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FLOOD VULNERABILITY ASSESSMENT USING GEOGRAPHIC INFORMATION SYSTEM (GIS): A CASE OF NEKEMTE TOWN

M.Sc. Thesis

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BY

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ABSTRACT

A flood vulnerability map gives the precise location of sites where people, the natural environment or property are at risk due to a potentially catastrophic event that could result in death, injury, pollution or other destruction. The main objective of the study is Flood Vulnerability Assessment in Nekemtetown. The expansion of the town near streams and rivers due to lack of land use planning policy and illegal settlements for the purpose of irrigation made the area to be visited by flood every year since 2000. In order to map flood vulnerability area, Multi Criteria Evaluation incorporated with ArcGIS was employed. The contributing factors for flood vulnerability in the town was identified and prioritized based on their respective order of significance through field observation of area under investigation. ArcGIS was used to build geodatabase, geo-referencing and topology creation of all selected factors to analyse the flood vulnerability of the town. Selected factors (criteria) map were developed in raster layer of 10 m pixel size. The raster layer of selected factor was reclassified and re-assigned from 1 to 5; where 1 indicates very low flood vulnerability whereas 5 indicates very high flood vulnerability. Pair Wise Comparison (PWC) method of idrisi32 software was used in order to determine weighted value. Weighted overlay was used to combine 5 reclassified raster layers of selected factors using 1 to 5 by 1 system of weighted overlay system based on their respective computed weight. Weighted overlay map of the study area resulted with four values: 2, 3, 4 and 5 which represents that low, moderate, high and very high flood vulnerability. Weighted overlay map result (Flood vulnerability map) was further analysed using area tabulation with kebele boundary and land use classes of the town. The area tabulation with kebele boundary result covered all the kebeles of the town from low to very high flood vulnerability. The result of this thesis will help Nekemte town Administration as a guide to protect the loss of property, human life and an infrastructure before the flood occurs in the area. Areas prone to flooding should be protected from any construction so as to avoid any calamities caused by storm water floods

Key words: Flood, Vulnerability, GIS, MCE

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LIST OF ACRONYMS AND ABBREVIATIONS

ASTER: Advanced Space borne Thermal Emission and Reflection Radiometer

DEM: Digital Elevation Model

DNA: Data Not Available

ESRI: Environmental System Research Institute

FAO: Food and Agriculture Organization

GIS: Geographic Information System

GPS: Global Positioning System

GWP: Global Water Partnership

ILWIS: Integrated Land and Water Information System

LiDAR: Light Detection and Ranging

MCE: Multi Criteria Evaluation

NAVSTAR: Navigation Signal Timing and Ranging

PWC: Pair Wise Comparison

SRTM: Shuttle Radar Topography Mission

TIN: Triangular Irregular Network

TM: Thematic Mapper

TVET: Technical and Vocational Education Training

WMO: World Meteorological Organization

WSDP: Water Sector Development Program

1. INTRODUCTION

1.1. Background

Vulnerability is the degree of loss to a given element at risk or set of elements at risk resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total damage) [1]. Vulnerability is a function of the character, magnitude, and rate of climate variation to which the system is exposed, its sensitivity, and its adaptive capacity [2]. A vulnerability map gives the precise location of sites where people, the natural environment or property are at risk due to a potentially catastrophic event that could result in death, injury, pollution or other destruction [3].

Flood is a temporary covering by water of land normally not covered by water. Floods occur naturally along most river systems. Flooding causes loss of human and animal life; structural damage to bridges, buildings, roadbeds, and utilities; soil erosion; destruction of property; and destruction of livestock and crops that provide food for people[4].

Each year there are between fifty and three hundred inland floods worldwide, impacting an estimated 520 million people and causing as many as 25,000 deaths. Since 1985, inland floods have killed approximately 130,000 people (not including loss of life from storm surge and tsunami-related floods). Globally, the greatest potential for flooding exists in Asia, where more than 1,200 floods occurred between 1900 and 2006, claiming an average of 5,300 lives and costing up to $207 billion in losses. Nearly 1 billion people, about one-sixth of the world's population, live in areas prone to flooding. Many of these people are among the world's poorest inhabitants, depending on fertile floodplain soils and wetlands for agriculture and economic opportunity [5].

The rainy season in Ethiopia is concentrated in the three months between June and September, when about 80% of the rains are received. Torrential downpours are common in most parts of the country. Large scale flooding is rare and limited to the lowland areas where major rivers cross to neighbouring countries. However, intense rainfall in the highlands causes flooding of settlements close to any stretch of river courses. The most serious flood problems are found in the Awash River basin. Irrigation development in this basin is quite advanced and is located in the flood plains on either side of the river, with close to 70% of the country's large-scale irrigated agriculture; thus, high economic damage occurs during flooding. It is estimated that in the Awash Valley almost all of the area delineated for irrigation development is subject to floods; this amounts to an inundated surface of some 200,000-250,000 ha during high flows. The other rivers where significant floods occur are the Wabi-Shebelle River in south eastern Ethiopia near the Somali border and Baro-Akobo/Sobat River in western Ethiopia, near the Sudanese border. Torrential rains, common during the rainy season, cause sudden rise in the flow of these streams, which bring about flood damages to settlements along their banks. A similar situation affected the town of Dire Dawa[6].

Nekemte town is characterized by mutually contributing socio-economic problems. Ever increasing rate of population pressure from excessive in migration, income shortage, urban poverty, flood risk, unemployment, and improper utilization of land and strikingly are among the town's socio-economic problems. Flood caused human catastrophe is rare in the town, limited areas are prone to flooding. Due to absence of proper storm water drainage channels along undulating topography, occurrence of flooding is frequent in Keso sub-city around Mariam river (Kebele 05, kebele 09), Bake Jama sub-city in vicinity of Bake Jama and Sun Shine Elementary Schools, Sorga lake, in Burka Jato sub city in between Burka Jato Elementary School and Gulity market center (Kebele 07), Cheleleki sub-city as well as in different parts of the city around Adiya river. Indeed, the illegal settlement of the people near the streams and rivers, improper land utilization, the creation of the town on a number of hilly areas and variation of topography from gentle slope to steep slope are the main causes for the problem [7, 8].

Geographic Information Systems (GIS) have been used in developing flood risk maps that show vulnerability to flooding in different places around the world [9]. In developed countries, production of flood risk maps has become important criteria for carrying out some major development interventions [10]. Some flood risk assessments have been done in some major cities of Ethiopia but the flooding menace is growing.

However, the country is still lacking in the use of scientific methods such as GIS applications to tackle such environmental issues.

Therefore, in order to assess flood vulnerability of Nekemte town; Multi Criteria Evaluation (MCE) method was used to analyse and find the flood vulnerable areas. In this study GIS was integrated with MCE. This study used five spatial criteria each was presented and stored in layer by using ArcGIS and the criterion values are generated. Rankg Method was used to rank every criterion under consideration in the order of their respective causative factor for flood vulnerability and Pairwise Comparison Method (PCM) used to compute weight value. The criterion maps are converted into grids (raster layer) and the mathematical processes are applied to the criteria with Weight Overlay. The mathematically combined raster layers of five criteria produced flood vulnerability map using Weight Overlay analysis of ArcGIS

1.2. Statement of the problem

The primary cause of urban flooding is a severe thunderstorm or a rainstorm proceeded by a long-lasting moderate rainfall that saturates the soil. Floods in urban conditions are flashy in nature and occur both on urbanized surfaces and in small urban creek that deliver water to large water bodies. Other causes of urban floods include: inadequate land use and channelization of natural waterways, failure of the city protection dike, and inflow from the river during high stages into urban drainage system, soil erosion generating material that clogs drainage system and inlets, inadequate street cleaning practice that clogs street inlets.

The major anticipated problems in most urban centres in general and Nekemte in particular encountered due to the expansion of the town near streams and rivers due to lack of urban land use planning policy and illegal settlements for the purpose of irrigation, unsustainable construction of building, roads, water supply line, telecommunication line and lack of ditch for new developed area,lack of maintenance of ditch, drainage and culverts for a long period of time, disposing garden waste, disposed cart away on the road for transportation which are changing the direction of natural drainage and cumulating the runoff to one point and leads to the mismatch of the volume of runoff with the volume of drainage capacity [7].

The heavy rain in June up to September is leading the people living in flood vulnerable area around the Chelelecki, LegaMarga, 07 and Mariam stream for high flood risks that destroyed the house, personal properties, house commodities, transportation systems, culverts and pollution of local waterways and receiving water bodies like Sorga Lake and Adiyariver.Stream overflow over the surrounding dry land caused soil erosion; damage farming lands and property, houses after the people were settled around the flood prone zone when the municipality gave the flood prone area for replacements of residential land classes reserved for investments in 2000[8].

1.3. Objectives of the study

1.3.1. General objectives

The main objective of this study is to Assess Flood Vulnerability using GIS for Nekemte town.

1.3.2. Specific objectives

The specific objectives of the study are to:

- identify flood vulnerability factors for flood vulnerability study
- generate flood vulnerability map for the Nekemte town using MCE and GIS
- identify the kebeles and land use classes vulnerable to flood hazard.

1.4. Research questions

This research will attempt to give possible answers to the following main research questions.

1) What are the factors necessary for mapping flood vulnerability of the Nekemte town?
2) Which parts of Nekemtetown is susceptible for flooding hazard?
3) Which kebeles and land use classes of the Nekemte town are vulnerable to flood hazard?

1.5. Significance of the study

The result of this study is expected to help the following institutions, public and/or individuals in the following ways:

The Nekemte town Administration to:

- protect the community, their property and life from damaging before, during and after the disaster occurs and guide and orient the investors and/or tourists to use appropriate places of the town for investment and recreational purpose respectively
- reserve the places prone to flood, for flood resistance activities by taking into account the rainy seasons of the town rather than for construction so as to avoid any calamities caused by storm water floods.
- support the processes of prioritizing, justifying and targeting investments in order to manage and reduce the risk to people, property and the environment

Researchers: to provide them as a baseline for a further study.

1.6. Scope of the study

The study was conducted in Nekemte town particularly in the boundary area of the town master plan revised in 2009 that covers 5380.8 hectares of land area. The study was highly focused on the Assessment of flood vulnerability to flood hazard in Nekmte town. The whole existing land use classes, drainage network, streams and rivers, slope, elevation and kebele Administrations boundary were particularly considered for flood vulnerability assessments of the town. The study looked into the direct causing factors for flood vulnerability such as urbanization expansion near rivers and streams, live at hilly foots, high slope and roads without drainage channels.

1.7. Structure of the study

This study report embraced five major chapters: Chapter one provides the background of the study, statement of problem, objectives of the study, research questions, significance, scope and limitations of the study. Chapter two highlights the related literatures, publications, research, booklets and flood vulnerability related notes.

Chapter three describes the study area location, data acquisition, methods of data analysis flow chart. Chapter four provides data analysis, factors developed for flood vulnerability assessment, results and discussion. Chapter five provides a brief summary of the thesis (conclusion) and recommendation of necessary activities that strengthen the findings of the thesis.

1.8. Limitation of the study

The following are the problems encountered during data collection and thesis writing. The objects on the ground like small streams and rivers were not shown on the digital map collected from Nekemte town Administration. However, GPS data collected for streams and rivers that did not mapped on the master plan of the town (Annex-1). And also unavailability of the experts in the Office is the greatest problem for delay of the thesis completion on the required possible time. Past flood risk was not yet delineated and mapped by Nekemte town Administration rather than taking immediate action being presented at area to reduce the problems happened. As a result an expert of flood of the Nekemte town Administration and residents around rivers and streams played a great role in showing the places hit by flood risk.

2. REVIEW OF RELATED LITERATURE

2.1. General Overview

Vulnerability can be defined as degree to which a system is susceptible to or unable to cope with adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which the system is exposed, its sensitivity, and its adaptive capacity [2].

Vulnerability=(Exposure)+ (Susceptibility) - Resilience..............................equation (1)

Exposure: Exposure can be understood as the values that are present at the location where floods can occur. These values can be goods, infrastructure, cultural heritage, agricultural fields or mostly people. The indicators for this component can be separated in two categories; the first one covers the exposure of different elements at risk and the second one give details on the general characteristics of the flood[3].

Susceptibility: Susceptibility relates to system characteristics, including the social context of flood damage formation. Especially the awareness and preparedness of affected people regarding the risk they live with (before the flood), the institutions that are involved in mitigating and reducing the effects of the hazards and the existence of possible measures, like evacuation routes to be used during the floods[3].

Resilience: Resilience to flood damages can be considered only in places with past events, since the main focus is on the experiences encountered during and after the floods. A vulnerability map gives the precise location of sites where people, the natural environment or property are at risk due to a potentially catastrophic event that could result in death, injury, pollution or other destruction. Such maps are made in conjunction with information about different types of risks. A vulnerability map can show the housing areas that are vulnerable to flooding hazards [3].

Floodplains have historically attracted socio-economic development and continue to support high densities of human population. This is particularly important where land resources suitable for human development are scarce. Especially in arid and semi-arid areas, flood waters represent a vital water resource. Floods can, however, also lead to wide-spread damage, health problems and the loss of human life. This is especially the case where development activities in the river channel and the adjacent floodplain have been pursued without taking into account the associated risks. Assets at risk from flooding can include housing, transport and public service infrastructure, commercial and industrial enterprises, agricultural land and the environmental and cultural heritage etc. [11].

2.2. Flood vulnerability and Flood risk assessment in different countries

Korea Developed Flood Vulnerability map for North korea, The main reason for natural hazard vulnerability in North Korea was forest destruction due to food and energy shortages. Therefore, to estimate the locations of vulnerable areas, factors with potential to natural hazard was selected and analysed. The study used a two-level approach in finding vulnerable areas. The two levels were called high level factors and low level factors. The high level factors considered were land use, soil, social aspect, hazard history, hydrology, meteorology, and topography. These factors included the sub-factors (Low level): elevation, slope, 100 year precipitation frequency, precipitation intensity, flood discharge, stream order, land cover, riparian buffer, soil permeability, soil loss potential, and property damage from flooding, return period, and populations. Selected factors were classified into 5 sub-factors based on their value range; very low, low, medium, high, and very high. After this, all sub factors within the same high level factor were overlaid. At this point, the vulnerable areas were found. Weight was applied for each factor and once complete, a natural hazard vulnerability map was generated. The final natural hazard vulnerability map showed five levels of vulnerability: very low, low, medium, high, and very high[23].

Another study show that Vietnam country mapped flood vulnerability area using GIS and Remote Sensing for the province of Ha Giang in North Vietnam which was frequently suffering from flash flood due to very heavy rainfall. They used land use derived from Landsat5 and Landsat7, to determine flood vulnerability and information on the topography; Shuttle Radar Topography Mission (SRTM) 90m grid size. For the area around the city of Hue a Digital Elevation Model (DEM) at 15m grid size was derived using ASTER data. All these data combined to derive flood vulnerability. For the area around Hue a separate analysis was carried out to identify land use changes between 1991 and 2003 in order to assess the influence of the floods in land use and to study forest changes as a possible indicator for increased flooding upstream the Huong River. Here, a flash flood risk map is constructed using topographic data from the SRTM mission. Using existing GIS data on soil properties in combination with slope and aspect information provided information on the possible vulnerability for flash floods. Furthermore, rainfall estimates was derived from low resolution meteorological satellite data. Together, these sources of information have been assisting the people of the Ha Giang province to better prepare for flash floods emergencies and to save human lives and properties [24].

Mapping Flood Vulnerability Areas in a Developing Urban Center of Nigeria was conducted by[25].They used an integrated approach of Remote Sensing and GIS techniques in order to map areas vulnerable to flood hazard in Gwagwalada urban area. Topographic Map and Landsat TM image of 1991 and 2001 respectively were processed, scanned, digitized, interpolated, classified and overlaid using ILWIS GIS software modules to generate classified Land use/land cover map, Digital Terrain Map and Flood vulnerability map of the study area. The results obtained shows that, areas lying along the banks of River Usuma are most vulnerable to flood hazards with the vulnerability decreasing towards the northern part of the town, much of the area is built up and this gives rise to high vulnerability to flash flood hazards [25].

2.3. Types and cause of flooding

Different types of flooding present different forms and degrees of danger to people, property and the environment, due to varying depth, velocity, duration, rate of onset and other hazards associated with flooding. With climate change, the frequency, pattern and severity of flooding are expected to change, becoming more uncertain and more damaging [4].

There are essentially two major causes of flooding: Coastal flooding which is caused by higher sea levels than normal, largely as a result of storm surges, resulting in the sea overflowing onto the land. Coastal flooding is influenced by the following three factors, which often work in combination: High tide level, Storm surges and wave action [12]

Inland flooding which is caused by prolonged and/or intense rainfall. Inland flooding can include a number of different types:

Overland flow occurs when the amount of rainfall exceeds the infiltration capacity of the ground to absorb it. This excess water flows overland, ponding in natural hollows and low-lying areas or behind obstructions. This occurs as a rapid response to intense rainfall and eventually enters a piped or natural drainage system.

Flooding from Rivers: rivers flood when the amount of water in them exceeds the flow capacity of the river channel. Most rivers have a natural floodplain into which the water spills in times of flood. Flooding can either develop gradually or rapidly according to how steeply the ground rises in the catchment and how fast water runs off into surface watercourses. In a large, relatively flat catchment, flood levels will rise slowly and natural floodplains may remain flooded for several days, acting as the natural regulator of the flow. In small, steep catchments, local intense rainfall can result in the rapid onset of deep and fast-flowing flooding with little warning. Such "flash" flooding, which may only last a few hours, can cause considerable damage and possible threat to life. Land use, topography and the form of local development can have a strong influence on the velocity and volume of water and its direction of flow at particular points. Flooding can occur when culverts and bridges are blocked by debris [13].

Flooding from artificial drainage systems results when flow entering a system, such as an urban storm water drainage system, exceeds its discharge capacity and the system becomes blocked, and / or cannot discharge due to a high water level in the receiving watercourse [13].

Groundwater flooding occurs when the level of water stored in the ground rises as a result of prolonged rainfall to meet the ground surface and flows out over it, i.e. when the capacity of this underground reservoir is exceeded. Groundwater flooding tends to be very local and results from interactions of site-specific factors such as tidal variations. While water level may rise slowly, it may be in place for extended periods of time. Hence,such flooding may often result in significant damage to property rather than be a potential risk to life.

Estuarial flooding may occur due to a combination of tidal and fluvial flows, i.e. interaction between rivers and the sea, with tidal levels being dominant in most cases. A combination of high flow in rivers and a high tide will prevent water flowing out to sea tending to increase water levels inland, which may flood over river banks [13].

2.4. Impacts of flooding

Impacts on people and communities: Flooding can cause physical injury, illness and loss of life. Deep, fast flowing or rapidly rising flood waters can be particularly dangerous.

Impacts on property: Flooding can cause severe damage to properties. Floodwater is likely to damage internal finishes, contents and electrical and other services and possibly cause structural damage.

Impacts on Infrastructure: Flooding can cause to businesses and infrastructure, such as transport or utilities like electricity and water supply, can have significant detrimental impacts on local and regional economies. Flooding of primary roads or railways can deny access to large areas beyond those directly affected by the flooding for the duration of the flood event, as well as causing damage to the road or railway itself [13].

Impacts on the environment : Significant detrimental environmental effects of flooding can include soil erosion, bank erosion, land sliding and damage to vegetation as well as the impacts on water quality, habitats and flora and fauna caused by bacteria and other pollutants carried by flood water [5].

2.5. Historical Background of Flood in Nekemte town

Flooding from rivers, estuaries and the sea pose are a serious threat to millions of people around the world.Problems related to flooding and vulnerability of the Nekemte town has greatly increased in recent decade due to several factors including changes in land-use in the hinterlands, urbanization of flood-prone sites, squatter settlements and sub-standard constructions, and increased household density.As a result, the overland surface water runoffs increased from time to time. This is due to the fact that roads, homes, and buildings, do not allow rain water to be absorbed into the ground. The increased in runoff cause flooding in downstream areas by exceeding channel capacities. These problems intensified due to improvements were not made and designed to accommodate future developments.

Drainage routes for areas upstream of a development site were not carefully determined. The development itself was not designed to minimize the likelihood of flooding as much as possible. The constructions of erosion control facilities were not preceded development. The only thing the municipality doing is to be appeared to where the flood occurred, identify the causes of that flood and take immediate actions like provision of drainage line, retain walls and if the problems happened on an existing drainage; check dam and additional culverts construction were taken in place which may leads to the exaggerated flood in the future time.

The prominent areas of the town are: Bake Jama floods along the stream crossing the town and Bake Jama Elementary School and joining the Lake Sorga. Burka Jato sub city, Cheleleki floods in the North East of the Town. The Keso sub city flood along the Mariam River.

2.6. Flood Risks in Nekemtetown

Road damage: The main roads crossing the town always collect run off all the three rainy seasons between June and September. In the rainy season the road taking to the Bake Jama Elementary School in Bake Jamakebele and the selected material road to ChelelekiMekaneYesus Church was closed and the surrounding students and the communities forced to use alternative routes in order to facilitate for their daily work and urgent cases (figure 2.1).

Drainage and culverts damage: The selected material road from BakanisaKase to Cheleleki across ChelelekiMekaneYesus Church which serve many vehicles serving as a weste disposal sites. These waste materials closed the stream channels and culverts. Therefore, streams overflow to the surrounding areas as well as over the culverts due to the clogs of rubbish. The stream over flow in the rainy season was damaged farming land, caused soil erosion, damaged of properties and 6 houses were closed in 2011 and residents were displaced from their home and took rental houses until the overflow was discharged and continued to flow in a normal drainage channels (figure 2.2)[8].

Soil erosion: making free flow of run off on the new earthen roads for a long distance along steep slopes, top of hills are the main causes of the flash flood in the town and hence so many places like Cheleliki around Ask Secondary School, Bake Jama along the route taking to Nekemte TVET College, local name Gedelgibuarea,keso sub city (05 and 09 kebele) and Board area were the most affected places. From the year 2008 to 2011 six places in Town was maintained and they are giving services like shopping and as a drainage channel in order to threaten the life and properties of the people around these dangerous place[8].

Figure 2.1. public roads closed due to stream overflow

Figure2.2. The Residential areas very near to rivers and stream

2.7. Geographic Information System (GIS)

[14] Described geographic information system (GIS) as a computer based information system used to digitally convert analog to digital application and keep track not only of events, things or activities but also the point where these activities occur. It helps to represent and analyze the geographic features present on the earth surface and the events including non-spatial attributes linked to the geography under study that are taking place on it.

[15] Mentioned that since the mid 1970's, specialized computer systems have been developed to process geographical information in many different ways. The GIS includes not only hardware's and software's but it also includes special devices used to input maps and to create map product together with communication systems needed to link various elements. A GIS makes it possible to link or integrate information that is difficult to associate through any other means and can use combinations of mapped variables to build and analyze new variables.

A Geographic Information System is a rapidly developing tool with a range of applications. GIS is defined as computer systems capable of assembling, storing, manipulating, and displaying geographically referenced information [16]. The power of GIS lies in its tremendous clarity of presentation and analysis. It has the ability to take scattered, confusing data and to represent its spatial relationships in such a way that researchers can realize new levels of understanding. In the context of flood hazard management, GIS can be used to create interactive map overlays, which clearly and quickly illustrate which areas of a community are in danger of flooding. Such maps can then be used to coordinate mitigation efforts before an event and recovery as cited in [17]. GIS, thus, provides a powerful and versatile tool to facilitate a fast and transparent decision-making. There are a number of GIS software, which include Arc View, Arc/Info, ILWIS, MapInfo, etc. Arc View, Arc GIS, GIS developed by ESRI is a powerful, easy to use, point-and click graphical user interface that makes easy loading of spatial and tabular data so that it can be display the data as maps, tables and charts. These provide the tools to query and analyze the data and present the results as presentation-quality maps [17].

2.8. Multi Criteria Evaluation (MCE)

[18] reported that Multi-criteria analysis is well suited to managing and evaluating structural programs in partnership since the opinions of national and supranational members may be expressed jointly without losing any of their specificity or having to make too many concessions regarding their value scales and the analysis is similar to the techniques adopted in the field of organizational development or information systems management.

In this study GIS was integrated with MCE. This study used five criteria each was presented and stored in layer by using Arc GIS 9.3 and the criterion values are generated. The criterion maps are converted into grids (Raster) using conversion tools of Arc tool box of GIS and the mathematical processes are applied to the criteria with Map Calculator. Ranking Method was used to rank every criterion under consideration in their relative importance and Pairwise Comparison Method (PCM) which is designed as a user interface to calculate the weights from input preferences embedded in ArcGIS.

At the end of the application, composite maps were created using Boolean Approach, Ranking Method, and Pairwise Method. There are three different results depending on the method that was been used. The three results are Weighted over lay, tabulate area of weighted over lay with kebele boundary and tabulate area of weighted overlay with land use(Residential, commercial centers) since the population density is large at all these locations. The purpose of these are to examine the coverage of flooding vulnerability in each kebele of the town and flooding vulnerability coverage on the residential where the people live in.

2.9. Digital Elevation Model (DEM)

A DEM can be represented as a raster (a grid of squares, also known as a height map when representing elevation) or as a vector-based triangular irregular network (TIN). The TIN DEM dataset is also referred to as a primary (measured) DEM, whereas the Raster DEM is referred to as a secondary (computed) DEM[19]. DEMs are commonly built using remote sensing techniques, but they may also be built from land surveying. DEMs are used often in geographic information systems, and are the most common basis for digitally-produced relief maps. The DEM could be acquired through techniques such as photogrammetry, LiDAR, and land surveying [20].

2.10. Global Positioning System (GPS)

The Global Positioning System (GPS) is a satellite-based navigation system made up of a network of 24 satellites (NAVSTAR Series) placed into orbit by the U.S. Department of Defence to determine the position of a feature on the earth's surface. GPS was originally intended for military applications, but in the 1980s, the government made the system available for civilian use [21]. GPS works in any weather conditions, anywhere in the world, 24 hours a day. GPS satellites circle the earth twice a day in a very precise orbit and transmit signal information to earth. GPS receivers take this information and use triangulation to calculate the user's exact location. Essentially, the GPS receiver compares the time a signal was transmitted by a satellite with the time it was received. The time difference tells the GPS receiver how far away the satellite is. Now, with distance measurements from a few more satellites, the receiver can determine the user's position and display it on the unit's electronic map. Certain atmospheric factors and other sources of error can affect the accuracy of GPS receivers [21].

A GPS receiver must be locked on to the signal of at least three satellites to calculate a 2D position (latitude and longitude) and track movement. With four or more satellites in view, the receiver can determine the user's 3D position (latitude, longitude and altitude). Once the user's position has been determined, the GPS unit can calculate other information, such as speed, bearing, track, trip distance, distance to destination, sunrise and sunset time and more. Therefore, GPS offers opportunity for easier and reasonably accurate location of features on the earth's surface at a low cost. Combined with GIS, the GPS offers a rapid means of presenting field information as thematic maps, tailored to individual needs. GPS can provide accurate coordinates sufficient to meet the requirements of the locational data policy [21].

2.11. Soil infiltration rate

Soil infiltration is the process of water entering the soil; the infiltration rate is the velocity at which water penetrates the soil surface. Soils with low infiltration can be responsible for runoff and flooding and can become saturated during rain events. This, in turn, decreases soil strength and increases erosion potential. It can also cause nutrient deficiencies in plants and generate anaerobic conditions. In dry soil, water infiltrates rapidly. This is called the *initial infiltration rate*. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate. This is called the basic *infiltration rate*[22].

The infiltration rate depends on soil texture (the size of the soil particles) and soil structure (the arrangement of the soil particles) and is a useful way of categorizing soils from an irrigation point of view. There are several factors that affect a soil's infiltration rate, including the type of soil, which is determined by the portions of sand, silt and clay in a soil. Infiltration rates are generally measured in millimeters or inches per hour, meaning that the given depth of a water layer can enter the soil within one hour. The infiltration rateis the velocity or speed at which water enters into the soil. It is usually measured by the depth (in mm) of the water layer that can enter the soil in one hour. An infiltration rate of 15 mm/hour means that a water layer of 15 mm on the soil surface, will take one hour to infiltrate[22].

In dry soil, water infiltrates rapidly. This is called the *initial infiltration rate*. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate. This is called the basic *infiltration rate*.

The infiltration rate depends on soil texture (the size of the soil particles) and soil structure (the arrangement of the soil particles) and is a useful way of categorizing soils from an irrigation point of view. The most common method to measure the infiltration rate is by a field test using a cylinder or ring infiltrometer[22].

Table 2.1. Basic infiltration Rates for various soil types

S/No	**Soil types**	**Basic infiltration rate(mm/hour)**
1	Sand	Less than 30
2	Sandy loam	20-30
3	Loam	10-20
4	Clay loam	5-10
5	Clay	1-5

Source: FAO, 1990

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3. METHODOLOGY

3.1. Description of study area

3.1.1. Location

The study area, Nekemte town is located at a distance of 328km west of Addis Ababa (Finfinne), 110km North East of Gimbi, the principal town of West Wollega Zone and 250 km North West of Jima town in Oromia Regional state and it covers 5380.8hectares of land area. The astronomical location of Nekemte, study area lies in between 9°02’ (in NunuKumba*Wereda*) to 9°07’ (in Ibantu*Wereda*) North Latitude and 36°28’ (in Diga*Wereda*) to 36°37’ (in Boneya*Wereda*) East Longitude [7]. This means, the study area extends for about 0°5’ south-north and 0°09’ east-west, which is an extension of 9.25kms and 16.65 kms earth distance south-north and east-west respectively. Annual rainfall and elevation of the town ranges from 1788mm to 2244mm and 1920m in the valleys to 2210m above sea level on hill tops.

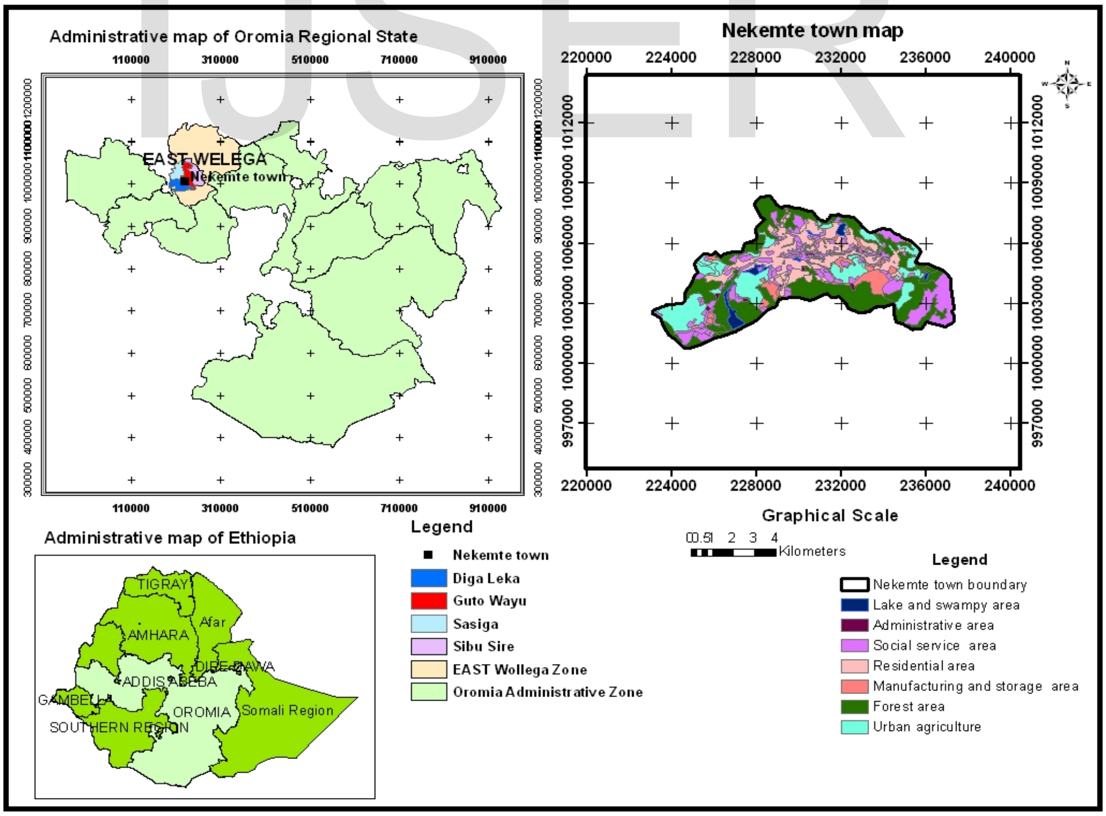

Figure 3.1. Location map of study area

3.1.2. Population

During 1865 when the first sample survey was conducted at national level the population size of Nekemte town stood 12,345. In the second round sample survey after five years in 1970 the population size grew to 16,228. In 1984 and 1994 the population size also resulted as 28,703 and 47,100 respectively. The 2008 census reveal, population size of the town is increased to 76,817. Therefore the population size of the town was growing at 4.6% per annum [26] as cited in [27].

3.1.3. Soil characteristics

Reddish brown clay soil is the dominant soil type, which almost monotonously cover the plains, gentle slopping terrains and steep slopping valley sides in Nekemte area. There is widely held belief that this soil is the product of alteration of the dominantly occurring porphyritic basaltic bed rock in the town and surrounding areas. A reddish brown sandy clay soil is the best type of soil for holding civil engineering structures, since it is underlain by basaltic rock which is its parent material and hence, there is no problem of foundation material for resting any structure in the town. Therefore, dominance of this soil in the town is an asset for Nekemte[7].

A reddish sandy soil also covers a wider area in Nekemte. This type of soil is loose and fine to medium grained. It is composed of angular grains of quartz and feldspar. Major occurrences of fluvial sediments are along banks of rivers (Gibe, Dedessa etc.). The fluvial sediments mainly comprise a mixture of coarse to fine sandy sediments. The thickness of soil covers in the town varies from place to place depending on topographic settings. As thick soil layer is common at valley surfaces and along sides of gentle sloping terrains, the thickness of soil layer is thin along surface of steep sloping valley sides and hill tops [7].

3.1.4. Socio-economic activities

According to the revised master plan document of Nekemte town [7], two major economic activity groups stood out as leading sources of employment in the town; i.e. public administration, social, cultural and personal services which were employing 41%

of total labour force, while trade was the second by providing 34% of the total labour force and investment activity following them.

3.1.5. Climatic condition

As data from National Meteorology Agency Nekemte Station reveal, Nekemete town was found in WoynaDega (semi-humid) climatic zone with annual mean temperature revolves around 20^{O}C as well as the mean monthly rainfall ranges from 149mm – 187mm.

3.1.6. Land Use

According to Nekemte town revised master plan [7], the land use classification consists of residential (47.9%), commercial (17.3%), green area (13.2%), street network (10.1%), transport (0.19%) and other special function (11.34%) out of the total master plan area of 5380.8hectares.

3.1.7. Geological Characteristics

The geology of Nekemte is part of the Northwest Ethiopian lithologic assemblages which include volcanic rocks of ashengi group and tertiary flood basalt sequence with intercalation of felsic lava and pyroclastic rocks (commonly on the upper part) which form the northwestern and southeastern plateaus and attain a thickness of up to 3 km. The Ashangi formation represents the earliest fissural flood basalt volcanism on the northwesternplateau[28].

Nekemte and its surrounding areas are formed by Lower Volcanics which include rocks of lower basalt and lower pyroclastic groups. These rocks are slightly weathered at surface, easy to break, shape and workable and hence used for different construction material and also good aquifer potential for holding groundwater. The geology of Nekemte and its vicinities is predominantly formed by Tertiary Volcanics which includes the following units. These are: Lower volcanic, upper volcanic, hypabyssal rocks and dykes and pugs and domes[28]

The Hypabyssal rocks including dolerite, basaltic dykes, plugs and domes of trachytic, phonolitic and syenite composition occur in various part of the area. These rocks are systematically aligned and form linear features that extend from Gedo to Shambu. This may indicate that they are intruded along weak zones; probably faults in the region where Nekemtebelongsto.The alluvial deposits occurring in Nekemte area are restricted to places in the valley plains, particularly, along the banks and within the courses of streams. These sediments are dominantly composed of silt clays when occurring on river banks and also include pebbles and even boulders when occurring in the river courses. The alluvial deposits which are very similar to the fine grained alluvial are found at foots of gently slopping valley sides and occur only in relatively few places[28].

3.1.8. Flooding

Though flood caused human catastrophe is rare in Nekemte, limited areas are prone to flooding. Due to absence of proper storm water drainage channels along undulating topography, occurrence of flooding is frequent in Keso sub-city around Mariam river (Kebele 05 and 09), in Derge sub-city in vicinity of Nekemte hospital (Kebele 07) as well as in different parts of Cheleleki sub-city. Indeed, the type of soil in Nekemte area is stiff clay, which is more or less resistant to erosion; however, soil degradation is apparent in many steep landscapes, particularly, where unwarranted constructions exist. As a result, gullies are apparent in a number of places[7].

3.2. Sources of data

There are generally two types of data sets have been used in this study: spatial and non-spatial data. Spatial data include SRTM 30m elevation data, Drainage network, Land use map, river and steam lines. Non spatial data are rain fall data. And also the data are further classified as Primary and secondary depending on whether the data has been used by some other institution and or organization, or for research or not (table 3.1).

SRTM is critical and most important among the spatial data sets. For the study area, Contours generated from SRTM data was transformed to ArcGIS to create TIN, digital elevation model (DEM), Slope and Elevation reclassification. All the rest data, except for stream lines that were not mapped on the master plan of the town which are collected with Hand held GPS others are in a digital map. The above data sets were transformed to ArcGIS and the database were generated for each selected factors.

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Furthermore, to confirm the existence and extents of flood vulnerability in Nekemte town, some interview with the experts of Nekemte town Administration and people living near flood zone by purposive selection method was made.

Primary data collection: Data collection with hand held GPS was held during reconnaissance survey to visit the flood prone areas in order to confirm its existence, extent and its current impacts and stream line and river banks data (Annex-1).

Secondary data collection: Information related to Assessment of Areas susceptible for flood were gathered, identified and used for the assessment.

In addition to Project study, research papers specific to the town, Books, booklets and other publications, the criteria used for this thesis were prioritized based on their relative importance and tabulated in the table 3.1.

Table3.1. Data source

S/No	Data	Type	Source	Purpose
1	Land use map	Secondary data(Digital)	Nekemte town Administration	Identify land use classes of the town
2	SRTM	Secondary data (Digital)	Nekemtetown Administration	Compute elevation and slope
3	Annual rain fall data of threestations	Secondary (attribute)	Ethiopia Meteorological Agency	Compute rainfall in the Nekemte town using interpolation raster(inverse distance weighted) method
4	Drainage Network	Secondary data(Digital)	Nekemte town Administration	Drainage density computations
5	GPS data	Primary data	Field data	Map rivers and stream line
6	Kebele boundary	Secondary data(Digital)	Nekemte town Administration	Flood vulnerability distribution to each kebele
7	Soil map	Secondary data(Digital)	Eastern Wollega Water, Mine and Energy Office	Identify soil types under the study area

3.3. Softwares

The following software were employed:

- ArcGIS 9.3: used for Geo-data-base creation, Geo-reference, Topology creation, Rasterization, Reclassification, Weight overlay.
- IDRISI32: used for Pair-wise comparison and compute weights of factors developed
- Auto CAD 2007: used for Check and export data to ArcGIS 9.3 environment
- Microsoft Office 2007: Used for research report writing and presentation
- Global Mapper 11.0: has been used for contour generation from SRTM data and export to ArcGIS.

3.4. Materials and equipment requirement

To speed up the accomplishment of this study next to budget and some other supporting things the following hard ware were played a crucial role in the data analysis:

Table 3.2. Hardware

S/No	Item	Description
1	Computer	Toshiba lap top and Desk top
2	Printer	HP and Laser jet A4 printer(colour and black)
4	Global Positioning System(GPS)	Hand held
5	Digital Camera	Sony

3.5. Methods

Even though there are many criteria used for delineating areas susceptible for flood, in this study, methodology used to analyse the data incorporated the methodologies used by [23]. Accordingly, two main stages were used in order to determine the flood susceptible areas in the study area. Firstly, five factors necessary for delineating flood vulnerability area were identified with their relative necessity for flood vulnerability identification. Secondly, by applying the Multi- Criteria Evaluation technique in finding the flood susceptible areas based on the flood related factors of the study area. In evaluating the flood vulnerability areas, Pair-wise Comparison Method was used supported by Idrisi32 software, spatial analyst of Arc GIS 9.3 was used to delineate the area of interest with the help of weighted overlay. Pair-wise comparison is an integral part of Analytical Hierarchy Process (AHP) for tackling sophisticated problems [29]. This helps in detecting the flood vulnerability areas in the study area by identifying the most flood significant criteria. The results of weighted over lay of five re-classified factors drainage density , distance to rivers and streams, elevation, potential to flood(soil, land use and rainfall) and slope was analyzed using kebele and land use polygon zonal tabulate area of Spatial Analyst Tools of Arc Toolbox.

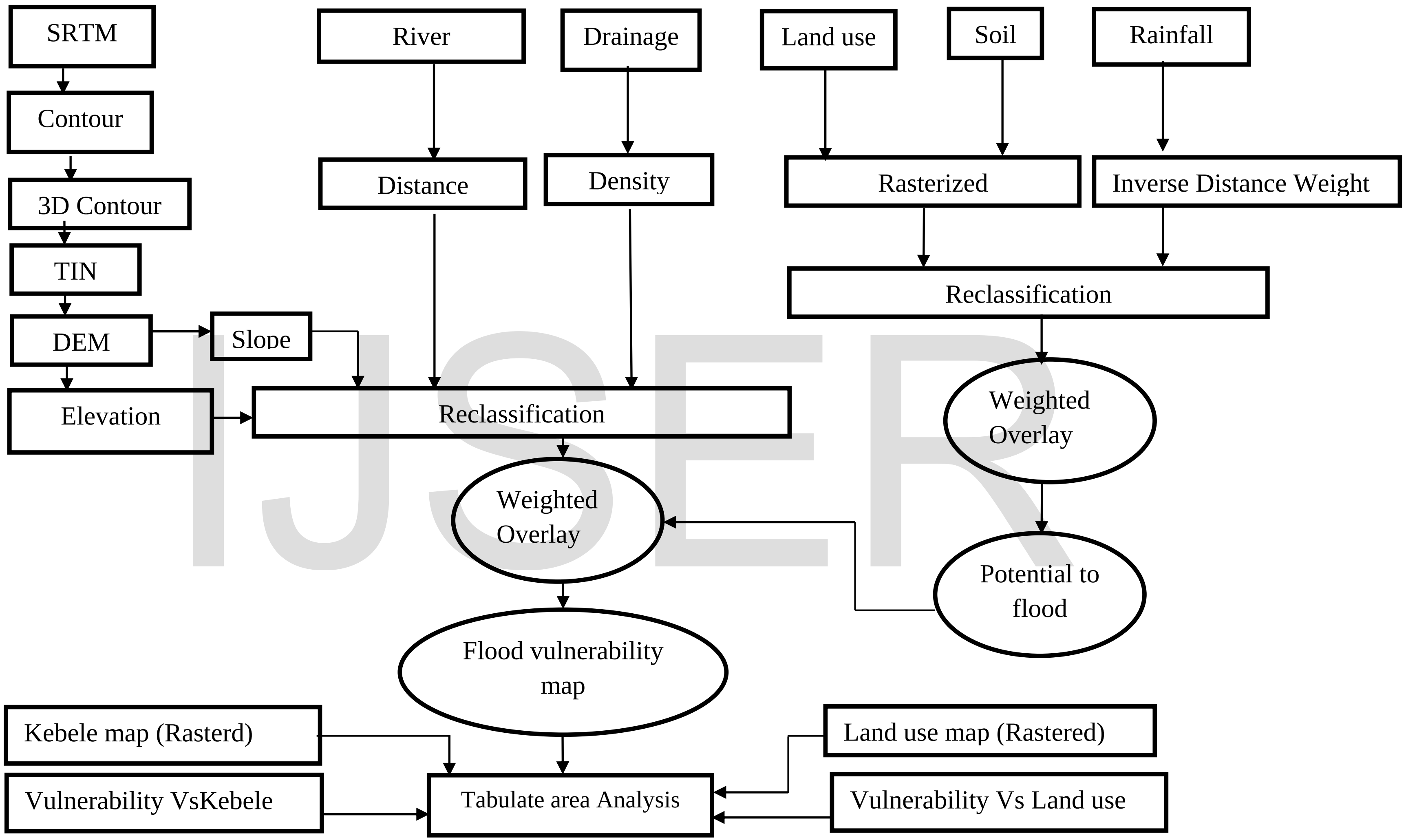

Figure 3.2. Technological scheme of method of data analysis

The Technological scheme of method of data analysisshown on figure 3.2 reveals, starting from top to bottom; there were five main selected factor (criteria) used in order to identify the flood vulnerable area. These are: slope, distance to stream and rivers, drainage density, potential to flood, slope and elevation. For each map the Geodatabase were created and digitized, topology creation, prioritizing based on related importance of their order of causes for flood, pair wise comparison method was used to calculate the weights of each selected factors identified.

Furthermore, weighted overlay of five selected factors were input in Weight Overlay of Spatial Analyst Tools of ArcGIS using 1 to 5 by 1. The weight overlay map was used for further analysis of area tabulation with kebele boundary and land use of Nekemte town.

4. DATA ANALYSIS, RESULTS AND DISCUSSION

4.1. Data analysis and Result

In this study the factors necessary for flood vulnerability were reviewed and incorporated with field survey, an interview with flood expert of the municipality and discussion with residents around the existing flood vulnerability was made.

To analyse the flood vulnerability of the town ArcGIS, Global mapper 11.0, idrisi32 software (PWC), and Multi criteria Evaluation were applied in producing and combining spatial and non-spatial data describing the causing factors. In the first part, the vulnerable area was produced by numerically overlaying a map layer describing the study area. The overlay was carried out as a Boolean overlay.

The evaluation of flood vulnerability was made after the maps of the criterion were prepared. The criterion maps were combined by logical operations such as intersection, union, weighted overlay in the Boolean approach. The criterion map layer reclassified using Ranking Method for each evaluation unit, the values between 1 and 5 were assigned after the reclassification, where 5 indicates very high flood vulnerability and 1 indicates very low flood vulnerability depending on the criteria’s class values.

Using Pair Wise Comparison Method(PCM)the criterion weights were calculated as 0.45, 0.26, 0.15, 0.09, 0.05, respectively for Distance to River and streams, Drainage Density, potential to flood,Slope and Elevation. With the input values in Pairwise Comparison Method, consistency ratio (CR) was found as 0.01. This indicates a reasonable level of consistency in the pairwise comparison of the factors. Weighted overlay was evaluated as 1 to 5 by 1 according to the respective percentage of each criterion and results obtained are 2, 3, 4 and 5 which indicates that low, moderate, high and very high flood vulnerability. For further identification and understanding Kebele Tabulation Area analysis with weighted overlay map of 1 to 5 by 1 was analyzed using Arc Toolbox/Spatial Analyst Tools/Zonal/Tabulate Area which result covered all kebeles of the town from low flood vulnerability to very high flood vulnerability.

Finally, Weighted Overlay map of the five selected factors area tabulation with Land Use classes wereanalyzed using the above discussed method which result covered all the land use classes of the town from low to very high flood vulnerability.

Figure (4.10) shows that result obtained after the final analysis (weighted over lay) of the selected factors. The result showed that the Nekemte town is covered with low, moderate, high and very high flood vulnerability area, which shows that as great cares should be done when the land development and uses are undertaken at any time.

4.1.1. Factors Development

The factors causing flood vulnerability were identified based on their relative impacts of increasing flooding vulnerability of the Nekemte town based on the availability of the data and topography of the town. Under mentioned are the factors selected for delineation of flood vulnerability:

4.1.1.1. Distance to Rivers and Streams Factor

Throughout history humans have found it desirable to construct cities along streams. Streams are sources of water for consumption, agriculture, and industry. Streams provide transportation routes, energy, and a means of disposal of wastes. Stream valleys offer a relatively flat area for construction. But, human populations that live along streams also have the disadvantage that the flow of water in streams is never constant. High amounts of water flowing in streams often leads to flooding, and flooding is one of the more common and costly types of natural disasters [30].

In Nekemtetown, humans are sensitive to flood because of high population density around rivers/streams, absence of zoning regulations, lack of flood control, and lack of emergency response infrastructure and early warning systems.

Therefore, catchments extent and the rivers are an essential element in flood vulnerability mapping. It is from this information flood prone areas are established, location of vulnerable population and infrastructure determined and levels of vulnerability determined. Since they provide the general overview of the flood vulnerability modelling domain and land uses types. The distance of rivers from residential and industries play a crucial role in order to protect any damaging from flood and others. Digital rivers and streams map of Nekemte town was imported to ArcGIS, Georeferenced, and digitized to line feature shape file and its topology was corrected. For some rivers/streams that are on the ground those did not provided in digital map were collected using hand held GPS Garmin60 (see Annex-1). Straight line distance from the rivers and streams were computed using Spatial Analyst/Distance/Straight Line. The Straight line distance generates geometry by encircling geometry at a specified distance. Straight line distance reclassified in five sub groups using manual classification scheme based on field observation with Nekemte town Administration flood expert, topography of the terrain, past flood risks, its proximity to and from the rivers and neighboring land classes. And new values were re-assigned according to flood vulnerability to flood hazard (table 4.1 and figure 4.1).

Table 4.1. Reclassified Distance to river and streams

Ranking	Distance to River and Stream(m)	Area (hectares)	% of Area	Remark
1	Greater than 400	2353.7	44	Very low vulnerability
2	300-400	543.6	10	Low vulnerability
3	200-300	678.3	13	Moderate vulnerability
4	100-200	794.9	15	High vulnerability
5	0-100	1010.2	19	Very high vulnerability
Total		**5380.778**	**100**	

Table 4.1 reveals that the highest area was covered by very low and very high flood vulnerability respectively 44% and 19 % whereas 10%, 13% and 15% area were respectively subjected to low, moderate and high flood vulnerability. Since the higher flood vulnerability and risks were more exaggerated near streams and rivers, very high flood vulnerability was the second largest value next to very low flood vulnerability of very far places from river and streams.

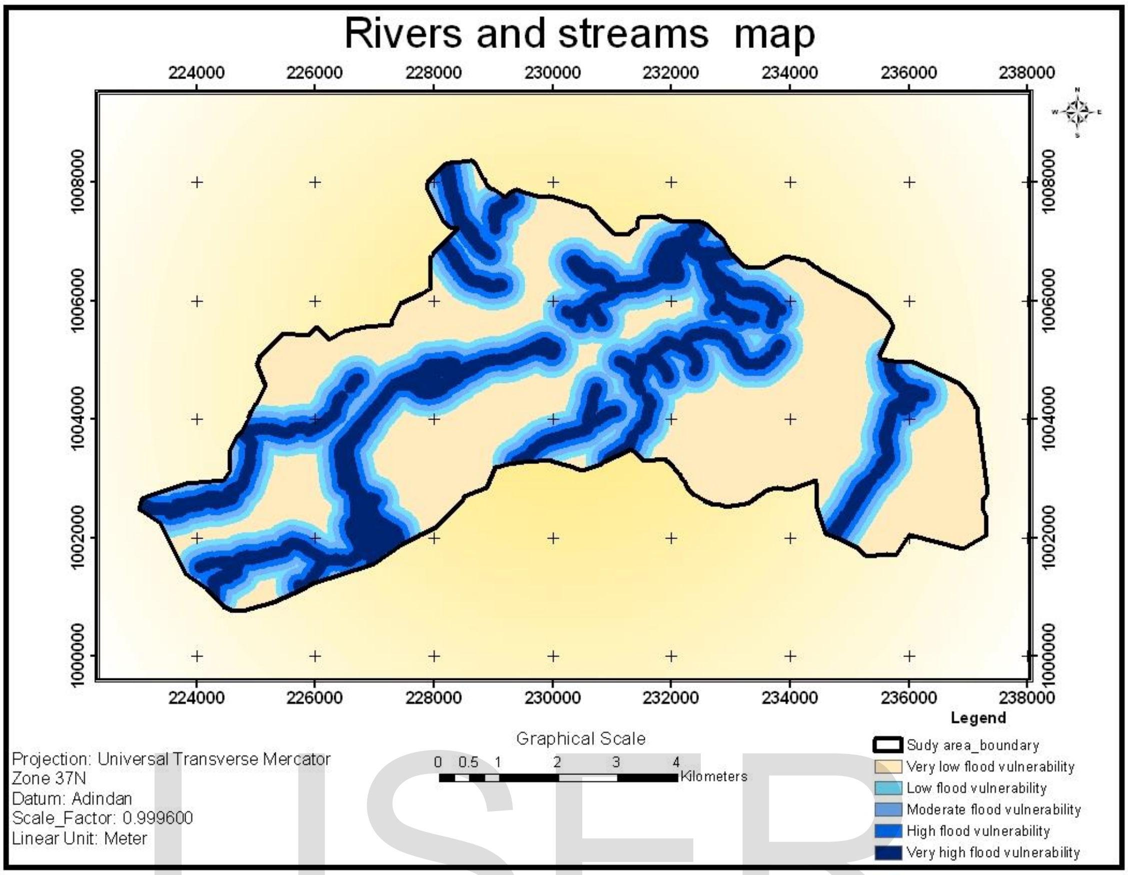

Figure 4.1. Reclassified Distance to rivers and streams data map of Nekemte town

4.1.1.2. Elevation Factor

As it was described in [6] metropolitan Addis Ababa, sprawling at the foothill of Entoto mountain range is traversed by several small streams originating from the mountain range. Torrential rains which are common during the rainy season in the town, cause sudden rise in flow of these streams which bring about flood damages to settlements along the bank of these streams. Such damages have often caused losses of property. Therefore, in order to find elevation factor of the study area, SRTM 30m elevation data has been used to create DEM. The SRTM data were prepared in grid size of 1^0 latitude x1^0 longitude, the data that can cover theNekemte town was identified by overlaying the study area with SRTM of Ethiopia. The SRTM data that fit the study area lies between 9^0 N to 10^0 N latitude and 36^0 E to 37^0 E longitude. Contours generated on Global Mapper and exported to ArcGIS:

-Open Global mapper/File/Open Data File(s)/browse and add data

-File/Generate Contours

-File/Export Vector Data/Export Shapefile/Save-in Export Line, close Global mapper.

-Open ArcGIS/Add/Saved Contour and Study area (Nekemte town boundary)

-Project coordinates to UTM using, ArcToolbox/Data Management Tools/Projections and Transformations/Project/input Data set or feature class (2D contour)/Output coordinate system in spatial reference properties/Adindan UTM 37N.Projection

-Clip 2D contour using Clip Analysis, Arc Toolbox/Analysis Tools/Extract/Clip/ input feature (2D contour) and Clip feature (Nekemte town)

-Convert vector contour (clipped contour) to 3D contour using, 3D Analyst/Convert/Feature to 3D.

-3D Analyst/Create/modify TIN/Create TIN from features.

-3D Analyst/Convert/TIN to Raster(DEM)

The DEM further reclassified into five sub group using Natural Breaks (Jet) classification schemes based on topography of the terrain, past flood risks, its proximity to and from the hilly area and neighbouring residents building. And new values were re-assigned according to flood vulnerability to flood hazard (table 4.2 and figure 4.2).

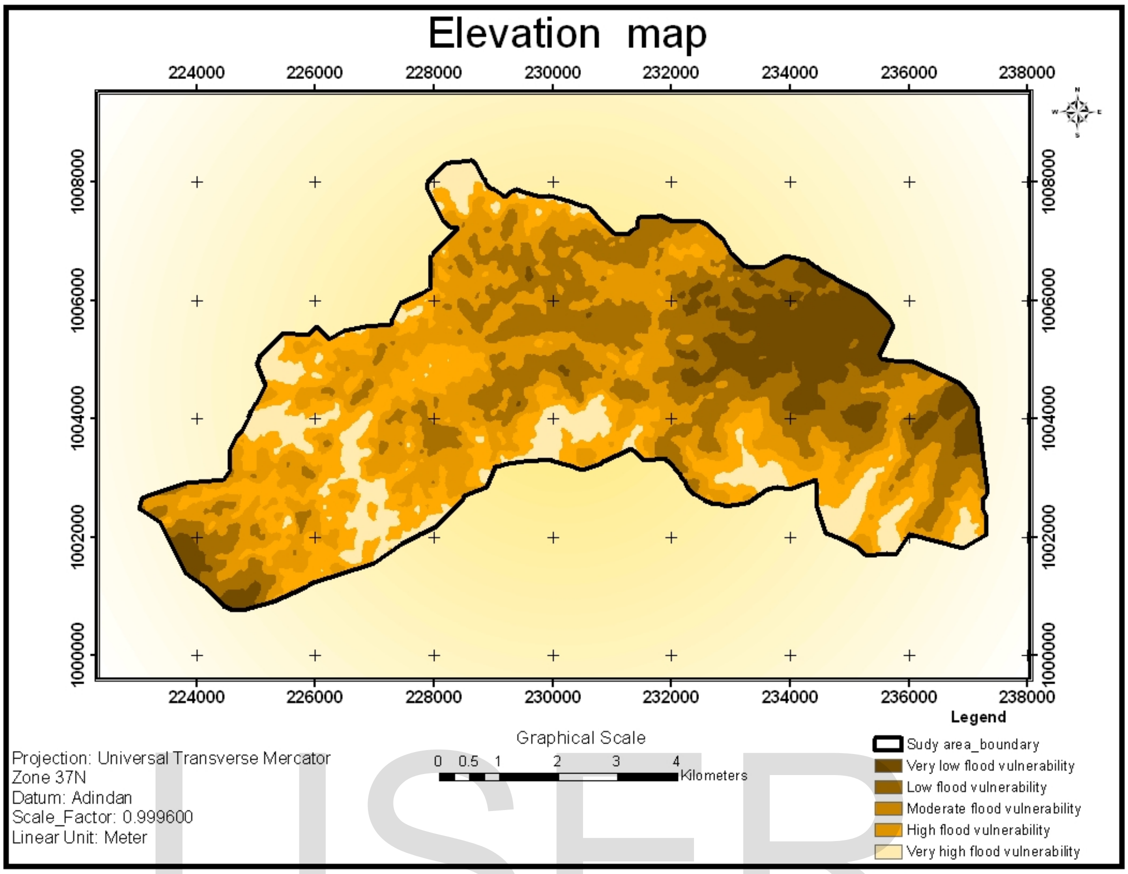

Figure 4.2. Reclassified Elevation data map of Nekemtetown

Table 4.2. Reclassified Elevationdata

Ranking	Elevation(m)	Area(ha)	(%) Area	Remark
1	2131.8-2210	624.0	12	Very low vulnerability
2	2094.5-2131.8	1367.5	25	Low vulnerability
3	2065-2094.5	1652.5	31	Moderate vulnerability
4	2032.2-2065	1178.4	22	High vulnerability
5	1920-2032.2	580.8	10	Very high vulnerability
Total		**5380.8**	**100**	

Table 4.2 indicates that the highest area (31%) subjected to the moderate flood vulnerability, whereas 12%, 25%, 22% and 10 % respectively covered the town as very

low, low, high, very highflood vulnerability. The arrangement of the values for the degree of vulnerability shows that the Nekemte town was built on hilly area.

4.1.1.3. Drainage Density Factor

The existing drainage networks of the town were digitized as it can be compatible in GIS environment. The roads with drainage was selected as a factor for flood vulnerability delineation for what the roads with drainages are expected to be face lesser flood damage. Using the Spatial Analyst/Density/kernel of ArcGIS line density of drainage was calculated. Line density calculates the density of linear features in the neighborhood of each output raster cell. Density is calculated in units of length per unit of area. Density units are based on the linear unit of the projection of input features or as specified by the output coordinate system environment setting. The computed drainage density layer was further reclassified in five sub groups using natural breaks (Jenks) classification schemes (table 4.3 and figure 4.3).

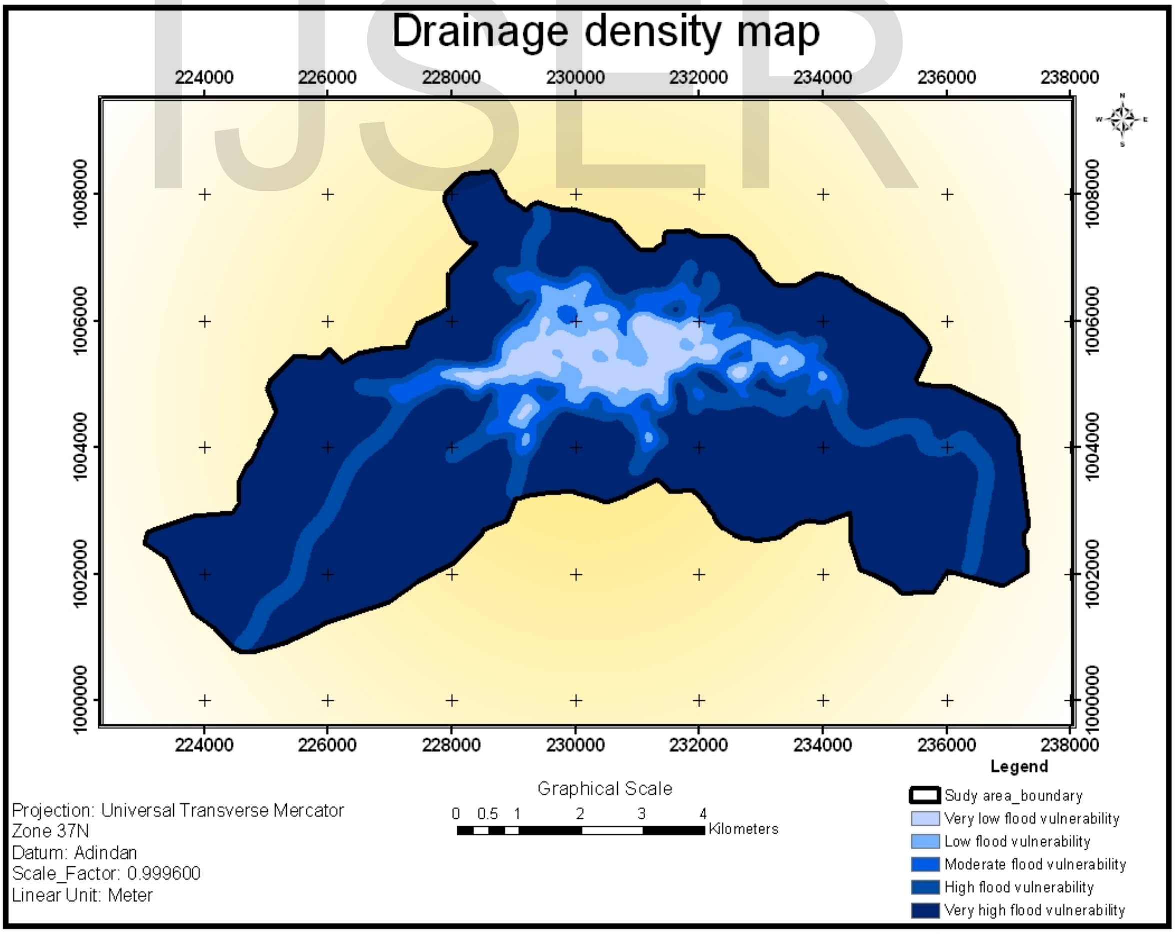

Figure 4.3. Reclassified Drainage density data map of Nekemte town

Table 4.3. Reclassified Drainage Density data

Ranking	Drainage Density (Km/ Sq. Km)	Area (hectares)	% of Area	Remark
1	16.34-24.05	3850.1	71.6	Very low vulnerability
2	11.18-16.34	691.5	12.9	Low vulnerability
3	6.01-11.18	335.4	6.2	Moderate vulnerability
4	1.79-6.01	266.6	4.9	High Vulnerability
5	0-1.79	237.2	4.4	Very high vulnerability
Total		**5380.8**	**100**	

Table 4.3 shows that the largest area (71.6%) was covered with very low flood vulnerability whereas 12.9%, 6.2%, 4.9% and 4.4% area in descending order were covered from low flood vulnerability to very high flood vulnerability resulting in increasing flood vulnerability of the Nekemte town.

4.1.1.4. Slope Factor

Slope is fundamental property of the landscape that drives movement of water and soil downwards and across the surface. Slope is a constraint on the use of land, as steep slopes are liable to be unstable and hence unsuitable for agriculture or urban development [31].

Slope data of Nekemte town was computed from SRTM data considering a contour interval of 10m on Global mapper and exported as vector data to shape file in order to make compatible on ArcGIS environment. Contour map was added to Arc map, converted to 3D feature and TIN was created using 3D Analyst/Convert/Feature to 3D and 3D Analyst/Create or Modify TIN/ Feature to TIN respectively. TIN converted to raster data (DEM). DEM was extracted by masking in order to fill gaps between the raster data of the DEM; from which slope was computed. The reclassification of the slope was made based on its suitability for all developments and use undertaken in a town like dense residential development, agriculture, industrial and institutional uses [32] (table 4.4).

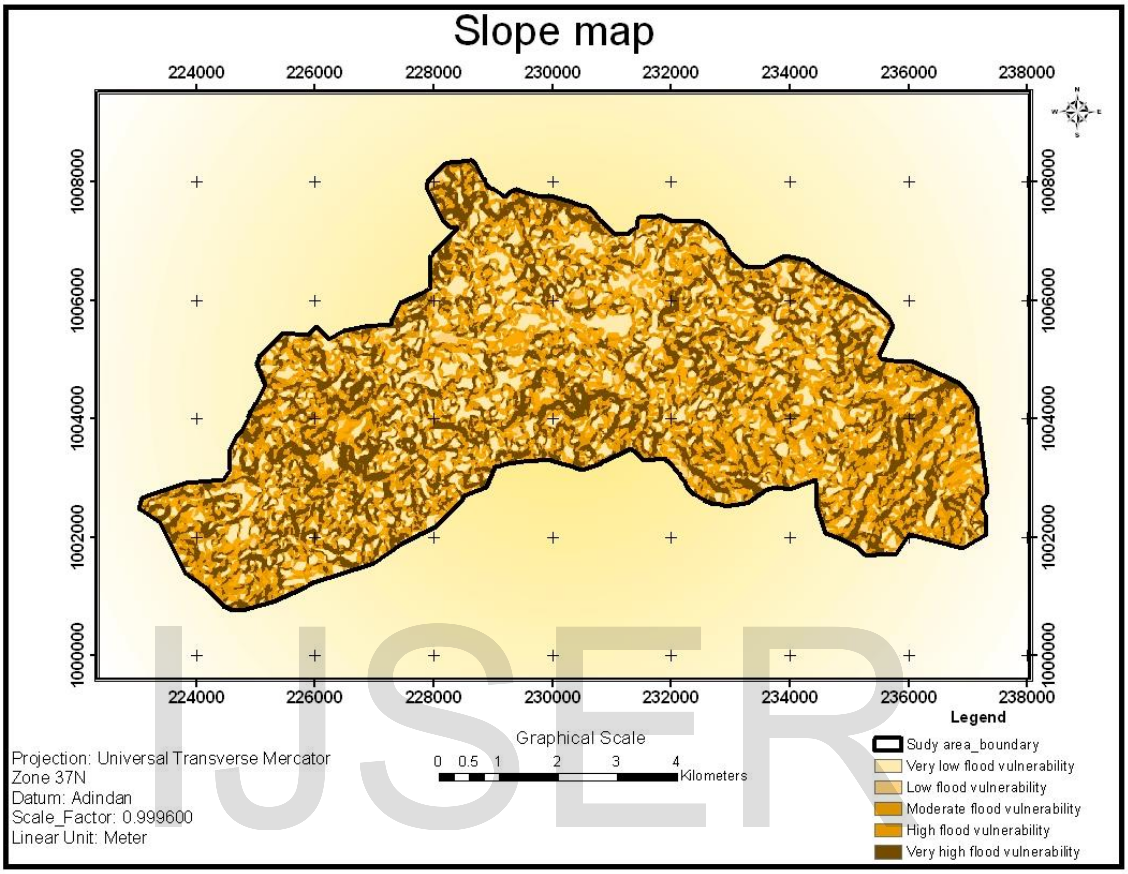

Figure 4.4. Reclassified Slope data map of Nekemte town

Table 4.4. Reclassified Slope data

Ranking	**Slope (%)**	**Area (ha)**	**% of Area**	**Remark**
1	0-3	890.6	17	Very low vulnerability
2	3-8	325.7	6	Low vulnerability
3	8-15	1035.2	19	Moderate vulnerability
4	15-25	1658.0	31	High vulnerability
5	Greater than 25	1471.3	27	Very high vulnerability
Total		**5380.8**	**100**	

Table 4.4 reveals that largest area 31%, 27% respectively subjected to high and very high flood vulnerability. The results obtained from slope totally shows that as thetown

was built on steep slope and undulating topography. 17%, 6% and 19% of land subjected to very low, low and moderate flood vulnerability.

4.1.1.5. Potential to Flood Factor

Potential to flood hazard criteria factor was developed from three sub factors like Average maximum daily rainfall map developed from annual rainfall data of three stations Nekemte, Arbgebeya and Mulatadigacollected from National Meteorological Agency for 12 years, 11 years and 9 years respectively, Soil map of Nekemte town generated from Oromia Regional State soil map by clipping the map using the boundary of the study area, with the help of clip analysis of Arc Toolbox and Land use map of study area reclassified based on two things in consideration such as runoff generation and existence of people in the area.

A. Land use Factor

Table 4.5. Reclassified land use classes

Ranking	Landuse class	Area (ha)	% of area	Remark
2	Forest area	1912.4	35.5	Low vulnerability
3	Agricultural, and Expansion area	1425.5	26.5	Moderate vulnerability
4	Services, Manufacturing and storage area,	1073.6	20.0	High vulnerability
5	Residential area	969.2	18.0	Very high vulnerability
Total		**5380.8**	**100.0**	

Table 4.5 reveals that the largest area(35.5% and 26.5 %) were subjected to low and moderate flood vulnerability, where the services, manufacturing and storage and residential were followed by 20% and 18% subjected to high and very high flood vulnerability.

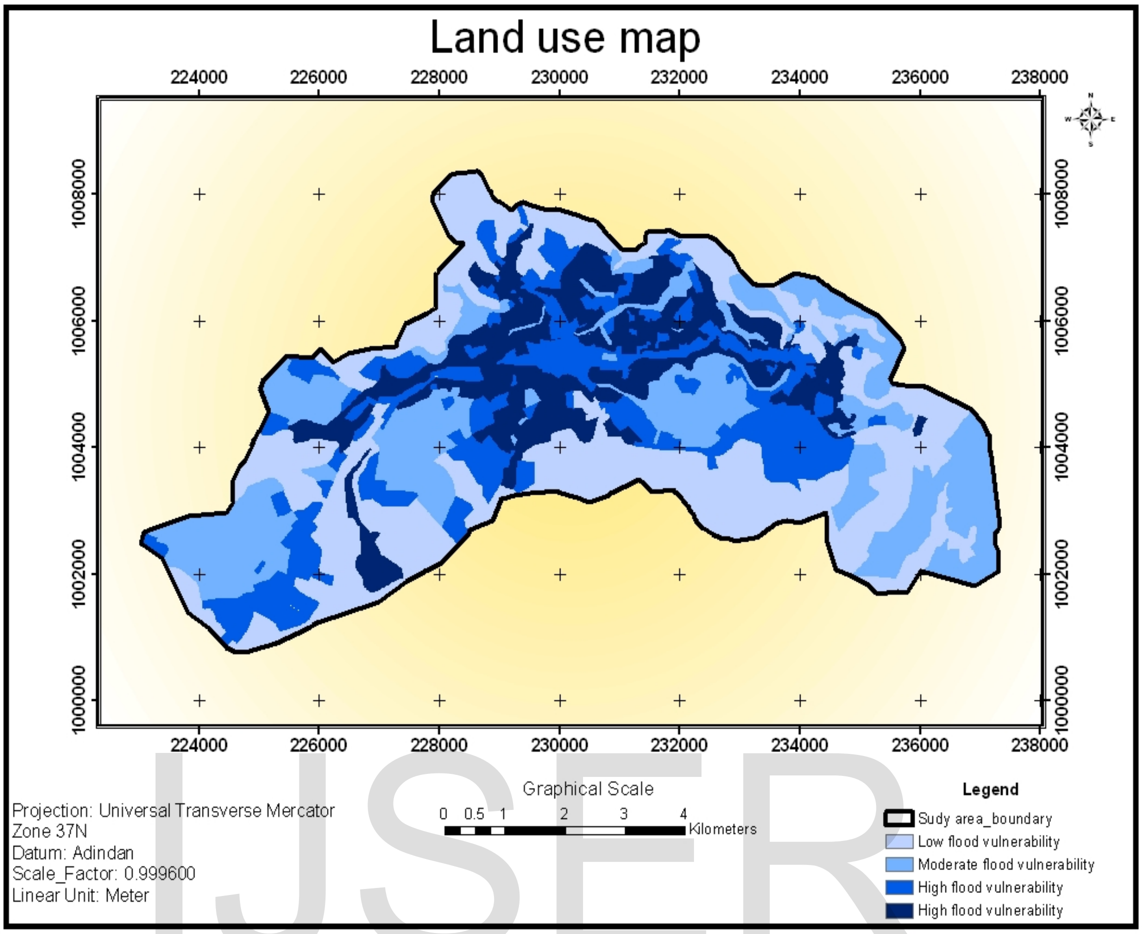

Figure 4.5. Reclassified Land userecordmap of the study area

B. Soil factor

Soil map of Nekemte was extracted from Oromia Regional State soil map using clip Analysis of Arc Toolbox. The study area has only two categories of soiltypes;wheredystricgelysols was the dominant and dystricnitosols covered the list area of the town.

The soil map was further reclassified on their capacity of soil infiltration rates fixed by [22] and reassigned as 3(moderate) and 5(very high) see table 4.6.

Gleysols (G) occur on level land, in many cases with a high water table. Their properties, such as texture, physical and chemical properties, vary widely. The Gleysols (and also Flavisols) formed in deposits of the tributaries of the Amazon for example are formed in very poor material deposited by the rivers carrying material derived from very poor eroded Oxisols, Ultisols and acid rocks. Gleysols aresaturated with water for prolonged periods, resulting in poor soil structure (especially when puddled).In other regions however,Gleysolsand Fluvisols may be among the best soils available if their drainage is well managed [33].

Nitosols are strongly weathered halloysitic or kaolinitic soils (1:1 lattice clays) formed in mostly basic parent material, the principal feature being the steady increase in clay with depth to a maximum in the middle layer and below that remaining uniform for some depth. The column extends normally down to a depth of 150 cm or more. Most Nitosols are red soils. Nitosols are among the best tropical soils. At low input levels eutricNitosols may well be cultivated for at least 1 out of 2 years, while dystricNitosols need a longer rest period. Nitosols respond well to inputs and under high levels of management they can be continuously cropped [33].

Table 4.6. Reclassified soil data

Ranking	**Soil type**	**Area (ha)**	**% of Area**	**Remark**
3	DystricGelysols	4842.4	90	Moderate vulnerability
5	DystricNitosols	538.4	10	Very high vulnerability
Total		**5380.8**	**100**	

The table 4.6 shows that the most dominant soil type in Nekemte town dystricgelysols has a high infiltration rate which indicates low amount of runoff generation and moderate vulnerability to flood hazards; since it has the capacity to cope with the amount of rain penetrating to it is moderate compared to other soil types, whereas the lesser area coverage of the soil is dystricnitosolshighly subjected to flood vulnerability.

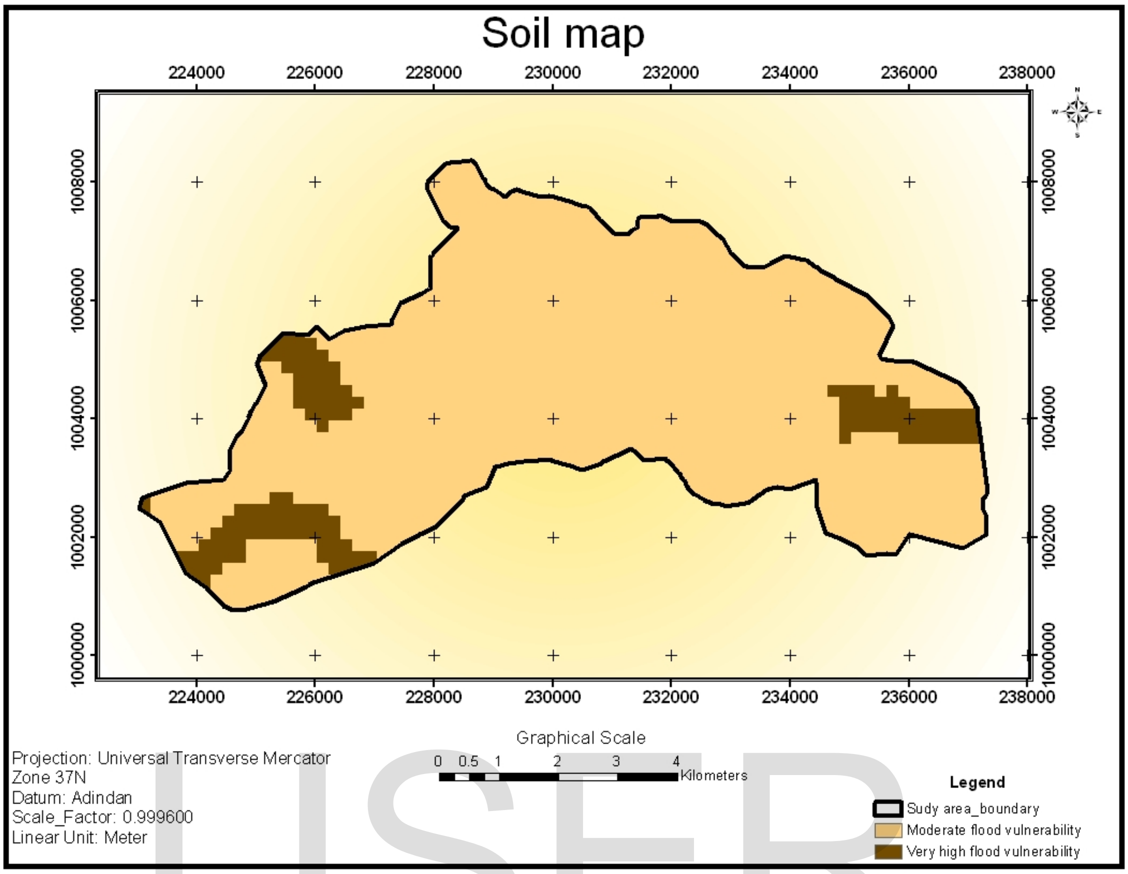

Figure 4.6. Reclassified soil data map of Nekemte town

C. Rainfall Factor

Annual rainfall data of three stations Nekemte, Arbgebeya and Mulatadiga of 21 years i.e from 1990 to 2010 collected from National Meteorological Agency(NMA). The data were recorded for the months of the year. Therefore, in order to find estimate intense rainfall, the maximum monthly rainfall data from each year from 2000 to 2011, 2000 to 2008, 2000 to 2010 for Nekemte, Arbgebeya and Mulatadiga respectively were identified and sum up, their average was computed and divided for the thirty days to obtain Average Maximum Daily (AMD) rainfall of the three stations(Annex_2). Geodatabase was created for the three stations, average maximum daily rainfall of the three stations recorded to their respective stations. Then the Average Maximum Daily rainfall data were interpolated using Spatial Analyst/Interpolate to Raster/Inverse Distance Weighted (IDW).Inverse Distance Weighted (IDW) is a method of interpolation thatestimates cell values by averaging the values of sample data points in the neighbourhood of each processing cell. The closer a point is to the centre of the cell being estimated, the more influence, or weight; it has in the averaging process. AMD rainfall were further reclassified in to five sub groups using natural breaks (Jenks) classification schemes (table 4.7 and figure 4.7).

Table 4.7. Reclassified of Average Maximum Daily Rainfall

Ranking	**Average Maximum Daily rainfall(mm)**	**Area (ha)**	**% of area**	**Remark**
1	11.97-12.97	318.6	6	Very low vulnerability
2	12.97-13.54	652.3	12	Low vulnerability
3	13.54-14.09	968.3	18	Moderate vulnerability
4	14.09-14.52	1352.6	25	High vulnerability
5	14.52-14.87	2089.0	39	Very high vulnerability
Total		**5380.8**	**100.0**	

Table 4.7 indicates that 39% of the total area subjected to very high flood vulnerability and 6%, 12%, 18% and 25% area respectively subjected to very low, low, moderate and high flood vulnerability. This is not to mean that there is this much differences between different places of the town. But since the interpolation was made between three stations of different distance from each other looks exaggerated difference.

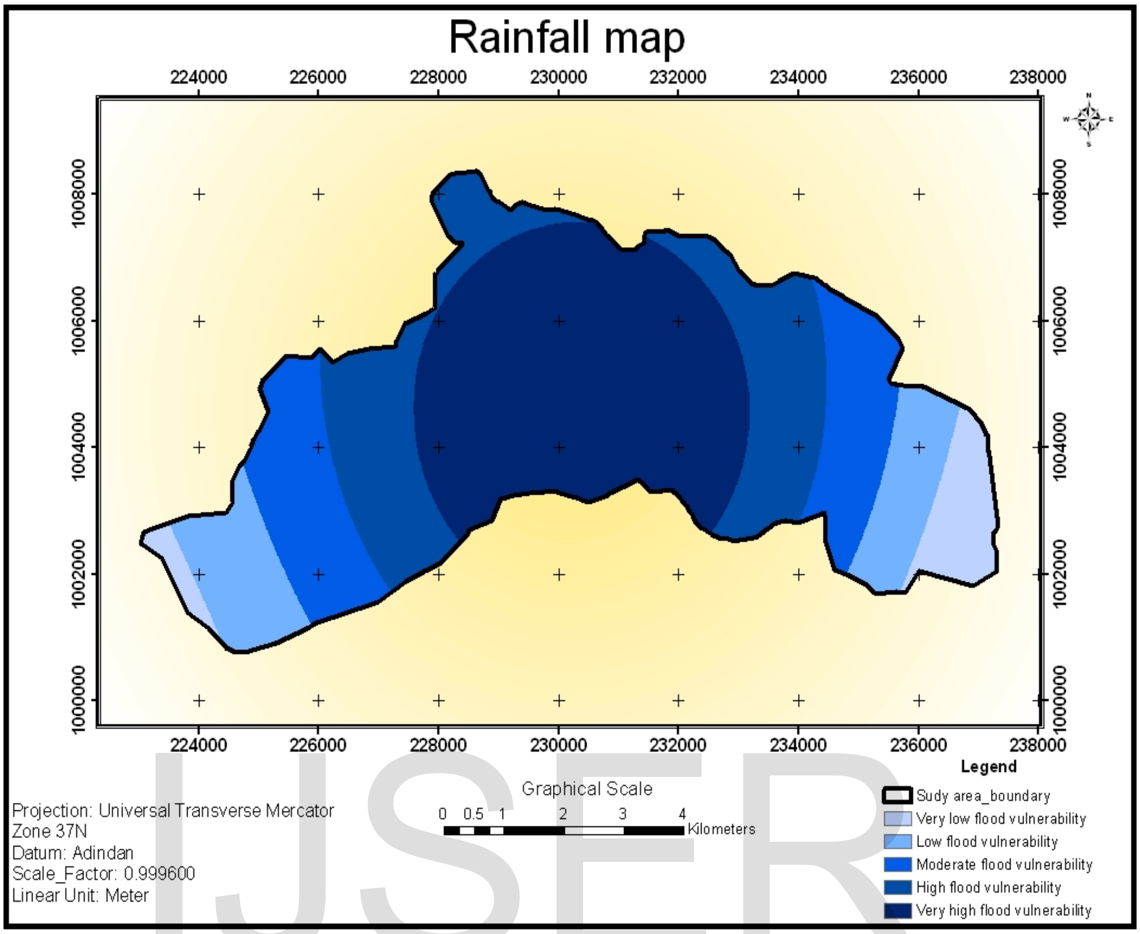

Figure 4.7. Reclassified AMD Rainfall data map of Nekemte town

Weight overlay Analysis of potential to flood

The weights of the factors under potential to flood factor of AMD rainfall, land use and soil raster layers were computed using edirisi 32 software as Data Entry/Edit Factors/Save as type Pairwise comparison (.*pcf)/close Edit dialog box/GIS Analysis/Decision Support/WEIGHT/browse previous pairwise comparison files/next/calculate weight analysis. Hence, the results of relative weights of AMD rainfall, land use and soil are 0.54, 0.30 and0.16 respectively.

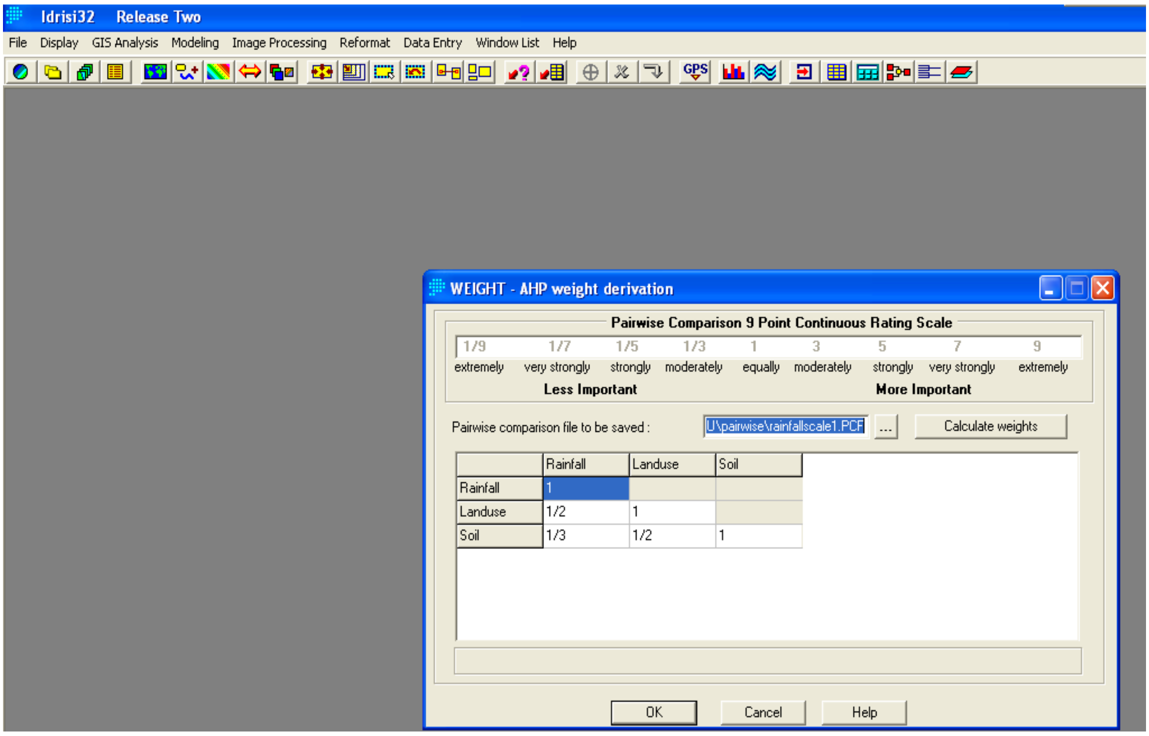

Figure 4.8. Pair wise matrix of potential to flood Factors

Three reclassified raster layer map of AMD rainfall, land use and soil overlaid accompanied with their computed weight using as the one explained in section 4.1.2.of this study. The results obtained embraced 2, 3, 4 and 5 respectively indicating low, moderate, high and very high flood vulnerability.

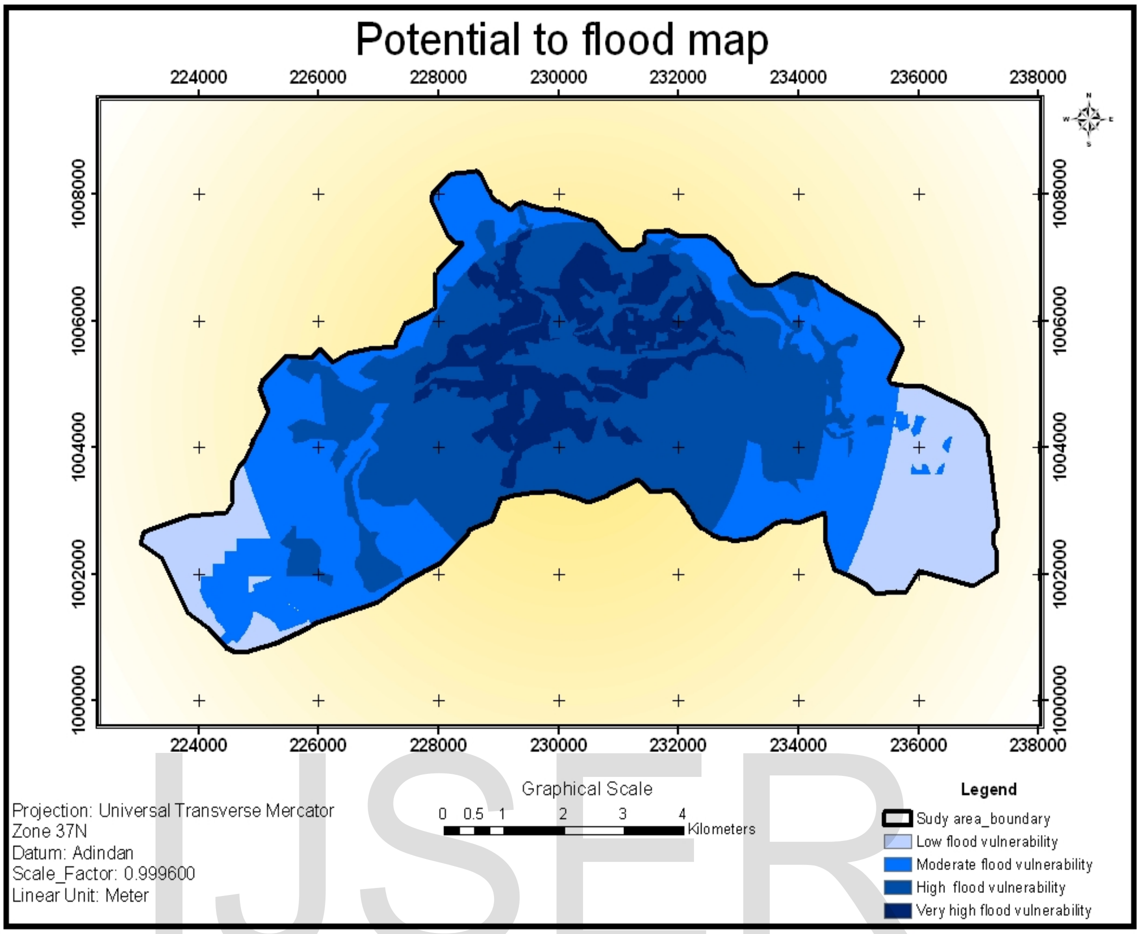

Figure 4.9. Potential to flood map of Nekemte town

4.1.2. Weighted Overlay Analysis

Weight is used to develop a set of relative weights for a group of factors in a multi-criteria evaluation. The weights are developed by providing a series of pairwise comparisons of the relative importance of factors to the suitability of pixels for the activity being evaluated. These pairwise comparisons are then analysed to produce a set of weights that sum to 1. The factors and their resulting weights can be used as input for the MCE module for weighted linear combination or ordered weighted average (or the SCALAR and OVERLAY modules). The procedure by which the weights are produced follows the logic developed by [29] under the Analytical Hierarchy Process (AHP). Accordingly, pair-wise comparison matrix was created by assigning weights according to the respective significance of contributing factors for flood vulnerability (figure 4.6). The weights are further evaluated in finding alternatives and estimating associated absolute numbers from 1 to 9 in fundamental scales of the AHP [16]. These weights were computed automatically in Idrisi32 software as it has been discussed in section 4.1.1.5. Hence, the results of relative weights of distance to rivers and streams, drainage density, potential to flood, slope and elevation are shown in (figure 4.10 and table 4.8). Furthermore, the obtained results were incorporated into ArcGIS software for spatial flood vulnerability mapping for the presumptive areas around the study area.

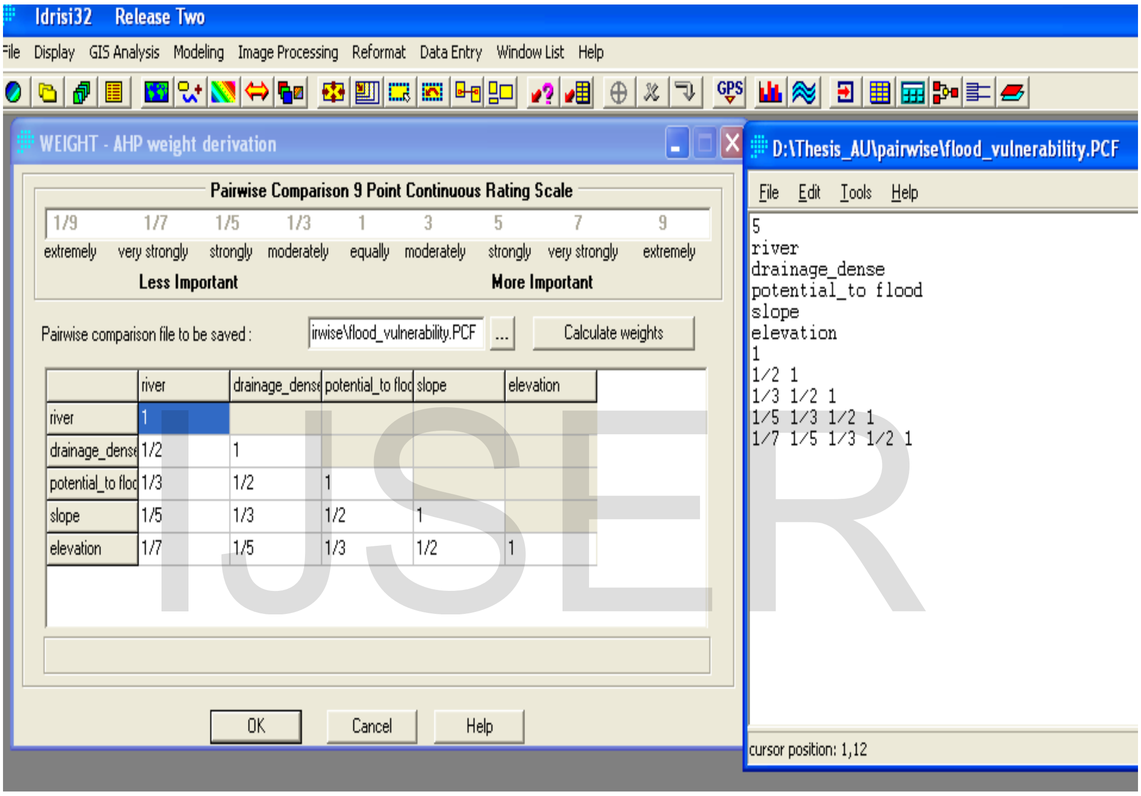

Figure 4.10. Pair wise matrix of Developed Factors

Table 4.8. Weights of Developed Factors

S/No	Selected Factors	Weights	% of weight
1	Distance to Rivers and streams	0.4446	45
2	Drainage Density	0.2619	26
3	Potential to flood	0.1524	15
4	Slope	0.0887	9
5	Elevation	0.0524	5
Total		**1**	**100**

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With acceptable Consistency Ratio (CR) of 0.01 which allow continuing to the next step for overlaying the developed factors accompanied with their respective weights computed.

The figure 4.11 indicates that flood vulnerability map of Nekemte town that was created after the five selected factors map of reclassified raster layers added to Arc Map, combined by a logical operation using Arc Toolbox/Spatial Analyst Tools/Weighted Overlay/Add the five raster layers to weighted overlay table accompanied with weights of each criterion (table 4.6). The result obtained encompasses only low, moderate, high and very high flood vulnerability. It is to mean that the Nekemte town has no very low flood vulnerability area according to the major five selected factors.

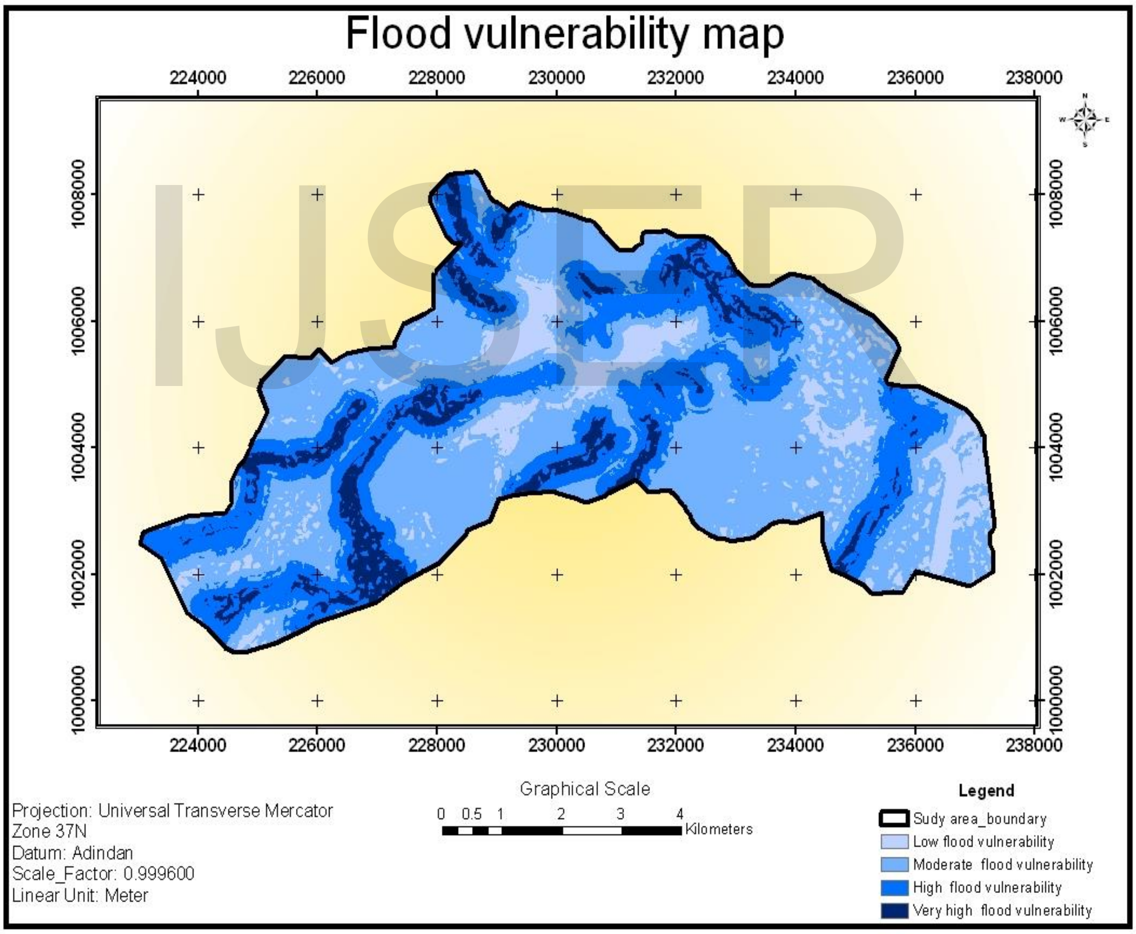

Figure 4.11. Flood vulnerability map of Nekemte town

Table 4.9. Flood Vulnerability of Nekemte town

Ranking	Area (ha)	% of Area	Remark
1	0	0	Very low flood vulnerability
2	626.9	12	Low vulnerability
3	2733.4	51	Moderate flood vulnerability
4	1567.3	29	High flood vulnerability
5	453.2	8	Very high flood vulnerability
Total	**5380.8**	**100**	

Table 4.9 shows that the largest area(51%)of the town were subjected to moderate flood vulnerability. 12%, 29% and 8% area of the town subjected to low, high and very high flood vulnerability respectively, whereas no area of the town subjected to very low flood vulnerability.From very high flood vulnerability to hazard (453.2 ha) 112.5ha are covered by marshy area and Sorgalake.

4.1.3. Area Tabulation Analysis

4.1.3.1. Flood Vulnerability versus kebele

The Nekemte town were categorized in eight kebele Administrations. The kebele boundary in digital map was imported to ArcGIS environment, Geo-referenced; digitized in polygon shape file and its topology were corrected in a geodatabase. Polygon shape file of the kebele boundary were rasterized using Arc Toolbox/Conversion Tools/To Raster/Polygon to Raster in a way that it can be compactable for ArcGIS. Area tabulation of vulnerability map with raster map of kebeles was undertaken using Arc Toolbox/Spatial Analyst Tools/Zonal/Tabulate Area.

Table 4.10. Flood vulnerability versus Kebele

		Flood vulnerability area in hectare and percent								Total	
		Low(2)		Moderate(3)		High(4)		very high(5)			
S/No	**kebele_Name**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**
1	BakeJama	33.5	0.6	325.1	6.1	128.8	2.4	51.3	0.9	538.7	10.0
2	BekenisaKase	10.5	0.2	204.6	3.8	70.5	1.3	7.9	0.1	293.5	5.5
3	Burka Jato	38.2	0.7	412.5	7.7	172.4	3.2	15.6	0.3	638.8	11.9
4	Cheleleki	90.6	1.7	235.0	4.4	231.7	4.3	60.2	1.1	617.5	11.5
5	Derge	66.7	1.3	346.1	6.5	162.9	3.0	55.9	1.0	631.7	11.7
6	Keso	79.2	1.5	98.5	1.8	156.0	2.9	64.9	1.1	398.7	7.4
7	Sorga	58.9	1.1	493.1	9.2	456.2	8.4	177.1	3.1	1185.3	21.9
8	University area	249.1	4.8	618.6	11.5	188.7	3.5	20.3	0.4	1076.7	20.2
Total		**626.9**	**12.0**	**2733.4**	**51.0**	**1567.3**	**29.0**	**453.2**	**8.0**	**5380.8**	**100.0**

Table 4.10 shows thatSorga, Cheleki andKeso respectively 3.1%, 1.1% and 1.1% area coverage were subjected to very high flood vulnerability; where Derge and Bake Jama following by 1.0% and 0.9% with very high flood vulnerability. The study confirmed that all the kebeles existed in high flood vulnerability with expected high value were also visited by flood since 2000 from low to high damaging rate. And also Sorga and Cheleleki area respectively subjected to high flood vulnerability with 8.4% and 4.3% respectively.

4.1.3.2.Flood Vulnerability versus land use

The land use type of Nekemte town was converted to ArcGIS environment has it has been described in section 4.1.3.1 of this research report. The land use classes (table 4.9) polygon features were converted to raster. Area tabulation of vulnerability map with raster map of land use was undertaken using Arc Toolbox/Spatial Analyst Tools/Zonal/Tabulate Area.

Table 4.11. Flood vulnerability versus Land use classes

	Flood vulnerability area in hectare and percentage								Total	
	Low(2)		Moderate(3)		High(4)		Very high(5)			
Land use classes	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**	**(ha)**	**(%)**
Forest area	111.4	2.1	973.9	18.2	583.6	10.8	243.3	4.3	1912.1	35.4
Agricultural, Expansion and Green area	7.9	0.2	20.8	0.4	93.0	1.7	20.6	0.4	142.4	2.6
Social service	245.4	4.7	575.6	10.7	269.9	5.0	90.5	1.6	1181.4	22.0
Administration office, Transportation and Manufacturing and storage	74.7	1.4	782.2	14.6	318.0	5.9	48.9	0.9	1223.7	22.8
Residential area	187.5	3.6	380.9	7.1	302.9	5.6	49.9	0.9	921.2	17.2
Total	**626.9**	**12.0**	**2733.4**	**51.0**	**1567.3**	**29.0**	**453.2**	**8.0**	**5380.8**	**100.0**

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Table 4.11 reveals that the largest area 1.6% and 4.3% covered the Social service and forest area respectively subjected to very high flood vulnerability whereas Administration office, transportation, manufacturing and storage and residential area are following by 0.9%. The largest area 10.8% and 5.6% of the forest and residential area were respectively subjected to high flood vulnerability. 5.0%social services, 5.9%Administration Office, Transportation and manufacturing and storage and 1.7% agricultural, expansion and Green areaof the total area of Nekemte town were respectively laid in high flood vulnerability. Densely populated area exists in the residential and commercial area for what people and the responsible authorized should care for any developments undertaken along the flood vulnerability area.

4.2. Discussion

The Nekemte town was subjected to flood vulnerability of low, moderate, high and very high respectively covering the area of 12%, 51%, 29% and 8% from total area of 5,380.8ha. The residential and commercial area, where dense populated are expected to live-in covered an area of 0.9% (49.9ha) and 5.6% (302.9 ha) were subjected to very high flood vulnerability respectively. A discussion with residents nearby rivers and streams and field observation confirm that unless the regular flood control structures built at stream over flow; the soil degradation, homeless in rainy season, property and infrastructural damage will increase in the town. Determining the flood susceptible areas is very important to decision makers for planning and management of activities. Decision making is actually a choice or selection of alternative course of action in many fields, both the social and natural sciences [34].

The largest area covered by very high flood vulnerability were Sorga, Cheleleki andKeso respectively 3.1%, 1.1% and 1.1% from the total very high flood vulnerability of Nekemte town of 8%.; whereas Derge and Bake Jama following by 1.0% and 0.9% . And also Sorga and Cheleleki area respectively subjected to high flood vulnerability with 8.4% and 4.3% respectively. The findings of this study show that areas near the rivers and streams and areas in between hilly area are the most vulnerable to flooding.

The discussion made with flood experts of the Nekemte town Municipality and residents near rivers and field survey also indicatethat development activities in the river channel and the adjacent floodplain have been pursued without taking into account the associated risks. Risk of flooding can be reduced by decreasing hazards, reducing or eliminating the vulnerability of the elements at risk, or a combination of both actions [35].Adoption of non-structural risk reduction measures for instance, development of land use planning can effectively reduce the effect of flooding on lives and property. Application of land use planning can reduce flood hazards by allocating less vulnerable land uses to the most hazardous areas or by avoiding development in those locations. Relocation of the residents of high risk areas would reduce their vulnerability.

In Nekemte town there is an opportunity for relocation of residents to reduce vulnerability. Accordingly, the potential land use type which is the least in terms of flood vulnerability to hazard (63% that include low and moderate vulnerability)and all other areas that were not attacked by flood and Agricultural, expansion and green area can be used as a good opportunity to relocate residents living in high flood vulnerability.

The study carried out in North Korea on Flood vulnerability mapping for North koreashow that the study emphasized on detail methodology of flood hazard, risk and its return period by splitting the factors as a high level and low levels and their weights were computed by input values based on their order of significance for causing flood vulnerability. Weight was applied for each factor and once complete, a natural hazard vulnerability map was generated. The final natural hazard vulnerability map showed five levels of vulnerability: very low, low, medium, high, and very high [23].

Another study carried out in Vietnam country for mapping flood vulnerability area using GIS and Remote Sensing shows that the criteria they employed for the study was land use derived from Land sat5 and Land sat 7 and information on the topography; Shuttle Radar Topography Mission (SRTM) 90m grid size. And DEM of 15m was developed from ASTER data and they identified land use changes between 1991 and 2003 to assess the influence of the floods in land use of the city area. Here, a flash flood risk map is constructed using topographic data from the SRTM mission. Using existing GIS data on soil properties in combination with slope and aspect provided information on the possible vulnerability for flash floods [24].In the two case studies the methodology were more or less similar where in the second case the rainfall data was not yet included.

In case of Nekemte town, the criteria factors like soil and land use classes reclassification were made based on infiltration rate and runoff generation rate , people expected to live therein respectively based the widely used technique [22]. The rain fall data, streams and rivers, slope, elevation and drainage density were the major factors played a crucial role to delineate flood vulnerability area.

The reclassified rainfall, soil type and land use reclassified raster layers were overlaid independently not to bring impacts on the existence and areal extents of other developed factors for flood vulnerability. The first two case studies results were obtained in the range number of very low, low, moderate, high and very high vulnerability. However, this study result obtained low, moderate, high and very high flood vulnerability. This is because of the reason that the study targeted on the past flood areai.e near streams and rivers(45%). The method become the best if in the feature it is possible to get intense rainfall of the area, capacity of river and drainage channels whenever new sites are developed.

The model studies discussed in this section reveals that different technological scheme and some different data resulted to the same range of values. It should be known that the topography, nature of the landscape, rivers and streams crossing the areas, characteristics of the soil, past damaging system of flood including land use and landscape of experienced area made disparity among the study'smethodology and results from country to country and state to states.

5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The process of vulnerability identification represents a very important contribution to decrease and protect the property, land use, infrastructure, and human life damage caused by flooding hazard. The purpose of the flood vulnerability study is to limit number of people settled in flood prone area and integrate flood risk into urban development.

In this study pairwise comparison method, an integration of GIS and MCE technique were found very essential tools for flood vulnerability assessment.GIS was used for geodatabase creation, geo-referencing, digitization, topology creation, rasterization, TIN creation, contour generation, clip analysis, extract by mask analysis, buffer analysis and slope calculation from DEM, reclassification, store raster and vector layer maps of all factors (criteria), multi-map layers overlay using Multi Criteria Evaluation system.

A composite map showing the flood vulnerable areas were created using multi criteria evaluation methods with GIS. In this application, the range numbers are designated as very high, high, moderate, low, very low on the output map depicting the level of flood vulnerability of the study area. However, the results obtained on the flood vulnerability map consistslow, moderate, high and very high flood vulnerability.

453.2ha(8%) area of total town coverage was subjected to very high flood vulnerability to flood hazard and 1567.3 ha(29%) area of the town subjected to high vulnerability.Sorga, Cheleki andKesokebeles respectively 3.1%, 1.1% and 1.1% area coverage were subjected to very high flood vulnerability; where Derge and Bake Jama following by 1.0% and 0.9%. The study confirmed that all the Kebeles existed in high flood vulnerability with high value were also visited by flood since 2000 from low to high damaging rate.The Largest area 1.6% and 4.3% covered the service and forest area respectively subjected to very high flood vulnerability. And also residential area where dense populated are expected to live-in covered an area of 0.9% (49.9ha) and 5.6% (302.9 ha) were subjected to very high and high flood vulnerability respectively.

The prominent factors that have highest weight and lowest weight affected the flood vulnerability were rivers and streams (45%) and elevation factor (5%) respectively. Rivers and streams affected the vulnerability due to the fact that people settled around the streams were facing flood risk than the places far from streams based on the past flood attack of the area. The past flood also occurred not only restricted to near rivers and streams but also on the low elevation found between the hilly foots. Therefore, elevation factor was considered with the lowest (5%) contribution when compared with the others four developed factors for flood vulnerability.

5.2. Recommendation

This study provided information on flood vulnerability at town level that could be used by the decision makers to act upon the current land use planning policy in reducing vulnerability to flood risk area in Nekemtetown. Accordingly, the following crucial recommendations need to be reviewed to reduce flood vulnerability to flood hazard in Nekemtetown

- The Nekemtetown Administration has to use GIS and MCE for future flooding hazard related complex problems. Because it can store vector and raster layer maps accompanied with their spatial and non-spatial data for solving any problems. Therefore, the responsible bodies have to update the geodatabase for the required disastrous reduction based on the type and rate of damage it has been aroused in previous time.
- Areas prone to flooding should be protected from any construction so as to avoid any calamities caused by storm water floods. These areas can be used for urban agriculture or urban green depending on the topography and soil nature of the locations. It is to mean that the depth, duration, velocity,characteristics of the slopes and soil infiltration rate should be taken in to account whilst changing the land use types.

- The run off generated from hilly tops should be treated in proper drainage channels to avert over flooding of residential neighborhoods and other urban areas.
- The Nekemtetown Municipality should arrange the means by which all people in the town could participate in minimizing the risks of flood through extensive planting trees on hill-sides and steep river banks and gorges.
- The existing and new road networks should be equipped with the necessary drainage networks according to the amount of run off coming to the roads from the surrounding catchment area.
- The Nekemte Administration should identify proper waste collection points and thereby put in place the necessary facilities, such as waste bins, transfer stations and the like in order to prevent drainage and culvert from closing due to dry waste materials from the house.
- Town Administration must aware Kebele Administrations to hold some responsibility for an open watercourse running through or adjacent to their property, regular routine maintenance should include clearing any build-up of silt and debris especially after leaf fall, removing any obstructions and litter (even if it did not originate from their property), cutting back overhanging vegetation, clearing any culverts and trash screens and ensuring the free flow of water through the system.
- Landowners should have the primary responsibility for safeguarding their land and other property against natural hazards such as flooding according to the construction and crops used in the vicinity of flood zone.

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ANNEX

Annex 1. Field data collected using hand held GPS (Germin 60)

Streamline GPS data

Point No	**Easting(m)**	**Northing(m)**	**Point No**	**Easting(m)**	**Northing(m)**
1	229716.488	1005185.009	13	228211.18	1004563.25
2	229514.689	1005130.469	14	228145.73	1004492.348
3	229394.401	1005086.837	15	228091.19	1004530.526
4	229296.528	1005032.296	16	228145.73	1004552.342
5	229029.281	1005026.842	17	228222.09	1004612.337
6	228990.195	1004999.572	18	228391.16	1004819.589
7	228843.844	1004988.664	19	228494.79	1004830.498
8	228734.764	1004917.762	20	227326.93	1004554.503
9	228680.224	1004901.4	21	227160.93	1004302.19
10	228691.132	1004857.768	22	227014.86	1004142.834
11	228467.517	1004748.687	23	226862.14	1003996.758
12	228407.523	1004666.877			

Source: Field survey data, August 2012.

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Annex 2. Rain fall data of National Meteorological Agency Nekemte, Arbgebaya, MulataDiga area.

Nekemte Annual Rainfall data

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Maximum
2000	0.3	0.0	2.9	107.2	224.9	509.3	332.2	540.9	240.8	138.8	19.2	19.7	540.9
2001	0.0	26.4	50.8	83.6	240.8	349.6	336.2	352.4	267.4	168.8	16.0	50.2	352.4
2002	24.9	21.1	74.3	106.2	77.4	376.8	427.3	260.3	186.9	117.6	0.2	33.0	427.3
2003	0.3	47.5	54.9	21.3	55.1	422.9	429.7	439.0	312.9	18.9	25.5	9.5	439.0
2004	7.2	6.9	12.7	76.6	206.3	286.6	409.9	433.0	248.9	71.9	20.2	11.9	433.0
2005	9.5	0.0	131.5	60.3	241.0	387.4	346.2	438.8	355.6	219.9	58.5	0.0	438.8
2006	0.5	4.8	27.7	71.3	209.4	350.6	476.0	339.1	278.3	213.8	50.4	88.6	476.0
2007	4.7	54.4	47.8	141.7	217.5	462.6	355.6	447.4	297.8	86.7	56.8	88.6	462.6
2008	13.1	0.0	0.1	227.4	368.3	416.7	412.1	384.9	301.7	235.5	82.0	0.0	416.7
2009	0	22.7	35.5	173.0	97.9	314.5	251.5	395.7	412.1	DNA	DNA	DNA	412.1
2010	7.6	25.5	3.5	28.1	534.3	518.3	432.2	318.7	368.8	134.4	81.3	16	534.3
2011	42	2	51.7	97.6	265.4	403.4	254.2	418.3	364.8	82.1	57.4	1.7	418.3
Sum	**110.1**	**211.3**	**493.4**	**1194.3**	**2738.3**	**4798.7**	**4463.1**	**4768.5**	**3636.0**	**1488.4**	**467.5**	**319.2**	**5351.4**
Av.	**9.18**	**17.61**	**41.12**	**99.53**	**228.19**	**399.89**	**371.93**	**397.38**	**303**	**124.03**	**38.96**	**26.6**	**14.865**

Source: National Meteorological Agency 2012.

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Arbgebeya Annual Rainfall data

Year	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Maximum
2000	0	0	0.5	121.0	121.8	320.0	243.5	239.9	153.5	103.3	20.0	5.4	320
2001	0.0	23.1	49.5	72.8	189.7	217.7	203.1	223.0	122.6	55.8	4.0	9.4	223
2002	20.2	4.8	42.5	92.1	108.5	200.4	204.1	145.2	103.5	47.3	0.0	38.4	204.1
2003	0.2	72.0	72.0	78.7	25.1	276.7	294.4	335.6	195.5	5.3	13.2	44.6	335.6
2004	4.5	15.8	29.9	44.4	138.2	309.1	239.6	245.6	160.7	82.5	28.4	2.0	309.1
2005	17.7	0.1	75.3	45.6	135.1	266.3	268.3	229.6	195.2	69.4	49.1	0.0	268.3
2006	9.5	2.5	66.4	DNA	138.1	212.8	298.6	216.5	138.1	72.6	8.0	83.4	298.6
2007	21.6	10.1	DNA	109.2	94.2	128.4	151.9	137.3	137.1	9.6	DNA	0	151.9
2008	11.1	0.0	2.2	125.5	309.3	128.3	291.9	166.0	238.9	98.7	116.4	105.9	309.3
sum	**84.8**	**128.4**	**338.3**	**689.3**	**1260.0**	**2059.7**	**2195.4**	**1938.7**	**1445.1**	**544.5**	**239.1**	**289.1**	**2419.9**
Av.	**9.42**	**14.27**	**37.59**	**76.59**	**140**	**228.86**	**243.93**	**215.41**	**160.57**	**60.5**	**26.57**	**32.12**	**8.96**

Source: National Meteorological Agency 2012.

Mulatadiga Annual Rainfall data

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Maximum
2000	0.0	0.0	0.3	98.0	0.0	363.7	231.0	340.5	223.3	151.6	54.3	50.8	363.7
2001	0.0	32.8	55.8	62.6	310.0	268.1	155.5	246.8	246.1	124.6	10.8	45.1	310.0
2002	24.5	3.2	71.0	73.7	79.0	260.1	262.8	320.1	166.0	96.7	3.2	30.5	320.1
2003	0.0	59.3	51.4	8.7	44.3	345.8	365.2	439.2	318.8	0.7	42.1	13.3	439.2
2004	7.9	12.9	47.4	52.4	214.9	422.6	363.4	370.3	290.2	55.2	33.4	1.7	422.6
2005	15.9	0.0	127.5	100.6	219.2	348.0	376.0	352.5	416.1	159.6	77.6	0.0	416.1
2006	6.4	21.1	56.8	58.0	161.7	282.1	340.4	230.8	216.6	148.4	14.1	61.0	340.4
2007	9.0	41.2	67.4	101.6	201.9	350.3	268.1	260.7	282.2	108.2	DNA	DNA	350.3
2008	15.6	5.0	3.6	241.7	232.8	293.7	385.3	262.9	222.6	106.5	67.6	2.6	385.3
2009	0.0	26.8	73.5	171.2	59.4	0.0	277.5	DNA	DNA	DNA	DNA	DNA	277.5
2010	12.0	16.7	5.0	26.5	351.0	347.5	340.2	252.9	292.7	73.9	46.4	0.0	351.0
sum	**91.3**	**219.0**	**559.7**	**995.0**	**1874.2**	**3281.9**	**3365.4**	**3076.7**	**2674.6**	**1025.4**	**349.5**	**205.0**	**3976.2**
Av.	**8.3**	**19.91**	**50.88**	**90.45**	**170.38**	**298.35**	**305.95**	**279.7**	**243.15**	**93.22**	**31.77**	**18.64**	**12.05**

Source: National Meteorological Agency 2012.