# The role of land use/land cover changes on flooding in Kwakwani watershed- Guyana

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**ABSTRACT**

Land use and land cover (LULC) changes affects the hydrological cycle and can intensify the impacts of hydrometeorological events such as flooding. Flooding often has disastrous consequences for communities and livelihoods. This justifies the need for spatial and temporal analysis of LULC change. In the Kwakwani watershed in Guyana, the largest impacts from floods were experienced in 2021 and 2022, resulting in losses to crops, livestock, infrastructure, and income. Hence, there is a need to assess the role of LULC change in the hydrological responses of the Kwakwani watershed to support risk management efforts. This study assessed the role of LULC change on flooding and hydrological response parameters in the Kwakwani watershed by examining its relationship with sediment yield, surface runoff, and evapotranspiration for four LULC years: (i) 2013, (ii) 2015, (iii) 2017, and (iv) 2019. The annual LULC changes for the watershed was more intense between the 2013 – 2015 years, which recorded active gains in cropland, wetland, grassland, and settlement, and active losses in cropland, wetland, and settlement. For the 2017 – 2019 years, changes in LULC were slow, with active gains in cropland and active losses in forestland. Further, the Soil and Water Assessment Tool (Q-SWAT) model was used to examine surface runoff, evapotranspiration, and sediment yields under these LULC change years. The annual average sediment yield was highest in 2019 which recorded 1.094 t/ha and the lowest in 2015 of 0.647 t/ha. Annual average surface runoff was highest in the 2017 which recorded 1019.8 mm and the lowest in 2019 which recorded 995.3mm. Evapotranspiration was highest in 2019 which recorded 494.8 mm and lowest in 2017 which recorded 459.6mm. Temporal and spatial variabilities in LULC can impact hydrological parameters in a watershed thus, increasing the vulnerability of livelihoods to floods.



**Key words:** SWAT+ model, Land-Use Land-Cover, Sedimentation, Surface runoff, Evapotranspiration, Kwakwani Watershed

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## GLOSSARY

CCRIF- Caribbean Catastrophe Risk Insurance facility

CFSR- Climate Forecast System Reanalysis

DREF- Disaster Response Emergency Fund

DRR- Disaster Risk Reduction

ET- Evapotranspiration

FAO- Food and Agriculture Organization

GLSC- Guyana Land and Survey Commission

HRU- Hydrological Response Unit

LSU- Landscape Unit

LULC- Land Use Land Cover

SDG- Sustainable Development Goal

SWAT- Soil and Water Assessment Tool

UN- United Nation

UNCED- United Nations Conference on Environment and Development

UNDP- United Nations Development Programme

UNDRR- United Nations Office for Disaster Risk Reduction

UNFCC- United Nation Framework Convention on Climate Change

USDA- United States Department of Agriculture

USGS- United States Geological Survey

WHO- World Health Organization

# 1 CHAPTER ONE: INTRODUCTION

## 1.1 Background of study

The intensity of land-use changes around the world is rapidly increasing, resulting in modifications and alterations to ecosystems and their functions (de Andrade Farias et al. 2020). This intensive global land-use change strongly correlates to the growth of the human population, therefore, the interaction between humans and the natural environment increases (Banba 2017). Between 1960 and 2019, land-use changes have accounted for 32% alteration of the global environment, amounting to 43 million km² of land (Winkler et al. 2021). Moreover, urbanization processes are regarded as the most influential anthropogenic factor that results in global LULC changes (Daramola et al. 2022; Haase et al. 2018). Land-use changes result in adverse impacts on the hydrological cycle, ecosystem functioning; and the climate at varying spatial and temporal scales (Velastegui-Montoya et al. 2022).

Land-use policies and regulations, therefore, is a key factor in environmental management which is used to attain global sustainable development (Banda and Shaw 2017). As a result, local, regional, and international policies have been formulated to address issues of land use. Most notably, Agenda 21 from the United Nations Conference on Environment and Development (UNCED) in 1992 has highlighted the importance of land use management and planning towards achieving sustainable development and has paved the way for the development of subsequent policies to address global issues of land-use (Banda and Shaw 2017).

Addressing global land-use and cover change and its impacts on climate is importantAs such, the United Nations Framework Convention on Climate Change (UNFCCC) recognizes the importance of land-use change in climate change mitigation and adaptation through the removal of greenhouse gases from the atmosphere and sequestration of carbon in terrestrial ecosystems (Banda and Shaw 2017).

Developing nations, to that end, are most impacted by land-use and climate changes due to their inability to respond to and prevent the subsequent consequence of these changes (Thapa 2021). Moreover, disaster risks in developing states such as the Caribbean region are increasing through losses of protective vegetation, unsustainable clearing of forests, and unsustainable agricultural practices (Fontes and Phillips 2019). As such, vulnerabilities are created by exposing the socio-economic environment to natural disasters.

Land use change and land use planning in disaster risk reduction and management are therefore important for regions such as the Caribbean, which aligns with the Sustainable Development Goal 15, of the 2030 agenda that aims to "protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss." The purpose of Disaster risk reduction (DRR) is to lessen the impacts of natural hazards and disaster by addressing these hazards and vulnerability (Prashar and Rahman 2017). Furthermore, disaster risk reduction into land-use planning will ensure the environment functions are protected, hence, reducing the risks and vulnerability to natural hazards on livelihoods.

One phenomenon that poor land use management contributes to is flooding disasters. Floods are frequently caused by heavy rainfall, snow melt, storm surges, and occur when the resulting waters expand and submerge land (WHO 2022). Flooding disasters are the most frequent type of natural disasters. Floods can occur within a short period (flash flood), minutes of heavy rainfall; or over a long period (NOAA 2022). Flooding, like any other disaster, can increase in severity when measures such as disaster prevention, land use management and planning are neglected and disregarded (Ighile 2020). To that end, global land use planning is an effective strategy to reduce exposure of people to floods (Rahman et al. 2017). Moreover, the existing conditions within a river basin or catchment area can predetermine flooding potentials (Seneviratne et al. 2014). As such, the characteristics (geology, landscape, topography, soils) of an area can play a pivotal role in flood disaster risk management. Alteration to these existing conditions may therefore amplify the conditions for flooding.

The economic losses to floods between 1980 and 2017 was estimated at 160 billion Euro, which affected over 2 billion persons globally (UNDRR 2022). Losses to floods have increased exponentially from 1980 to date (Ritchie and Roser 2021). As recent as 2020, 34.2 million people were affected by flooding events, resulting in the loss of lives and properties (Statista 2022). The impacts of flooding disasters can be extensive, resulting in the loss of lives, livelihoods, infrastructure, biodiversity, and ecosystem services. Flooding events globally are increasing in frequency and intensity and are expected to continuously escalate as a result of change in climate (WHO 2022). As such, livelihoods will continue to experience losses at greater magnitudes.

Furthermore, the Caribbean is at high risk of flooding due to its geographic location, exacerbated by climate change, weakness in drainage facilities and the built environment, land degradation, and mismanagement of municipal wastes (Fontes and Phillips 2019). Additionally, the Caribbean has recorded a reduction in wetland and forest covers which resulted in a reduction to its buffering mechanisms against flooding disasters (Seneviratne et al. 2014). In Guyana, flood is considered a yearly recurring natural disaster.

Guyana is susceptible to flooding disasters due to its low-lying geographic topography (2m meter below sea level), location and precipitation intensity (70-90 inches yearly), leading to the overflow of watersheds during rainy seasons. Guyana has experienced many floods in recent years especially during the events of La Nina. In 2021, the flooding events in Guyana affected approximately 52,000 households throughout the country, with flood water levels reaching as high as 14 feet in the Kwakwani community (IFRC 2021). Land-use/cover has been implicated as a factor that has exacerbated the impacts of flood in Guyana. As such, the 2005 floods were exacerbated by the blockage of conservancy drainage, resulting in the overtopping when excess water from rainfall accumulated in the conservancy (UNISDR 2014).

In a watershed, land-use changes affect the hydrological and ecological systems and processes that influence flooding (de Andrade Farias et al. 2020). Understanding how these systems and processes are affected by LULC change can therefore feed into the development of appropriate mitigation and management measures. Hydrological modeling is one strategy which can provide information on the effects of LULC change on the environment. According to Neitsch (2011) the SWAT+ model is a watershed to river basin-scale model, developed by USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research, that simulates the quantity and quality of ground and surface water, environmental impact prediction of land uses, land management practices and climate change. It is also used in soil erosion assessment for prevention and control, pollution from nonpoint source control and general management in watersheds. The SWAT+ model divides watersheds into sub basins, which are further divided into Hydrological Response Units (HRU’S) and Landscape Units (LSU) consisting of homogeneous land use and soil characteristics. The watershed being divided allows for the dissimilation of dominant land use, soil type and management. The SWAT+ model increases flexibility in spatial representation for processes and interactions within a watershed. The SWAT+ model utilizes the QGIS (QSWAT) interface. This allows for the simulation of hydrology of a watershed separated into two sections, that is, the land phase of the hydrological cycle and the routing phase of the hydrological cycle (Wangpimool et al. 2013).

Hydrological parameters can influence floods. As such, this study enumerated the LULC changes within the Kwakwani watershed and its impact on hydrological parameters (sediment yield, surface runoff, and evapotranspiration). Furthermore, the study incorporated a community-based assessment to understand the impacts of recent flooding events on the livelihood of people and their perception towards land-use impacts on floods.

### 1.1.1 Study Area

The area modelled for this study is the Kwakwani watershed, located in the Upper Demerara-Berbice Region of Guyana. The study area is found at 5° 15′ 50.76″ N, 58° 3′ 51.48″ W and covers an area of approximately 16,188.93 ha which encompasses humid forests accounting for 76% of the tree cover (Global Forest Watch 2022). The Berbice river is the main drainage channel that passes through the Kwakwani study area, flowing in a northward direction and empties into the Atlantic Ocean. Kwakwani experiences two rainy seasons, the first season starts from December to February and the second season starts from April to August.

The Kwakwani watershed/study area is home to approximately 2504 people, i.e., 695 households (Bureau of Statistics 2012). The main socio-economic activities within the Kwakwani area include agriculture, mining, and forestry (Bureau of Statistics 2012). Presently, the forest industry accounts for the highest contributor to income generation within Kwakwani, by producing logs and lumber for the international and local markets. Agriculture is largely done on subsistence level, which also provides income generation through retail markets.

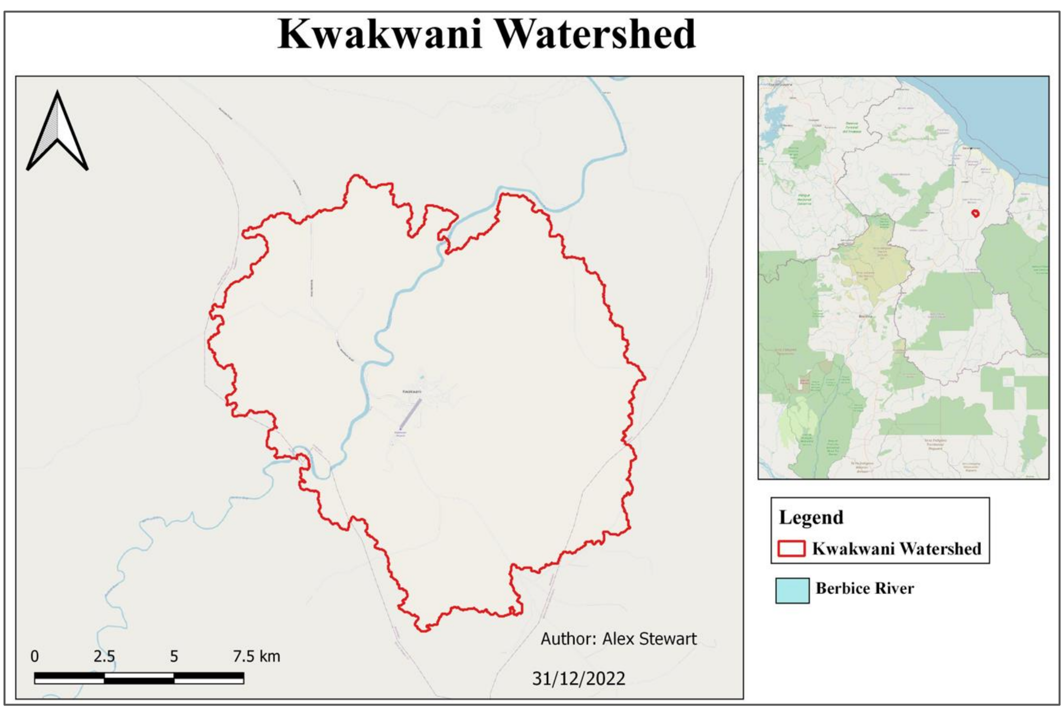


**Figure 1.1 Map of Study Area**

## 1.2 Purpose of study/ rationale

Precipitation intensity is the primary factor that contributes to flooding events and is estimated to increase as a result of changes in the climate (Tabari 2020). Similarly, land use and land cover changes can also influence the hydrological responses of catchments to precipitation events and affect the intensity and magnitude of floods, consequently increasing impacts to livelihoods and the environment (Nuissl and Seidentop 2021). In Guyana, development activities rely heavily on the use of natural resources. As such, intense manipulation of natural resources may hinder ecosystem functions including mitigation of natural disasters. Increases in flooding disasters and its impacts have been recorded across several regions in Guyana. Most notably, the years 2021, and 2022 have recorded an all-time high in flooding disasters in the Kwakwani community.

However, there is limited data available on the impacts of LULC change on flooding. Therefore, the purpose of this study was to investigate the role LULC change plays on flooding in the Kwakwani watershed since the Kwakwani community is highly dependent on the use of natural resources for livelihood support. As such, analyzing the changes in surface runoff, evapotranspiration, and sedimentation under temporal LULC change conditions for the Kwakwani watershed may give inferences into land uses and its influence to floods.

The information from this study can allow for better understanding of measures that can be implemented to aid in flood risk management and future development in Kwakwani watersheds and watersheds in other regions of Guyana.

## 1.3 General Objective

The general objective of this study was to investigate the role of land use/land cover changes in floods in the Kwakwani watershed.

## 1.4 Specific Objectives

The specific objectives of this study were:

- To perform a LULC change analysis of the Kwakwani watershed for the period 2013-2019.
- To perform an analysis on the surface runoff, sediment yield, evapotranspiration, of the Kwakwani watershed within the period of LULC change analysis.
- To conduct a community assessment in the Kwakwani to assess the perception of participants on the role of LULC changes and flood occurrences within the Kwakwani watershed and to assess the impacts of recent flooding events on the livelihood of people.

## 1.5 Limitations of Study

In order to assess the performance of a model, sufficient observed or measured data was needed to determine the correlation with simulated data. However, there were no weather gauges within the watershed to measure observed hydrological parameters. As such, the study relied on unobserved data for validation. There was also the unavailability of suitable Landsat 8 OLI images for the study area to conduct a LULC change analysis beyond 2019. As such, the LULC change scenario was limited to the year 2019 where suitable Landsat 8 OLI images were available for the study area.

# 2 CHAPTER TWO: LITERATURE REVIEW

## 2.1 Land Use and Land Cover Changes

Land cover is defined as the visible and physical components on the earth's surface within a specific time frame (Coffey 2013). It includes therefore the present conditions which can be naturally occurring or conditions as a result of human development. Land cover can be subjected to changes through land uses. Land use on the other hand refers to the anthropogenic manipulation of the earths components to obtain benefits from the land resources (Hasan et al. 2020).
Land use and land cover are important component of ecosystem stability. Land use and land cover (LULC) changes therefore can result in the alteration of services provided by ecosystems which are essential for human wellbeing (Anley 2022). LULC changes has accounted for an estimated loss of USD 20 trillion per year in ecosystem services between 1977 and 2011 (Costanza 2014). Unmanaged changes in land cover as such can result in the increase in ecosystem service degradation. Anley (2022), found that the reduction in ecosystem services value in Ethiopia was as a result of LULC changes which amounted to USD 9.3 million between 2000 and 2020. LULC changes can therefore degrades ecosystem services which can pose impacts to the livelihoods of populations who are dependent on it.

LULC change are further understood to exacerbate the severity of natural disasters because of the changes to the regulating services of ecosystems. For example, the removal of mangroves for development purposes within the Siangshan Wetland in Hsinchu, Taiwan has led to the increases in flooding within the coastland regions. These mangroves ecosystem once acted as a natural barrier that intercepted the forces of the waves, thus reducing flood risks (Chen et al. 2018). Many methods and analyses have been developed and used to support studies on impacts of LULC changes on ecosystem and their services. To understand the effects of LULC and floods, Panahi et al. (2010) calculated the area changes within two flood periods for the Madarsu Basin of North-eastern Iran. This research found that floods in 2003 were ten times larger than previous floods in 1964. Further examination of the land changes within the area indicated that stable forested area and range lands transitioned significantly to agriculture lands. Severity of floods within the two time periods were therefore linked to the disruption to the moisture retention capacity of soils within the area. Similarly, Junger et al. (2022) study on analysing the current land uses and changes in Austria flood-prone areas found that human activities have significantly reduced spaces for rivers, thus amplifying the impact to their livelihoods from flooding events since the holding areas for flood waters had expanded towards human settlements.

## 2.2 Divers of LULC change

Within the last millennium, approximately three quarters of the earth surface has been altered, resulting in significant loss of biodiversity, natural systems and changes in climate, all of which are attributed to human development (Winkler et al. 2021). Land use change to that extent has accounted for 32% alteration of the global area between 1960 and 2019 accounting for approximately 43 million km$^2$ of land (Winkler et al. 2021).
In the global land use system, urbanization is considered as one of the major driving forces that accounts for changes in the natural ecosystems (Nuissl and Seidentop 2021). Urbanization has been considered as the most significant form of LULC changes because of the detrimental changes to the dynamics of ecosystems (Haase et al. 2018). Many studies have estimated and projected

global urbanization. Moreover, the notable changes in land uses as a result of urbanization can be seen in the increases in built-up areas, signifying a spread in physical development.

According to the United Nations (2019), in Latin America and the Caribbean, urbanization is projected to range at 83 percent in 2050 with parallel increases in population growth. Such urbanization will threaten biodiversity, increase carbon emission, and exacerbate the risks of natural disasters, especially flooding since soil sealing will be high in urbanised areas (Nuissl and Seidentop 2021). An object-based image analysis approach used to monitor LULC change in a river basin in India found that urbanization or built up areas has increased drastically, adding 288 $km^2$ within seventeen years (Samal and Gedam 2015). Understanding the impacts of urbanization within the basin, especially on the hydrology required a model that would have simulated the hydrological components with respect to the changes as a result of urbanization. Urbanization was however felt due to the decrease in waste land and increase in water bodies which caused irreversible impacts to nature within the river basin. Similarly, Arifeen et al. (2021) explored LULC change detection and urban dynamics of the Gazipur district of Bangladesh by using satellite imagery and discovered that urban area developed by 500% from 1990 to 2020 with majority of conversion from agriculture land to built-up areas. Urbanization will therefore inevitably result in the conversion of land, with the subsequent impacts to the natural environment and the likely increase in disaster risks. Specifically, the conversion of earth surfaces through urbanization changes or alters the hydrodynamics and flood plain structures within a catchment therefore increasing flooding incidents (Nath et al. 2021). LULC changes often implicates the natural environment resulting in severe losses to forests. Potapov et al. (2022), estimated the global LULC change between 2000 and 2020 and found that global tree cover was reduced while cropland and settlements expanded. Specifically, LULC changes occurred in the following classes according to Potapov et al. (2022):
Forest Dynamics- Between the years 2000 and 2020 forest areas declined by 1 million $km^2$. Moreover, South America experienced the highest net loss of forest in the 20 years period followed by Africa.

Cropland Dynamics- Global cropland area expanded by 2.3 million $km^2$ between 2000 and 2020. South America and Africa accounted for the highest increases in cropland within the 20 years study period. Cropland increases were at the expense of natural vegetation which inclusive of pasture and forest lands.

Built-up Dynamics- Built up areas increased by 50% between 2000 and 2020, which was largely as a result of urbanization. China, USA, India, Brazil, Russia, Indonesia, and Canada, accounted for half the total percent of built-up between 2000 and 2020.

## 2.3 Land Use and Land Cover Changes and Hydrology

LULC is one of the most influential factors on hydrological properties within a watershed (Leta and Koriche 2017). Many studies have established strong correlations with LULC changes on hydrological parameters. de Oliveira Serrao et al. (2021) evaluated the LULC changes over a 40-year period within a Brazilian basin and found that the hydrological processes are severely altered when the natural environment was altered. LULC change in this instance, was due to urbanization and deforestation, and resulted in the increased surface runoff, and sedimentation. Furthermore, these changes had consequences to livelihood activities such as agriculture, food security and health; environmental services such as groundwater recharge and flood prevention (de Oliveira Serrao et al. 2021). Nath et al. (2021) study on the impact of urbanization on LULC change in Guwahati, India found that urban built-up areas had doubled in 30 years resulting in irreversible impacts to ecosystems. Moreover, it was found in this study that urbanization resulted in the decline in the groundwater level. Similarly, Suman et al. (2018), reported that the increase in built up in the Howrah Municipal Corporation, India severely impacted hydrological processes responsible for ground water recharge.

### 2.4 Impact of Land Use Land Cover on Surface Runoff

Surface runoff is used as a parameter in a hydrological model to decipher the movement of water within a watershed. It is affected by factors such as land slope, soil type, land use and climate. Surface runoff is one of the most sensitive parameters that can be investigated when changes occur within a landscape (Wangpimool et al. 2013). A range of studies have been carried out to investigate the impacts of LULC on surface runoff within watersheds and landscapes.
The surface runoff investigated in a Brazilian basin over a period of 40 years, found that LULC changes impacted the rates of surface runoff (de Oliveira Serrao et al. 2021). Moreover, the topology of the landscape impacted the rates of surface runoff in the basin. It was also found that surface runoff was lowest in sub-basins that were downstream when compared to sub-basins that were upstream. Furthermore, areas that were predominantly forested had less surface runoff when compared to areas that were dominated by pasture lands (de Oliveira Serrao et al. 2021). Therefore, vegetative cover and topology can play a role in the rates of surface runoff that occurs within a landscape. Moreover, changes in these parameters as a result of anthropogenic developments can impact the surface runoffs. Furthermore Kumar et al. (2022) explained that as urbanization increases, soil infiltration decreases, thus reducing base flow which contributes to stream flows, which therefore subsequently increases the surface runoff that leads to flooding.

### 2.5 Impact of Land Use/ Land Cover on Evapotranspiration

LULC changes impact the rates of evapotranspiration within a catchment (Kumar et al. 2022). As such, as deforestation occurs, the rate of evapotranspiration is impacted due to lower leaf canopy areas from the removal of vegetative cover, and high surface temperatures from exposure to direct sunlight (de Oliveira Serrao et al. 2021). Furthermore, forested areas tend to have a higher interception of water than cropland or barren lands, as such this allows for direct evaporation of water from precipitation resulting in higher evapotranspiration rates within a landscape (de Andrade Farias et al. 2020).
Kumar et al. (2022) study to understand the impacts of LULC change and climate change on hydrological components in the Usri watershed of India found that evapotranspiration tends to decrease due to the increase in urbanization, and decreases in wetlands and forest cover. As such, the analysis revealed that as forest cover, water bodies and bare lands decreased, the evapotranspiration also decreased by 4.4, 11.8 and 0.8% respectively. Changes in land use patterns can therefore result to the impact to evapotranspiration. Similar, Chen et al. 2011, found that the evapotranspiration under bare lands were lower than lands that were under wheat cultivation. Forest or vegetative cover can play a significant role in the rates evapotranspiration within a landscape.

## 2.6 Impact of Land Use/Land Cover on Sediment Yield

Sediment yield intensity is as a result of the intensity of surface runoffs. It therefore is dependent on topographic factors such as slopes, vegetation over, management practices and soil type (Netzer et.al 2014). Moreover, greater the surface runoff within a landscape, the greater will be the erosivity, resulting in higher sediment yields (de Oliveira Serrao et al. 2021). Sediment yield is therefore correlated to surface runoffs.

LULC changes can therefore affect sediment yield by altering the topography of a landscape.

de Oliveira Serrao et al. (2021) in their study found that areas within a Brazilian basin that lacked forest were less resistant to sediment yield. Such changes to the landscape were attributed to anthropogenic developments, which resulted in the decrease of forest cover. In de Oliveira Serrao et al. (2021) study also, the sediment yield recorded was 3 t/ha in 2009. Moreover, this occurred in sub basins that were predominantly under agriculture lands.

Thomas et al. (2015) in their study found that the sediment yield within a watershed increased by 0.25 t/ha due to LULC change between 1996 and 2007. Moreover, the findings in this study provided information that will support soil conservation measures within the watershed such as avoidance of development within the watershed. Furthermore, de Andrade Farias et al. (2020) found that under a regeneration LULC scenario, the sediment yield that occurred was significantly lower when compared to a landscape degradation scenario within a watershed.

Similarly, the results produced from a SWAT model utilized by Netzer et.al (2014), found that the sediment yield from Guyana rivers was 30.8M17t/ha. Agriculture was labelled as the largest contributor to sediment loss amounting to an estimated 12.1M t/ha, while mining was approximately 8.4M t/ha, and logging at 883,000t/ha yearly. These land use activities therefore signify that greater the clearance of the vegetative cover, the greater the sediment yield.

## 2.7 Flood projections and impacts

Seneviratne et al. (2014) predicted a rise in the magnitude and frequencies of flooding in the 21st century. Moreover, the United Nations (2022) has predicted the rise in the world population of 8.5 billion by 2030, a further increase of 9.7 billion by 2050, and 10.4 billion by the year 2100. The rise in human population and natural disasters therefore increases the susceptibility of livelihoods. Furthermore, the IPCC (2015) predicted that the increases in global climate events will result in increases in global economic, social, and environmental losses.

According to the UNDP (2013), the increase in flood losses is attributed to population increases, increase in property value, lack of awareness of natural risks, and urbanization in flood prone areas. The costs associated with flooding can be divided into impact or damage cost and cost for risk reduction and adaptation (Seneviratne et al. 2014). Floods are threats to the livelihood of individuals which can result in the long-term impact to health, economies, and the environment, depending on its magnitude and location. Floods frequently affect agriculture, resulting in infertility to lands and loss to crops; groundwaters contamination leading to water-borne diseases; and geomorphology changes in water bodies, resulting in the impacts to aquatic life (Aldardasawi and Eren 2021).

Floods have accounted for 44% of all disasters that have occurred between 2000 and 2019, affecting 1.9 billion people, resulting in huge economic losses and human casualties (Yu and Wang 2022). Caribbean countries are at high risk of flooding due to its geographic location, exacerbated by global climate change, inadequate drainage facilities, poor planning of built environment, land degradation, and mismanagement of municipal wastes (Fontes and Phillips 2019). In the recent past, flooding has led to devastating effects experienced by Caribbean states. In 2018 flooding events affected the livelihoods of an estimated 150,000 people in Trinidad, and 75% of farmers incurred losses to crops and livestock. Additionally, it is estimated that Jamaica will lose approximately USD 96.3 million, or 0.84% of their GDP to floods (Fontes and Phillips 2019). In 2005, Guyana experienced one of the most severe flooding in history resulting in significant impacts to the livelihoods of 274,774 persons, and an economic loss of USD 465 million (UNISDR 2014). In May 2021, 52,000 people were affected by flooding across Guyana resulting in damages to homes, crops, and livestock (DREF 2021).

The existing conditions within a river basin or catchment area can predetermine flooding potentials of an area (Seneviratne et al. 2014). Alteration to the existing watershed conditions may therefore amplify susceptibility to flooding. As such, the characteristics (geology, landscape, topography, soils) of a catchment can play a pivotal role in flood risks.
Alterations of land cover results in changes in soil and land surface properties and hydrological processes such as infiltration, runoff water retention and accumulation (Seneviratne et al. 2014). Moreover, reduction in wetland and forest covers reduces the functions of buffering flooding events (Seneviratne et al. 2014).
In the Caribbean, flooding events have been exacerbated by losses of protective vegetation, unsustainable clearing and degrading of forests for development, and increase in soil erosion from agricultural practices (Fontes and Phillips 2019). These practices alter surface conditions and therefore contribute to runoff and sediment yields in rivers. Fontes and Phillips (2019), has attributed the cause of flooding in Jamaica to drainage characteristics of catchment areas, landscape, annual rain falls and land cover and uses. Furthermore, the urbanization reduces infiltration and percolation through soil, therefore decreasing the time to initiation of surface runoff and peak flows - a recipe for flooding.Inappropriate land-use has been implicated in past flooding events in Guyana, specifically, the blockage of conservancy drainage, resulting in the overtopping when excess water from rainfall accumulated in the conservancies (UNISDR 2014).

## 2.8 Soil and Water Assessment Tool (SWAT)

Environmental modelling can assist in decision making and management in land use systems. SWAT is a semi-distributed hydrological model that can be used to predict and evaluate the impact of anthropogenic development on hydrological processes (Kumar et al. 2022). SWAT model watershed applications are primarily based on the simulation of the water balance equation. The SWAT model was developed by the Agricultural Research Service of the US Department of Agriculture (USDA-ARS) (Neitsch 2011). The SWAT model is a time, semi-distributed, river basin model, developed to predict the long-term impacts of land use management practices and climate on water, sediments and agricultural chemical yields within a complex basin (Neitsch 2011). The SWAT model divides watersheds into sub basins, which are further divided into Hydrological Response Units (HRU'S), consisting of homogeneous land use and soil characteristics (Neitsch 2011).

Recognizing the need for a revised SWAT model due to numerous limitations and a lack in model development, the SWAT + model was developed. The revised model increases flexibility in spatial representation for processes and interactions within a watershed (Bieger et al. 2017). The model was jointly developed by the USDA Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research (Bieger et al. 2017).

SWAT+ model utilizes similar equations as the SWAT model in estimating surface runoff, evapotranspiration, sediment loss, soil water, and plant growth.

**The hydrological component**, driven by the soil water balance is represented as:

$$SW_t = SW_o + \sum_{i=1}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})$$

*$SW_t$ - soil water content (mm),*

*$SW_o$ - initial soil water content on day i (mm),*

*t - time (days),*

*$R_{day}$ -amount of precipitation on day i (mm),*

*$Q_{surf}$ -amount of surface runoff on day i (mm),*

*$E_a$ - amount of evapotranspiration on day i (mm),*

*$W_{seep}$ -amount of water entering vadose zone/ unsaturated zone from the soil profile on day i- (mm),*

*$Q_{gw}$ - amount of return flow on day i (mm).*

**The Curve number (CN)** is used to estimate surface runoff corresponding to the various soil types and land use and is represented as:

$$Q_{surf} = (R_{day} - I_a)^2 / (R_{day} - I_a + S)$$

*$Q_{surf}$ - accumulated runoff or rainfall excess (mm $H_2O$),*

*$R_{day}$ - rainfall depth for the day (mm $H_2O$),*

*$I_a$ - initial abstractions which includes surface storage, interception and infiltration prior to runoff (mm $H_2O$)*
*S - retention parameter (mm $H_2O$) – computed from $S = 25.4(1000/CN - 10)$, where CN is curve number for the day.*

**Evapotranspiration is calculated as:**

$$\lambda E = \Delta\,(H_{net} - G) + \rho_{air} \cdot c_p \cdot [e_{zo} - e_z] / r_a \,/\, \Delta + \gamma \cdot (1 + r_c/r_a)$$

*$\lambda E$ - latent heat flux density (MJ $m^{-2}$ $d^{-1}$),*

*E - depth rate evaporation (mm $d^{-1}$),*

*$\Delta$ - slope of the saturation vapor pressure-temperature curve, de/dT (kPa $^{\circ}C^{-1}$),*

*$H_{net}$n - net radiation (MJ $m^{-2}$ $d^{-1}$),*

*G - heat flux density to the ground (MJ $m^{-2}$ $d^{-1}$),*

*$\rho_{air}$ - air density (kg m-3)*

*$c_p$ - specific heat at constant pressure (MJ $kg^{-1}$ $^{\circ}C^{-1}$),*

*$e_{zo}$ - saturation vapor pressure of air at height z (kPa),*

*$e_z$ -water vapor pressure of air at height z (kPa),*

*γ - psychrometric constant (kPa ˚$C^{-1}$),*

*$r_c$ - plant canopy resistance (s $m^{-1}$),*
*$r_a$ - diffusion resistance of the air layer (aerodynamic resistance) (s $m^{-1}$).*

The SWAT tool has gained popularity since the advent of the application. More so, researchers have increased the use of the model to interpret and understand how hydrological parameters are affected from anthropogenic developments.
de Oliveira Serrao et al. (2021) conducted their study to understand the impacts of LULC changes on sediment yields and the hydrological processes in a Brazilian basin utilizing the SWAT model. The study was able to visualize the changes that occurred over a 40-year period and understand the impacts of the various land uses had on the sediment yield, surface runoff, and the hydrological cycle.
Moreover, the SWAT analysis was able to validate whether the simulated data and the measured data corresponded. As such, flow dynamics was tested and yielded favorable results which was indicated by the correlation and determination coefficients of 0.87 and 0.76 respectively.

Thomas et al. (2015) utilized the SWAT model to investigate the impacts of LULC on soil and water losses from a watershed in northern Taiwan. Similar to de Oliveira Serrao et al. (2021) research, this study was able to determine the effects of LULC changes on sediment yield within the watershed between two LULC scenarios. In contrast however, the study did not use a SWAT validation to determine the accuracy between the simulated data and measured data.

Leta and Koriche (2017), utilized the SWAT model to determine the impacts of LULC change on sediment yield and stream flow within the Finchaa reservoir in Ethiopia. Like the researches mentioned above, the SWAT model was able to identify the intensity of each LULC scenario on the hydrological process. Moreover, performance of the model was tested on stream flow and yielded coefficients of determination and Nash- Sutcliffe values of 0.83 and 0.74.
In Nigeria the SWAT tool was used to assess the role of LULC change and surface runoff on sediment yield in the Kaduna watershed. Like the study in Ethiopia the ability of the model to carry out its function was determined using the Nash-Sutcliffe (NS), the coefficient of determination and yielded values of 0.71 and 0.86 respectively. This concluded that the SWAT model performed acceptably in determining stream flow and sediment yield estimation for the watershed (Daramola et al. 2022).
A technical report by Netzer et.al (2014) titled "incorporating water quality as a co-benefit of Guyana's REDD+ and water quality" utilized the SWAT model to assess baseline flow and water quality in Guyana. The study found that the model was able to accurately estimate the total flow of fresh water for Guyana at 3,084$km^3$ per year. Moreover, the model pinpointed the rivers that contributed 95% to the flow of the freshwater.

## 2.9 Flood Studies Using SWAT

Various models have been utilized to simulate flood over the years, much of which had insufficiently represented the spatial characteristics of catchment areas where the studies have been executed. This problem was solved by the use of the SWAT model (Duan et al. 2019).

Deforestation and degradation of landscapes are well known to cause flooding from increases in surface runoff which transports sediments directly into surface waters (Netzer et.al 2014).
Accurately assessing hydrological phenomena can therefore provide information for land use management, which is important in mitigating effects of disasters such as floods (LV et al. 2020). Sensitivity analyses in the SWAT model are conducted to determine how hydrological flows are affected by various parameters within a watershed. Wangpimool et al. (2013), performed sensitivity analysis on 27 parameters for annual flow within a watershed in the pursuit of evaluating the hydrological cycle for flash flood warning systems in Thailand. In this study, it was found that the estimated annual average for surface runoff in the watershed was about 1,638.50 million $m^3$. This was the most consistent parameter in the sensitivity analysis that gave inferences into the characteristics of each sub-basins that would further feed into generating flood hazard mapping for improved flash flood warnings.
Duan et al. (2019), conducted a research to simulate the sub daily mountain flood processes for a high flood prone area in Xinjiang, China. The study was based on the use of a SWAT model to accurately forecast and simulate floods. The study demonstrated that it was feasible to simulate flooding for the daily and sub-daily scales. Moreover, with the ability to simulate and forecast floods it was found that disaster prevention can be improved utilizing the SWAT model in flood analysis (Duan et al. (2019). Sufiyan and Magaji (2018), modelled hazard for the Terengganu, Malaysia watershed using the SWAT model. It was found that with the removal of forested areas within the watershed, the more susceptible other areas will be to flooding from inundation. Moreover, the model was successful in depicting areas that will be at high risk for flooding based on the nature and orientation of slopes, soil classification, and land cover. Furthermore, the SWAT model was able to simulate the 3D flow of water from sub basins to the point of deposition. With that, the SWAT model can be applied in the management of watersheds to ensure minimum disruption to the hydrological cycles that may result in flooding. Additionally, being able to delineate floodplains can feed into land use planning that will improve disaster risk management.
Using the Soil and Water Assessment Tool, de Oliveira Serrao et al. (2021) found that for each sub basin in the watershed, high values of surface runoff and sediment yield were related to land use that are predominantly pasture as compared to land use that are dominated by forest within the Brazilian basin. Therefore, as land use are converted from forest to pasture lands, the sediment yield and surface runoffs increase.

# 3 CHAPTER THREE: MATERIALS AND METHODS

## 3.1 LULC Change Analysis

### 3.1.1 Landsat-8 OLI Image Acquisition

The shapefile for the study area (Kwakwani) was obtained from the United Nations Office for the Coordination of Humanitarian Affairs (OCHA) online portal under the subnational administrative boundaries for Guyana section. This shapefile was used as a search criterion to obtain Landsat-8 OLI satellite images from the United States Geological Survey Earth Explorer (USGS Earth Explorer) data portal for 2013, 2015, 2017, and 2019. Other criteria utilized included cloud cover range of 0 to 10%. Additionally, all Landsat-8 OLI images were of similar time periods, as such images chosen were within the dry season.

### 3.1.2 Band Processing

A supervised classification, using the semi-automatic classification plug-in (SCP) tool in QGIS 3.22 was used to process and classify the Landsat-8 images for the various years into five LULC classes.

The Landsat-8 images obtained for each year were stacked/merged using bands 1 to 7. The shapefile for the study area (Kwakwani) was then used to clip each Landsat-8 image.

The IPCC LULC categories was used identified the LULC classes for the clipped Landsat 8 images as mentioned above.

These classes were settlement, cropland, forestland, wetland, and grassland (IPCC 2003). Various band combinations were used iteratively to better identify and create the various training land use land cover classes manually using the Create a Region of Interest (ROI) polygon tool in the SCP. Training classes were identified based on knowledge of the terrain, field observation, and Google Earth time lapse tool. LULC classification for each image was conducted on the macro class ID with the maximum likelihood algorithm.

To obtain the watershed shapefile, one resulting LULC classified image from the previous step was used in the SWAT + model application to delineated the watershed found within the study area. The resulting watershed shapefile was then used to clip the LULC classified images for 2013, 2015, 2017, and 2019 (*see figure 3.3 for the delineated watershed*).

The LULC change between 2013 to 2015 and between 2017 to 2019 was done using the image differencing tool.

### 3.1.3 Accuracy Assessment

Error matrix was used to evaluate the accuracy of LULC maps produced. The matrix is the results comparing ground control pixels with pixels in the classified images. Google Earth Pro was used to randomly extract ground truth points for the five land use classes. For each year, backdating was done in the Google Earth Pro (using the time lapse tool) to accurately capture the land use covers at the various times. For each study year, 200 points were used (minimum 40 per class).

### 3.1.4 LULC Representation

The LULC classes description below was based on the IPCC classification.

The settlement class represented built up or developed areas such infrastructure developments such as roads, and human settlements.

The forestland class represented all areas with woody vegetation.
The cropland class represented arable lands and agroforestry systems where the vegetation is below the threshold for forestland class.
The grassland class represented pasture lands not considered as croplands and falls below the threshold of forestland. It also includes bare lands.
The wetland class represented areas covered by water for throughout the year, it includes also reservoirs and lakes.

#### 3.1.5 Intensity Analysis

The Microsoft Excel intensity calculator developed by Safaa Zakaria Aldwaik (2009), was used to conduct intensity analysis to track the LULC changes in the Kwakwani watershed at the time interval, category, and transition levels between the LULC years. The intensity analysis facilitated the representation of the changes that occurred between the LULC classes over the two LULC change periods, that is 2013 to 2015 and 2017 to 2019.
The intensity analysis was used to determine in which period the overall change in the LULC was slow or fast. It was used also to identify which LULC class were dormant or active. Furthermore, the intensity analysis was used to determine which LULC class avoided or targeted each other.

## 3.2 SWAT+ Modelling

The SWAT+ modelling required spatial and non-spatial datasets for the study area (watershed) to model the impacts of LULC on hydrological parameters. As such, the SWAT+ model utilised climatic data (daily precipitation, maximum and minimum temperature, relative humidity, solar radiation, and wind speed data); digital elevation model (DEM), land use, and soil data for the Kwakwani watershed.

#### 3.2.1 Climate Data

Daily climatic data obtained, included precipitation, temperature, solar radiation, wind speed, and humidity. The daily climatic data were collected from the Climate Forecast System Reanalysis (CFSR) for the period of 1991- 2021 (30 years).

The data obtained for each of the climatic parameter was processed and arranged using Microsoft excel and save as Comma delimited (*.csv) files for compatibility with the SWAT + model.

### 3.2.2 Digital Elevation Model (DEM)

A single date DEM imagery for the study area, characterized by a 30 m x 30 m resolution was obtained from the United States Geological Survey Earth Explorer (USGS Earth Explorer) data portal. The watershed shapefile used for the LULC change analysis above, was used to clip the DEM imagery. The resulting image was assigned the projected coordinate of PSAD56 / UTM zone 21N - EPSG:24821 to be compatible with the SWAT+ application. *(see figure 3.1 for the resulting DEM)*

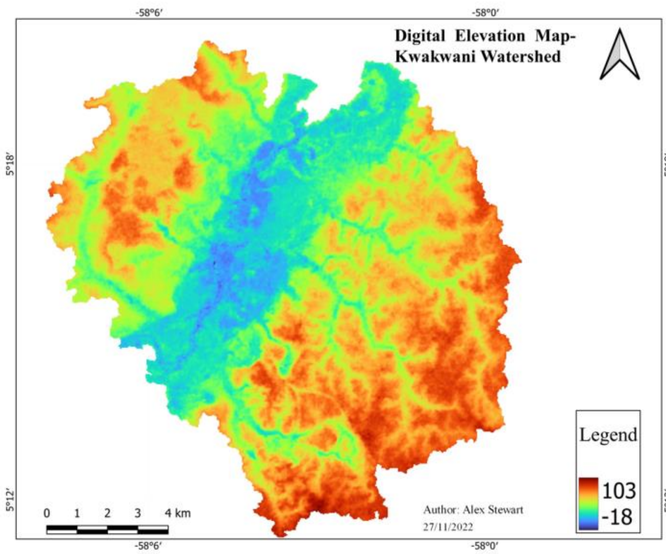


**Figure 3.1 Digital elevation map of the Kwakwani watershed study area.**

### 3.2.3 Land Use Data

The LULC maps for each year that was developed for the LULC analysis above were assigned the projected coordinate of PSAD56 / UTM zone 21N - EPSG:24821 for compatibility with the SWAT + model. The land use classes of Forestland, Grassland, Cropland, Wetland, and Settlements were re-coded into WATR, AGRL, FRST, PAST, and URBN respectively for compatibility in the SWAT+ model.

### 3.2.4 Soil Data

Soil data was obtained from the FAO Digital Soil Map of the World (DSMW) global soil database. The watershed shapefile used in the LULC change analysis above was used as a clip to obtain the soil data for the study area in Arc GIS. The resulting map was given the projected coordinate of PSAD56 / UTM zone 21N - EPSG:24821 for compatibility with the SWAT + model *(see figure 3.2 for soil map).*

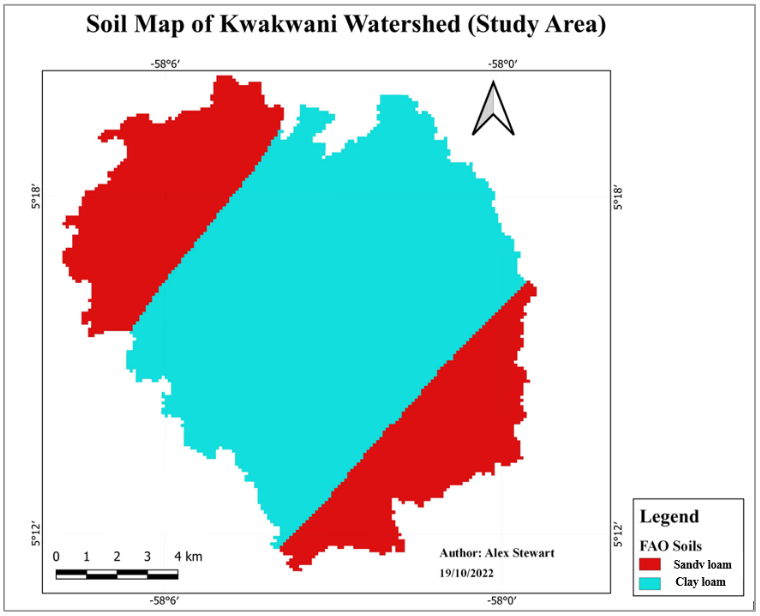


**Figure 3.2 Soils maps for soil types found within the Kwakwani watershed.**

The figure 3.3 below represents the steps taken to simulate the impacts of LULC on sediment yield, surface runoff, and evapotranspiration using the SWAT+ model.

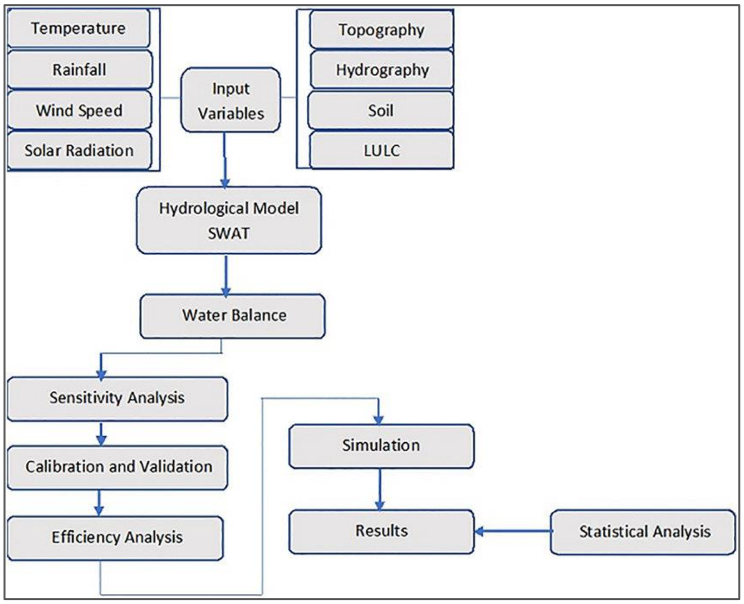


**Figure 3.3 Methodology used for the SWAT model. (Source: Samuel et al. 2020)**

### 3.2.5 Watershed Delineation

The watershed delineation process by the SWAT+ model delineates possible watersheds found within a geographic area primarily based on elevation of the land. One watershed was delineated by the model for the Kwakwani watershed *(see figure 3.4).*

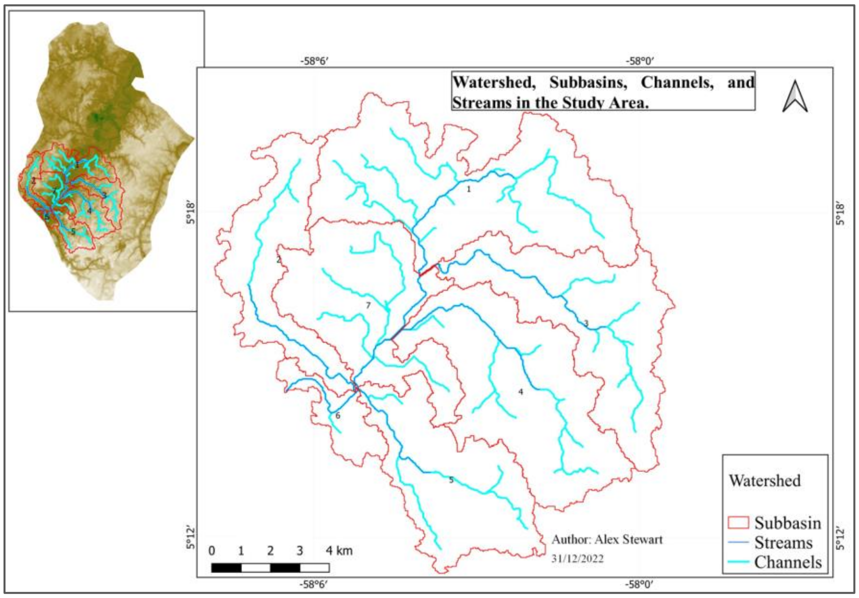


**Figure 3.4 Watershed delineated by the SWAT model showing sub basins, channels and streams**

## 3.3 Community Assessment

The questionnaire method was utilized to conduct a community assessment to understand the impacts of flooding disasters on livelihoods in Kwakwani. Based on the population size of the Kwakwani community, a total of 248 households were selected for sampling. Three visits were made to the Kwakwani community to complete the assessment.

Questionnaires developed were administered to the residents of Kwakwani to document their experiences and perception on flooding impacts and LULC changes. According to Doyle et al. (2020), this method is excellent for collecting data within areas where the data may not be readily available.

### 3.3.1 Target Population and Sampling Method

Since sampling and participation of the entire population within Kwakwani watershed was not possible due to budget and time, a subset of the population was done. As such, the Krejcie and Morgan's 1970 method to determine population size for sampling was used (Krejcie and Morgan 1970). This resulted in the selection of 248 households out of a total of 695 for sampling (Bureau of Statistics of Guyana 2012).

The research planned on selecting households for sampling based on their lot numbers, however, many of the household in the community were without a lot number. As a result, houses were selected for participation in the survey based on the location of the houses. This resulted in the sampling of every other home to make up the 248 samples needed for the survey.

### 3.3.2 Questionnaire Survey

The questionnaire administered consisted of twenty questions in total, in three sections. Section one consisted of four questions aimed at collecting demographic information. Section 2 consisted of seven questions aimed at collecting information on current and past LULC activities. Section three consisted of nine questions, aimed at collecting information on flooding impacts. Prior to administering the questionnaire, the purpose of the survey was explained and permission was sought from the respondents.

All participants were informed of their rights and were required to provide consent to participate in the survey. Only the completed surveys, that satisfied the criteria were used for the data analysis.

## 4 CHAPTER FOUR: RESULTS

### 4.1 LULC Change Analysis

Figure 4.1 below represents the LULC classification for 2013, 2015, 2017, and 2019. It can be seen that the Forestland class was the highest land cover in each year. Classification errors can be seen between 2013 and 2015 where the Settlement class shrinks and also where the wetland class increased in 2015. Between 2017 and 2019 cropland class showed an increase.

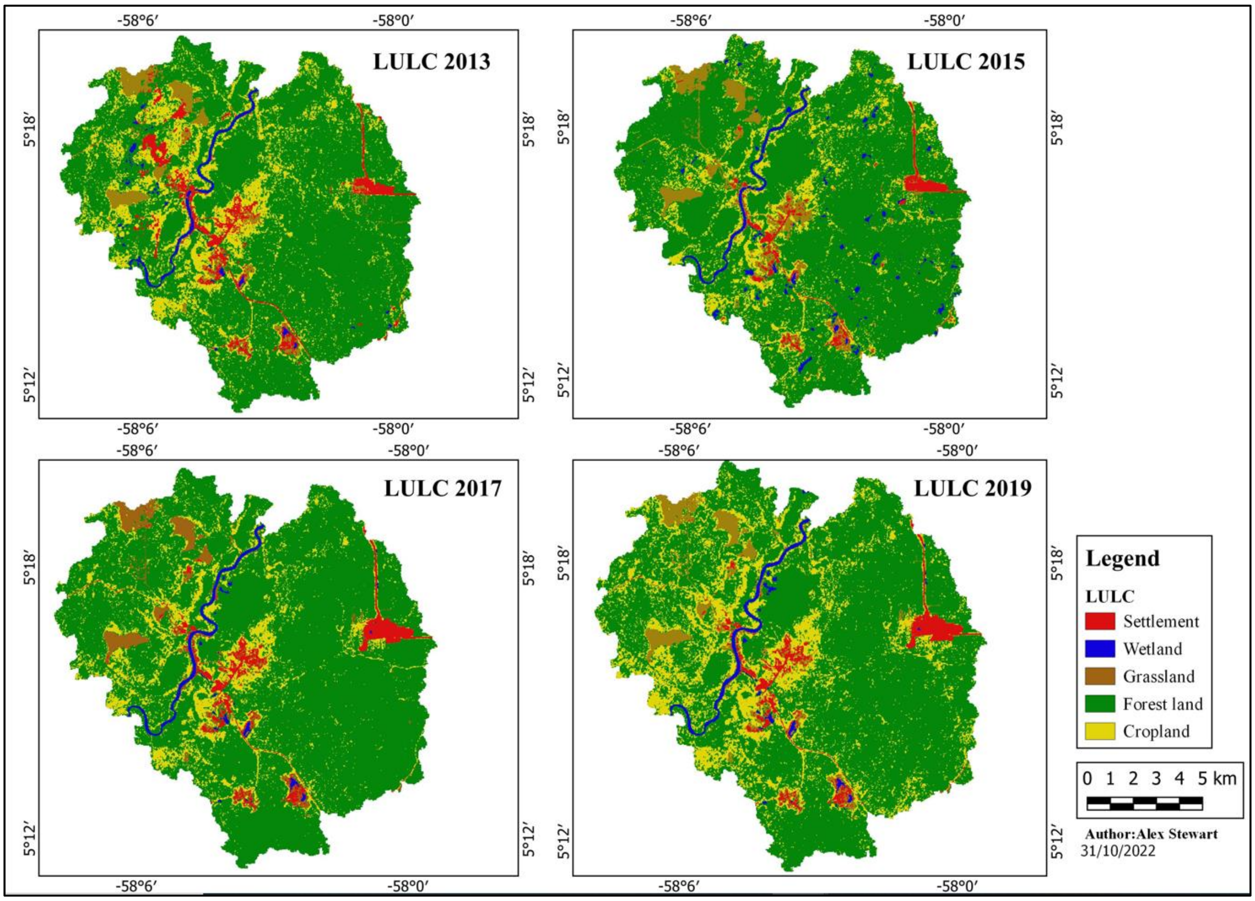


**Figure 4.1 LULC classification for 2013, 2015, 2017, and 2019 for the Kwakwani watershed.**

Table 4.1 below shows the LULC area and percentage within four LULC change years. The results revealed that forestland accounted for the highest land use coverage in each LULC year, followed by cropland; while grassland and settlement percentages fluctuated throughout; and the wetland class recorded the lowest percentage throughout the LULC scenarios.

**Table 4.1 LULC area and percentage within four LULC change scenarios.**

| Year | Land Use | Land cover(ha) | %Cover |
|---|---|---|---|
| | Settlement | 533.8 | 3.3 |
| | Wetland | 127.4 | 0.8 |
| 2013 | Grassland | 470 | 2.9 |
| | Forestland | 12,455.70 | 76.9 |
| | Cropland | 2,601.90 | 16.1 |
| | Settlement | 231.9 | 1.4 |
| | Wetland | 128.4 | 0.8 |
| 2015 | Grassland | 723.2 | 4.5 |
| | Forestland | 13,320.10 | 82.3 |
| | Cropland | 1785.5 | 11 |
| | Settlement | 377.4 | 2.3 |
| | Wetland | 144.8 | 0.9 |
| 2017 | Grassland | 473.5 | 2.9 |
| | Forestland | 13,400.40 | 82.8 |
| | Cropland | 1,793.60 | 11.1 |
| | Settlement | 378.7 | 2.3 |
| | Wetland | 151.4 | 0.9 |
| 2019 | Grassland | 472.9 | 2.9 |
| | Forestland | 12,147.40 | 75 |
| | Cropland | 3,039.30 | 18.8 |

### 4.1.1 Accuracy Assessment

The accuracy assessment demonstrated that the overall accuracy of each map produced was over 80% for all years. There was visibly confusion or misclassification between the wetland class and the forestland class in 2015 (*see figure 4.1*) which may have accounted for 2015 receiving the lowest overall accuracy.

**Table 4.2 Accuracy assessment**

| LULC year | Samples Count | Overall Accuracy |
|---|---|---|
| 2013 | 200 | 86.21 |
| 2015 | 200 | 83.11 |
| 2017 | 200 | 87.00 |
| 2019 | 200 | 85.00 |

### 4.1.2 LULC Change Detection

The LULC changes that occurred between 2013 to 2015 and 2017 to 2019 are represented in figures 4.2 and 4.3 below. The maps pin points where the changes have occurred amongst the LULC classes

Table 4.3 represents the changes in the number of pixels that each land-use class underwent between 2013 to 2015. The forestland class underwent the highest changes between 2013 and 2015. These changes are represented spatially in figure 4.2.

**Table 4.3 Variation matrix for land use classes based on number of pixels.**

| | | 2015 | | | | | |
|---|---|---|---|---|---|---|---|
| | **Categories** | Settlement | Wetland | Grassland | Forestland | Cropland | Total |
| | Settlement | 3068 | 68 | 2297 | 1836 | 666 | 7935 |
| | Wetland | 4 | 1691 | 86 | 525 | 39 | 2345 |
| **2013** | Grassland | 357 | 34 | 6023 | 505 | 252 | 7171 |
| | Forestland | 249 | 1522 | 1132 | 120569 | 7992 | 131464 |
| | Cropland | 128 | 292 | 865 | 15661 | 13969 | 30915 |
| | Total | 3806 | 3607 | 10403 | 139096 | 22918 | 179830 |

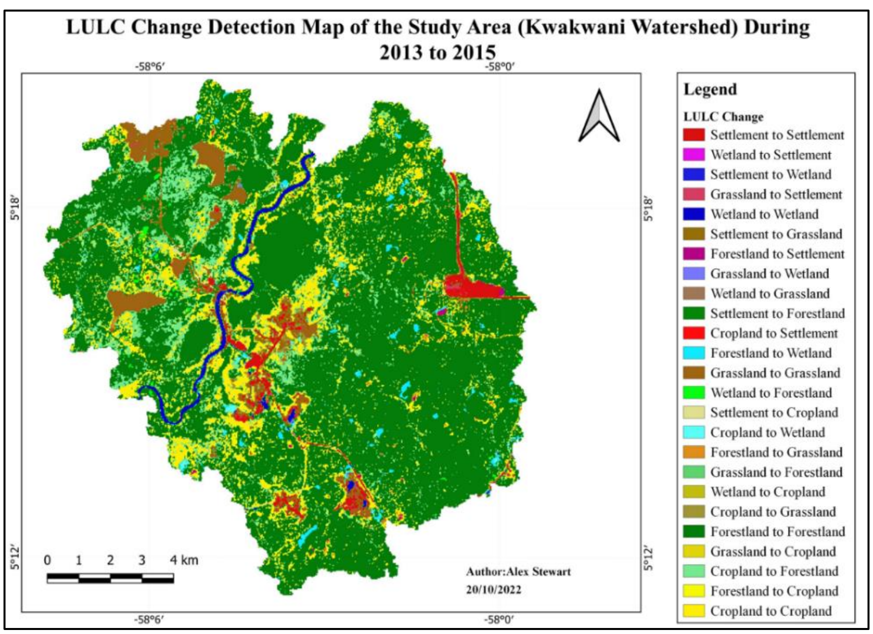


**Figure 4.2 LULC changes between 2013 and 2015**

Table 4.4 represents the changes in the number of pixels that each land-use class underwent between 2017 to 2019. Zero changes categories between 2017 to 2019 were observed which included changes from wetland to settlement, grassland to wetland, cropland to wetland, settlement to forestland, grassland to forestland, wetland to forestland, and wetland to croplandThe forestland class underwent the highest changes between 2017 and 2019. The changes are represented spatially in figure 4.3 below.

**Table 4.4 Variation matrix for land use classes based on number of pixels.**

| | | **2019** | | | | | |
|---|---|---|---|---|---|---|---|
| | **Categories** | Settlement | Wetland | Grassland | Forestland | Cropland | Total |
| | Settlement | 5079 | 1 | 175 | 0 | 6 | 5261 |
| | Wetland | 0 | 2223 | 6 | 0 | 0 | 2229 |
| **2017** | Grassland | 84 | 0 | 7398 | 0 | 100 | 7582 |
| | Forestland | 66 | 182 | 162 | 129431 | 11857 | 141698 |
| | Cropland | 30 | 0 | 6 | 130 | 22894 | 23060 |
| | Total | 5259 | 2406 | 7747 | 129561 | 34875 | 179830 |

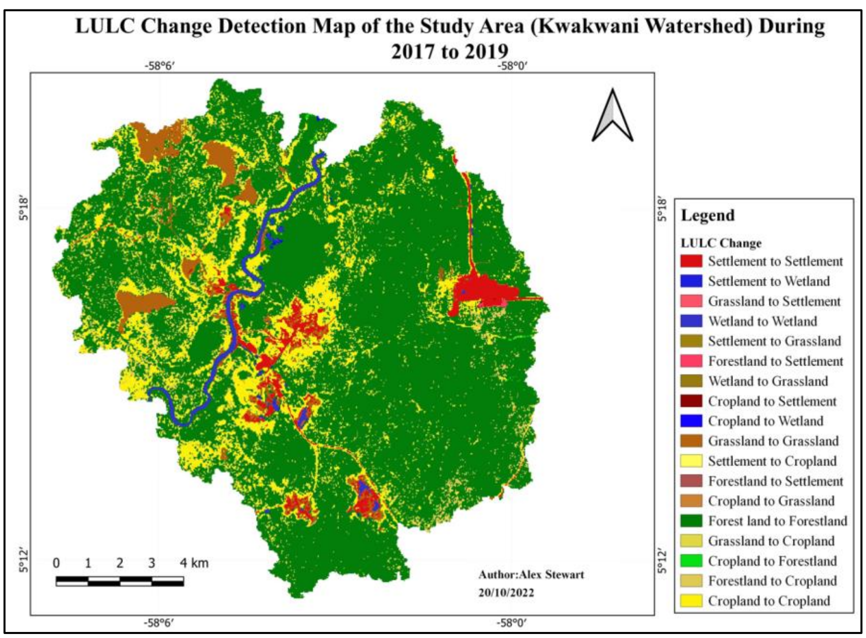


**Figure 4.3 LULC changes between 2017 and 2019**

## 4.2 Change Intensity Analysis

The LULC transfer matrix for the LULC years has been used to determined the LULC changes for the Kwakwani watershed.

### 4.2.1 Change Intensity for 2013 to 2015 and 2017 to 2019

Figure 4.4 below shows the change intensity, and the total change area for Kwakwani watershed for two-time intervals. The blue bars indicate the percentage of change in the time intervals or periods of the study. While the orange bars are expressing the intensity of change during the study periods. The red broken line represents the uniform intensity threshold which was 4.39. Orange bars extending beyond this line considers the change as fast. It can be seen that the total land use changes were fast during 2013 to 2015, while changes were slow between 2017 and 2019.

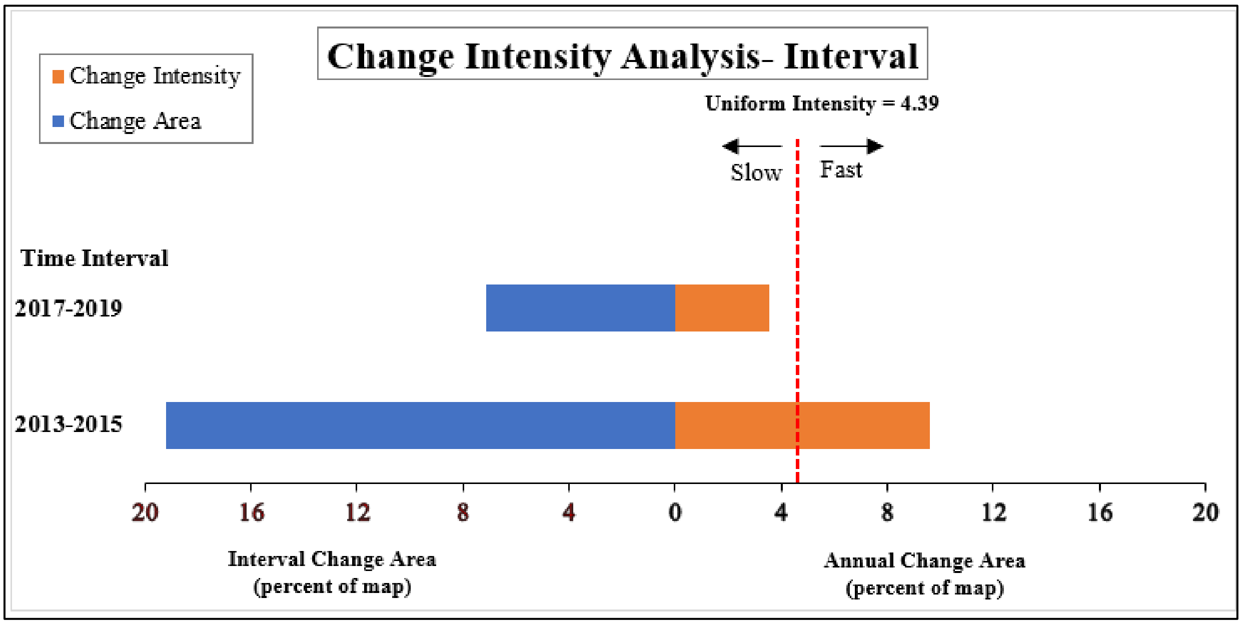


**Figure 4.4 Change intensity analysis for the Kwakwani watershed for two-time intervals, 2013 to 2015 and 2017 to 2019.**

### 4.2.2 Category Level Change Intensity (2013 to 2015)

Figure 4.5 below depicts the intensity of changes with respect to the LULC classes for the study period 2013 to 2015. The figure indicates whether the intensity of the changes in gains or losses were dormant (lower than the uniform intensity) or active (greater than the uniform intensity) amongst each land use class for the period. The blue bars extending to the right represents loss in the LULC class while the orange bars represent gains for the LULC class. The red broken line represents the uniform intensity of 9.6%. It can be seen that the cropland, wetland, and settlement experienced active loss and gains between the time period. the change intensity for forestland was dormant.

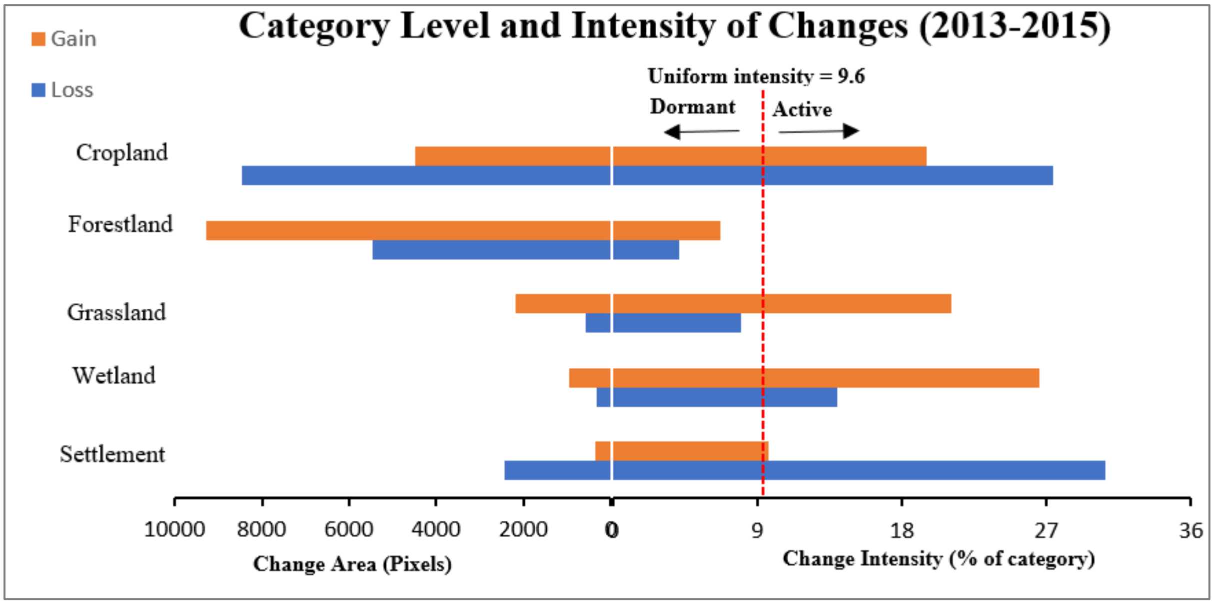


**Figure 4.5 Categorical change intensity of LULC classes for the study period 2013 to 2015.**

### 4.2.3 Category Level Change Intensity (2017 to 2019)

Figure 4.6 below depicts the intensity of changes with respect to the land use classes for the study period 2017 to 2019. The blue bars represent gains, while the orange bars represent loss in the LULC class. The red broken line represents the uniform intensity percentage which was 3.5%. It can be seen that cropland, and the wetland classes were active in gains during this period. Forestland was the only class that was active in loss for this period.

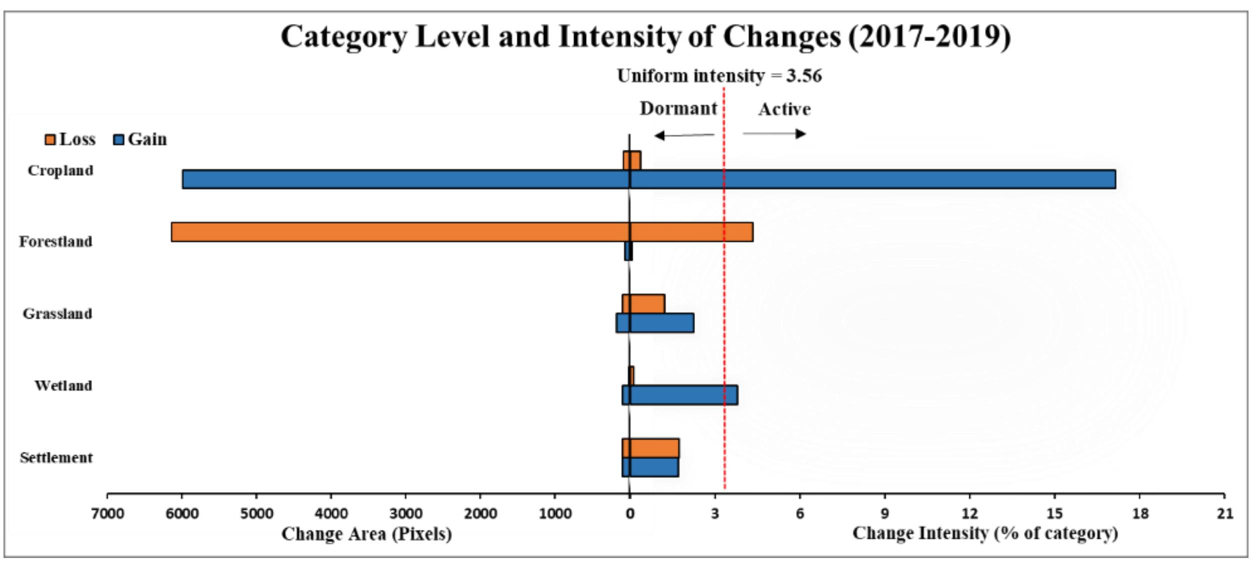


**Figure 4.6 Intensity of changes that occurred amongst the LULC classes during 2017 to 2019.**

### 4.3 Transition of LULC classes between 2013 to 2015

The blue bars in each graph below represents the transition area in pixels while the orange bars represent the transition intensity in percentages. The red broken line represents the uniform intensity. The orange bars extending beyond the broken line will indicate that the LULC class under review targeted the other classes. Bars that does not extend beyond the red broken line, indicates that the LULC class under review avoided transition to that class.

#### 4.3.1 Transition from the other classes to Settlement

Figure 4.6 below shows that during 2013 to 2015, settlement targeted the grassland class and avoided all other classes. The transition intensity was 2.52% with an overall uniform intensity of 0.21%.

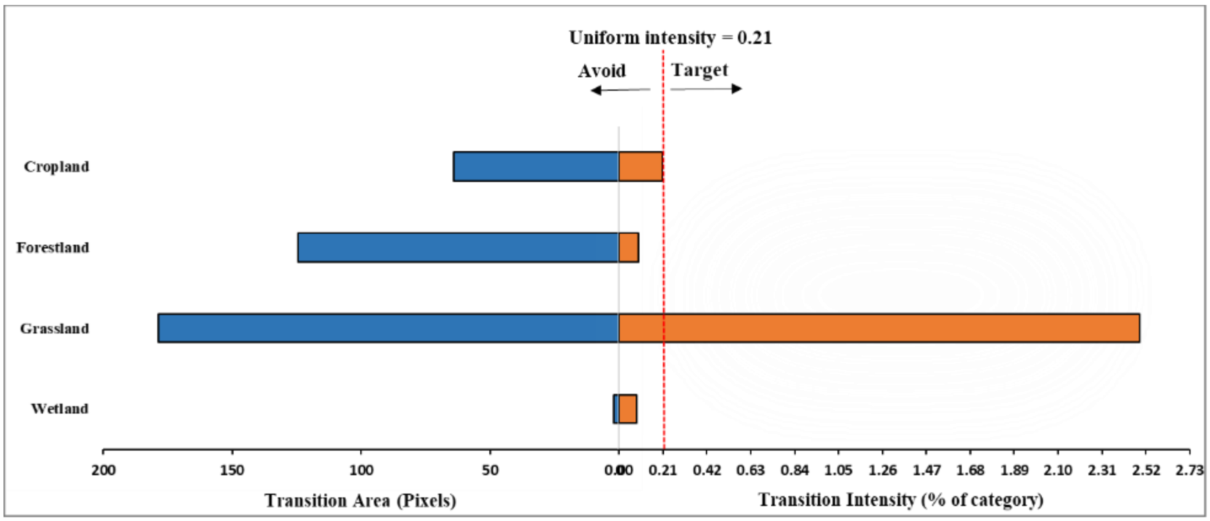


**Figure 4.7 Transition from the other classes to Settlements between 2013 to 2015.**

#### 4.3.2 Transition from the other classes to wetland

Figure 4.7 below shows that wetland targeted the forestland class and avoided the others. The uniform intensity of was 0.54%.

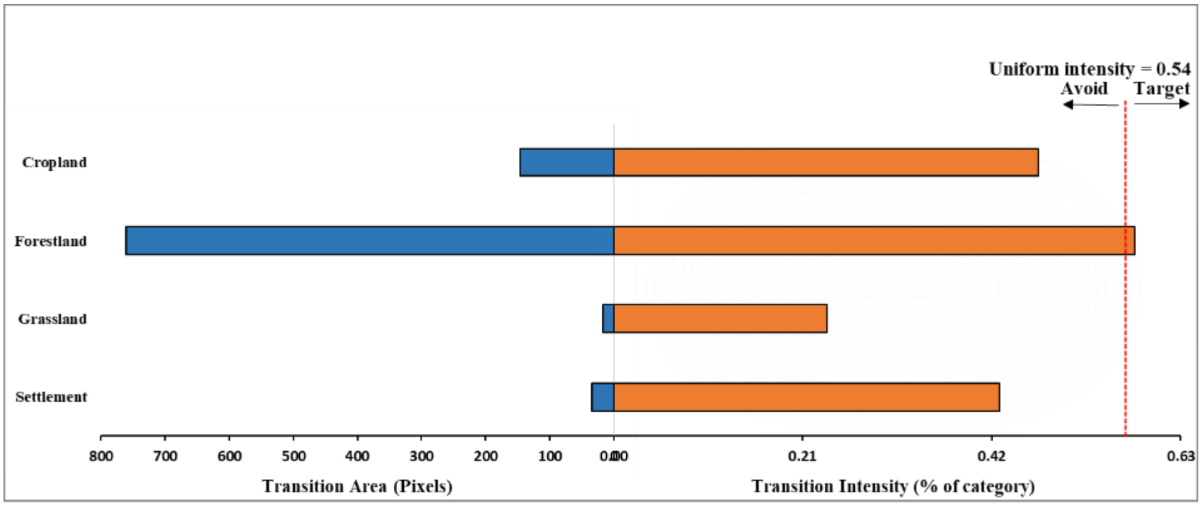


**Figure 4.7 Transition from other classes to Wetland between 2013 to 2015.**

## Transition from other classes to grassland

Figure 4.8 shows that during this period, grassland targeted settlement with a transition intensity of 14.5%, followed by wetland with a transition intensity of 2% and cropland which had a transition intensity of 1.5%. The uniform intensity was 1.27%.

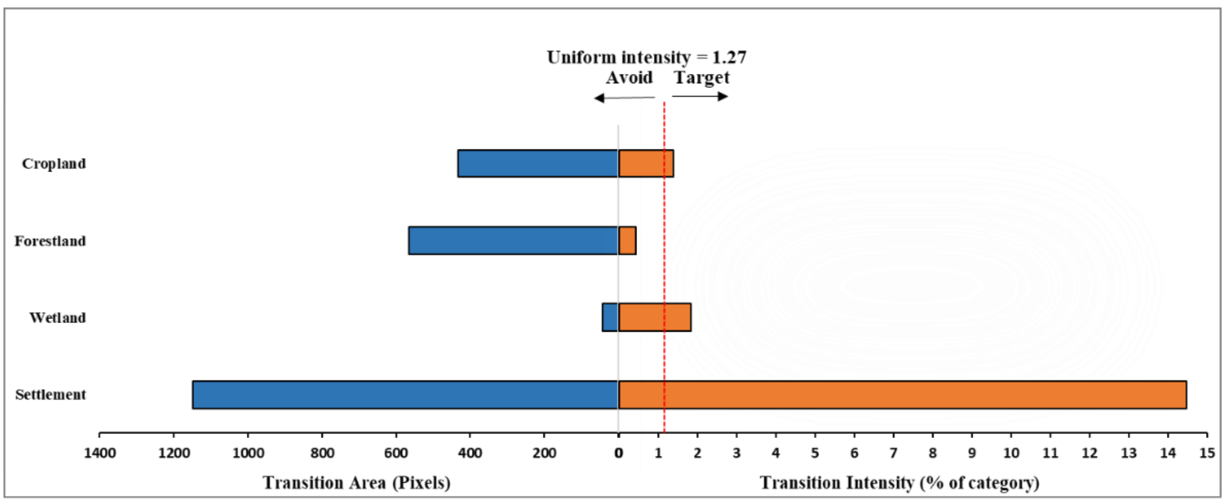


**Figure 4.8 Transition from other classes to Grassland between 2013 to 2015.**

### 4.3.3 Transition from other classes to forestland

Figure 4.9 below shows that forestland targeted the cropland class during this period with a transition intensity of 25%. The uniform intensity of 19.15%.

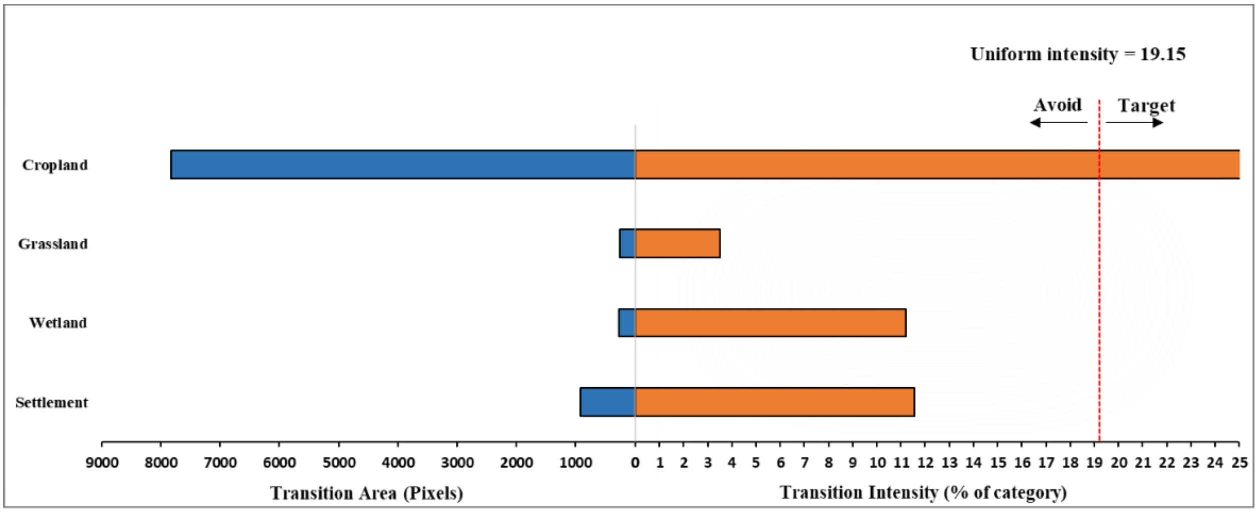


**Figure 4.9 Transition from other classes to forestland between 2013 to 2015.**

### 4.3.4 Transition from other classes to cropland

Figure 4.10 below shows that cropland targeted settlement and forestland LULC cover class during this period. The transition intensity was 4.2% and 3.1% respectively with a uniform intensity of 3%.

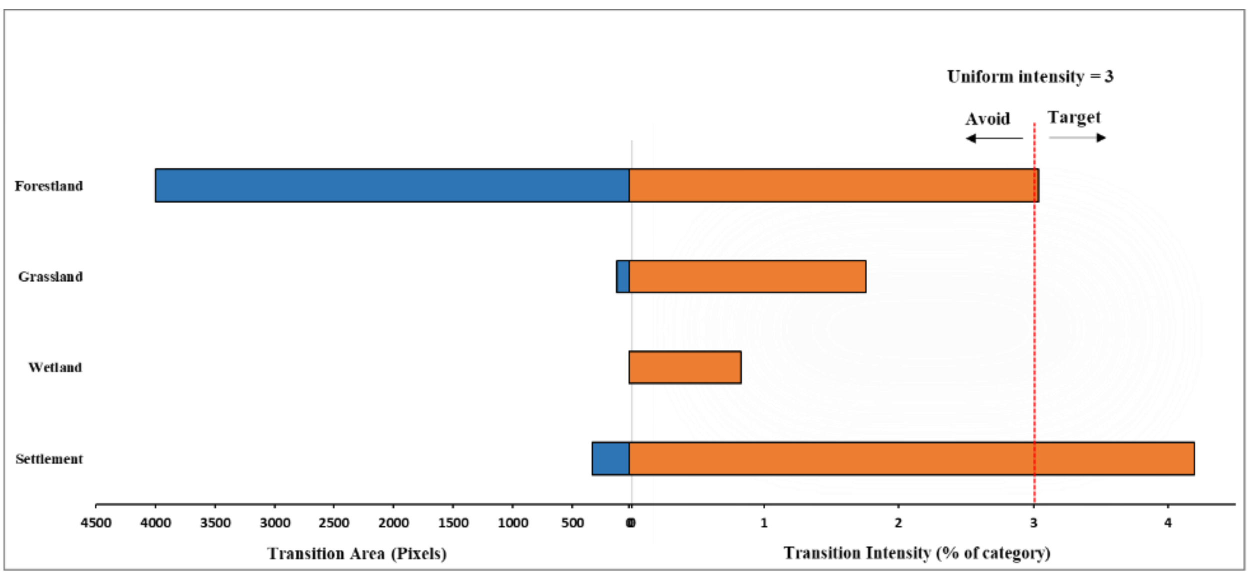


**Figure 4.10 Transition from other classes to cropland between 2013 to 2015.**

## 4.4 Transition of LULC classes between 2017 to 2019

The blue bars in each graph below represents the transition area in pixels while the orange bars represent the transition intensity in percentages. The red broken line represents the uniform intensity. The orange bars extending beyond the broken line will indicate that the LULC class under review targeted the other classes. Orange bars that does not extend beyond the red broken line, indicates that the LULC class under review avoided transition to that class.

### 4.4.1 Transition from other classes to settlement

Figure 4.11 shows that settlement targeted grassland with a transition intensity of 1% and targeted the cropland class with a transition intensity of 0.06% during this period. The uniform intensity was 0.05%.

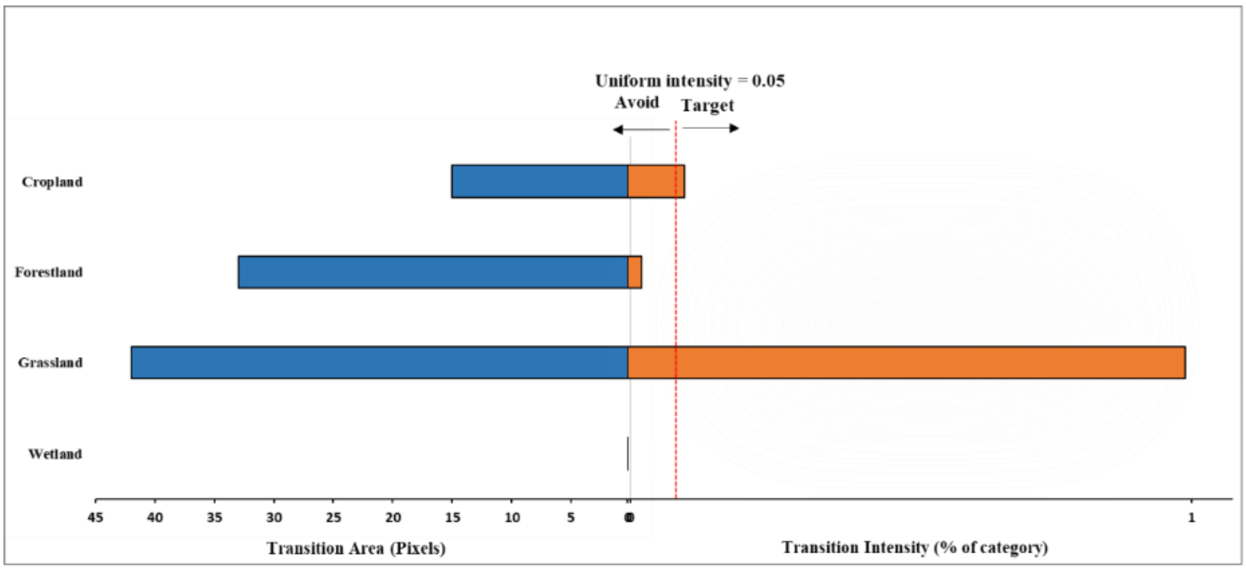


**Figure 4.11 Transition from other classes to Settlement between 2017 to 2019.**

### 4.4.2 Transition from other classes to wetland

Figure 4.12 below shows that wetland targeted only the forestland land-use class during this period with a transition intensity of 0.06% and avoided all other classes. The uniform intensity was 0.05%.

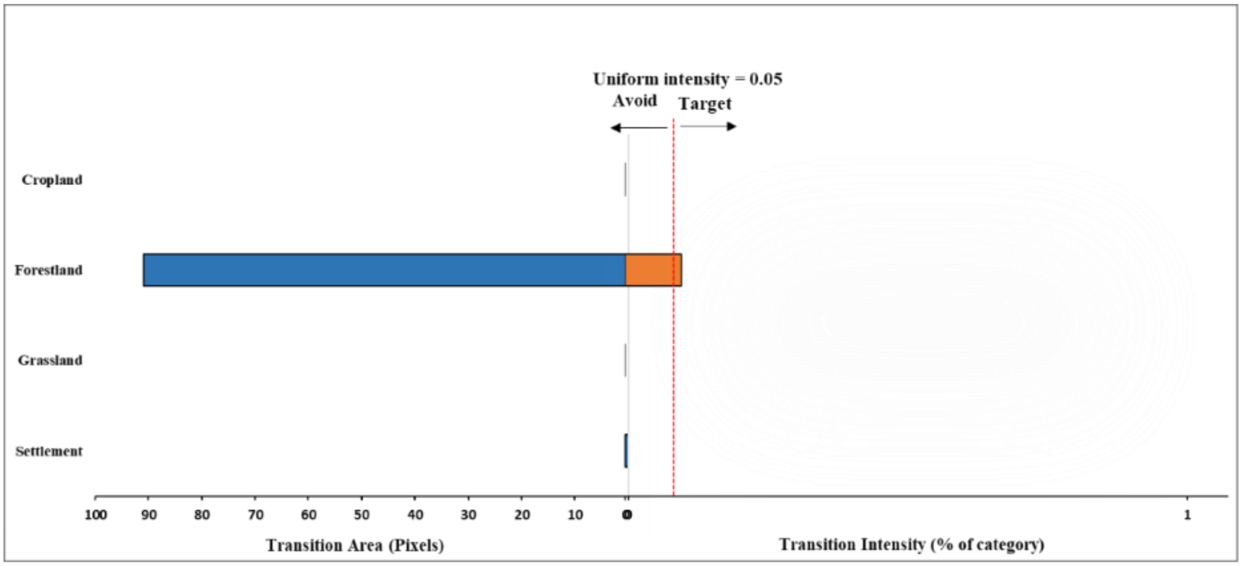


**Figure 4.12 Transition from other classes to Wetland between 2017 to 2019.**

### 4.4.3 Transition from other classes to grassland

Figure 4.13 below shows that grassland targeted settlement with a transition intensity of 1.8% and the wetland class with a transition intensity of 0.12%. The uniform intensity was 0.10%.

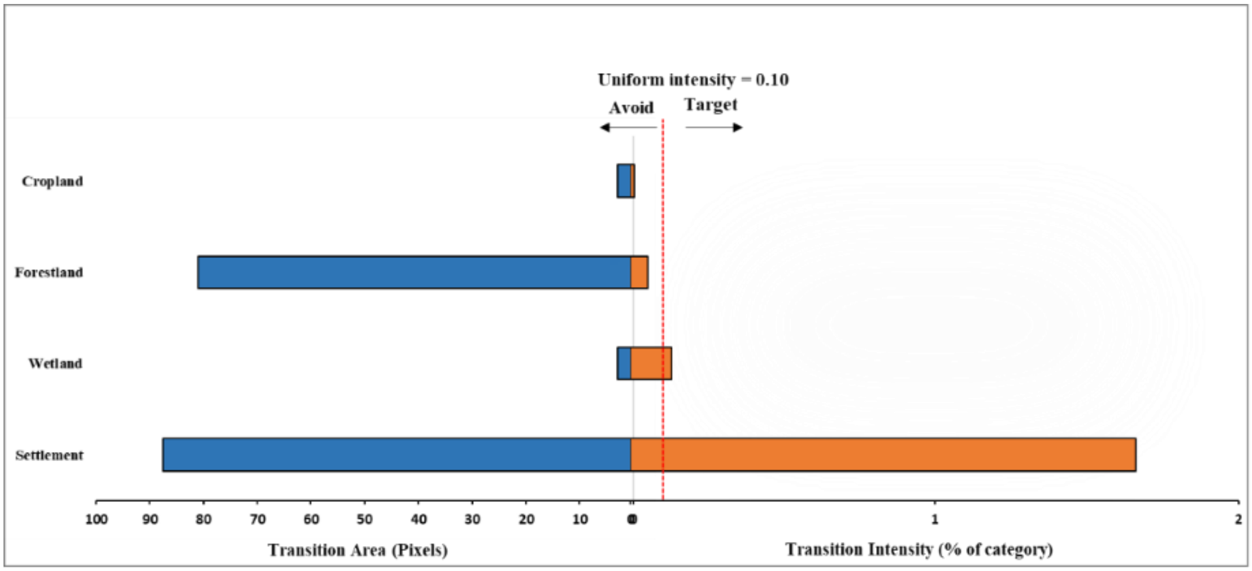


**Figure 4.13 Transition from other classes to Grassland.**

4.4.4 Transition from other classes to forestland

Figure 4.14 below shows that forestland targeted cropland during this period with a transition intensity of 0.3% and avoided the other land-use classes. The uniform intensity was 0.17%.

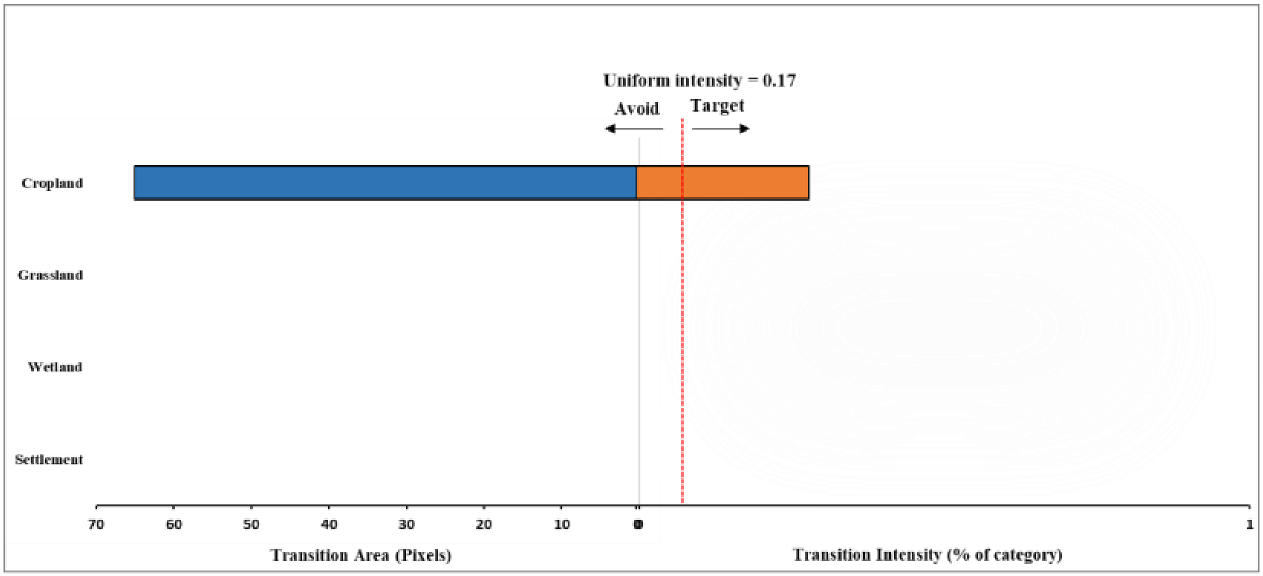


**Figure 4.14 Transition from other classes to Forestland between 2017 to 2019.**

### Transition from other classes to cropland

Figure 4.15 below shows that cropland targeted only forestland during this period with a transition intensity of 4.5% and avoided the other land-use classes. The uniform intensity was 3.8%.

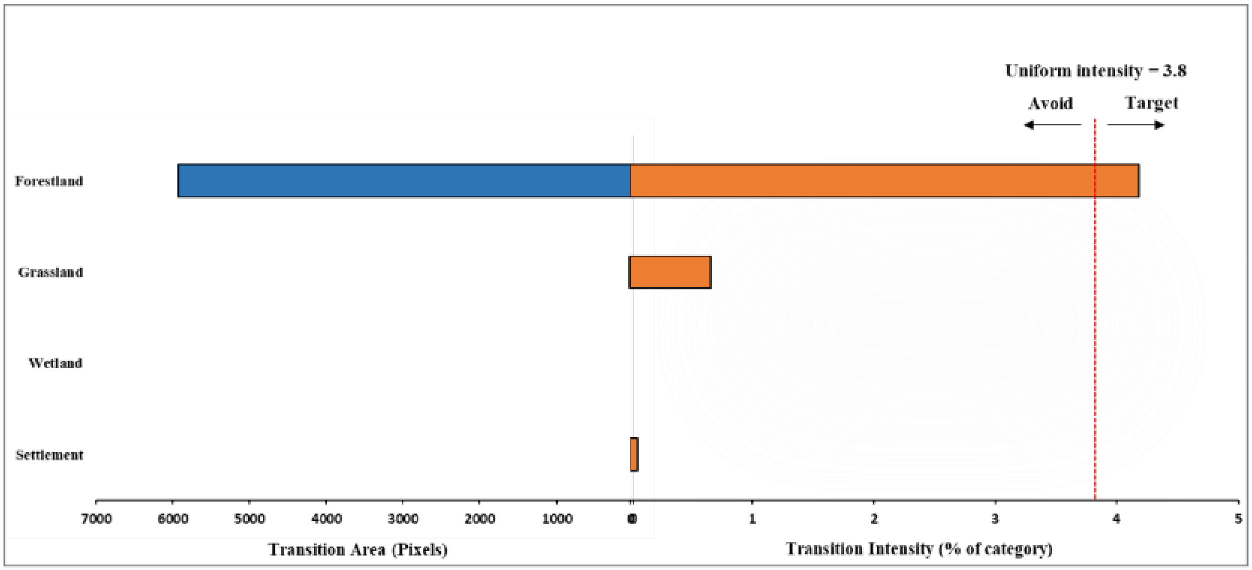


**Figure 4.15 Transition from other classes to Cropland between 2017 to 2019.**

## 4.5 SWAT Analysis- Hydroclimatic Conditions and LULC change years

### 4.5.1 Simulated Surface Runoff

Figure 4.16 below represents the simulated surface runoff that occurred under the 2013 LULC year in the Kwakwani watershed. It can be seen that he highest percentage of surface runoff over the landscape was recorded within the magnitude of 910 – 1010 mm. While the lowest percentage of surface runoff was recorded within the magnitude of (1160-1330) mm.

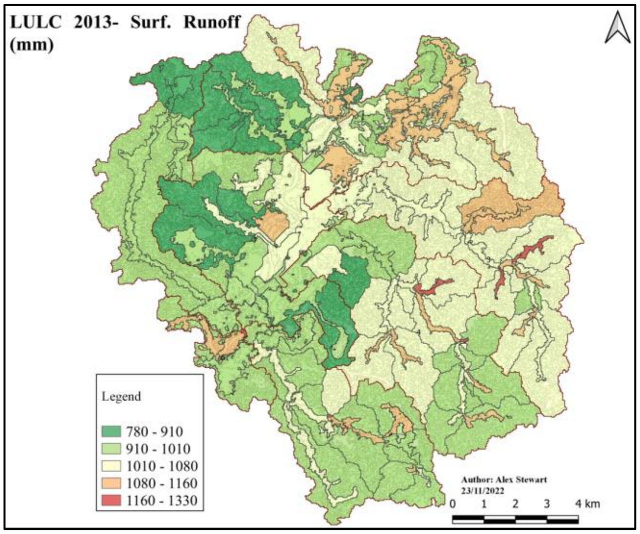


**Figure 4.16 spatial distribution of surface runoff under the 2013 LULC year.**

Figure 4.17 below represents the simulated surface runoff that occurred under the 2015 LULC year. It can be seen that the highest percentage of surface runoff over the landscape was recorded within the magnitude of 920-1010 mm. The lowest percentage of surface runoff was recorded between the magnitude 1160-1270 mm.

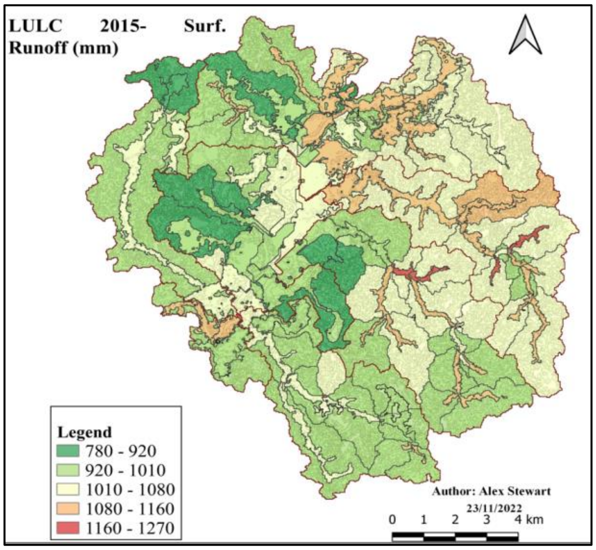


**Figure 4.17 spatial distribution of surface runoff under the 2015 LULC year.**

Figure 4.18 below represents the simulated surface runoff that occurred under the 2017 LULC year. It can be seen that the highest percentage of surface runoff over the landscape was recorded within the magnitude of 950-1030 mm. The lowest percentage of surface runoff was recorded within the magnitude 1190-1410 mm.

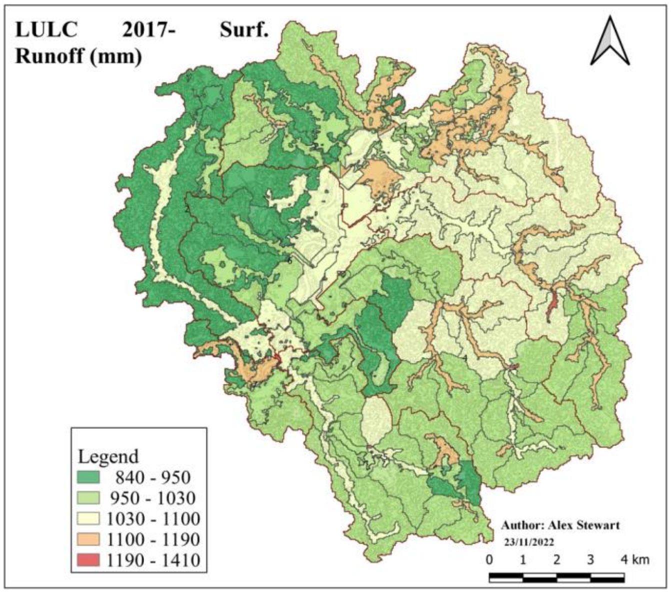


**Figure 4.18 spatial distribution of surface runoff under the 2017 LULC year.**

Figure 4.19 below represents the simulated surface runoff that occurred under the 2019 LULC year. It can be seen that the highest percentage of surface runoff over the landscape was recorded within the magnitude of 930-1020 mm. The lowest percentage of surface runoff was recorded within the magnitude 1180-1360 mm.

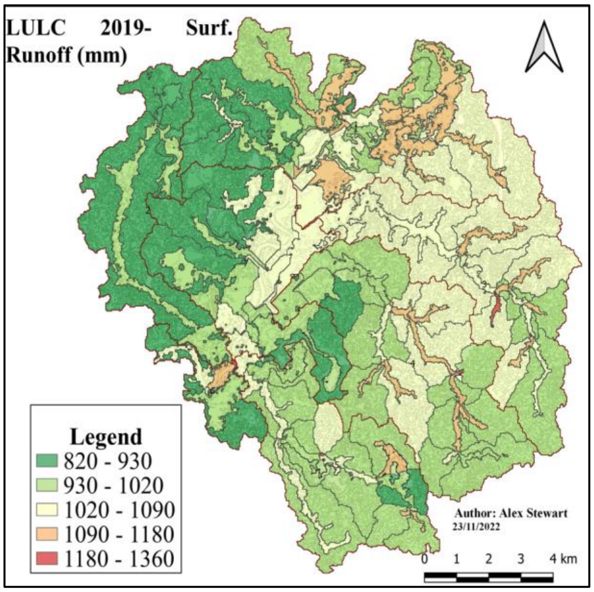


**Figure 4.19 spatial distribution of surface runoff under the 2019 LULC year.**

### 4.5.2 Descriptive Statistics for Surface runoff in the LULC years

Table 4.5 below shows the descriptive statistics for surface runoff under each LULC year. It can be seen that they year 2017 recorded the highest annual average surface runoff of 1019.8 mm, while the lowest surface runoff was recorded in 2019 of 995.3 mm. This information is depicted in the bar chart in figure 4.20 below.

**Table 4.5 Descriptive statistics for surface runoff**

| LULC Year | Mean | Mode | Median | Std. Deviation | Std. Error | Minimum | Maximum | Confidence level interval (95%) |
|---|---|---|---|---|---|---|---|---|
| 2013 | 1005.4 | - | 945 | 360.3 | 68.10 | 322 | 1883 | 139.7 |
| 2015 | 1013.07 | - | 949.5 | 362.0 | 68.41 | 316 | 1893 | 140.3 |
| 2017 | 1019.8 | - | 949 | 360.1 | 68.06 | 327 | 1890 | 139.6 |
| 2019 | 995.3 | - | 943.5 | 361.7 | 68.35 | 315 | 1883 | 140.2 |

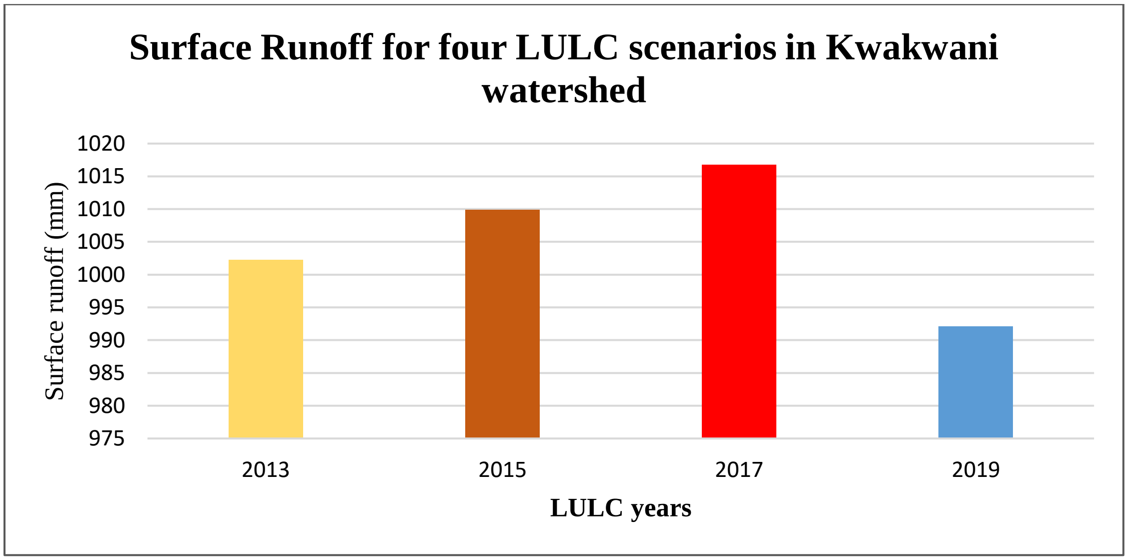


**Figure 4.20 mean surface runoff for LULC years**

### 4.5.3 Simulated Sediment Yield

Figure 4.21 below represents the simulated sediment yield that occurred under the 2013 LULC year. It can be seen that the highest percentage of sediment yield over the landscape was recorded within the magnitude of 0- 0.48t/ha. The lowest percentage of surface runoff across the landscape was recorded within the magnitude of 8.9 – 14.09 t/ha.

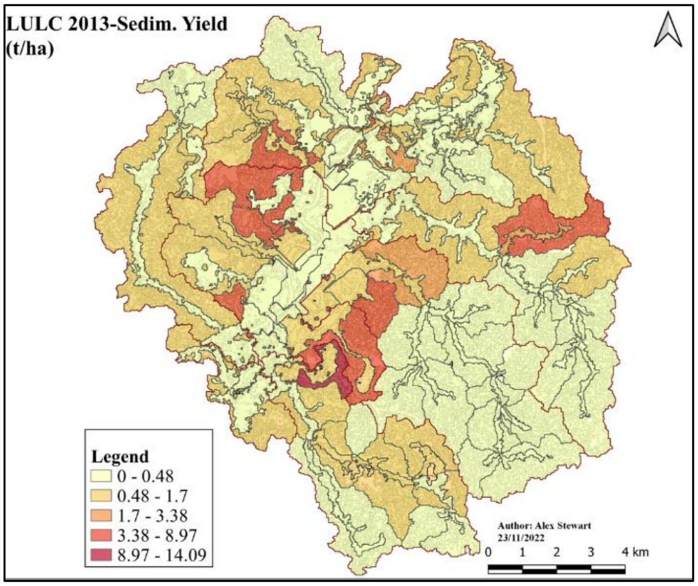


**Figure 4.21 Sediment yield under the 2013 LULC year**

Figure 4.22 below represents the simulated sediment yield that occurred under the 2015 LULC year. It can be seen that the highest percentage of sediment yield across the landscape was recorded within the magnitude of 0.0- 0.5 t/ha. The lowest percentage of surface runoff across the landscape was recorded within the magnitude of 6.2 – 10.3 t/ha.

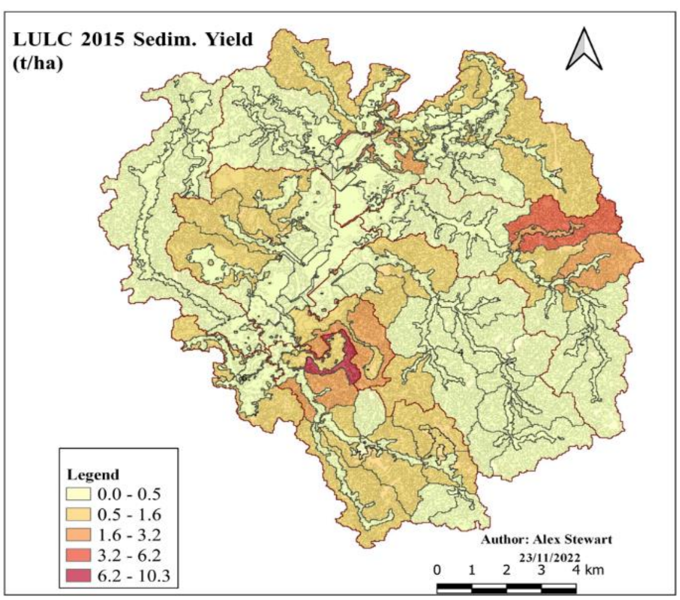


**Figure 4.22 Sediment yield under the 2015 LULC year**

Figure 4.23 below represents the simulated sediment yield that occurred under the 2017 LULC year. It can be seen that the highest percentage of sediment yield across the landscape was recorded within the magnitude of 0.0- 0.5 t/ha. The lowest percentage of surface runoff across the landscape was recorded within the magnitude of 8.1 – 11.2 t/ha.

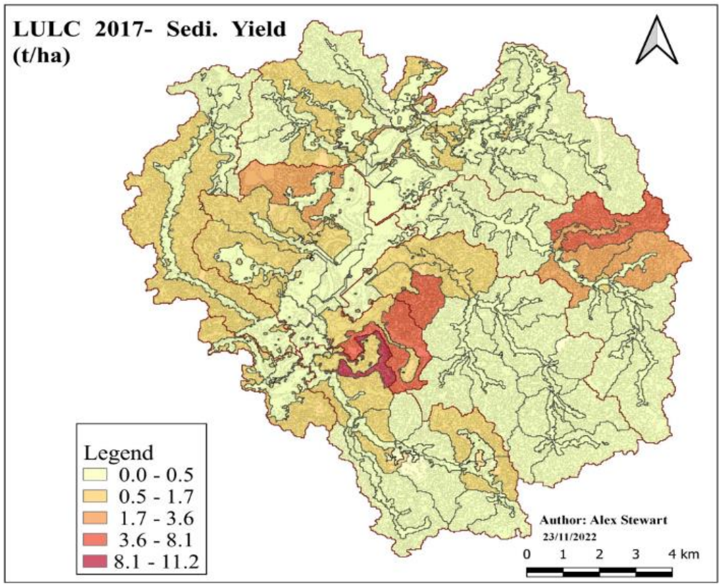


**Figure 4.23 Sediment yield under the 2017 LULC year**

The figure 4.24 below represents the simulated sediment yield that occurred under the 2019 LULC year. It can be seen that the highest percentage of sediment yield across the landscape was recorded within the magnitude of 0.0- 0.6 t/ha. The lowest percentage of surface runoff across the landscape was recorded within the magnitude of 8.1 – 12.3 t/ha.

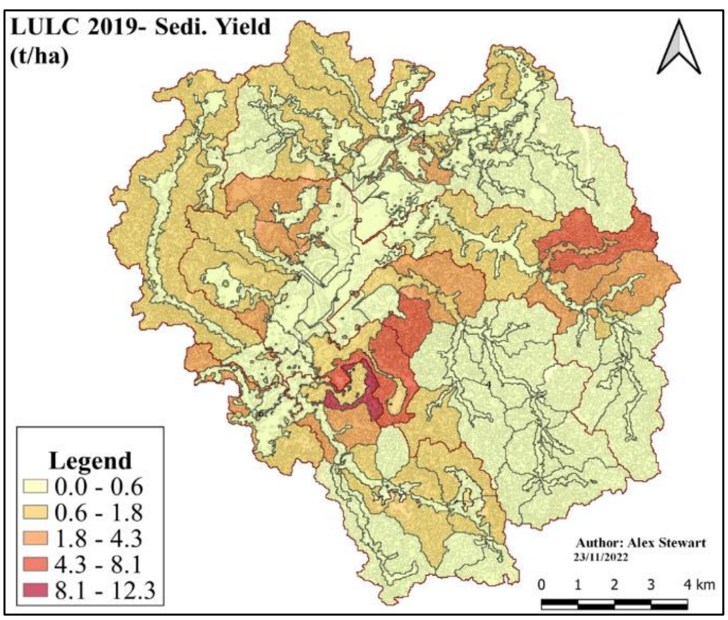


**Figure 4.24 Sediment yield under the 2019 LULC year**

### 4.5.4 Descriptive Statistics for Sediment yield

Table 4.6 below shows the descriptive statistics for sediment yield under each LULC year. It can be seen that the year 2019 recorded the highest annual average sediment yield of 1.094 t/ha while the lowest sediment yield was recorded under the 2015 LULC year of 0.613t/ha. This data is represented in figure 4.25 below.

**Table 4.6 Descriptive statistics for sediment yield**

| LULC Year | Mean | Mode | Median | Std. Deviation | Std. Error | Minimum | Maximum | Confidence level interval (95%) |
|---|---|---|---|---|---|---|---|---|
| 2013 | 1.079 | - | 1.028 | 0.509 | 0.09 | 0.335 | 2.246 | 0.197 |
| 2015 | 0.647 | - | 0.613 | 0.319 | 0.06 | 0.181 | 1.386 | 0.124 |
| 2017 | 0.783 | - | 0.783 | 0.354 | 0.06 | 0.256 | 1.586 | 0.137 |
| 2019 | 1.094 | 0.837 | 1.022 | 0.571 | 0.107 | 0.283 | 2.422 | 0.221 |

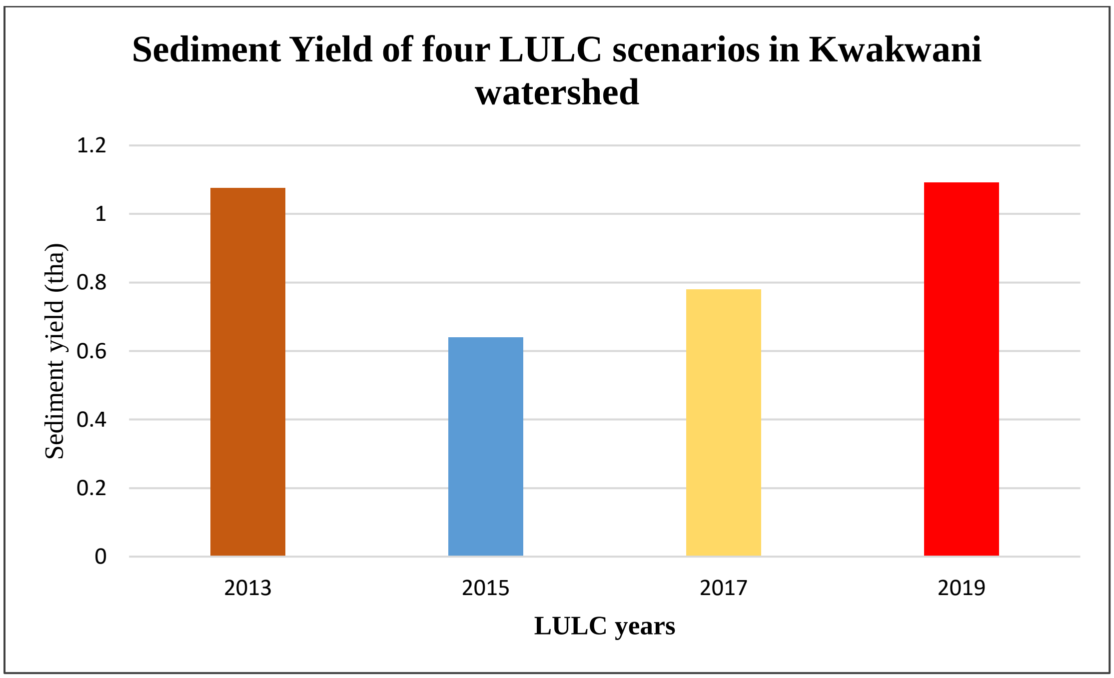


**Figure 4.25 mean sediment yield for LULC years**

4.5.5 Simulated Evapotranspiration

Figure 4.26 below represents the simulated sediment yield that occurred under the 2013 LULC year. It can be seen that the highest percentage of evapotranspiration across the landscape was recorded within the magnitude of 350-450 mm. The lowest percentage of evapotranspiration across the landscape was recorded within the magnitude of 850-1180 mm.

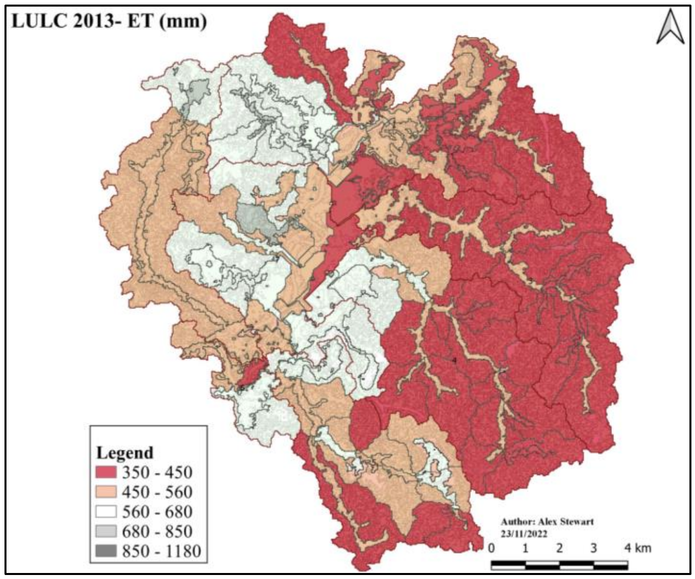


**Figure 4.26 Evapotranspiration under the 2013 LULC year**

Figure 4.27 below represents the simulated sediment yield that occurred under the 2015 LULC year. It can be seen that the highest percentage of evapotranspiration across the landscape was recorded within the magnitude of 430-510 mm. The lowest percentage of evapotranspiration across the landscape was recorded within the magnitude of 850-1100 mm.

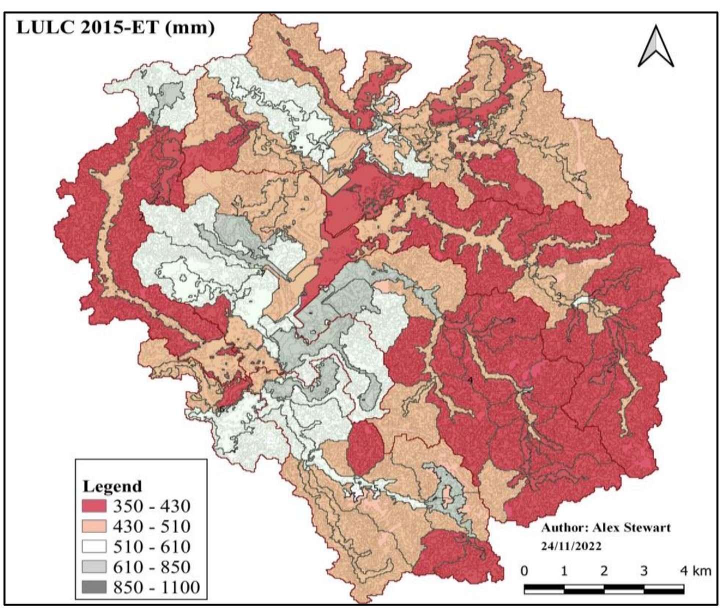


**Figure 4.27 Evapotranspiration under the 2015 LULC year**

Figure 4.28 below represents the simulated sediment yield that occurred under the 2017 LULC year. It can be seen that the highest percentage of evapotranspiration across the landscape was recorded within the magnitude of 350-420 mm. The lowest percentage of evapotranspiration across the landscape was recorded within the magnitude of 670-860 mm.

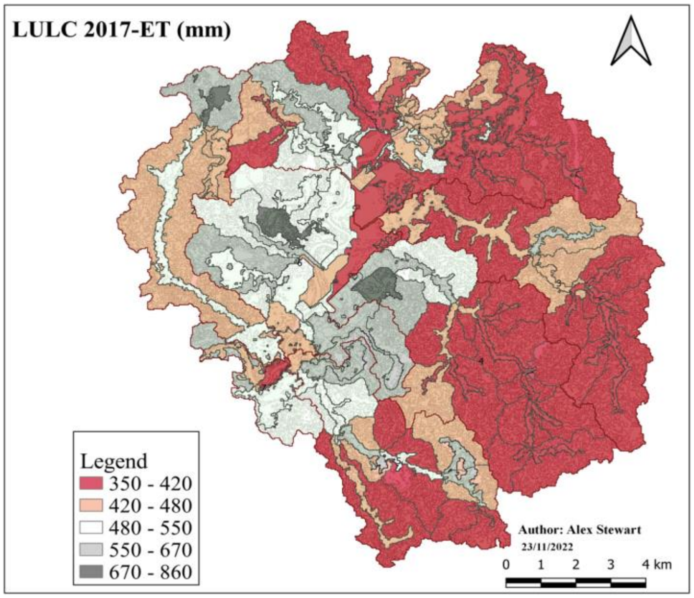


**Figure 4.28 Evapotranspiration under the 2017 LULC year**

The figure 4.29 below represents the simulated sediment yield that occurred under the 2019 LULC year. It can be seen that the highest percentage of evapotranspiration across the landscape was recorded within the magnitude of 350-430 mm. The lowest percentage of evapotranspiration across the landscape was recorded within the magnitude of 670-860 mm.

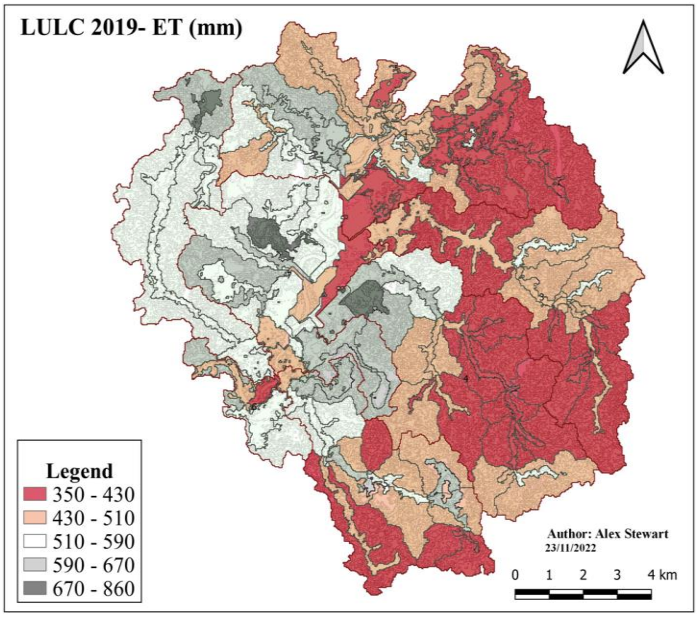


**Figure 4.29 Evapotranspiration under the 2019 LULC year**

### 4.5.6 Descriptive Statistics for Evapotranspiration

The table 4.7 below represents the evapotranspiration that occurred for each LULC year. It can be seen that the year 2019 recorded the highest annual average evapotranspiration of 495.8 mm, while the lowest evapotranspiration was recorded in 2017 of 459.6 mm. This data is represented in figure 4.30 below.

**Table 4.7 Descriptive statistics for evapotranspiration**

| LULC Year | Mean | Mode | Median | Std. Deviation | Std. Error | Minimum | Maximum | Confidence level interval (95%) |
|---|---|---|---|---|---|---|---|---|
| 2013 | 484.3 | 578 | 582.5 | 220.9 | 41.7 | 58 | 830 | 85.6 |
| 2015 | 465.8 | 603 | 560.5 | 213.6 | 40.3 | 57 | 823 | 82.8 |
| 2017 | 459.6 | 563 | 553.5 | 210.2 | 39.7 | 57 | 811 | 81.5 |
| 2019 | 494.8 | 612 | 594.5 | 225.8 | 42.6 | 59 | 873 | 87.5 |

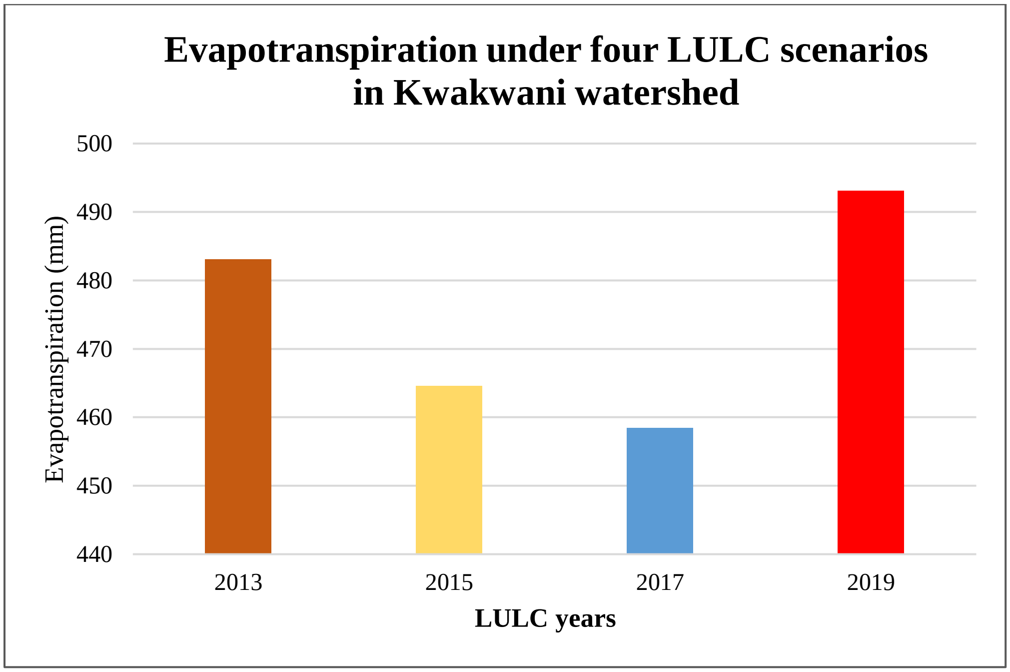


**Figure 4.30 mean evapotranspiration for LULC years**

## 4.6 Community Assessment

### 4.6.1 Demographics of Participants

Table 4.8 below shows the number of males and females' participants for this research. The data shows that 81% of the respondents were females, while 19% were males. Further, Figure 4.31 shows the leading age group of the participants - 25-34 years' age group.

**Table 4.8 Distribution of participants by gender that participated in the community assessment**

| Gender | Frequency | Percentage |
|---|---|---|
| Males | 47 | 19.0 |
| Females | 201 | 81.0 |
| Total | 248 | 100 |

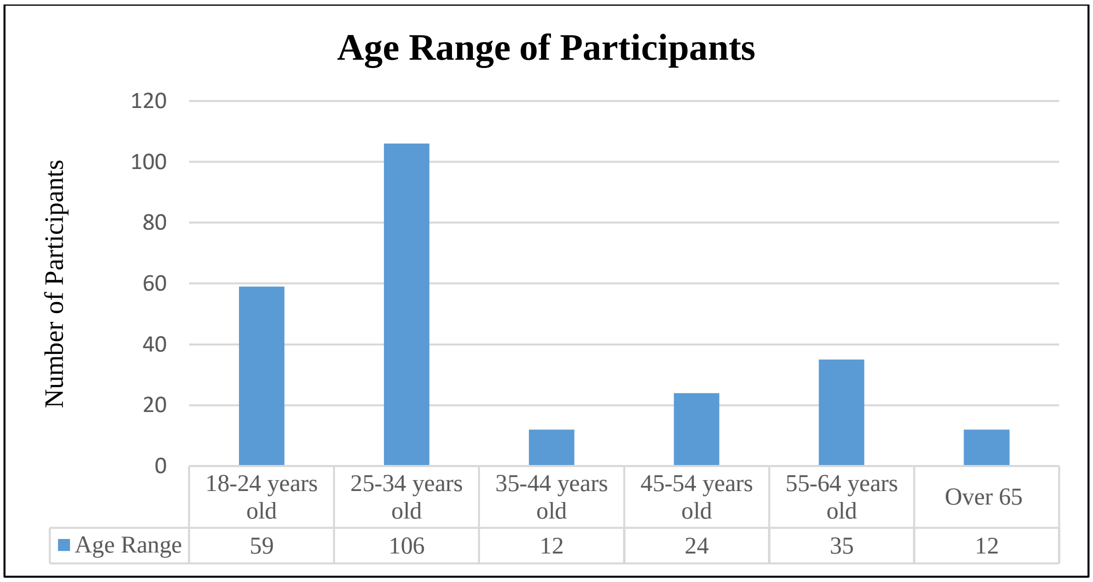


**Figure 4.31 Distribution of participants by age group.**

Table 4.9 below shows that most of the participants (67%) resided in the community for over 20 years; 24% resided between 15-20 years and 10% between 11-15 years. Furthermore, most of the participants have resided in the community for a decade or more.

**Table 4.9 Number of years the participants resided in the community**

| Range | Frequency | Percentage |
|---|---|---|
| 0-5 years | 0 | 0.0 |
| 6-10 years | 0 | 0.0 |
| 11-15 years | 24 | 9.7 |
| 16-20 years | 59 | 23.8 |
| Over 20 years | 165 | 66.5 |
| Total | 248 | 100 |

### 4.6.2 Economic activities

Figure 4.32 below shows that the Forestry sector is recorded as the main economic activity for the community, followed by Agriculture and Construction.

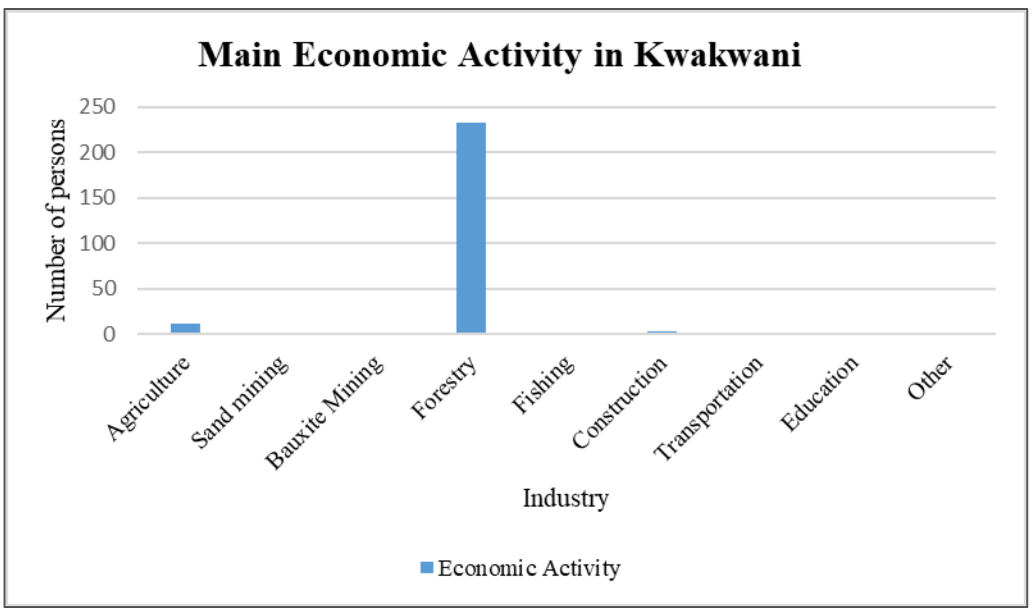


**Figure 4.32 Main economic activities within the Kwakwani watershed**

4.6.3 Flooding and Impacts

The impacts of recent flooding on livelihoods was assessed. Figure 4.33 below shows that 95% of the respondents were affected by recent flooding events. Furthermore, figure 4.34 shows in which year participants were mostly affected by floods, whereby 2021and 2022 were indicated as the years for the most recent flood experiences.

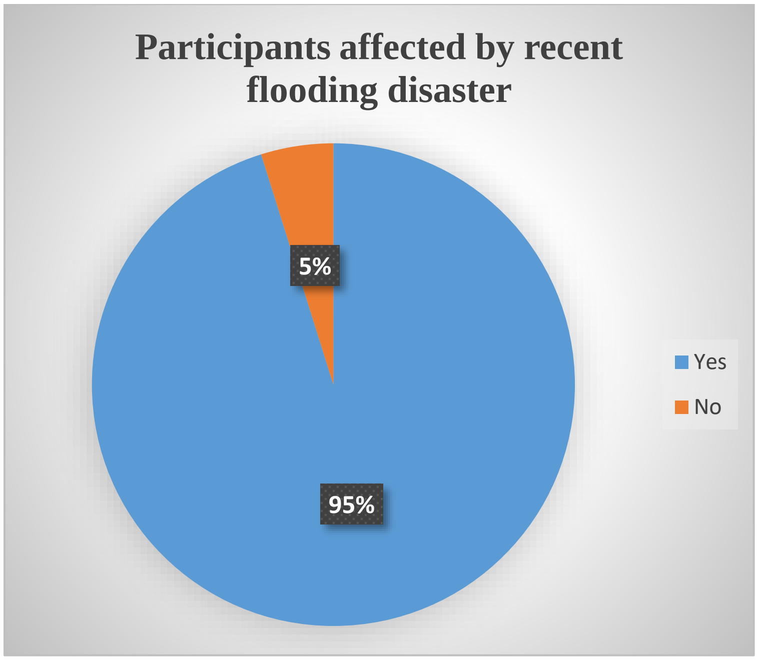


**Figure 4.33 Proportion of respondents affected by recent flooding events**

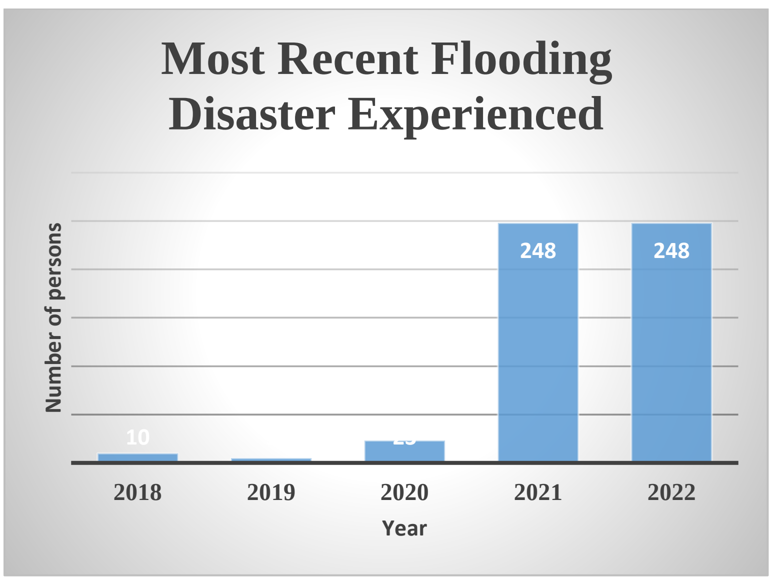


**Figure 4.34 year participants were mostly affected by flooding**

Figure 4.35 below depicts the ways in which participants indicated they were affected during flood events in the Kwakwani watershed. Majority of the participants indicated that they were affected by damages to property (houses, shops, and business). Loss of crops and income affected also a large number of the participants.

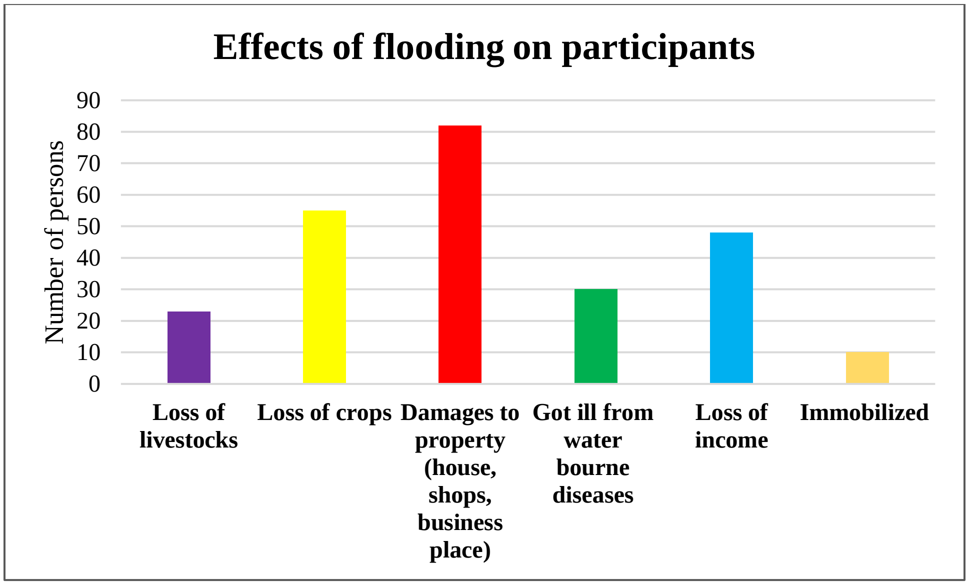


**Figure 4.35 ways in which participants were affected by the recent flood in the Kwakwani watershed.**

Figure 4.36 below represents the responses given by the participants on what measures can be put in place to prevent and reduce the impact of floods in the Kwakwani watershed. 96% of participants indicated that dredging of the river will reduce floods.

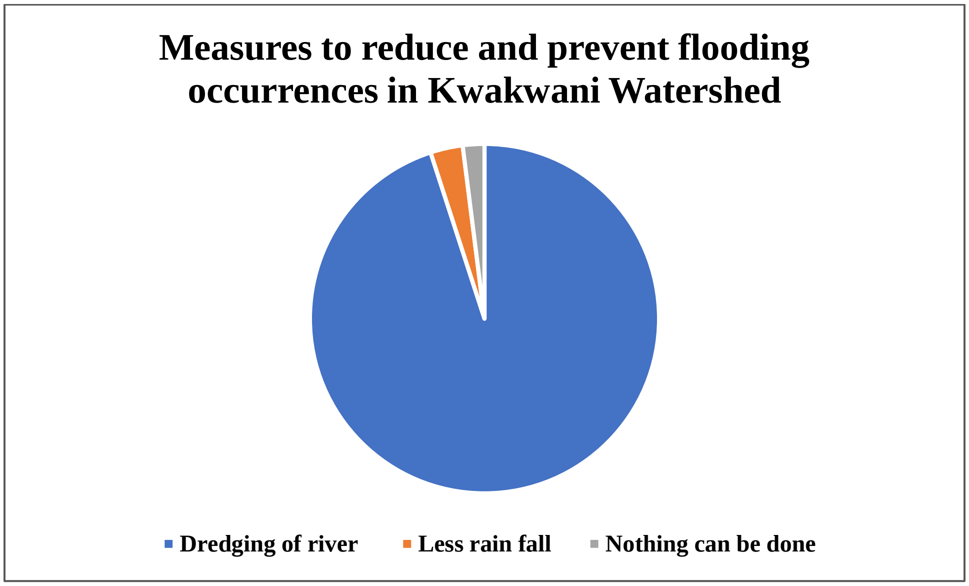


**Figure 4.36 Measures to reduce and prevent the occurrence of floods**

The researcher further proceeded to enquire about the coping mechanisms adopted by participants during floods. Figure 4.37 indicates that majority of respondents indicated that they moved in with family or friend. A large number of participants indicated also that they evacuated to higher ground or to a temporary shelter during the recent floods.

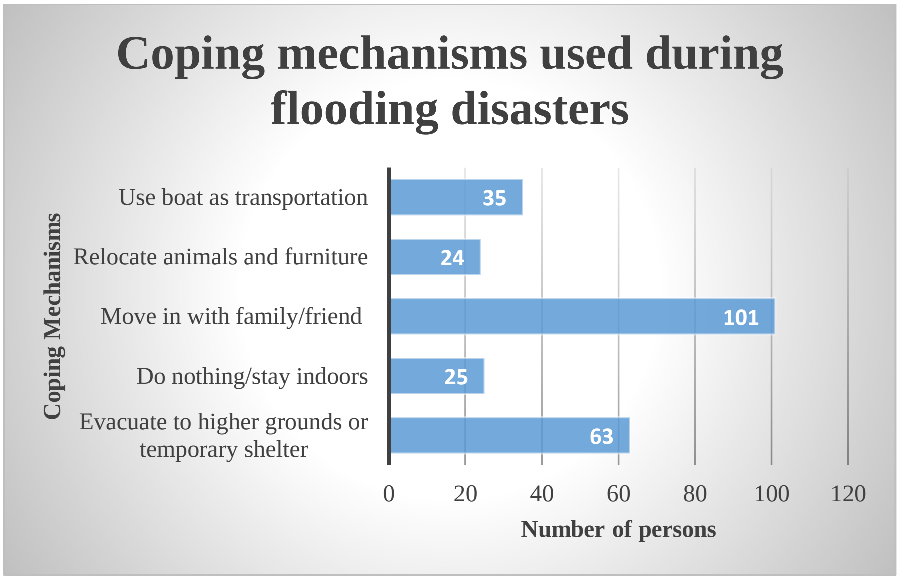


**Figure 4.37 Coping mechanisms employed during flooding disasters in the Kwakwani community**

### 4.6.4 Perception to land use activities contributing to flooding

Figure 4.38 below indicates that majority of participants believed that land use activities did not contribute to flooding experienced in the Kwakwani's watershed.

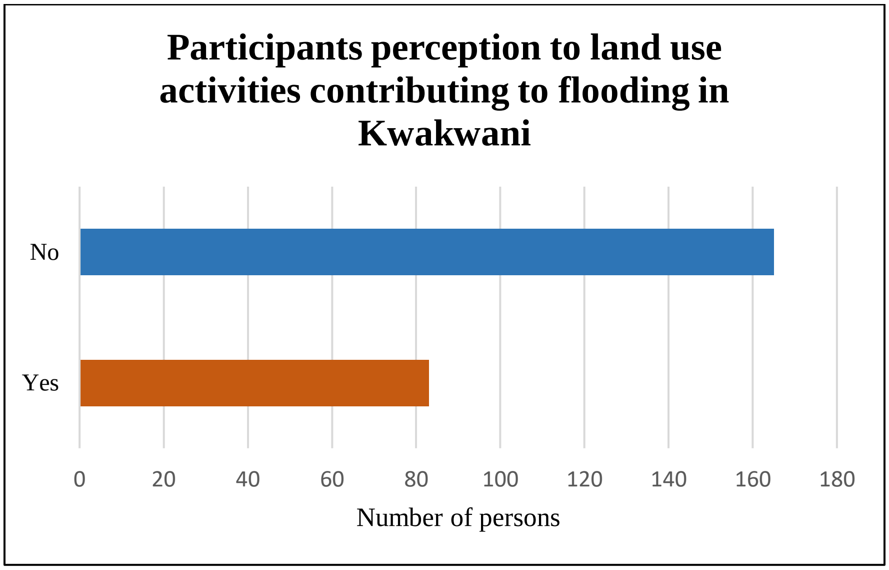


**Figure 4.38 Participants perception to land use activities contributing to flooding**

Figure 4.39 below depicts that majority of the participants perceive LULC changes in the Kwakwani watershed is as a result of housing development, followed by agriculture farming and logging

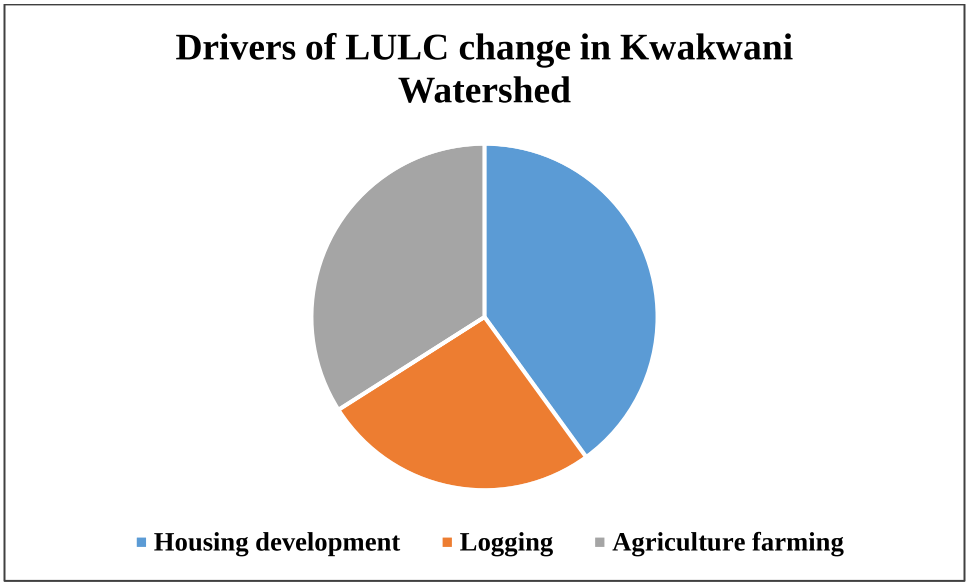


**Figure 4.39 drivers of LULC change**

# 5 CHAPTER FIVE: DISCUSSION

## 5.1 Land Use Land Cover Changes in Kwakwani watershed

Intense anthropogenic development leads to LULC changes which can contributes to the severity of hydrometeorological events (de Andrade Farias et al. 2020). As such, changes in the forest cover within the Kwakwani watershed may have implications on flood intensity.

Change intensity analysis was used to analyze how LULC changes were occurring within the Kwakwani watershed. Figure 4.1 depicts the changes that would have occurred over the four LULC change years. Likewise, table 4.1 presents the percentage and the amount of changes that would have occurred between each LULC years. Noteworthy, are the changes that may have occurred as a result of human development. These changes were the fluctuation in the percentages of cropland, settlement, and the forestland percentages over the years.

According to Niya et al. (2019) intensity of changes in land-use correlates with the intensity of development within an area.

The time interval analysis has indicated that LULC changes were faster during the 2013 to 2015 period than the 2017 to 2019 period within the Kwakwani watershed (*see figure 4.4*). This may be related to the intensity of changes that would have occurred in the earlier time period from land use activities. Similarly, Niya et al. (2019) found that changes in LULC changes were faster in earlier years than the later years. This occurred because policies were implemented later which saw strategic management in the land management in Qeshm Island- China. This study did not investigate land management policies that governs the use of resources in Kwakwani watershed, nevertheless it was found that the main economic activity were forestry and agriculture (*see figure 4.32*) which is done on medium and large scales. Moreover, these are activities that can result in LULC changes observed for the Kwakwani watershed.

Intensity analysis at the category level indicated that cropland, wetland, and settlement were active in gains and losses between 2013 and 2015 (*see figure 4.5*). While cropland and wetland only were active in gains, and forestland was active in loss (*see figure 4.6*). Noteworthy, the cropland and settlement has accounted for the highest amount of change between the LULC change years. Niya et al. (2019) conducted an intensity analysis to characterize land use and found that changes in land use were because of economic growth and human development which accelerated the LULC changes. These drivers of LULC change may be similar to the changes that have occurred within the Kwakwani watershed.

Moreover, Huang et al. (2018) also conducted a study to analyse LULC changes and found that land use change intensity is associated with human developments. Huang et al. (2018) indicated that cropland, and settlement underwent active gains within the coastal zone of Longhai, China.

At the transition level, there were changes and differences amongst the transited classes. Most notably, the forestland class was the main supplier for most of the other classes. This may be justified by the rise in demand for construction which converts forestlands into settlement areas. Additionally, in Kwakwani forestry accounts for the main economic activity (*see figure 4.32*) which utilizes forest resources. As such, the dependency on the forest resources may have accounted for changes observed. Niya et al. (2019) also found that changes in the dense vegetation class has occurred because of the high dependency for development.

Intensity analysis can therefore be used to advance the understanding in the relationship between the LULC classes within a watershed.

## 5.2 SWAT + model simulation- LULC change and hydrological parameters

The SWAT+ model was successful in simulating the impacts of LULC changes on hydrological parameters such as sediment yield, evapotranspiration, and surface runoff under the four LULC years for the Kwakwani watershed. As such, under the four LULC years the maps produced depicted spatially where the various intensity of sediment yield, surface runoff, and evapotranspiration within the landscape occurred. The variations in these parameters under the four years can be attributed to the LULC changes that would have occurred between 2013 to 2019. According to de Andrade Farias et al. (2020), the topographic nature of watersheds, and spatial distribution of land use can result in the modification of hydrological parameters. Figure 4.16 to figure 4.19 represents the spatial distribution for surface runoff. Subtle differences can be observed in the magnitude of surface runoff that has occurred between the LULC years. Moreover, de Andrade Farias et al. (2020) pointed out similar observations to this study whereby, under different LULC change conditions, spatial variation in surface runoff were observed across the landscape which were depicted using maps. Moreover, spatial representation for sediment yield and evapotranspiration were represented in figures 4.21 to 4.24 and figures 4.26 to 4.29 respectively for the LULC years. Subtle differences were also observed when between the LULC years. This reiterates that spatial representation can used to identify areas that may require land management interventions to reduce sediment yield, surface runoff, and increase evapotranspiration.

### 5.2.1 LULC change impacts on surface runoff in Kwakwani watershed

Surface runoff refers to the quantity of rainfall that enters streams, rivers, lakes, or a catchment immediately after rainfall. It’s a process that begins after the rainfall intensity exceeds the infiltration capability of the soil (Balasubramanian 2017). Surface runoff, according to Balasubramanian (2017) is also dependent on meteorological factors which includes rainfall intensity and duration; physiographic factors which includes land use and soil type.

This study examined the surface runoff that occurred under four LULC years (2013, 2015, 2017, 2019) in the Kwakwani watershed. The results generated by the SWAT+ model for the watershed found that the highest surface runoff was recorded in 2017 (1019.8 mm), followed by 2015 (1013.07 mm), 2013 (1005.4 mm), and 2019 (995. mm). This can be an indication that under various LULC, surface runoffs may increase during climatic conditions such as intense precipitation.

Edivaldo Afonso et al. (2021) study that examined the impacts of land use and land cover changes on hydrological processes using the SWAT model and found that land use had also altered the surface runoff within the Itacaúnas river watershed in Brazil. Minimum and maximum surface runoff for the river basin were 413 mm and 1307 mm respectively. Similar to this study, the 2013 to 2015 period recorded fast LULC changes which also recorded high surface runoff values of

10005.4 mm and 1013.07 mm respectively. The change intensity analysis saw active gains in settlement, wetland, grassland, and croplands for 2013 and 2015 LULC years. Edivaldo Afonso et al. (2021) study found that sub basins that were predominantly pasture land had a higher surface runoff value in the Itacaúnas River Watershed. Similarly, Leta and Koriche (2017) noted that sub basins that were dominated with agriculture and mining recorded the highest values for surface runoff. Therefore, as land use changed between 2013 to 2019 within the Kwakwani watershed from forested areas to settlement, cropland, and grassland, the surface runoff may have increased as a result. Also, this study found that forestlands were actively being converted by other LULC classes.

**Figure 5.1 Land-use that can contribute to increases in surface runoff.**

de Andrade Farias et al. (2020) modelled surface runoff response to land-use changes in the Mundau watershed, Brazil and found that low density of vegetation cover was the leading cause of high surface runoff. It was also found that changes in land use increases surface runoff due to the lack of precipitation interception (de Andrade Farias et al. 2020). Hence, variations for surface runoff that was recorded in the Kwakwani watershed under the LULC years may have been as a result of changes in the forest cover. Increases in surface runoffs by LULC changes therefore may be a factor which can exacerbate hydrometeorological events such as flooding in the Kwakwani watershed. Figure 5.1 indicates conditions described by de Andrade Farias et al. 2020 and Leta and Koriche (2017) for the occurrence of high surface runoff in the Kwakwani watershed. Moreover, it was confirmed by Kumar et al. (2022) that clearances in land cover are the basis for intensifying the occurrences of flooding due to the increases in surface runoff and lack of soil infiltration.

### 5.2.2 LULC change impacts on sediment yield in Kwakwani watershed

Sediment yield is a quantification of the amount of sediment per unit area leaving a catchment area or watershed during a specific period of time. Sediment yield can be affected by factors such as rainfall intensity, elevation of land, soil type, and land use (Vicente and Guzman 2021).

The highest sediment yield was recorded under the 2019 LULC year with a value of 1.094 t/ha, followed by 2013 (1.079 t/ha), 2017 (0.78 t/ha), and 2015 (0.64 t/ha). Studies have found that LULC changes correlates to changes in sediment yields. The change intensity for this study found that land-uses were actively changing. Most notably, forested areas were converted throughout the LULC years, to other classes such as grassland, settlement, and cropland. These conversions may have had implications on sediment yield in the Kwakwani watershed. de Oliveira Serrao et al. (2021) found that LULC changes over a 40-year period have impacted sediment yield. Under the LULC years examined values of 0.3 to 0.7 t/ha were recorded. These values were similar to this finding from this research which yielded minimum and maximum values of 0.64t/ha to 1.094 t/ha respectively.

**Figure 5.2 Land along the watershed are cleared**

Thomas et al. (2015) used the SWAT model to investigate the effects of LULC change on sediment and water yields in Yang Ming Shan National Park, Taiwan between 1996 and 2007 and found that over the two LULC change scenario, land use within the national park has contributed to the increase in sediment yield. Thomas et al. (2015) recorded an increase in sediment yield of approximately 0.25 t/ha from 1996 to 2007. This further reiterates that, as land use changes, so does the sediment yield parameter. Contrary to this study, there were fluctuations in the sediment yield over the LULC years.

Similar to Thomas et al. (2015) study, in this research it was found that forestland was decreasing and agriculture and settlements were increasing over the four LULC change years. Therefore, increases in land uses that strip the watershed in Kwakwani from forest cover may have created the environment for sediment yield changes under the four LULC years. With that being said, LULC scenarios 2019, and 2013 recorded the highest sediment yields. These two LULC years also recorded the highest percentage land-use in cropland and settlement. These are activities that involved the removal of the natural vegetation.

Furthermore, Leta and Koriche (2017) investigated the impacts of land use land cover change on sediment yield in the Finchaa Hydropower Reservoir, Ethiopia and also confirmed that sediment yield increases when LULC is altered. Four LULC change scenarios were examined - conversion to agriculture partially; conversion to grassland; complete afforestation and complete deforestation. The scenario that was labelled complete afforestation, has resulted in the reduction of sediment yield. Therefore, implying that the more forestland cover there is within a watershed, the less likely sediment yield may increase. As such, the LULC scenario 2015 and 2017 recorded the highest forest cover, which also recorded the lowest sediment yield.

Within the Kwakwani watershed, it was found that land use activities such as, housing, roads, agriculture, and logging occurs in close proximity to channels and streams that are responsible for drainage of the watershed. These are activities that contribute to the increase of sediment yield (Anneseyee 2020), due to the removal of forests which leaves the land exposed to the elements of climate. According to Leta and Koriche (2017), the changes in LULC can be responsible for the fluctuation of hydrological responses within watersheds by impacting river flows. This subsequently results in sedimentation problems within watersheds, hence, affecting flood controls (Leta and Koriche 2017). Figure 5.3 and figure 5.4 represents conditions found by Anneseyee (2020), Leta and Koriche (2017), and Thomas et al. (2015) that increases sediment yield within a landscape.

**Figure 5.3 Land clearing for housing construction.**

**Figure 5.4 Land clearing for agriculture farming.**

Sediment yield losses below 1 t/ha per year does not present erosion risks, while values between 1 t/ha per year to 5 t/ha per year is considered as low risk for erosion (de Andrade Farias et al. 2020). As such, although the Kwakwani watershed does not present a risk for erosion based on the classification by de Andrade Farias et al. (2020), changes in the land-uses over the years has resulted in erosion to low risk. This should therefore be an indication for early warning of LULC changes impacts on sediment yield, which may subsequently exacerbate the intensity of floods.

According to Daramola et al. (2022) stream sedimentation, the process by which stream sediments are transported and deposited into a stream, is as a result of upland activities. It was further explained that as the river accrues sediment, the water volume decreases. Moreover, under extreme climate conditions such as rainfall, the resulting water from runoffs and direct deposits leads to an overflow causing potential flooding. Sedimentation, therefore, affects the competencies of flood mitigation and results in a host of environmental impacts (Dowlat 2022).

### 5.2.3 LULC impacts on evapotranspiration in the Kwakwani watershed

Evapotranspiration refers to the sum of the processes whereby water moves from soil surfaces to the atmosphere through evaporation from water bodies and transpiration from via plants (USGS 2022).

Evapotranspiration in this study for the Kwakwani watershed was found to be highest in the 2019 (493.131 mm) followed by 2013 (483.06 mm), 2015 (464.628 mm), and 2017 (458.486 mm) respectively. High evapotranspiration rates correlate to high leaf area indexes. de Andrade Farias et al. (2020), found that as forests decrease, the rate of evapotranspiration decreases because the forest cover decreased due to deforestation resulting in less direct interception of water by the forests. This was confirmed for two LULC change scenarios where evapotranspiration was significantly higher in 1987 under a regeneration scenario than in 2017 under the degradation scenario which recorded evapotranspiration of 820.8mm and 522.25 mm respectively (de Andrade Farias et al. 2020).

Similarly, the conversion of forested areas in the Kwakwani watershed was occurring, which may have led to fluctuations in the evapotranspiration recorded over the LULC years, whereby, the LULC year of 2015 and 2017 recorded the highest forest cover as compared to LULC year 2013 and 2019.

de Oliveira Serrao et al. (2021) found that processes of construction in watersheds, expansions of urban areas, and deforestation can contribute to the changes of evapotranspiration. Within the Kwakwani watershed, LULC classes such as settlement, and cropland have increased from the 2013 to 2019. Similar to this study, Kumar et al. (2022) found that as land use patterns changes evapotranspiration is impacted. This fluctuations in evapotranspiration in the Kwakwani watershed therefore may be an indication of a rise in urban expanses.

Observed changes in the evapotranspiration within a landscape can indicate therefore a change in forest structure. This can further be used to understand how changes in evapotranspiration can contribute to the impacts of hydrometeorological events such as flooding.

## 5.3 Perception of LULC changes and flooding in Kwakwani watershed

This community assessment report below provides information for the perception of participants on the role of LULC changes and flood occurrences within the Kwakwani watershed. It also examines the effects of recent flooding events on the livelihoods of persons residing in the Kwakwani watershed.

The analysis found that most participants (66.5%) perceived that land uses and land use changes does not contribute to flooding in the Kwakwani watershed as seen in figure3.38. Such a perception suggests a low awareness of the role of LULC change in increased risk of flooding. Gapinski et al. (2020) findings were similar to this whereby, most persons perceive large forested areas as a negative element that prevents access to land and other resources. Such perception reiterates that without education on the impacts of LULC alterations, the environment's function to naturally regulate climate extremes may be impacted, subsequently affecting livelihoods from events such as floods. Participants who believed that LULC changes can contribute to flooding explained that removing forest completely for the construction of housing and agriculture often result in heavy flow of waters over the land causing erosion and transport of soil into the river resulting in clogging. Moreover, it was of the belief of the participants that floods occurred because of the shallowness of the river which hinders its holding capacity of water during rainy seasons. Furthermore, participants believe that flooding can be reduced and prevented by dredging of the river to remove excess sediment (*see figure 4.36*).

**Figure 5.7 Slash and burn agriculture practiced in Kwakwani watershed**

Participants perceived housing expansion, agriculture activities, and logging as the main drivers of LULC changes within the Kwakwani watershed (*see figure 4.39*). Similar to this finding, Belete et al. (2020), found that it was of the perception of community members that LULC changes occurred because of cropland expansion, and population growth. Additionally, Musetsho (2021), found that community members perceived deforestation, as the highest driver of LULC change.

Furthermore, residents have indicated that since the closure of the bauxite mining industry in Kwakwani, no dredging of the river has occurred. As such, with LULC changes over the years contributing to the sediment yield, surface runoff, and decrease in evapotranspiration, flood mitigation may have been affected. Subsequently resulting in impacts to flood mitigation. Daramola et al. (2022) and Hupp et al. (2009) indicated that increases in sedimentation of rivers, channels, and streams can lead to an increase in the intensity of flooding events across a landscape.

98% of the respondents indicated that they were affected by the recent flooding events; where every person affected indicated that the 2021 and 2022 flooding events were the most extreme ever experienced. Coping mechanisms employed by the residents varied depending on their exposure to the floods. 40.7% of the residents indicated that move in with family/friends were their best choice since flood waters made living in the area impossible because of the levels the flood waters reached.

**Figure 5.8 Indicating the height of flood water reached during the 2021 flooding event (main river in the background).**

Other methods to cope with the floods included use of boats as transportation, relocating livestock, and furniture, evacuated to higher grounds or temporary shelter, and did nothing. During the flooding events, losses were experienced in which damages to property were recorded as the highest impact. Other impacts included loss of crops, loss of livestock, illness, loss of income, and immobilization.

In Kwakwani, flood is the most frequently occurring disaster. As a consequence, it impacts the livelihoods of people living in the watershed. The analysis reveals that the most severe consequences of flooding have been recorded in the year 2021 and 2022 during the rainy seasons *(see figure 4.34).*

**Figure 5.9 Road development usually affected by floods in Kwakwani**

In flood plain management, zoning and implementations of regulations is an effective strategy whereby land use management is controlled in the zones. This sees the implementation of building to reduce impacts from floods (Rahman et al. 2017). Development within the Kwakwani watershed may be lacking the use of policy instruments such as building codes to guide development. Figure 5.8 depicts the height that flood waters have reached in areas that were used for housing developments. Davis (2022), has estimated that the use of building codes can reduce losses from flooding by 1.6 billion USD. An article by Dowlat (2022) also indicated that when building codes are violated in flood plains, settlements become severely impacted during inundations.

## 5.4 Flood plains in Kwakwani watershed

Flood plains refers to flat areas of land that are adjacent to rivers or streams which are subjected to flooding after events of prolonged precipitation or storms (National Geographic 2022). This means that as rivers reach its holding capacity from overland flows during a precipitation event, it overflows onto flood plains. Flood plains are therefore functioning as a storage capacity for flood waters until it recedes.

The floodplains delineated by the SWAT+ model (*see figure 5.5*) for the Kwakwani watershed can signify the possible implications for livelihoods dwelling within this area may experience during flooding events. Moreover, it is within the flood plains delineated by the SWAT + model that settlement land use occurred. As such, human development within floodplains will may become affected during inundations. This is supported by the IFRC (2021) who found that approximately 500 residents within the Kwakwani watershed were affected by flooding, resulting in losses to homes, livestock, crops and livelihoods.

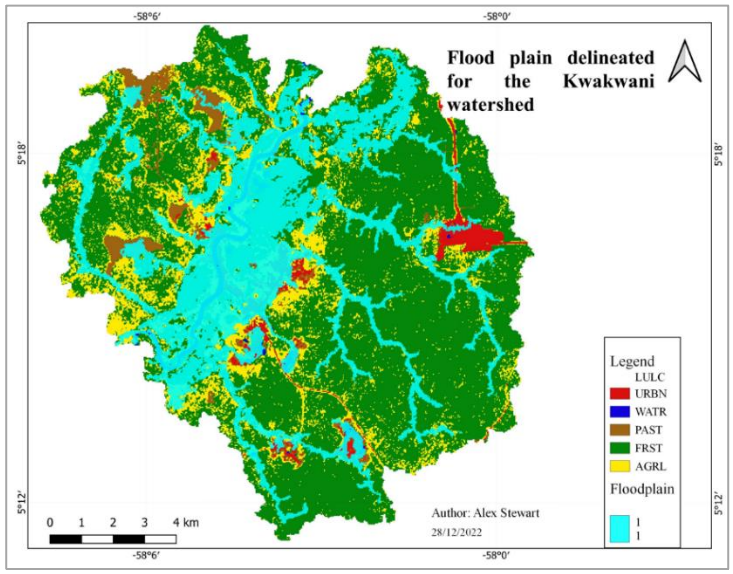


**Figure 5.5 Flood plain map for the Kwakwani watershed.**

**Figure 5.6 Housing development in the Kwakwani floodplain**

Riverine lands and floodplains play key roles in the provision of a number of ecosystem services which benefit the livelihood of the people. However, the removal or alteration of the natural ecosystems in these areas for developmental purposes increases the risk of adverse impacts to livelihoods, such as flooding controls (Gapinski et al. 2020). A healthy wetland therefore mitigates risks associated with flooding (Parker and Oates 2016).

The increase in development which results in LULC changes within flood plains in the Kwakwani watershed may increase the risk associated with flooding in Kwakwani. According to Hupp et al. (2009), human alteration of flood plains may lead to changes in sediment supply conditions which subsequently impacts the natural regulation of over banks flow. As a result of land clearances within flood plains in Kwakwani, may result in streams becoming clogged with debris and sediment from overland flow, resulting in impacts to natural flood water regulation, thus causing prolonged and frequent flooding.

The Kwakwani watershed landscape has recorded fluctuations LULC as a result of human development which was indicated by the LULC change analysis conducted between 2013 to 2019. The Kwakwani watershed also has a floodplain, as such, land use planning is important.

In flood plain management zoning and implementations regulations is an effective strategy whereby building codes and land use management are enforced to reduce impacts from floods (Rahman et al. 2017). As such, this tool can be used as a means of reducing risks of livelihoods to floods in the Kwakwani.

# 6 CONCLUSION

Analysing spatial and temporal LULC changes of a landscape can be used to signal where the impacts of management practices on the environmental services within a landscape are occurring. Such analysis can contribute to land use planning and management. The LULC analysis found that the Kwakwani watershed was experiencing LULC changes between 2013 to 2019. The LULC changes were fast between 2013 and 2015 and was slow between 2017 and 2019. Moreover, the study found that forestland, which occupied most of the land cover within the watershed, was the most converted land cover. Furthermore, LULC changes have led to changes in hydrological parameters such as sediment yield, surface runoff, and evapotranspiration in the Kwakwani watershed. Long term changes in these hydrological parameters can therefore intensify hydrometeorological events such as flooding, resulting in significant impacts to livelihoods.

The SWAT+ tool was useful in simulating the temporal and spatial variability of sediment yield, evapotranspiration, and surface runoff under the LULC years. As such, as forestland cover is converted, sediment runoff, and surface runoffs can increase, while evapotranspiration decreases within the Kwakwani watershed. It can therefore be concluded LULC changes has a role on hydrological parameters that are essential for flood mitigation within the Kwakwani watershed.

Knowledge of the importance of LULC contribution to hydrometeorological events such as flooding is important to guide land use and land management decisions. There was a difference in perception amongst the participants on the contribution of LULC changes to floods in the Kwakwani watershed.

# 7 RECOMMENDATION

It was found that LULC changes impacts hydrological parameters as such, through the governing authorities, land-use should be guided by policies for flood plains and watershed management. Future studies should investigate the impacts of LULC changes on water yield, and water quality within the Kwakwani watershed.

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