plate 8: Gully erosion effects in Amalemba informal urban settlement.

(Source: Author, 2020)

Supporting findings from similar studies affirm that there is a significant relationship between rate of runoff and soil erosion. Runoff water detaches soil particles by the energy of the flowing runoff. The soil materials are transported by suspension, solution, saltation or rolling larger particles (Oxford Univesity, 2018). The forms of erosion resulting from the transporting effects include rill, sheet and gully; these effects of runoff cause great damage (FAO/UNESCO, 2006).

4.3.4 Solid waste disposal

Further, photographic evidence and observation during fieldwork revealed that in Amalemba informal urban settlement, there was no formal refuse collection and disposal, a situation that contributed to the dumping of refuse in non-designated areas. Inadequate garbage removal services led to major environmental problems. Refuse was disposed close to the dwelling units and surrounding earth streets. This accumulated waste got into the open drains blocking them hence reducing the flow capacity of runoff as illustrated in Plate 9.

Plate 9: Refuse dumped close to dwelling units in Amalemba informal urban settlement.

(Source: Author, 2020)

The situation was attributed to water disposal practices by the residents. A majority 37 (67%) respondents poured waste water on the ground, 10 (19%) into open channels between structures and open drains in front of the structures while 8 (14%) drained water into a cesspool. This unconventional disposal of solid waste accounted for adverse effects experienced by residents as illustrated in Figure 16.

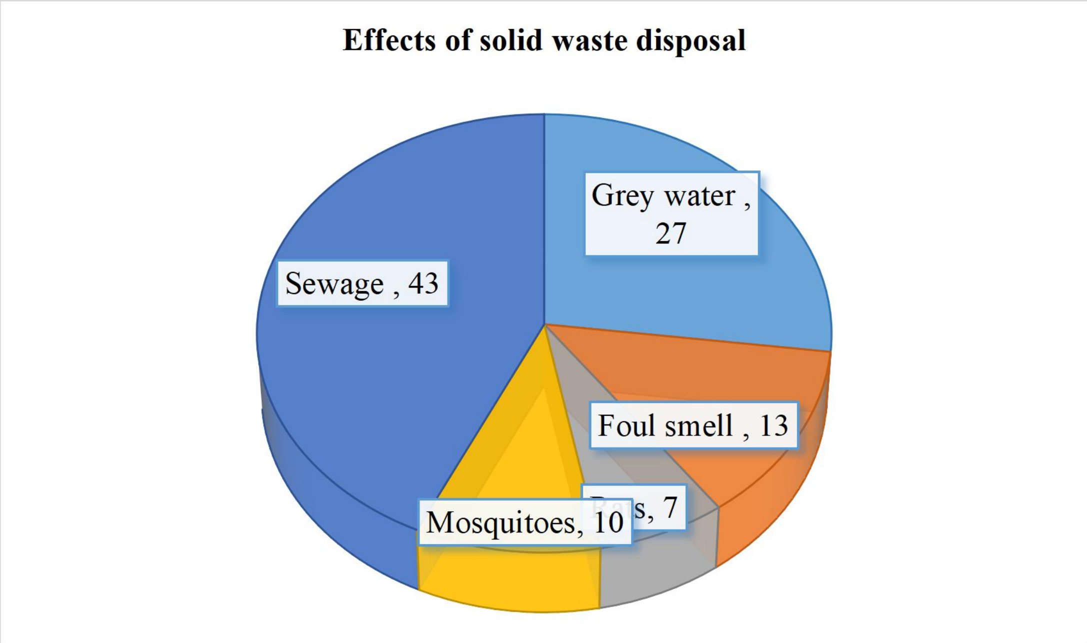

Figure 16: Adverse effects experienced by residents due to unconventional disposal of solid waste in Amalemba informal urban settlement.

(Source: Author, 2020)

The views in Figure 25 were affirmed by one resident during an interview:

> …., people in this area throw off rubbish in different ways, on the farm, dustbins, open compost heaps. The county council does not collect the waste or inform residents on how to dispose the waste. We dispose rubbish in any manner the house owners see fit. Some litter is burnt but most of the litter is left lying around the compounds, a practice that is detrimental to health. Runoff cause injuries to residents of Amalemba informal urban settlement who wade through the waters. The injuries also result from metallic items such as nails and broken bottles carried by the raging waters in the open drains (Jane, Personal communication 2020).

4.3.5 Rainwater effect from the roof

Field observation results and informal interviews revealed that the residents of Amalemba informal urban settlement rarely harvested rainwater; over 83% of the observed shacks lacked means of harvesting water. During focus group discussions; it emerged that the situation was attributed to two key factors; the length of the roofs overhang in many of the shacks were too short to support a gutter to harvest rainwater and second, the roofs were too old with a lot of rust which would potent a health risk to consumers of the harvested water as shown in Plate 10.

Plate 10: Roofs without gutters in Amalemba informal settlement.

(Source: Author, 2020)

The traditional galvanized metal roofing contributed great concentrations of runoff in Amalemba informal urban settlement. Roofs collected atmospheric deposition and transported it to the drainage system which also caused blockage of the open drains.

4.4 Runoff Management Practices

Findings from interviews with key informants and FGDs with residents revealed that two approaches were used to mitigate the adverse effects of runoff in Amalemba informal urban settlement. On-site runoff management was utilized by the residents own initiative while institutional runoff management was a formal approach by the County government. Each of the two approaches had its own strengths and limitations, but more crucial was the complementary interaction of the two strategies in the management of runoff.

4.4.1 On-site runoff management in Amalemba informal settlement

This segment describes acts that drain and control the runoff of Amalemba residents in their stands. These initiatives included deliberate runoff control activities to mitigate flood threats. Nevertheless, certain initiatives had a positive effect, rather than solely geared at runoff control. The shack or stand level was all weighed. The runoff management actions worked in four key ways: barrier, runoff channel/path, temporary storage or increased runoff penetration. From field observation, the study identified several methods that residents in Amalemba used to mitigate the quantity and effects of runoff as illustrated in Table 13

Table 13: Onsite management practices

Residents' approach	Frequency	Percentage (%)
Open drains	22	40.0
Vegetation filter	19	34.6
Earth banks	8	14.5
Old tires & cement bags	4	7.3
Detention ponds	2	3.6
Total	**55**	**100.0**

4.4.1.1 Digging of detention ponds

Field observation demonstrated that detention ponds were used to collect and infiltrate runoff to the underlying soils. The control of runoff volume using detention ponds was cited by residents during focus group discussion as one of the local methods that they used. The detention ponds provided temporary storage of runoff and quantity management by storing it momentarily, and then discharging it gradually to lessen downstream flooding.

In an interview, one resident observed that;

> …the rain water is a major problem in this area especially in March to June. In order to avoid the destruction of my house and vegetable farm I normally dig a ditch using a *jembe* (hoe) to reduce pooling of water around the house (Omar, personal communication 2020)

Plate 11 illustrates a detention pond dug around Amalemba primary a higher ground of the settlement by Amalemba informal urban settlement residents to control runoff.

Plate 11: A detention pond near Amalemba Primary to control the flow of runoff from the upper catchment into the informal settlement.

(Source: Author, 2020)

4.4.1.2 Use of open drains

Field photography was used to demonstrate how open drains were used by residents to manage runoff in Amalemba informal urban settlement. Open drains were used as an alternative to closed pipe systems which provided opportunities to reduce runoff velocity and promote infiltration as illustrated in Plate 12. Using a stainless tape measure, it was established that the open drains had an average depth of 1 m and average width of 1.5 m. They had contrasting vegetation cover properties in different locations within the settlement ranging from bare ground to vegetated ones.

In an interview, the County Engineer in charge of construction works stated:

> …the vegetated drains reduce the time it takes runoff to reach the receiving stream by slowing velocity of runoff and providing some infiltration. Open drains also provides a low cost alternative to enclosed pipe system which offers some water quality benefits if properly designed (Adeya Stanley; County Works Engineer, personal communication 2020).

Plate 12: Open drains in Amalemba informal urban settlement as an alternative to enclosed pipe system.

(Source: Author, 2020)

4.4.1.3 Vegetation filter

Green infrastructure was used to manage runoff in the areas where they were grown, although interviews with residents revealed that runoff management was not the primary purpose of planting the vegetation. Findings from the field observation demonstrated that the vegetation types included grass filter strips, vegetables and flowers. Vegetated areas provided a filtering area for runoff besides increasing infiltration into the soil. Plate 13 illustrates the use of vegetation as a filter to runoff debris and as a means of reducing runoff velocity in the settlement. Most of the vegetation filters comprised vegetable gardens. The use of recycled mosquito nets on the small gardens was a common practice in the settlement. Most of the residents used the nets to protect the crop from invasive pests and chicken destroying the crop.

Plate 13: Vegetation filter with recycled mosquito nets in Amalemba informal urban settlement.

(Source: Author, 2020)

In one of the focus group discussion with the residents, a respondent gave another perspective on the immediate use of the vegetated areas;

> ....boundaries of the plots are marked by planting of trees in line, by flowers, or by use of mosquito nets. Apart from that, some of the plants like Aloe Vera are medicinal, they serve as a fence and make the appearance of my compound beautiful (Mwaserera, personal communication 2020)

4.4.1.4 Heaping soil against the base of the shack

To avoid runoff infiltration into the shack from under the walls, most of the residents strengthened the wall base of their shacks seasonally. Plate 14 shows that the method of enhancing shacks consisted of laterite or mud heaping against the wall base, packing stones and tough materials to reinforce the wall base.

Plate 14: Heaping mud on shack base for stability in Amalemba informal settlement.

(Source: Author, 2020)

The stability of the shacks in the case of wind-storm during rainfall is increased by this technique. These enhancements were usually made when the long rain season was about to or had just began in the Month of March.

4.4.1.5 Use of old vehicle tyres and cement bags

From the focus group discussions it was established that worn out vehicle tyres were arranged to form a base for the cultivated plots in Amalemba informal urban settlement. Cement bags were used to form a retaining wall as well as act as footpath through the settlement as illustrated in Plate 15. The footpath was used to prevent runoff from flooding the shacks as well as an obstacle to prevent the cultivated area from being filled with water. As observed by one of the residents, these measures were overwhelmed by excessive volume of runoff that was generated in the informal settlement.

Plate 15: Cement bags filled with soil used to control runoff in Amalemba informal urban settlement.

(Source: Author, 2020)

4.4.2 Institutional Runoff management

Amalemba informal settlement has benefited from the Kakamega County Government residential upgrade interventions. However, the interventions have had very minimal strategies in terms of runoff management.

4.4.2.1 Street sweeping

The County government undertakes regular sweeping of open market areas, pavements and sidewalks in order to remove accumulated debris, sediments and trash materials from the environment. Lorries later come to carry the refuse from the selected parts in the settlement to the ultimate destination. In spite of this arrangement, some of the residents still dumped waste close to the open ditches and other unsuitable sites. Such action blocks the free passage of runoff through open trenches and ditches.

In an interview, the County Engineer in charge of construction works stated:

> …, The County has sub-contracted contractors to do maintenance of solid waste and drainage to reduce siltation in the drainage channels. They work from 5 am to 8 am to pave way for continuity so as to minimize disruptions to transport and market movement (Adeya Stanley; County Engineer, personal communication 2020).

The purpose of street sweeping was to remove accumulated materials between storms, to prevent transportation of pollutants to surface waters and blockage of drainage systems during storm events. The approach was suitable in urban areas where there was significant accumulation of materials on paved surfaces. On the same note, the Water Engineer observed;

> …the method requires a lot of labor and equipment such as brooms, shovels, gloves, overcoats, industrial boots… Duty rosters must be developed to avoid sweeping in periods of high pedestrian and vehicle activity to avoid disruption of movement (Moses Juma; Water Engineer, personal communication 2020).

4.4.2.2 Graveling of walkways

From focus group discussions, graveling of footpaths within the settlement was useful during runoff control management. The main purpose was to provide a steady ground to step on when all over the place in the settlement was muddy or flooded after rainfall. During the graveling of the road, water-bars were used to direct water off the road while humps were formed in the gravel along the road to impede runoff flow. The graveling materials were not cemented, but were arranged in a configuration that allowed infiltration of excess overflow on the pathway. Additionally, this form of graveling walkways contributed some aesthetics and landscape value around the structures in the settlement. The image in Plate 16 illustrates how the technique was used to control and manage runoff in Amalemba informal urban settlement.

Plate 16: A gravel road in Amalemba informal urban settlement.
(Source: Author, 2020)

4.4.2.3 Tarmacking of roads and construction of drainage channels

County Engineer in charge of works through interview confirmed that the County Government through World Bank had opened up one access road in the informal settlement and tarmacked it. This road linked the informal settlement to the main Kakamega-Kisumu highway through Amalemba primary school. This move improved pedestrian flow, vehicle accessibility, allowed ambulance entry in case of emergencies and improved runoff management in the informal settlement. The road had to some extent improved the flow of runoff; the drainage channels along the road provided channels for runoff flow by gravity to the stream hence reducing instances of ponding of water on such roads as illustrated in Plate 17.

Plate 17: Kakamega Prisons-Amalemba settlement tarmac road.

(Source: Author, 2020)

4.4.2.4 Construction of culverts

A culvert is a closed conduit used to transport water from one place to another, usually from one side of the road to the other. A few runoff control guards were strategically positioned for maintaining and running off routes along and away from the informally situated settlement, according to the County Engineer interview. These culverts were used for the transport to the bottom for disposal in highway ditches at the top of the village. Both greywaters and runoff were collected and drained in the principal drainage to the Isiukhu River. They also served as temporary "bridges" for residents to enter their shacks in the informal town settlement during the flash floods, as shown in Plate 18.

Plate 18: A Culvert in Amalemba informal urban settlement used to convey runoff.

(Source: Author, 2020)

4.4.2.5 Construction of scour checks

Scour checks are semi-pervious typically loose rock constructions that are placed in a series along open drainage channels. The Water Engineer through interview explained:

> Where steep gradients exist, the water gains high speed as it moves to the low point. Without protective measures, scouring is likely to occur. Therefore, scour checks prevent erosion in the trenches by slowing down the water. The scour checks hold back the silt carried by the water flow and provide a series of stretches with gentle gradients hence reducing velocity of runoff (Water Engineer, personal communication 2020).

The image in Plate 19 illustrates scour checks constructed by the County Government to manage the speed of runoff heading to the low point of Amalemba informal urban settlement towards River Isiukhu.

Plate 19: Scour checks on Kakamega-Kisumu road constructed to prevent erosion and slow down the runoff in the trenches.

(Source: Author, 2020)

4.4.2.6 Practice of urban Agriculture

Urban agriculture involved cultivation of crops and using land for gardens or agro-forestry as shown in Plate 20. Kakamega County uses complementary municipal by-laws to enforce practices related to Urban Agriculture as opined by the County Engineer (Construction Works) in an interview:

> The County enforced regulations on urban policy open space. For instance, crops planted should not exceed 1.5 m and cattle grazing is restricted in town because it interferes with landscaping. The offenders' cattle is confiscated and released upon payment of a fine (Adeya Stanley; County Engineer, personal communication 2020)

Plate 20: Use of Urban agriculture to improve ground cover in Amalemba informal urban settlement as a measure of reducing runoff velocity.

(Source: Author, 2020)

CHAPTER FIVE

DISCUSSION

5.0 Introduction

This chapter reflects on the main findings of the study with regards to the four specific objectives i.e. human and physical features that influence runoff generation, runoff discharge, effects of runoff on the environment and runoff management practices in Amalemba informal urban settlement.

5.1 Human and Physical Features that Influence Runoff Generation

Built up areas constituted the largest land cover (70.4%) in Amalemba informal urban settlement followed by grasslands 10.3%, bare ground 8.2%, trees 4.8% while all weather and tarmac roads had the least portion at 3.6% and 2.7%, respectively. The built up areas comprised building, roads and open drains. Runoff contributing areas consisted of impervious areas: roofs, streets and paved surfaces while bare ground, trees and grass constituted pervious surfaces. Buildings were comprised of few permanent houses and shacks that were roofed with iron sheets. Rooftops acted as impervious surfaces that generated runoff. The increase in runoff was also because of roof catchment that was without gutters and tanks for rainwater harvesting. Consequently, the available surface for infiltration in the settlement was limited leading to increased runoff generated from the iron roofed structures, pavements and tarmacked roads. Residents of Amalemba informal urban settlement rarely harvested rainwater because the length of the roofs overhang in many of the shacks were too short to support a gutter to harvest rainwater. As a result, the situation contributed to higher volumes of runoff experienced in the settlement. In terms of slope Amalemba informal urban settlement was one among the low points around Kakamega Town.

This explained why the drainage trenches and drains along the roads from the town were directed towards Amalemba informal urban settlement area. The runoff was conveyed by gravity devoid of pumping due to the fall in gradient. These findings follow the conclusion of Roesner (1999), who observed that paved surfaces and rooftops allow no water to infiltrate leading to significant production of runoff in periods of heavy rains.

5.2 Runoff Discharge in Amalemba Informal Urban Settlement

The study found that precipitation amount had the biggest consequence on runoff. The linear regression relationship of cumulated rainfall events and measured runoff discharge volume for the various plots showed statistically positive correlations (Table 9). The correlation (r) between rainfall and runoff discharge on bare ground was $r = 0.9934$, p-value 8.0×10^{-30}, on 50% grass cover: $r = 0.9822$, p-value 2.2×10^{-22} while 100% grass cover yielded $r = 0.9672$, p-value 2.1×10^{-24}. In the three cases the p-value was less than 0.05 at 95% confidence level. Consequently, rainfall and runoff discharge were found to have a statistically positive significant relationship. These results agree closely with the study done by Kure and Yuya (2008), that rainfall has a direct positive statistically significant relationship on the occurrence and volume of runoff. The study also established that slope and land cover influenced runoff volume generation. Bare surface produced higher discharge than vegetated surface. The results implied that vegetation cover influenced generation of runoff. There was lower volume on vegetated surface due to higher infiltration capacity than on bare surface. The low generation of runoff on 100% grass cover surface demonstrates the significance of thick surface cover at reducing water losses. The grass cover was effective in producing surface unevenness that aided in delaying the flow of runoff thus improving penetration and reducing movement of water and soil on the surface.

Steeper slopes generate more velocity than gentle slopes and can convey runoff in a shorter period. The study findings agree with those of Schwartz and Evett (2003), who concluded that an area densely covered with vegetation yields less runoff than bare ground. Additionally, short growing grass and cow-peas were effective in forming a surface roughness that helped in impeding the flow of runoff. These findings closely agree with the work of Wemple and Jones (2003) that there is a positive relationship between runoff and gradient but moderated with presence of vegetation cover.

5.3 Effects of Runoff in Amalemba Informal Urban Settlement

The production of runoff had adverse effects on buildings, land and the physical environment in general. This was more pronounced during the long rains in March to June. During peak rainfall, residents experienced flooding that led to destruction of farmland, houses and constrained movement. Development of dangerous gullies caused physical damage to infrastructure like roads and drainage systems occasioning disruption of services. In addition, deposition of particles carried by runoff caused channel sedimentation and silting up by solid wastes. The biggest problem was how waste water was disposed, in view of the fact that about 80% of the water ended up as waste. The main issue was where and how waste water was drained. This problem was complicated by the clay loamy soils in Amalemba informal urban settlement which had low impermeability and therefore generated high volumes of runoff with devastating consequences. The study findings relate closely with the work of Zablon, (2015) that large volumes of runoff coupled with poor drainage impact negatively on human beings. The resultant flooding causes injuries, disrupts transport infrastructure, spreads water borne diseases and destroys property.

5.4 Runoff Management Practices in Amalemba informal settlement

5.4.1 On-site runoff management practices

A majority of Amalemba informal urban settlement residents had devised means of protecting their personal effects from being carted away by runoff. One of the solution used by residents to manage runoff was by a detention pond. It was used to dispose of water back into the natural circulation through seepage. Equally, small embankments and contrivances served as breakwater at the drainage channels close to houses. In this way, the effects of floods were mitigated besides protection of property from destruction. Vegetation filter provided limited runoff volume control; the method was more effective upon combination with other runoff volume management methods. Stands without vegetative materials like grass were at times flooded whenever it rained. The use of old tyres and cement bags provided a physical barrier for the runoff. The inner wall chamber of the tyres where garden wastes were mixed with soil presented favorable conditions for the germination of seeds. This allowed soil and organic matter to be retained within the tyres favoring the development of a vegetative cover. The system for slope protection using scrap tyres reduced the erosive effects thereby improving the management of runoff. The findings in this study follow similar conclusions by Button (2010), that onsite runoff management practices on a local scale have potential to manage runoff volume and mitigate its effects.

5.4.2 Institutional runoff management practices

The County Government of Kakamega provides basic services that are geared towards runoff management and improvements in the urban environmental condition. Street sweeping was undertaken primarily for aesthetic purposes and as a safety control measure. Street cleaning reduced massive buildup of debris and prevented blocking of waterways in the settlement. The tarmac road in the informal urban settlement was planned and designed to conform to the natural drainage pattern. Scour checks were constructed besides the tarmac roads along open drainage channels to detain and reduce the velocity of runoff. This was particularly useful on the gently sloping channels that conveyed large volumes of runoff.

Urban agriculture offered a promising new approach to managing runoff by reducing the volume of water that flowed into the drainage systems in Amalemba informal urban settlement. The vegetable raingardens captured large quantities of runoff in the settlement and used this water to contribute to the important practice of urban food production. Urban farms improved the food security of households and helped residents to gain new knowledge and technical skills in farming within the settlement. These findings closely follow the conclusions of Van Megen (2018), that street sweeping, urban agriculture and scour checks have a significant mitigation role where accumulation of materials on paved surfaces is significant. However, the practice is applicable only in areas with suitable sub-surface soils with high permeability.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.0 Introduction

With the advance of urbanization and increasing population in Kakamega Town, the requirements for housing and other amenities have increased along with greater demands for access and transport. Amalemba informal urban settlement situated at the lower point of Kakamega Municipality receives runoff from all the major generation points in the town. This makes it highly vulnerable to runoff related impacts.

6.1 Summary and Conclusions

6.1.1 Physical features that influence runoff generation

The study highlighted human and physical features that influenced runoff and their impacts on the residents. It also identified some of the issues that had contributed to high incidences of runoff in the informal settlement. Consequently, services like waste disposal machineries were lacking, forcing the residents to dump wastes in drainage channels. Built up areas and clay-loam soil constituted the largest surfaces that precipitated a probability for high runoff rates.

6.1.2 Runoff discharge

Amalemba informal urban settlement experienced high rainfall levels over the long rains season, April to June 2020. The average amount of rainfall received over the three months was high, 293.6 mm. The total amount of rainfall received annually during the long rain season between April and June (2017 to 2019) was 2642.4 mm (average 880.8 mm per year). Rainfall and runoff discharge volume showed statistically significant positive correlations. The slope in the settlement varied from gentle to moderately steep (10% - 15%), the slope properties affected runoff volume in combination with land cover and rainfall volume. Bare ground produced high runoff volume than areas with grass cover. The 100% grass cover surface generated the least runoff volume at both 10% and 15% slopes. However, the 50% grass cover surface produced more runoff than the 100% grass cover at 10% and 15% slopes. A steeper slope combined with bare ground produced significantly higher average volume of runoff compared to the other surfaces. Longer precipitation periods contributed to greater runoff volume generated by all the three types of surfaces.

6.1.3 Effects of runoff in Amalemba informal urban settlement

Most respondents who had lived in Amalemba informal urban settlement for a considerable length of time had witnessed many runoff incidents. They had also over the years suffered from various afflictions and diseases arising from the degraded environment. The production of runoff had adverse effects on paved surfaces, buildings, land and the physical environment in general. Increased volumes of runoff in March/June caused erosion of topsoil, washing away of crops and destruction of farmland. Runoff also caused physical damage down-slope including the washing away of road sections and the development of dangerous gullies. Deposition of particles carried by runoff caused channel sedimentation and blocking up of drainages by solid wastes.

6.1.4 Runoff management practices in Amalemba informal urban settlement

Runoff management practices in Amalemba informal urban settlement were in two broad categories: on-site and institutional. On site interventions instituted by the residents included: digging of detention ponds, use of open drains, vegetated filter strips, heaping soil against the base of shacks and use of old vehicle tyres and cement bags as a barrier. However, the existing framework in Amalemba informal urban settlement was such that there was little effort at tackling the runoff situation. Members of the settlement hardly came together to offer substantive solutions and strategies for mitigating the impacts of runoff. There was little or no concerted effort at the community level to address this problem. The County Government has attempted to solve runoff challenges by instituting regular sweeping of open markets and streets, graveling streets and tarmacking of roads, constructing runoff management culverts and scour checks, constructing drainage channels along the roads and encouraging urban agriculture.

6.2 Recommendations

6.2.1 Recommendations of the study

Based on the results, the study advises that individual attempts to combat runoff and floods are not always successful. The people must come together and make arrangements for how to keep the drains free of the garbage. Individualistic approaches to mitigation and reduction must now give way to a systemic and result-oriented strategy. This holistic approach must include all stakeholders in the informal settlement process. The stakeholders here include the Kakamega County Government, landlords or landowners, tenants and public service providers such as the Ministry of Works. A formidable team of stakeholders should come up with a workable plan to alleviate, handle and monitor the runoff crisis that is currently buffeting the informal urban settlement of Amalemba.

6.2.2 Recommendations for further study

Based on the findings in the study, some recommendations for further study related to runoff generation and management in Amalemba informal urban settlement are presented as follows.

a) This study analyzed volume of runoff plus the interventions thereof. There is need for an inquiry to determine the quality of water used and pollutant concentration within Amalemba informal urban settlement.
b) There should be mapping of the runoff hotspots using GIS technology and an electronic feedback system for the residents.
c) Proper and regular channelization of the existing drainage network in Amalemba informal urban settlement and construction of a detention pond at River Isiukhu in order to mitigate the effects of runoff downstream.

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APPENDICES

Appendix I: Research Permit

CONDITIONS

1. You must report to the County Commissioner and the County Education Officer of the area before embarking on your research. Failure to do that may lead to the cancellation of your permit
2. Government Officers will not be interviewed without prior appointment.
3. No questionnaire will be used unless it has been approved.
4. Excavation, filming and collection of biological specimens are subject to further permission from the relevant Government Ministries.
5. You are required to submit at least two(2) hard copies and one(1) soft copy of your final report.
6. The Government of Kenya reserves the right to modify the conditions of this permit including its cancellation without notice

REPUBLIC OF KENYA

NACOSTI

National Commission for Science, Technology and Innovation

RESEARCH CLEARANCE PERMIT

Serial No. A 8229

CONDITIONS: see back page

THIS IS TO CERTIFY THAT:
MR. PATRICK KHAKABO MUSONYE
of UNIVERSITY OF ELDORET, 170-50100
Kakamega,has been permitted to
conduct research in *Kakamega* *County*

on the topic: *URBAN RUNOFF GENERATION AND MANAGEMENT: A CASE STUDY OF INFORMAL SETTLEMENTS IN KAKAMEGA MUNICIPALITY*

for the period ending:
22nd March,2017

Permit No : NACOSTI/P/16/43890/9004
Date Of Issue : 22nd March,2016
Fee Recieved :ksh 1000

....
Applicant's Signature

....
Director General
National Commission for Science, Technology & Innovation

Appendix II: Letter of Introduction

I Musonye Patrick Khakabo from University of Eldoret am conducting a research titled "Generation and Management of Runoff in Amalemba, An Urban Informal Settlement in Kakamega Municipality, Kakamega County, Kenya". I would like to take a little of your time to ask some questions relevant to my research. All information you provide will be kept strictly confidential and used for the purpose of the study only.

Name…………………………………… Signature………………………

Appendix III: Questionnaires

Questionnaire for Amalemba informal urban settlement residents:

Do not write your name, phone number or any identification details on this form.

Please answer all questions by writing in the spaces provided.

1. What are some of the effects of floods/runoff in Amalemba?

   ____

   ____

   ____

2. What has the community done to control the floods or reduce the impact of flooding?

   ____

   ____

   ____

3. What measures has the local administration enforced to mitigate against flooding?

   ____

   ____

   ____

Appendix IV: Focus Group Discussion (FDG) for Residents

Section A:

i. Length of stay in the settlement__________________________

Section B: Research Questions

1. Name the effects of runoff in this settlement?

a) …………………………………………………………………………………

b) …………………………………………………………………………………

c) …………………………………………………………………………………

d) …………………………………………………………………………………

e) …………………………………………………………………………………

f) …………………………………………………………………………………

2. What practices do you use to manage runoff?

a) …………………………………………………………………………………

b) …………………………………………………………………………………

c) …………………………………………………………………………………

d) …………………………………………………………………………………

e) …………………………………………………………………………………

Appendix V: Interview Schedule for Water Engineer/County Engineer (Construction Works)

Section A:

i. Working experience (years) __________________________

Section B: Research Question I

What are the causes of runoff in Amalemba informal urban settlement?

a) ………………………………………………………………………………
b) ………………………………………………………………………………
c) ………………………………………………………………………………
d) ………………………………………………………………………………
e) ……………………………………………………………………………

Section C: Research Question II

State the effects of runoff in Amalemba informal urban settlement

a) ………………………………………………………………………………
b) ………………………………………………………………………………
c) ………………………………………………………………………………

Section D: Research Question III

1. State the measures taken by the County Government to manage runoff in Amalemba Informal urban Settlement

a) ………………………………………………………………………………
b) ………………………………………………………………………………
c) ………………………………………………………………………………
d) ………………………………………………………………………………

2. State the challenges you encounter while managing runoff in Amalemba Informal urban Settlement

a) ………………………………………………………………………………
b) ………………………………………………………………………………
c) ………………………………………………………………………………
d) ………………………………………………………………………………

Appendix VI: Kakamega monthly averages of weather elements for 2017-2019

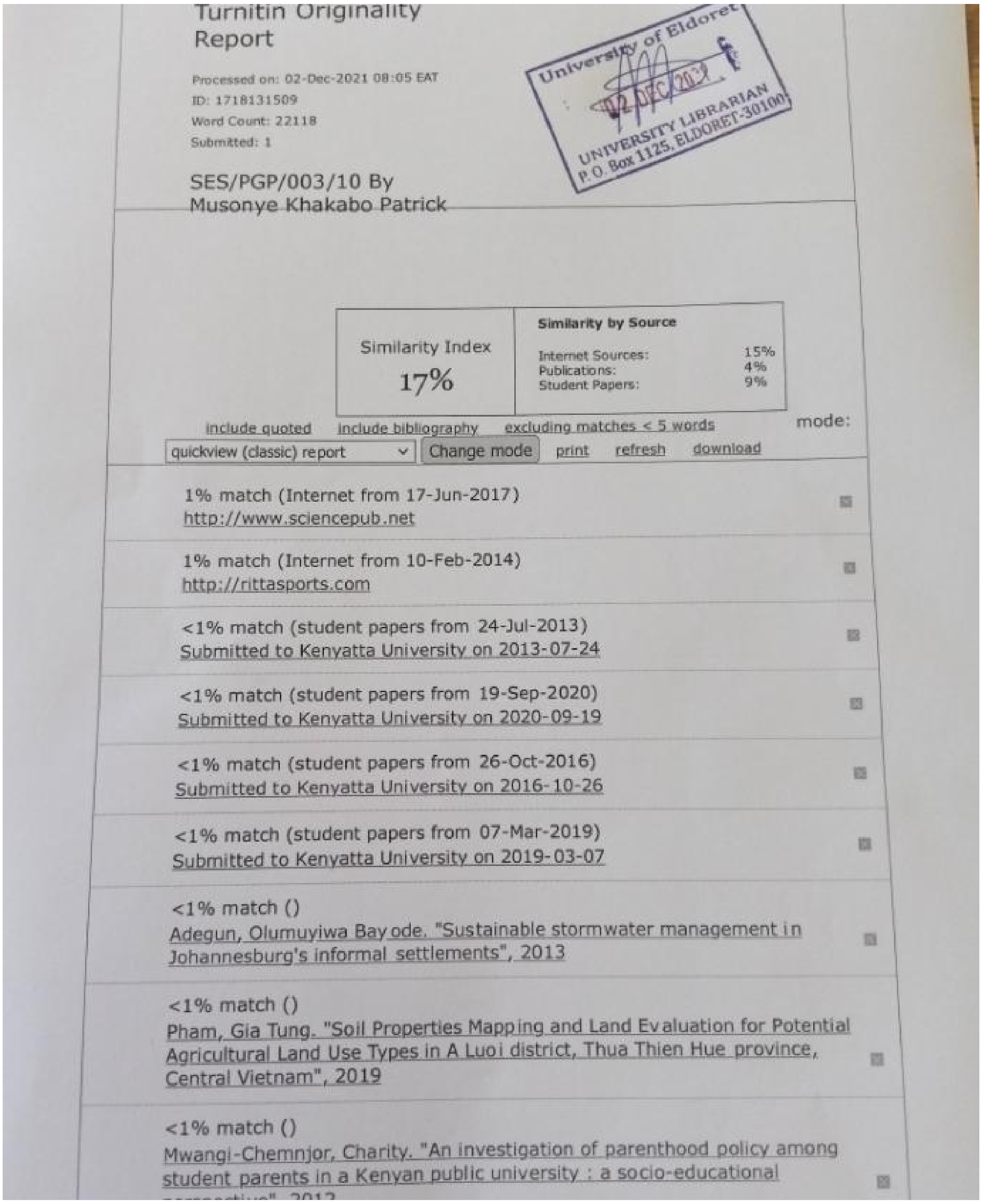
Year/Month 2017	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
RAINFALL (***MM***)	37.1	142.6	204.8	201.9	217.5	171.6	196.8	162.4	244.0	123.4	131.5	176.6
MAX. TEMP. ***(^0C)***	///	///	30.7	29.8	27.9	28.6	27.3	27.4	27.3	28.4	28.6	28.8
MIN. TEMP. ***(^0C)***	14.8	15.5	15.5	16.0	16.0	15.0	15.2	14.8	15.0	15.2	15.1	15.4
R/HUMIDITY ***(%)***	43	52	59	61	73	70	73	73	73	58	64	64
WIND SPEED ***(KM)***	63.5	93.3	78.6	69.5	56.2	54.3	52.5	61.3	62.6	56.1	63.5	64.7
EVAPORATION (***MM)***	5.7	5.4	5.0	4.8	3.6	4.0	3.8	3.8	3.6	4.1	4.8	///
2018												
RAINFALL ***(MM***)	62.2	78.4	201.5	553.5	364.6	276.9	184.5	223.1	118.9	190.2	34.2	176.6

MAX. TEMP. ***(⁰C)***	29.9	31.2	28.2	26.5	27.2	27.0	27.0	27.4	28.6	28.0	29.3	28.8
MIN. TEMP. ***(⁰C)***	14.9	15.7	15.8	16.1	15.9	15.3	14.8	14.6	14.4	15.1	15.0	15.4
R/ HUMIDITY ***(%)***	57	44	70	78	76	75	72	72	65	68	42	64
WIND SPEED (***KM)***	70.5	92.1	73.5	59.4	53.3	52.3	54.4	63.0	68.1	60.1	78.6	64.7
EVAPORATION (***MM)***	///	///	///	///	///	///	///	///	///	///	///	///
2019												
RAINFALL ***(MM***)	23.3	46.8	63.5	252.3	328.7	275.4	157.6	243.9	198.0	349.5	201.9	279.7
MAX. TEMP. ***(⁰C)***	30.2	32.0	31.8	30.2	28.2	26.4	26.9	27.1	27.3	26.6	27.1	28.6
MIN. TEMP. ***(⁰C)***	14.8	15.4	15.6	16.3	16.3	16.3	15.3	14.9	14.8	15.2	15.7	15.7
R/	52	46	51	63	73	78	73	71	71	76	70	75

HUMIDITY ***(%)***												
WIND SPEED ***(KM)***	82.7	84.9	81.4	72.0	53.4	47.4	54.9	67.3	73.6	61.5	60.9	64.8
EVAPORATION ***(MM)***	///	///	///	///	///	///	///	4.1	4.4	4.2	8.2	4.0

Source: Kakamega Meteorological Weather Station (Computation Data Sheet)

Appendix VII: Similarity Report



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