Jimma University

Jimma Institute of technology

Faculty of Civil and Environmental Engineering

Environmental Engineering Chair

Assessing Watershed Vulnerability Using Weighted Overlay and Analytical Hierarchy Techniques: The Case Study of Gojeb River Watershed–Kaffa, Ethiopia

By

Melkamu Shegeto Shatachi

A Thesis Submitted to Faculty of Graduate Studies of Jimma University for Partial Fulfillment of MSc in Environmental Engineering.

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Main Advisor:Dr.Ing.Fekadu Fufa(PhD).
Co-Advisor:Seifu Kebede(MSc).

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Jimma, Ethiopia

DECLARATION

This Thesis is my original work and has not been worked and presented for a degree in any other university

Name Signature

This Thesis has been submitted for examination with my approval as a University Supervisor.

Main Advisor:-Dr.Ing Feqadu Fufa(PhD)._____ _____

Co-Advisor:-Seifu Kebede(MSc) _____ _____

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Acronomies	Meaning
GIS	Geographic Information System
AHP	Analytical Hierarchy Process
WQI	Water Quality Index
DEM	Digital Elevation Model
Km	Killo Meters
Mm	Millimeters
GC	Gregorian calender
FDRE	Federal Democratic Republic of Ethiopia
GPS	Geographic Position System
LULC	Land Use Land Cover
EC	Ethiopian Calendar
GRWS	Gojeb River Watershed
GOB	Gibe-Omo Basin
SNNPRS	Southern Nations Nationalities & People
GRC	Gojeb River Catchment
ESIA	Environmental &Social ImpactAssessment

ABSTRACT

Understanding the susceptibility of Watershed is very crucial issue in identification of the health status of water bodies. The watershed characteristics such as size, shape, slope, drainage density, land use, geology, soil type etc. are some common factors affecting the health of watershed. As this watershed characteristic can influence the vulnerability to pollution, it's better to assess them. Assessing Watershed vulnerability and identification of risk is very important input for understanding the status of watershed health condition. Gojeb Watershed was investigated to indentify the extent of vulnerability so that parts and zones of vulnerability extent to be well defined. Therefore, the aim of this study was to assess the vulnerability of Gojeb River watershed using weighted overlay and Analytical Hierarchy techniques. The method used to study Gojeb Watershed was done by using the combination of Software. GIS spatial analysis tool was used to produce the maps that show the vulnerable parts of the Watershed. Using these maps AHP analyzed which parts of Gojeb Watershed were affected with respect to the extent of susceptibility in percentage of area coverage. The analysis was done using five main factors that influence water quality. Land use land cover, soil type, annual average rainfall, slope gradient, and bedrock type were the main factors considered based on their contribution to water pollution. The main findings obtained were identifying the vulnerable parts of the watershed and showing it by thematic maps. Accordingly, 0.24 % were very high vulnerable, 5.7 % were high vulnerable, 38.6 % were moderately vulnerable, 55 % were low vulnerable and 0.47 % were very low vulnerable to contamination. This study clearly defined and relates how land use, slope, precipitation, geology and soil factors affect the watershed of Gojeb River. Therefore, It is concluded that Gojeb River Watershed to be exposed to vulnerability to contamination in some parts and hence, need reclamation work. The recommended measures for reclamation were to take the action of reforestation and terrace building.

Keywords: AHP, Gojeb River Watershed, Land Use Land Cover, Susceptibility, ArcGIS,

CHAPTER ONE

1.1 Background

Natural resource utilization especially water resource usage is becoming series and burning issue for human being. As the natural resource is crucial in life, it is necessarily to take care and protect to sustain for the coming generation. The water bodies' contamination due to non-point sources to pollutions is degrading water quality from time to time. Some studies explain that many water bodies like rivers, streams and lakes are becoming impaired due to the non-point sources to pollution(Jabbar et al., 2019). The main important natural resource in life is water. Water is a non-renewable resource and need protection both in quantity and quality. As water in the watershed is contaminative and renewable it is to be with much attention to maintain its natural existence in the watershed. Water yield and water quality degradation in the watershed is always basic thing for all human activities and hence determine the availability of adequate and pure water(Zengin *et al.*, 2017).

Watershed is defined as it is clearly delineated geographical area with relatively high altitude where water flows in a network sewage flow form toward downstream area. Water always flows from high elevation to low elevation in the manner of network(Lai *et al.*, 2016).

The drainage arrangement and flow pattern of a given watershed characteristics are determined by many morphological factors from where they flow. Accordingly, physical parameters like vegetation cover, geological type and the like physical factors are determinant in affecting drainage and flow conditions of water with in a watershed(Kumar and Sharma, 2013).The most important thing to affect a given watershed is its topographic characteristics. These characteristics are watershed size, watershed shape, form factor, shape factor, circularity ratio, elongation ratio, average slope, aspect, average elevation and maximum watershed relief. The topographic characteristics of a watershed can directly influence the flow rate, erosion, soil and land use land cover(Yilmaz, Göl and Ediş, 2011).Watershed is not only about water but also all about socio-political-ecological unit that has a great influence on food security, economic unit and hence, can play a great role to afford to any people in any country(Husic *et al.*, 2019).

Changes in precipitation pattern due to changes in climatic conditions can highly alter water qualities of a given watershed. Variation of precipitation in timing and amount can drive watershed's quality by the transportation and mobilization of pollutants from any surface water to aquifer(Shami *et al.*, 2020). The amount and quality of water with in a particular watershed can be affected by the change occur in land use land cover (LULC) pattern. Misused land use land cover can change the watershed's characteristics by affecting vapor transpiration, soil moisture content, infiltration rate, water flow, surface runoff, and soil erosion(Alemayehu, Asfaw and Tirfie et al 2020). Watershed management intervention can facilitate the infiltration rate and minimize the occurrence of runoff and, hence, the generation of vegetation, soil fertility, ground water table can highly be improved(Tesfaye and Debebe, 2018).

One of the main conditions which can determine the condition of watershed is land use land cover that can highly influence water quality. It is clear and quantifiable that water quality and land use to be correlated. Among many land use types, agricultural land use is positively correlated with nutrients, sediments, pesticides and herbicides that may inter into streams and rivers. Excess nutrients and manure with in agricultural fertilizers may contribute negatively to water quality degradation. Pesticides and herbicides cause runoff. The sediments and soil erosion cause water turbidity. When we come to urban land use it also affect water quality degradation. Soiled wastes, washed from hard surfaces, inputs of nutrients from falling septic, sewerages and etc can influence water quality to be deteriorated in the case of urban land use. Therefore, urban land use influence water quality by adding phosphorus into streams and nitrates(Thenepalli, Ramakrishna and Ahn, 2017).The other important factor that can affect the quality and availability of water in a given watershed is precipitation and temperature. Precipitation is one of the important variables to determine the water yield of the basin. The variation of the temperature and precipitation pattern can bring a change in water cycle processes and hence can affect water availability. Change in temperature and precipitation can have direct influence on ground water discharge and evaporation. More intense precipitation and longer draught periods could be the cause to ground water table decrease(Eromo *et al.*, 2016).One of the main factors to affect watershed vulnerability in this study is the slope gradient. The slope gradient can influence the water balance through precipitation events. It affects the surface flow of runoff and intrusion of organic and inorganic materials, nutrients,

and sediments that flow into water bodies like rivers and streams. When the slope is steeply, the flow rate during raining is high and hence sediments and suspended materials could be transported into water bodies. The slope gradient of Gojeb watershed is calculated using ArcGis(Arriagada *et al.*, 2019).

The other powerful agent to watershed's water quality degradation is the interaction in between the surface water and ground water. Whenever surface water interacts with underground water, there will be mineral interaction. Minerals from sedimentary, igneous or metamorphic can chemically react with the minerals in water and hence water quality can easily be degraded. Therefore, water-rock interaction can determine water quality. The depth of underground water is also one of the main factors for water quality degradation of watershed(Skaggs and Chescheir, 2013).The water quality of surface waters like rivers, streams and lakes are directly related with or dependent on three key processes. These key processes are:-The application or presence of constituent sources within the watershed, the transportation or mobilization of constituents from their sources, and their delivery to receiving streams and rivers(Shami *et al.*, 2020).

The urban land use with steeper slope is forcing factor to high sediment and nutrient transport than other land use following agricultural land use type. When slope gradient increases, the flow rate of sediment and the transportation rate of nutrient rises until reaches to 30% and then decrease. In forest and grass land use type sediment and nutrient also increase until 15% slope then after declined. In the case of Urban land use type as slope increase ,the flow rate of sediment also increase(Nasidi *et al.*, 2019).The vegetation cover of a watershed plays an intercepting role with canopy cover, thus protecting soil from erosion. The forest covered watershed has less exposure to surface erosion while timber harvesting changes canopy cover and exposes mineral soil to water and wind resulting in a lower amount of evapo-transpiration (Mousazadeh *et al.*, 2021).The effects of hydrological character change due to land cover change can influence different types of water cycle components. The runoff formed or amount of water entered to soil profile are determined by factors such as soil type, vegetation cover and root(Siva Subramanian *et al.*, 2021).

Gojeb River is an Eastward flowing tributary of the Omo River which is one of the 12 basins of Ethiopia. Gojeb watershed is part of Omo-Gibe watershed and located in south west Ethiopian region. Gojeb watershed climatic condition varies along with the North to the Southern parts of the watershed. Accordingly, the northern part is with high elevation and dense forest and hence high amount of annual rainfall. When we come to the south part, it is lowland, with relatively high temperature(Alemu, Kebede and Moges, 2019). For last 30 years there was a great change in land use land cover in Southwest part of Ethiopia. Gojeb watershed has lost huge forest cover. Totally dense forest has been changed to agricultural land use or to any other land use type. About 105,000 ha dense forest was removed and changed to agricultural land use and of 41,000 ha of dry forest was changed to cultivation and hence high soil erosion occurred since 1986(Eromo *et al.*, 2016).Low agricultural productivity due to soil erosion caused by ridged topography, mismanagement of land resource , change of vegetation cover are major problems in many parts of Ethiopian highlands. One of the victims of such a series problem is Gojeb watershed. In 1977s many settlers come from the northern parts of our country. This new settlers deforest the dense forest seeking for agricultural land. Since then high part of the region was exposed to the change of land use and soil erosion happen(Alemu, Kebede and Moges, 2019).Any river basin's water quality can be affected by the bedrock type of the basin. The watershed beneath is formed by different types of rock materials such as igneous, sedimentary and metamorphic. In addition to these rock types there also be glacial deposits which can typically affect water quality of the river, streams and lakes. Due to chemical processes within the geochemical interaction some minerals may infiltrate from mother rocks to water. The water properties of aquifer can be changed because of the dissolution of chemicals like carbonates and evaporate minerals through fractured limestone or dolomite(Jabbar, Grote and Tucker, 2019).The relationship between the feature of watershed shape and erosion process can determine the flood potential of the basin. In a given basin the probability of risky flood occurrence increases with the decrease of bifurcation ratio of the basin. This indicates that the probability of the flood occurrence to happen in some parts of the basin but not within the entire parts of the basin(Ahmad *et al.*, 2015).

Changes in water bodies of a watershed because of precipitation can have a significant effect on water temperature. Direct transfer of thermal energy in runoff is the direct influence of precipitation. In relation to air temperature the changes in hydrology which influences the thermal capacity and energy balance of the entire watershed that contribute to stream flow and groundwater discharge. This temperature-based influence can affect water bodies in different extent during dry and wet season. Longer residence time and low stream flow volumes are because of reduced thermal capacity. This event can contribute to diurnal increase in water temperature. Many watershed researchers have been doing their research of investigating water by concerning on the physiochemical properties of surface water and mathematical model. By doing this research time and financial feasibility were cumbersome. Research based on the above method was site specific and hence, need laboratory apparatus. The gap to be filled in this study was how to investigate watershed health without any site specific methods so that any research cost and time to be feasible. It aims assessing watershed assessment by using publically available and known factors such as geological, hydro geological and climate parameters(Latebo *et al.*, 2021).The main initiating factor to execute this study were the degradation of soil following over grazing, expansion of cultivation, population number increase, expansion of agricultural investment and climatic changes. These activities were pushing Gojeb River Watershed to convert the existing land use types. For last few decades land use land cover (LULC) were completely changed due to socio-economic and bio-physical driving factors. Therefore, it is obvious that Gojeb River Watershed to be under severe pressure to land degradation and hence, watershed vulnerability to be expected(Eromo *et al.*, 2016).

1.2 Statement of the problem

Since contemporary times it is common that many basins' water volume and water quality is being deteriorated. As any water catchment, Omo-Gibe basin is one of the victims of this contemporary problem. The main problem we would know today can be observed interims of water volume decrease, the water taste and water color change of the entire river. Gojeb River was with huge amount of water in volume and its water quality was not as such contaminated. Now a day its volume is decreasing and its color is being changed. Gojeb River is surrounded with dense forest, some life activates are being changed from years to years. Investors of the agriculture sectors are using some pesticides and herbicides around this river. In addition to use chemicals land usage is exposing the soil to be eroded. Including to investments some other impacts for watershed are practiced. One of these practices is deforestation. The coverage of the forest of this watershed area is highly decreasing through time(Adugna and Gebresilasie, 2018).

Considering all this impacts and its extent and type of watershed susceptibility can be measured. As each parameters have their own negative influence on the watershed, it is necessary to evaluate each. What can be understood from all these problems are their general influence? Therefore, climate change, land degradation, population number expansion all are pushing factors to vulnerability to contamination of Gojeb River Watershed.

LULC within Gojeb Catchment identified were bare land, crop land, grassland, forest, settlement, water body, wood land and shrub land. Among these LULC the vast was occupied by forest. In 1986 the forest covered area was 60% and decrease to 45% in 2016(Yang *et al.*, 2020). The economic impact due to this eco system valuation was 2.51 billion in 1986 and decreased to 1.97 billion in 2016. The economic impact of the watershed susceptibility is one of the main pressures on the dwellers of the Watershed. In addition to economic impact, social impact is also concerned. Due to land degradation, less productivity and deforestation activity youths are becoming job less and less employment. This situation created social impacts.

Environmental the existing condition is becoming series from time to time. The rate of deforestation, land degradation, and related issues are continuing without any scientific management. For last 30 years 56,000ha of forest was changed to cultivable land and 105,000

ha was changed to different types of land type(Eromo *et al.*, 2016). Interims of soil degradation the environmental problem is alarmingly increasing. Studies reveal that 13.5 Mg/ha soil to be eroded annually(Alemu, Kebede and Moges, 2019). Human life quality with in Gojeb River Watershed is not qualified and is poor. This is because of small land to each house hold, land degradation and poor management of natural resource. The solution is preparing a road map how to protect natural resources like water, soil, forest and other components of the watershed(Alemu, Kebede and Moges, 2019).

1.3. Rational of the study

Ethiopia is water tower of Africa because of its water resources which belongs to 12 water basins. Among this basin Omo-Gibe is one of the largest basins and located in southwest Ethiopia. Gojeb River is the component of Omo-Gibe basin which is originated from south west highlands. It flows through dense forests of Kaffa. The motivating factor to this study was the conditions and human activities observed in this watershed. It has been observed with high deforestation rate, land degradation, agricultural activities and it were easily understandable that demography of the region to increase. These all human activities inform us that some environmental problems to occur and that's why the motivation to study were inspired.

1.4 Research Questions

- How could land use type, bedrock type, slope gradient, average annual rainfall and soil type be a vulnerability factors in the case of Gojeb River Watershed**?**
- Which part of Gojeb river watershed is highly vulnerable, moderately vulnerable and which is less vulnerable?
- What the Gojeb River Watershed looks like?

1.5. Objective

1.5.1 The aim of the study:

The aim of this study is to evaluate the Vulnerability of Gojeb river watershed using weighted overlay and analytical hierarchy technique.

1.5.2The Specific Objective of the study are:-

- To quantify the vulnerable parts of the watershed,
- To evaluate and identify the extent to which the watershed is affected, and
- To prepare the thematic map that shows vulnerability of the watershed.

1.6 Significance of the study:-

As any academic research, this research is supposed to fill the gap of knowledge in watershed of Gojeb River. Our water resource, soil, forest, life activity and related factor will be investigated through different techniques and finally their interrelationship will be devised. Generally, all factors that can affect both water quantity and quality of Gojeb River Watershed can clearly be determined. The contribution of this study to the society is informing that the different parts of Gojeb River Watershed is becoming affected and hence, protect as the community. The Government of different level is also stakeholders of this study. This study can give them how to utilize natural resource like water, forest, soil and others. They will use some facts as input in their policy devising regarding to water resource utilization

1.7. Scope

To study Gojeb River Watershed, it is necessary to gather many data as much as possible. Among this data, generation of soil type, slope elongation, Rainfall distribution, geological condition, drainage density, hydrological pattern, and hydraulic parameters are majors that were collected using different methods.

1.8 Limitations of the study

Whenever this thesis was done there was a lot of factors that were imposed on the activities. Due to shortage of some important data and accesses the result was meaningfully affected.

CHAPTER TWO

2. LITERATURE REVIEW

The literature reviews of this research emphasis on watershed characteristics and its vulnerability to pollution. Researches done on watershed by different scholars and governmental institutions were reviewed well. All revived literatures focuses on the meaning of watershed, the Gojeb Watershed characteristics like geology, land use, precipitation, soil type and slope gradient of the study area. Various types of the document were verified to relate their contribution to water pollution and hence how they can be an agent to susceptibility. Accordingly, the impact of land use, hydro geological condition, slope gradient, precipitation, soil type of the region and other physical characteristics to watershed vulnerability was described.

2.1 Watershed

Watershed can be described as any surface area from which runoff resulting from rainfall is collected and then finally drained into common outflow point called outlet of the watershed. It is a vast land area that channels rainfall and snowmelt to creeks, streams, and rivers and eventually to outflow points such as reservoirs, bays and streams(S *et al.*, 2019). The total topographical area drained by a stream system and collected to a single point so that function as a hydrological unit and a holistic ecosystem in terms of materials, energy and information that flow through it(Zhu *et al.*, 2021).

Watershed of any basin can never be considered as only the hydrological unit. It is also social, political, ecological components by which the rural people rely on for their security, food, shelter and other demands(Tadesse *et al.*, 2019). Watershed can never be considered only as hydrological unit but it can also be considered as socio-political and ecological entity that plays crucial role in determining food, social and economic security and provides life support services to the rural people(Tesfaye and Debebe, 2018). All water bodies like rivers, lakes, seas, streams are discharged by networked sewerage flowing into one point .This one point is a downstream of the watershed where all flow is collected to a single point and end of it. This end point is considered as the outlet of the watershed(Shami *et al.*, 2020).

The availability of water yield within a given watershed is not dependent only on the amount of rainfall but it is also dependent on some other factors such as Geological condition, Soil Properties, climatic conditions, forest ,watershed area, drainage density etc(Bekier *et al.*, 2021). Agricultural productivity is highly related to water resource. As world population is increasing, the demand for food production is also increasing. Because of high crop production demand water scarcity faces throughout the world. Effective water and land use for adequate agricultural productivity tends us to consider our watershed health. Therefore, watershed is not only hydrological unit but also it is social, economic and food security unit for human being(Diriba and Meng, 2021).

2.2 Gojeb Watershed

Gojeb watershed is part of the Omo-Gibe basin and formed along with Gojeb River. Omo-Gibe watershed is one of the 12 basins of Ethiopia and it is the third largest basin next to Blue Nile and Baro-Akobo basin respectively. The north western part of the Omo-Gibe basin is Gojeb catchment and is mainly located in South Western Ethiopian Regional State particularly in Kafa, Jima and Dawuro Zones(Alemu, Kebede and Moges, 2019). The Gojeb watershed catchment take small tributaries along with the main streams called GeshyRiver that flows to Gojeb to its outlet. This catchment agro ecologically falls in the wet/moist and is found in sub moist lowland ,tepid sub moist mid highlands, tepid humid to sub humid mid highlands and warm sub humid low lands(Dagnachew *et al.*, 2020).

One of the Gojeb River Watershed tributary is Geshy River and joins it at its outlet at Gojeb kebele. Geshy River along with small streams and tributaries collectively feed Gojeb River Watershed. This River flows from west to Gojeb River its total watershed covers 9628 hectares(Dagnachew *et al.*, 2020). The main land use type of Gojeb watershed is forest land, grass covered, crop covered (Agricultural land), water body, swampy areas. Especially the northwestern part of this catchment is with high portion of agricultural practices and hence vegetation cover and dense forest are being deteriorated(Watershed *et al.*, 2021).

The land use land cover of Gojeb catchment is changed due to the expanding investments. The investments on crop production like fruits, coffee, spices and other cash crop are becoming dominant means agricultural production. This vast agricultural practice makes the coverage of dense forest, grass land and shrubs to be removed and the land to become bare. Therefore, this crop production is leading the eco system of the region by exposing soil erosion and change rate of runoff(Shiferaw *et al.*, 2021). Gojeb watershed is part of Omo-Gibe basin and cover total area of 6932.23 Suqare Km and climatically tropical cool humid with land use land cover identified as much as 25 types.The larger land use of this watershed is 269,499ha and the small one is 0.03ha(Shiferaw *et al.*, 2021).

2.3 Factors Affecting Watershed Susceptibility

2.3.1 Land Use Land Cover

Land use land cover is the physical and biophysical cover of the Earth's surface that includes forest, water, vegetation, crop, bare, artificial structure and other forms. The change of land use can be described in two ways; Namely Conversion and modification. Conversion means changing the existing land use to the other one whereas modification is change within one form due to physical or functional attributes. The change of these land use type can have a potential to bring an environmental impact by degrading water,soil,or affecting hydrological responses(Husic *et al.*, 2019). Degradation of water quality is becoming series global issue because of some pollutant. Pollutants from agricultural practices and activities, urbanization, industrialization and land degradation are causing water pollution. Agricultural land uses produce some chemicals that are potential to degrade water quality. This all point and non-point sources of pollution impaired water bodies(Jabbar, 2019). Some land use land cover types (LULC) such as agriculture, forest, grass, had been shown to have non-point pollutant. For instance, agricultural land use has often been positively correlated with nutrients, sediments, and pesticides found in streams. The transportation of nutrients within each land use can easily degrade water quality through sedimentation or turbidity(Zhao *et al.*, 2015).

The land use land cover change can severely affect the soil erosion and hence deteriorate water quality. The dense forest cover can be deforested and hence, the land use type may be changed to cultivation. Vegetation cover of grassland, shrub land and some swampy areas are cleared and soil tends to be exposed to erosion. All forms of land use were changed to cultivation and the LULC types are changed into agriculture in Gojeb Watershed(Dagnachew *et al.*, 2020).As if Water of either streams or rivers can never meet the WHO standards of drinkable water quality. The Physiochemical parameters of streams water can be affected due to change of land use land cover of the watershed. The physiochemical parameters are positively correlated. The only physiochemical parameter that is negatively correlated is temperature and dissolved oxygen. A few variable considered as indicators were needed to characterize the impact of land use land cover types on either stream or river water quality. Some biodegradable discharges in rivers as the possible cause of observed temperature. The positive correlation between turbidity and ph was not significant but could still be linked to the fertile soil(Cho *et al.*, 2013).

The relationship between the total cultivated land and the concentrations of chemicals like phosphorous and nitrogen is positive. This can happen due to developed and vast agricultural practices in the watershed. When the soil is exposed to the chemicals that are applied for crop production in agricultural field, chemicals like nitrogen and phosphorus from ammonia can pollute the water bodies. The fertilizers applied in the agricultural field will get into the runoff and flow into the river and finally pollute the rivers water. On the other hand, the vegetation on the surface of soil of the agricultural field can absorb and retain the pollutant. Therefore, the cultivated land can highly influence the water quality of the watershed(Huang *et al.*, 2013). The land use in developed regions and undeveloped regions are different in their potential of risk. In the region where there is economic activity and development there will always be negative impact on water quality whereas undeveloped regions like covered with forest do have positive impact on water quality. The type of land use difference will be the factor to be a cause for water pollution. The land use type like urban, residential and agriculture are positively related to total phosphorus production and with high probability to water quality degradation. It is found that total phosphorus was significantly positively related to commercial, residential and agricultural land use, but non-significant relationship with forest, and BOD had a significant positive co-relation with residential and commercial lands,

significant negative correlations with forest but no significant correlation with agricultural land(Permatasari, Setiawan and Effendi, 2017).

In any watershed the relationship between the water quality and land use are directly related to the land use types like original forest, artificial forest, construction land, farm land, and other forms of land use has their own extent of effects on the degradation of water quality(Cheng *et al.*, 2020). One of the land use change that can have a potential to pollute our water and the whole ecosystem is the process of urbanization. Many researchers has analyzed that the relationship between the land use change and water quality degradation to be correlated. The rivers and streams are polluted by human activities like industrialization, urbanization and land use conversion. The exponential population growth is positively related to water quality degradation through nutrient transport and microbial load. The ecological and environmental pollutants can easily be generated in urban areas than any other land use types relatively. Therefore, urban development and the expansion of industries degrade water quality by generating solid wastes, chemicals, polluted and processed water and increasing septic products(Issaka and Ashraf, 2017).

The fastest economic growth and urbanization are becoming the main factor for water quality degradation. The lakes, streams, rivers and the like water bodies are becoming degraded and deteriorated in their water quality. A significant correlation exists between water quality and land use and hence different land use type affect water quality(Luo, 2020). The land use change conducted across the world shows that many dense forest covered countries and regions are changed in to agricultural lands. In addition to agricultural lands there are also some changes into residential land use type. Vast dense forest coverage has been deforested and replaced by crop cultivation land use. In many parts of the world in addition to the forest the wet and paddy land were changed to some uses. What we can deduce from many researches is the depletion of forest and wet land to become higher and higher. The high rate of forest depletion is affecting water body's water quality and the watershed susceptibility is becoming vulnerable(Tibkaew and Shrestha, 2008).

In forest dominating region the change of forest cover will affect watershed by water quality degradation. Now days it is clearly known that both forest cover change and climatic change are the two main factors for watershed vulnerability. However, it shall better to identify their individual effects. For small watershed the effects of climatic factor is negligible. For large watershed the change of forest cover can significantly affect the stream flow by altering its pattern, magnitude, frequency and quality(Cui, Liu and Wei, 2012).The highest qualified water and sustainable water resource is always found in forest land use watershed religion. Land cover which is highly dense forest with other types of forests is positively correlated to water quality of watershed. Even though water can be polluted by the activities within forest, forest always provide quality water to the watershed(Chishugi *et al.*, 2021). The Earth's biogeochemistry, hydrology and climate can be changed by the influence of the land use land cover change. The extent of the impact of the land use land cover change is not linear and easily generalized but it is complex and difficult to understand. The conversion of dense forest land use type to any land use type can badly affect the ecosystem especially the soil and hence degrade water quality of the river and streams. The transformation of forest and grass land use type into agricultural land use affects the soil's carbon, nutrient and organic content. The deforestation activity can cause the soil to lose its fertility and makes it easily to be eroded. This event by itself can cause sedimentation and turbidity that can harm water quality(Ahmee, 2020).

In the same urban development condition protecting native forest is very important to maintain water resources generally and ground water particularly. Maintaining and protecting forest land use sustainability can minimize the combined effects of water pollution and ground water yield. The future land use type change is an alarming that ground water discharge and the water quality degradation will be endangered(Bremer *et al.*, 2021).The water quality of rivers and streams can highly be affected because of the forms and types of land use within a given watershed. In different watershed areas there are different forms of human activities that can change the land uses of that particular watershed. These human activities which disturb the land use pattern can cause the runoff to be formed and hence water quality can easily be degraded(Huang *et al.*, 2013).

2.3.2 Precipitation

Rainfall and its intensity pattern can effectively affect the topographic configuration of the land surface. Each watershed has its own runoff pattern and a soil erosion rate that depends on geology, vegetation, and land use land cover. The fluctuation of precipitation and runoff characteristic can change the sedimentation and soil erosion rate. Excessive run off due to high storm can increase the rate of sedimentation and soil erosion. The high volume of sedimentation and high rate of runoff flow due to topography is responsible to water quality degradation(Bansal, James and Sheley, 2014). Sediment concentration due to rainfall is dependent on the amount of the rain. Sediment concentration is higher when the rainfall is high. This is because when the rain is high, its detaching capacity is high. When the flow discharge is high its sediment concentration is low(Aksoy and Kavvas, 2005).The climatic change like temperature and rainfall pattern fluctuation can influence water quality of a watershed. Depending on the magnitude of temperature change there will be water quality change in physiological, biological and chemical properties of water. As temperature increase, the volume of water increase and hence fresh water runoff also increase. This may initiate salinity and can affect aquatic life(Yilmaz, Göl and Ediş, 2011). The water balance equation of a particular watershed shows that the change in moisture storage over a given period of time equals to the sum of inflow and outflow over that period of time. Accordingly, the changes in watershed storage is the sum of precipitation and inter basin abstract as a gain and surface and sub-surface flow at the outlet of the watershed .One of the loss from the watershed is evapo-transpiration. Generally the water balance or the water availability of a given watershed is calculated by using energy balance. All the water stored within the watershed is the water entered into the watershed and its storage capacity is based on the loss from the watershed i.e. Storage=Inflow-Outflow.

$$S=P-ET-Q+W$$

Where s=storage=precipitation,ET=Evapo-transpiration,Q=Stream discharge at watershed outlet,W=gains and losses of the interbrain transfer of the abstracted water(Ferguson and Maxwell, 2010).

The ground water can easily be polluted by land disposal of either liquid or solid waste materials which are disposed as waste materials from different point and non-point sources onto the Earth's surface. Manure, sludge and industrial wastes are good examples of land disposals. One of these disposed pollutants may occur as individual mounds or can collectively distribute and mixed to be distributed or flow over the land. If these disposals contains soluble substances within them and infiltrate in to water bodies, then they can infiltrate into underground water and hence can be an agent to water pollution(Kaur and Sooch, 2016).The rainfall characteristics like amount, duration, Intensity are very important storm characteristics that determine how the watershed responds to hydrology to each individual storm events. The amount of precipitation is the amount of rainfall depth in mm, duration is the time it takes to rain in Hr, and intensity is the amount of rain over which the raining occurred measured in inches per hour. The runoff and soil erosion occur with the increase of average annual precipitation. The amount, duration and intensity of the storm is very influential on watershed's hydrological response. Sometimes the same storm that occurs on the same watershed will generate different volume of runoff and peak flow. This difference may be due to soil type and land use. Generally precipitation amount, intensity and duration can highly affect watershed water quality through runoff and erosion(Zhu *et al.*, 2021). The relationship between the rainfall and soil erosion is directly proportional to each other. If the rainfall is high, the amount of runoff volume will be high. As runoff volume rise, the total loss of soil by erosion increase. The eroded soil affects the water quality in terms of sediments and turbidity. It could be attributed to the effect of runoff during rainy season. Generally the soil loss and amount of annual rainfall is correlated positively in highlands of Ethiopia (Husic *et al.*, 2019).

The hydrological cycle is interrelated with the land use land cover condition and their characteristics. The land use land cover type can affect both the infiltration and runoff amount by falling the rainfall to occur. The land cover condition can affect both surface flow and underground water flow. Surface runoff and ground water flow are the main determinant components of stream flow. The rainfall contributed to the formation of surface run off whereas ground water flow is directly from infiltrated water. The source of stream flow is mostly from surface runoff during wet season whereas during the dry seasons the stream flows from ground water(Tesfaye and Debebe, 2018).

The rainfall kinetics energy and the runoff it generated can be a cause for the detachment and displacement of the soil particles. The soil physical and chemical characteristics can easily be affected due to the rain storm. Either during or between the rainstorms, there may be short term and long term effects for soil erosion. Change in soil properties affects erosion response; spatial partitioning between hill and inter hill; threshold hydraulic condition for rill incision and rill network configuration. The rain reaching the ground can be affected by interception due to vegetation cover have less potential to detach soil. The variation of land surface in vegetation cover makes the soil erosion dynamics complex. Therefore, the watershed susceptibility due to sediments and soil erosion is dependent on not only on vegetation cover but also on amount of rainfall and its variation(Wilber, 2008). The water resources are vulnerable, and have the potential to be highly impacted by the increase of urbanization. The increase of climatic change due to high precipitation is damaging many components of whether condition. Those higher precipitation due to climatic change brought drought, runoff, less productivity, less ability to crop cultivation, huge runoff, less productivity, land degradation. Higher and intense rainfall event will increase amount of runoff and will overload river or streams and other water structures. When precipitation variability is high more frequent the runoff occurs. This more frequent runoff can harm water quality and the entire watershed is affected(Sharma, 2017).

All watershed types are responsive for higher annual precipitation and storm. This hydrological event is capable to bring some destructive and unpredictable effects on land and water resources. Naturally it is self-evident that precipitation is the only event for watershed to get water. It is possible to say precipitation is the main natural input of water to the watershed. As we know the water from the precipitation discharges the ground water through different mechanisms and hence it helps vegetation grow. Whenever precipitation water move down side to ground water, chemicals from pesticide, herbicide and the other pollutants transported to ground water and polluted it.The transportation of rainwater carries sediments from surface and increase pollution through sedimentation and turbidity(Bansal, James and Sheley, 2014).

During flood time high amount of polluting minerals such as Mg, Ca and P can be carried into streams or lakes. The frequent occurrence of rainfall and the related hydrological condition pave the way for the transportation of sediments containing pollutants. Polluting materials with sediments could be dissolved with in the runoff and carried from land to water when there is flood occurrence due to rainfall. Phosphorus on the soil surface can be transported to water bodies when the soil is eroded. This event transport pollutant materials to water and can be potential pollutant. (Sadeghi and yaghamaei: 2015)

2.3.3 The Impacts of Geology on Watershed

The bedrock formation type of any watershed is potentially capable to determine the chemistry of its water. The hydrochemistry of stream water can be varying from one place to the other one due to its underlying rock type. The igneous rock can never allow surface water to be mixed with aquifer due to its resistance to water flow inside it. However, rocks like crystals and sedimentary type rocks are with faults and they let surface water to enter into aquifer and hence water chemistry can be altered(Alonso and Castro, 2007). Bedrock of a given watershed is crucial to water pollution because of its chemical behavior to let water to interact with soluble materials with in the rock and affect being soluble with in water(Jabbar, 2019).The drainage density of a given basin indicates moderate permeability of the surface of the Earth and is important to analyze the morphology of the Earth surface. It is affected by bed rock type, vegetation coverage, terrain, climatic condition, filtration capacity and the effect of drainage intensity(Malik, Al-shammary and Al-hamzawy, 2016).

Any watershed has its upstream and downstream parts and is linked through hydrology. The activities in the upstream side have high impacts in the downstream parts of the watershed. The land use condition or natural resource rehabilitation condition in the upstream side would increase or decrease the rate of sedimentation and hence can deteriorate the water quality in the downstream. Biophysical and geological situation of the watershed is very crucial to the health of the watershed in both streams. Watershed with permeable geological and soil properties can let the percolation of water to ground water and this may enhance the ground water discharge. This cycle could link the hydrology of the upstream and downstream well(Cho *et al.*, 2013).

The characteristics of topography of the watershed has an effect on variability of sediment, nutrient, salt concentration in water bodies, heterogeneity in landscape can significantly affect spatial differences in river/stream water quality. The extent of watershed health is directly related with land use, land cover, human activities like urbanization and industries. In addition to human activities, there are also some natural factors like geology, climate and relief are also factors to water pollution of rivers and streams(Chishugi *et al.*, 2021). For a given rainfall pattern, the type of geological condition and its formation process can determine the discharge and sediment load of the watershed. Each and every type of rock and soils and their process of formation can affect water percolation, infiltration rate, and runoff. This is because of the pore size of soils and rocks difference. Therefore, the water exchange through rocks from surface to ground water depends on rocks and soils type of the watershed. The soluble pollutants within the rock may melt and enter to the either aquifer or streams could influence water quality of the watershed(Adams, 2014).

Different types of geologic condition beneath watershed are capable to affect water quality. Rock types like sedimentary, igneous, metamorphic, fractures, glacial deposits are potentially capable to influence on water quality of watershed. The water between the aquifer and ground water may pass through different chemical reactions. Thus, rock-water interaction due to chemicals with in rock can affect water pollution by transporting polluting materials from one part to the other. Water flowing through fractured rocks can transport polluting chemicals like dolomite, limestone and carbonates. Due to these transported chemicals water in the acquirer can easily be polluted. Finally, the quality of surface water can be contaminated because of the exchange of water in the acquirer and hence susceptibility can occur (Walter et al. 2017)

2.3.4 The Impacts of Slope on Watershed

The main contaminant carrying nutrient and sediments rate of transport is directly dependent on the gradient of slope. In addition to land use land cover, the slope gradient is factor for the rate of their transportation. For all land use type, as slope gradient increase or become steeper, the flow rate is high. Whenever the slope is high, the surface runoff is high and the infiltration is low, and hence, the slope gradient steepness can increase the flow rate of nutrient and sediment become high. In this regard, for cultivated land the value of sediment and its flow rate also increase with the increase of slope. In cultivated land and urban land use the sediment load and their transport rate increase and become fast due to their agricultural and construction activities respectively(Husic*et al.*, 2019).Water quality degradation due to soil erosion is highly related to the topographic features of the watershed. The extent of soil erosion by the effect of topography is in relation to the slope gradient and due to the length of the land. The surface flow and soil erosion are determined by these parameters. The erosion intensity and slope are different in under different rainfall and different land use land cover condition(Koralay, 2018).

Slope is a responsible factor for water susceptibility because of its tendency to govern the topographic condition and material flows above surface. It plays some essential roles in the occurrence of surface water flow and landslide in combination with the other factor. The slope gradient can affect surface and sub surface flow state based on gravity, soil water content, soil structure, erosion potential, hydrological and geomorphologic conditions. Slope condition that is expressed in either steepness or gentleness can affect water pollution of watershed by facilitating flow rate and soil erosion(Kiresehir et al,2020). The effect of slope gradient can produce huge amount of nutrient and sediment to carry and transport into water bodies so that watershed susceptibility easily happen. As slope steepness increase near to 30 % values of sediment and nutrient loss also increase in agricultural land use. The slope condition which can affect flow rate and detaching capacity of erodible soil is steep. As soon as slope is high , the flow rate of runoff and the rate of detaching soil particle will be fastest. Therefore, this condition enable high amount of sediment and nutrient to be carried into water bodies. Finally water pollution and generally watershed susceptibility occur in different aspects (Megersa et al, 2019).

The length (LS) and steepness of slope can highly influence water pollution of watershed through runoff speed and volume. The rate of water induced soil erosion may be facilitated due to steep slope. Especially in the region where there is high rainfall intensity including other considerable factors, the volume and rate of sedimentation due to soil erosion would be high. With the increase of runoff water due to high rain, it can increase the erosive of runoff. As the result the water travels in high velocity and hence can carry the high load and sediments into water bodies. Finally this huge volume of sediments could pollute water.(Belayneh et al, 2019)There is also clear but indirect relationship between the slope gradient and watershed susceptibility. The direction of the slope can affect the occurrence of the landslide due to the influence of the slope in determination of the amount of sunlight that will affect the weathering of rocks in combination with rainfall. This event eases the way of rock weathering and hence can cause the occurrence of landslide and due to this landslide and rock-water interaction watershed vulnerability would be high. Slope gradient above 45% is with high tendency for such a land slide and rock weathering to take place.(Amaliah et al, 2021)

2.3.5 **Soil Type**

Soil erosion is one of the environmental problems that have reduced crop productivity, degrade water quality, decrease reservoir's volume and destruct habitat. It is also considered as essential source of non-point sources for pollution for water bodies(Zhang and Huang, 2014).The impacts of soil properties on the hydrology of a watershed due to the variation of land use are very striking. The difference of water table between forest land use and agricultural land use are obviously observed. The difference of water table depth due to land use type can affect the cumulative and annual outflows because of the hydraulic conductivity and drainable porosity of the soil. This phenomena predicts that the hydrology and water quality of a watershed to be highly related(Skaggs and Chescheir, 2013).There are many factors that influence soil erosion and hence water quality degradation takes place. Among those factors the main are excessive rain, water depth, flow velocity, shear stress of overland flow, and the capacity of the soil to resist erosion. According to kinetic wave theory, those factors vary with the variation of the slope gradient of the watershed. This theory has generalized and devised the formula how to describe the soil erosion in relation to slope gradient difference. The critical slope gradient describes that the soil bulk density, the soil particle size, surface roughness, runoff length, excesses of net rain, friction coefficient to be the main factors for soil erosion. The critical slope gradient is easily calculated and estimated theoretically to be within the range of 41.5 to 50 degrees(You *et al.*, 2019).

The topographic condition of a given area is responsible to soil loss. The topography along with soil particle size highly influences the rate of soil loss. As the steepness of slope increase the tendency of the soil to detachment increase. This soil characteristics and its erodiblity is dependent on its particle size and topography of the watershed. Slope gradient of the watershed is one of the main important factors that influence the process of drainage, runoff and soil erosion. The total loss of soil can be expected to increase with the increase of slope gradient. This is because the increase of slope would accelerate the surface runoff and decelerate the infiltration rate of the flowing water within watershed. Accordingly the slope can be categorized into gently sloping (2-5%), slopping (5-10%), strongly slopping (10-15%) and moderately steep (15-30%)(Aytenew, 2015). Soil erosion occur after some procedures followed by one another. Before full erosion takes place events like soil particles loosening,

transport and deposition. The top soil rich in organic materials and nutrients is transported to elsewhere or buildup by these three processes. These processes are very responsible and fastest if the area is sloppy. All factors like land use, slope and high rain together can severely affect nearby water bodies. Runoff occurrence is followed by rainfall and due to this reason soil sedimentation transported to rivers.(Issaka and Asraf:2017). Water quality can be degraded physically, chemically and biologically because of soil particles. As soil can be the source of soluble materials, it can affect water quality by influencing the turbidity, Ph, and other water quality parameters by the sediments it carries. Materials like pebbles and sands which are bigger and heavier in their particle size settles first whereas materials like silt and clay which are larger in particle size float on the surface of the water. The floaters can easily affect the turbidity of water. In addition to turbidity, electrical conductivity also increases due to soluble materials. Therefore, watershed vulnerability due to soil type will be high(Rickson:2014).

The watershed susceptibility assessment can be calculated by calculating the weights of each main factors and assuming their sub criteria. Land use land cover, slope gradient, annual average rainfall, soil type and geological conditions are main factors and have their own weight with accordance to their contribution to water pollution. All of the main factors also have their sub criteria. Each criterion is ranked according to the rate of contribution. For instance, land use is main factor under which agriculture, crop production, bush land, grass land and forest are sub criteria and given 1-5 rank. Rain fall is main factor and its sub criteria are given based on the amount of rainfall in milli meter. Slope is main factor and its sub criteria are ranked with according to its value from gentleness to steep. Soil is also main factor and its sub criteria is given from sandy soil to clay and ranked. Geology labeled in such a way that its sub criteria is considered from igneous to sedimentary(Jabbar, 2019). Rating main factors and ranking sub criteria are very crucial to determine the vulnerability of watershed assessment. Main factors that can potentially affect water quality and their sub criteria are responsible to identify the zones of vulnerability. The assumption works by considering the response of watershed to contamination and the extent of influences by sub criteria. The overlay method is applied to assign the relative weight of main factors with accordance to the impact on water quality(Ka 2022). Soil water holding capacity has its significant effect on environmental pollution. After the total amount of water is drained out from the soil pores, it

can be potentially capable to resist climatic changes. To improve the soil water holding capacity is to enhance soil resilience to the increasing climate variability. This results in adaptation to occurrence of intensive rain and the waves of drought. Whenever, the soil water holding capacity increase, the rate of infiltration increase and hence surface runoff become lower. In this context the events of soil erosion during high rainfall will be low and therefore, watershed susceptibility is less probable ((Abdallah et.alr, 2021).

CHAPTER THREE

3. MATERIAL AND METHODS

3.1. Location of Gojeb Watershed

Ethiopia is the water tower of Africa and belongs to 12 River basins and Omo—Gibe is one of them. Gojeb Watershed is part of Omo-Gibe and found in Northwestern of it. It is mainly located in the South West Ethiopia and flow toward south east. It is mainly found in Southern Nations Nationalities and Peoples Regional State. As it is the northwestern part of Omo-Gibe basin, it shares the two national regional states; Oromiya National Regional States and the South Nations Nationalities and People Regional State. Gojeb River starts its flow from Kafa zone then it extends to Omo and finally becomes parts of Omo-Gibe Watershed (Fig 1). Gojeb River is known as Omo River in its lower reaches, Southwest ward from its confluences with Gibe River. The main tributary to Gojeb River is Geshy River at Gojeb Kebele. Geographically Gojeb watershed lies between 07˚02' - 7˚53 N latitude and 35.36˚12' and - 37˚34 E .The altitude of this watershed ranges from 817 to 2500 meters above sea level and its total drainage area covers 6665.25 square kilometer.

Agro-ecologically, Gojeb watershed can be categorized as wet-moist regime and is found in warm sub-moist lowlands and tepid sub moist mid highlands and tepid humid mid highlands, and warm sub-humid low lands. The lowest rainfall would be from November to February and the highest is from June to September. Annual rainfall varies from about 1000 mm in the extreme south (lowland) and 1450 mm in the highland northern parts of the Gogeb River. There are five types of soils in the Gojeb Watershed region, namely: Fluvisols, Cambisols, Verticals, Regosols, Lepotosols. The land use land cover (LULC) of the region is mainly with cropland, forest land, shrub land, woodland and swamp.

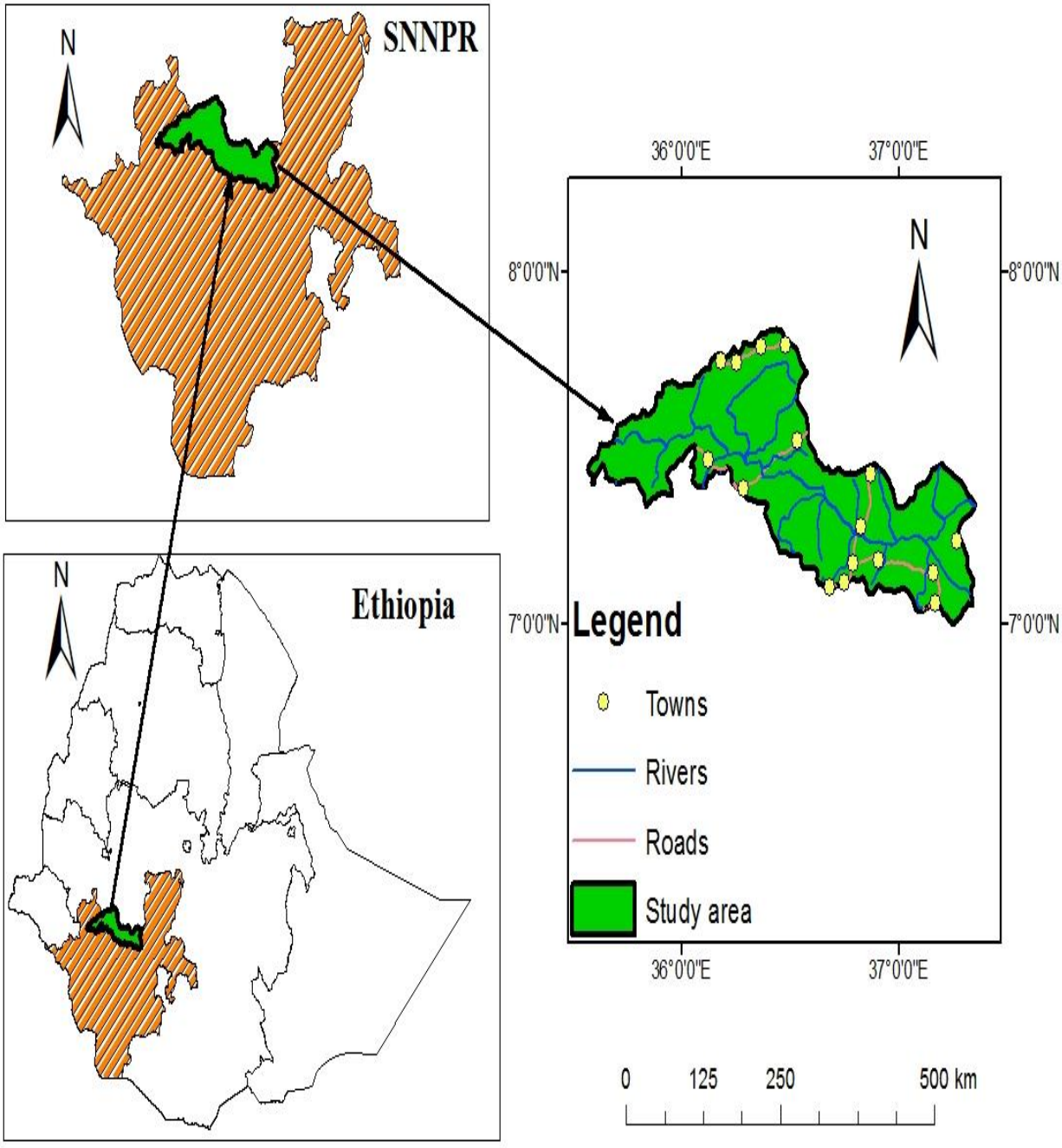

Figure.1. Location Map of Gojeb Watershed

3.2 Research Design and Period

This research was carried out on the basis of combined techniques like basic, applied, quantitative and empirical research. It was expressed by theoretical, field work, numerical value and some formulas. GIS and AHP software were used since they are best to manipulate data in watershed assessment. The research period was February 2022 to September 2022.

3.3. Data Source and Type

All necessary data were obtained from field, from offices like agriculture, water and mineral, and environmental protection departments of Kafa Zone. The techniques used for research include literature review, collection and organization of all necessary data from various types of sources, reports, maps, metrological stations.

3.4 Data Collection Technique

Data for research were collected by different mechanisms. Collection of appropriate data were done by using GPS, Observation, Oral asking of the community, Desk Study; land use, precipitation, bedrock type, slope, soil type were found from GIS software. The GIS software application was mainly utilized to delineate maps of land use, precipitation, geology, soil type, slope gradient of Gojeb Watershed. Data like rainfall, temperature, and inventory were collected from different governmental organization.

3.5 Data Processing

3.5.1. GIS Data Processing

GIS technologies using remote sensing data were used to prepare thematic maps of Gojeb Watershed. The land feature and slope of the study area were generated from Ethiopian Digital Elevation model DEM 30X30. The land use map of study area was created from Ethiopian land use map. The soil type, geology, rainfall are mapped from their respective GIS data of Omo-Gibe Watershed data. Using this GIS technology land use land cover, slope, geology, soil type, precipitation pattern were identified. The main activities were done to delineate the map of Gojeb River Watershed using GIS and the produced map were added to AHP toview the health status of the entire watershed. The main reason why GIS was preferred

to produce the thematic map was easily to investigate the physical characteristics of the watershed such as slope gradient, elevation of the study area, land use, bed rock, precipitation, soil and other important factors were identified. GIS used publically known and available data like hydrology, geology and other climatic data. No other alternative way to calculate Geographic Information System software than GIS for my study and hence I preferred to use it. The thematic maps generated are:-

3.5.1.1 Land Use Land Cover

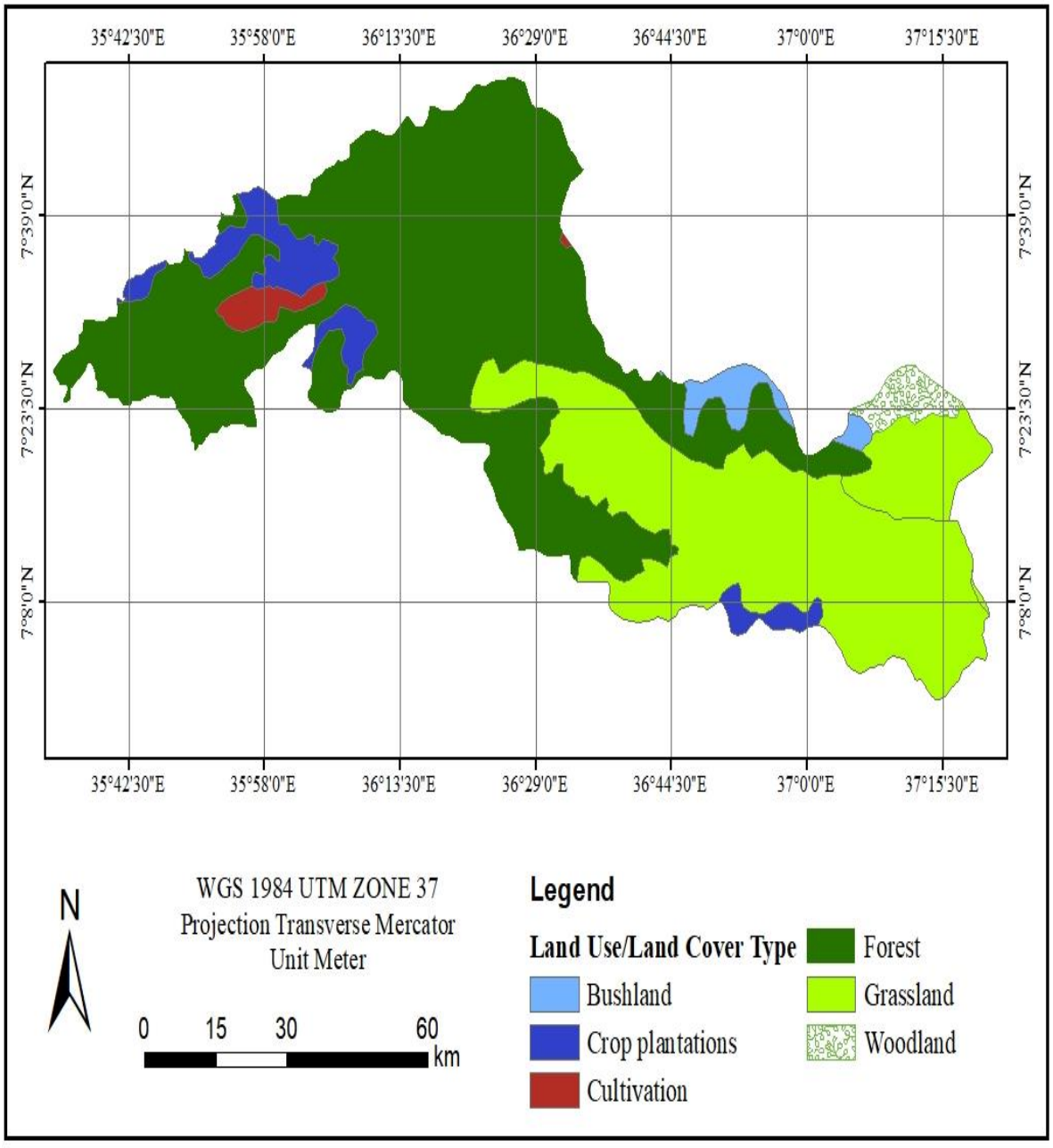

Figure 2 Map of LULC of GojebWatershed

It is clear that watershed health is vulnerable to land use land cover. Agricultural land use, forest land use or other types of land use can matter on the health of the watershed. The land use pattern of Gojeb Watershed is dominantly classified in to 6 main land use categories. Accordingly, extensive cropland and mainly dominated by different types of cropland, dense forestland, bush lands, woodland, cultivation, grassland area are easily identifiable types of land use around Gojeb Watershed. The dense forest of Gojeb Watershed was changed to crop land both by house hold farmers and agricultural investors. The total population of the Gojeb Watershed is estimated about 3,320,571 of which 1,320,571(50.07%) are men and 1,316,780(49.93) are women and only 9.2 % of this catchment is urban inhabitants. Since 1977 EC significant land use change happen due to settlement and investment. The major changes were expansion of crop land at the expense of other land use at the rate of 29.56 % in 1978, 38.91% in 1987, 46.62 % in 2001 and 52.74 % in 2015.Since 1978, 9030 hectares of dense forest were changed to crop land.

3.5.1.2 Geology of Gojeb Watershed

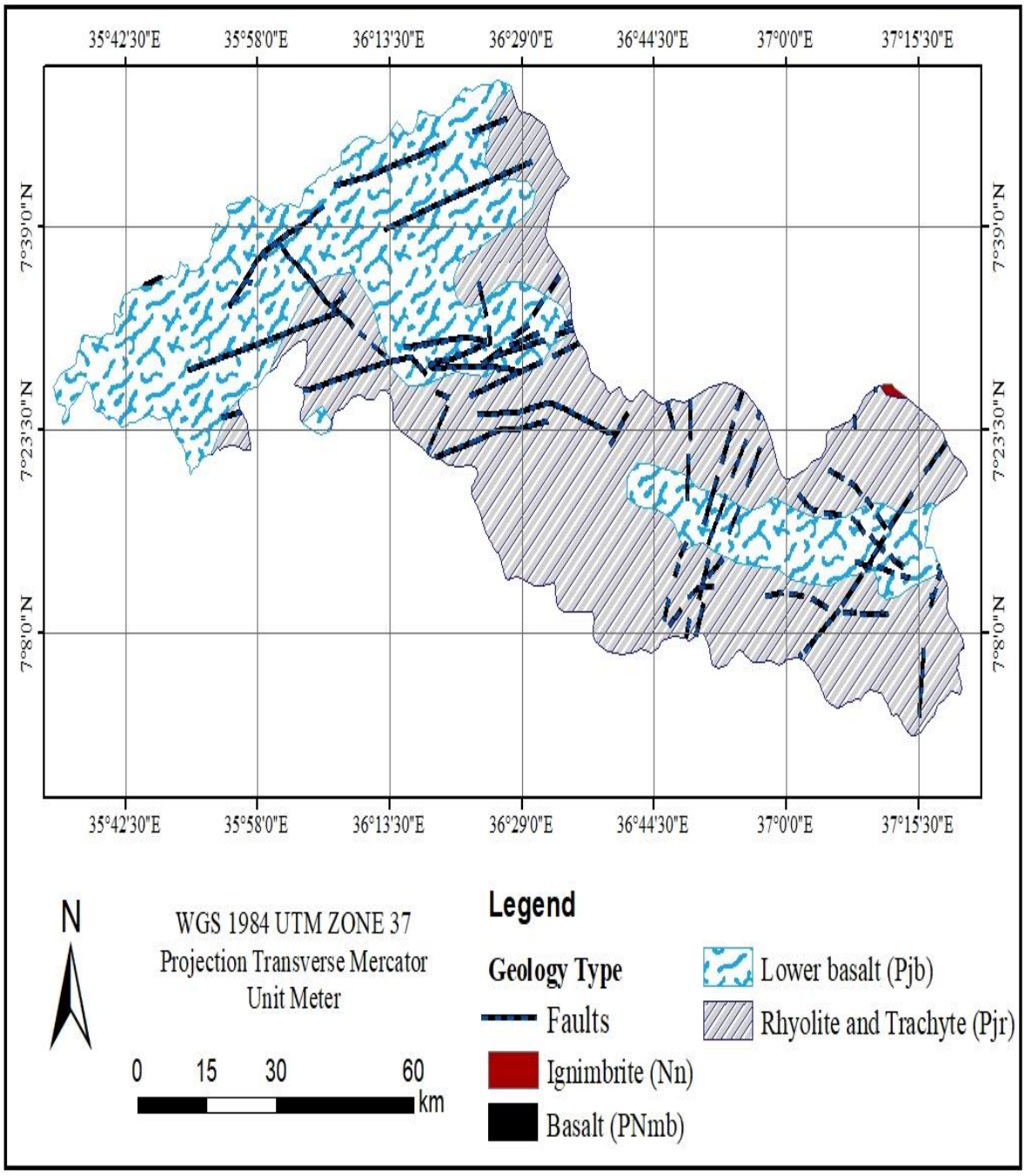

Figure 3.Map of Geology of Gojeb Watershed

The geological condition of the watershed can affect its health. Different types of rocks and minerals react with water in different manner and their physical and chemical reaction have potential to pollution of water. Gojeb Watershed can be described in various types of bed rock types with different characteristics due to their interaction with water.

The most important and dominating rock type in Gojeb Watershed region is igneous, ashes, basalt types and other volcanically formed types of rock. The vast majority parent materials are highland soils that form igneous type of rock. It is formed under the influence of a pluvial regime and relatively warm temperature have weathered to form deep well drained clay soils. Generally the rock types in Gojeb Watershed are not directly responsible for water pollution due to their nature in interacting with either surface or aquifer.

3.5.1.3 Slope Gradient

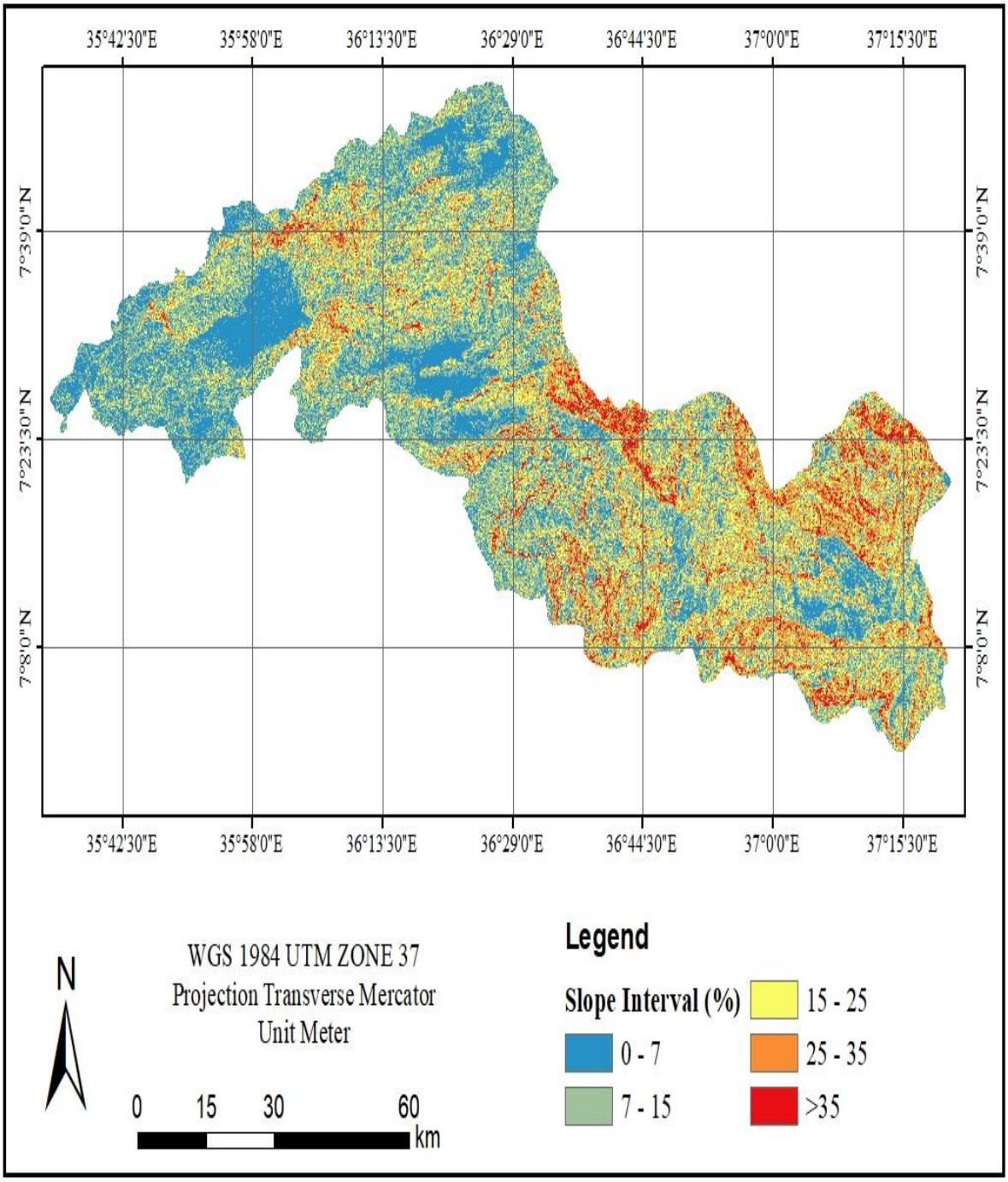

Figure.4 Map of Slope of Gojeb Water

The slope gradient of the Gojeb Watershed is describable from its topographic condition. Its topographic variation is characterized from its physical nature. Almost most of its northern and central part is mountainous and to hilly terrain cut deep incised gorges. The southern part of the Gojeb Watershed is mostly is a flat alluvial plain extended with hilly areas. The topographic condition of this basin is from steep parts to flat and finally gentle slope at its outlet. The slope angle and aspect direction of Gojeb watershed is very important to determine as a main factor for susceptibility .The slope of this basin ranges from below 1% to above 5%. From the northern parts of the basin to the central parts the slope gradient is steep. Its range is from 3345 masl in the north to 806 masl in the south. The upper and the central part of Gojeb Watershed is relatively steep slope. The highland areas of the central and upper parts of this basin are with dissected hills and steep. When we come to the southern parts of the Gojeb Watershed, it is flat and relatively gentle and undulating slope.

3.5.1.4 Average Annual Rainfall.

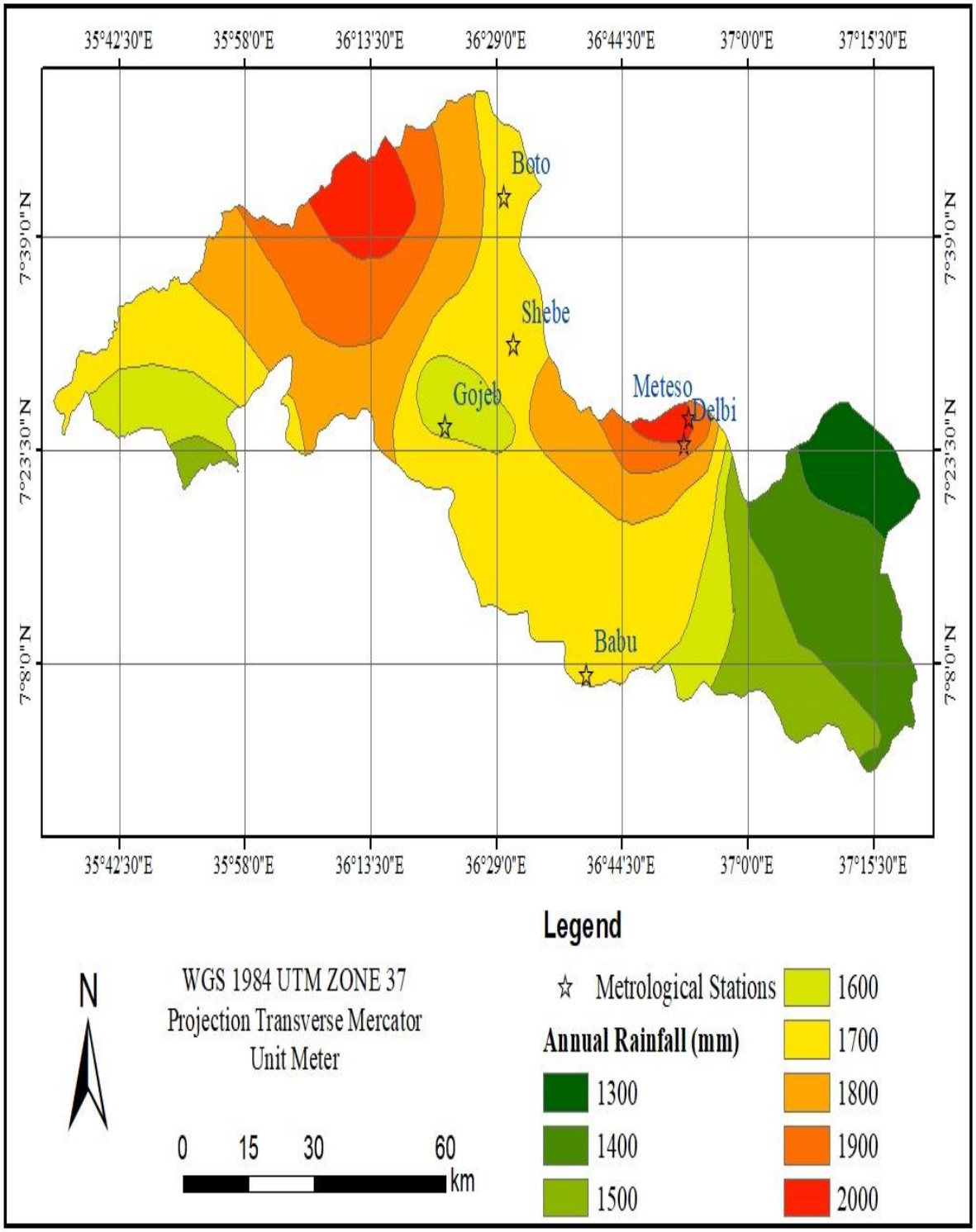

Figure 4. Map of Average Annual Rainfall ofGojeb Watershed

The Gojeb Watershed climatic condition varies as elevation varies. The elevation in the north western part is high while the south eastern is low. The rainfall of Gojeb Watershed is unimodal and its amount increase with the increase of elevation .The mean annual rainfall of this watershed vary from 1391 mm in the southern part to 1884 mm in the north and northwest parts. The temperatures of the catchment also vary as the elevations vary. The minimum temperature of the catchment 14.4 degree celicius in the north and the maximum temperature is 25.9 in the downstream which is southern part of the catchment. Its altitude in the southern part of the catchment is 814 masl and 2500 masl in the northern.

The unique characteristic of the rainfall of the Gojeb catchment is its high amount of rain and long time of wetness. The lowest rainfall season is from November to February. The rest seasons are with high rainfall. This region gets rain for 9 months within a year.

3.5.1.5 Soil Type

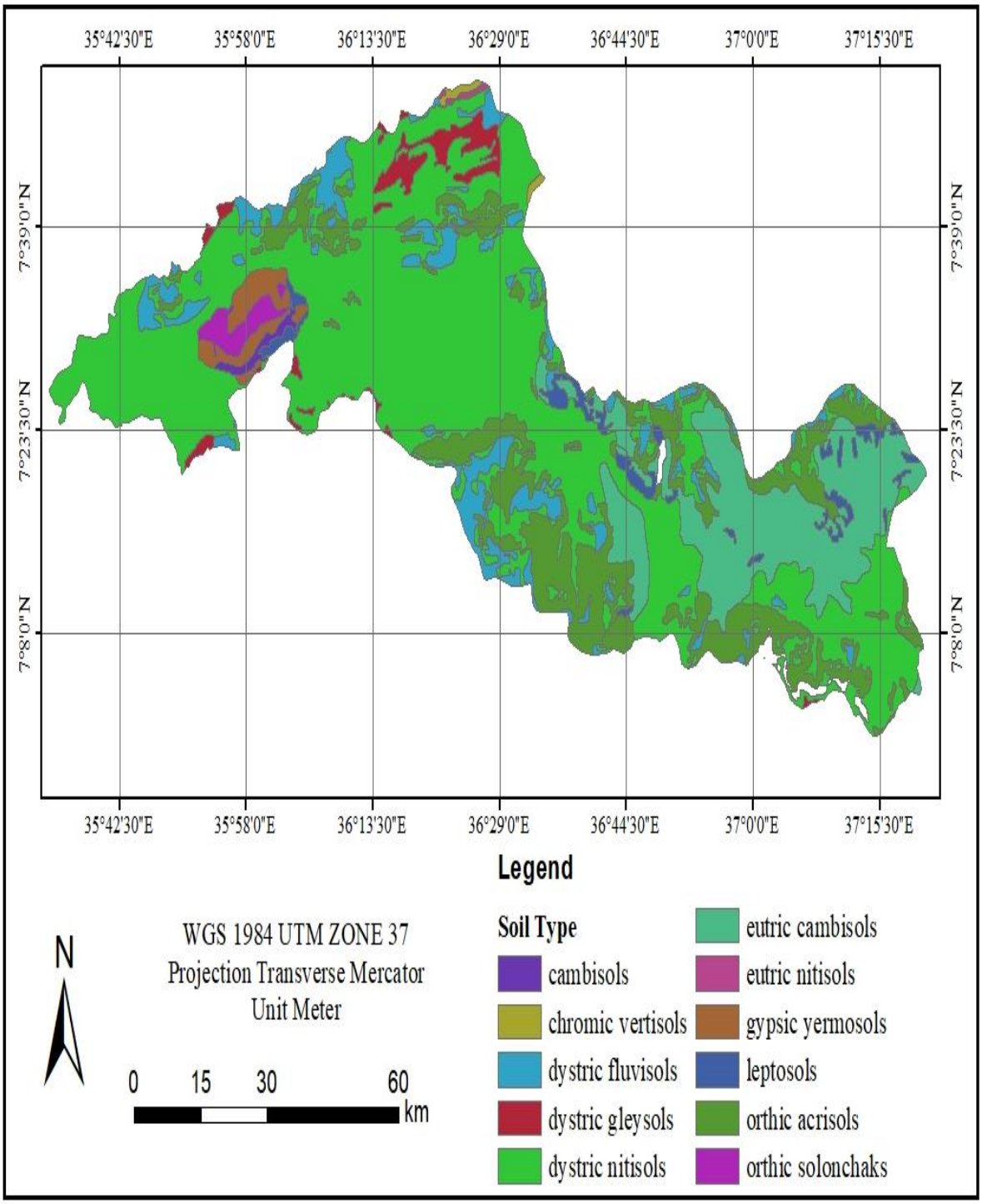

Figure 5. Map of Soil type of Gojeb Watershed

The soil condition of Gojeb Watershed is almost the same with Omo-Gibe basin.In this catchment the main soil types are five , namely , Fluvsols , Cambisols , Vertisols , Regosols , and Lepotosols .As the physico-chemical properties of soil determine the detachability and transportation of soil, it is important to classify the types of the soils of the entire basin. The lower part of Gojeb Watershed is mostly dominated by loamy soil. This soil type is easily erodible and detachable. The upper and central part of the basin is more of clay dominant. Rarely clay and sandy type of soil are also identified. When we come to more centers where Geshy sub catchment is found the dominant soil type is clay soils. This type of soil is well known in its slow infiltration rate. The clay type of soils are with low detachability and high resistant to erosion. The southern part which is around the outlet of the basin the soil characteristics is more resistant to the impacts of the kinetic energy of the rainfall.

3.6 Analytical Hierarchy Data Processing

Multi criteria decision making tool (AHP) is very technical to calculate different factors (Overlays) for a given condition. The comparative weights of each identified factors were measured both in quantity and quality. Five main factors were used to assess watershed susceptibility in this thesis. Each determinant factor are weighted and ranked with according to their impact on water quality. The weights and rank are given based on their relative impacts on water quality. I.e. which factors can influence water quality than the other? (Jabbar et al.2019).The GIS maps which are in polygonal forms were changed to raster data. These raster data were reclassified to be added into AHP. AHP considered those 5 factors with their respective weight given (Ka: 2022)

Each factor was classified into 5 categories. The land use, rainfall, slope, soil type, and bedrock type were 5 factors having their respective weight were identified. These 5 main factors were also reclassified with according to their extent of contribution to vulnerability. Each of main criteria were reclassified into sub criteria. For instance land use were given weight of 40% and reclassified into crop/cultivation, bush land, grass land and forest. These reclassified sub criteria were ranked 1-5. Soil type was given the weight of 20%were considered as main factor accounting 5 % and reclassified as igneous, sedimentary,

metamorphic and ranked 1-5. These all factors were reclassified according to their weight and their values were added into AHP (Siqeria et al. 2017)

In addition to GIS its extension so called AHP was highly implemented in my work. AHP was preferred to be used in this study. The reason to use AHP was it is cost effective and time effective. AHP is also capable to calculate the weight of each overlay and their contribution to pollution. Many studies in relation to watershed were done by either mathematical model or physiochemical assessment method so far. These two common and old methods need high financial cost and long time. Therefore, AHP is relatively economically feasible and time effective and hence, I preferred to use them. In addition to time effectiveness and cost feasibility AHP is preferable because it easily measure the overlay factors when different factors could have their own contribution to pollution. Field observing and oral communication were held to clearly understand what is really found on ground. In this way how agricultural activities are being done and types of fertilizers farmers have been using were identified. The land use condition, the extent of urban type, the settlement pattern, deforestation, and other visible factors were seen. This direct observation helps me to clearly understand the condition on the ground.

Table 1 the relative weight and rating scores of factors and sub criteria for assessment of watershed susceptibility

Factor	Weight	Sub Criteria	Rate
		Cultivation	5
		Bush land	4
		Grassland	3
		Woodland	2
		Forest	1
LULC	0.40		
		Clay Loam	5
		Silty Loam	4
		Silty Clay loam	3
		Loam/silty	2
Soil	0.2	Sandy	1
		>2000mm	5
		1900-2000mm	4
		1800-1900mm	3
Average Annual rainfall (mm)	0.2	1700-1800 1300-1700mm	2 1
		>35 %	5
		25-35%	4
		15-25%	3
		7-15%	2
Slope (%)	0.15	0-7%	1
		Ash flows	5
		Flood basalt	4
		Upper basalt/Shale	3
		Lower basalt/Clay stone	2
		Rihyolite/trachite/Sandy stone	1
Geology	0.05		

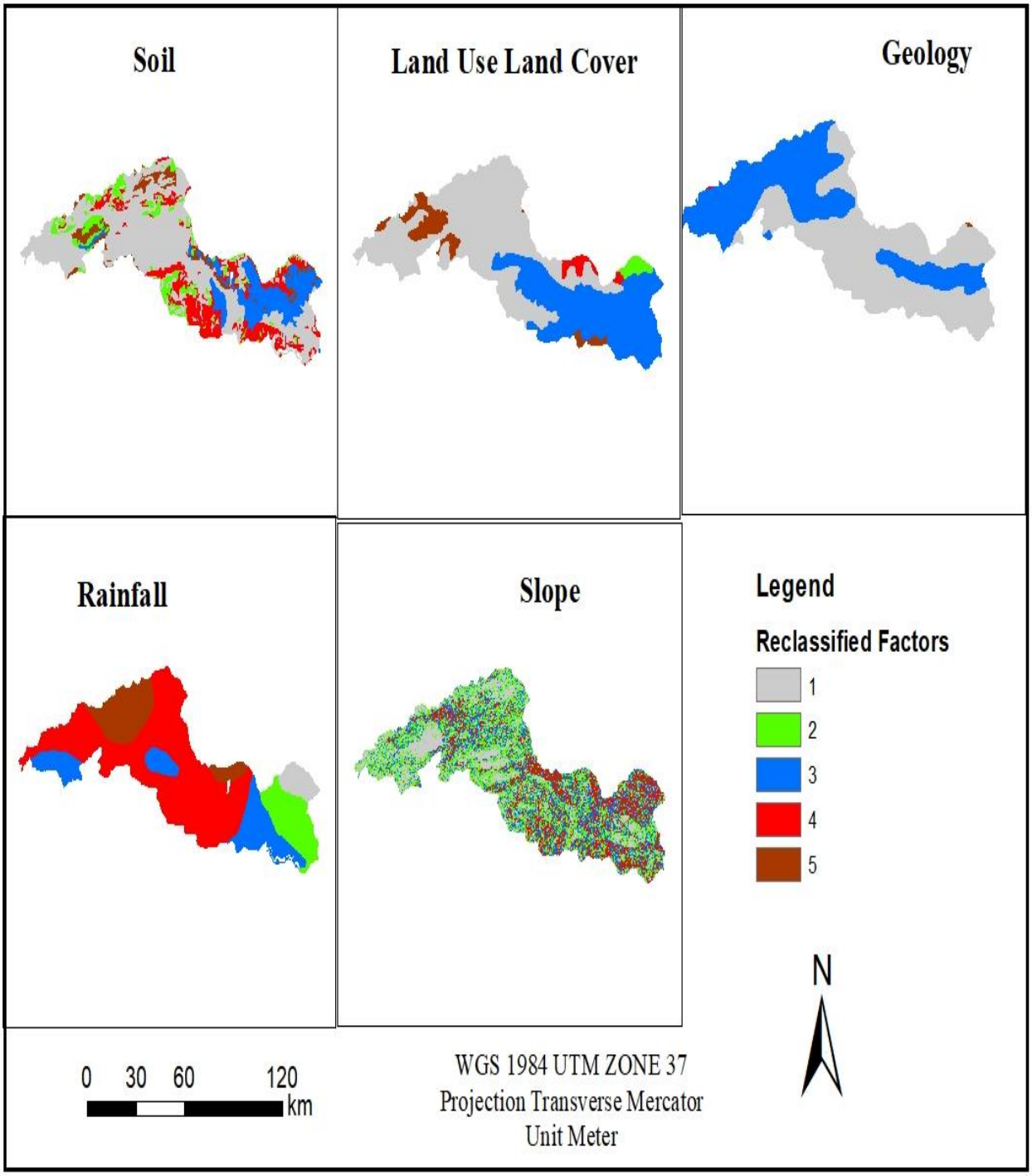

Fig 7 Map of reclassified sub criteria

The Gojeb watershed region as any part of south west Ethiopia and it is with variety of topography. The topography of the region is with highlands, lowlands, plateau and valleys. The ups and downs of the topographic condition of Gojeb Watershed region are very decisive on the entire characteristics of the watershed. The Gojeb River is one of the catchment in Omo-Gibe basin and most probably the largest river in Southwest Ethiopian Regional State. Gojeb River flows from Kafa high lands and flow toward southeast direction and joins Omo River at its outlet in Dawuro Zone and finally enters Rudolf Lake. This River descends through canyons and deeply incised valleys to broad tectonic depression. The slope varies from steep in the north and flat in the south. It is full of streams and rivers that flow from the highlands. The margins of the southern part of Gojeb Watershed are demarcated by massifs of volcanic rocks that rise 1500 m above the basin floor. These rocks are mountain blocks and have their own group. The upland proper consists of ridges and rolling platforms, with average slopes of 5-10 degree. In the Northern part the watershed is high land plateau whereas the southern part is lowland plateau. The southwest part of Ethiopia generally, Gojeb Watershed particularly, is interconnected with the valleys and depression and mountains. Generally, Gojeb Watershed comprises topographic features ranging from rugged and hilly terrains to flat plains. The major faulting and folding that created Gojeb River basin, highlands and its geologic condition is not well known. Some Geologists argue that the lacustrine and deltaic sequence to be developed to form the entire Omo Gibe basin. After this event no subsequent deformation appears so that effective change to occur. The Geological condition of the Gojeb River bed is most probably similar to that of Omo-Gibe Watershed. It mostly comprises a Precambrian crystalline basement, covered by tertiary volcanic rocks. It is also surrounded with isolated exposures of quaternary volcanic rocks, lacustrine deposits and alluvial sediments. The soil condition of this region is dominated with the soil that contain high amount of organic materials. This organic material containing soil is called peat soil. Next to the pit soil the most dominant soil is clay soil and loamy clay soil. The major soils of the study area include typical wet tropical soils such as Nit sols which are dominant in more hilly areas. The Planosos and Vertsols form a dominant soil type in the lower lying of the watershed.

CHAPTER FOUR

4-RESULTS AND DISCUSSIONS

4.1 Results

Five main factors were given their respective weight with accordance to the extent to which they contribute to water pollution. In addition to main factors, sub criteria were selected and given based on their influence to pollution. Accordingly, the vulnerability extent of Gojeb Watershed were classified as very high, high, moderate, low and very low susceptible zones. According to the specific objectives:-

- 3175 hectare which is 0.47 % out of the total Gojeb Watershed is very low susceptible
- 366,945.07 hectare which is 55% out of the total Gojeb watershed is low susceptible
- 257,735.57 hectare which is 38.6% out of the total Gojeb watershed is moderately susceptible.
- 38,509.54 which is 5.7% out of the Gojeb watershed is high susceptible
- 160 hectare which is 0.24% out of the total Gojeb Watershed is very high susceptible to pollution.

Table.2 Zones of Susceptibility status of Gojeb Watershed.

No	Status of Susceptibility	Area in Hectare	Area covered (%)
1	Very low Susceptible zone	3175	0.47
2	Low Susceptible zone	366,945.07	55
3	Moderate Susceptible zone	257,735.57	38.6
4	High Susceptible Zone	38,509.54	5.7
5	Very High Susceptible zone	160.09	0.24

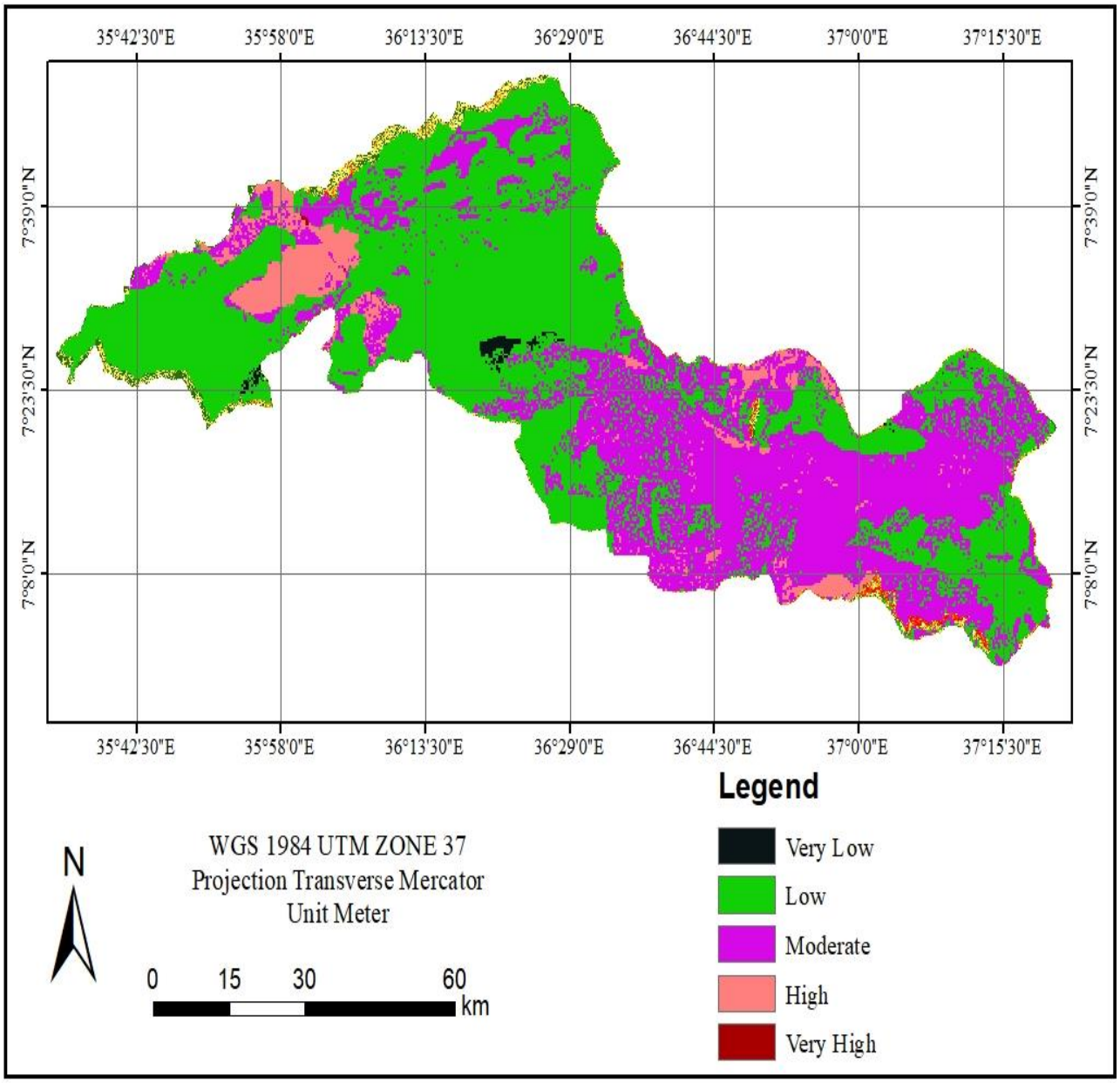

Figure 8 Gojeb Watershed relative susceptibility Zones by AHP.

4.2 Discussion

Each evaluation of vulnerability under the area considered shows that to what extent the specific zone is exposed to water pollution of Gojeb watershed. Considering all factors to vulnerability thematic map was prepared and revealed that which zones are affected severely, moderately and lowly was clearly stated with its respective factor.

The Gojeb Watershed vulnerability was evaluated depending on the map showed in figure 8. According to the map produced above the relative susceptibility of the Gojeb Watershed along the North to South and East to West were with remarkable differences. In the southwestern and northeastern part of the watershed, the vulnerability to pollution is very high. The total area which is labeled as very high to vulnerability is 160 Ha which accounts (0.24 %) of the total watershed area.

In the case of southwestern parts of the watershed the vulnerability of the watershed to pollution is very high because of the land use and soil type. The land use in this region is agricultural land use and hence crop production is dominant (Fig 2). Agricultural land use is high factor to watershed vulnerability because of the chemicals it utilizes for crop production. Most of agricultural activities demand fertilizers, herbicides and insecticides. These chemicals containing pollutants like nitrogen (Nitrate compounds) and phosphorus. As soon as these compounds are sprayed, they can flow in the form of runoff into surface water and can pollute water easily. The other contributory factor for vulnerability of southwestern part of Gojeb watershed is soil type. The dominant soil type of this region is gleysol type. Gleysol type of soil is most dominantly clayey and loamy group of soil. Soil can pollute the water by dropping soluble materials it contains in to water of rivers and streams. Sometimes those soluble materials can dissolve in water and be source of pollution. Soil also can carry sediments and these sediments can pollute water physically, biologically and chemically. In our case the sediments are clay and loamy. Clay by its nature stays on water and can cause water turbidity than sandy soils. Both clay and loamy soils can affect water quality by increasing salinity. Therefore the southwestern parts of the Gojeb watershed is high vulnerable to pollution due to agricultural land use and soil type.

Parts of the north eastern of Gojeb Watershed is also very high vulnerable to pollution. Very high vulnerability in the north eastern parts of the Gojeb Watershed is due to land use type and slope gradient. As mentioned above crop production pollutes water by chemicals in the fertilizers it utilize. This region is dominated by crop production and hence exposed to pollution. Soils also have impacts on water quality by its nature. It either dissolves pollutants or increase turbidity. The other main factors here are slope and rain. The slope gradient of northern gojeb watershed is high or can be characterized as steep. Slope gradient influence water pollution by its nature to facilitate runoff. Runoff containing soluble and non soluble sediments can easily flow in fast velocity. Infiltration rate will be low and flow velocity is high. In this way our watershed could be exposed to pollution. When we came to rain, its impact is also as solid as that of slope. The region of northeast of Gojeb watershed is rainy. Because of this high rain huge sediment with runoff can join water bodies. The sediments in the runoff due to high rain can affect the turbidity, electro conductivity and other water properties. The land use, rain, slope, and rain are responsible factors for very high vulnerability of the north eastern parts of Gojeb watershed.

The next considerable zone of the Gojeb Watershed is highly vulnerable zone to contamination. It is found in the south east, south west and north central parts of the watershed and its total area is 38,509.54 Ha which accounts 5.7 % out of the total Gojeb watershed cover. These portions of Gojeb watershed are high vulnerable due to several factors in together.

In the first instant both in south and in north the common factor to high vulnerability is land use type. The land use type in south west, south east and north centre is agricultural land use which is dominated by cultivation and crop plantations (Fig 2). The mentioned area utilizes chemicals for fertilizer, herbicides and insecticides for their crop production. This chemical utilization has a potential to pollute water. This is one of the reasons to contaminate Gojeb watershed.

Average annual rainfall has highly influenced the north central part of Gojeb watershed. This region receives 1700mm-2000mm rainfall annually which is very high amount than any region in the watershed. High amount of annual rainfall could be a potential factor to watershed vulnerability because rainfall and pollution level are directly interrelated. High

amount of rainfall can be an agent to carry sediment in the form of runoff water. Hence, north central part of Gojeb watershed is high vulnerable due to sediment loads carried by high rainfall in the region. The soil type of north center and southern east and west parts of Gojeb watershed are with considerable domination of arci sol and nito sol type. Both arci sol and nito sol are rich in clay type of soil. Clay rich type of soil is highly responsible for water pollution because of their capability to carry sediments and hence, increasing turbidity and electro conductivity. Therefore, soil properties of the north center, south west and south east of Gojeb watershed is responsible to high vulnerability. One of the important factors for high vulnerability of north center, southwest and south east is slope gradient. The slope of the mentioned region of Gojeb watershed is high (Fig 4). Slope gradient let the high amount of rain's runoff to flow with high speed and hence, detaching soil particle rate increase. In this regard it can affect vulnerability high. Geological condition of the south west, south east and north center has its own impacts on vulnerability to watershed. The bed rock type of the mentioned region is dominated with upper basalt and lower basalt which are igneous types of rocks (Fig 3). However, faults are exposing factors to contamination. Because of geologic faults and ashes it is clear that water rock interaction to take place. Therefore, to some extent bedrock type could have an impact to vulnerability. Generally, rainfall, slope, land use, soil type and geologic conditions are major factors to high vulnerability of southwest, southeast and north center of Gojeb Watershed.

From the total area of Gojeb Watershed 257,735.57 hectare which is 38.6 % is moderately vulnerable to watershed pollution. Moderately vulnerable portion is the mostly the south central and the north eastern part. This region is moderately affected because of many reasons. It is clear from land use, slope, and rainfall maps (Fig 2, 4 and 5). The rainfall of this region is as low as less influencing factor. The slope is not steep but moderate. The land use type is bush land and to some extent forest cover is also high. Therefore, the mentioned region is moderately vulnerable to watershed pollution due to rainfall, slope and land use type.

The largest area of Gogeb watershed is low vulnerable zone. It covers 366,945.07 hectares which is 55 % out of the total area. It is found in the southern western tip, south eastern part, north center and northern tip. The south tip, the south eastern are low vulnerable due to three main factors; namely land use, slope and average annual rainfall.

One of the major influencing factors for susceptibility is land use land cover.The most dominating land use type in the southwest, south and south east is grassland. As we know grass land is not polluting land use type and hence the region gets free of pollution due to land use type. The next factor for less susceptibility is slope. The slope gradient in the south of Gojeb watershed is moderate and tends to gentle. Gentle slope can never increase the flow velocity of runoff whenever there is continuous rainfall. Slope also affects by reducing infiltration rate. Hence, slope of the southern region is not positively related to watershed vulnerability.

Average annual rainfall of the south part of Gojeb watershed is less than the central and the northern part. As rainfall is less, its contribution to water pollution is less. This is because when the rain amount is less, the volume of sediment load carried in the rain water would be negligible.

The north tip and the north central part of Gojeb watershed is low vulnerable because of forest cover. The land use in the north is most dominantly forest. Forest land use is negatively related with watershed vulnerability.

The very low vulnerable part of Gojeb watershed is 3175 hectares and accounts 0.47% of the total. It is very low vulnerable because of all main factors like soil, land use, slope, bed rock and rainfall. The land use type and water quality is related directly. The land use type in the central part and in the north the entire region is covered with full dense forest. This dense forest is not responsible to affect water quality negatively and hence, low vulnerability observed. Next to the land use of the watershed considerable factor to vulnerability is bedrock type. The geologic type of the northern and central gogeb watershed is majorly dominated with igneous type of rocks. The watershed’s water quality can be affected by geologic condition of the region. Different types of rocks such as igneous, sedimentary and metamorphic rocks can affect water quality on the basis of their properties. Gojeb watershed in its central and northern part is dominated with igneous rock. Geochemical reaction with in igneous rock is weak and can never let water to percolate through it. This rock-water interactions prohibit water pollution to occur and hence, gojeb watershed is low vulnerable in the region where there is igneous rock is abundant.

CONCLUSION

This study used the so called Analytical Hierarchy process (AHP) method and tried to describe and evaluate five main factors which are responsible for water pollution of the watershed. These factors were weighed independently and are namely slope gradient of the watershed, annual average precipitation, Bedrock type, Land Use Land Cover and Soil type. Each factor has its respective influence on water quality degradation of Gojeb Watershed. It is carefully evaluated which factors can highly affect water quality and which affects with low extent and their respective zones. Accordingly, Gojeb watershed is with very high susceptibility threat in the South western and north eastern parts due to LULC and soil type than other factors. The total area classified as very high vulnerable to contamination is 160.09 hectares which is 0.24 % of the total watershed in area. The high vulnerability zone of Gojeb watershed is found south east, south west and north center. High vulnerable parts of the watershed are 38,509.54 hectares and it is 5.7% out of total. It is high vulnerable to pollution because of factors like land use type, slope gradient, soil type, bedrock type and soil type. These all factors contribute the watershed to be vulnerable to pollution.

Some parts of southwest, southeast, central and northeastern part of Gojeb Watershed is moderately vulnerable to pollution. Moderately vulnerable region is 257,735.57 hectares and accounts 38.6 % out of the entire Gojeb Watershed. Its moderate vulnerability is due to factors such as land use land cover, slope and average annual rainfall.

The southern tip, southeast, the central and northern tip of this watershed is low vulnerable. Total area labeled as low vulnerability is 366,945.07 hectares and accounts 55% of the total watershed area. The low vulnerability occur because of factors like land use land cover, slope gradient and rainfall size. The land use land cover of indicated zone is covered with dense forest cover. Forest is negatively related to water pollution and hence this zone is low vulnerable to pollution. The slope of the south part is gentle than the north. As the slope is less, the tendency to carry the sediment and run off is in low flow velocity and this condition minimizes the probability of water pollution. The rest zone of Gojeb Watershed is very low vulnerable portion to pollution. Very low vulnerable zone is as wide as 3175 hectares and it is 0.47 % out of the Gojeb watershed.

Recommendation

The susceptibility of Gojeb Watershed is in threat and need to reclaim through different techniques. Now a day the growing household level land shortage creates landless youths. Because of this reason agriculture land seekers are in need to get the land and may be one factor to land use type conversion from forest to crop land use. Therefore, it is better to strengthen off-farm income generating activities to accommodate the increasing population. Governmental and Non-Governmental institutions must create work opportunity to landless youths in non-agricultural activities so that pressure on land to be minimized.

The other important measure to reclaim this watershed is forest resource development, protection and need to be devised to counteract the deteriorating forest, shrubs and bushes. The reforestation and protection of trees and shrubs must be done to sustain the natural ecosystem to reclaim the water quality of the Gojeb Watershed.

In addition to the above measures the soil and water conservation activities are very important. Water and soil must be protected through different mechanisms by making the empirical methods more scientific and technology supported. Terrace building and other conservation techniques must be developed to reclaim the Gojeb Watershed from susceptibility to water pollution.

The major action to overcome the challenge of the Gojeb Watershed susceptibility is studying to better understanding of the current challenge. In relation to Gojeb Watershed susceptibility to water quality degradation require further and detail research and investigation to understand all the impacts. This research will guide us to evaluate all the necessary factors and enable us to take immediate measures to protect it.

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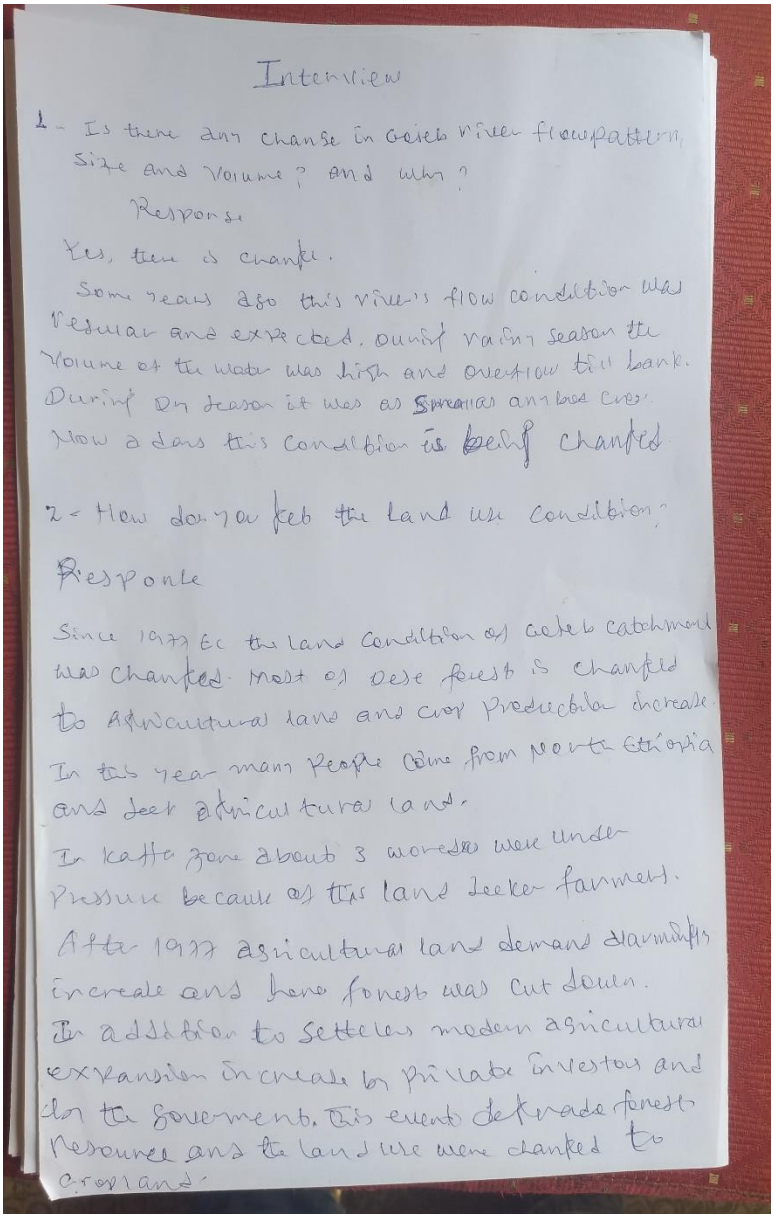
APPENDIX

On site Photos at Gojeb River

Interview Evidences



Interview

1 - Is there any change in Gelab river flow pattern, size and volume? and why?

Response

Yes, there is change.

Some years ago this river's flow condition was regular and expected. During rainy season the volume of the water was high and overflow till bank. During Dry season it was as Stream and base Cross. Now a days this condition is being changed

2 - How do you feel the land use condition?

Response

Since 1977 Ec the land condition of Gelab catchment was changed. Most of Dese forest is changed to Agricultural land and crop Production increase. In this year many people come from north Ethiopia and seek agricultural land.

In katta zone about 3 woredas were under Pressure because of this land seeker farmers.

After 1977 agricultural land demand dramatically increase and have forest was cut down.

In addition to settelers modern agricultural expansion increase by private investors and also the government. This events degrade forest Resource and the land use were changed to cropland.

3- Do you perceive soil erosion in Gobeb area?

Response. Yes

The farmland around Gobeb catchment is experiencing soil erosion from time to time.
Soil from the Northern and steep areas are washed away during rainy season. Especially woredas like Gimbo, Gawata, Adiro, Shebe are seriously experiencing server soil erosion.

4- What is the severity of soil erosion?

Response:- It depends

In some areas where slope is steep and rain condition is high, the severity is high.

In the parts of Gobeb catchment where rain is low and slope is moderate, the severity is moderate

Generally rain condition is low and slope is gentle no soil erosion and can be described as minor soil erosion.

Generally soil erosion consequently occur in the parts of Gobeb catchment where high rain fall, steep slope and less forest areas.

5- What is the cause for soil erosion you think?

- Deforestation
- Steepness of slope
- High amount of Rainfall
- Runoff coming from upslope
- Ploughing way.

6- What would be the possible consequences of soil erosio

- Soil fertility decrease and affect production
- Land productivity become less and lower from time to time
- Crop yields could be changed.
- Rills and gullies can be created.

7- How can we control the soil erosion?

In our locality soil erosion can be controlled by three mechanisms.

a- By Afforestation.
b- By terracing.
c- By changing the ploughing methods