**Flood Hazard Mapping using GIS in Kenya – A HEC-RAS Model Applied to Mapping the Enkare Narok River**

**Alvin Igobwa Mugwe**
**092975**

**Submitted in partial fulfillment of the requirements for the Degree of Financial Economics at Strathmore University**

***Institute of Mathematical Science***
**Strathmore University**
**Nairobi, Kenya**

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## ABSTRACT

The purpose of this project is to come up with a visual tool to aid in the visualization of flood prone areas, determine the causes of floods and estimate the total damage caused by floods in Narok town. The study uses Advanced Spaceborne Thermal Emission and Reflection Radiometer(ASTER) 30m resolution Digital Elevation Models (DEMs) for the extraction of the river properties and geometry and Hydrological Engineering Center – River Analysis System (HEC-RAS) for the hydrological routing of the Enkare Narok river so as to carry out the unsteady flow simulation that yields the production of the flood prone areas, and the cause of flooding. This flood hazard map will help in the forecasting of floods and further help in the creation of an early warning system.

With the global warming temperature staying at this level, it has caused heatwaves in Pakistan being labelled as the worst heatwaves, and an increase of the ice caps being melted and most importantly (to our cause) an increase in the ocean temperatures, (Asrar, 2019). As average temperatures have risen in regions across the world, during heavy downpours, more rain has increased. It is because hot weather has higher humidity. Although global warming emissions continue unabated, scientists expect rains to rise by more than 40% by the end of the century during the heaviest precipitation across Europe. Rainfall may not necessarily lead to floods, but it does increase the probability of occurrence, (Denchark, 2019).

### 1.3 Global view on flooding

Floods contribute to 56% of all weather related disasters and furthermore have the highest probability of occurrence (43%), (Davies, 2015). Due to the relatively high likelihood of flood occurrence, floods have caused the death of 2.3billion people from 1995 to 2015 and with the UN having reported a growth in not only frequency but damage as well, floods are a real and actual problem to deal with[1]. (Jacobs, 2016) Assessed that flooding has been increasing from 1980 to 2010 and further predicted that by 2050 flood losses will increase fivefold. The prediction is attributed to the increasing value of land and more importantly climate change around the flood plains.

### 1.4 Floods in Kenya

According to the United Nations Office for the Coordination of Humanitarian Affairs (UNOCHA), the main cause of flooding in Kenya is heavy precipitation, more specifically the March-May heavy rains. These floods are the major causes of displacement and deaths and have displaced 211,000 people, injured 33 and killed 72.

Figure 1 displays the prevalence/ occurrence of disasters in Kenya. From a general view, it is clear to see that floods are ranking second in prevalence by taking the share of 29%. The focus of this

[1] The website reflects a project done by the United Nations report "the Human Cost of Weather Related Disasters"

However, when we take into consideration deaths, floods jump to second, as per figure 3, with a share of 38%.30% of people were affected by floods in Narok which is a third of the population. Flood prediction can be able to minimize the number of people who are affected whilst also reducing the other hazard types since crops and vegetation are affected in one way or the other. Aside from having damage reduced, lives can be saved if the population is prepared enough for it.

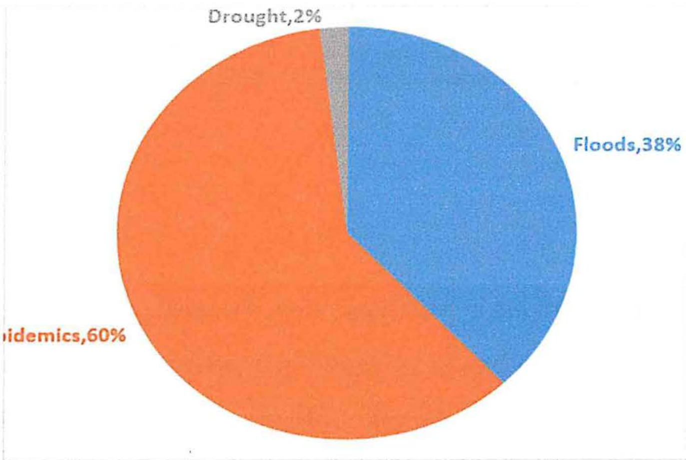


*Figure 3 People Killed/ adversely affected by hazards in 2015: Source (Alfred)*

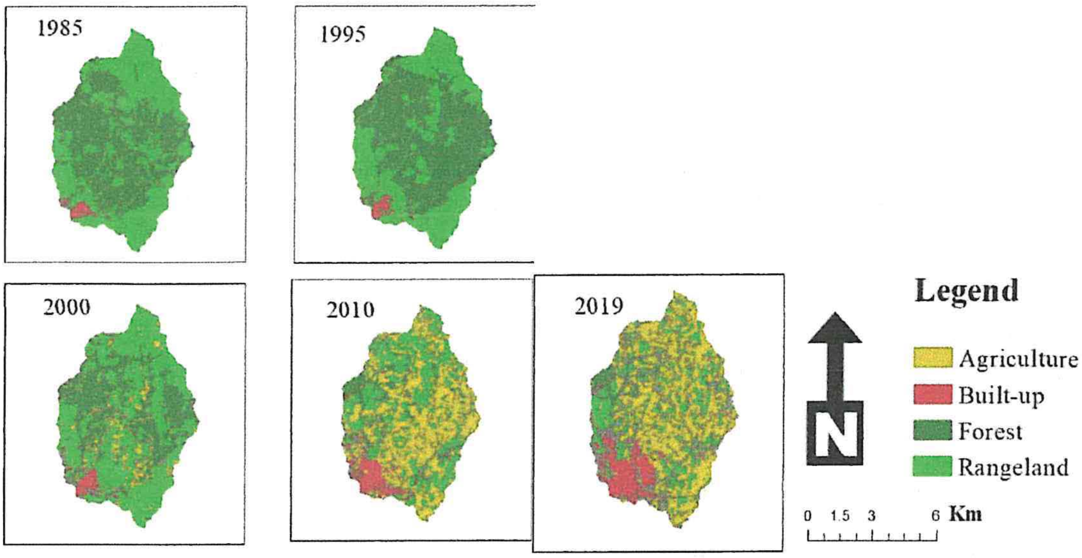


*Figure 5 the figure above is the diagrammatic representation of the degradation of forest cover in Narok County and the increase in agricultural land and urbanization, from the years 1985 – 2019. Source: (Nzitonda, Mwangi, Mwangi, & Gathenya, 2019).*

## 1.7 Effects of the flooding

Floods that have occurred during the heavy rain seasons of March-April-May (MAM) and October-November-December (OND) from the 2010 -2015 period led to approximately 75 damaged houses, 88 deaths, 62 families displaced 29 serious injuries and 3 missing people (Narok County Flood Early Warning Communication Strategy, 2020). The floods also contribute to an economic upset to the county as a whole. The Maasai Mara game reserve and the Paradise Lost serve as the two hot tourist attraction sites for international and local tourists, respectively. The Maasai Mara game reserve is accessible through the Narok-Mai Mahiu highway which once collapsed causing a number of tourists to be left stranded as they couldn't leave their hotels and also caused the cancelation of many potential tourists to the site due to the fear of floods occurring during their stay (Narok County Flood Early Warning Communication Strategy, 2020).

## 1.7 Problem Statement

Floods have reoccurred in Narok Town, especially the low-lying land in Olopito. Recently, flood has hit the area of Ololunga and Mau Areas on 17 December 2015, which the area itself does not normally experience floods. Due to this, the flood has destroyed a big amount of properties and made the community live in discomfort. When a flood occurs, it becomes a serious problem because flood may cause damages to crop, properties, and public facilities. Besides, loss of life

## Chapter Two: Literature Review

### 2.0 Introduction

Natural disasters happen every year and their impact and frequency have drastically risen in the past few years, mostly due to environmental degradation, such as deforestation, intensified land use, and the increasing population (Vincent, et al., 1997). Floods in Kenya are the most disastrous when it comes to economic loss as it takes the 93 percent in economic damage related to natural disasters (Narok County Flood Early Warning Communication Strategy, 2020). The 1997/98 floods labeled as the El Nino floods resulted in approximately $800 million in economic losses (Otiende, 2009), such economic losses includes considerable damage to highways, settlement, agriculture, and livelihood.

### 2.1 Theoretical Research

The techniques used to detect flood in urban areas with SAR pictures have taken advantage of several helpful resources and sources of knowledge to minimize the influence of these effects on flood detection accuracy. As an example, a SAR end-to-end simulator (Speck, et al., 2009) was built along with high-resolution LIDAR data from the Tewkesbury urban area (UK) in the algorithm for the near-real-time flood detection of metropolitan regions with TerraSAR-X images (Speck, et al., 2009). When the effects were masked during almost real-time processing, 75% of the unmasked flooded pixels in urban areas could be correctly classified.

Hydrological simulations with HEC-RAS and HEC-GeoRAS used in research at the Nullah Lai Basin, Rawalpindi in Pakistan focused on no-risk evaluation and risk mapping for various scenarios (Fowze, Gunasekara, Liyange, & Hazarika, 2008). Nineteen floods occurred between 1944 and 2002 and were analyzed during the period 1981, 1988, 1997 and 2001 with extreme flood events. The conclusion was that the integrated modelling approach employed in the study works well to identify flood vulnerable areas at a specific discharge value with a proper evaluation of flood depths. In the GIS environment, the use for the estimation of flash flooding of remote sensing databases such as Landsat Thematic Mapper (ETM) plus, Shuttle Radar Topography Mission (SRTM) has been utilized (Ahmad, Mohsin, & Zakir, 2010). HEC-RAS Software Peak flows were derived from a frequency analysis and the calibration run is carried out, simulating the event for a return period of 50 years. (Youssef, Pradhan, & Hassan, 2011).

of wavelengths, the angle of the radar look and polarization, that can conceal essential parts from ground sensors (Speck, et al., 2009).

Forkuo sought to address the requirement for an efficient and economical flood map methodology (Forkuo, 2011). This produced a potential flood hazard map on a geomorphic basis composed of flood hazard index maps that have been developed which integrates river flow-specific variables. DEM was used for morphometric analysis in their field of study Wadi Dahab Egypt (Orman, El-Rayes, Gereish, & Schroeder, 2011). Then, by defining the ridgelines (water divide) between sub-bases, delineate the basin borders; snap pour point tool was used to ensure that the high-accumulated flow points are chosen using the watershed tool during drainage basins.

(Diakakis, 2011) examined a basin morphometry-based flood hazard mapping method known as Arc Hydro Model. A right DEM consistency, the direction of flow, accumulation of flow were developed and used. Results were produced as maps classifying the catchments by their peak flow into five classes. The proposed approach used necessary morphometric variables such as a catchment area, a tap and a point height, which can be inferred from topographic maps.

Time–frequency analysis is a common technique for studying signals whose spectral characteristics change over time, the principal method being the short-time Fourier transform or spectrogram. (Oosterban, 1994) Identified three frequency analysis methods: the interval method, the theoretical frequency distribution method, and the rating method. The latter approach consists of using the statistical distribution function for data adaptation. Since the series does not indicate whether one distribution is more appropriate than another, the goodness-of-fit test shows how well the distributions are used to select the proper placement (Hailegeorgis & Alferdsen, 2017). The PGIS approach was used to gather data on recent fluvial events and to identify significant flood events in the field of spatial analysis. In order to include people in decision-making, the PGIS uses geographic information systems which provide for qualitative (people survey, observation) quantitative (measuring) methods. PGIS is used in various sectors: indigenous land mapping in flood management and in managing natural resources (Houessou-Dossou, Mwangi, Njuguna, & Abiero, 2019).

Specifically, the aim of this paper is to analyze the dynamic of flow in the Enkare Narok River basin. For this, HEC-RAS model is to be used to calculate the main flow characteristics along the study reach. This will allow locating the high, low, and constant flow characteristics areas; the large and narrow section areas will also be identified. Certain parameters such as total surface area, volume decrease from upstream to downstream. These results will be very useful to the decision makers for water management, hydraulic structure implementation, environmental planning, and flood control administration along the Enkare Narok River.

The purpose of this study is to produce floodplain maps for the major Enkare Narok River in the study area at various flow rates. Three flow rates are to be analyzed, and the resulting floodplains mapped using QGIS. For a more accurate analysis of the floodplains and affected areas, the floodplain areas will be mapped with specific shapefile features within the study area.

## 2.4 Conceptual Framework

The following conceptual framework shows the interaction of different variables in creating a flood map using HEC-RAS and DEMs.

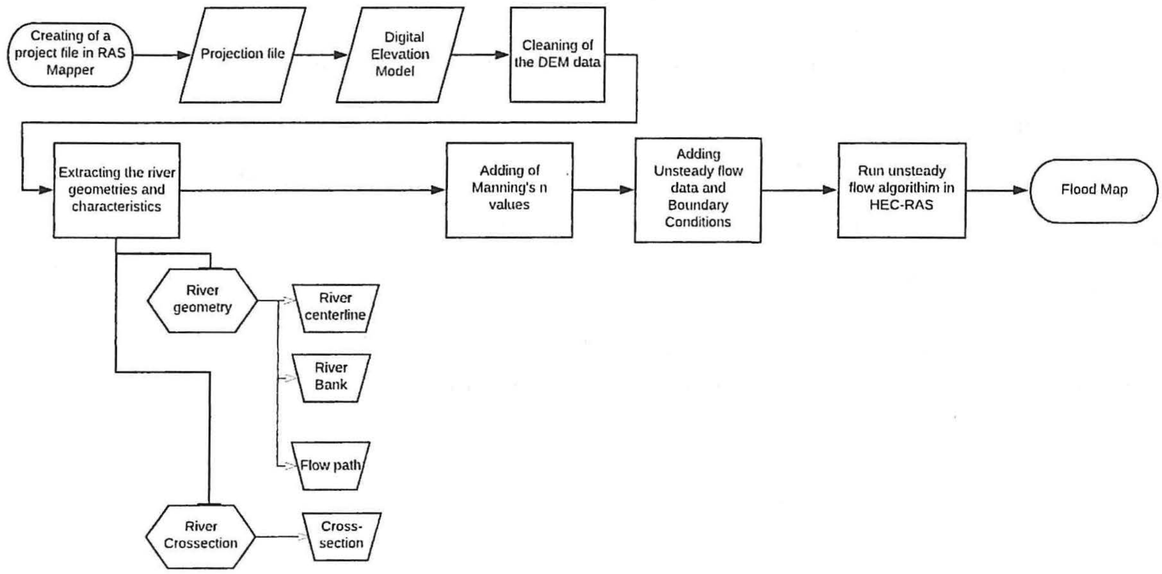


*Figure 6 Conceptual Framework*

*Figure 7 Flood basins in Kenya*

From Figure 7 above the areas highlighted in blue represent the flood basins of Kenya from the World Resources Institute.[2] Flood basins/ flood plains are regions of land nearby a stream or waterway, which extends from the banks of its channel to the base of the encasing valley dividers, and which encounters flooding during times of high release (Goudie, 2004). The highlighted areas include; Tana River region, Busia region, Turkana and more. However, it is key to note that the Narok region has not been highlighted despite all the floods that occur in Narok. This goes to show the sampling reasoning of choosing Narok as the study area.

### 3.3 Data collection

From the above texts, topographical data is key for the workings of the model as it shows the river profiles, catchment, station cross-section cut lines, bank stations and flow paths. As such Digital elevation model data is required for the analysis. As such, the project utilized the Digital Elevation Model (DEM) data for the year 2019, November as during that period which lies in the OND period where high levels of rainfall occurs and most of the floods. The data was collected from the Earth data[3] website for NASA where a 30m resolution DEM data for Narok was obtained. The

[2] https://www.wri.org/resources/data-sets/kenya-gis-data
[3] https://earthdata.nasa.gov/

building blocks of the unsteady flow analysis. It utilizes the use of partial differential equations that describe the flow in which the material density is constant within a fluid parcel of an arbitrary cross-section of a river. The partial differential equations as described from (Saint-Venant, 1871) are:

$$\frac{\partial A}{\partial t} + \frac{\partial (Au)}{\partial x} = 0$$

And;

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + g\frac{\partial \zeta}{\partial x} = -\frac{P}{A} * \frac{\tau}{\rho}$$

where x is the space coordinate along the channel axis, t denotes time, A(x,t) is the cross-sectional area of the flow at location x, u(x,t) is the flow velocity, ζ(x,t) is the free surface elevation and τ(x,t) is the wall shear stress along the wetted perimeter P(x,t) of the cross section at x. Further ρ is the (constant) fluid density and g is the gravitational acceleration.

i. Compute weight surface from $w(x, y) = f(s(x, y), d(x, y))$ as $W = \frac{D}{S}$

j. Derive updated elevation surface using, $zAB = zAw + zB(1 - w)$.

The steps followed above are taken care of by the GIS software QGIS, by using the raster tool 'merged' and placing the DEM's available. This leads to the output below:

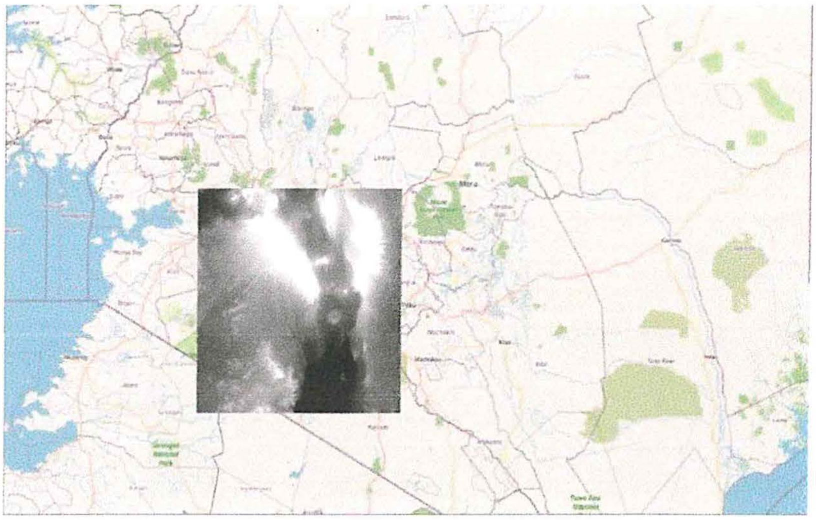

*Figure 9 Merged STRM DEM of Rift Valley region*

The figure represents the Narok water basin, whose coverage is still too large as Narok town is the main study area. As such by clipping the raster image again we can get the Narok town DEM which can be analyzed. The spectral image of Narok town highlights the topography of the land where, the dark shaded areas, that is, the areas in red, signify the low lying areas, whereas the light colored areas (the green and yellow areas) represent the high-land areas.

### 4.3 Data Analysis

The challenge of using a 30-metre resolution DEM is that the river path is not clearly visible. Figure 12 showcases the overall terrain of the land but the river path is not clearly visible for the extraction of the river properties. For this reason, the use of google satellite images was used in the extraction of the river properties.

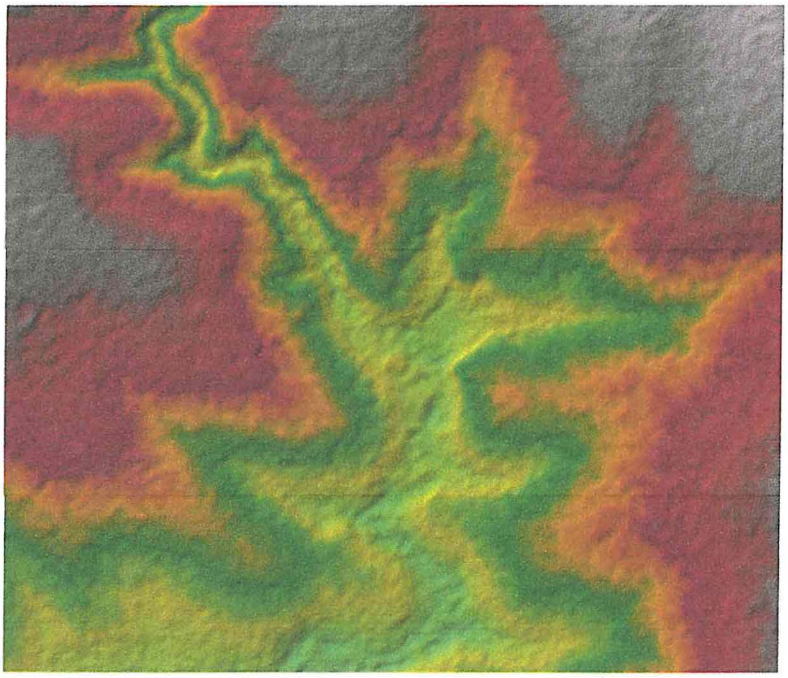

*Figure 12 Narok town DEM seen through RAS-Mapper*

### 4.3 Mapping the flood prone areas in Narok town

The flood mapping process of Narok town utilizes the foundations of hydraulic routing and the unsteady flow analysis of Enkare Narok River. The mapping process utilizes the river properties extracted from Figure 13 River Properties extracted from Google Satellite, and requires the addition of Manning's n values, which are the determinants of roughness/ friction applied to the flow by the river channel[5]. The manning's values are applied to each cross-section of the river channel (identified by the dog-leg shaped green lines that cut across the river channel at various points). The next step is to enter the unsteady flow data. In our situation, a flow hydrograph will be used as the upstream boundary condition, which implies that the conditions for water flow are dominant in upstream. The values used in the water flow are derived from the (Water Resources Situation Report, 2018), by looking at the Nzoia discharge rate and the national discharge rate that varies between $30m^3/s$ to $400m^3/s$.

After completion of the above, a 100-year[6] flood map is created, displaying the potential flood hotspots following the Enkare-Narok River. The dark-blue regions display areas where the height of water will possibly exceed 1 meter. The flood map shows that the lower regions of Narok town and the highway are most likely to be affected by floods.

[5] The manning's values can be calculated, but for this study, the use of the manning's values tables was used. The tables used were extracted from https://www.engineeringtoolbox.com/mannings-roughness-d_799.html

[6] 100 – year flood maps are described as a medium probability flood zone area. In contrast a 1000-year flood map is an extreme event that showcases a high probability chance of a flood occurring. (Maftei & Papatheodorou, 2014)

# Chapter 5: Policy Recommendation

From the guiding objectives, we see that there are three main issues that need to be addressed in Narok Town. First, the cause of flooding in Narok. Given that the study highlights that the cause of flooding is the bursting of the Enkare Narok river, it is imperative that the government sector comes with a solution to curb the bursting of the river. Thus, an implementation of protective dykes will help in the mitigation of river floods in Narok town (Weingartner, et al., 2019).

Secondly, the damages that occur during flooding. Given that the most likely affected areas is the town according to Figure 15, and with the knowledge that Narok town lies in a basin like topographical region, a potential solution by the government sector could be to relocate the town altogether. Given that when floods occur in Narok town, the citizens are told to relocate to highland areas; it would make sense to relocate the whole town. The feasibility of urban relocation is one that is difficult as the problem arises with asking the people to shift their lifestyles and homes, on top of being very expensive to shift a whole town (The conversation, 2013). This can therefore be met by the private sector, specifically the insurance sector to provide affordable insurance covers for the buildings that are located in Narok town.

Lastly, when it comes to the mitigation of the flood prone areas, the public sector should liaise with the private sector in the creation of a flood early warning system that would help in the warning of citizen prior to a flood event. This would help in saving lives and property. (Weingartner, et al., 2019) Reported that an early warning system helped in saving a county up to $1 million in damages.

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