Assessment of flood risk using GIS based approach: The Case of Kebena River in Addis Ababa City

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Abstract- Flood is a major threating problem to the local community at worldwide particularly in developing countries. Urban floods have emerged as a pressing concern in Ethiopia, particularly in areas like Addis Ababa city. Kebena river, which is one of the major watershed catchment in Addis Ababa, is frequently affected by these floods which has been resulting in great socio-economic damage. In order to minimize and avoid the problem, there should be a research that can identify and understand the causes and consequences of flooding in the study area. The study used Geographic Information System (GIS) technologies to make analysis of Land Use and Land Cover changes dynamics, flood exposure components for the flooding hazards, Vulnerability and flood risk mapping of the study area. The Land Use and Land Cover Change dynamics in the study area were found to be high, with built up area increasing by 41.63%, agricultural land decreasing by 50.21%, bare land decreased by 75.78%, Forest land decreased by 7.51% and open land decreased by 11.58%. The flood risk map was developed by overlaying the flood hazard analysis layer which considers six flood causality factors (reclassified Soil data, Elevation, Rainfall precipitation, Drainage Density, Slope and Distance to River), Land Use and Land Cover of the study area and population density map. The result has revealed that, 24.4% (879 ha) of the basin was characterized by very high flood risk level and 13.2 % (477 ha) of the study area was characterized by high flood risk level. On the other hand, 19.1% (687 ha) of the study area fall under moderate flood risk level zone. The rest of the study area which is 33.3% (1,200 ha) and 10% (358.93 ha) of land falls under low and very low flood risk level respectively.

Index Terms- Addis Ababa, Flood hazard, Geographic Information System, Kebena, Land Use and Land Cover Change.

I. INTRODUCTION

Urban flood is a serious problem in cities worldwide, especially with increasing climate change and urbanization (Yan et al., 2018). Urbanization restricts where floodwaters can go by covering large parts of the ground with roofs, roads and pavements, thus obstructing natural channels (Elhag, Ali, & Ali, 2019). Large-scale urbanization and population increases have led to large numbers of people, especially the poor, settling and living in floodplains in and around urban areas (Douglas et al., 2008). Millions of people throughout the world who live in river basins are seriously at risk from river floods. Extreme flood hazards at the national level could delay development for a few years (Pauw, Thurlow, & van Seventer, 2010). A flood may leave people without shelter at the household level (Hernández-Guerrero, Vieyra-Medrano, & Mendoza, 2012) restrict opportunities for participation in economic activities (Linnekamp, Koedam, & Baud, 2011) and could make diseases more prevalent. Climate change may cause flood impacts to become even more severe in the future (Nyakundi, Mwanzo, & Yitambe, 2010).

In order to plan capacity improvement in the disaster reduction process, flood and flood coping strategies will be useful. To put it another way, the local community and local government will be involved in creating the better flood coping strategies, especially by looking at flood features and current flood coping mechanisms (Burby, 2003). With limited attention paid to metropolitan centers, the majority of studies in developing countries concentrate on rural adaptation to the projected negative effects of climate change. Rapid urbanization has resulted in a big population living in slums and substandard housing, and cities are expanding quickly (Weldesilassie, 2014). Their vulnerability to flooding and other extreme weather events rises since they typically have limited access to essential utilities like water and sanitation (Warner, Waalewijn, & Hilhorst, 2002). Although the influence of many climate change scenarios are projected on a global basis, most regions of the world lack knowledge of the precise nature and scope of such effects on local watersheds or communities (Burton, 1997).

Hence, it's crucial to determine how climate change is affecting local communities at the District/Woreda level. The study will focus on urban areas and communities flood risk and social vulnerability impacts. The particular focus is on flood incidence along Kebena River bank in Addis Ababa, capital city of Ethiopia, which is treated as a case. The city's political, geographical and socioeconomic context makes the city a useful exemplar for other cities in Africa and for other regions within the country. The African Union, the United Nations Economic Commission for Africa, as well as several other foreign organizations, embassies, and consulates have made Addis Ababa an increasingly significant global city. The city has its own administrative council, made up of elected officials, and it is constitutionally empowered to make decisions about policy, strategy, and development plans (Meheret, 1999).

According to world population review, more than 5 million people are thought to live in the city of Addis Ababa alone, and in recent years, the city's yearly population growth rate has been estimated to be 3.8%. More than any other urban settlement in the nation, Addis Ababa's founding and growth have been linked to the quick transition of land from rural to urban usage. Environmental issues have been significantly exacerbated by the city's rapid and largely uncontrolled geographical and demographic growth (UNDP, 2004).

Besides that, within city, development is increasingly located where exposure to climate change hazards is potentially high especially in slum and marginal areas, for example on sloppy and within flood plains (B. Wisner, Blaikie, Blaikie, Cannon, & Davis, 2004). The study area was undertaken in the Yeka and Kirkos sub-city, which is likewise along a river system that has been the source of the aforementioned difficulties. These sub-cities, which are among the oldest and most prosperous areas of Addis Ababa and are home to a large number of low-income residents, have a detrimental effect on flood problems.

According to (Tefera & Abebe, 2007) the study an increase in precipitation indicates there will be more water available, which, if not used wisely, will likely result in runoff. If the city does not have a more capable drainage system to handle the additional runoff, this increase in runoff will have consequences for flooding and result in the loss of lives and property. In addition to causing intense storms, this increase in precipitation will raise the risk of vector-borne diseases like malaria and diarrhea and have an adverse impact on the lives of the poor. These storms will also cause damage to homes, social services like schools, road infrastructure, and infrastructure. Since the majority of urban agriculture is located along riversides, floods have an impact on the livelihoods of impoverished people, particularly those who depend on urban agriculture for their primary source of income.

Community-based approaches to flood disaster risk management have become increasingly important in a society faced with complex and uncertain change. Local knowledge and social capital can be obtained through grassroots activity, allowing for the generation of adaptable solutions to deal with livelihood risk and boost resilience (Maskrey, 1989). Bottom up activity can fill in the gaps left by past top-down and centralized types of management and lessen our reliance on quick technical fixes and expert-driven solutions (B. a. L. Wisner, H.R., 1993). To understand how people are adjusting to gradual changes and coping with dramatic catastrophes, as well as how this may affect their future livelihoods, empirical evidence from field-based case studies is required (Warner et al., 2002). In a study on climate risks in Ethiopia, emphasized the need to shift from a disaster-focused view to a long-term perspective, which emphasizes livelihood security and vulnerability reduction (Conway & Schipper, 2011). By taking these facts into consideration, it is possible to determine the level of local flood vulnerability and to prepare the necessary proactive adaptation strategies.

Thus, the objectives of this study are (1) to analyze LULC change dynamics; (2) to map flood hazard, vulnerability, and risk zones in the Kebena River watershed. Factors such as LULC, soil type, slope, elevation, drainage density, rainfall distribution, distance to streams, and population density are used as main predictive and determinant factors to map analyze flood vulnerability.

II. DESCRIPTION OF THE STUDY AREA

Addis Ababa the capital of Ethiopia and Africa is characterized by a mountainous environment with numerous streams that descend to the south and merge to produce medium-sized rivers in the heart of the city (ORAAMP, 2002). The estimated area of the city is 527 km2 with a population density of 5,165 persons/km^2. It is considered as one of the largest cities in Africa with more than 3.5 million residents. According to Ethiopian Statistics Service (ESS, 2021) Population Projection Towns, Addis Ababa population estimated to be **3,774,000** (1,782,000 Female and 1,992,000 Male). The population is expected to increase by 3.8% per year. The Kebena River, which runs through the study area, is one of the major tributaries of the large Akaki River, which rises in Addis Ababa's center northern region. The research area's estimated total area is 3,601.93 ha, and its estimated altitude is between 2012 and 3016 meters above sea level.

The Kebena River originates in a mountainous region that is primarily covered with forests of Eucalyptus globulus and Juniperus procera, huge agricultural plains, and sporadic villages. The upper catchment's topography has a steep slope gradient. The river goes through various physical changes in the middle catchment. In recent years, the area around the river has experienced rapid population growth, leading to the development of numerous informal communities in close proximity to the river and in the adjacent districts (AACPPO, 2017). The lower catchment of Kebena River is predominantly built-up area, whereby some nearby residents use the polluted river water to irrigate urban agriculture.

2.1. Geographical Location

The study area is located in Addis Ababa, the capital of Ethiopia. Geographically, the study area of stream stretch is located at 9O05’50.38” N, 38^{O}46’08.14” E to 8^{O}59’54.50” N, 38^{O}46’36.70” E, in the central highlands between 2312 and 3016 m altitude. The Kebena, Big Akaki and Little Akaki rivers originate on nearby Entoto and Yeka Mountain and flow through the city from north to south (Figure 1).

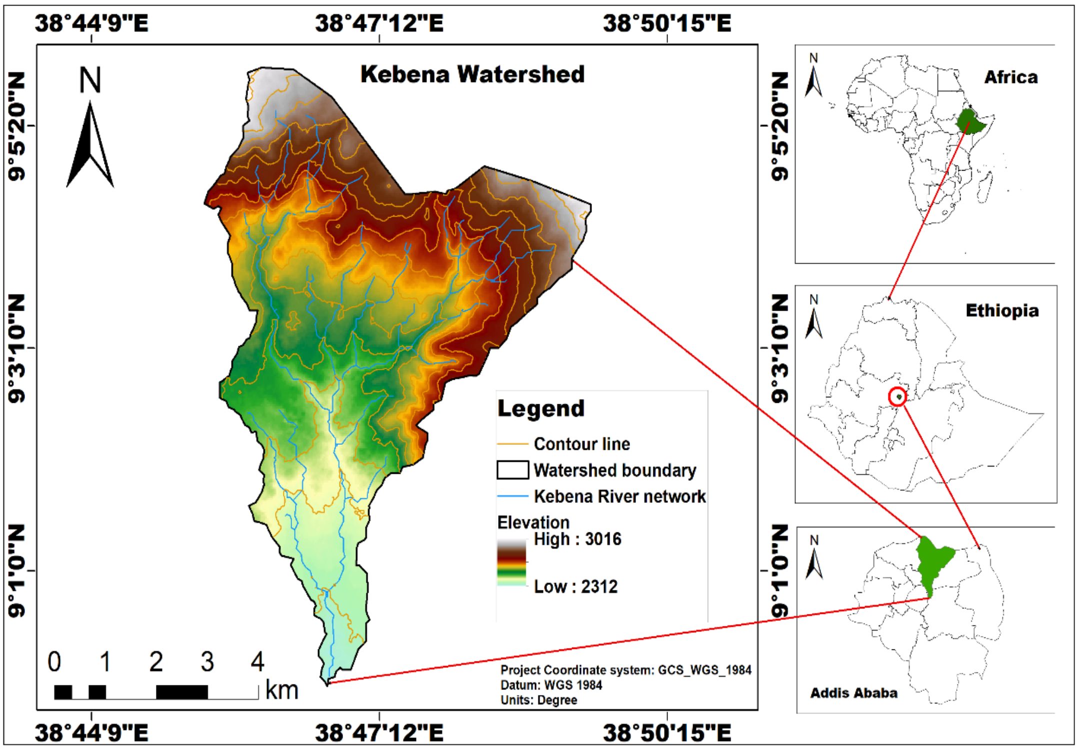

Figure 1: Geographical location of the study area

2.2. Topography

The research area, which reaches into the highlands of central Ethiopia, is situated on a plateau with an elevation range of 2312 to 3016 meters. The primary river systems that cross the sub-cities from north-south to east have generated numerous gullies and sporadic natural waterways, which significantly sever the urbanized study area.

2.3. Rainfall and Temperature

The climate of Addis Ababa is highland subtropical. Depending on height and dominant wind patterns, the city's highland climate zones can vary in temperature by up to 10°C. Because of the city's proximity to the equator and high elevation, temperatures are consistently moderated throughout the year. Since no month has mean temperatures above 22°C, the climate is therefore maritime, even if its height were to be ignored. Mid-November to January is when it tends to rain on and off. Winters in highland climate zones are typically dry, and Addis Ababa is currently in this dry season.

Data from Ethiopia's National Metrological Institute (NMI) show that during this time of year, daytime maximum temperatures are typically no more than 23°C and overnight lows can drop to freezing. February to May is the shortest rainy season. With minimum temperatures in the range of 10-15 °C, the disparity between the maximum daytime temperatures and the lowest nighttime temperatures is not as great as it is at other times of the year. The city has lovely rainfall and mild temperatures at this time of year. During the dry and wet seasons, the river's water flow volume changes dramatically. According to the metrological stations of NMI, the study area experiences highest levels of rainfall in the months of July and August, which averages over 299.2 mm per month at its peak period (Figure 3.2), while 23.9 °C in the month of March and 7.8 °C in the month of December of average maximum and minimum air temperatures per month, respectively (Figure 2, 3 and 4).

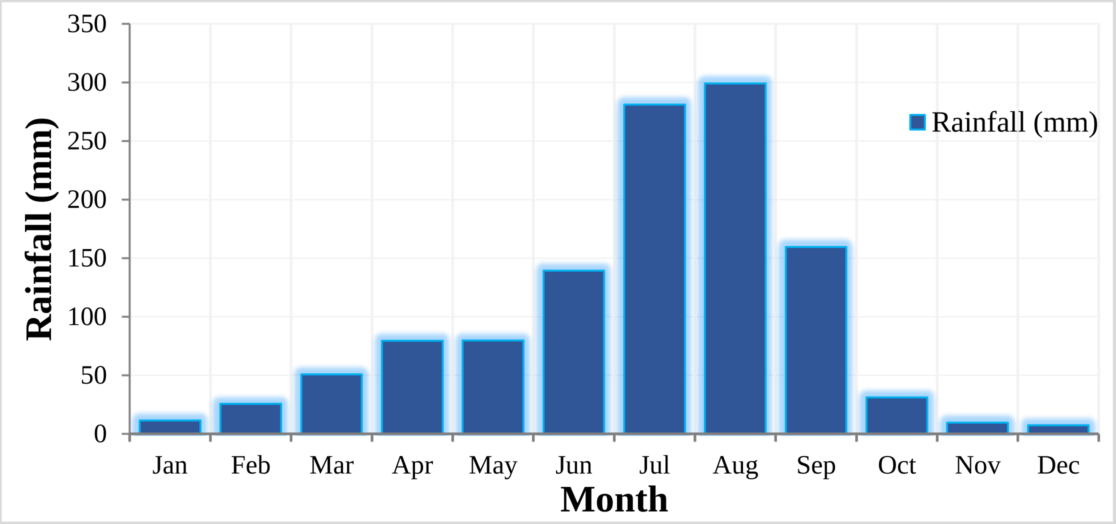

Figure 2. Mean monthly rainfall distribution (1990-2022)

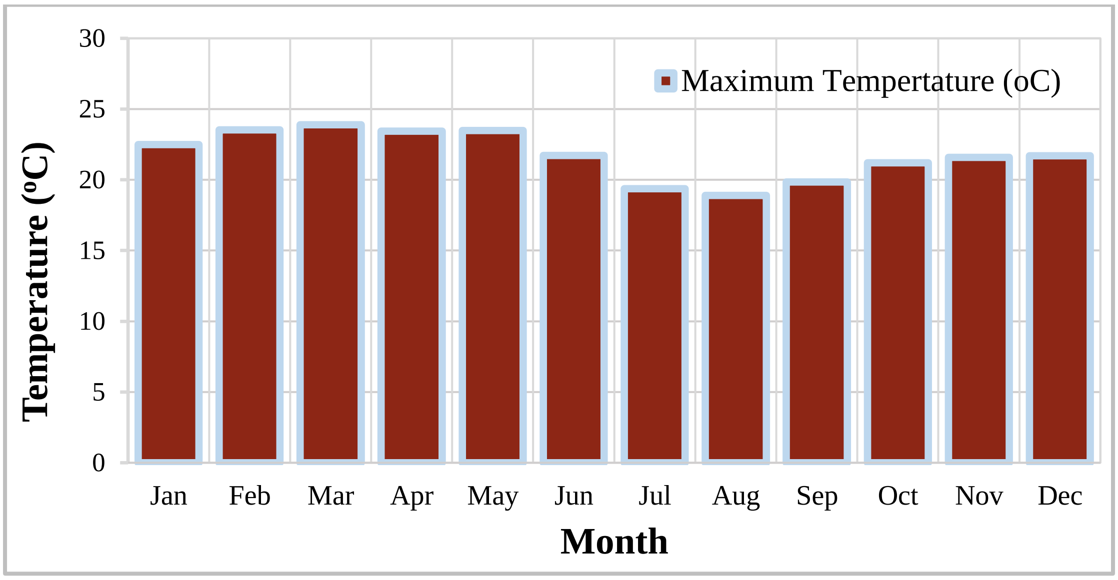

Figure 3. Mean maximum monthly temperature distribution (1990-2022)

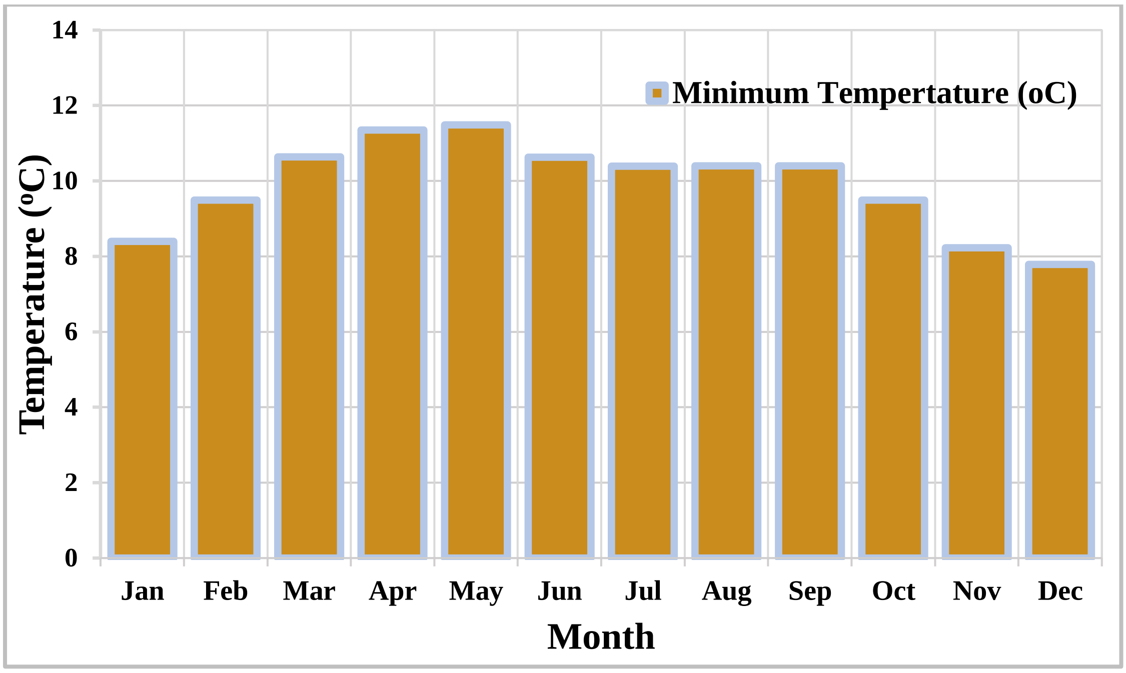

Figure 4. Mean minimum monthly temperature distribution (1990-2022)

III. METHOD OF DATA ANALYSIS AND INTERPRETATION

3.1. Satellite imagery

Different data sources were used to collect and analyze both primary and secondary data. This study uses remote sensing and a geographic information system to gather data on how much change there has been during the last 20 years of the study period. The United States Geological Survey (USGS) website (http://www.earthexplorer.usgs.gov) provided the temporal satellite pictures of the years 2000 (Landsat 4-5 TM) and 2021 (Landsat 8-9 OLI), which were used to construct the necessary data to meet the main study concerns and objectives. UTM WGS 84 Zone 37N was used to reference and project all of the Landsat pictures. The Landsat picture has a spatial resolution of 30 m and is frequently used for geospatial analysis and the identification of changes in land use and cover (Kassawmar, Zeleke, Bantider, Gessesse, & Abraha, 2018).

Table 1. Landsat imagery used for the study (source: USGS platform)

No	Satellite sensor	Resolution	Platform	Path	Row	Date
1	TM	30m	Landsat 4-5	168	054	January 28, 2000
2	OLI	30m	Landsat 8-9	168	054	January 21, 2021

3.2. Image processing and classification

Digital image pre-processing is the improvement of digital image for human interpretation (Bakker et al., 2001). Preprocessing has been done after downloading and extracting the Landsat images from the years 2000 and 2021. These include layer stacking and merging, gap filling, picture mosaics, and improvements to the image's quality and readability to make it more useful and ready for further analysis.

Table 2. Land Use and Land Cover types

LULC Class	Description
Forest	Mixed forest lands with area spanning at least 0.5 ha covered by primary or secondary, usually multi-storied, natural vegetation of trees.

Agriculture	Arable and fallow land that grows annual crops or perennial crops on the small scale or commercial level by rain fed or irrigation schemes.
Bare land	Land areas of exposed soil and barren area influenced by human impact. It includes properties with surfaces that comprise mainly soil and minimal vegetation cover.
Built up	Areas of intensive use with much of the land covered by structures (e.g., cities, towns, villages). It includes roads and paths in settlement.
Open land	Non-built-up (no houses, Offices or other permanent structures) land with no, or with significant vegetation cover

3.3. Accuracy assessment

ArcGIS version 10.3 and 10.7.1. were used for flood analysis, producing maps and statistical report generation. In order to reduce uncertainty, accuracy assessment was carried out in order to collect better data from sample locations (ground control points) using GPS and comparing that data to the classification of the maps. Confusion/ error matrices are the most typical ways to display map classification accuracy outputs (Erener, Düzgün, & Yalciner, 2012). For this study,150 pixels were randomly selected from the classified images and the reference data collected on the real ground. The overall map classification accuracy for the year 2000 and 2021 was 88.7% and 92.7% with kappa coefficient values of 0.837 and 0.88 respectively.

3.4. Parameter selection

LULC, soil type, elevation, slope, drainage density, rainfall, amount, distance to streams, and population density parameters were selected to investigate flood hazard, vulnerability, and risk in the study watershed. These parameters were selected according to the literature presented in Table 3 and the nature of the study area and available data.

Table 3. Parameters used for the study

Parameter	References
LULC	(Desalegn & Mulu, 2021) ; (Sarkar & Mondal, 2019)
Soil type	(Desalegn & Mulu, 2021) ; (Sarkar & Mondal, 2019)
Elevation	(Desalegn & Mulu, 2021) ; (Sarkar & Mondal, 2019)
Slope	(Desalegn & Mulu, 2021) ; (Sarkar & Mondal, 2019)
Drainage Density	(Desalegn & Mulu, 2021) ; (Sarkar & Mondal, 2019)
Rainfall	(Desalegn & Mulu, 2021) ; (Sarkar & Mondal, 2019)
Population Density	(Sarkar & Mondal, 2019)
Distance from river	(Elkhrachy, 2015)

IV. RESULTS AND DISCUSSION

4.1. Analysis of LULC change dynamics for flood vulnerability of the study area

The results of the land use and land cover (LULC) change analysis in the study area from 2000 to 2021 reveal significant changes that may contribute to the flood vulnerability of Kebena River. The 20 years period of study results indicate a noticeable expansion of built-up areas, with built-up land cover occupying a larger proportion of the catchment. The coverage of built-up area increased with a drastic loss of forest land, Agricultural land open and bare lands. The analysis revealed that built-up area coverage increased in 41.63% from 1441.46 ha in 2000 to 2041.57 ha in 2021 with an annual rate of +2%. On the contrary, agriculture land coverage decreased in 50.21% from 845.44 ha in 2000 to 420.92 ha in 2021, Forest land decreased in 7.51% from 1104.21 to 1021.24 ha, bare land decreased in 75.78% from 106.24 to 25.73 ha and Open land decreased in 11.58% from 104.58 to 92.47 ha with an annual rate of -2.4%, -0.4, -3.6 and -0.6% respectively (Table 4).

Table 4. Change in the five LULC categories during 2000 to 2021

LULC categories	2000		2021		2000 - 2021 Changed area (%)	Annual change rate (%)
	Area (ha)	Area (%)	Area (ha)	Area (%)		
Agriculture	845.44	23.5	420.92	11.7%	-50.21	-2.5
Bare Land	106.24	3	25.73	0.7%	-75.78	-3.8
Built up	1441.46	40	2,041.57	56.7%	+41.63	+2.0
Forest	1104.21	30.7	1,021.24	28.4%	-7.51	-0.4
Open Land	104.58	2.8	92.47	2.6%	-11.58	-0.6

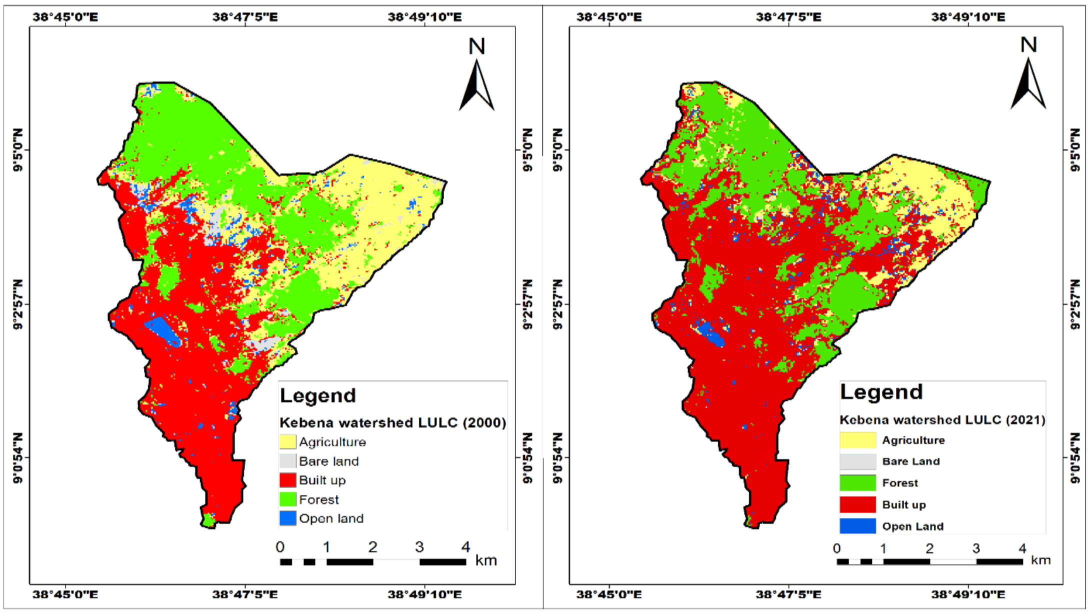

Figure 5. Land Use Land Cover in Kebena River Catchment

4.2. Analyses of Flood Hazard factor for the study area

In this study, a multi-criteria evaluation approach was utilized to weight and combine six sub-layers including, soil type layer, drainage density layer, distance from river layer, slope layer, elevation layer and rainfall variability layer, in order to generate robust flood hazard layers. This integrated approach allows for a more holistic and sophisticated analysis, accounting for the interplay of different variables that contribute to flood hazard at the study area. By incorporating these multiple layers, the resulting flood hazard map provides a more accurate and comprehensive understanding of the potential flood hazards in the study area, enhancing the reliability and applicability of the findings for urban planning and disaster management efforts.

4.2.1. Soil layers

Diverse soil sorts have distinctive capacities to penetrate water. (Morgan, 1995) stresses that the amount of water that will be available for surface runoff after a rainstorm event is controlled in large part by infiltration, a fundamental factor that considerably controls the rainfall runoff process. Flooding can be greatly caused by the kind of soil since it has an impact on how water moves through the ground. Clay soil naturally has a low capacity to hold water, making it highly likely to stop water from penetrating the earth and generating floods. Vertisol-covered ground is extremely susceptible to flooding, according to numerous researchers. The binding ability of the soil particles determines whether a soil has a high or low erosion potential.

The soil types and some of the critical physical properties determine important features of the hydrology such as runoff, recharge and discharge at the different locations of the catchments in the sub-watershed. The soil map of the study area was extracted from the surveyed map of Ministry of Irrigation and Energy in 2004. As indicated by (Kabite, 2011), the soil classes in Addis Ababa are Classic Xerosols, Chromic Luvisols, Eutric Nitisols, Leptosols, Orthic Solonchaks and Pellic Vertisols. The upper catchment of Kebena watershed is dominantly occupied by Calcic Xerosoles (40.78%) followed by Orthic Solonchaks (21.24%), which are not suitable for crop cultivation. Only less than 10 % of the area has Leptisoles (5.54%). Whereas the middle catchment zone is largely covered with Eutric Nitisols (29.98%), which are well drained and deep agricultural soils and Pellic Vertisols (0.61%) towards the lower part (Figure 6), which are poorly drained. Although the soil is good for agriculture because of its high clay content, it has a serious limitation of water logging and is often left uncultivated. Especially on the flat terrain, the soil remains inundated and wet throughout the year.

Table 5. Table Reclassified value of Soil type in the study area

No	Soil type	Area (ha)	% Cover	Rank	Level of flood Hazard
1	Pellic vertisols	22.53	0.63%	5	Very high
2	Orthic solonchaks	779.2	21.64%	4	High
3	Calcic xerosols	1497.2	41.56%	3	Moderate
4	Eutric nitisols	1099.7	30.53%	2	Low
5	Latosols	203.3	5.64%	1	Very low

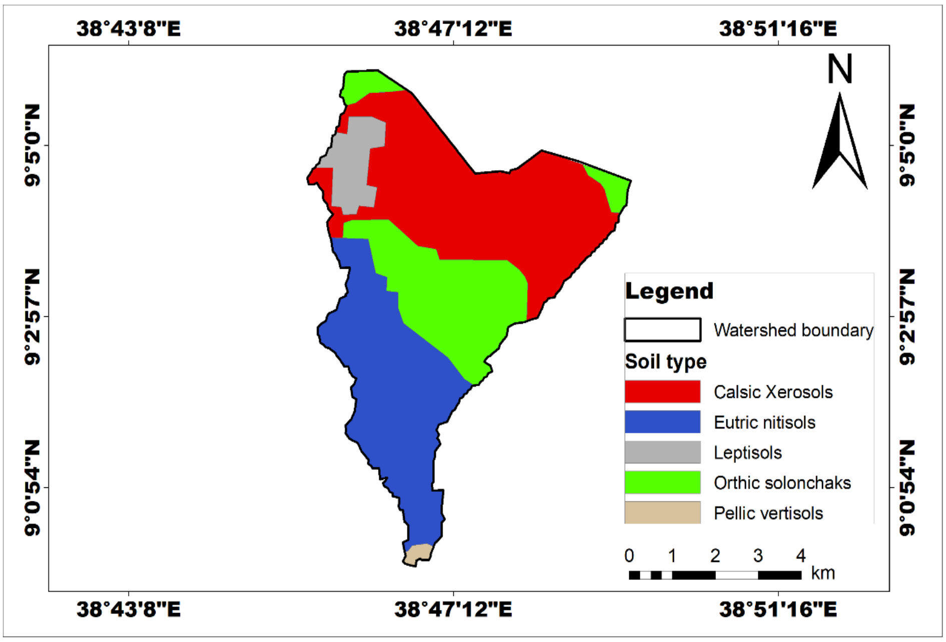

Figure 6. Soil types of the study area (source: extracted shape from surveyed map of Ministry of Irrigation and Energy in 2004)

4.2.2. Drainage density

The slope, the nature and attitude of the bedrock, and the local and regional fracture pattern are all crucial factors in how a drainage system develops in a given area. The ratio of drainage length to basin size is known as drainage density (DD), and it is a fundamental idea in hydrologic analysis. Permeability, surface erodibility, vegetation, slope, and time all affect drainage density. Infiltration is inversely related to drainage density. Higher drainage density indicates more runoff for the basin area and decreased risk of flooding. These factors are also associated with erodible geology materials. Hence, the rating for drainage density decreases as drainage density increases.

Arc Hydro10.3 software, which works as an extension on Arc GIS software (10.3 version) were used to make drainage density map of the study area. The study area's drainage density was calculated using the spatial analyst's line density module. The line density module calculates the magnitude per unit area by considering polyline features within a certain radius around each cell. Using standard classification techniques, such as quantiles, the density layer is further classed into five sub-groups. This method of classification allows us to select the number of intervals by dividing the attribute value range in to subranges of equal size, with Arc Map determining the location of the breaks. The drainage data is extracted from 30 m Digital Elevation Model (DEM) of the study area and for the analysis, up to six stream orders have been considered. The drainage classes are 0 – 0.1 km/km^2, 0.2–0.4 km/km^2, 0.5–0.7km^2, 0.8–1 km^2 and > 1 km/km^2. There is a strong correlation between flooding and drainage density. The rank and the level of flood risk of the drainage density classes are given in Table 6 below.

Table 6. Table Reclassified value of drainage density in the study area

No	Drainage density (km/km^2)	Rank	Level of flood Hazard
1	>1.0	5	Very high
2	0.8 – 1.0	4	High
3	0.5 - 0.7	3	Moderate
4	0.2 - 0.4	2	Low
5	0 - 0.1	1	Very low

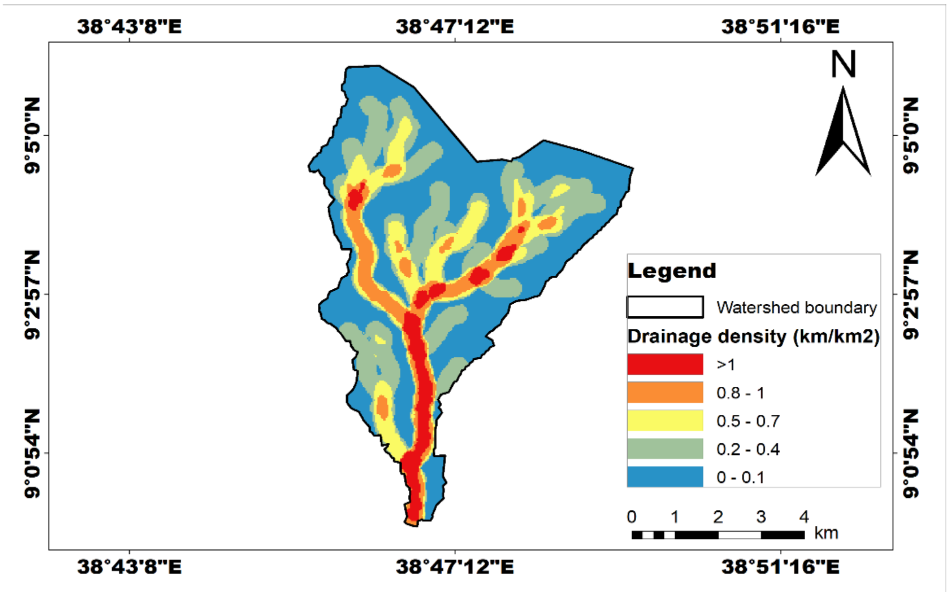

Figure 8. Drainage density distribution map and drainage density value of the study area

4.4.3 Elevation

The most important factor that controls the preparation of flood hazard maps is elevation. Areas located in higher elevations are generally less susceptible to flooding, while lower elevations are more susceptible to flooding. Because the law of gravity forces water to flow from higher places to lower areas, the possibility of flooding is high in low-lying and flat terrains. Most of the Addis Ababa city administration is located in the Awash River basin, and the Kebena River is one of the tributaries of the larger Akaki River. Low-lying areas in the Kebena River Basin are more likely to be inundated by flood waters because the law of gravity forces water to flow from high to low. In this analysis, the elevation of the study area was redistributed using GIS and it was identified that the area with low elevation has a high probability of being affected by floods.

DEM with GIS software were used to analyze the elevation level of the Kebena river basin and its risk to flooding. To obtain the final raster elevation values, the raster elevation was obtained from filled DEM in a GIS environment using a 3D analyst tool. The elevation was then categorized using an equal interval scheme into five groups. According to their propensity for flooding, the higher the elevation value, the lower the risk of flooding, and the higher the elevation value, the higher the risk of flooding. The rank and the level of flood risk of the elevation classes are given in Table 7.

Table 7. Table Reclassified elevation value of the study area

No	Elevation interval (m)	Rank	Level of flood Hazard
1	2312 - 2450	5	Very high
2	2451 - 2564	4	High
3	2565 - 2683	3	Moderate
4	2684 - 2814	2	Low
5	2815 - 3016	1	Very low

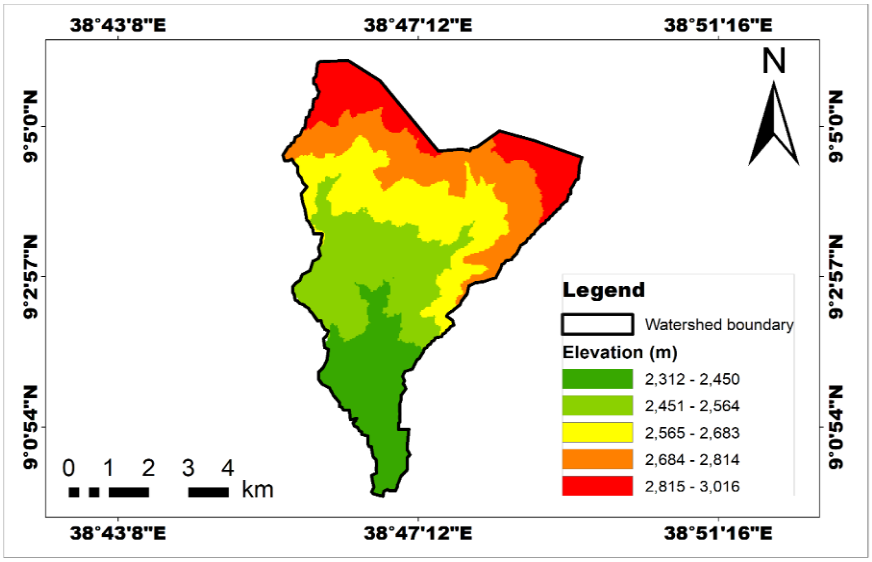

Figure 9. Elevation map of the study area

4.4.4 Slope

In hydrology study, slope plays an important role in controlling surface water flow and is an important geological condition for this study. Flatter surfaces are more susceptible to flooding than steeper surfaces because water moves more slowly, collects for a longer time, and accumulates on them (Rimba, Setiawati, Sambah, & Miura, 2017). The slope of a river in an area has a direct relationship with the speed of the river flow. The causes of flooding are steepness or slope and wide river basin. If an area is very steep, there will be a low rate of runoff and a high surface waterflow, resulting in high levels of flooding. Due to the increase in the speed of the flood flow in the area of high slope, it moves the material from the soil and erodes the soil in high condition. The slope of the study area is prepared by taking a digital elevation model and using the tools we use to create slopes in ArcGIS. Areas with low slope are more prone to waterlogging and flooding, while areas with high slope are less likely to flood and retain water.

The catchment is distinguished by diverse topographical features which stretches from mountainous terrain to flat plains. After dividing the digital elevation model (DEM) into five slope classes based on FAO slope classification, the highest slope value with fewer floods and the least with high probability to be hit by flooding. From the divided slope classes 28.5% of the total area has very gently sloping (0–2% gradient), whereas 33.6% and 23.5% of the entire areas are characterized as gently sloping (2-8% gradient) and sloping to strongly sloping (8-15% gradient). The remaining land slopes are divided into moderately steep and steep, which covered the areas of 11.1% (15-30% gradient) and 3.3% (>30% gradient), respectively.

The reclassified slope was given a value between 1 and 5, with 5 representing a significant danger of flooding and 1 representing a very low risk of flooding, producing a very low flood rate. The break values and the description of the new slope classes are given in table 8.

Table 8. Modified form of FAO slope classification in the study catchment.

No	Class description	Slope classes (% gradient)	Area (ha)	Proportion (%)	Rank	Level of flood Hazard
1	Flat to very gentle	0-2	1025.25	28.5	5	Very high
2	Gently sloping	2-8	1210.5	33.6	4	High
3	Sloping to strongly sloping	8-15	847.01	23.5	3	Moderate
4	Moderately steep	15-30	401.31	11.1	2	Low
5	Steep	>30	117.86	3.3	1	Very low

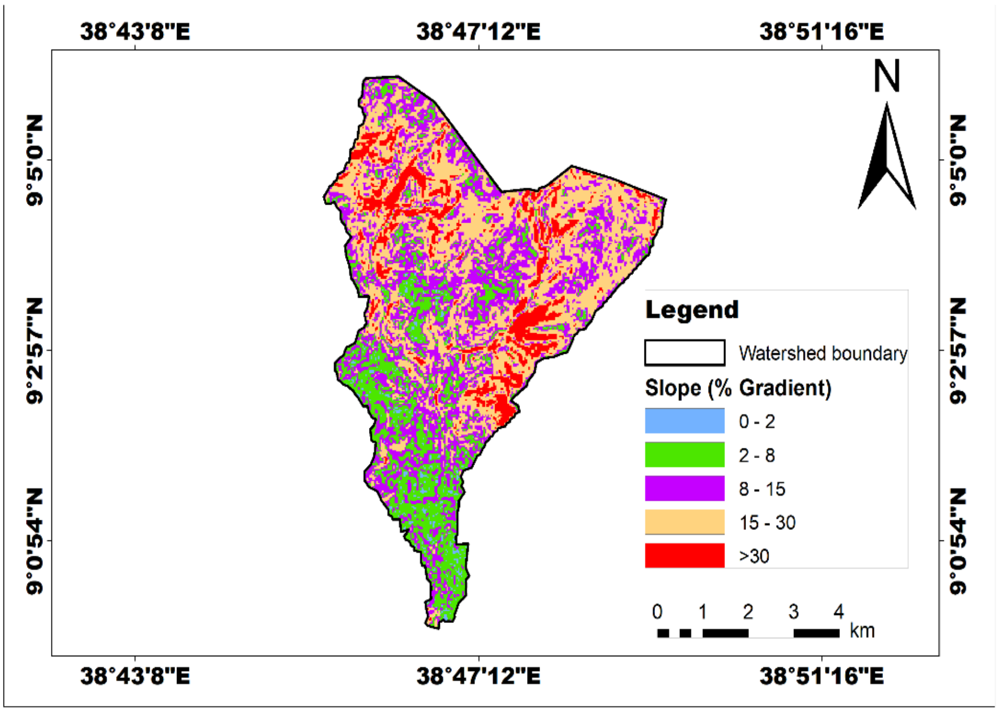

Figure 10. Slope classification

4.4.5. Rainfall variability

Heavy rainfall in an area inevitably increases surface runoff, which is likely to cause flooding. High-energy rainfall can cause significant runoff because the land cannot absorb all of its moisture into the ground. In our country, whether in the city or in the countryside, rainfall is the main cause of flooding and the amount of rain or humidity that an area receives during the period of the rainy season plays a major role in the flood. Every drop of rain has the potential to go underground or become a surface runoff. When heavy rain falls for a series of hours, it adds a lot of surface water. The reason is that the soil loses its ability to absorb the rainwater when it is wet and holds a lot of moisture in it (degree of permeability/infiltration decreases). But on the contrary when the surface water increase, then flood will overflow from the normal drainage and flooded the low plains in the area.

Rainfall data were analyzed by taking three stations from National Meteorological Institute (NMI) in the last 33 years to explore the rainfall conditions of the study area and to investigate the cause of floods, by taking the rainfall data from year 1990-2022. Using ArcGIS, Spatial interpolation of rainfall from the point data has been carried out using an Inverse Distance Weighted (IDW) technique. The IDW interpolation technique employs a linear weighted combination of multiple sample points to determine cell values. Once the interpolate surface is generated, it is converted in to raster layer and classified in to five classes using an equal interval scheme as shown in table 9. The reclassified rainfall was given a value 1 to 5 with the higher value 5, showing high influence resulting in very high flood rate, while the lower value 1, resulting in a very low flood rate and demonstrating very little influence. Therefore, an area with very high rainfall was ranked as 5 and an area with very low rainfall was ranked as 1.

Table 9. Reclassified annual rainfall value of the study area

No	Annual rainfall (m)	Rank	Level of flood Hazard
1	1300 - 1380	5	Very high
2	1220 - 1290	4	High
3	1160 - 1210	3	Moderate
4	1090 - 1150	2	Low
5	965 - 1080	1	Very low

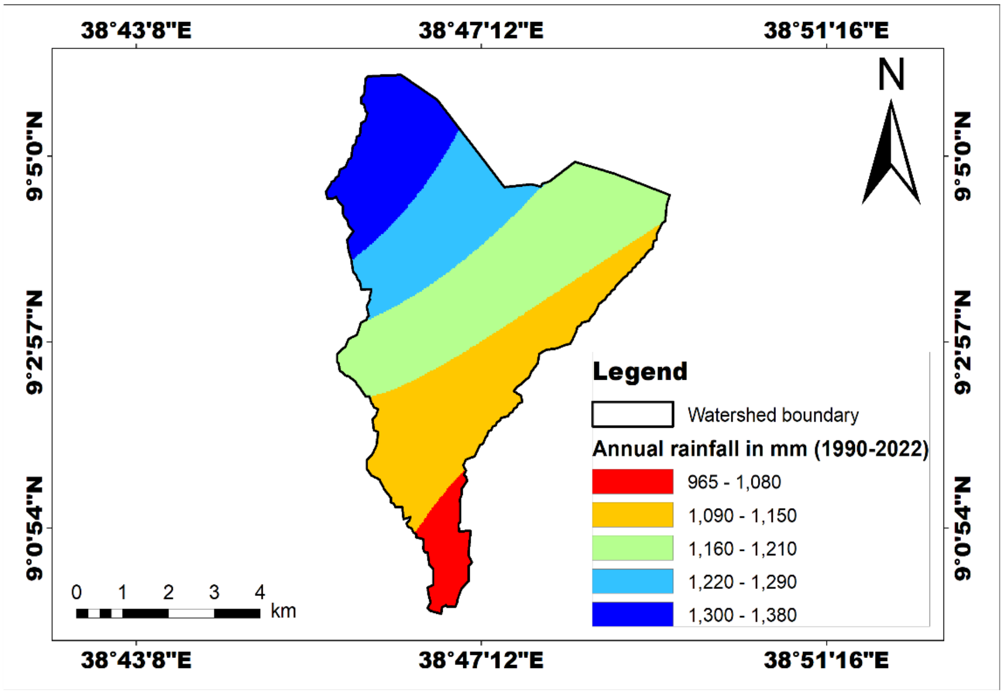

Figure 11. Annual rainfall map of the study area (from 1990-2022)

4.4.6 Distance from river

Areas located closer to rivers are at a higher risk of flooding due to their proximity to the water source. During heavy rainfall or increased river discharge, these areas are more susceptible to inundation, as they are located in the floodplain or flood-prone areas. Areas in close proximity to rivers may experience other flood-related hazards, such as riverbank erosion, river channel migration, and sedimentation. Riverbank erosion can lead to loss of land, infrastructure, and agricultural fields, while river channel migration can alter the course of the river, potentially affecting nearby settlements or infrastructure. Sedimentation can also occur when rivers overflow their banks, depositing sediment and debris on adjacent lands and increasing the risk of flooding in downstream areas. One of the major aspects in mapping flood hazards is the distance to the river. These river channels have been cushioned by considering the range at which serious harm to life and property can occur. Additionally, this will aid in determining the distances from active channels for the safe evacuation of anyone in danger. The distance to the active river channel has been computed by dividing in to five classes with respect to the flood vulnerability namely, very high (0-30m), high (30-50m), moderate (50-100m), low (100-400m) and very low vulnerability (400-1000m) both sides of the river channels with spatial analyst and 3–D analyst based on the researcher field experience.

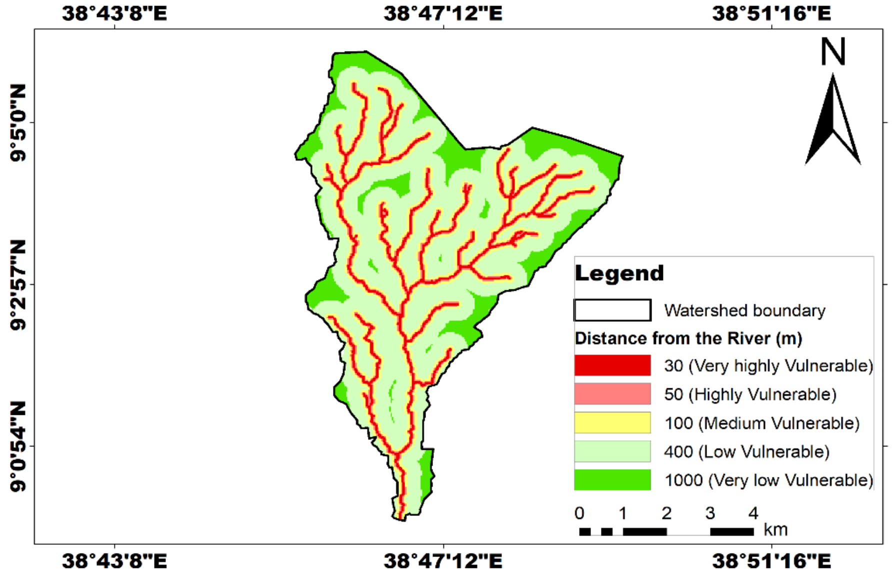

Figure 12. Distance from river map of the study area

4.5. Flood Hazard map

The result of the final flood hazard analysis indicates that 407.44, 975.17, 1020.02, 755.1 and 444.2 ha of Kebena River watershed were very high, high, moderate, low, and very low to flood hazard, respectively. Figure 13 indicates that deep blue and apatite blue colors represent very high and high flood-hazard area, respectively. Moreover, desert sand, lemon grass, and dark green colors show moderate, low, and very low flood-hazard zones, respectively.

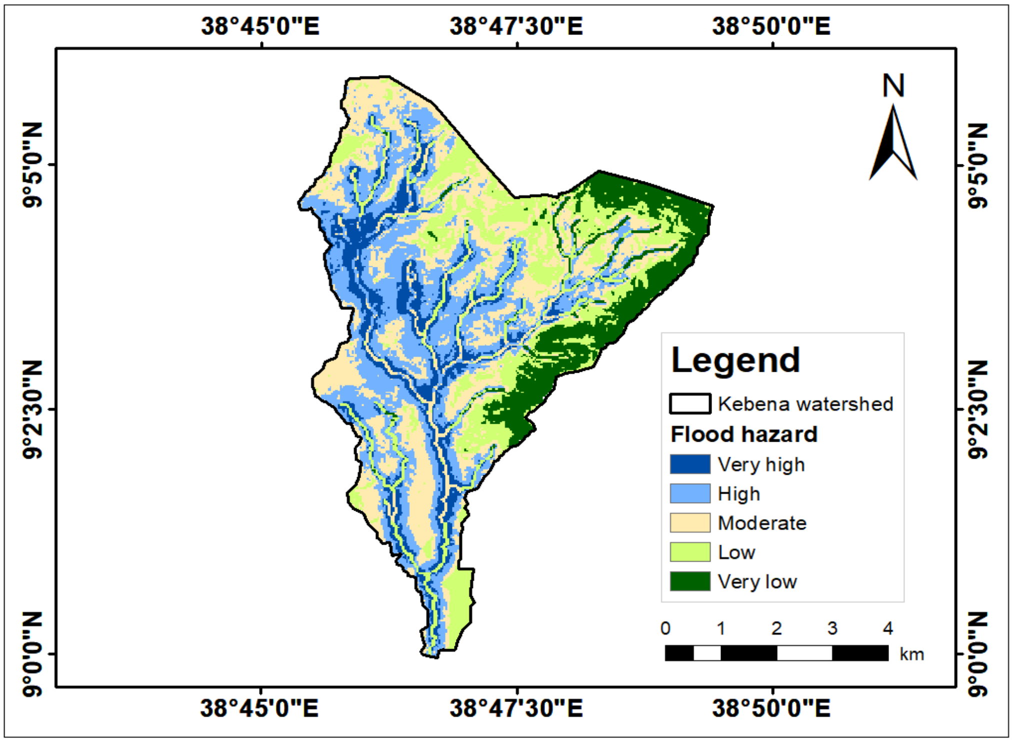

Figure 13. Flood Hazard map of the study area

4.6. Flood Vulnerability factor analysis

4.6.1. Current Land Use Land Cover of the study area

The land use land cover of the study area was prepared by downloading the satellite image from USGS and processing the downloaded satellite image with ArcGIS 10.3 and 10.7.1 version. The study area of Kebena river watershed covers a total area of 3,601.93 ha as it is indicated in table 10 bellow. According to the Landsat 8-9 sporadic settlements/Built up area is the most dominant covering about 56.7 % of the area. The forest land, which includes the natural forest, the Eucalyptus globulus plantation and riverine vegetation, is the second dominant land use and accounted for 28.4% of the total land area which is followed by cultivated land covering 11.7% of the total area. The area with bare soil and open land is very small and accounted only a total sum of 3.3%.

Table 10. Reclassified Current Land Use Land Cover of the study area

No	LULC type	Area (ha)	% Cover	Rank	Level of flood hazard
1	Bare Land	25.73	0.7%	5	Very high
2	Built up	2,041.57	56.7%	4	High
3	Open Land	92.47	2.6%	3	Moderate
4	Agriculture	420.92	11.7%	2	Low
5	Forest	1,021.24	28.4%	1	Very low
	Total	**3,601.93**	**100%**		

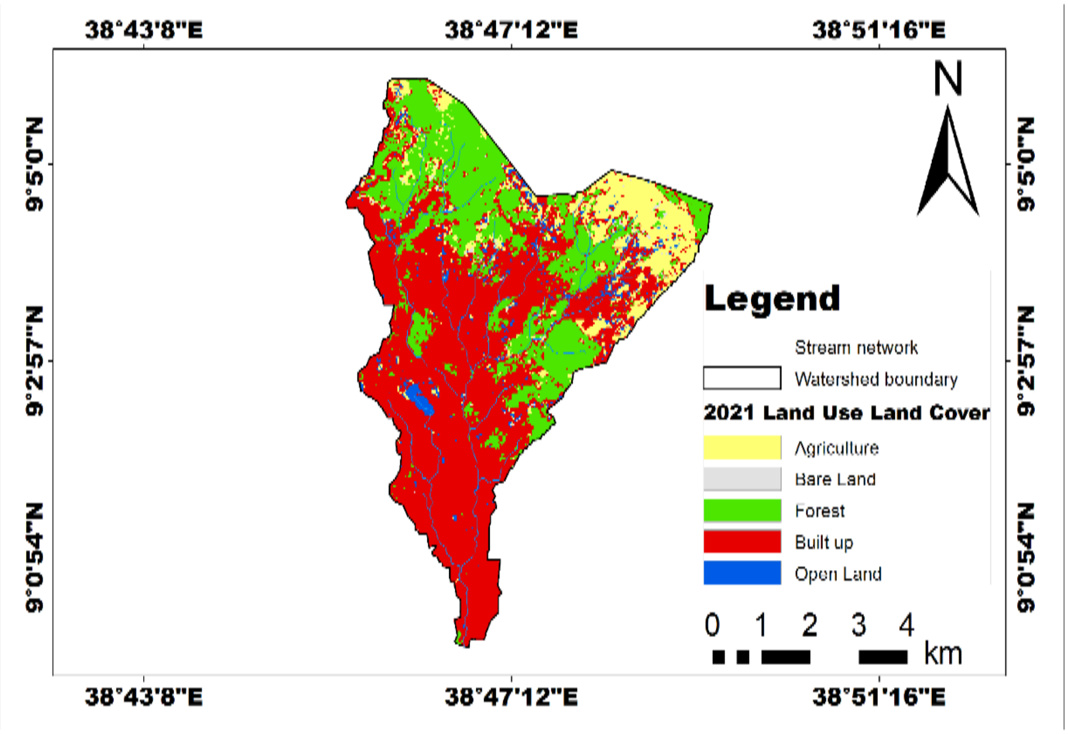

Figure 14. Land use and land cover map of 2021

4.6.2. Population density map

Population density layer was used for flood vulnerability parameter (Sarkar & Mondal, 2019) because flood hazard and its vulnerability are very severing in the area of settlement than other open environment. Population density is a crucial factor that must be considered when creating a flood vulnerability map for the affected area. To quantify the assets under potential threat, the sub city wise population density has been chosen as an important variable. The study area is a densely populated area with a population of over 1,641,397 people. There are five sub cities in Kebena river watershed namely Bole, Gullele, Arada, Yeka and Kirkos sub city (Figure 15). The population density in these sub cities is very high, with an average of over 14,628 people per square kilometer (Table 11). The high population density makes the area more vulnerable to flooding, as there are more people living in a small area. The high population density in the area means that there is a greater risk of damage to buildings, roads, and other infrastructure, as well as a higher risk of injury or loss of life.

Table 11. Population density data of the study area (source; CSA website)

Addis Ababa Sub-city	Study Area (km^2)	July, 2022 (from CSA website)	
		Population	Population density/km^2
Bole Sub City	1.04	233,805	3,566.7
Kirkos Sub City	0.3693	314,739	21,324.6
Yeka Sub City	24.69	331,304	5,682.0
Arada Sub City	2.42	298,044	30,075.1
Gulele Sub City	7.5	463,505	12,492.8

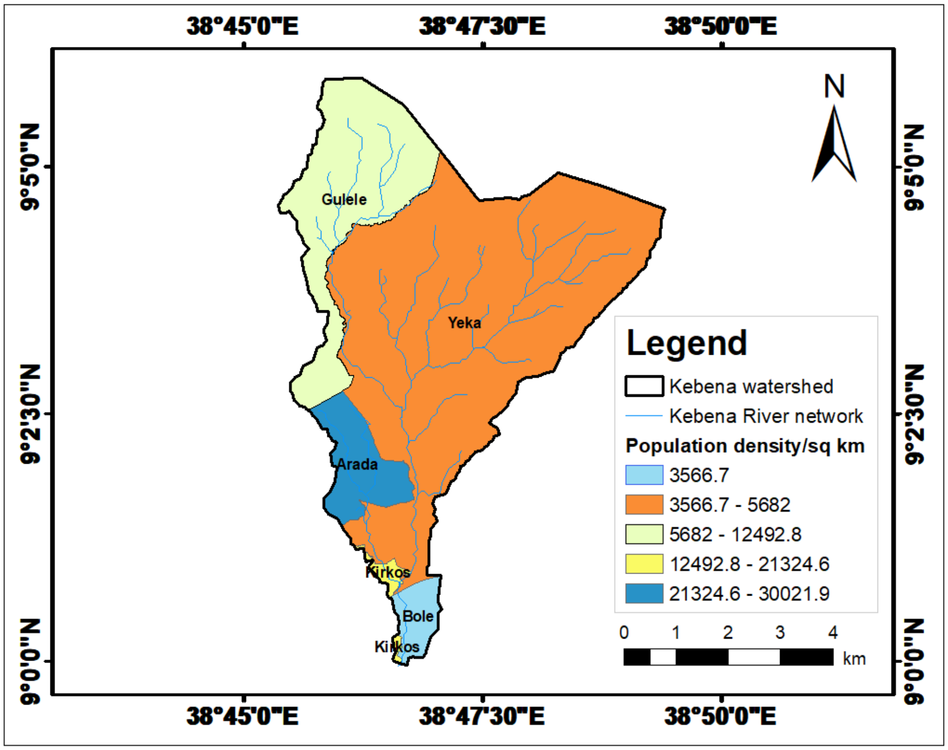

Figure 15. Population density map of the study area

4.7. Flood Vulnerability map of the study area

The result of the final flood vulnerability analysis indicates that 1842.8, 687, 35.9, 662.4 and 373.83 ha of Kebena River watershed were very high, high, moderate, low, and very low vulnerable to flood, respectively. Figure 16 indicates that the red and electron gold colors represent very high and high flood-vulnerable area, respectively. Moreover, yellow, light green, and dark green colors show moderate, low, and very low flood-vulnerable zones, respectively.

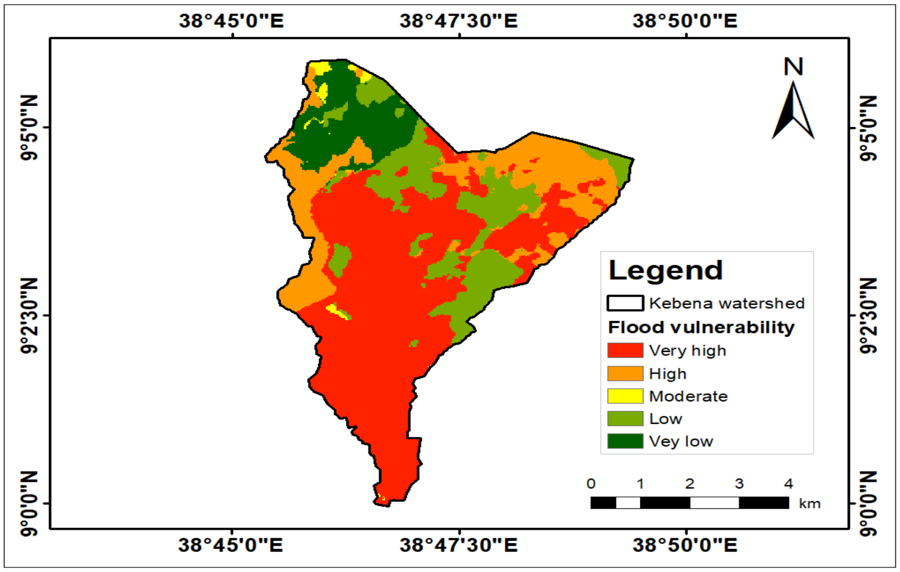

Figure 16. Flood vulnerability map of the study area

4.3. Flood risk mapping of Kebena River

Flood risk analysis is one of the most important tools for understanding and identifying flood potential risk and vulnerability of river flooding in research area. In fact, it helps us to manage and reduce flood risk and make better decisions. Flood risk considers the probabilities associated with flood events with their extent and the vulnerability of those areas considers the characteristics related to the flood prone areas to possible damage (Hadaro, 2019). The final flood risk map has five layers and is presented in a logical order, with classifications ranging from Very high to Very low flood risk. The catchment's upper, forested portions had little flood risk, whereas the areas along the drainage basins and densely populated areas had the highest risk. Various writers employ the same strategy for mapping flood risk (Feyissa, Zeleke, Gebremariam, & Bewket, 2018). Using GIS-based mapping techniques, the flood risk zones of the Kebena catchment were also examined. The examination was conducted using the general risk equation shown below (Shook, 1997).

Risk = (Elements at risk) *(Hazard*Vulnerability)

Flood risk analysis is computed by Weighted Overlay setting equal importance to all factors and this was done by consulting experts in the area of discipline based on their knowledge of the field and reviews of the literature in order to make it simple to determine how variables would affect value (Table 12). The two aspects at risk in the research area, present land use and population density, are generated variables for overlay along with the flood hazard analysis layer.

Table 12. Factors for flood risk assessment

Factors	Weight	Sub-factors	Ranking
Flood Hazard	0.34	Very high	5
		High	4
		Moderate	3
		Low	2
		Very low	1
Land use types	0.33	Bare land	5
		Built up	4
		Open land	3
		Agriculture	2
		Forest	1
Population	0.33	21,324.6 - 30,075.1	5
		12,492.8 - 21,324.6	4
		5,682.0 - 12,492.8	3
		3,566.7 - 5,682.0	2
		3,566.7	1

As shown in the map (Figure 17), the area covered by red colored is found to bet very high-risk area to flood and covers 10% (358.93 ha) of the study area. On the other hand, it's feasible to draw the conclusion that homes in red-colored areas are extremely vulnerable to floods. Flood risk locations are those with an electron gold color and it occupied about 33.3% (1,200 ha) of the study area which is the largest part of the catchment indicating the fact that most areas of the catchment are high risk areas to flood. Whereas the Yellow-colored areas is moderate and covers 19.1% (687 ha) and Lemon green color is low risk area and covers 13.2% (477 ha) of the study area. Only green-colored areas which covers 24.4% (879 ha) of the study area are found to be not risk area (very low risk) for flooding in the catchment (Table 13).

Table 13. Level of flood risk and area coverage in the study area

No	Flood risk	Area coverage (ha)	Percent (%)
1	Very high	358.93	10
2	High	1,200	33.3
3	Moderate	687	19.1
4	Low	477	13.2
5	Very low	879	24.4

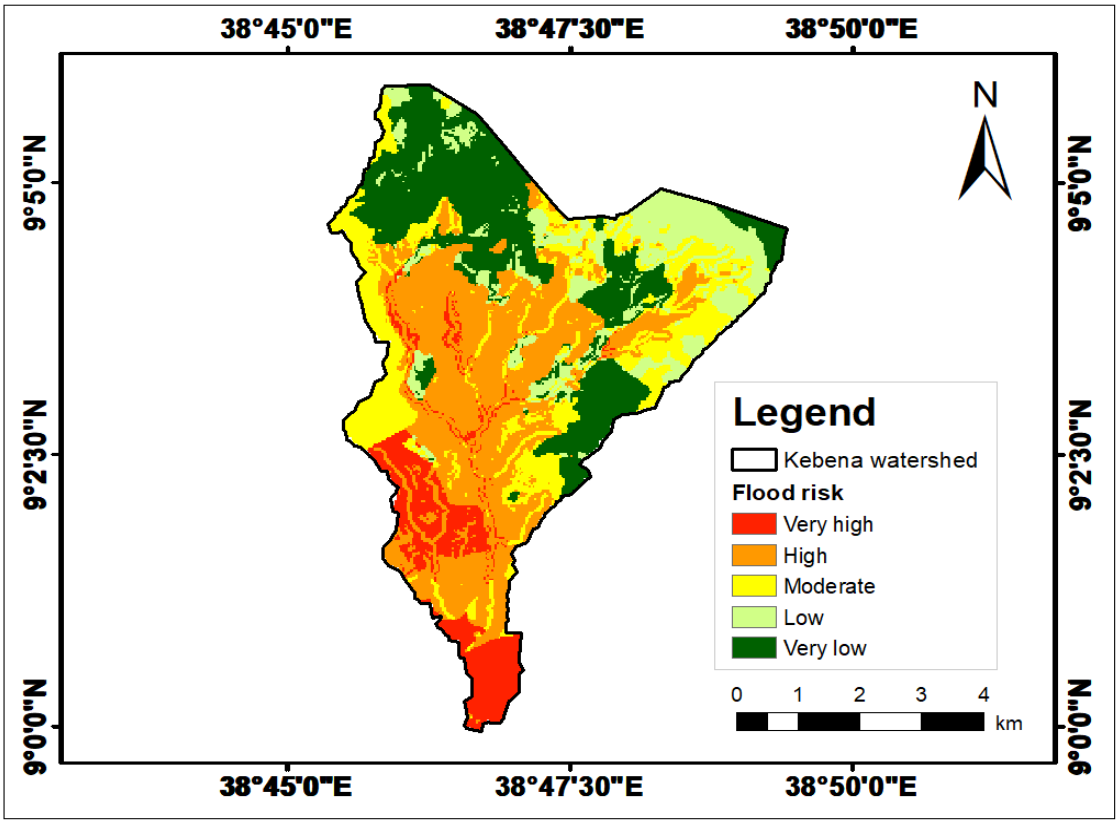

Figure 17. Flood risk map of the study area

V. CONCLUSION

Flooding in Kebena River watershed causes a considerable damage to life and property. The study shows that Land use and Land Cover (LULC) changes dynamics are important drivers of environmental change, and their impacts can be felt across various ecosystems. The Kebena River catchment is no exception, as the LULC changes that have occurred in the catchment over the past two decades, spanning from 2000 to 2021, have significantly impacted the hydrology of the area and contributed to the increased flood vulnerability of the Kebena River. The analysis of LU/LC changes dynamics has revealed that the increase in built-up areas (41.63%), accompanied by the loss of forest land (7.51%), agricultural land (50.21%), open land (11.58%), and bare land (75.78%), has altered the catchment's water balance and increased the amount of surface runoff during the rainy season.

To make flood risk map, analysis was made based on multiple factors, including land use pattern in flood-prone areas and population density per square kilometer with the integration of flood hazard analysis of the study area. The generated flood risk map consists of five categories: very low, low, moderate, high, and very high flood risk areas, covering 879 ha (24.4%), 477 ha (13.2%), 687 ha (19.1%), 1,200 ha (33.3%), and 358.93 ha (10%) of land coverage, respectively. The results of the study show that a substantial proportion of the catchment area is exposed to flood risks, with significant areas falling under moderate to very high-risk categories. Therefore, decision-makers must prioritize the implementation of flood risk management strategies and invest in the necessary infrastructure to protect the community and reduce the risk of property damage and loss of life in the future.

The findings of this study can help guide policymakers in making informed decisions about urban development, disaster preparedness, and mitigation measures in the Kebena River catchment and other similar urban areas facing similar challenges. Ultimately, this study highlights the importance of proactive and sustainable urban planning that prioritizes the safety and well-being of vulnerable communities in the face of climate change and other environmental hazards. Thus, it has been concluded that the approach used in this thesis is very much useful in delineating the flood hazard map, the flood vulnerability map and ultimately to the flood risk map in Kebena River watershed.

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