Original Research Article

Participatory Geographic Information System (PGIS) Mapping; an Integrated Flood Management Tool in the Flood Prone Areas of Kano Plains, Nyando Sub-county, Kisumu County, Kenya

ABSTRACT

For decades floods have continuously threatened communities' livelihoods and destroyed properties and the ecosystem as a whole. In an attempt to minimize the destructive nature of these events, different flood mitigation strategies have been employed. Nevertheless, the challenge with these strategies employed is that they seldom give an audience to the people affected, instead of focusing on technical solutions. Thus the need to employ an integrated floods management approach that puts local knowledge into consideration. Although some studies have emphasized the need to have this incorporated with technical expertise to get more lasting solutions to the negative flood effects, much work still needs to be done. This study was conducted in the Nyando sub-catchment, Kano Plains in Kisumu County, Kenya. The study utilized both qualitative and quantitative methodologies. A stratified sampling technique was used to select the three flood-prone areas in Kano Plains, namely, Nyando**,** Miwani, and Lower Nyakach as study sites. A simple random sampling technique was then used to select 100 households for the survey. Purposive sampling was used to select the key informants. Methods of data collection included questionnaires, key informant interviews, focus group discussions (FGDs), GIS-integrated participatory community mapping, and desk reviews. The main research findings were that a majority (65.93%) of respondents in this study live downstream of river Nyando, of which 60.00% resided in Nyando Division, thus exacerbating the risk of floods. The study concluded that Miwani**,** Nyando, and Lower Nyakach were found to be the flood risk areas in the Nyando sub-catchment area.

1.0 **INTRODUCTION**

Communities living in flood plains across the globe have had notable change in inundation patterns over the years in terms of frequency, intensity and predictability (Terumoto 2006; Parasiewicz *et al*., 2019*)*. Floods account for 84% of worldwide disasters according to AghaKouchak *et al.*, 2020 and Perera *et al.*, 2020. Some of the notable disasters include loss of lives, destruction of socio-economic infrastructure, and spread of diseases like diarrhea, typhoid, cholera and malaria among others (Getso & Haruna 2021). Degradation of the natural environment has often been mentioned as a natural hazard risk factor, although little has been done in terms of policy formations to tackle the challenge. Scholarly studies have noted that sub-Saharan Africa has often reported cases of floods, and this has been mainly due to climate change, which has led to the loss of lives and property worth billions of dollars. The main reason for this being poor planning for such incidences (Ndalilo *et al.*, 2020*;* Mngumi, 2020).

To minimize disasters and to recover the local community to its previous state, integration of local knowledge with the institutions to empower the local community and to gather local knowledge on disasters to develop a cyber-based geographical information system is required (Senanayake *et al*., 2003; Misra *et al.*, 2020). Forrester (2003), defined Participatory Geographic Information System (PGIS) as the most useful tool for extracting local knowledge, perceptions of environmental problems and hazards, and presenting and communicating it to environmental scientists. He further noted that citizen maps have the clarity and conciseness that allows decision makers to take into account community inputs which used to be ignored. Morse *et al.*, 2020, noted that in seeking land reforms in South Africa, Public Participation GIS (PPGIS) should not be conceptually, empirically or politically disconnected from core GIS and Society concerns. IFAD (2009) recognized that PGIS uses methods, such as mental mapping, participatory sketch mapping, transect mapping, and participatory 3-dimensional modeling. All of these methods are commonlyassociated with Participatory Learning in Action (PLA) initiatives. Kenya has had serious floods and drought disasters throughout the nation causing major destructions and even causing deaths in some instances.

1.1 **Statement of the Problem**

Since floods have been a frequent occurrence in Nyando river basin, this has substantially caused degradation in the area. Nyando River passes through Kano Plains and traverses a wide area of the lower Kano Plains, which is prone to frequent flooding. Such floods normally cause psychosocial problems, poses danger to health, disrupts settlements and infrastructure, causes food insecurity due to losses on farms, and a general malaise of the population, as a result hindering any type of development of this high potential Kano Plains (Opere, 2013; Kitheka, *et al*., 2021). According to Vella (2012) in 2009, 1126 people (206 households) lost their houses and an additional 3,000 people were affected in various ways by the floods, schools were destroyed and subsequently closed, diseases associated with floods such as cholera breakout was recorded and about 2,000 farmers' crops got washed off in Kano Plains.

The upstream of Nyando River basin, which is known for rejuvenation of water resources, has been depleted (Achieng *et al.*, 2020). Nyando River has its source in Kericho and Nandi Counties, and both Counties have an altitude of over 2000m above sea level and a mean annual rainfall of between 1800mm and 2000mm (Michella *et al.*, 2019). Nyando River basin is more sharply characterized upstream, however on reaching the plains, close to Lake Victoria, the tributaries disperse as a result of periodic deposits, that lead to overflow of the banks before ending in the wetlands near the lake (Olang *et al*., 2009; Guya, 2019), and this appears to accentuate the intensity of floods in the area.

1.2 **The use of PGIS in Flood Risk Mapping**

The residual risk of flood hazard needs to be seriously taken into consideration. This should involve local planning and precaution, including flood protection strategies. Since flood hazards and vulnerability are not continuous events, there should be corresponding analyses and production of up to date maps, after significant changes with minimal expenses (B¨uchele *et al*., 2006; Aksha *et al.*, 2020). Vulnerability related to floods often amounts to the level of risk over socio-economic support systems of a community (Cannon, 1994; Munyai *et al.*, 2020). However, approaches to flood mitigation should normally be based on a holistic assessment of the flood risk, and an accurate analysis of uncertainties related to assessment techniques (Su, 2020). Flood hazards result from natural events, and these often lead to tragedies which are associated with complex socio-economic, political, and environmental processes (Flood Mitigation Strategy, 2009). Therefore, communities' role in the identification and recognition of areas prone to floods is very important. By using FGD forums, participants can interact with each other, thus indicating coping mechanisms and strategies, as well as the importance of social networks (Nethengwe, 2007). Forrester (2003) and Ndzabandzaba (2020) stated that Participatory GIS (PGIS) evolved from conventional GIS, which was seen to be all about modern science, and gave power to the "experts" instead of the people. Therefore, PGIS was considered as the best tool for environmentalists to realize affordable, efficient and timely solutions, and to accommodate the views of communities affected by disasters and hazards (Forrester, 2003; Ndzabandzaba 2020). PGIS therefore aids in visualizing flood vulnerability, by combining mental maps generated by the community with spatial information from the "expert". Perspectives by the local people of flood vulnerability could be better understood through Participatory methods employed in PGIS, which emphasize bottom-up representations. Mapping by local communities can complement the work by scientists and planners of flood hazards to identify high risk groups (Nethengwe, 2007; Kyem, 2021). This study applied the PGIS concept by engaging the community in mental mapping of areas prone to floods and comparing their findings with the traditional GIS based flood vulnerability maps.

1.3 **Integrated Flood Management Approach in Flood Management**

According to Flood Mitigation Strategy (2009), opportunities for effective integrated flood management should enable the government realize that vulnerability is heightened by several physical factors. These include exposure to floods, the degree of protection from flood hazards, the quality of available infrastructure, the level of access to relevant resources, and the capacity to avoid, withstand or recover from flood hazards. In addition, other factors such as poverty, overpopulation, level of education, poor land-use practices, and absence of flood mitigation mechanisms also heighten the vulnerability of the population to floods (Flood Mitigation Strategy, 2009). For instance, women are forbidden from owning land in some cultures and this prevents them from making important decisions on issues regarding land (Nethengwe, 2007, Kyem, 2021). Many affected people are neither aware of some coping strategies used elsewhere. However, sufficient knowledge and capacity is available in the country for flood management, and this can also address the country's social, economic and other development policies (Flood

Mitigation Strategy, 2009). This study sought to explore existing opportunities, by applying integrated flood management (IFM) approach. This approach considered various organizations and/or institutions, socio- economic activities in the area, geomorphology (geology and slope), and precipitation as variables for effective adoption of IFM.

1.4 **Conceptual Framework**

In IFM, the first concept involves envisioning what the river basin should be. The second idea is to incorporate sustainable livelihoods opportunities to improve performance of the system holistically (World Meteorological Organization and UNEP 2004).

The current study adopted a conceptual framework that combines conventional/traditional GIS data sources such as land use patterns, slope, soil, stream network, and administrative boundaries with community local knowledge generated through mental mapping of flood prone areas. This approach was adopted in the PGIS database to analyze differential flood vulnerability among the local communities.

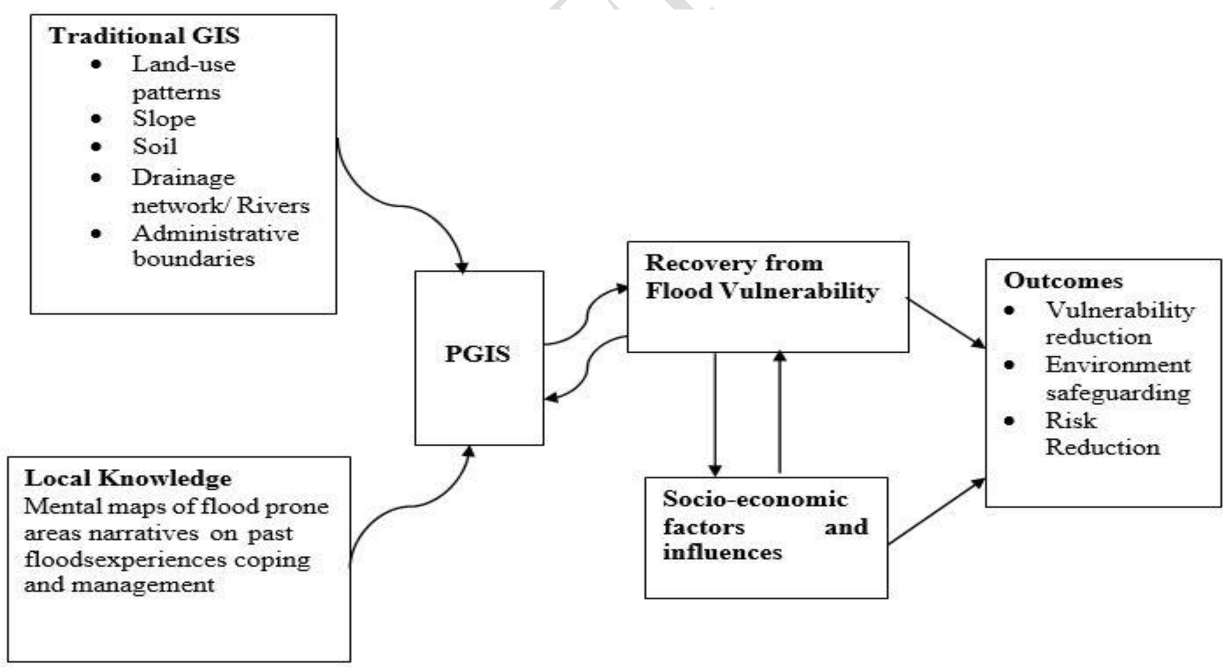


Figure 1: PGIS model linking GIS to local knowledge for flood vulnerability mapping (Adopted and modified from Nethengwe, 2007)

2.0 MATERIALS AND METHODS

2.1 **Introduction**

This section covers the research design, study area, sampling procedure, sample size, research instruments and data analysis.

2.2 **Research Design**

This study adopted a descriptive research design, which involves describing the characteristics of a phenomenon and collection of information through interviewing or the administration of questionnaires to a selected sample size. Descriptive design is useful for extensive research, and is not only convenient for fast data collection but also ensures a high level of confidentiality (Orodho, 2003). Descriptive design was chosen because it helped in the collection of data from the respondents spread across the study area. The study used the procedure of Rea and Parker (2014), due to its ability to bring out issues important for development and management of human resources and their expectations.

2.3 **Study Area**

This research was carried out in the Kano Plains in Nyando sub-County, Kisumu County, Kenya (Figure 2). The study focused on three sites on Kano plains, namely Nyando, Miwani and Lower Nyakach. Kisumu County is bordered by Nandi County and Nandi Hills to the North, Kericho County to the East, and Homa Bay County to the South, and Nyabondo Escarpment to the South-East (NEMA, 2004; Republic of Kenya, 2001). Kano Plains is located between longitude 0050'S and longitude 0010'S, and latitudes 33005'E and latitude 34025'E (NEMA, 2004). The Nyando basin has various land use characteristics, largely influenced by rainfall patterns and socio-cultural practices (Olang and Fürst, 2011). Main soil type in the area comprise vertisols, which is used to grow sugarcane, rice and cotton. However, there is a significant reduction in total cotton production per hectare (WMO and UNEP, 2004). The floodplain has minimal rainfall, with mean annual rainfall ranging between 800 mm and 1200 mm. However, the northern and southern parts of the basin experience more than 1600 mm respectively. Most of the rainfall is experienced in the north in Nandi Hills, and this gradually reduces towards the southeastern side (WMO and UNEP, 2004). A peculiar characteristic of Nyando floodplains are the frequent floods aggravated by human activities due to the growing human population (Olang and Fürst, 2011). The rapidly expanding number of people in the basin is the main reason behind the majority of the land cover dynamics (Olang and Fürst, 2011). The upper catchment is mainly thick forests (e.g., Tinderet Forest), whereas the middle catchment has, scattered trees and grass, as a result of clearing, cultivation and burning due to human settlement (Opere, 2013). The study area is captured in figure 2 below:

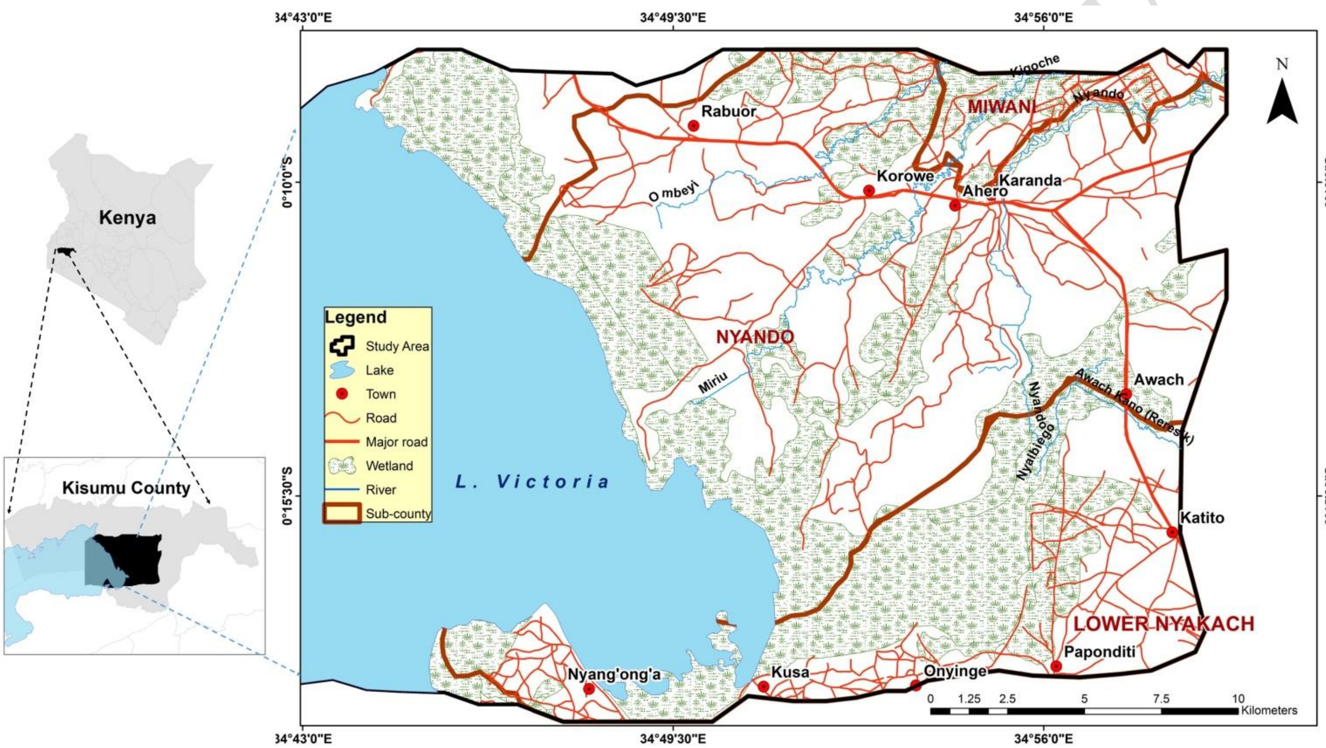


Figure 2: Map of the study area (Source; RCMRD Geoportal (2019)

2.4 **Sampling Procedures and Sample Size**

The research was carried out in three sites namely; Nyando Sub County, Miwani sub location and Lower Nyakach location. According to Kenya National Bureau of Statistics KNBS (2009) census, the study area has 208,566 households (N). Stratified sampling technique was employed in this study to select the three study sites. Simple random sampling technique was used to select the 100 households that participated in the study; while purposive sampling technique was used to select the key informants.

The sample size was calculated from a total of 208,566 households in the three study sub-counties, using Yamane (1967) formula.

$$n = \frac{N}{[1+N(e)^2]}$$

Where;

n = Sample size

N = population size

e= margin of error

The formula is useful in places with known populations; and the sample size obtained was:

Population size (N) = 208,566 Margin of error (e) = 10 percent

N = 208,566/1+208,566 $(0.1)^2$

n = 99.95

n = approximately 100 respondents which were proportionately distributed in accordance tothe individual populations in each of the three study divisions.

The distribution of the respondents was as per Table 1;

Site	Sample size	Population	Percentage (%)
Miwani	34	70,066	33.59
Nyando	38	79,711	38.22
Lower Nyakach	28	58,789	28.19
Total	100	208,566	100.00

2.5 **Research Instruments**

The research instruments used for data collection in this study were; questionnaires, key informant interviews, focus groups discussions (FGDs), GIS-integrated participatory community mapping and desktop reviews. Weighted analysis was done for land cover, DEM, soil and river datasets as corroborative data for the community identified flood risk areas.

2.6 **Data Analysis**

Quantitative data collected using questionnaires was cleaned, verified, and entered into the SPSS software for analysis. Data was analysed using descriptive statistics, and this was done as per the study objectives, to show relationship between socio-economic factors and their influence on IFM in Nyando. The results were summarized and presented in tables, pie charts, and graphs. In addition, SPSS was used for Chi-square ($\chi2$) test which is one of the most useful non-parametric tests, also called a distribution free test for testing hypotheses when the variables are nominal (Pearson, 1900). Flood risk boundary maps were generated from the satellite Landsat images of scale 1:10,000 for the years 2011 and 2018 using ArcGIS 10.5 software. Topographical features such as the old and new channel banks, various types of vegetation, soil types, stratification and drainage provided indicators on flood prone areas. The generated maps were finally used, since they provided a clear indication of risk areas as well as fluvial and coastal flooding (SEPA 2011; Quinn *et al.*, 2013). These helped to detect differential spatial risks and levels of vulnerability. Data collected using household survey included measurement of elevation (through GPS coordinates). Participatory GIS approach was employed to gather and integrate the local community's knowledge with technical knowledge regarding spatial depiction of areas highly affected by floods. After orienting the participants and identifying the exact location using a topographical map of the study area, the mapping process started by the participants placing a tracing paper on the area's topographical map, and drawing on the tracing paper the boundaries of the areas affected by floods, according to them (Weiner and Harris, 2003). They then, identified each area according to the flood intensity (Very severe, Severe, and Moderate) as well as spatial-based socio-economic activities, which were also labelled appropriately, even on the final digital mental map.

3.0 RESULTS AND DISUSSIONS

3.1 Introduction

This section presents the analyzed data of the research's finding including the demographic characteristics of the sampled respondents. In addition, the chapter presents and discusses the results based on the main objective of the study; to map the flood prone areas of the study area using participatory GIS as an integrated flood management strategy.

3.2 Questionnaire Return Rate

Even though 100 questionnaires were distributed to the sampled respondents, only 91 were completed and returned; thus giving a return rate of 91%. Mugenda and Mugenda (2003) say that a return rate of 60% is good and 70% and above is excellent. Therefore, the results presented in this chapter were based on this value.

3.3 Gender of the Respondents

The study comprised 50.55% females and 49.55% males. From this finding, it shows that the information collected was representative, with a ratio of 1:1 since both had equal chances of airing their views regarding the topic of this study. It has been widely acknowledged that men and women are affected differently by disasters due to the differences that exist in their social relations; as such the study was true to consider the gender ratio therein. However, contrary to the findings of Odeyemi and Peter (2018), the study found the contribution of gender to be differential vulnerability small, this is because it was established that in most households, both gender was affected by floods in similar ways. Losses that occurred affected both gender almost in equal measure as gender roles in the modern days cross-cut and therefore both gender were likely to be affected equally.

3.3.1 Level of Education of the Respondents

The study established that the level of education attained by the respondents were as summarized in Table 2. The education level of the respondents pertinent in the study since it showed various community members' knowledge on the potential flood hazards and the level of awareness on their vulnerability to flooding in Kano plain. It also helped in determining the push and pull factors for residing in flood plain and their knowledge in the coping strategies to the flooding.

The study established that the level of education attained by the respondents were as summarized in Table 2

Education Level	Frequency (n=91)	Percentage (%)
Secondary	47	51.65
Primary	37	40.66
Tertiary College/University	6	6.59
No formal Education	1	1.10
Total	91	100.00

Source, Author, 2022.

Majority of the respondents had formal education, as shown in Table 2. This signified their level of knowledge and understating of the relevant issues pertaining to this study. The findings here corroborate those of Odeyemi and Peter (2018) that acknowledged education to be an indicator of cultural capital that gives a prediction of potential vulnerability to disasters.

3.3.2 Period of Respondents' stay in the Study Area

The period of respondents' stay in the study area was as shown in Table 3.

Time	Frequency (n=91)	Percentage (%)
1 – 3 Years	2	2.20
4 – 5 Years	44	48.35
More than 5 Years	1	1.10
Resident by Birth	44	48.35
Total	91	100.00

Source: Author, 2022

The study found out that 48.35% of the respondents had either resided in Kano Plains for a period of 4 - 5 years or being residents by birth, 2.20% had stayed for 1 - 3 years, and only 1.10% had resided for more than 5 years after relocating to the flood plain. Table 4.4 shows that a majority (48.35%) of the respondents had These findings revealed that most respondents had resided in the study area and therefore must have experienced flooding, similar to those of a survey carried out on flood victims of the 2002 Melde Flood in Eilenburgh (Kuhlicke, 2010).

3.4 **Geographical and Land-use Determinants of Floods in Flood Risk Areas of Kano Plains**

This study examined the influence of geographical and land use determinants of floods in the study area. These were established using mainly data from satellite images, topographical maps, and community mental maps. Therefore, the results presented here were based on an analysis of the rivers/streams network, slope, soil, and land use. An integrated flood vulnerability map was also generated by overlaying the digitized community mental maps with a flood vulnerability map of the area.

3.4.1 Influence of stream network

As illustrated in Figure 3 below, floods are more prone to areas with dense network of streams at the river mouth, and Nyando and Nyakach sub-counties were found to be highly affected.

Figure 3: Drainage distribution in the study area (Source; RCMRD, 2021)

Regions with multiple drainage networks were found to have high incidences of flooding. South western part of the study area registered low drainage influence hence had low incidences. The results here were similar to a study by Otiwa and Onywere (2015) who found drainage network to be a significant factor influencing flooding.

3.4.2 Influence of Slope on Floods

The slopes in the study area ranges from a level of 0 degree on the shores of Lake Victoria, to a high of 34.86 degrees in Nandi hills towards the southeast corner of Figure 4. Areas with a low slope experience more floods than high lying areas.

Figure4: Influence of slope on floods within Kano Plains (Source; Author 2021)

From Figure 4, the influence of slope on flooding ranges from Very High (Category 5), at the shores of Lake Victoria to the southwestern side of Kano Plains, to Very Low (Category 1), which is the catchment of Nyando River, located in the northeastern part of Nandi Hills. The table 4 below, captures analyzed data as per the geo-spatial analysis of DEM of the study area.

Table 4: captures analyzed data as per the geo-spatial analysis of DEM of the study area

Category of Slope	**Level of Flooding**	**Slope (Degree**
1	Very Low	9.31-34.86
2	Low	4.52-9.3
3	Medium	2.33-4.51
4	High	0.83-2.32
5	Very High	0-0.82

These findings correspond with those of Chukwudi *et al.*, (2018), who found that low lying areas were most susceptible to floods as most people residing there relied on the rivers and streams as their main sources of water, thus exposing them to the flood risks.

3.4.3 Influence of Soil types on Floods

As shown in Figure 5, Kisumu Central and the areas surrounding Lake Victoria have poorly drained clay soil. Areas with very poorly drained soils, imperfectly drained soils and poorly drained soils were more susceptible to flooding unlike areas with well drained soils. Soil drainage also affects the water infiltration rates, whilst well drained soils have higher infiltration compared to poorly drained soils (Otiwa and Onywere 2015). During rainfall seasons, flooding occurs severely in the poorly drained soils compared to well drained soils.

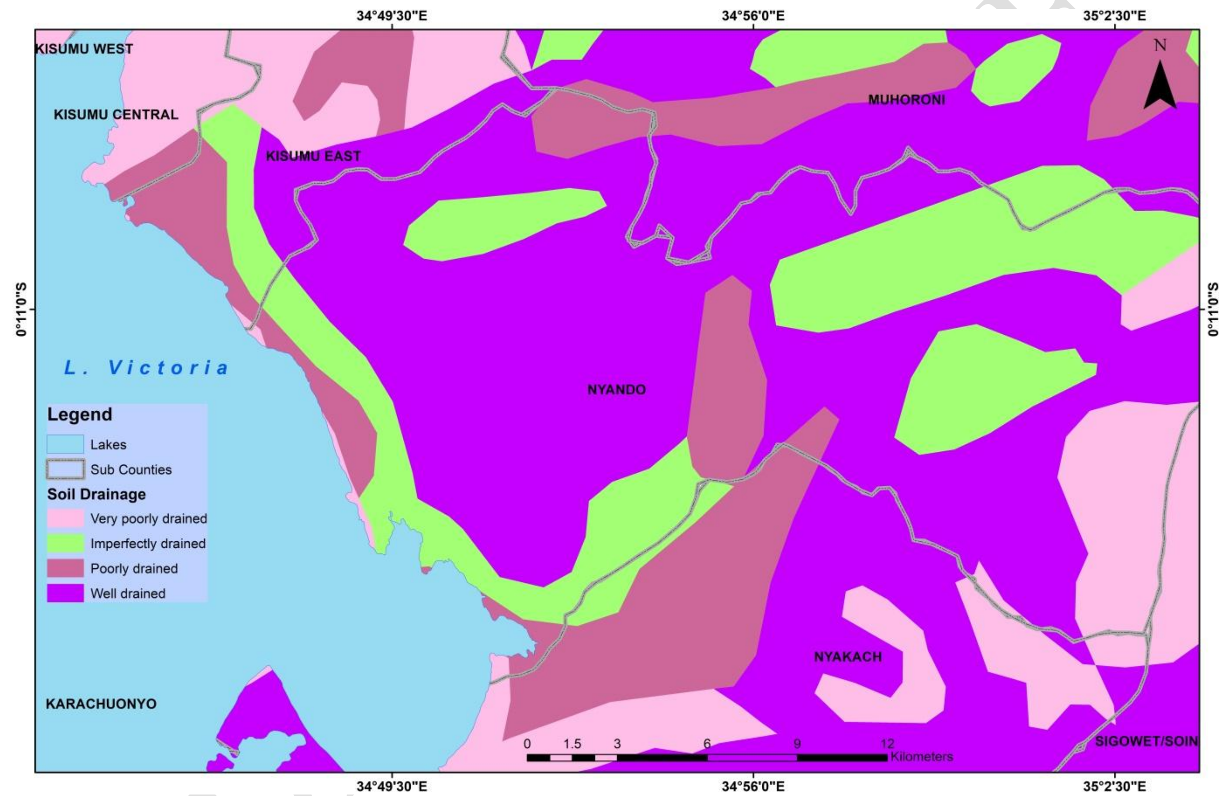


Figure 5: Soil drainage map of the study area (Source; Author, 2022)

The poorly drained soils found along the shore of Lake Victoria (Figure 5) were found to be highly vulnerable to flooding. This finding agrees with that by Andi *et al*. (2017), who note that during the rainy season, the infiltration process decreases overtime in the poorly drained soils due to water logging as a result of a high rainfall intensity, and this condition leads to flooding.

3.4.4 Influence of Land Use

The study identified seven land use types as follows: dense agriculture, sparse agriculture, bushland, plantation, swamp, town, and water body, as shown in Figure 6.

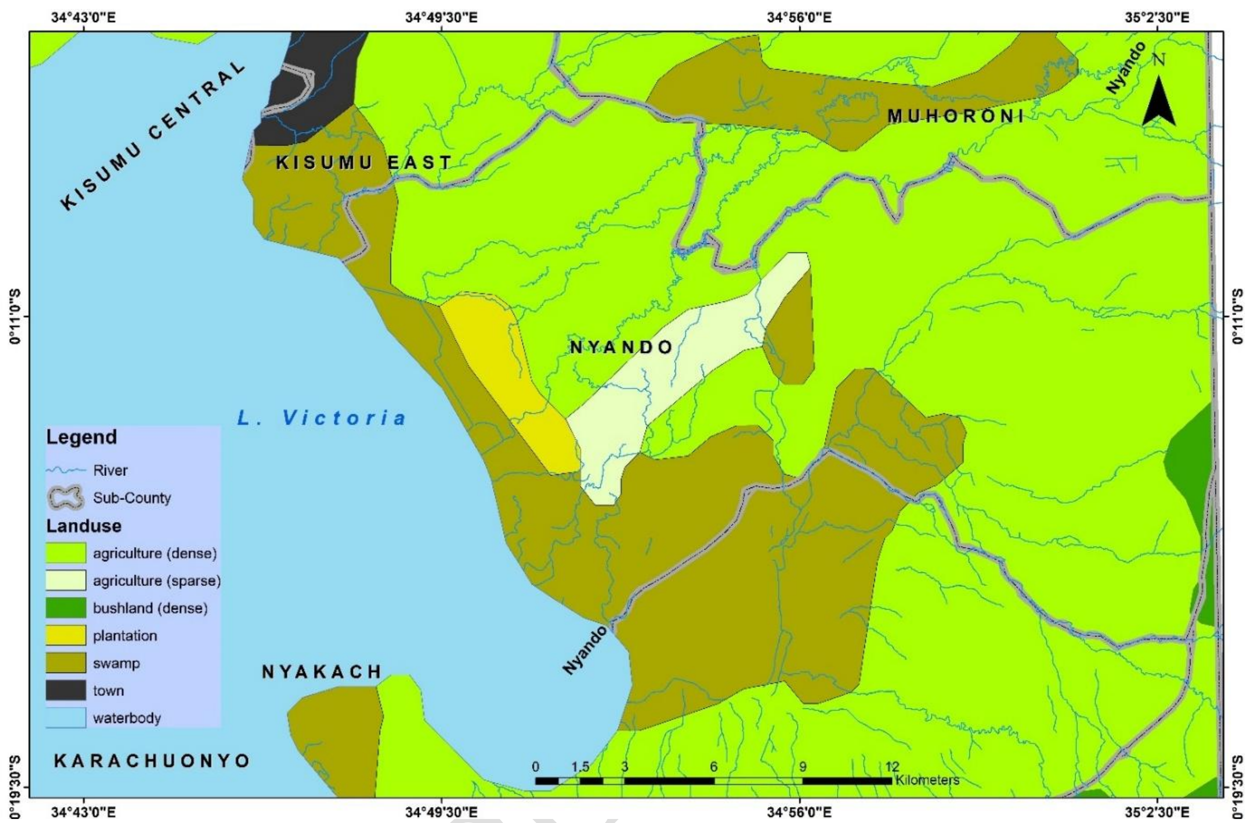


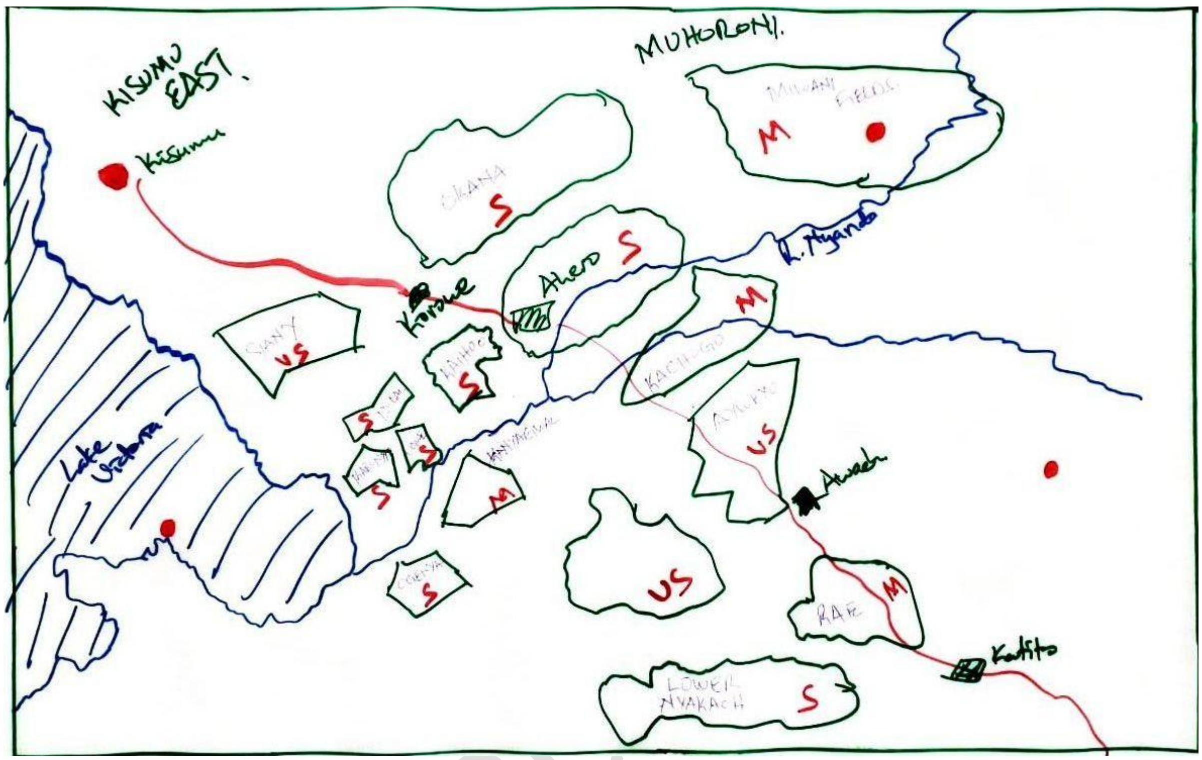
Figure 6 ***Land use map***

Source: Generated from Landsat 8 of 10/05/2017 using ArcMap 10.7 (2019)

The study established that areas with forests or vegetation cover had high infiltration rates and consequently had low flood susceptibility, these included agriculture and Bush land (Chukwudi *et al.* 2018). Plantations and swamps signified areas with moderate flood susceptibility. Although surface runoff is generally considered high in built-up areas because of impervious surfaces, this was not the most likely factor to contribute to floods in this study. This is because only a small area of Kano plains consists of towns (except Ahero) with buildings and pavements that can cause significant runoff which can lead to floods. The findings here contradict that of Andi *et al.* (2017) conducted in Okazaki city which basically had a larger built up area.

3.5 **Community Mental Map**

The community through the FGD forums came up with the community map of the areas in Kano Plains that were frequently flooded. The areas identified were categorised into moderate, severe, and very severe flood hit areas as illustrated in figure 7.



VS= Very Severe
S= Severe
M= Moderate

Figure 7: Crude Community Mental Map

3.6 **Integrated Flood Vulnerability Map for Lower Kano Plains**

An overlay of the flood vulnerability map was made with the mental map for Lower Kano Plains. The overlay was made of the “local knowledge” and “expert knowledge” to assess the flood vulnerability based on spatial position. Figure 6 indicate the delineated local and expert flood prone areas in Lower Kano Plains which are mainly located in Kanyagwal, Rae, Kochogo, Ogenya,Kabonyo, Nyachira Siany and Lower Nyakach. Miwani area at the northern section of the map was also found to be highly flood vulnerable. They lie within the 26.36% of the study areacategorized as Very severe flood vulnerability.

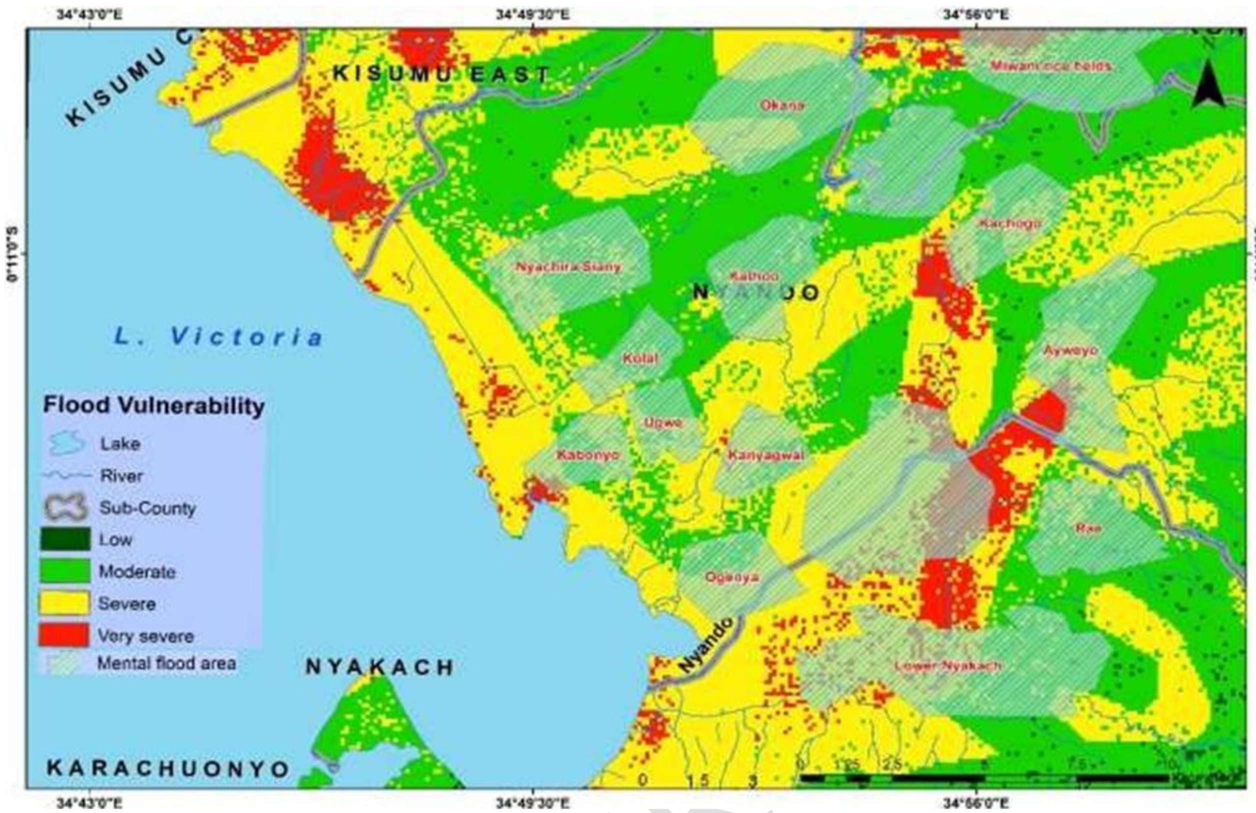


Figure 6: Integrated flood vulnerability map for study area (Source; Author, 2022)

3.7 **Spatial Distribution of Flood Risk and Vulnerability in Lower Kano Plains**

In analyzing the weight of the other determinants, it is evident that slope has the highest weight (Table 5). This implies that slope contributes more to flooding than the other variables. Slope influences the flow direction; it also has dominant influence on drainage flow, duration of water infiltration and duration of flow.

Table 5 Weighted flood vulnerability ranking

Variables	Relative Weight (%)	Reclassified Factors	Flood Vulnerability Index
Slope	30	0 – 0.82	5
		0.83 – 2.32	4
		2.33 – 4.51	3
		4.52 – 9.3	2
		9.31 – 34.86	1
Soil	25	Well drained	1
		Moderately drained	3
		Poorly drained	4
		Very poorly drained	5
Land use	20	Agriculture (dense)	2
		Agriculture (sparse)	2
		Bush land	2
		Plantation	3
		Swamp	4
		Town	1
		Water body	5
Rivers	25	Very High	5
		High	4
		Medium	3
		Low	2
		Very Low	1

Source: Adopted and modified, Andi et al. (2017)

The data from the table 5 was used in overlay analysis and presented as a vulnerability flood predication map (figure 7) and was noted that 26.36% of the study area was categorized as Very severe flood vulnerability, and this was largely located on the lowlands around Lake Victoria, as well as the northern and southern part of the map.

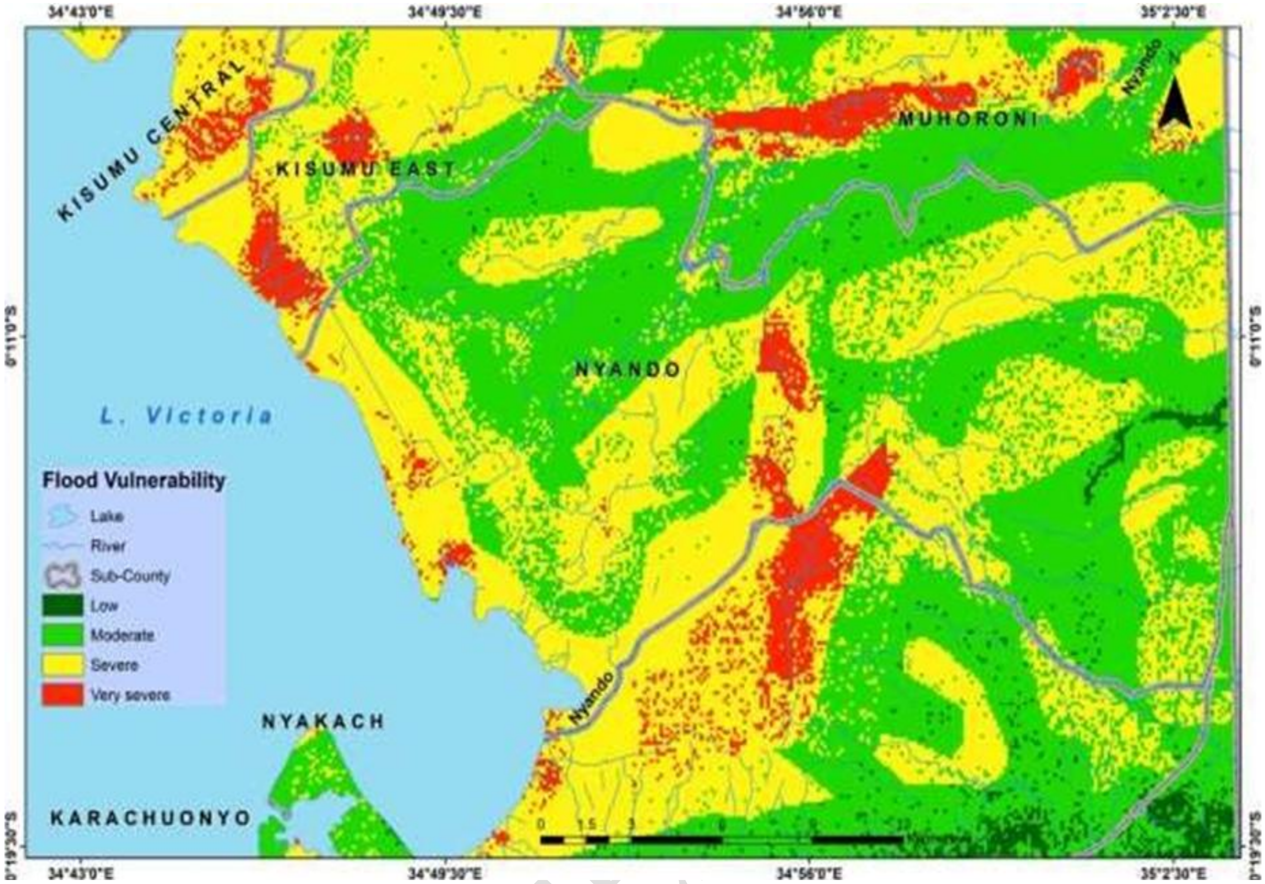


Figure 7: Flood vulnerability and prediction map for the study area (Source; Author, 2022)

4.0 SUMMARY OF FINDINGS

Through the GIS analysis on the effects of geographical factors such as soil type, drainage pattern, slope, as well as land use on flooding, the study revealed that these contribute significantly to flooding. These findings supported communities identified flood prone areas in the study area. For instance, slopes in the study area were found to range between 0 degree on the shores of Lake Victoria, to a high of 34.86 degrees on the hills towards south western regions of the study area. A vast area of the study area was found to have poorly drained clay soil that exacerbated flooding. On land use, it was found out that areas with plantations and swamps were significantly affected by floods. The study also found out that the lowland areas of the study area were classified as being highly vulnerable to flooding, as per the results of overlay vulnerability and predication mapping of the study area.

4.1 Conclusion

The study concluded that part of the study area sites of; Miwani, Nyando and Lower Nyakach, at the mid and downstream of River Nyando were classified as the flood risk areas in the Nyando sub-catchment. The study also found out that community identified flood prone areas coincided with the traditionally mapped flood prone areas of the Kano plains in the GIS platforms.

Consent

As per international standard or university standard, respondents' written consent has been collected and preserved by the author(s).

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