ADDIS ABABA UNIVERSITY
ADDIS ABABA INSTITUTE OF TECHNOLOGY, SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

GROUNDWATER VULNERABILITY AND POLLUTION RISK ASSESSMNT IN THE CASE OF UPPER AWASH RIVER BASIN

Thesis submitted to the school of Civil and Environmental Engineering, Addis Ababa University, Addis Ababa Institute of Technology for the degree of Master of Science in Civil and Environmental Engineering/Water supply and Environmental Engineering

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February 17, 2019
Addis Ababa, Ethiopia

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3. Dr. Ing. Mebruk Mohammed (PhD) (External Examiner		07/07/19

Acknowledgements

It is my pleasure to acknowledge my advisor, Dr. Assie Kemal, for his valuable advice and follow up.

I would like to extend my heartily thanks for MOWIE (GIS and Information management directorate and Groundwater directorate), Ethiopian Geological Survey, Water works, design and Supervision enterprise (Hydro-geology case team), Addis Ababa City Water supply and Sewerage Authority (Water Quality case team leader and Hydro-geology Case team leader) and Oromia Regional State Water Resources and Energy Bureau, Water supply facility Operation and maintenance team

My pleasure is also extended to Dr. Agizew Nigussie (school Dean) and Dr. Mebruk Mohammed for their technical and valuable advises.

And I am proud to forward my heartfelt thanks for International Non-Governmental Organization (INGO), Pact Ethiopia has given me the opportunity to learn, adapt and innovate.

Acronyms and Abbreviations

GIS: Geographical Information System
ANSWERS: Areal Non-point Source Watershed Environment Response Simulation
GWLF: Generalized watershed loading Function
WAM: Watershed Assessment Model
GLEAMS: Groundwater Loading Effects of Agricultural Management Systems
AGNPS: Agricultural Non Point Source Pollution Model
SEDMOD: Spatially Explicit Delivery Model
SA: Scottish Approach
ANFIS: Adaptive Neural Fuzzy Inference System
BASINS: Better Assessment Science Integrating Point and Nonpoint Sources
SWAT: Soil and Water Assessment Tool
IWMP: Integrated Watershed Management program
IWRM: Integrated Water Resource Management
AMD: Acid Mine Drainage
BMP: Best Management Practices
FAO: Food and Agriculture Organization of United Nation
IWSM: Integrated Watershed Management
WHO: World Health Organization
WSP: Water Safety Plan
WASH: Water, Sanitation and Hygiene
EDWS: Ethiopian Drinking Water Standard
MOWIE: Ministry of Water, Irrigation and Electricity
EIA: The Environmental Impact Assessment
UARB: Upper Awash River Basin

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Abstract

Water used for different purposes is harvested in the watershed system; largely in the river basin system. To maintain the requirement of these purposes, both quantity and quality of water for ecological, social and economical development could be manage appropriately through integrated water resource management. However, scarcity and poor water quality are the major challenges of the world due to climate change and water pollutions. These challenges trigger further ecological, economical and public health impacts. In Ethiopia, evidence shows that upper Awash River sub-basin is the most impacted river basin that is why protection of both groundwater and surface water resources come to an essential approach through investigation of hazards, vulnerability and consequences of the water sources. This research is designed to identify vulnerable and risk of ground water pollutions so as to indicate the requirements of protection of vulnerable aquifer considering seven important factors of groundwater vulnerability as well as land use management. To achieve these objectives, digitized data for parameters and secondary data from concerned sectors have been collected. These collected data and Shape files have been analyzed using ArcGIS 10.2 software and SPSS version 24. Sensitive analysis, model validation, vulnerability index and risk index have been produced. Accordingly, as the difference in percentage (6.48% - 16.77%) of theoretical weights and effective weights is not much more differ, theoretical weights are used for DRASTIC model analysis and also variation index due to removal of each parameter, the most sensitive parameters to groundwater pollution orderly are Impact of Vadose Zone, Depth of water, Aquifer media, Soil type, Topography, Net Recharge and Hydraulic conductivity. The validation confirmed that 72% of variation in index values is related with nitrate concentration and a unit increase of nitrate concentration increase vulnerability index by 2.26 times.

Step by step analysis of each intrinsic parameter has been done. Upper Awash sub basin has 18% high and very high vulnerable area; 26% moderately vulnerable area and 57 % very low and low vulnerable areas whereas only 1% of the area is high risk of pollution; 31% of the area is moderate risk pollution; and 67% of the area is low risk for groundwater pollution.

The output of this study will have greatest advantage for groundwater protection measures provide that the limitation of environmental variability and qualitative index methods. Researchers are recommended to support these findings with field observations and strong approaches for further potential risks of groundwater in those identified vulnerable areas.

CHAPTER ONE

1. INTRODUCTION

1.1.Background

Water used for different purposes is harvested in the watershed system that comprises the complex interaction of surface water and groundwater sources. To maintain the requirement of these purposes, both quantity and quality of water for ecological, social and economical development could be manage appropriately through Integrated Watershed Management (IWSM) approach which addresses the interdependence of the different uses and interests of users of water resources(Ministry of Water Resources(MoWR) and Ministry of Water Resource (MoWR) 1999). Beside addressing other socioeconomic dimensions, evidences are shows that watershed management could also reduce problems of public health and enhance overall empowerment of families; that means IWSM is a sound approach so as to improve sustainability and social-ecological resilience (Nerkar et al. 2015) (Parkes et al. 2010). In the scope of IWSM, watershed characteristics such as population growth, agricultural practices, industrialization, mining, urbanization, local climate, and hydro-geological characteristics are factors that are causing deterioration of quantity and quality of water sources.

In the water sector and in this era, scarcity and poor water quality are the major challenges of the world due to climate change and water pollutions which are also high influential factors on public health (Kundzewicz et al. 2016) (Bunch et al. 2014). The linkage between water quality and public health was understood since long time as the result through protection of water sources starting from which water is harvested is more effective than treating contaminated water sources (Davies and Mazumder 2003).

Since then to protect public health, water treatment alone is not sufficient as it is not physically or economically feasible options. As a matter of facts, World Health Organization (WHO) designed five components of preventive management framework for safe drinking water. These include health based targets, system assessment, operational monitoring, management plans and system independent surveillance(Davison et al. 2005). The first two components have direct relation in this research concern on groundwater vulnerability assessment to protect ground water sources for domestic use.

Hence, understanding the vulnerability of groundwater is the bases for water quality management in terms of areas that need protection from potential pollutants in order to incorporate public health, irrigation and industrial water quality standards in the integrated watershed management system as well as it provides inputs for revision of policies and strategies of water sector and environmental protection. Groundwater vulnerability assessment result has crucial importance for groundwater protection particularly for the study areas, upper Awash River basin, part of the Awash River basin which have intensive agricultural irrigation schemes, different types of industries (up to largest scale industrial village), millions of urban and rural residents including Addis Ababa and emerging cities in Oromia regional state. This is therefore the study provide strong evidences related to groundwater vulnerability using GIS based overlay analysis of hydro-geological characteristics of the sub-basin. It is also indicating areas for further investigation on the level of groundwater pollution risks.

1.2. Statement of the Problem

Safe and adequate water supply has huge contributions for health and well-being of humans, ecosystem and socio-economic development. However the adequacy and safeness of water is not evenly maintained throughout the world. The solutions of these problems are beyond the water sector capacity in areas with already-scarcity and deterioration of quality water resources. It is may be because of high demands and climate change; for instance, water withdrawals have tripled over the last 50 years, and water pollution and degradation of water quality is becoming the front critical concern at global level(United, n.d.).

In 2015, around 29% (844 million people) of the world population had not basic drinking water services. The problem is much more in African content; for instance, from 10 countries of the world with limited water supply services eight countries are located in Sub-Saharan Africa(Water 2017). In connection to these, the problem may be underestimated as comprehensive adequate and safe water supply data in terms of accessibility, quality and public health effects are not sufficiently reported and managed. As part of Sub-Saharan region, for example in Ethiopia with limited evidences, Ethiopian Health and demographic Survey (EHDS 2016) revealed that more than 91% of the households were not treating their drinking water. Only 7% of households use appropriate treatment methods. Thus, vulnerability assessment is important at least to protect groundwater sources from contaminants.

Like water quantity, water quality is importantly significant so as to satisfy basic human and environmental requirements; however it has get less investment, scientific support, public attention and political commitment. That is why insufficient data is suggested that there has been an overall improvement in water quality on a global scale (Allouche et al. 2017). Despite the fact that to safeguard the residents of Upper Awash River Basin and its downstream, application of risk-based water management approached based on WHO's framework is crucial; however, the reality of practicing water quality monitoring and surveillance is very poor particularly in developing countries; for instance, across 10 countries of sub-Saharan Africa, most concerned institutions are not applying water tests specified by WHO guidelines(Peletz et al. 2016).

In Ethiopia, water quality issues are boldly written in the Ethiopian water resource policy and strategy legal document but water quality management is still challenged.

Beside institutional based poor management of water quality by service providers, existence of deterioration of drinking water quality have been justified in many peer reviewed articles. Expansion of agricultural land with utilization of pesticides, fertilizers and organic matter, soil erosion sediments ; growth of the livestock sector associated waste, including manure and veterinary medicines and growth promoter hormones are major concerns in Agricultural sector which are having serious implications on water quality(By, n.d.). As part of the world and being developing country, these problems are manifested in Ethiopia as a whole and in the study area.

In other hand 80% of wastewater simply disposed to the ecosystem without being treated at global level (Nations 2017). Particularly in low income countries only 8% of the wastewater is treated the other huge proportion of the wastewater discard and causes surface and groundwater pollutions (Resource, n.d.). Urbanization which requires high demand of water supply with high discharge of wastewater to the ecosystem is also one of the global challenges. In 2014, 54% of the world's population was living in urban areas and by 2050 it is projected to be 66%. Urbanization is faster in Africa than other regions. As part of Africa, Ethiopia is expected to become significantly more urbanized in the coming years (Nations 2014). Having this, urbanization is assumed to be more in the upper Awash River basin areas due to the presence of Addis Ababa and cities in the Oromia regional state.

Upper Awash River Basin (UARB) which is among the sub basins of Awash River basin is prone to water pollution because of population growth, industrialization, urbanization, poor wastewater disposal systems, agricultural expansion and flowering farms, loss of vegetation, soil erosion and other significant factors. For instance, presence of higher concentrations of metals such as As, Cr, Fe and Pb around impacted areas had been confirmed in the sub basin(Itanna, n.d.) (Ethiopian Journal, Studies, and Vol 2013). Critical Water quality deterioration situations are also observed similarly in other three river basins of Ethiopia (Nile, Omo - Gibe, and Tekeze) as the result of agricultural practices, coffee processing, and urban landscapes compared to non impacted forested landscapes (Awoke et al. 2016). These all have negative impacts on public Health and ecosystem at large.

Awash River basin is the most important but polluted river basin than other basin of Ethiopia. It has different scale irrigation schemes, industrial corridor, drinking water supply schemes for urban and rural residents, untreated different sources of waste water, and eroded soils which are all critically affecting water quality of the river basin system(Hague 2013). To solve water pollution challenges, focusing on water quality management through inter-sectoral collaboration supported by scientific evidences and system management are some of the urgent options; however, basin wide analysis shows that lack of cooperation between stakeholders, lack of knowledge and evidence for policy documents and decision making, absence of enforcement strategies, unavailability of appropriate working guide lines and disconnected institutional setup at the grass root level are still major problems for the sector (Awoke et al. 2016) (Capacity, n.d.). Therefore, this study provides inputs for water quality management to protect groundwater from potential contaminants by analyzing hydro-geological parameters and mapping areas to be protected. It is because water in most parts of Awash River is not fit for bathing and drinking due to untreated sewages from urban centers and industrial effluents from several manufacturing and agro-processing, tanneries and leather processing, food and beverage, textiles, metal and chemical industries, sugar and cement factories, construction material quarry sites and natural systems. Pollute water bodies and recharges from precipitation contaminate groundwater (A. River et al. 2017), (Report 2016).

1.3. Significance of the Study

Upper Awash River basin is home of millions of peoples with many industrial areas and different settlement patterns like urban, semi-urban and rural villages. In the sub- basin, there are more economical areas which may have contribution of point and non point sources of water pollutions. Good water quality together with adequate quantity of water are necessary for the achievement of one of the Stainable Development Goal (SDG) that aim to ensure availability and sustainable management of water and sanitation for all including water quality targets which requires a preventive approach better than depend on water treatment and water testing for only selected hazards.

Awash River basin is the most polluted basin of Ethiopia because of population growth, urbanization, industrialization, agriculture and climate change as well as geological formation and Interaction of surface water to groundwater contribute for pollution of groundwater. As the result, protection of groundwater should be done before contamination as polluted groundwater is not easily treated or removed from the groundwater reservoir.

Groundwater is a crucial resource for the multi aspect of country's development programs, considered as the most resilient sources particularly during drought and currently it is significant source of drinking water for urban and rural residents in the basin. Achievement of SDG, application of environmental impact regulation of the country could not be realized without understanding of vulnerable areas and designing of groundwater quality protection mechanisms. Therefore, the result of this study is significant to minimize groundwater pollution risks by applying protection measures on the identified vulnerable areas and aquifers for risk based water quality management. And also MOWIE and Awash River Basin administration Authority benefited to achieve water sector goals and to have inputs for the revision of water sector strategies as well as environmental protection regulations.

Generally, the study results are important to mainstream groundwater protection mechanisms by consider different management scenario for groundwater resources management; resource allocation and prioritization of groundwater-related activities and integration with different land uses; for sector integration so as to define role and responsibilities, bases for further research and inputs for risk based management of groundwater resources.

1.4. Research Questions

What is the status of vulnerability of groundwater in Upper Awash River Basin?

What are the most sensitive factors for the status of groundwater vulnerability?

What are the vulnerable areas (woredas) that overlaid in the result of the model?

What the specific interventions (recommendation) based on delineated vulnerable zones?

What are thematic areas of future investigation based on the lessons from the investigation?

1.5. Objectives of the Study

1.5.1. General Objective

- The general objective of this study is to prepare groundwater vulnerability map that indicates delineate vulnerability zones for contaminations, identified intrinsic properties of the aquifers in order to assist groundwater resources management (planning, protection, and monitoring of groundwater) for Upper Awash River Basin (UARB).

1.5.2. Specific Objectives

- To identify intrinsic properties of the upper Awash river basin aquifer that aids in groundwater quality management and protection measures
- To produce groundwater vulnerability map that indicating vulnerable zones for contamination in the case of Upper Awash River Basin (UARB)
- To map groundwater pollution risk in relation to land use land cover

CHAPTER TWO

2. LITERATURE REVIEW

Safe and adequate water supply is a prerequisite for human wellbeing and development. To achieve this water quality objective, it can be implemented by using a combination of methods including protection of water sources, management of distribution systems, monitoring treatment processes, and safe handling and storage. The overall process could be supported by the development of drinking water guidelines that fit national, regional and local contexts focusing on the environmental, social, economic and cultural circumstances. Water quality describes chemical, physical, and biological characteristics of water. The characteristic of water quality called parameters or quality indicators which can be measured in the natural bodies, in the drinking water and in the discharged water(*Water Quality Modelling for Rivers and Streams*, n.d.). Each indicator requires specific techniques of detection and analysis for specific prevention and controlling tasks. Any use of water has its minimum and maximum values which are determined after appropriate procedures and different considerations. In the practical point of view, the most significant water quality indicators are Temperature, pH, Dissolved oxygen (DO), Turbidity, Conductivity, Total organic carbon (TOC), Bacteria, Viruses, Chemical oxygen demand (COD), Biochemical oxygen demand (BOD), Metals and non-metals (Cr, Cd, Ni, As, Hg, Na, Br.), Phosphates, Nitrogen compounds, Organic compounds, Suspended Solids (SS), and Total Dissolved Salts(TDS). Although water quality standards for domostic, reacrtional, industrial, irrigation and ecosystem have been developed by the responsible bodies arround the world, water pollutions are challneging and affecting human welbeing, ecosystem health and development due to different factors. Consquently, to protect water qaulity from water pollutants, the first step should be identification of vulnerable water sources including surface and sub-surfaces. This is therefore, this groundwater vulnerability assessment using the delineated vulnerable zones for contaminations for prioritizing areas during groundwater management and environmental protection programs accomplished in Upper Awash River Basin (UARB). This literature review tried to summarize thematically focusing on groundwater vulnerability, the requirements of groundwater protection from pollutants and associated factors with surface and subsurface water pollutions.

2.1. Water pollution and associated factors

Around the Globe, research findings are justifying strongly the presence and variability of water quality parameters with respect to spatial and temporal variations. The variability attributed time to time and place to place which have complex relationship with the wellbeing and health of human being and the ecosystem at large. These are depending on watershed characteristics that influence largely the hydrological responses of the area. For instance, except forest land, land use- land cover, impervious surfaces, and crop land have negatively correlated with water quality.(Chen et al. 2016). In contrast this study conducted in China, average nitrate loadings were high in the forested zone and significantly lower in the grassland zone in Netherlands(Hefting et al. 2006). The dynamic of Biliuhe water Reservoir approved that water quality was worsened in summer and better in winter season and even it has been better from upstream than downstream it(T. Wang, Xu, and Liu 2017). It is confirmed that the spatial and seasonal changes were also influencing the surface water quality of Burio River in Costa Rica (Mena-Rivera et al. 2017). Water quality parameters are very dynamic during flooding which one of the hydrologic event from the watershed characteristics; especially at the beginning of the event in the urban settings, pathogen and contaminant levels in the flood water are almost as high as in sewers(Nguyen et al. 2017). In Songhua River basin, human activities are influencing water quality. Among those activities, industries located at its upstream were the major pollutant sources of water resources (Wei et al. 2017). Collectively water quality has many diminutions and affected by complex factors attributing to the watershed characteristic such as climate, vegetation, geology, topography and socio- economic characteristics. For detailed review, the following explanations are given to major factors which have high impact on water quality.

1. Impact of Climate change on water quality

Climate change is induced by emissions of green-house gases anthropogenic. The period from 1983 to 2012 was the warmest of the last 1400 years particularly in the northern hemisphere. Projected surface temperature over 21st century indicates that extreme precipitation events will become more intense and frequent which will have impacts on the natural systems of the Earth (IPCC 2014). In Ethiopia because of climate change, spring and summer rains have declined by 17.5% since the mid-1970s (USGS 2012). For instance, the trend analysis in the selected sites shows that *Kiremt* seasons have been decreased in some sites where as *Belg season* has not significant change (Dr.Ing.Abdulkarim 2006). At watershed scale also there was significant decline of rainfall in June to September for the Baro-Akobo, Omo-Ghibe, Rift Valley, and Southern Blue Nile watersheds (Toggweiler and Key 2001).

It is noted that climate change affects the overall hydrology cycle. Both water quantity and quality are extremely influenced by climate change through reduction of available water sources or increases the exposure to unsafe drinking water. Floods and droughts are some of the main results of climate change which are affecting biological, physical and chemical components of water quality ultimately leading to the risk of waterborne diseases("Impact of Climate Change on Waterborne Diseases" 2012). Evidences are pinpointing that the risks of campylobacteriosis and salmonellosis are associated with weekly temperatures; Erratic, irregular and severe rainfall events are also associated with the occurrence of Cryptosporidium species (Semenza et al. 2012). For instance, impact of climate change on water quality across six rivers of United Kingdom shows that a wide range of impacts are identified depend on river character, catchment location, and flow regime (Whitehead et al., n.d.).

Extreme temperature and rainfall increase the concentration of Dissolved Organic Matter (DOM), nutrients, pathogens and toxics in the water bodies. These increments of contaminants are able to create Disinfectant Byproducts (DBPs) in drinking water; speed up the growth of pathogenic organism, boost pathogen survival probability and facilitate the transportation of emerging substances. It is justified that watershed storm water is one of the source of coliform organisms. In case of USA, half of the waterborne disease outbreaks were occurred during the last half century followed by a period of extreme rainfall. Articles are justifying climate change has strong relation with poor water quality and occurrence of waterborne disease; hence, increased temperature threaten waterborne diseases linked with water quality (Jung et al. 2009). In other hand, amplified water temperatures will affect chemical reaction kinetics that lead to deteriorations of water quality. Dried up rivers due to climate change have lower flows and minimal velocities. Higher water residence times in rivers and lakes will enhance toxic algal blooms and reeducation of Dissolved Oxygen (DO) levels. Storms at the end of drought periods will flush nutrients from urban and rural areas(Taylor et al., n.d.). In general, seasons of the year in the context of climate variability influence water quality; rainy season carries dead vegetation which can causes color and taste, organic extracts and bacteria in to the water bodies whereas in dry season produces much more dissolved salts and minerals. Floods and low flows are seasonal effects having negative roles on water quality(Yu et al. 2015).

2. Impacts of Land use-land cover on water quality

Food and Agriculture Organization of United Nation (FAO) indicated that the presence of association of population growth with increased demand for agricultural land and forest loss. For example, there was 7 million hectares loss per year in tropical countries from 2000–2010 (Challengesopportunities 2016). These loses affects the contribution of forest in maintaining water quality through reduction of soil erosion and sediment in water bodies(*' PSFTUT BOE XBUFS*, n.d.).

In 2009, the world's agricultural production has grown at least 3 times over the period while the cultivated area has grown only by 12%. Almost around 11% of the world's land surface for crop production which accounts for 70% of all water withdrawn from aquifers, streams and lakes. And also 40% of the irrigated area is now reliant upon groundwater("Agriculture , Forestry and Other Land Use Emissions by Sources and Removals by Sinks," n.d.). Reviewed reports are also showing that changes in land use create impacts on ecosystem to sustain food production, maintain freshwater and forest resources, regulate climate and air quality, and control infectious diseases(Foley et al. 2005).

Deforestation of forests and change to crop land, and pastures or grass land resulted in deterioration of water quality. This is witnessed that forest provides improved water quality condition. For instance, in North America, majority of municipalities relied on forested watersheds to provide adequate quantities of high quality water for human use(Neary, Ice, and Jackson 2009). In other hand , higher total nitrogen concentrations and electric conductivity in streams were related to land use which is dominated by pasture and narrower riparian forests whereas higher diversity of macro invertebrates and DO concentrations were higher in wider riparian forests (Tanaka et al. 2016). In 2006, the impact of land use on water quality is also documented in the upper Nisa catchment in the Czech

Republic; it is because of settlement areas and arable land. Smallest level of concentration for all monitored parameters except Cd, Mn, SO_4 in the forest areas where as densely populated areas reduce water quality (Kändler et al. 2017). The impacts of land use on the water quality in a river system at different scales were found to be significantly associated (Vrebos, Beauchard, and Meire 2017).

In case of Ethiopia, land use land cover are affected by land degradation which mainly because of rapid population growth, soil erosion, deforestation, and unbalanced crop and livestock production (Taddese 2001). For instance, in Lake Ziway watershed which is neighboring the study area, the change of woodlands into agricultural lands and settlement areas are the major changes. Agricultural lands and settlement areas increased from 57% to 75% in 2014 after 41 years are resulted in the decrease of woodlands from 26.16% to 6.6 3%. This is due to anthropogenic factors including population growth, land policy changes and deforestation(Desta, Lemma, and Gebremariam 2017). Environmental Impact Assessment (EIA) carried out in two large scale Irrigation Schemes located in upper Awash River basin and Blue Nile Basins shown that there were different impacts due to irrigated schemes on soil and water quality, downstream and hydrology; accordingly groundwater table has risen due to improper irrigation management and seepage of reservoirs in the Upper Awash River Basin (UARB) site; this leads to quality of ground water contamination (Ruffeis et al. 2016).

The association of land use and land cover with water quality with an ultimate impact on the occurrence of public health problems demonstrated and justified around the world. Little Miami River watershed in the USA, lower water quality was observed at downstream at which urban land was dominated and nearby point source pollution attributed(X. Wang 2001). Riverine Phosphorus export, the soil total Phosphorus and Olsen Phosphorus contents in croplands were all positively related to anthropogenic Phosphorus. Although the livestock accounted for the largest part of the anthropogenic Phosphorus, the cropland contributed the greatest to catchment Riverine Phosphorus export (Meng et al. 2017). In Huzhou city, Chemical Oxygen Demand (COD) and petroleum were increased more in the period of flooding while Dissolved Total Phosphorus (DTP) and Total Nitrogen (TN) were polluting more in low flow water period(Xiao et al. 2016).

Water quality problems associated with pathogens have been associated with grazing animals whereas animal production are associated with Nitrogen and phosphorous(Hubbard, Newton, and Hill 2004). At watershed scale in a pasture-dominated watershed, buffer strips and grazing management were two most important Best Management Practices (BMP) to avoid water quality problems due to total nitrogen and total phosphorus from the pasture areas (Chaubey et al. 2010). These reviewed documents have strong evidences on land use-land covers which are influential factors for water quality improvement at watershed level in particular at river basin in general.

3. Impacts of Population, urbanization, industrialization & mining on Water quality

The impact of population growth, urbanization, industrialization and even mining on water quality is well documented around the world. In Sri Lanka, from Kelani River, the analysis of impact of population growth on the water quality witness that when the population density is approximately less than 2375 people/Km^2, the water quality satisfies drinking and bathing water quality standards at the watershed level whereas when the population density is less than 2672 people/Km^2, it can be used for fish and other aquatic organism (Liyanage and Yamada 2017). In 2015, sample results from five rivers located in Korea reflected that moderately urban land uses were has negative impacts on water quality; however, very low and very high urbanization have not had relationships with water quality. Despite this evidence, when urban land used more than 31.5% of the watershed areas, more comprehensive best practice management would be required to improve stream water quality(Hwang et al. 2016). In addition, in 2017, incremental of housing construction rates and industrialization were affecting the water quality of rural areas in Beijing (Zhang et al. 2017). These are also supported by other evidence conducted in Shanghai which is indicating that spatial pattern of surface water quality was determined by the level of urbanization(Junying Wang et al. 2008).
Specifically the pH of stream water has been fluctuated from 2 to 11 because of industrial wastewater effluents. It impacts on multiplication of microorganisms in relation to natural purification of water in stream and river bodies (Ntengwe 2005) and point sources from industrial effluents are contributory to microbial pollution of river and water quality parameters (“No Title” 2013). Samples of water from River Ona and River Alaro (Nigeria)

are indicating the levels of nitrate, chloride, total phosphorus, total solids and oil and grease were higher in the industrial zones due to industrial discharges which had negative impact on the surface water qualities (Osibanjo, Daso, and Gbadebo 2011). Study conducted in three cities of Africa such as Accra, Addis Ababa and Hyderabad were shown that urban growth, wastewater production and use of urban irrigation land are leading to environmental degradation particularly it created negative impacts on downstream areas (van Rooijen et al. 2010). It is also realized in Awetu - Kito drainage system located in Jimma town is affecting BOD, DO and Orthophosphates of the downstream water quality because of industrial and institutional activities. In this article, Small-scale industries, institutions and residential areas were contributing 50%, 15% and 23% of the water pollution load on Awetu river, respectively (Environment Journal 2016). On top of it, in Jimma zone, the effect of coffee processing plant is affecting the physicochemical properties of receiving water bodies due to effluent discharge on downstream sites compared with upstream sites (Tekle et al. 2015). In Ethiopia, from the type of industries, textile is the first and food industry is the second sources of pollutants (Ademe and Alemayehu 2014).

In other hand, mining has greatest impact on water quality; for example, in South Africa, water quality problem was below standards due to the presence of acid mine drainage. it is recognized as one of the more serious environmental problems in the mining industry (Ochieng, Seanego, and Nkwonta 2010). In Streams of Aljustrel Mining Area (Portugal), because of impact of Acid Mine Drainage (AMD) on Water Quality, Stream Sediments and Periphytic Diatom Communities were confirmed that highest metal concentrations were found at impacted sites as well as presence of more spatial variations were identified than seasonal variation(Teixeira et al. 2008). In addition, around Akyem-Abuakwa areas more than 26% of the variability of Arsenic and Mercury as the primary contaminants were accounted because of Artisanal gold mining (Attua, Annan, and Nyame 2014). In Zhulube catchment (Zimbabwe), gold panning was also induced increase of sediment, elevation of sulphates and introduction of the toxic metal mercury into the aquatic environment(Basin et al. 2004). It is due to easy, quick and inexpensive processes mercury in the gold mining is used (Hrqdugr et al. 2013). Water quality is highly degraded and high pollution potential occurred in Malaysia, Bestri Jaya mining catchment (Ashraf, Maah, and Yusoff 2012). In general, evidences are realized that mining industry whether in small or large scale is affecting water quality of the catchment areas having ultimate effect on surface water and groundwater quality.

4. Effects of topography and hydrogeology on water quality

Watershed planning should consider the percentage of impervious surface in the watershed in order to design preventive measures to achieve the desired level of surface and sub-surface water quality in a given system (Brabec, Schulte, and Richards 2002). Percentage of impervious surface area is a suitable indicator of water quality. As per the reviewed article, planning to be less than 10% of impervious surface area is essential strategy to mitigate the degradation of water quality in a particular areas (Kim et al. 2016). The slope of the area within the watershed system is also determining water quality of downstream by creating fast runoff flow rate. It is justified by the spatial analysis of factors responsible for incidence of waterborne diseases in Ile-Ife, Nigeria; most reported cases were occurred due to environmental factors including topography of the area (Emmanuel et al. 2012). However, catchment with steeper slope greater than 15^0 was negatively correlated with major ions assumed to be presented in water(S. Li et al. 2013).

The nature of hydrogeology of watershed has influential effect on water quality. For instance, clay type soils are producing mud; cultivated lands may yield silt, fertilizers, herbicides, and insecticides to the water bodies which have an effect of color. Fractured rock media facilitate transportation of bacteria, silt and different chemicals within groundwater basin. Different mineral contents of water which have negative or positive outcome on health are dependent upon geologic formations of watershed at small or large scales. The influence of variability of natural landscape (slope) and silt - clay superficial geology deposits on water quality were confirmed in the southern Ontario watersheds (Sliva and Williams 2001). The reasons why Arsenic occurred in groundwater are due to deposites of alluvial lacustrine origin, Volcanic deposits, Geothemal systems and Uranium and gold mining activities("43-Arsenic in GW of Wester US.Pdf," n.d.). On top of it, mobilization of Arsenic in sedimentary aquifers might be due to agricultural irrigation whereas elivated arsenic concentrations in the deeper subsurface are associated with compaction caused by gound water withdrawals. Water and rock interactions at a given temprature, pressure and chemical conditions is also determinng spcific conductivity, PH, Calcium, and HCO3 which are important chemical parameters for the dissolution of fluoride to groundwater from floride rich minirals. That means, Alkaline medium, high concentration of HCO3, and moderate specific conductivity are favourable for flouride dissolution(Ahmed 2001). Hydrochemical variations of water quality are controlled by geological, geochemical, geomorphological and climatologically factors. Total ionic concentrations were increased from the highlands towards Ethiopian rift valley in accordance with regional groundwater flow directions; i.e. the rift valley waters have very high TDS characterized by high Na and HCO_3 whereas highland waters are predominantly fresh with low total ionic concentrations with dominant ions of Ca, Mg and HCO_3 (Ayenew and Ababa 2005).

5. Water Pollution impact on Public health and Ecosystem

Analysis of impact of water pollution on public health and ecological health is important to understand the important features of risks related to groundwater susceptibility and aquifer sensitivity, hazards and exposure status of the public as well as the ecosystem health in order to protect groundwater and surface water sources. It helps to identify research needs and to provide information for decision making (Eisenberg et al. 2002). To justify the importance of this study, water pollution impacts on public and ecosystem are described as follows.

5.1. Waterborne Diseases

In line with the association of water quality and human heath, water related diseases had been classified in to four classes before 45 years such as waterborne, water washed, water based and water related insect vectors; adapted in 1975 and in 1996 and recently unitary environmental classification was done that shown different seven categories such as a) Feco-oral waterborne and water-washed diseases; b) Non-feco-oral water-washed diseases; c) Geohelminthiases; d) Taeinases; e) Water-based Diseases and f) Insect vector diseases (Mara and Iseases 2015). Despite these classification made, efforts were not including chemicals borne water borne diseases. In this case, classification of water related disease was mad based on the difination of water-related disease: It is any significant or widespread adverse effects on human health, such as death, disability, illness or disorders, caused directly or indirectly by the condition, or changes in the quantity or quality of any waters. Accordingly, the modified seven categories of water-related disease are including waterborne microbiological disease; waterborne chemical disease; water hygiene disease; water contact disease; water vector habitat disease; excretal disposal disease and water aerosol disease. (Sketch, n.d.).

The most common causative agents of waterborne diseases are bacteria, virus and protozoa. Globally, a diarrhea disease is the leading causes of childhood morbidity and mortality; for instance, 1.731 billion episodes of diarrhea were affecting under five children and 700000 episodes of diarrhea led to death in 2010 and 2011 respectively. The burden of diarrheal diseases in developing countries is worst as diarrheal disease contributes to one in eight deaths among under five children mostly in developing countries (Walker et al. 2013). In 2015 an estimated 2.3 billion illnesses and 1.3 million deaths resulted from diarrheal disease worldwide (Kotloff 2017). Increased access to tube-wells is associated with a lower risk of childhood diarrhea. Intermediate- depth wells are associated with more childhood diarrhea compared to shallower or deeper wells (Wu et al. 2011). Childhood diarrhea in high and low hotspot districts of Amhara Region, northwest Ethiopia: a multilevel modeling. In his study, childhood diarrhea occurrences remained high. Both individual- and community-level factors including water supply, sanitation and hygiene determined the occurrence of diarrhea (Azage et al. 2016). In this regard, there is insufficient data at the targeted sub basin level to quantify the impact of water quality problems on the occurrence of waterborne diseases including harmful chemicals.

5.2. Impacts of major chemical contaminates

a) Pesticides

The term "pesticide" is a composite term that covers all chemicals used to kill or control pests. These include herbicides, insecticides, fungicides, nematocides and rodenticides. 60% of herbicides, 90% of fungicides and 30% of insecticides are known to be carcinogenic. To protect human health and the environment, Stockholm Convention on Persistent Organic Pollutants (POPs) were endorsed so as to eliminate worldwide production, use and emission of POPs by targeting an initial list of 12 pesticides. In May 2009, 9 additional chemicals were added to the list of POP in to the Stockholm Convention in 26 August 2010 which are still produced and in use ("No Title," n.d.).

In Africa, pesticides are used to increase agricultural productions and to control many vector-borne diseases. approximately 30% of pesticides marketed in developing countries do not conform to international standards, contain active ingredients exceeding toxic thresholds, and do not exclude other toxic substances(Of and Health 2014). In water quality management, pesticide are becoming a concern of the world as pesticides and their metabolites found everywhere in the ecosystem and even the human body parts; particularly, persistent organochlorines in ecosystems have raised concern about the possible ecological effects. (*Problems, Improvements, Alternatives*, n.d.).

The trends of pesticide use and drivers for safer pest management are increased in four African countries such as Benin, Ethiopia, Ghana and Senegal as the result of growing cotton, vegetables, pineapple, cowpea, and mixed cereals and legumes. Beside this incremental, less attention have been given for farmers and consumers health than exports and local markets (Williamson, Ball, and Pretty 2008). Ethiopian smallholder's herbicides have grown rapidly for cereals production from 2004 to 2014. These increased use of herbicide has an implications for rural labor markets, potential environmental and health considerations, and capacity development for the design and effective implementation of regulatory policies on herbicides (Tamru et al. 2017). In Jimma Zone, DDT, endosulfan, cypermethrin, and permethrin were detected in samples collected from market (Mekonnen and Agonafir 2017). In other countries, Neonicotinoid insecticides are widespread in surface waters across the agriculturally intensive Midwestern United States (Klarich et al. 2017); in water of the cotton-growing areas of the Southern US, Mississippi Embayment(Thurman et al. 1998); and even in most people bodies in the United States despite the fact that DDT was banned from use in the United States in 1972 (Gilden, Huffling, and Sattler 2010). Therefore, to protect groundwater from specific vulnerability of insecticide pollution, identification of sensitive zones in order to prevent groundwater pollution hazards.

b) Heavy metals

Heavy metal is chemical with relatively dense metal or high atomic weight including Cadmium, mercury, lead and Arsenic. All of which appear in the World Health Organization's list of 10 chemicals of major public health concern. They become concentrated as a result of human caused activities and can enter plant, animal, and human tissues via inhalation, diet, and manual handling. From a public health point of view, the term heavy metal usually refers to a metal or semi-metal that has the potential to cause human or environmental toxicity. These may include lead, mercury, cadmium, cobalt, nickel, iron, thallium, bismuth and arsenic (Of and Health 2014).The main threats to human health from heavy metals are associated with exposure to lead, cadmium, mercury and arsenic from water sources are

The sources of cadmium are re-chargeable nickel–cadmium batteries, waste products as these are rarely re-cycled, Cigarette, in ores together with zinc, lead and copper, phosphate fertilizers, industrial emissions, sewage sludge to farm land and other. The exposure of cadmium is mostly contaminated water used for irrigation and mostly responsible for kidney damage, bone effects and fractures (skeletal damage) where ouch-ouch disease with weak evidence of human carcinogen (Järup 2017). Mercury is the most toxic heavy metal to human being and ecosystem as well. It has become part of the environment owing to anthropogenic activities including agriculture, municipal wastewater discharge, mining, incineration, and discharges of industrial wastewater. Metallic mercury finds its entry into to water and soil through erosion of natural deposits, discharges from industries and runoff from landfill sites. (Järup 2017)(Jan et al. 2015)**.** Lead emissions from petrol, lead-based paints, lead in food containers and in other conditions that contribute contamination of water. Lead toxicity is a particularly insidious hazard with the potential to cause irreversible health effects(Järup 2017), (Jan et al. 2015)**.** Human is exposed from Arsenic via intake of food and drinking water. Inorganic arsenic is present in groundwater used for drinking. Volcanic activity, weathering of rocks, geothermal waters, and forest fires constitute some of the natural sources of arsenic. Smelting of non-ferrous metals and the production of energy from fossil fuel are the two major anthropogenic source or industrial processes that lead to arsenic contamination of air, water and soil. Its applications in animal feed, glass and ceramics, herbicides, pesticides, wood preservatives, metallurgical operations and many others contribute to its anthropogenic pollution (Järup 2017).(Jan et al. 2015)**.** It is estimated that around 200 million people are exposed predominantly through drinking water, having its concentration greater than the prescribed limit**.** Long and short -term exposure to arsenic in drinking-water is mainly related to increased risks of skin cancer, some other cancers such as liver, kidney, and lymphatic cancer, development of neoplasms, hyperkeratosis and pigmentation changes (Tchounwou, Centeno, and Patlolla 2004)

The main threat to human health from heavy metals in the African Region is from exposure to mercury, lead, cadmium and arsenic (Of and Health 2014). Ilesha gold mine sites, southwest Nigeria, Cancer risk showed that only Arsenic exceeded acceptable risk for carcinogenic adverse health risk for children and adults and this make Arsenic to be carcinogenic in the water of the study area (Odukoya et al. 2017). Large proportion groundwater is contaminated with high concentrations of arsenic (Salah, Zaidan, and Al-rawi 2012). Karnaphuli River, Bangladesh, the presence of heavy metals in water and sediments from point sources were approved. It is also noted that industrial effluent and domestic sewage discharges were having significant heavy metal concentrations (Mohammad et al. 2016). Watershed of Guanting Reservoir, China, Soil type and soil chemical parameters were also involved in heavy metal retention in soils (Xu et al. 2013). Heavy metals via dietary intake of foodstuffs from the wastewater irrigated site of a dry tropical area of India; wastewater irrigation led to accumulation of heavy metals in food stuff causing potential health risks to consumers(Singh et al. 2010). Heavy metal contamination of shallow groundwater wells in an agricultural area in Ubon Ratchathani province, Thailand revealed that people living in warmer climates are more susceptible to and at greater risk of ground- water contamination because of their increased daily drinking water intake (Robson 2013). Studies of these diseases suggest that abnormal incidence in specific areas is related to industrial wastes and agriculture activities that have released hazardous and toxic materials in the groundwater and thereby led to the contamination of drinking water in these areas (Farag 2000).

6. Impact of groundwater pollution on irrigation and ecosystem

Water quality for irrigation to increase production of crops, vegetables, fruits and industrial inputs, has to maintain acceptable standards so as to attain irrigation objectives and the ecosystem of the surrounding. For instance, there are encounter challenges due to use of Wastewater for Irrigation in developing Countries. It is because undesirable constituents in wastewater can harm human health and the ecosystem. Risk management and provisional solutions are needed to prevent adverse impacts from wastewater irrigation (Qadir 2010).

Even though the nutrients contained in the wastewater is considered as beneficial to agriculture, the contaminants present in it pose environmental and health risks. A case study conducted in India shows that higher rates of morbidity exist in the wastewater irrigated villages when compared to the control village (Srinivasan and Reddy 2009). This is applied through risk-based Assessment of Soil and Groundwater Quality to keep standards and remediation. In the case of serious soil contamination the site has to be remediated, making it necessary to determine the remediation on the basis of site-specific risks to humans and ecosystems and, besides, actual risks due to contaminant migration groundwater and mix to surface water sources (Swartjes 1999).

In other hand, excessive salts in groundwater is one of the major constrains in agro-well farming thus irrigation with poor quality waters may bring undesirable elements to the soil affecting its fertility that affect suitability of irrigation waters such as Electrical conductivity (EC), Sodium percentage (Na %), Sodium adsorption ratio (SAR), Residual sodium carbonate (RSC). Beside ground surface contaminants, in the reference article conducted in Jaffna, Sri Lanka, 35.3% of the tested groundwater wells have unsuitable irrigation water quality due to bicarbonate hazard which is influenced by carbonate rock dissolution("Irrigation Water Quality Based on Hydro Chemical Analysis , Jaffna , Sri Lanka" 2010). Groundwater quality for irrigation is also influenced by hydro-geochemical evolution mechanisms in for instance, Pengyang in China; Calcite and dolomite are found saturated in groundwater and thus tend to precipitate out, while halite, fluorite and gypsum are unsaturated and will dissolve into groundwater during flow. Weathering-dominated, and mineral weathering (carbonate and silicate minerals) and ion exchange are the most important factors controlling groundwater chemistry(P. Li, Wu, and Qian 2013).

Generally, the effect of poor quality irrigation waters on the nutrient leaching and groundwater quality is justified in ample of evidences. Irrigation with poor quality water, which is generally more sodic and saline than regional groundwater, increases the rate of sodification and salinization of shallow groundwater (Geology 2007). The change of ground surface land use and land cover threat groundwater quality and ecosystem integrity, particularly in shallow aquifers where links between groundwater and surface activities are most closely (Korbel, Serov, and Lim 2013). High nitrate concentrations also, resulting from intense manure application, homogenize the contents of the major dissolved ions, fertilization impact on groundwater and water-rock interactions (Upc et al. 2015). To ensure groundwater quality and its suitability for drinking and agricultural use, it requires special care to provide adequate drainage and introduce alternative solutions (Elango 2005). Application of clay deposits on sandy soils modifies the distribution of soil water content in the root zone area where water could be retained by clay deposits applied in the subsurface layer (Al-omran and Wahb-allah 2010).

2.2. Groundwater Vulnerability Assessment and Modeling

Water quality of groundwater in Ethiopia varies widely. It is primarily influenced by Geo-morphological, geographical setting, climatic condition, physico-chemical, biological and anthropogenic influences like industrial, municipal and agricultural activities. Pollutants found in groundwater can be classified into two broad groups: biological and chemical, and within the latter they can be further sub-classified into two other groups: inorganic and organic (Postigo et al. 2018). For instance, turbidity, TDS, chloride and conductivity of some of the samples were above the WHO acceptable limits which are associated with municipal waste dumpsite in Oke-afa, Oshodi/Isolo Area of Lagos State (Kayode, Okagbue, and Achuka 2018). Hydro-geochemical characterizations of major factors are affecting the quality of groundwater in southern Iran, Janah Plain (Zarei, Sedehi, and Raeisi 2014). Natural and anthropogenic factors affecting the groundwater quality in the Nandong karst underground river system in Yunan, China. The analysis point out that geology and land uses revealed contamination from human activities such as sewage effluent and agricultural fertilizer; water – rock interaction in the limestone-dominated system; and water– rock interaction in the dolomite-dominated system were the three major factors contributing to groundwater quality (Jiang et al. 2009).

In addition, geochemical processes controlling groundwater quality under semi arid environment: A case study in central Morocco is indicating three potential processes affecting groundwater quality that comprises evaporation, water rock interaction, admixture of waters (Karroum et al. 2017). Natural and anthropogenic factors affecting the groundwater quality in Serbia: severe pollution with Mn, As, NO3, Ni, Pb whereby anthropogenic origin of these contaminants was indicated from industrial, urban effluent and agricultural activity (Devic, Djordjevic, and Sakan 2014). There are three mechanisms involving in groundwater pollution. Physical processes: advection, diffusion, dispersion, evaporation, infiltration, filtration, and volatilization; geochemical processes: acid – base reactions, sorption–desorption, ion exchange, oxidation-— reduction, precipitation, dissolution and surface complexation; and Biochemical processes: transpiration, bacterial respiration, decay, and cell synthesis (Postigo et al. 2018).

Generally, groundwater protection is complex and groundwater is affected by a wide range of natural processes and human activities, particularly those involving land usages. To have a common understanding of the available techniques of vulnerability assessment, scientists of different groundwater vulnerability forums have outlined the various methodologies for groundwater vulnerability assessment. Groundwater contamination is an increasing water resources problem. Since the remediation program is extremely expensive, the most reliable protection of groundwater sources is to prevent and control groundwater pollutions. For effective protection of groundwater, it is necessary to take into account all pollutants and all possible actions that should take place in the catchment area and where a potential risk to groundwater exists. The sensitivity of the aquifer or naturally existing sensitivity (internal sensitivity) is a measure that indicates the easiness with which water enters into aquifer and moves through it. To apply source protection measures, except knowledge of the natural sensitivity; it is necessary to know the source and type of pollution. Thus, the concept of vulnerability is introduced into issue of groundwater protection. Vulnerability is the degree to which human or environmental systems are likely to experience harm due to perturbation or stress, and can be identified for a specified system, hazard, or group of hazards. Create maps of groundwater vulnerability is widely used in developed countries and is a very important tool for the protection of groundwater. Vulnerability maps are used extensively in the past 30 years. To date, there is no generally accepted standard method of mapping. Among commonly used models, DRASTIC method is appropriate and mostly applied. DRASTIC is the oldest and most frequently used method(Had, Lazovi, and Mulaomerovi 2015). Consequently, risk assessment of groundwater, starting from vulnerability assessment, with multi-source pollution by a long-term monitoring programme is needed so as to protect and strengthen the defense line of the aquifer (Zeng, Zhang, and Yang 2018).

Groundwater pollution risk mapping, hazard identification and vulnerability assessment can be applied for the effective protection and sustainable supply of groundwater. Around the world, there is different method of pollution risk and vulnerability assessment. In this review, major approaches, methods and models are described by giving emphasizing to vulnerability assessment. A comprehensive model for ground water risk assessment was proposed by combining the hazard of contaminated sources (H), ground water intrinsic vulnerability (V) and groundwater function value (F), and verified in Jilin City of North East China to indicate the contamination occurrence probability in order to generate overlaying groundwater pollution risk maps (El et al. 2017). GIS based Groundwater Risk Assessment Model (GRAM) is used to produce likelihood of release of hazards, likelihood of detection of hazards, consequence of hazards and residual risk of groundwater contamination in terms of nitrate in the groundwater basin. It is considering land use map and soil map was used to produce map for likelihood of release of pollutant. GRAM is practiced for the assessment of risk to pollution in Kathmandu Valley, Nepal (Valley et al. 2016). Groundwater Risk Index (GRI) is designed to be used by end-users (e.g. governments, NGOs) as a multi criteria diagnostic tool to identify and determine the probability and severity of an entity experiencing the adverse effects of groundwater mining (Lezzaik, Milewski, and Mullen 2018). A Case Study, in the Lower Liaohe River Plain, China is practicing Relative risk model (RRM) coupled with a series of indices, such as a groundwater vulnerability index, which includes receptor analysis, risk source analysis, risk exposure and hazard analysis, risk characterization, and management of groundwater. The risk map is products of the probability of environ mental contamination and impact. The reliability of the RRM was verified using Monte Carlo analysis. it is a powerful tool for ecological risk assessment (ERA) (X. Li et al. 2015).

A new approach is designed to assess groundwater vulnerability to contamination from anthropogenic activities and sea water intrusion from which parametric methods were then linked to a novel land use index to create a more robust “global risk index”, useful for assessing aquifer vulnerability to pollution and seawater intrusion risk. The Global risk map shows three risk classes': low (25%), moderate (64%) and high (11%) depending on the hydro-geological characteristics, land use, distance from the coast and human impacts in most of t he study area (Allouche et al. 2017).

Based on guidelines to groundwater vulnerability mapping for Sub-Saharan Africa, three basic vulnerability methods are advised to be adopted; namely, subjective overlay or index methods, statistical methods and physically based methods. The subjective or index-based method is the most important and commonly used method. From overlay or index methods, parametric method such as DRASTIC, SINTACS, SEEPAGE, EPIK, HAZARD_PATHWAY-TARGET, GOD, AVI, & PI, Non-Parametric like Indicator kriging and Hybrid methods like ISIS can be described (Oke and Fourie 2017b). The importance of groundwater vulnerability maps in the protection of groundwater sources is obviously indicated in the case study of Sarajevsko Polje as it is point out that establishment of legal regulations in each country based on the assessment result should be taken as the best tool for the fight against pollution of groundwater(Had, Lazovi, and Mulaomerovi 2015).

Vulnerability of groundwater resources to contamination and how to identify risk factors so as to design protection measure is one of the basic parts of Integrated Water Resource Management (IWRM). Consequently, determination of vulnerability of groundwater is depend on purpose and scope of the study, scale, data availability, time, cost, and beneficiaries of the output. Assessment of ground water vulnerability is one of functions of integrated watershed management. This study is aiming to understand the exposure status of drinking water in the case of UARB. Instead of identifying actual ground water contamination as it is complex to evaluate within the watershed scale or river basin scale; assessment of ground water vulnerability is the widely used approach to protect ground water from harmful contaminants. Vulnerably is indicating the sensitivity of groundwater to contamination, and is determined by essential characteristics of the aquifer.

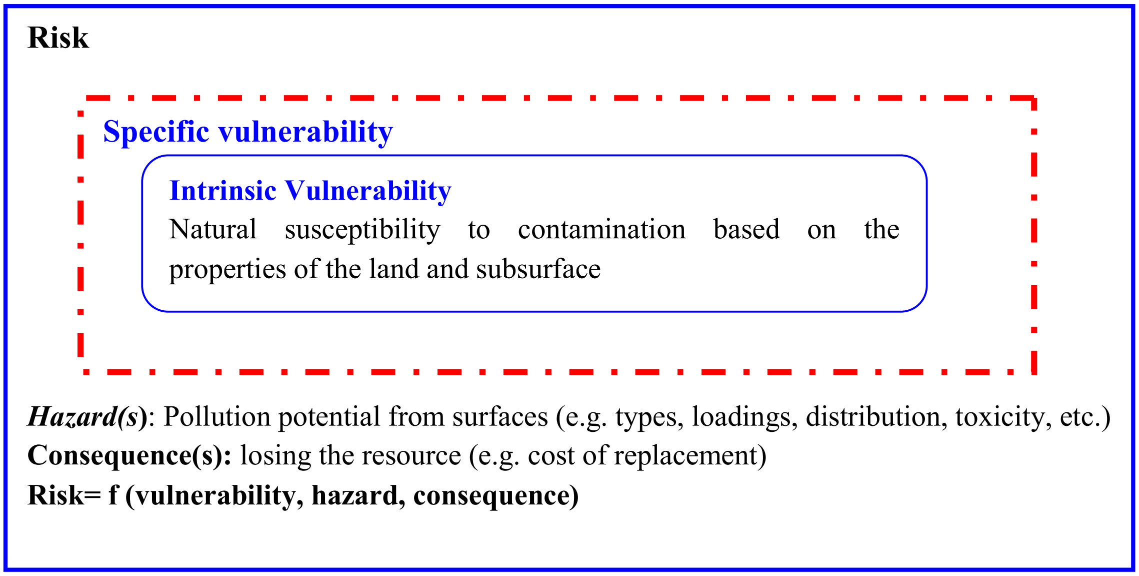

Figure 1: The relationship among Risk, vulnerability, Hazards and Consequences [Modified from the reference (Talwar, Liggett, and Talwar 2014)**]**

Groundwater Vulnerability Assessment (GWVA) model Integrated Water Resource Management is categorized in to three categories; firstly, indexing and/overlaying methods which is including DRASTIC, GOD, EPIK, and Aquifer Vulnerability Index (AVI); secondly, logistic regression approach and process based methods (SAAT/SWAT) with in statistical method and thirdly, numerical models such as MODFLOW, FEFLOW (Talwar, Liggett, and Talwar 2014). Within these three categories, delineating groundwater vulnerability and mapping protection zones are the principal purposes of the model. Specifically, GOD-S is the refined version GOD index by considering soil media properties; DRASTIC-Fm is a modified version of DRASTIC which is considering the characteristics of fissured hard-rock aquifers. The fractured media parameter (Fm) was derived from the map of tectonic lineaments density using four classes with ratings ranging from 4 to 10 scales. SINTACS was created for vulnerability assessments and mapping in medium and large scale maps, and the multiplier weights of normal string were used; as well as DISCO is carried out in the vulnerable springs and in the mineral water wells related to a highly heterogeneous and fractured media aquifer (Meerkhan et al. 2016). In other hand, Groundwater Risk Assessment Model(GRAM) for Well field protection was practiced in South Australia which was undertaken by focusing on “multi-barrier” approach, by identifying weakest barrier, likelihood of release, contaminant pathway and consequence equation so as to pinpoint risk management action. In this multi-barrier approach, identification of the weakest barrier is necessary to enable effective risk management (Somaratne, Zulfic, Ashman, Vial, and Swaffer 2013)

To summarize three categories of Groundwater vulnerability assessment methods, the following descriptions are depicted.

A. Index based methods for Groundwater vulnerability Assessment

Methods of vulnerability assessment such as DRASTIC, GOD, and SI have been evaluated in the assessment conducted in Kathmandu Valley, Nepal. DRASTIC and SI methods are delineate around 80% of the groundwater basin area under high vulnerable zone. From the perspective of risk to pollution results, DRASTIC and GOD methods are comparable. However, Sensitivity index (SI) method was found as the most suited for Kathman-du, Nepal.

GOD method is a method for the assessment of vulnerability of an aquifer against the vertical percolation of pollutants through the unsaturated zone. It has three parameters such as Groundwater occurrence (G), Overall aquifer class (O), and Depth of ground water table (D) whereas SI method is used to assess vulnerability of vertical agricultural pollution generated mainly by nitrates and pesticides. The SI method can be used to evaluate the groundwater vulnerability assessment from large to medium scale aquifers and suited if the pollution is released from agricultural or rural areas. This method is based on five parameters; D: depth to groundwater table; R: effective recharge; A: aquifer, T: topography (slope) and Land use (LU) (Shrestha, Ka, and Prasad 2016).

B. Statistical methods for Groundwater vulnerability Assessment

Statistical method also the other methods for groundwater quality assessment; there ample number of evidences to justify statistical methods used for water quality analysis; It is used to characterizing hydro-chemical properties and pollution sources identification of groundwater in Salawusu aquifer system of Ordos Basin, China. The descriptive statistical method, Piper trilinear diagram, ratios of major ions and canonical correspondence analysis are employed to investigate the hydro-chemical evolution, determine the possible sources of pollution processes, and assess the controls on groundwater compositions(Yang et al. 2016). The method, Bayesian spatial statistical method is highly multipurpose over other methods for groundwater vulnerability projections in future scenarios (Stevenazzi et al. 2017). Statistical method can analysis Hydro-geochemical characteristics, groundwater contamination, identification of controlling factors of groundwater hydro-geochemistry using different statistical approaches such as principal component analysis (PCA) Correlation analysis (CA), Hierarchical cluster analysis (HCA) and R- Model factor analysis. The progress of groundwater quality analysis shows that integrating hydro-chemical data and multivariate statistical methods are used to analysis factors influencing contamination due to natural and anthropogenic impacts (Redwan and Moneim 2015). It is justified that hydro-geochemical processes affecting ground water pollution in arid areas were approved using an integration of geochemical equilibrium and multivariate statistical techniques. The techniques able to quantify the degree of geogenic factors (dissolution of various minerals: calcite, aragonite, gypsum, anhydrite, halite and fluorite), ion exchange processes, anthropogenic factors such impact of irrigation return flows, and application of potassium, nitrate, and phosphate fertilizers, most likely contribute to further declines in groundwater quality(El et al. 2017).

In addition, statistical methods such as regression discriminate analysis, likelihood ratio functions, and weights of evidence can be used to reveal the relationships between the investigation data and the factors related to the contamination. Statistical methods are easy to validate using new groundwater contamination information and can comprehensively analyze contamination related factors. However, for pollution risk assessment, the requirements of large amount of observed contamination data hinder to apply in the groundwater quality assessment(Zhao and Pei 2012).

C. Physically based methods for groundwater vulnerability assessment

Simulation models use numerical models to describe these related migration and transformation processes. By virtue of simulation models, a numerical indicator that characterizes the pollution risk, to a certain extent, can be calculated. For example, there are several main pesticide transport models that are widely used today such as PRZM, ArcPRZM-3 and MACRO, PEARL linked with the SWAP model, LEACHM, GLEAMS, RZWQM, HYDRUS-1 D and the Attenuation Factor (AF) models. The application of simulation models for groundwater pollution risk assessment. Helps to reduce subjectivity and can quantitatively describe the risk. Such models usually require abundant data about crops, soil geology, hydrology, meteorology and pesticide characteristics (Zhao and Pei 2012)

2.3.Ground-water Risk Assessment Model (GRAM)

Groundwater risk assessment can be done to evaluate risks due to pollution of a specific natural aquifer. The assessment is aiming to present the level of a particular contaminates in ground-water systems. Natural characteristics of the aquifer and the presence of potentially polluting activities are quantifying the risk level which can be prioritized to control through implementation of groundwater protection measures. For this purpose, land use and land cover is an important parameter in assessing risks in combination with aquifer vulnerability assessment. Land use parameter is vital because it can reflect human activities like agriculture, urban planning (settlement), industrial development and deforestation/aforestation which have greatest influence for natural feature changing (Shrestha, Ka, and Prasad 2016; Lezzaik, Milewski, and Mullen 2018; Boughriba and Barkaoui 2010; Salwa Saidi, Bouri, and Ben 2010). Recently developed model known as Gglobal Risk Index assumed to evaluate groundwater potential risk. The approach uses standard for land use rating and weight so as to produce risk maps. Geographical based Ground water Risk Assessment Model (GRAM) was used to produce likelihood of release of hazards, likelihood of detection of hazards, consequence of hazards and residual risk of groundwater contamination in terms of nitrate in the groundwater basin. Therefore, GWRAM refers to the process of determining potential impacts of any pollutant based on hazard, intrinsic vulnerability of ground water to contamination, and potential consequences of the contamination event. (Junjie Wang, He, and Chen 2012; Caniani et al. 2015; Somaratne, Zulfic, Ashman, Vial, Swaffer, et al. 2013; Somaratne, Zulfic, Ashman, Vial, and Swaffer 2013)

2.4. Application and Procedure of DRASTIC model

Evaluation of aquifer vulnerability using Geographical Information System (GIS) with DRASTIC Model has been conducted in Mysore City; Karnataka, India. GIS based application of the DRASTIC model is found to be suitable method to analyze groundwater vulnerability. It is validated by positive correlation between groundwater vulnerability and concentration of nitrate in groundwater (Study et al. 2015). Evaluation of local groundwater vulnerability based on DRASTIC method is also confirming application of sensitivity analysis provides credible information on assigned rating, weight and assessing the contribution of each parameter to vulnerability in Lahore, Pakistan (Muhammad et al. 2015). DRASTIC model of groundwater vulnerability assessment helps to wisely resource allocation, prioritization of interventions, groundwater monitoring and to provide a practical educational tool. It can also be used with other information such as land use, potential sources of contamination, and beneficial uses of the aquifer to protect groundwater resources through establishing legal frameworks for appropriate use of resources for different purposes. According to the guidelines, DRASTIC model has assumptions: the contaminant is introduced at the ground surface and flushed into the groundwater by precipitation; the contaminant has the mobility of water and the area should be 100 acres or larger, contaminant travels with water at the same rate as water, the aquifer is unconfined and the dominant pollutants are not pesticides (Oke and Fourie 2017b).

DRASTIC-based assessment groundwater vulnerability in the Gümüşhacıköy and Merzifon basin (Amasya, Turkey) has been also done by mapping three aquifer vulnerability zones by using overlapping analysis. It is justified that 16% of the targeted basin had high vulnerability and 47% low vulnerability (Ersoy and Gültekin 2013). In Southern Taiwan, Pingtung Plain, DRASTIC model provide a reliable prediction for use in groundwater vulnerability assessment to nitrate pollution and can correctly identify the groundwater protection zones(Liang et al. 2016). Assessment of intrinsic vulnerability to pollution in Southeast Morocco, Tafilalet plain, is also shows that the relevance of GIS performances multi-criteria analysis delineates vulnerable zones for groundwater protection actions (Baki et al. 2017). In order to modification of the mineral systems approach to an assessment of groundwater vulnerability of acid mine drainage have been investigated using GIS based groundwater vulnerability modeling Witbank, Ermelo and Highveld Coalfields in South Africa which provides useful spatial information for advising policy and decision makers on the relative vulnerability of groundwater (Sakala et al. 2017). DRASTIC is also used for evaluation of groundwater pollution risk by pesticides by modifying DRASTIC model in terms of rating and weighting parameters (Zhao and Pei 2012).

The DRASTIC model originated from physical characteristics which affect the ground water pollution potential that would have able to map data. These physical characteristics are Depth to water, Recharge (net), Aquifer media, Soil Media, Topography, Impact of the vadose zone and Conductivity (hydraulic) of the aquifer. To quantify the degree of vulnerability, numerical ranking system is used to assess ground water pollution potential in hydro-geologic setting has been devised using the DRASTIC factors. The DRASTIC system contains three significant parts; weights, ranges, and ratings. Governing equation for each parameter is assigned rate and weight is described as follow ("0-0-0DRASTIC EPA.Pdf," n.d.).

$$\mathrm{DI} = \mathrm{Dr} * \mathrm{Dw} + \mathrm{Rr} * \mathrm{Rw} + \mathrm{Ar} * \mathrm{Aw} + \mathrm{Sr} * \mathrm{Sw} + \mathrm{Tr} * \mathrm{Tw} + \mathrm{Ir} * \mathrm{Iw} + \mathrm{Cr} * \mathrm{Cw}$$

Where,

DI = DRASTIC Index

r = the rating for the parameter

w = an assigned weight for the parameter

The model is advantageous to evaluate the vulnerability to pollution of groundwater resources based on hydro-geologic parameters without extensive, site specific pollution data. It is also inexpensive method to identify areas that need more investigation such as risk assessment study as risk is a function of vulnerability. The moderate vulnerability class is associated with the uses of pesticides which is quickly dissolved and transport through the vadose zone and reaches groundwater reservoir (Ersoy and Gültekin 2013) (Al-abadi, Al-shamma, and Aljabbari 2017).

In Lahore, Pakistan from the result of the method evidence is shown that land use and development activities, industrial and agriculture areas are highly vulnerable as compare to settlement areas. Collectively, the DRASTIC combination with GIS mapping inform decision makers the importance of ground water vulnerability assessment for environment, economy and social development (Muhammad et al. 2015). Using a software package Analytic Hierarchy Process AHP-DRASTIC and GIS for specific aquifer vulnerability assessment were used to predict areas which are more likely than others to become contaminated as a result of activities at or near the land surface. Analytic Hierarchy Process (AHP) is used for to compute ratings and weights of the criteria and sub-criteria of all parameters used in the DRASTIC model(D. Thirumalaivasan, Karmegam, and Venugopal 2003).

In addition, an extension to the DRASTIC model to assess groundwater vulnerability to pollution was applied to the Haouz aquifer of Marrakech (Morocco). Unlike the DRASTIC model and other models that are currently available, this new approach distinguishes between the vertical vulnerability of the aquifer, which is related to the intrinsic parameters of the vadose zone, and the susceptibility of the aquifer when the latter is contaminated by pollutants, which is related to the intrinsic parameters of the saturated zone and anthropogenic activities(Sinan and Razack 2009). The extension theory in the groundwater vulnerability evaluation is also applied by modifying DRASTIC model based the local hydro-geological conditions in order to get a relatively accurate result as DRASTIC results might not consistent with the groundwater quality. DRASTIC index grade is influenced by subjective factors so that the new method (extension theory) should solve effectively by classifying the ground-water vulnerability grades(Bai, Wang, and Meng 2011); however, in Kancheepuram district, Tamil Nadu, India, DRASTIC model is compared with groundwater quality data and results have shown a strong relationship between DRASTIC specific vulnerability index and nitrate-as-nitrogen concentrations (S. K. D. Thirumalaivasan 2014). It is also recommended by scholars that modification of DRASTIC Model to map groundwater vulnerability to pollution using Nitrate Measurements in Agricultural Areas is better than the original method for nonpoint source pollutions in agricultural areas which is confirmed by Pearson correlation (Javadi et al. 2011).

In other hand, an improved DRASTIC index was developed to consider hydro-geological factors like multi-layer vadose zone and preferential flow and specific properties of contaminants like sorption and decay. Hence, the study justified to include into a GIS system. It is particularly used for site specific environmental impact assessment for new developments, vulnerability assessment and integrated water resource management (Jovanovic et al., n.d.).

It takes into account the properties of the earth materials (geological, hydrological and hydro-geological characteristics of an area) but is independent of the nature of the contaminants. The seven parameters which are making the word DRASTIC are described in detailed as follow

1. Depth to water table (D)

The depth to water table is one of the seven parameters of DRASTIC model which can determine the length of travel of infiltrating water through the aquifer. It is directly associated with the contact time with the aquifer media that is required for pollutants so as to attenuate process in the unsaturated zone. The rating value of the depth to water table decreases with increasing depth as the closer the water table to the surface from which potential pollutants are originated, the more vulnerable it is to contamination. Interpolation technique is used to generate a raster map of the water table elevation from suitable season and groundwater level point measurements. The points are obtained from monitoring sites for groundwater modeling. That is the rainy season is recharging groundwater so that depth of water table becomes the highest elevation that should be taken as groundwater depth for vulnerability assessment by subtracting water table elevation from the ground surface elevation. After that based on the calculated depth, predetermined rating values should be assigned to each class ranging from deep groundwater to shallow groundwater starting from 1 to 10 respectively (Elçi 2017)(Krishna et al. 2015).

2. Effective Recharge (R)

Effective or net recharge is the amount of precipitation water infiltrates from the surface of the earth to the subsurface (aquifers). It has greatest contribution for the aquifer vulnerability since dragging down surface pollutants occurred through recharge of surface runoff in to the subsurface but there are some events of concentration reduction because of dilution during travelling through the unsaturated and saturated zones of the aquifer system. The common unit of recharge is in millimeters/year. It is the main mechanism to transfer different contaminant from the surface of the earth to the subsurface water. It is divided into three groups:

a) Direct recharge of water from surface vertically to unsaturated zone of the aquifer.
b) Indirect percolation of water into the saturated zone from riverbeds and others; and
c) Localized recharge of groundwater from the vadoze zone to the saturated zone of the aquifers.

When net recharge of aquifer is high, the possibility of contaminating the water table is higher (Elçi 2017). As the result of these, calculation of recharge parameters in the vulnerability assessment is difficult. Hydrological precipitation-runoff models or field experiments are commonly method of calculation of effective recharge. For example, the value of recharge can be drive from precipitation and evapotranspiration data for each raster cell:

$$\text{Net Recharge} = (\text{Mean Anual precipitation} - \text{Mean Annual Evapotranspiration})\text{X}$$
$$\text{Recharge ratio}$$

The recharge ratio is dependent on the land surface type that determine the ultimately reaches to the phreatic surface. Ratios are assigned for various land uses, for example, cultivated land, pasture, forests, and urbanized areas (residential/industrial areas and highways/roads) are assigned 0.60, 0.65, 0.70 and 0.20 respectively. The calculated recharge is classified into five ranges such as agricultural land, built-up area, forest area, waste land and water bodies so that the rating values are assigned ranging from 10 to 1 as per the high recharge rate contribute high vulnerability to low recharge areas with low vulnerability areas. In this case, the spatial distribution of precipitation and evapotranspiration which are obtained by interpolation of the data from meteorological stations located in the targeted river basin (Oke and Fourie 2017b)(Vulnerability et al., n.d.).

3. Aquifer Media

The aquifer is a porous and permeable geological formation that serve as a hydro-geological reservoir. The groundwater flow is related to the porosity, permeability and transmissivity of aquifer. There are three types of aquifers: the confined, unconfined, and leaky aquifer. In the case of intrinsic vulnerability assessment, aquifer has its own characteristic that determines contaminant transpiration mixed with groundwater. The aquifer media parameter is including materials which stores groundwater and provides an environment for aquifer attenuation processes. This attenuation potential depends on the amount and sorting of fine grains that establishes the aquifer media. To estimate this parameter, well log data and digitized geological map are important after analyzing these. Based on specification of aquifer material types, there are Seven different aquifer media types that can be rated accordingly assigned ranging from 10 (karstic limestone) to 2 (tuff) of aquifer type (Oke and Fourie 2017b)(Vulnerability et al., n.d.).

4. Impact of Vadose Zone

The unsaturated zone, sometimes called the vadose zone, is the zone between the ground surface and the water table (Book- (1).This is because of unsaturated zone is including capillary fringe above the groundwater or the rain-saturated top soil are portions that are saturated, the term vadose zone is suitable to clearly indicating the nature of vadose zone on the intrinsic vulnerability of the aquifer. For the surface fluid contaminant, unsaturated zone is the protection shield of the hydro-geological system of the groundwater.

The unsaturated zone is the media that connects hydrologic cycle of the surface component to groundwater. It has attenuation capacity because of the hydrolithologic features such as texture, mineral composition, grain size, fracturing, etc. it is the media with the role of transferring pollutants from the surface to the groundwater reservoir. Accident spills of chemicals, application of fertilizers and pesticides on the land surface, leaks from gasoline storage tanks, septic tank drainage, leaching from landfills are examples of anthropogenic activities that contribute to the leaching of contaminants through the unsaturated zone into the groundwater. The impact of vadose zone is related to the attenuation potential of the soil cover and underlying subsurface materials. Attenuation typically depends on permeability and mineral composition of vadose zone material.

Using interpolation (inverse-distance-weighted) of data for unsaturated zone lithology from well logs, the vadose zone will be mapped. The created layer map is grouped into seven classes ranging 1-10. The rating value of vulnerability is least for silt/clay formation in the vadose zone and the most for fractured formations (e.g. Limestone). In other hand if there is unavailability of vadose zone data, information of the soil media can be used to derive the approximate ratings for vadose zone as the result a raster data by defining ratings for the vadose zone media (using soil media data) map can be prepared (Krishna et al. 2015) (Vulnerability et al., n.d.).

5. Soil type

The soil is the part of the ground surface that made the layer of vadose zone. The Soil type affects the pollutant transportation due to the nature of the soil and physicochemical processes carried out in the vadose zone such as sorption, ionic exchange, oxidation; or biological activity. It is the first protection line in the hydro-geological system where several important processes related with attenuation capacity of the soil. The soil type parameter is mapping by using a digital soil texture map. Different types of soil can be evaluated in terms of their abilities to retain pollutants; for example, by sorption or biochemical reactions. These processes are usually governed by the clay and organic matter contents of the soil. The rating value of soil type can be given ranging from 10 for bare rock, gravel that able to pass contaminants easily to 1 (clay) that hider the transportation of contaminants. For soil type, there are seven classes to be rated subjectively. (Oke and Fourie 2017b) (Krishna et al. 2015) (Vulnerability et al., n.d.)

6. Topography (T)

Slope is one of the factors affecting groundwater vulnerability to the surface contaminants originated from natural or anthropogenic processes. It determines precipitation rate and displacement velocity of water over the equipotential surface. Low slope or flat land suit the pollutant which may have less velocity and provide opportunity to percolate in to the subsurface to mix with groundwater. Slope is also inherent factor for the soil type and thickness which can indirectly affecting attenuation capacity of the hydro-geological system. In other hand, areas with steeper slopes cause more runoff with less infiltration that attribute small risk of groundwater contamination. The land slope map is obtained from digital elevation map from concerned mapping authority or mandated institutions. Slope values are then grouped into seven classes and rating value ranges from 1 to 10. (Oke and Fourie 2017b) (Krishna et al. 2015) (Vulnerability et al., n.d.).

7. Hydraulic Conductivity

Hydraulic conductivity is measurement of the ease of a particular fluid passing through the pore space of a porous medium. It is the medium and fluid properties which describes the relative ease with which a particular liquid will flow through the medium. This parameter has held the dimension of velocity, cm/sec or feet per day, and is a second-order tensor quantity. Its physical meaning is stated as, “The volume of liquid flowing perpendicular to a unit area of porous medium per unit time under the influence of a hydraulic gradient of unity. Hydraulic conductivity determines the rate at which a contaminant moves, which depends on the inter-connectivity of voids within the aquifer. The higher hydraulic conductivity of the aquifer is the higher the vulnerability of aquifer to groundwater pollutants. Hydraulic conductivity represents the groundwater mobility capacity inside the saturated media, thus the mobility potential of hydro-vectored contaminant having density and viscosity almost the same as groundwater. That is hydraulic conductivity parameter refers to the ability of the aquifer materials to transmit water and controls the rate at which groundwater flows with control of groundwater contaminant movement.

To calculate hydraulic conductivity of the aquifer and interpreted in to digital map, Conductivity values for the aquifers were usually derived from groundwater flow models and represent averages over large areas. For instance, most of the bedrock aquifers the alluvium and terrace aquifers have higher hydraulic conductivity values, ranging from 100 to greater than 2,000gpd/ft. In the absence of unavailability of hydraulic conductivity data, information of the aquifer media was used to derive the approximate ratings for hydraulic conductivity. It was converted to raster data according to the defined ratings(“No Title,” n.d.).

In other hand Specific capacity is usually given as auxiliary information in the well log and can be calculated after well drilling is completed. It is referring to whether the well will provide an adequate water supply. Specific capacity is calculated by dividing pumping rate over drawdown (Q/S). Saturated hydraulic conductivities are estimated using specific capacity data that are available for the aquifer. Inverse-distance-weighted interpolation is again used to obtain the two-dimensional, continuous distribution of hydraulic conductivity. The resulting raster map is further grouped into four classes based on typical DRASTIC rating values, ranging from low to high hydraulic conductivity(Alemayehu, Kebede, and Liu 2017) (Vulnerability et al., n.d.).

Short review of risk evaluation of groundwater pollution by pesticides shows that index methods require few field data inputs, easy calculations and more suitable for assessment of large areas. However, such methods have many faults related to subjectivity when values and weights are assigned, too simple to reflect their complex relationships, ambiguous and open to many interpretation; absence of accepted validation method (Zhao and Pei 2012). Particularly for Sub Saharan countries, DRASTIC does not account factors related to large water bodies, karst topography, contaminant types (pit latrines, soak ways, overpopulations), human activities, land use and fate of contaminants. The practicalities of vulnerability assessment in developing countries for example in Sub-Saharan African countries are facing different challenges because of lack of hydro geological data; unable to establish contextual vulnerability assessment methods; groundwater-related legislation which harmonized into a directive; Scarcity of skilled hydrogeologists and lack of funding, poor policies and legal tools (Oke and Fourie 2017a).

Groundwater pollution risk map is also obtained by overlaying the DRASTIC vulnerability map with land use (Ouedraogo, Defourny, and Vanclooster 2016). Consequently, to promote protection of water sources from pollutants, understanding of aggravated factors is vital to prioritize areas and design protection mechanism. This study serves as an input for decision making and practitioners for academicals for further investigation.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Parameters and Sources of data

In this study, under listed parameters (variables) are collected and used for analysis

- Geo-referenced Area of the study areas (River basin, Sub river basin)
- Rainfall distribution (Annual)
- Slope in % (topography)
- Land use and land cover characteristics
- Hydrogeology (aquifer characteristics)
- Ground water depth (water table)
- Characteristics of vadose zone
- Hydraulic conductivity for each aquifer type
- Soil media (type)

Table 1: Sources of each parameter and required data

S/N	Parameters	Information/data sources	Organization
1	Depth of Water	Well logs	Addis Ababa water and sewerage Authority, MOWIE and Oromia Water resources and Energy Bureau
2	Net Recharge	Annual participation meteorological stations Evapotrispiration data from reference(Berehanu et al. 2017) Runoff coefficient from references (Manmohan Kumar Goel (Applicationsnow et al. 2011)	National Meteorology Authority
3	Aquifer Media	Geological map (shape files)	Ethiopian Geological Survey and MOWIE
4	Soil Media	From Soil Survey and FAO references	MOWIE
5	Topography	Topographical map	MOWIE
6	Impact of the Vadose Zone	Geological map (shape files)	Ethiopian Geological Survey and MOWIE
7	Hydraulic Conductivity	Geological map (shape files) with range of values for hydraulic and permeability	Ethiopian Geological Survey and MOWIE
8	Land use and land cover	Land use and land cover map (shape file)	Satellite data’s and MOWIE

3.2. Study Area

Ethiopia has 12 hydrological divided basins from which Awash River basin is one of the basins with 110,000 km^2 drain areas and 1200km lengths. It has more than 3000 meter elevation in the central highlands from which the river originated. Awash River Basin is the most important river basin in Ethiopia. It is divided in to sub- basins; the upper most sub basin is the upper Awash River basin which is the target area for this study. It is started at Ginchi highland and end at Koka water reservoir Dam. It is located between latitudes of 8°16'and 9°18'and longitudes of 37°57'and 39°17. The Upper Awash River Basin has an area of about 11,300km^2 and the length of the river up to Koka is around 220km. The sub basin has high water supply demand for drinking, irrigation, and hydropower generation. In the upper basin, there are four major tributaries such as Akaki, Holeta, Berga and Legedadi Rivers. In the upper Awash basin Melka hombole, Melka Kunture, Mojo, and Akaki stations have automatic water level recorder (Authority and Werer 2017b).

It has less than 20C^o mean daily temperature. According to daily long-term rainfall records, the mean annual rainfall of the sub-basin is 981mm. The rainfall pattern is unimodal type and the main rainy season is from June to September. The maximum rainfall has been recorded as high as 280 mm mostly in July with the wet season lasting from June or July to September. The dry period is between October and February. The remaining months (March through May) have moderate rainfall (HALCROW, 1989).

The land use/cover (LULC) of Upper Awash Basin consists mainly of cultivated agricultural land, grass land, shrub land, forestland, rural and towns settlements. There are a lot of small, medium and large scale irrigation development activities in the upper basin (Authority and Werer 2017b) (A. River et al. 2017). The soil type in the Upper Awash Basin is diverse. The most common soil types are Clay, Sand, Clay-Loam, Silty-Clay-Loam, Sandy-Clay, and Silty - Clay. The Hydro-geological condition of the basin is a function of the geomorphology, lithostratigraphy of Tertiary and Quaternary volcanic units, tectonics and the general dipping of the underlying Mesozoic sedimentary rocks. The most common forms of three aquifer systems are Alluvial and lacustrine sediment aquifer which mainly found in Ada'a plain around Mojo and Debrezeit. (Report 2016).

There are 26 Woredas with exclusion of towns in the upper basin and almost more than 2 million peoples in the rural; almost all woredas are located in Oromia region ("Adama Science and Technology Client : Awash Basin Authority" 2017).

Livestock population: there are a total of 662,559.00 livestock in the sub-basin. From Which 44% are cattle, 33% are poultry, 20% is sheep and other species of Animals are accounting 3% from the total population. There are more than 246 different kinds of industries such as Brewery, Chemicals and Construction Inputs, Food and Beverage, Leather and Leather Products, Leather Goods & Garment Producers, Meat and Milk, Metal, Tannery, and Textile/ Garment. These industries are located 69.11% in Addis Ababa, 6.69% in Alem-Gena, 5.69% in Bishoftu and 4.07% in Adama. Major industries are located in the upper Awash River basin ("Adama Science and Technology Client : Awash Basin Authority" 2017).

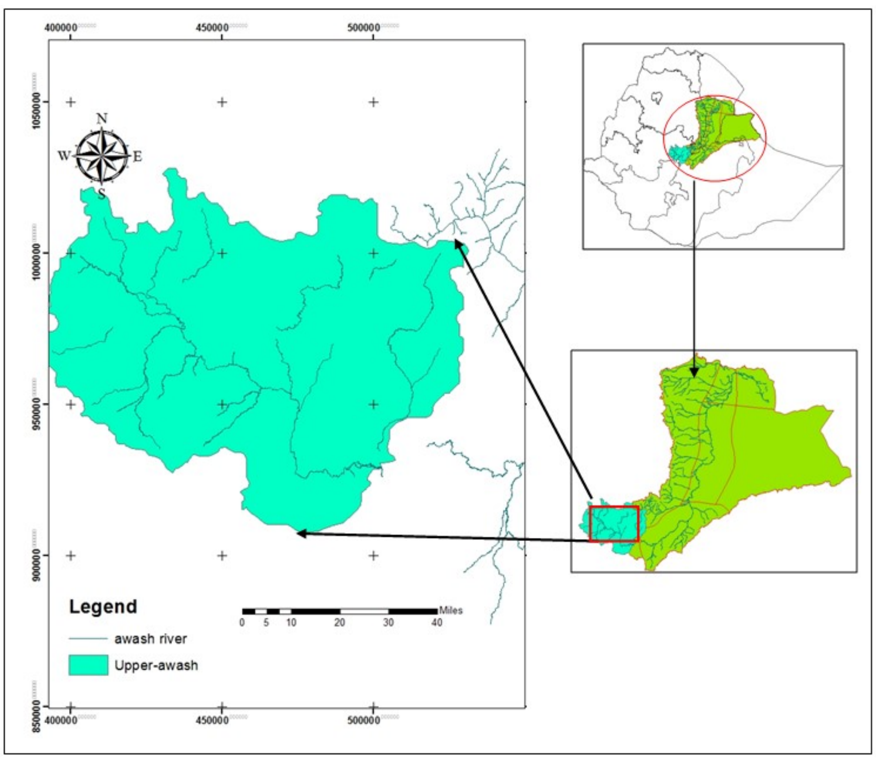

Figure 2: Map of study area, Upper Awash Sub-river Basin (December 2018)

3.3. Study Period

This study was conducted from October 2017 to June 2018 as per the school Academic calendar starting from preparation of the thesis proposal to final delivery of results. Dissemination of research findings for concerned bodies will be done as per the requirement.

3.4. Spatial Analysis and Vulnerable Area Mapping

This GIS based DRASTIC modeling has been simulated using basic map making and spatial analyst extension of the ESRI's Arc GIS10.2 software. It is an ArcGIS tool (Spatial Analyst) that able to process different layers of digital maps in to vulnerable zones through calculating the vulnerability index, and analyzing the spatial variability of the groundwater vulnerability (Elçi 2017). For each DRASTIC parameter digital geospatial data sets are created using collected shape file format from different sources such as Ministry of Mater, Irrigation and Electricity (MOWIE), Geological Surveys of Ethiopia, Ethiopian Water works and Design Enterprise, Addis Ababa Water supply and Sewerage Authority, National Metrological Agency, Oromia Regional state Water Resource and Mining Bureau and Academic Reports. Vector formats converted in to raster, assigning weights and ranks of the seven parameters, using raster calculator from the ArcGIS 10.2, after that the DRASTIC indices are computed based on the governing Equation, rating and weighting system of DRASTIC model

$$\boldsymbol{DIV = Dr * Dw + Rr * Rw + Ar * Aw + Sr * Sw + Tr * Tw + Ir * Iw + Cr * Cw} \quad \text{Eq. (1)}$$

Where:

DIV= DRASTIC Index Value

r = rating for the parameter

w = given weight for the parameter

D: Depth to Groundwater

R: Net Recharge

A: Aquifer Media

S: Soil Media

T: Topography (slope)

I: Vadose Zone

C: Hydraulic Conductivity of the Aquifer

The detail procedures for each parameter are depicted as follow

Depth to water table (D): the depth to water level (static water level of the well) is determining the travelling of contaminants in the unsaturated zone through infiltration. The closer the water level to the surface from which potential pollutants are originated, the more vulnerable it is to pollution. The digital map of water depth is done by using ArcGIS 10.2 interpolation technique as it is the most common approach for vulnerability assessment(Oke and Fourie 2017a). The generated raster map of the water depth has been used for analysis. The data were collected from Addis Ababa water and Sewerage Authority, Ethiopian Water works and design Enterprise and Oromia regional state Water resource, Energy and mining Bureau. For this analysis 457boreholes were used. After that based on the calculated depth, predetermined ratings are assigned to each class ranging from deep groundwater to shallow groundwater starting from zero to more than 30.5 meter with rank of 1 to 10 for 7 classes respectively.

Effective Recharge (R): it has greatest contribution for the aquifer vulnerability since dragging down surface pollutants occurred through recharge of surface runoff in to the subsurface. Annual precipitation map is produced in the ArcGIS environment using Thiessen polygons from rainfall 9 gauging stations located within the study area. To get the effective recharge from the produced annual participation map, annual evapotrinspiration map also produced secondary data source because of unavailability of input parameters of evapotrinspiration data from meteorological stations located in the study areas. Recently produced land use land cover data has been collected from Awash River Basin Administration basin.

Using map Algebra from ArcGIS Spatial Analyst extension tools, raster calculations were made based on Eq.2 formula. Recharge ratio or runoff factors (Table 2) were obtained from reference (Manmohan Kumar Goel (Applicationsnow et al. 2011)

$$\mathrm{R} = (\text{Mean Anual precipitation} - \text{Mean Annual Evapotranspiration})\text{X Recharge ratio}$$

Eq. (2)

The recharge output raster has been given ranks and weight to be suitable for overlay analysis

Table 2: Land use characteristics and Runoff coefficient

S/N	Land use characteristics	Runoff coefficient	Recharge Ratio
1	Built area	0.8	0.20
2	Forest	0.27	0.73
3	Open field/lawn	0.25	0.75
4	Agricultural field fields with clay	0.4	0.60
5	Agricultural field fields with Sand	0.3	0.70
6	Water bodies	0.15	0.85

Aquifer Media (A): Groundwater flow is related to the porosity, permeability and transmissivity of aquifer. The aquifer media parameter is including materials which stores groundwater. To estimate this parameter, Geological map from Ethiopian Geological Survey has been used and process with the help of ArcGIS environment starting from provision of geo-referencing, and making appropriate shape and raster file formats as required for the overlay analysis. The geological parameter (aquifer media) has been classified into basalt, sand and gravel and igneous (weathered) based on DRASTIC model guideline. Accordingly, ranking has been given 9, 8, and 4 respectively.

Impact of Vadose Zone (I): The impact of vadose zone has been estimated based on the local geological maps as described in the Aquifer media. According to the Groundwater vulnerability assessment guidelines (Table 3) impact of vadose zone was digitalized from the Upper Awash sub river basin geological map.

Soil type (S): The soil type map has been prepared based on FAO soil type map and converted to soil texture map using world soil database (Nachtergaele et al., n.d.). The soil type parameter is mapping by using a digital soil texture map. Accordingly, the rating value of soil type can be given ranging from 10 for bare rock, gravel that able to pass contaminants easily to 1 (clay) that hider the transportation of contaminants. The seven categories have been rated using the guideline with a given weight of 2 for soil type (Table 3)

Topography (T): Slope determines precipitation rate and displacement velocity of water over the equipotential surface. The study area slope map has been obtained from digital elevation map from MOWIE/Information and GIS directorate. Slope values are then grouped into seven classes and rating value ranges from 1 to 10. The slope raster map has been extracted out from the large digital file.

Hydraulic Conductivity (C): it is the medium and fluid properties which describes the relative easiness of water flows through the aquifer. Hydraulic conductivity determines the rate at which a contaminant moves, which depends on the inter-connectivity of voids within the aquifer. Hydraulic conductivity raster map has been prepared using the geological nature of the aquifer of the sub basin as it is possible to use information of aquifer media in the absence of unavailability of hydraulic conductivity data("No Title," n.d.). To provide ranking for each geological material, hydraulic conductivity has been estimated. (Scbwartz and Sons, n.d.)

Table 3: DRASTIC rating and weight values for the study area

Rating	Depth of water table (m) W= 5	Net Recharge (mm/y) W= 4	Aquifer Media W=3	Soil Media W=2	Topography (%) W=1	Impact of Vadose Zone W=5	Hydraulic Conductivity (GPD/ft2) W= 3
10	0.0 -1.5		Karst Limestone	Thin or absent, gravel	0-2	Karst Limestone	>2000
09	1.5 - 4.5	>250	Basalt	Sandstone & volcanic	2-6	Basalt	
08		180-250	Sand and Gravel	Peat		Sand and Gravel	1000-2000
07	4.5 - 9		Massive Sandstone and limestone	Shrinking/ aggregate clay /alluvium		Gravel, sand	
06		100-180	Bedded sandstone and lime stone	Sandy loam, schist, sand, karst volcanic		Limestone, Sandstone Bedded limestone, sandstone, shale, Sand and Gravel with significance Silt & clay	700-1000
05	9 -15		Glacial	loam	6-12		
04			Weathered Metamorphic/igneous	Silt loam		Metamorphic/igneous	300-700
03	15 - 23	50-100	Metamorphic/ Igneous	Clay loam	12-18	Shale	
02	23 - 31		Massive Shale				100-300
01	>31	0.0-50		Non-shrink & Non-aggregated clay	>18	Silt/Clay	1-100

DRASTIC Index Value (Levels of vulnerability):

After the seven parameters have been analyzed by the aforementioned methods and procedures, the final ground water vulnerability map has been produced using Algebra map, raster calculation tool in the ArcGIS environment. And the map has been divided in to five classes to interpret the vulnerability levels of the study areas. These classes are

1) Very low vulnerable, DIV= 35-85; 2) Low vulnerable, DIV = 85-109; 3) Moderate vulnerable, DIV = 109-138; 4) High vulnerable, DIV =138-166 and 5) Very high vulnerable, DIV = 166 -210.

Land use land cover (LULC): it is incorporated as one model parameter for groundwater pollution risk analysis. The land use/land cover map has been combined with groundwater vulnerable map to produce groundwater pollution risk map. The weight for land use and land cover is taken as 5 and the ranking value is described in table 4. Finally, the map has been produced by map algebra in the ArcGIS environment base on Eq.3 (Allouche et al. 2017).

$\mathrm{LUI} = \mathrm{Lr} * \mathrm{Lw}$ Eq.3

Where;

LUI= Land use index; Lr = Land use rating; Lw = Land use weight

Table 4: Land use and cover categories, weight and rating values

/N	Land use and cover categories (weight =5)	Rating
1	Croplands	10
2	Built-up areas	9
3	Urban areas	8
4	Non-irrigated field crops	7
5	Grassland/scrublands	4
6	Water bodies	3
7	Bare areas/uncultivated	1
8	Forest/tree/marsh	1

Groundwater pollution Risk Calculation: to map the final groundwater pollution risk, the Eq.4 is calculated using ArcGIS, special analysis tool- Map Algebra.

$\mathrm{GWPRI} = \mathrm{DVI} + \mathrm{LUI}$

Where;

GWPR = Groundwater Pollution Risk Index; DVI = DRASTIC Value Index and LUI = Land Use Index

Table 5: Groundwater pollution Risk Index Values

S/N	Risk Class	Total Index Value
1	Low	<165
2	Moderate	166-207
3	High	208-249
4	Very high	>270

3.5. Sensitivity Analysis of DRASTIC Model

Sensitivity analysis has been done to evaluate the degree of vulnerability for each parameter or consistency of the analytical results. Assigned rating and weight for the contribution of each parameter to vulnerability index was checked for biasness as it may avoid errors and uncertainties of the individual parameters. It help to understand are insensitive or have not any influential efforts on the outputs in significant manner (Muhammad et al. 2015). The single parameter sensitivity test is used to estimate the role of each parameters considered in the model on the vulnerability measure by comparing the real or "effective" weight of each parameter with that of the corresponding assigned or "theoretical" weight. The effective weight in one of the subarea has been obtained using the following equation:

$W_{Pi} = \frac{P_{Ri} P_{Wi}}{DVI_i} * 100$ Where:

W_{Pi} = effective weight of parameter P for subarea donated AA

P_{Ri} = Parameter rating value (Maximum)

P_{Wi} = Parameter Weight value (constant)

DVI_i = DRASTIC Vulnerability Index for the subarea donated by AA.

Theoretical weights are calculated based on DRASTIC Equation as per the guideline.

In addition, using the Arc GIS environment, the degree of sensitivity associated with removing one or more map layers tested based on the following formula(Krishna et al. 2015).

$$S_i = \left| \frac{V_i}{N} - \frac{V_{xi}}{n} \right|$$

Where:

- Si= Sensitivity for i^{th} sub-area associated with the removal of one map (x-factor),
- V_i= is vulnerability index for the i^{th} sub-area,
- V_{xi} = Vulnerability index computed for i^{th} sub-area excluding one map layer (x),
- N = Number of map layers used to compute vulnerability index and
- n = Number of map layers used for sensitivity analysis. To assess the magnitude of the variation created by removal of one parameter, the variation index was computed as:

$$V_{ari} = \left(\frac{V_{i-Vxi}}{V_i} \right) * 100$$

Where:

Vari= Variation index of the map removal parameter; and

Vi = Vulnerability index and

Vxi= Vulnerability index for the i^{th} sub-area in two different conditions as mentioned above.

Therefore, Variation index estimates the effect on vulnerability indices due to removal of each parameter. Its value can be either positive or negative, depending on vulnerability index.

3.6. Validation of DRASTIC Model

Validation is done by taking Nitrate concentration of boreholes collected from MOWIE, Water Works, design and supervision Enterprise, Oromia regional state Water, mining and

Energy Bureau, Addis Ababa Water Supply and Sewerage Authority. Selection of Nitrate concentration for validation is due to the contaminant nature of nitrate to the groundwater (Elçi 2017). The model is validated by comparing the model output (DRASTIC index) with the observed nitrate concentration in groundwater in the study area using SPSS (statistical Package for Social Science) version 24. The analyze describes, evaluates and predicate the relationship between dependent variable and independent variables.

Therefore, Nitrate concentration assumed to be dependant variable (Con-NO3) and DRASTIC Value Index is independent variable. The model: $Y_i = \beta_o + \beta_1 X_i + \varepsilon_i$

Where, Y_i = Dependent variable; B_o=Population Intercept; B_1=Population Slope Coefficient; X_i=Independent variable and E_i =Random Error term

That means, Con-NO_3 = Slope X DVI + Intercept + Random Error,

To determine the coefficient of determination (R^2) or R-squared that measures the portion of the total variation in the dependent variable that is explained by variation in the independent variable, the following formula is used to validate the output.

$$R^2 = \frac{\mathrm{SSR}}{SST}, 0 \le R^2 \le 1$$

Where; $SST = SSR + SSE$

$$\mathrm{SST} = \sum (y_i - \bar{y})^2$$

$$\mathrm{SSR} = \sum (\hat{y}_i - \bar{y})^2$$

$$\mathrm{SSE} = \sum (y_i - \hat{y}_i)^2$$

$\bar{Y}$ = Average value of the dependent variable

y_i = Observed value of the dependent variable

$\hat{y}_i$ = Predicted value of y for the given xi value

Percentage of the variation (change) in the concentration of nitrate is attributed to the effect of DRASTIC Value Index size. The remained percentage is unexplained variation in the concentration of nitrate due to the factors that are not considered in the DRASTIC value Index

3.7. Limitation of the study

Groundwater vulnerability and pollution risk assessment is a complex approach that considers hydro-geological, topographical and land use and cover factors; however, due to the nature of the study, the following limitations are identified for this study.

- The study is not taking different season in to account which may affect the depth to water level measured and other parameters.
- The net recharge is taken only direct recharge, it is not including recharges from water bodies like streams and river recharge
- Hydraulic conductivity is mapped based on the nature of the aquifer but it may not reflect the actual hydraulic conductivity of aquifers.
- The vulnerable assessment is not able to address water quality problems/hazards due to natural geological formations
- Sampling techniques and analysis of concentration of Nitrates were not clearly known as the sources is secondary sources.
- Confined aquifers are treated as it is unconfined for depth of water and net recharge parameters that are mostly affected by the confinement status of the geological formation.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Aquifer intrinsic properties and Spatial Analysis

This Groundwater vulnerability and pollution risk assessment has been simulated using GIS based DRASTIC model and Groundwater Pollution Risk model. Spatial analyst extension of the ESRI's Arc GIS10.2 software able to process different layers of digital maps in to vulnerable zones through calculating the vulnerability index, and analyzing the spatial variability of the groundwater vulnerability (Elçi 2017) and the level of groundwater pollution risk in the study area (Lezzaik, Milewski, and Mullen 2018; Allouche et al. 2017).
Pollution vulnerability of aquifer is associated to lithology of the aquifer, geometry of the reservoir and hydrogeology of the targeted area. Overlay analysis of hydro-geological parameter maps are used to evaluate intrinsic vulnerability and the risk of pollution due to the potential impact of land uses is also analyzed (Baghapour et al. 2016). Intrinsic vulnerability assessment is aiming to evaluate the properties of the hydrogeological materials through which external contaminants pass down before reaching the aquifer system. It considers the geological, hydrological and hydrogeological characteristics such as depth of water, amount of ground water recharge, soil type, unsaturated zone (Vadoze zone), hydraulic conductivity nature of the aquifer as well as type of geological materials, and also topographic characteristics of the surface of the area.

As shown in the following maps, the intrinsic vulnerability to human or natural impacts in the case of Upper Awash sub river basin has been assessed. The result of each intrinsic parameter is described as follows.

A. **Depth to water level (D):** it is determining the length of transport of infiltrating contaminated water in the unsaturated zone. The rating value of the depth to water table decreases with increasing depth as the closer the water table to the surface from which potential pollutants are originated, the more vulnerable it is to contamination. Predetermined ratings are assigned to each class ranging from deep groundwater to shallow groundwater starting from 0 - 1.5 meters to more than 30.5 meters with scale of 1 to 10 for 7 classes respectively.

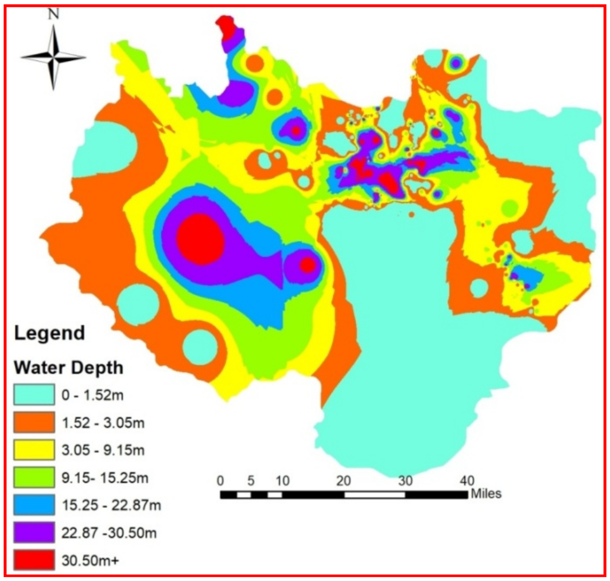

Figure 3: Map of water table, Upper Awash Sub-river basin (June 2018)

According to the result of the analysis, the mean water depth to the surface level is 39.16m. From 436 boreholes, more than 223 boreholes (51.2%) had greater than 30.05 meters of depth to the ground surface. When the depth is becoming more distant to the surface level, water depth for pollution has no significant contribution due to their depth that have minimum ranking for vulnerability (Table 6). It is evident that when the depth of water is less than 3m, the probability of being vulnerable is high where as more than 6m may not have significant contribution provide that other factors play their own roles (Jia et al. 2014).

Table 6: Water Depth Statistics, Upper Awash River Sub basin, December 2018

S/N	Description		# of Boreholes	%	% of area covered
1	Total number (N)		436	100	
2	Water Depth category	0-1.5 m	19	4.4	34.40
		1.5m – 3.05m	19	4.4	20.98
		3.05 – 9.15m	32	7.3	16.00
		9.15 – 15.25m	53	12.2	13.14
		15.25 – 22.87m	40	9.2	7.30
		22.87 – 30.50m	50	11.5	6.12
		30.05m+	223	51.2	
3	Statistics	Mean	39.16		
		Median	32.00		
		Std. Deviation	30.842		
		Minimum	1		
		Maximum	180		

B. Effective Recharge (R)

Net recharge has greatest contribution for the aquifer vulnerability since passing down surface pollutants occurred through recharge of surface runoff in to the subsurface. It is the main mechanism to transfer different contaminant from the surface of the earth to the groundwater sources. The result of the net recharge has been calculated by considering the annual rainfall, estimation of annual evapotranspiration and land use land cover characteristics of the study area. Based on 10 year compile rainfall data, the mean annual rainfall of the 9 meteorological stations has been 1072.12mm/year; specifically, maximum amount 1551.3mm/year has been recorded in Sutan meteorological station whereas minimum amount 810.9mm/year has recorded in Debrezeit station. However the mean annual rainfall when compared to the Awash River basin is higher. Awash River basin has around 557mm/year mean annual rainfall ("ESTIMA TION OF MONTHLY REFERENCE EV APOTRANSPIRA TION (ETO) FOR AREAS WITH IN ADEQUATE METEOROLOGICAL DATA IN ETHIOPIA Yilma Seleshi Department of Civil Engineering Yilma Seleshi" 2002) ;

The finding of the rainfall for this study is aligned with evidences generated in the basin. For example, the mean annual rainfall over the entire Western catchment is 850 mm and over the headwaters of the Awash is 1,216 mm (Chemeda, Mukand, and Babel 2010). Particularly the mean annual rainfall amount in the targeted areas like Addis Ababa indicated that the annual average rainfall is about 1150mm(Vulnerability et al., n.d.) and in the Modjo River Catchment which is part of the Upper Awash River Basin is around 922.75mm (M. River 2008). In addition, rainfall in the basin has been estimated to 39845Mm3/yr) and 72 % (28383 Mm3/yr) of this amount of rainfall is lost through evapotranspiration, 18 % (7386 Mm3/yr) runoff and 10% (4074 Mm3/yr) is rechargeable water (Mccomick and Peden, n.d.)

Evapotranspiration of the study area has been taken from peer reviewed article and estimated based on acceptable methods for estimation evapotranspiration that consider associated factors like temperature, sunshine, wind speed, and air humidity and also the considered data as a secondary sources has been triangulated with other studies. The mean annual evapotranspiration is taken as 776mm/year. This amount is between maximum and minimum amount when it is compared to mean annual potential evapotranspiration of Ethiopia that ranges from 620 mm in the central highlands to 2350 mm in the southeastern and northeastern lowlands of the country (Kidanewold, Melesse, and Seleshi 2013). However, a little bit lower as per the report from the Awash River basin which varies from 1,200 mm over the western and northern highlands to more than 2,200 mm over the eastern lowlands of the basin. (AWASH River Basin Authority 2017b). In addition, study conducted in Modjo River Catchment in the part of Upper Awash River Basin. The mean annual potential evapotranspiration of the study area is 1213.03 mm (M. River 2008) which is higher than by 36%.

Accordingly, 30.39% of the area has < 50.8mm/year; 21.77% of 50.8mm/y – 101.6mm/year; 15.55% of 101.6 – 177.8mm/year; 25.43% of 177.8 – 254.8mm/year; and the other 6.86% of the area has a net recharge of >254mm/year the net recharge is calculated as 139.7mm/year by considering land use land cover characteristics and evapotranspiration of the sub basin. The result is placed in the range of 51.5 mm/year to 157 mm/year as per the evidence of one article that was conducted in the sub basin (Berehanu et al. 2017). In contrast, study conducted in Modgo River Catchment, the annual net recharge has been computed as 71.59mm/year(M. River 2008)

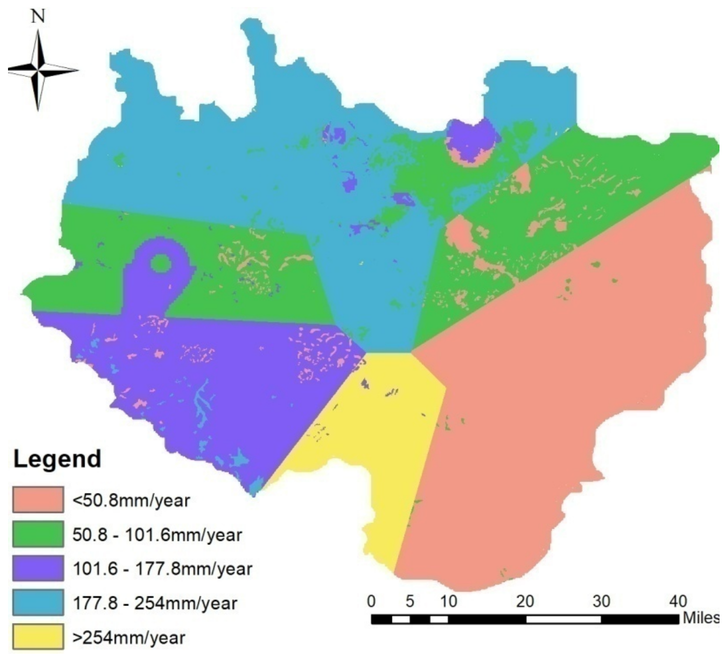

Figure 4: Map of recharge (mm/year), Upper Awash Sub-river Basin (June 2018)

C. Aquifer Media

Aquifer is a rock type which is holding and passing water as it has fractures or open spaces. Groundwater flow is related to intrinsically the porosity, permeability and transmissivity of aquifer(Hydrogeology, n.d.). In this study, the aquifer media parameter is included due to this nature associated with vulnerability of pollution. Upper Awash Sub-River basin in terms of area is covered by the geological formation of Nazirate series (38.59%), Tarmaber- Megezez (21.31%), Quaternary Sediments (20.11%), and other Alajae Formation, Bishoftu Formation, Chilalo formation, Dino formation, Quaternary basalt and Rhyoilitic Volcanic Centers (20%). To have geological parameter finding for the overlay analysis, nine geological units have been sorted out into three in order to provide weight and ranks as per acceptable ground water vulnerability analysis. Accordingly, Basalt is covering 28.54%, Sand and gravels is 46.07% and weathered/other forms of igneous rocks is 25.39% of the area of the sub-basin.

Upper Awash River Basin has four principal geologic units such as flood basalts at the base of all the volcanic formation and resting unconformable on Mesozoic sediments; second basalt sequence; felsic volcanics containing ignimbrites, tuffs and rhyolites and younger intercalation of basalts and ashes. As a whole the basalts may constitute up to 60 % of the total volume. As per the reference, the four hydrostratigraphic units are Basal sequence, upper sequence, shields and Quaternary basalt sequence. Termaber and Alaji formations are among upper sequences that have lightly weathered, permeable and relatively higher productivity aquifers, water table varies between 0 and 250 m, and yield generally up to 20 l/s. This type of rock has greatest contribution for the transmission of pollutants to the subsurface and therefore these are rated as 9 for the vulnerability index. In other hand, Quaternary basalt sequences are thinly bedded and highly productive with dual porosity nature. The Nazareth series volcanics have also low permeability, low yields and confining layer which may not have vulnerable intrinsic nature. (Hydrogeology, n.d.). Quaternary sediments had been originated from fluvial, lacustrine, eolian, eluvial and marine. The lacustrine beds are mostly redeposit volcanic sands, tuff with calcareous material and diatomite. The thickness of these sediments of undifferentiated continental origin (gravel, sand, silt and clay) reaches 10 to 20 meters at places increased towards the plateau (Mengesha T. 1996)

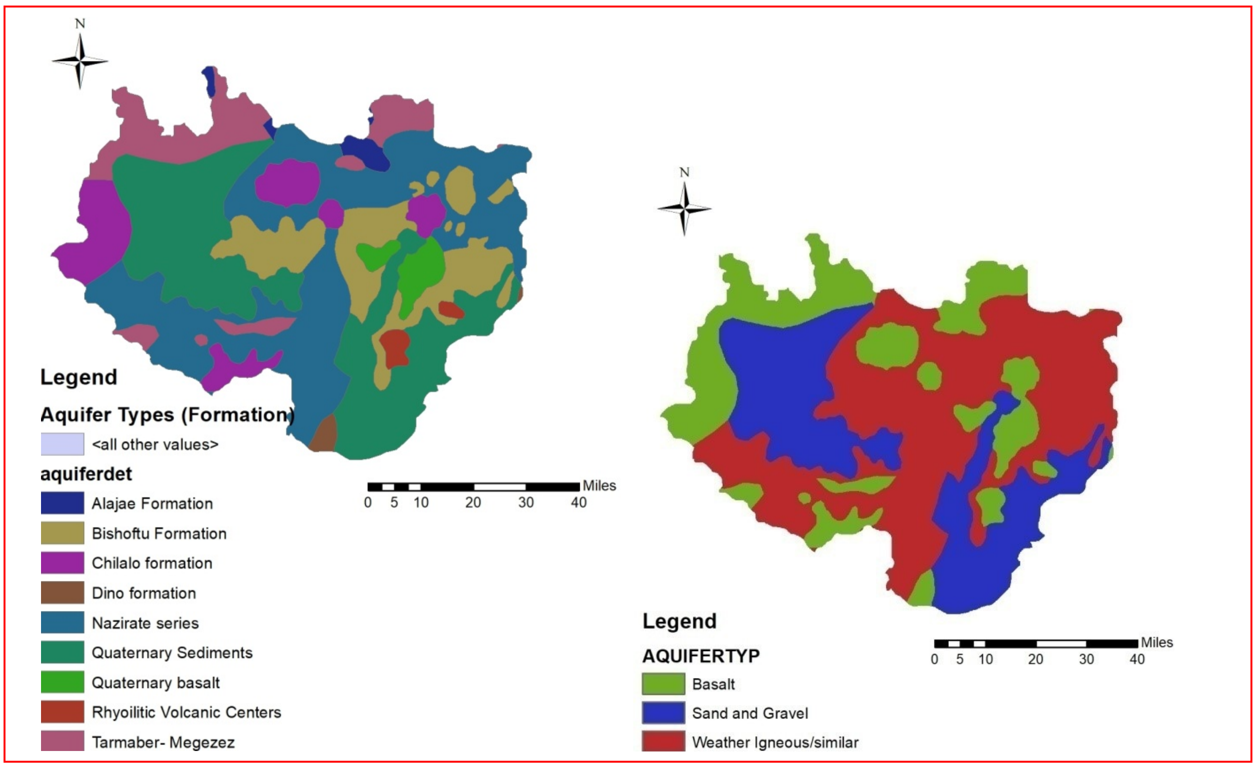

Figure 5: Geological map of Upper Awash Sub-River Basin, December 2018

D. Impact of Vadose Zone

The Vadose zone (unsaturated zone) is significant reservoir for the capture, storage, and release of contaminants from the surface to the subsurface. It is the media that connects hydrologic cycle of the surface component to groundwater. In this study as described in the methodology section, the impact of vadose zone on fate and transport of contaminates has been estimated based on the local geological characteristics as described in the Aquifer media; based on the guideline 9 scale is given for Basalt, 8 scale for sand and gravel and 4 scale is given for weathered/other forms of igneous rocks with the weight of 5. The assumptions for rating is considering the age scale of the basin geology and geological feature with increased age with high pressure and less porous spaces in the unsaturated zone (Vadose zone). Contaminant flow rates in unsaturated zone are substantially slower than rates of saturated flow due to unsaturated hydraulic conductivity, variations in texture and pore-size distribution in the vadose zone, chemical characteristics of the contaminant and the environmental conditions that exist in the vadose zones(Edition, n.d.). Generally, for the impact of Vadoze zone, digital raster map has been produced in order to run overlay analysis with other 6 parameters using ArcGIS environment (see Figure 6)

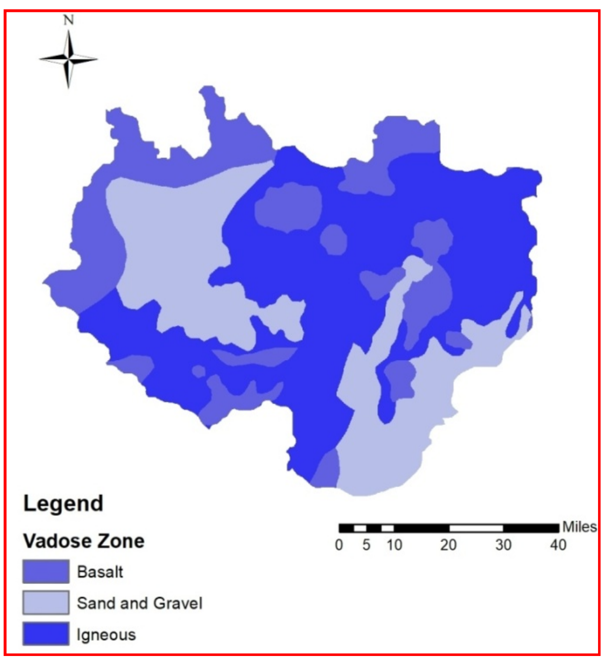

Figure 6: Map of Vadose Zone, Upper Awash Sub-Basin (December 2018)

E. Soil type

The soil is the part of the ground surface. The Soil type affects the pollutant transportation due to the nature of the soil and physicochemical processes carried out in the vadose zone such as sorption, ionic exchange, oxidation; or biological activity. The soil type map has been prepared based on FAO soil type map and converted to soil texture map using Harmonized World Soil Database (HWSD) manual and Microsoft access database.(Nachtergaele et al., n.d.). After that soil type parameter for groundwater vulnerability assessment has been incorporated as one of the parameter by providing 2 for weight and rates for each soil type. Accordingly,10 value for Thin soil, 6 value for Sandy Loam, 5 value for Loam, 4 value for Silt Loam, 3 value for Clay loam and 1 value for clay has been given. The analysis shows that 48.78% of the area of the sub-basin is covered by Silt Loam, 26.10% by Loam, 14.48% by Clay, 10.21% by Clay Loam and 0.43% by thin and sandy loam soil type (Figure 7). The rating and the coverage indicates that loam and clay loam with a value of 5 and 3 and 36.3% of the proportion area is having high contribution for vulnerability of ground water for the overlay analysis in the DRASTIC model.

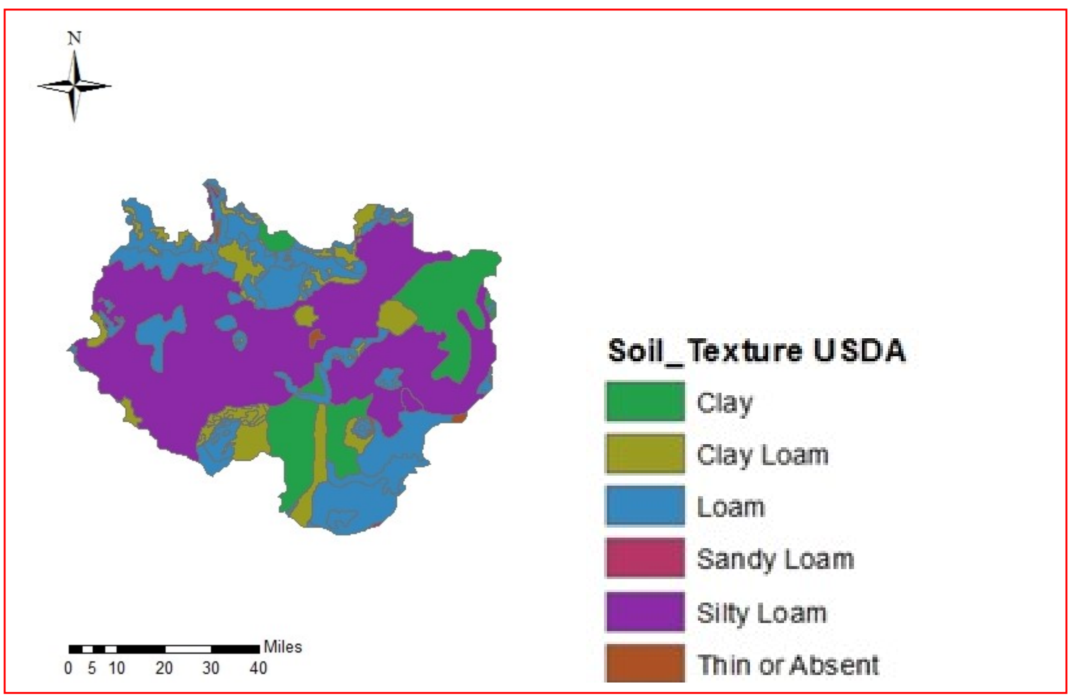

Figure 7: Map of Soil texture, Upper Awash Sub-basin (December 2018)

F. Topography (T)

The study area slope map has been obtained from digital elevation map of the sub-basin and analyzed for raster map. The analyzed slope map indicated that 45.36% of the sub-basin area is having slope less than 2%, 38.43% of the area with 2-6% slope, 13.22% of the area with 6-12% slope and the rest 3% of the area is having more than 12% slope and 10, 9, 5, and 3-1 scales have been given for each category respectively. Even though the weight for slope is 1, 83.79% of the area has got the largest rank (10 and 9) for vulnerable analysis. Consequently, it is the fact that sub- catchments of Upper Awash sub river basin such as Melka-Kuntre (0.92), Akaki (0.61), Hombole (0.94) and Koka (0.67) have highest elongation ratio (Re) values which indicates the presence of relatively high infiltration capacity due to relatively flat slope (low relief) and low runoff. (Sedimentation and Project 2016)

Slope determines precipitation rate and displacement velocity of water over the equi-potential surface. Lowest slope is suitable for pollutants to percolate in to the ground to mix with groundwater. Slope is also inherent factor for the soil type and thickness. In other hand, areas with steeper slopes cause more runoff with less infiltration that attributes small risk of groundwater contamination. In contrast of this, topography within the watershed system is determining water quality of downstream through creation of fast runoff flow rate. (Emmanuel et al. 2012), (Sliva and Williams 2001).

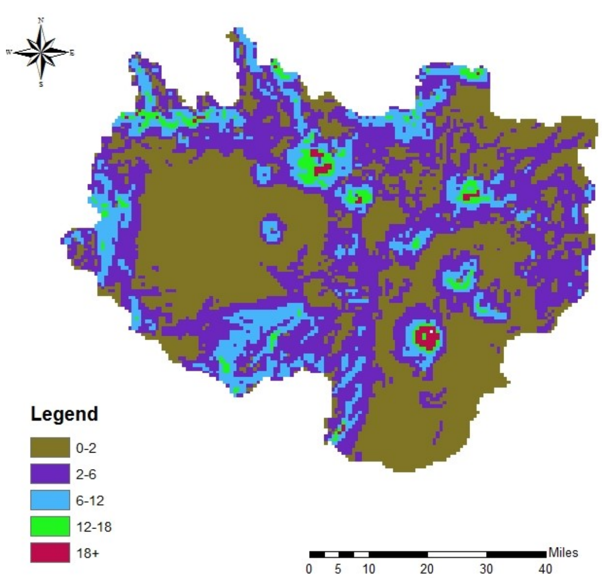

Figure 8: Map of slope (%) of Upper Awash Sub-River Basin (December 2018)

G. Hydraulic Conductivity

Hydraulic conductivity determines the rate at which a contaminant moves, which depends on the inter-connectivity of voids within the aquifer. In the absence of availability of hydraulic conductivity data, this study taken aquifer media information using standard hydrology book ("No Title," n.d.). As the result, the map has been produced by providing 3 weights for hydraulic conductivity and rating from 9-4 scale for the three categories (Figure). As indicated above, the geological units of Upper Awash Sub-River basin are Nazirate series (38.59%), Tarmaber- Megezez (21.31%), Quaternary Sediments (20.11%), and other Alajae Formation, Bishoftu Formation, Chilalo formation, Dino formation, Quaternary basalt and Rhyoilitic Volcanic Centers (20%). The hydraulic conductivities of Nazareth series basal varies from 50 to 27,000 m2/day with thickness of more than 300 m. The aquifer system of Termaber formation is attributed as fractured aquifer with high transmissivity which varies from 0.5 to 1,400 m2/day but lower storage capacity. In other hand, the hydraulic conductivity of Sands and associated quaternary sediments ranges up to 120 m2/day and prevalent in Becho plain, Akaki plain and other pocket areas in the study area. Generally, the geological nature shows that the easiness of contaminant movement from the surface of the ground to the sub-surface due to high hydraulic conductivity rate, fracture and thickness of the aquifer. This increases vulnerability of the area for ground water pollution.

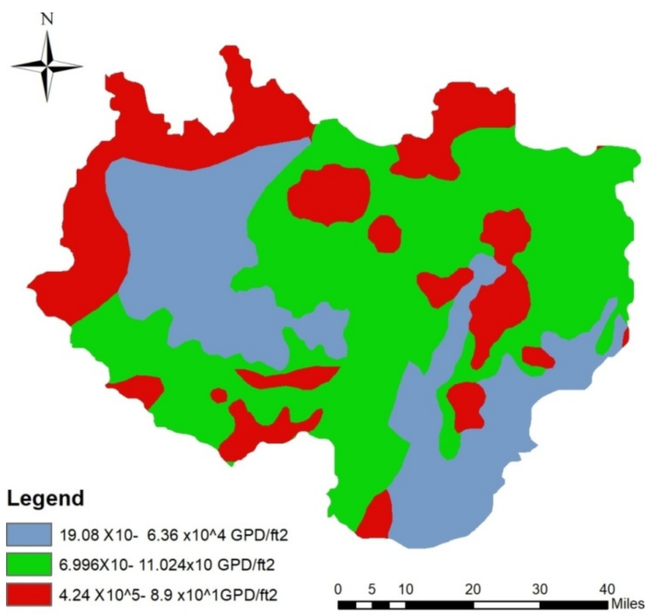

Figure 9: Map of Hydraulic conductivity of Upper Awash Sub-River Basin (December 2018)

4.2. Sensitivity Analysis

Sensitivity analysis has been done to evaluate the degree of vulnerability contributed by each parameter and consistency of the analytical results. Sensitivity analysis result has used to check the assigned rating, weight and degree of contribution of each parameter for the output of vulnerability index value. It found out which parameter is the most sensitivity or insensitive of outputs in significant manner (Muhammad et al. 2015). The single parameter sensitivity test is used to estimate the role of each parameters considered in the model on the vulnerability measure by comparing the real or "effective" weight of each parameter with that of the corresponding assigned or "theoretical" weight. The effective weight in one of the subarea has been obtained using the following equation:

$W_{Pi} = \frac{P_{Ri}P_{Wi}}{DVI_i} * 100$ Where:

W_{Pi}= effective weight of parameter P for subarea donated AA

P_{Ri}= Parameter rating value (Maximum)

P_{Wi} = Parameter Weight value (constant)

DVI_i= DRASTIC Vulnerability Index for the subarea donated by AA.

Table 7: Effective weight of seven parameters

S/N	Parameters	For Effective weight			For Theoretical weights			Different in %
		$P_{Ri}P_{Wi}$	DVI_i	W_{Pi}	$P_{Ri}P_{Wi}$	DVI_i	W_{Pi}	
1	Recharge	24	169	14.20	36	210	17.14	6.48
2	Water Depth	50	169	29.59	50	210	23.81	-14.10
3	Hydraulic Conductivity	30	169	17.75	30	210	14.29	-14.11
4	Topography (Slope)	10	169	5.92	20	210	9.52	16.77
5	Vadose zone	45	169	26.63	50	210	23.81	-7.94
6	Soil type	20	169	11.83	20	210	9.52	-14.13
7	Aquifer type	27	169	15.98	30	210	14.29	-7.95

Theoretical weights are calculated based on DRASTIC Equation as per the guideline. By taking on area within the study area, the above weights are calculated. The difference of effective and theoretical weight in percentage is not significantly far apart from each other, the study use the theoretical weight as it is as per the DRASTIC guideline (standard)(Muhammad et al. 2015). It is noted that this sensitivity analysis is crucial for validation and consistency evaluation of the analytical results.(Napolitano and Fabbri 1996)

By taking on area within the study area, the above weights are calculated. As the difference in percentage is not much more different from each other, it is decided to use the theoretical weights for DRASTIC model as per the guideline (standard)(Muhammad et al. 2015)

On top of this, the degree of sensitivity associated with removing one or more map layers tested based on the following formula(Krishna et al. 2015).

$$S_i = \left|\frac{V_i}{N} - \frac{V_{xi}}{n}\right| \quad \& \quad S = \left(\frac{\left|\frac{V_i}{N} - \frac{V_{xi}}{n}\right|}{Vi}\right) \text{x } 100$$

Where:

- S_i= Sensitivity for ith sub-area associated with the removal of one map (x-factor),
- V_i= is vulnerability index for the ith sub-area,
- V_{xi} = Vulnerability index computed for ith sub-area excluding one map layer (x),
- N = Number of map layers used to compute vulnerability index and
- n = Number of map layers used for sensitivity analysis. To assess the magnitude of the variation created by removal of one parameter, the variation index was computed as:

$$V_{ari} = \left(\frac{V_{i-Vxi}}{V_i}\right) * 100$$

Where:

Vari= Variation index of the map removal parameter; and

Vi = Vulnerability index and

Vxi= Vulnerability index for the ith sub-area in two different conditions as mentioned above.

Table 8: Variation index of the map due to removal of parameter, Upper Awash Sub-Basin (June 2018)

S/N	Removed parameters	Vi	Vxi	Var in %	Vi/N	Vxi/n	Si	S
1	Aquifer	169	155	4.32	24.14	25.83	-1.69	-1.00%
2	Recharge	169	143	11.73	24.14	23.83	0.31	0.18%
3	Water Table	169	133	17.9	24.14	22.17	1.98	1.17%
4	Soil	169	154	4.94	24.14	25.67	-1.52	-0.90%
5	Vadose Zone	169	125	22.84	24.14	20.83	3.31	1.96%
6	Hydraulic Conductivity	169	144	11.11	24.14	24.00	0.14	0.08%
7	Slope	169	152	6.17	24.14	25.33	-1.19	-0.70%

Therefore, Variation index estimates the effect on vulnerability indices due to removal of each parameter. Its value can be either positive or negative, depending on vulnerability index. Variation index directly depends upon the weighting system. The most sensitive to groundwater pollution is the parameter in order to increase Impact of Vadose Zone, Depth of water, Aquifer media, Soil type, Topography, Net Recharge and Hydraulic conductivity

Hydraulic conductivity raster layer is less affecting the variation in the final ground water vulnerability index value as the variation index (S) has the least average value after its removal (= 0.08%) where as high variation of the vulnerability index is calculated after the removal of Impact Vadose zone raster layer that has the highest variation index (1.96%) as compared to other parameter after removal. It is supported by article which explains as depth to water is a parameter that strongly affects vulnerability particularly if it is unconfined or semi-confined aquifer but less in confined aquifer(Napolitano and Fabbri 1996).

4.3. Validation of DRASTIC Model

The final output of the DRASTIC model has validated using 222 borehole's nitrate concentrations that are located in the sub-basin (Figure 9). Validation using nitrate concentration is one of the method in the DRASTIC model validation due to contaminant nature of nitrate for groundwater through agricultural activities (application of fertilizers and livestock wastes), and percolation of residential and industrial wastewater (Elçi 2017). The process has been done by comparing the model output (groundwater vulnerability index) with nitrate concentrations (mg/l) to analysis the association of groundwater vulnerability index value with the concentrations. Nitrate concentrations greater than 2mg/l assumed to be caused by human activities and thus more than 2mg/l nitrate concentration has been taken(Wick, Heumesser, and Schmid 2012). The association between the vulnerability indices and nitrate concentration is confirmed and the variation is explained by R square with a value of 72%. (Table 9). This indicates that 72% of variation (changes) in index values is related with the effect of nitrate concentration whereas the other 28% of the variations is not explained by the contaminant concentration of nitrate. The validation process has also produced predicable model, if the nitrate concentration is increased by a unit, the groundwater vulnerability index will be increased by 2.26 times (P-value <<0.05) (Table 9).

Therefore, in accordance with this validation result, the DRASTIC model input parameters are validated to be accepted (Oke and Fourie 2017a),(S. K. D. Thirumalaivasan 2014),(Salwa Saidi, Bouri, and Ben 2010), (Junjie Wang, He, and Chen 2012).

The percentage of cropland positively and temperature due to evapotrinspiration and precipitation due to dilution are correlated negatively with nitrate concentration in groundwater) (Mahvi et al. 2005).There are also positive correlations of Nitrate concentration in the Vadose zone with groundwater depth increased due to inactive gentrification process and greater nitrate nitrogen leaching in the cotton root zone.(Field, n.d.) (Province 2015)

Table 9: Regression analysis of Index value and NO_3 concentration, Upper Awash River basin, Dec 2018

S/N	Descriptions		Result value	P-value
1	Groundwater Vulnerability Index Value (N=222)	Mean	95.03	
		Std. Deviation	29.30	
		Variance	121.22	
		Minimum (mg/l)	2.00	
		Maximum (mg/l)	44.00	
2	Nitrate Concentration (mg/l) (N=222)	Mean	10.11	
		Std. Deviation	11.01	
		Variance	858.624	
		Minimum	63	
		Maximum	168	
3	Regression	Sum of Squares	136983.36	0.000
		Degree of freedom (df)	1	
		Mean Square	136983.36	
		F	571.06	
4	Residual	Sum of Squares	52772.47	
		Degree of freedom (df)	220	
		Mean Square	239.88	
5	Total	Sum of Squares	189755.84	
		Degree of freedom (df)	221	
6	Measure of variation	Adjusted R Square (R^2)	0.721	0.000
7	Coefficients (B) within 95.0% CI	Intercept	72.16	0.000
		Slope	2.26	0.000
	Model	$GWVI= 72.16 + 2.26NO_3$		

The source of Nitrate in groundwater is coming either by the natural processes (atmospheric fixation, lightning storms) or through anthropogenic activities (fertilizer applications, septic tanks, waste water) (Torfs 2015). Generally, from the report of Awash River Basin administration Authority, the concentration of nitrate (7.44mg/l) in upper Awash River sub-basin is greater than other sub-basins and catchments. It is almost aligned and justified with the mean concentration (10.11mg/l) of this study, ("Adama Science and Technology Client : Awash Basin Authority" 2017).

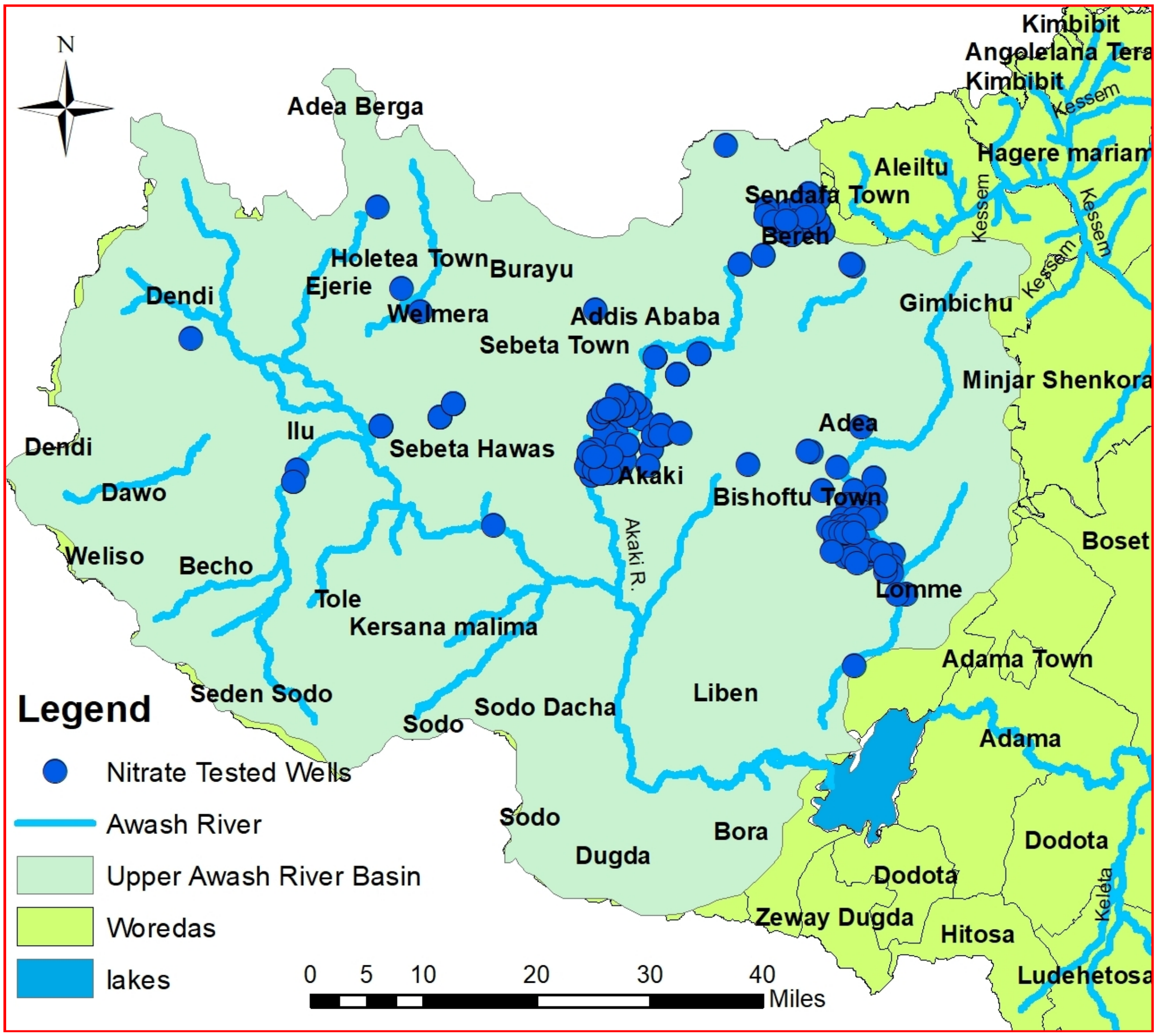

Figure 10: Map of Wells with Nitrate concentration (mg/l) map , Upper Awash Sub-Basin (December 2018)

4.4. DRASTIC Model Vulnerability Mapping

The study demonstrated the integrated approach with GIS and DRASTIC model to derive a groundwater vulnerability to pollution map. These groundwater vulnerability index is categorized in to very low vulnerable (<85), low vulnerable (85-109), moderate vulnerable (109-138), high vulnerable (138-166) and very high vulnerable (166-210). Accordingly, based on zonal statistical procedure, 18% of the area of Upper Awash Basin is having high and very high vulnerable for pollution, 26% of the area is having moderately vulnerable and 57 % is very low and low levels of vulnerabilities (Figure 9).

The status of vulnerability of groundwater in Upper Awash River Basin as indicated by the findings,43% of the areas which are located in western part of the sub-basin; particularly, woredas such as Ejere, Becho, Adaberga, Holeta, Ilu, Dawo, Tole, Kersanamalima, Sodo, Sebeta, Bereh and pocket area of south western part of Addis Ababa are are having vulnerable areas. In this area, there are evidences which pointed out the presence of surface water pollution and different types of risk of pollution because of urban areas and different types of industries. For example, low water quality statuses due to poor farming, untreated effluents from factories and poor provision of sanitation facilities to the riparian communities are pointed out in evidences(Degefu, Lakew, and Teshome 2013); the drinking and irrigation water quality indices of the upper basin were found to be poor. (Keraga, Kiflie, and Engida 2017). Upper Awash river basin is one of the most important river basins among any other sub basins. The basin has intensive agricultural irrigation schemes, different types of industries (up to largest scale industrial village), millions of urban and rural residents including Addis Ababa and emerging cities in Oromia regional state. There are many industries, different kinds of factories, institutions, irrigation schemes, and other residential areas which have greatest contribution for groundwater pollution. Beside natural factors, anthropogenic activities are one of the major environmental problems in urban and industrial areas; however, it is not supported by articles which can show the vulnerability of these areas.

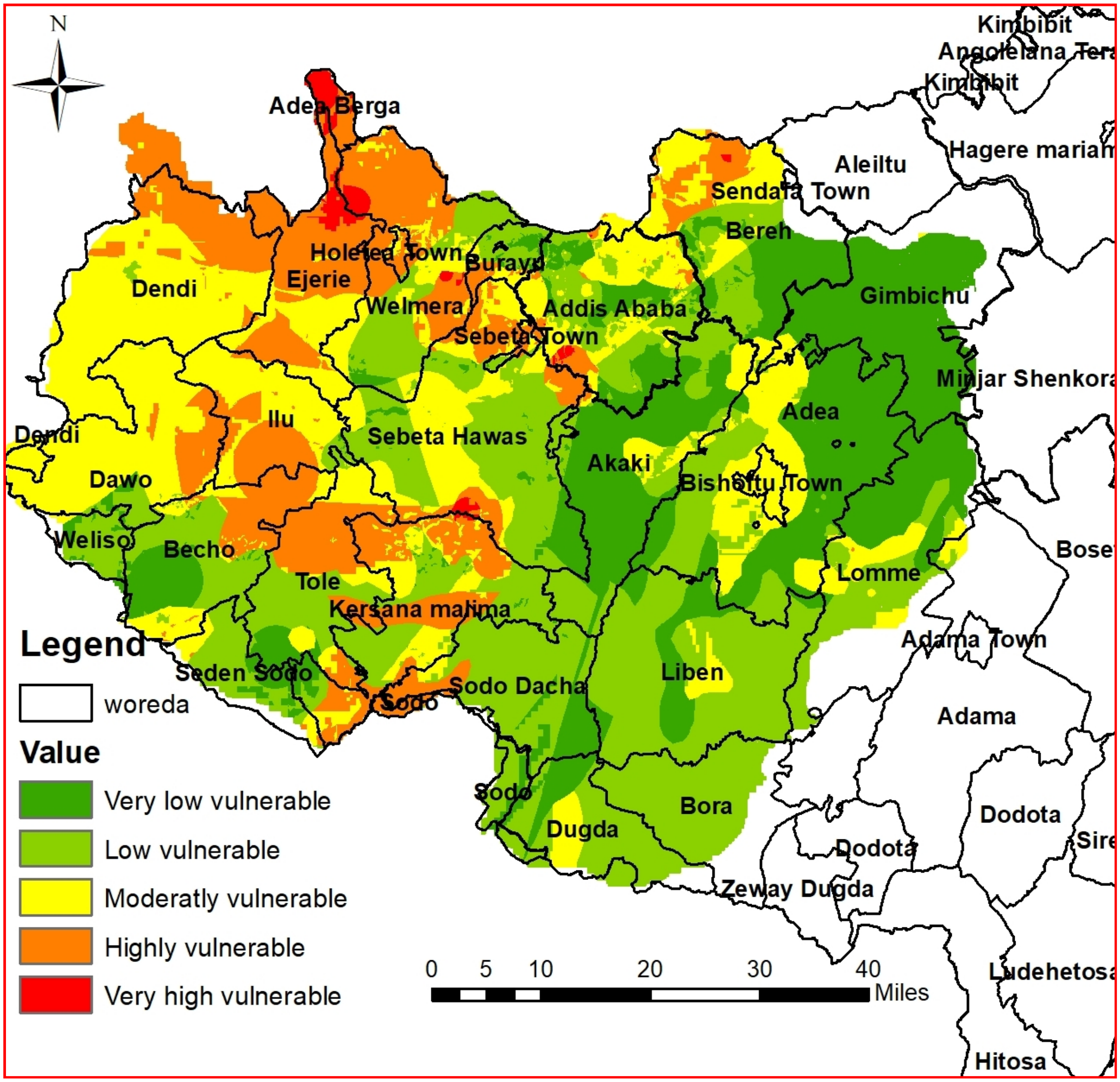

Figure 11: Map of DRASTIC Index, Upper Awash Sub- basin, December 2018

4.5. Groundwater Pollution Risk

Land use land cover is one the model parameter for groundwater pollution risk analysis. In this study, the land use/land cover map with a given weight and rank has been combined with groundwater vulnerable map to produce groundwater pollution risk map (Figure 10). The weight for land use and land cover is taken as 5 and the ranking value is described in the methodology section (Allouche et al. 2017).

The shape file has been converted to raster map in order to calculate the share of land use land cover for the risk analysis. As shown in table 10, 86% of the area is covered by Agricultural land, 6% is covered by settlement including urban areas and 5.92% is also covered by forest whereas 2% of the area covered by the rest four types of land use land cover.

Table 10: Land use land cover type of Upper Awash River sub basin, December 2018

S/N	Land use Land Cover type	%
1	Agriculture Land	86.217
2	Settlement	6.077
3	Forest (including Eucalyptus and Acacia trees)	5.92
4	Bare Land	0.780
5	Shrub Land	0.747
6	Grass Land	0.262
7	Water Body	0.249
	Total	100

The land use land cover map of this study is almost similar with the report of Awash River basin Administration authority (A. River et al., n.d.). According to the evidence, the land uses such as settlement and Agricultural land types are increased from 1986 to 2013(Authority and Werer 2017a). These expansions have influential factors for the groundwater pollution risk level.

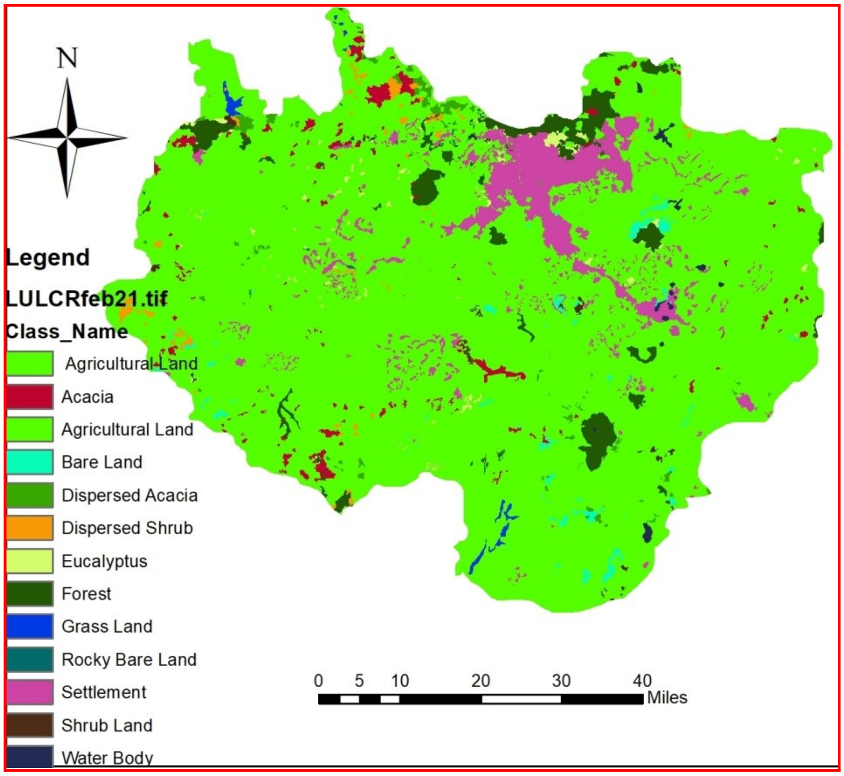

Figure 12: Land use Land cover of Upper Awash River Sub-basin, December 2018

Calculation of the final Groundwater pollution Risk level has been done using the value of DRASTIC index and Land use index. The result of the analysis is interpreted based on the four class of risk level such as low risk (<165), moderate risk 166-207 values, high risk with 208 – 249 values and very high risk is more than 270 values. In addition to the aforementioned DRASTIC index results, Land use index has been calculated using land use land cover characteristics of the sub basin. Accordingly, only 1% of the area of Upper Awash River Basin is high risk; 31% of the area is moderate risk which are located in the western part of the sub basin where as 67% of the area is low risk for groundwater pollution. The detailed map is depicted below in Figure 10.

Findings of this study are supported by other evidences. For instance, in Lake Ziway neighboring the study area, Agricultural lands and settlement areas increased from 57% to 75% after 41 years are resulted in the decrease of woodlands from 26.16% to 6.6 3% due to anthropogenic factors (Desta, Lemma, and Gebremariam 2017). These evidences are comparable with 86.20% of agricultural and 5.9% mixed forest with the study area which indicate the change of woodlands to agricultural lands and settlement areas are the major changes. Agricultural expansion and forest loss affects water quality by increasing soil erosion and sediment deposit in surface water sources and thus interaction of surface and groundwater invite pollutants in to the aquifers (*’ PSFTUT BOE XBUFS*, n.d.). In the country, land use land cover are affected by land degradation which mainly because of rapid population growth, soil erosion, deforestation, and unbalanced crop and livestock production (Taddese 2001). large scale irrigation schemes located in upper Awash River sub-basin shown that groundwater table has risen due to improper irrigation management and seepage of reservoirs which leads to quality of ground water contamination (Ruffeis et al. 2016). Therefore, the study findings with supporting documents have strong evidences on the association of water quality and land use-land cover characteristics. This confirms the value of the findings to appropriate land management and urban planning.

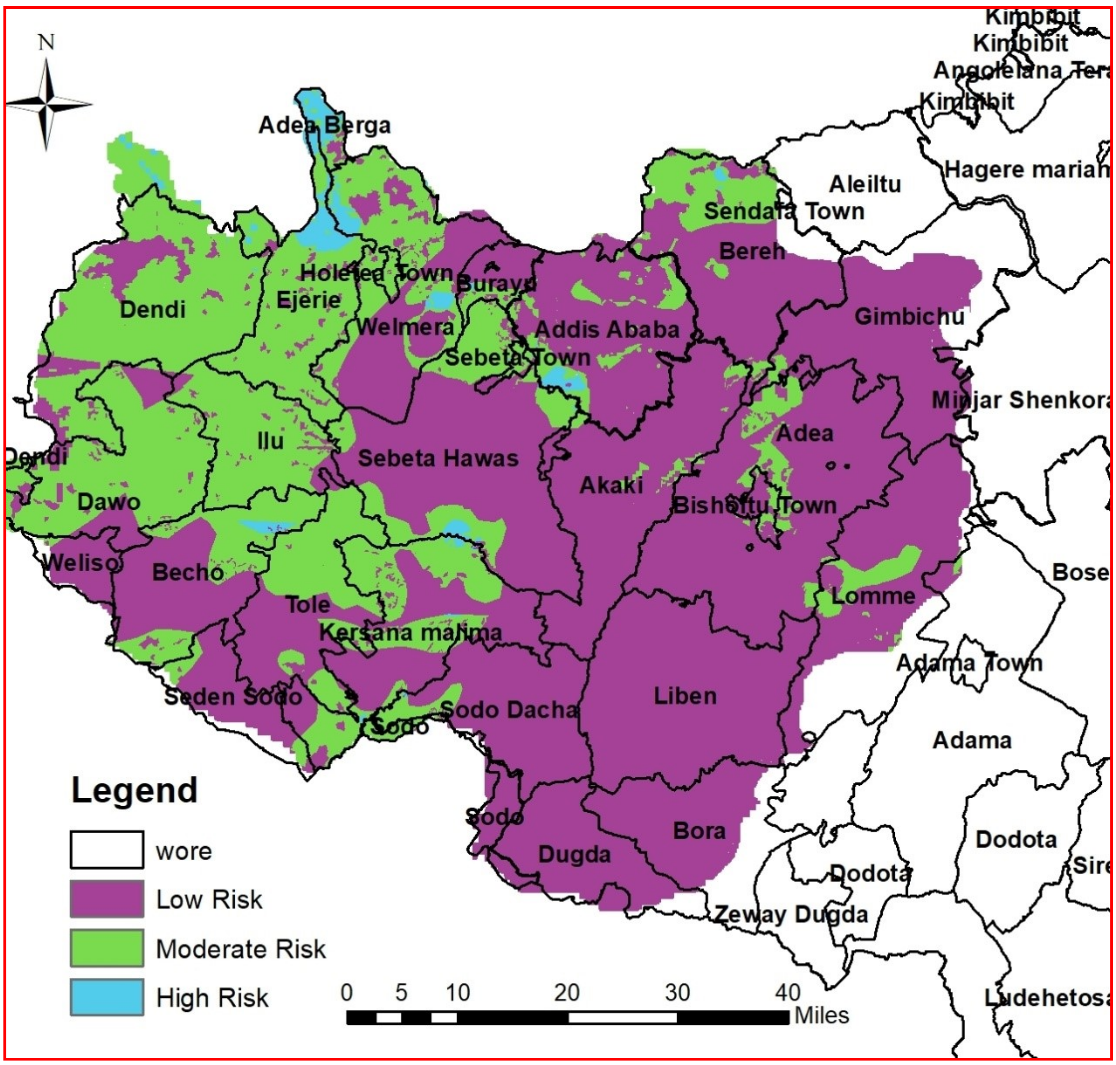

Figure 13: Groundwater risk index, Upper Awash River sub Basin, December 2018

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

Upper Awash sub river basin is the most impacted basin in Ethiopia by urbanization with poor waste disposal and drainage systems, climate change, industrialization, expansion of agricultural activities and natural phenomena which lead to pollutions of ground and surface water sources. These contribute to high mortality and morbidity rate, high cost for drinking water treatment and unsuitability for irrigation and even for industrial use. In contrast, water quality protection and practices are given less attention; water quality issues are not integrated in to water resource management as part of the natural ecosystem protection, land management, urban planning and rural development activities. Therefore, these validated findings are indicating the most sensitive intrinsic factors for vulnerability, vulnerable areas for groundwater pollution, and which areas have potential risks of groundwater pollution.
The most sensitive to groundwater pollution is the parameter in order to increase Impact of Vadose Zone, Depth of water, Aquifer media, Soil type, Topography, Net Recharge and Hydraulic conductivity. This output emphasize that the need of prioritization of the most sensitive parameters during groundwater protection and land planning measures. Collectively, the overlay analysis of seven natural hydrogeological setting (intrinsic parameters) highlighted 18% of the sub-basin are high and very high, 26% moderately vulnerable for groundwater pollution. Almost more than 44% of upper Awash River sub-basin requires sound groundwater resource protection measure to reduce existing vulnerability. In other hand, around 32% of the Upper Awash sub basin has exposed for moderate risk of groundwater pollution which needs timely and appropriate interventions by the concerned bodies.

Finally, these findings were produced based on overlay analysis method by considering seven hydrogeological parameters and land use land cover parameter with specific weighting and rating. Consequently, beside advantages for the identification and prioritized zones within the limitation of environmental variability and qualitative index method; future research on specific vulnerability, hazardous and groundwater pollution risks are advised to be conducted in future.

5.2. Recommendations

This study identified the most sensitive intrinsic parameters for groundwater vulnerability, vulnerable areas for groundwater pollution as well as mapped groundwater pollution risk areas. And therefore, to minimize environmental and public health risks, the following recommendations are forwarded so as to be implemented by the concerned bodies.

1. To implement groundwater protection measures to protect already identified vulnerable zones from groundwater pollutions due to urbanization, industrialization and expansion of agriculture which are common feature of the upper Awash River Sub-basin. These further invite appropriate liquid waste disposal system in urban settlement settings, industry effluents management, agricultural input handling and management as well as to conduct additional environmental impact assessment for newly developments.
2. To practice remedial actions for pollution risk exposed zones to reduce risks through urban and agricultural planning including legal measures.

- To conduct regular monitoring and evaluation whether protection, remedial actions and corrective actions are undertaken as required including field survey and water quality tests.

3. To strength groundwater management including revising of policies, institutional arrangements and technical capacity for risk management by providing priority for pollution vulnerable and exposed areas of upper Awash River sub-basin.
4. To do further researches to improve limitation of overlay analysis studies and uncertainty due to the complex nature of hydro-geology properties and natural heterogeneity so as to model groundwater quality for appropriate management and protection measures.

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