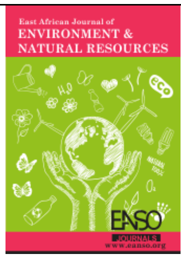

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Original Article

Mapping Land Use Land Cover within Flood Risks and Safe Zones in Budalangi Sub-County, Kenya

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Floods, Flood risk, Fluvial/Riverine Flooding, Safe zones, Budalangi.

ABSTRACT

Riverine flooding is associated with not only displacement of people but also loss of property and lives in the lower course of rivers. However, there is a dearth of literature on land use and land cover within flood risk zones and safe zones within the Western Region in Kenya. Using Landsat Satellite Images and household survey, this study aimed at mapping land use land cover within flood risk and safe zones in Budalangi sub-county, Kenya. A sample size of 162 household heads was selected using stratified random sampling. Flood stage scenarios were hypothesized and overlay analysis was done to determine the locations for evacuation and land use at risk. Descriptive data analysis was adopted to analyze data from respondents. Analyzed Landsat Satellite Images reveal that 39.1 % (76.2 Km2) of the study area were flood risk zones while 60.9 % (118.8 Km2) were safe zones. Ninety percent (90 %, 68.6 Km2) of the flood risk zones were located within altitudes less than 1144 m above sea level (a.s.l) while safe zones were located in areas with more than 1144 m a.s.l. Within the flood risk zones, 57.0 % (39.1 Km2) was covered with papyrus vegetation, 19.2 % (13.2 km2) with riverine vegetation, 18.4 % (12.6 km2) with farmlands and 5.4 % (3.7 km2) with buildings or bare lands. Ninety percent (90 %) of the safe regions were found within learning institutions, market centres and administrative centres. The majority of the respondents (n = 157, 96.9 %) had experienced flooding on their farmlands and some of them (n = 125, 79.6 %) indicated that floods had destroyed their crops. The flooding that occurred frequently within the study area during the high rain season was mainly mitigated through terracing and the use of canals. The current study concludes that flood risk zones were covered by natural vegetation while safe zones were occupied by human settlements. This study suggests that residents in flood-prone areas should avoid residing within flood-risk zones during rainy seasons.

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INTRODUCTION

From a spatio-temporal perspective, surface floods mainly occur within the coastal regions (coastal flooding), urban areas and rural areas (pluvial flooding) and river's flood plains (fluvial/ riverine flooding) especially during heavy downpours (Riedel *et al.*, 2024; Shen *et al.*, 2023; Singh *et al.*, 2023). Riverine flooding has been gaining prominence in flood risk discourse due to the fact that the flood inundation areas are larger as well and the inundation period of these floods is relatively longer (Jia *et al.*, 2022; Maciel *et al*., 2022). For instance, some of the river's flood plains in China were flooded with water for approximately two months (Jia *et al.*, 2022) while others in the Amazon Basin experienced flood inundation for a period of about three months (Maciel *et al*., 2022). Moreover, flooding of rivers affects a large geographical area (Sanyal & Liu, 2004; Tripathi *et al.,* 2022) such a case within the Blue Nile and White Nile Basins in Sudan where an estimated area of between 200 and 500 square kilometres experience flood inundation (Abdelmoneim *et al.,* 2023).

With regard to the causes of riverine flooding, seasonal variations in climatic patterns influence the occurrence of floods within the lower courses of rivers. Specifically, high precipitation within the river basin is one of the main causes of floods in the lower courses of the rivers (Andang'o, 2023; Jia *et al.*, 2022; Jain *et al.*, 2005). In the Far East of Asia, most of the floods occurred during the monsoon season since this is the period when heavy rainfall is experienced in the region (Jia *et al.,* 2022; Jain *et al.*, 2005; Naeem *et al.*, 2021; Tripathi *et al.*, 2022). Moreover, the high volume of water from the watershed and catchment areas contributes immensely to flooding along the lower course of the river (Andang'o, 2023; Fleischmann *et al*., 2022; Jia *et al.*, 2022; Naeem *et al.*, 2021). Proximity to and the nature of the river mouths is one of the factors that leads to floods within the flood plains of rivers since these areas have low altitudes (Odero *et al.*, 2022). Another factor that leads to the frequent occurrence of floods is soil type such that flood-prone areas have poorly drained soils such as clay soil since they retain a lot of water and soak easily during the rainy season (Basri, *et al.*, 2022; Odero *et al.*, 2022). Moreover, land use has some influence on the occurrence of floods such that areas covered with swamps and plantations were indicators of flood vulnerability (Basri, *et al.*, 2022; Odero *et al.*, 2022).

Within the lower courses of rivers, the natural environment is highly affected by the riverine flooding phenomena. Extreme riverine floods have led to not only an increase in the erosive power of the coastal currents but also excessive deposition or erosion of materials within the river deltas (Fu *et al.*, 2023). Within the fluvial sediment materials, some traces of minerals can be identified (Weber & Lehmkuhl, 2024) as well as sand (Stutenbecker *et*

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al., 2023). Flooding frequencies have a strong relationship with the soil properties within the flood plains of rivers (Rayburg *et al.,* 2023). Riverine vegetation may also be affected especially the vegetation cover, the species availability and the height of the vegetation during the riverine flooding (Hooke *et al.,* 2023). In addition, riverine flooding affects the richness, diversity and abundance of the animal species found within the lower courses of rivers (Marino *et al.,* 2024).

Riverine flooding has led to colossal damage on the human infrastructure e.g. buildings, roads, bridges, schools, hospitals religious institutions etc (Chan *et al.,* 2024; Lawanson *et al.,* 2023; Schilling *et al.,* 2024). Further, riverine flooding has had negative consequences on crop production within the flood plains of rivers since it destroys crops (Balgah *et al.,* 2023; Lawanson *et al.,* 2023; Schilling *et al.,* 2024). In some cases, livestock farmers usually lose their flock to flood-related hazards within the lower courses of rivers (Balgah *et al.,* 2023; Lawanson *et al.,* 2023). Flood-prone areas are associated with health-related complications such as injury, waterborne diseases (diarrhoea, typhoid and cholera), as well as death within the lower courses of rivers (Balgah *et al.,* 2023). Moreover, floods are linked to the displacement of people with a net effect on budgetary allocations by the national government (Das & Samanta, 2023; Lawanson *et al.,* 2023).

However, riverine flooding has been associated with positive impacts on human life. For instance, eroded soil nutrients and minerals in the upper courses of rivers during flood seasons are deposited in the lower courses resulting in the formation of fertile soils suitable for agricultural production especially paddy rice (Aldardasawi & Eren, 2021; Svetlana *et al.,* 2015). Also, riverine flooding is significant in recharging the underground water which is critical during the dry season when the underground water is the source of water for domestic, irrigation and industrial use in arid areas (Svetlana *et al.,* 2015; Talbot *et al.,* 2018). Moreover, the floods that occur along the rivers are critical in the maintenance of the bio-diversity and biological productivity within the flood plain which may attract tourists (Svetlana *et al.,* 2015; Talbot *et al.,* 2018). Lastly, flood deposits contain not only sand but also minerals that can be exploited for the economic gain of the local residents (Gibson & Shelley, 2020).

Nevertheless, the negative impacts of flooding along the lower course of river Nzoia supersede the positive effects, especially in Budalangi Sub-county. For instance, in 2010 about 2,700 people were displaced and about 3,011 homes in all five locations in the sub-county were submerged in flood waters (Dulo, S *et al.,* 2008). While examining the impacts of floods on food security and income levels within the Budalangi sub-county, some scholars affirm that there was a decline in agricultural production which exacerbated food insecurity problems and poverty levels (Mutiso, 2011, Republic of Kenya, 2004; Dulo *et al.,* 2010). Although the construction of dykes is one of the main strategies that have been employed to reduce the impact of floods within Budalangi sub-county, the negative effects of riverine flooding are still enormous.

The identification of the location of flood risk and safe zones is critical in the planning and allocation of both human and financial resources by the National Disaster Operations Centre (NDOC) during flood peak seasons. Equally important to local residents is the delineation of the areal extent to which flood risk zones and safe zones cover so that they can move to such areas during riverine flooding seasons to reduce on loss of property as well as lives (Gaya *et al.,* 2020; Mwangi, 2016). Remote sensing and Geographical Information System (GIS) based models offer a better understanding of the spatial and temporal perspective of this phenomenon (Gaya, 2020; Mwangi, 2016). Although studies have been conducted using GIS and remote-based frameworks such as ‘Application of GIS and remote sensing in

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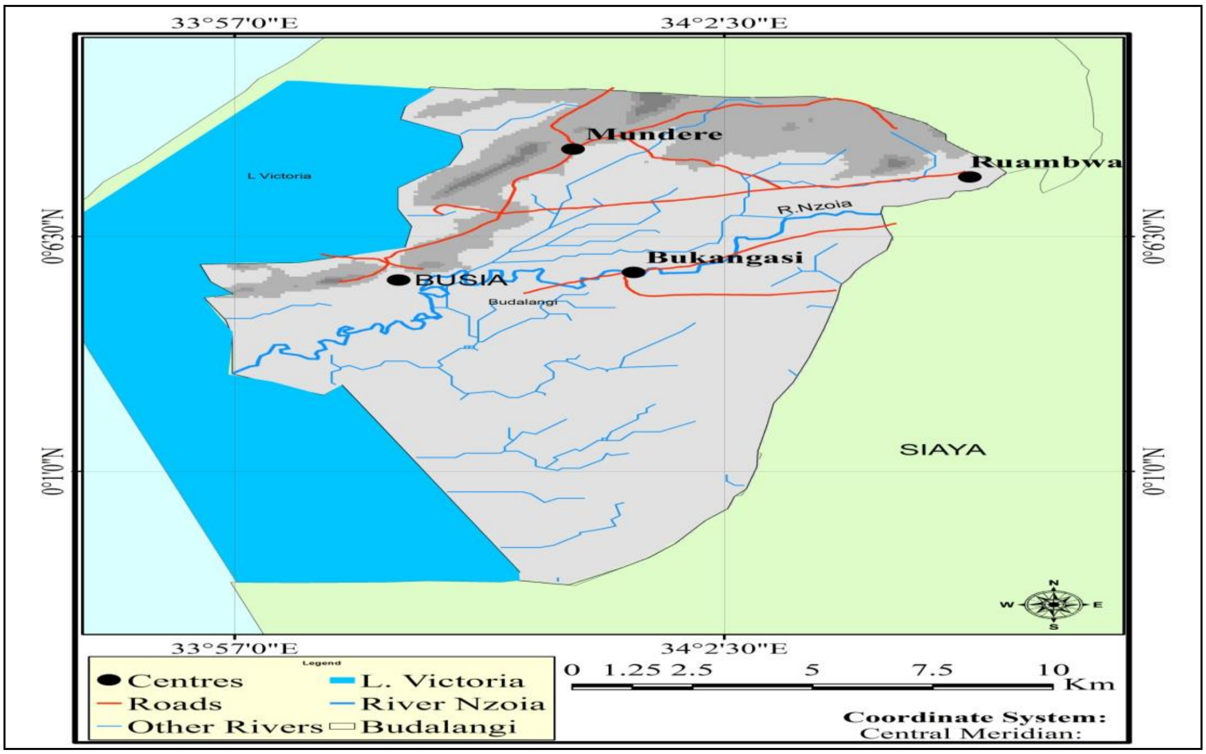
flood management in the Lake Victoria basin' (Gaya, 2020) and 'GIS-based modelling of land-use dynamics in River Nzoia Basin in Kenya (Akali, 2015), none of these have focused on mapping the flood risk zones and safe zones within Budalangi sub-County. Thus, this study therefore aimed to: identify the location of flood risk and safe zones, map land use land cover within the flood risk and safe zones and examine flood occurrence, damage to property and control of floods within Budalangi Sub-County in Kenya.

MATERIALS AND METHODS

The current study was conducted within the lower course of River Nzoia within Budalangi sub-county in Kenya. This sub-county lies between latitudes 1^0 30^1 N and 0^0 05^1 S and longitudes 34^0 00^1 and 35^0 45^1 E. River Nzoia is the largest river within the Lake Victoria basin in Kenya. It originates from the forested highlands of Mt. Elgon and Cherangani Hills. It runs approximately in the South-West direction and stretches about 334 km with a catchment area of about 12,900 km^2 (NRBMI, 2011). The floodplain of River Nzoia falls between 1100 m and 1350 m height above sea level (Mutiso, 2011).

Figure 1: Map of the Study Area



Source, *Authors (2018)*

Mean monthly rainfall varies between 1000 mm and 1500 mm with double maxima experienced between April and May as well as between July and November (Nyadawa *et. al.*, 2010). The recent quaternary sediments and tertiary volcanic rocks as well as rocks of the Kavirondian and Nyanzian rock systems dominate the River Nzoia basin (Mutiso, 2011). Black cotton soils (vertisols) with heavy alluvial deposits cover most parts of the river basin (Mutiso, 2011).

Budalangi Sub-county is subdivided into six locations; Bunyala East, Bunyala West, Bunyala South, Bunyala North, Bunyala Central and Khajula location. The population of the sub-county was estimated to be 72,563 people (Government of Kenya [GoK], 2019). The population density of the

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area is 354 persons per square kilometre with an average household size of about 4 persons per household (Onywere, 2011). Almost 90 % of the population lives in rural settlements and 70% of the total population lives below the poverty line. In addition, most of the rural residents in Budalangi Sub-county engaged in agricultural activities as well as fishing within Lake Victoria (Nyadawa *et. al.,* 2010). The farms are privately owned and on average 1 – 3 hectares (Opondo, 2013). Since time immemorial, people have settled within the flood plain which experiences perennial flooding. Although within the Budalangi Sub-county, there are protection earthen dykes, water usually overflows these dykes during high rainfall discharges.

A cross-sectional survey research design was adopted. In this study, the target population included all the 15245 households found within the upper and lower zones of Budalangi sub-county. The upper zones of Budalangi Sub-County include Bunyala West location, Bunyala North location and Bunyala East location while the lower zones of Budalangi Sub-County encompass Bunyala Central location, Khajula location and Bunyala South Location. Yamane's formula was used to compute the 162 households and a stratified sampling technique was used to select the household heads located along the main roads. The first household was randomly selected by considering the first thirty households from the chief's office. Questionnaires were used to collect quantitative data on land use land cover at flood risk zones, extent of flood risk areas, flood frequency, property damage and local flood control measures.

Mapping of land use land cover of the study area was done through the use of 2016 Landsat 8 images. Elevation analysis was done using void filled 2013 Shuttle Radar Topography Mission (SRTM) image. This analysis aided in delineating all features at risk. Moreover, Global Positioning System (GPS) coordinates were pegged on sample locations as well as other elements that required elevation verification. GPS picked elevations of various households and their spatial location for mapping of elevations and ground truthing. Flood stage scenarios were hypothesized below and above the actual flood stage to determine locations for evacuation in case of various magnitudes of flooding. The features at risk were also evaluated by using existing land use land cover and an overlay analysis taken to determine the areas and land use at risk.

RESULTS AND DISCUSSION

This section focuses on mapping land use and land cover within flood risk zones and safe zones in Budalangi Sub-county in Kenya. Specifically, it focuses on identifying the location of flood risk zones and safe zones, land use and land cover within flood risk and safe zones as well as flood occurrence, property damage and flood control measures as discussed below.

Flood Risk Zones and Safe Zones

The first objective of this paper was to identify the location of flood risk and safe zones within Budalangi sub-county. Using remotely sensed data (2016 Landsat 8 images), the analyzed results indicated the location of the flood risk and safe zones (Figure 2) below. As shown in Figure 2, the South and Southwestern parts of the sub-county were flood-risk zones. This implies that the zones nearer Lake Victoria as well as those along the lower course of River Nzoia were more prone to floods. Also, Figure 2 demonstrates that the Northern, North Western, North Eastern, Eastern and South Eastern parts of the study area were considered to be safe zones from floods. It can be construed that regions that were far away from Lake Victoria Basin as well as the flood plain of the River Nzoia Basin were safer.

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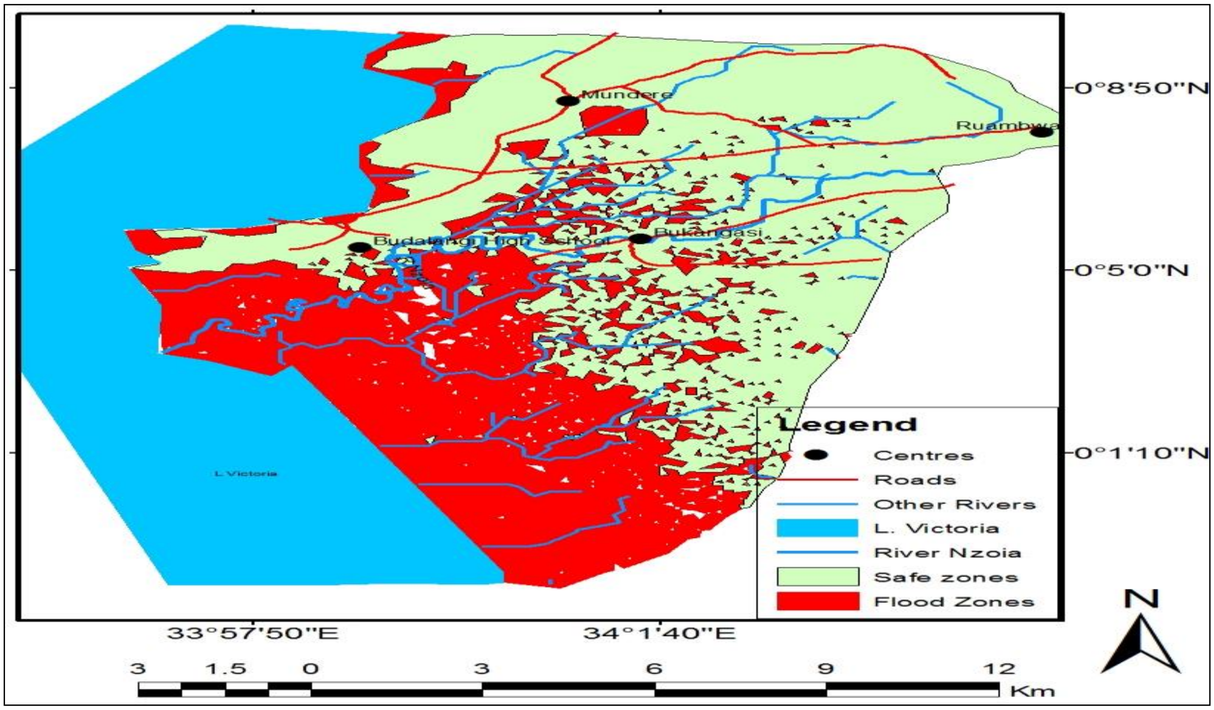
Figure 2: Flood and Safe Zones Map



When more elevation analysis was carried out using GPS, it was revealed that the Southern and South Western regions of the study area had lower altitudes while the Northern, North Eastern and Eastern areas had higher altitudes. Although from Figure 2 there was spot flooding in higher altitude areas (Northern, North Eastern and Eastern) of the study area, 90% of the flood risk zones were located within the lower altitude areas in Budalangi sub-county. This revelation confirms the academic documentation of Odero *et al* (2022) who reported that 'very severe flood vulnerability' was observed within the lower altitude areas near Lake Victoria. On the other hand, it is clear from Figure 2 that flooding did not occur in all the flood risk zones since they were far away from the flood plain of River Nzoia or the shores of Lake Victoria. This could be attributed to spatial variations in altitude within the flood risk zones. This finding is similar to the research results of Odero *et al*. (2022) who pointed out that flood risk zones such as Nyando and Nyakach were located in areas that were near the river mouth of River Nyando in Kisumu County.

It was imperative to determine the actual area that was prone to floods as well as those that were considered safe. From the analysis of the 2016 Landsat 8 images, it was observed that 118.8 Km^2 (60.9 %) of the total areas in Budalangi Sub-county were regarded to be safe zones while 76.2 Km^2 (39.1 %) of the Budalangi sub-county were flood-prone zones (Figure 3). This implies that a large percentage of the area within the Budalangi sub-county was confirmed to be safe for human settlement and related economic activities.

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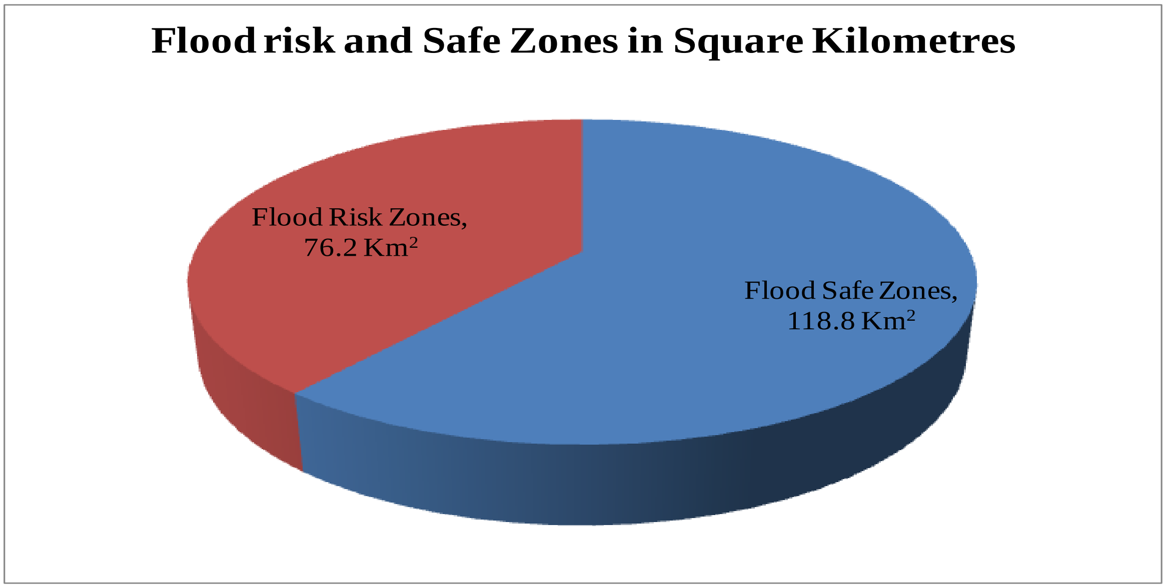
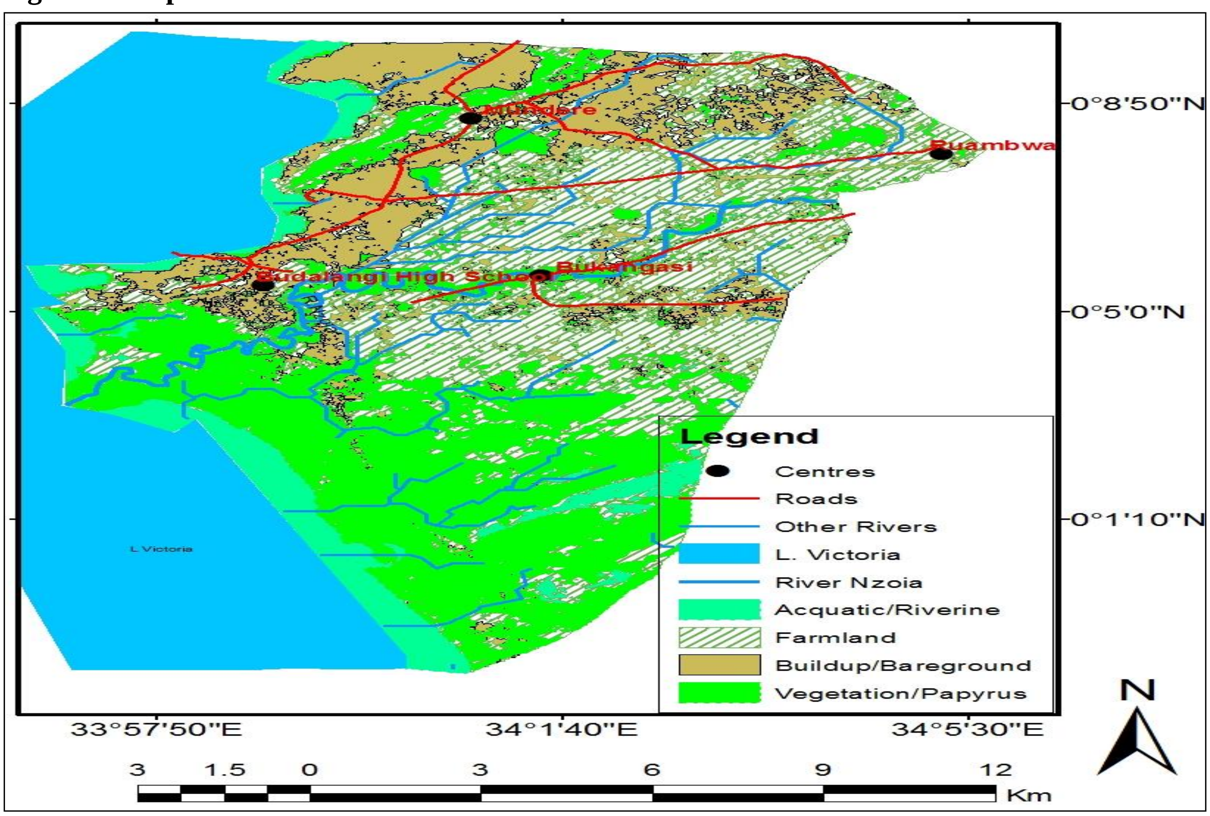
Figure 3: Percentage of Flood Risk and Safe Zones



Land Use Land Cover in Flood Risk and Safe Zones

The second objective of this paper was to map land use and land cover within the flood risk and safe zones. From the analysis of the 2016 Landsat image, the results are shown in Figure 4 below.

Figure 4: Map of Land Use Land Cover in Flood Risk and Safe Zones



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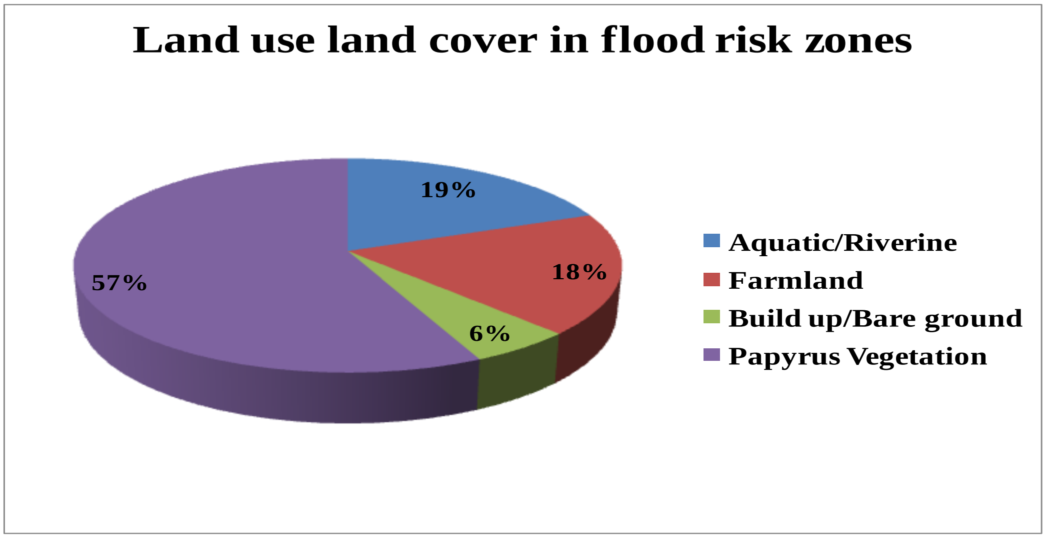
With regard to land cover within the flood risk zones, Figure 4 demonstrates that the main land cover was papyrus vegetation and riverine vegetation. Also, there was minimal land use such as farmlands and built-up areas. Figure 4 reveals that the natural land cover was closer to Lake Victoria as well as along the floodplain of River Nzoia.

Figure 5: Land Use Land Cover Within Flood Risk Zones



In terms of the areal extent of land use land cover within the flood risk zones, it was noted that 57.0 % (39.1 Km^2) was covered with papyrus vegetation, 19.2 % (13.2 km^2) with riverine vegetation, 18.4 % (12.6 km^2) with farmlands and 5.4 % (3.7 km^2) with buildings or bare lands. This finding resembles the study carried out in Nyando by Odero *et al.*, (2022) which demonstrates that swamps and plantations were good indicators of areas being susceptible to floods.

From Figure 4, it was further revealed that ninety percent (90 %) of the safe regions were found in the North, North East and Eastern parts of the Budalangi sub-county. Some of the prominent land uses within these safe zones were schools such as Budalangi High School, St. Peter's Ruambwa Primary School, Namalo Primary School and Nandekere Primary School. Through observation and information collected from respondents, the safer regions had numerous houses, farmlands, schools and religious institutions. This indicates that the flood-safe regions were likely to have human settlement and therefore more anthropogenic activities. Further, this could be due to the fact that there was less damage during floods and therefore permanence in settlement.

However, there were some pockets of papyrus vegetation along the River Nzoia. This is consistent with the findings of Osere (2020) who reported that during the floods experienced in Budalangi Sub-county in 2020, some of the displaced persons had camped at Namalo Primary School and St Peter's Ruambwa Primary School. Also, it was established that other flood-safe zones included Bukangasi, Bunyala West location, East of Mundere and Musokoto village. It was revealed through observation and interviews that most of the displaced persons due to floods set camps within their neighbouring schools.

Flood Occurrence, Damage and Control

The last objective was to examine flood occurrence, damage to property and control of floods. In order to examine the occurrence of floods, the farmers were asked to state whether their farms had ever experienced flooding. It was noted that a majority of the respondents (n = 157, 96.9 %) had experienced flooding on their farmlands while a few

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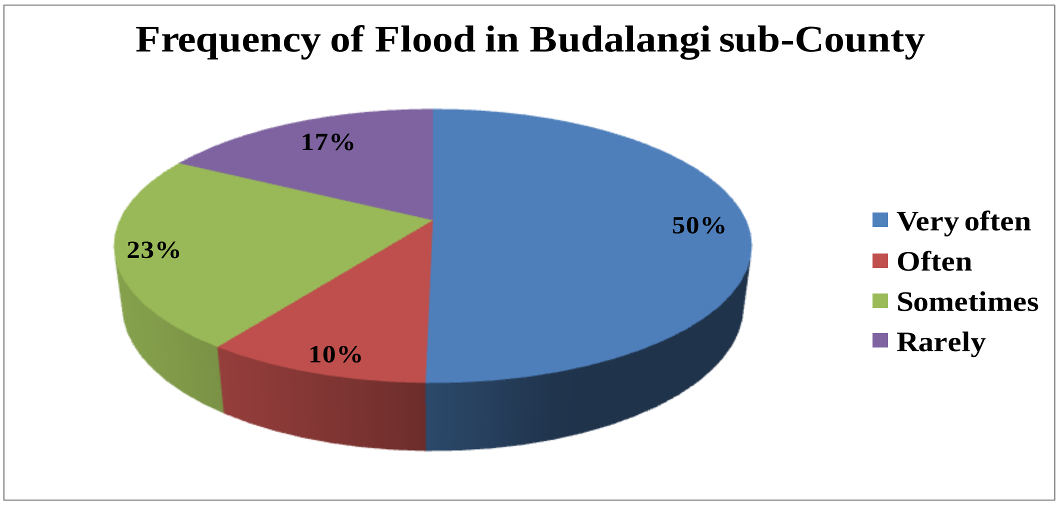
(n = 5, 3.1 %) said they had not experienced floods on their farms. This could be attributed to the idea that although most of the residents had built their houses on safer grounds, their farms could still experience floods due to proximity to River Nzoia or Lake Victoria as well as heavy rains. This is in line with Ochola (2009) who found out that 97 % of the respondents had experienced flooding on their farms during rainy seasons Nyando sub-county. Among the respondents who stated that they have not experienced flooding on their farms (2.5%), the majority neither owned land nor had their farms on higher grounds. Moreover, this finding concurs with the observation of Krasiewicz & Wierzbicki (2023) who reported that the losses caused by floods were less in far areas from the natural river levee compared to areas that were nearer the natural river levee.

Moreover, the study further sought to establish the frequency with which the households had experienced flooding on their farms. The results were analyzed and presented as shown in Figure 6 below.

Figure 6: Flood Frequency



From the sub-set of respondents (n = 157, 96.9 %) that had experienced floods on their farms, the study further sought to establish the frequency with which these households had experienced flooding on their farms. The respondents were asked '*How often do you experience floods on your farm?*' The results were analyzed and presented as shown in Figure 6 below. From Figure 6, about half the number of respondents (n = 79, 50.3 %) noted 'Very often', 15 of the respondents (9.6 %) said 'Often', 36 of the respondents (22.9 %) reported 'Sometimes', and 27 of the respondents (17.2 %) indicated 'Rarely'. This finding demonstrates that flooding was experienced more often on most of the farms within the Budalangi sub-county. This revelation supports the results of the study conducted by Schilling *et al.*, *(*2024) across the Mississippi-Atchafalaya River Basin in North America where they found out that floods that occurred during high stream volume lead to loss of agricultural lands.

Also, the paper sought to establish the extent of property damage due to floods in Budalangi sub-county. The sub-set of respondents who indicated being affected by floods (n = 157, 96.9 %) were asked to select from a 3 (three) point Likert scale of: 1 = Minimal damage, 2 = Some damage and 3 = Extreme damage the extent of damage to their properties on the farm. The results were analyzed and presented as shown in Figure 7 below. As shown in Figure 7, the majority of the respondents (n = 125, 79.6 %) reported that floods had destroyed their property to an extreme extent, 23 of the respondents (14.6 %) revealed that floods had

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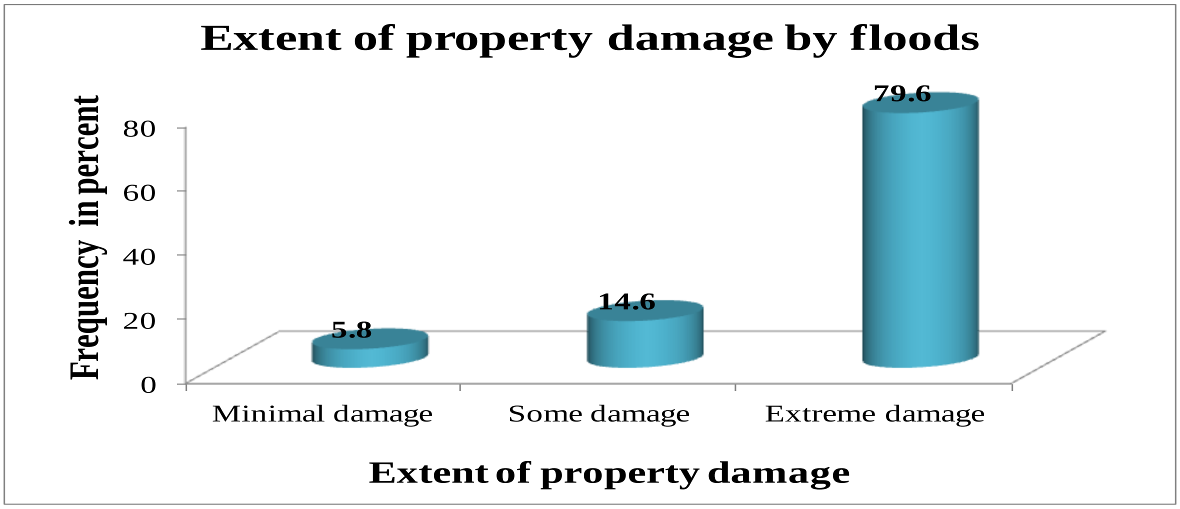
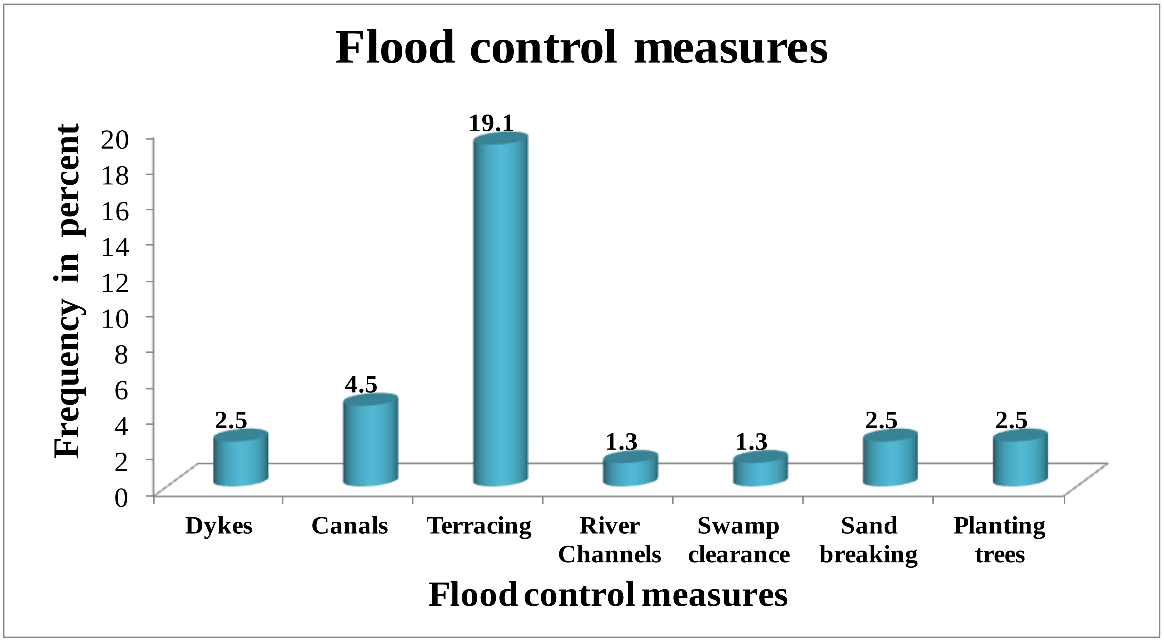
destroyed their property to some extent and the remaining 9 respondents (5.8 %) noted that floods had destroyed their property to minimal extent. Through informal discussions, it was noted that the most affected property was crops on the farms since almost half of the population was engaging in mixed farming. This implies that the land use of farming was highly affected by floods. In line with the studies conducted previously by Onywere *et al* (2011), it was noted that the floodplain supports arable farming during the dry seasons but they are destroyed during floods.

Figure 7: Property Damage Levels



In this paper, it was critical to establish the flood control measures adopted by the respondents in the study area. The sub-set of respondents (n =157) who were experiencing floods on their farms were asked to state the main flood control measure they had adopted on their farm to mitigate the floods. The results were analyzed and presented in Figure 8 below.

Figure 8: Flood Control Measures



Source: *Field research data, (2018)*

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It is clear from Figure 8 that, 4 of the respondents (2.5 %) had constructed earthen dykes, 7 of the respondents (4.5 %) had dug canals, 30 of the respondents (19.1 %) had dug terraces, 2 of the respondents (1.3 %) were using river channels, 2 of the respondents (1.3 %) did swamp clearance, 4 of the respondents (2.5 %) were sand breaking and 4 of the respondents (2.5 %) were planting trees. This result confirms that a majority of the respondents in the study areas were using terracing as a mechanism for mitigating the impact of floods on their farms. As confirmed by Onywere et al (2011) in their research, they found out that the dykes built along the River Nzoia were less effective due to the fact that high sediment deposits usually block the river course leading to rivers changing direction.

CONCLUSIONS

This paper deduced that most of the flood risk zones were located within the South and South Western parts while the flood safe zones were found in the Northern, North Western, North Eastern, Eastern and South Eastern parts of the study area. This was due to the fact that safer regions had a higher altitude while the flood risk areas had lower altitudes. With regard to land use land cover in flood risk and safe zones, it was established that safer zones were suitable sites for: the construction of houses, play fields, establishment of schools and religious institutions; farming activities; and construction of roads. But, flood risk zones were regions suitable for the growth of swamp vegetation particularly, papyrus and riverine.

In this paper, it was inferred that most of the farmers had experienced flooding on their farms especially those near the lake or floodplain of River Nzoia. Regarding the frequency of flood occurrence, most farmers affected by floods lamented that it was a very frequent phenomenon in the areas. In addition, floods destroyed the properties of the local residents to an extreme extent, especially the crop farms.

Recommendations

Based on the finding that most of the safe zones were located in higher altitude areas, we suggest that local residents planning to purchase land for settlement as well as looking for evacuation sites during flooding within Budalangi sub-County should do so in the Northern, North Western, North Eastern, Eastern and South Eastern parts. Moreover, using the information obtained on the flood risk and safe zones, the organizations dealing with disaster management in Kenya National Disaster Operations Centre (NDOC) would use the above information when allocating their human and financial resources during floods in Budalangi sub-County. Guided by the revelation that flood risk zones are within low-lying areas, the Ministry of Interior and Coordination of National Government in collaboration with the State Department for Special Programmes would use this information. Since the current study focused on mapping the land use land cover within flood risks and safe zones in Budalangi sub-county, in Kenya, we therefore recommend that similar studies should be conducted in other areas facing riverine flooding in Kenya and across the world using mixed method approaches.

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