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GROUNDWATER QUALITY, VULNERABILITY AND POTENTIAL ASSESSMENT IN KOBO VALLEY DEVELOPMENT PROJECT, ETHIOPIA

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GROUNDWATER QUALITY, VULNERABILITY AND POTENTIAL ASSESSMENT IN KOBO VALLEY DEVELOPMENT PROJECT, ETHIOPIA

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ABSTRACT

This study deals with investigating the groundwater quality for irrigation purpose, the vulnerability of the aquifer system to pollution and also the aquifer potential for sustainable water resources development in Kobo Valley development project. The groundwater quality is evaluated up on predicting the best possible distribution of hydrogeochemicals using geostatistical method and comparing them with the water quality guidelines given for the purpose of irrigation. The hydro geochemical parameters considered are SAR, EC, TDS, Cl^-, Na^+, Ca^{++}, SO_4^{2-} and HCO_3^-. The spatial variability map reveals that these parameters falls under safe, moderate and severe or increasing problems. In order to present it clearly, the aggregated Water Quality Index (WQI) map is constructed using Weighted Arithmetic Mean method. It is found that Kobo-Gerbi sub basin is suffered from bad water quality for the irrigation purpose. Waja Golesha sub-basin has moderate and Hormat Golena is the better sub basin in terms of water quality. The groundwater vulnerability assessment of the study area is made using the GOD rating system. It is found that the whole area is experiencing moderate to high risk of vulnerability and it is a good warning for proper management of the resource. The high risks of vulnerability are noticed in Hormat Golena and Waja Golesha sub basins. The aquifer potential of the study area is obtained using weighted overlay analysis and 73.3% of the total area is a good site for future water well development. The rest 26.7% of the area is not considered as a good site for spotting groundwater wells. Most of this area fall under Kobo-Gerbi sub basin.

KEYWORDS

WQI
GOD Rating System
Vulnerability
Geostatistical Method
Weighted Arithmetic Mean
Aquifer Potential,
Spatial Variability
Weighted Overlay Analysis.

ACRONYMS

B-Boron

BK-Bayesian Kriging

Ca-Calcium

Cl-Chloride

Co-SAERAR- Commission for Sustainable Agriculture and

D-Depth to Water Level

EC-Electrical Conductivity

ENGDA- National Groundwater Database Association

Environmental Rehabilitation of Amhara Region

FAO-Food and Agricultural Organization

G-Groundwater Occurrence

GIS-Geographical Information System

H-Aquifer Thickness

HCO_3-Bicarbonate

h-Static Water Level

IDW-Inverse Distance Weighting

ITCZ- Inter-Tropical Convergence Zone

KCl-Pottasium Chloride

KGVDP-Kobo Girana Valley Development Project

K-Hydraulic Conductivity

k-Proportional Constant

MAE-Mean Absolute Error

ME-Mean Error

Meq-miliequivalent

MS-Matrix System

NaCl-Sodium Chloride

Na-Sodium

OK-Ordinary Kriging

O-Overlying Lithology

PCSM-Point Count System Model

RBF- Radial Basis Functions

RMSE-Root Mean Square Error

RSC-Residual Sodium Carbonate

RS-Rating System

SAR-Sodium Adsorption Ratio

SO_4-Sulphate

STL-Static Water Level

TDS-Total Dissolved Solids

T-Transmitivity

UK-Universal Kriging

UTM-Universal Transverse Mercator

WAWQI- Weighted Arithmetic Water Quality Index

WHO-World Health Organization

Wi-weight of parameter

WQI-Water Quality Index

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1. Introduction

Most of the Earth's liquid fresh water is found, not in lakes or rivers, but is stored underground in the aquifers. Indeed, these aquifers provide a valuable base flow supplying water to rivers during periods of no rainfall. They are therefore an essential resource that requires protection so that groundwater can continue to sustain the human race and the various ecosystems that depend on it. The contribution from groundwater is vital; according to Morris and et.al, two billion people depend directly upon aquifers for drinking water, and 40 percent of the world's food is produced by irrigated agriculture that relies largely on groundwater. In the future, aquifer development will continue to be fundamental to economic development and reliable water supplies will be needed for domestic and irrigation purposes. Water stored in the ground beneath our feet is invisible and so its depletion or degradation due to contamination can proceed unnoticed, unlike our rivers, lakes and reservoirs, where drying up or pollution rapidly becomes obvious and is reported (Morris et al. 2003).

Hydro geologic or ground water parameters include the depth of the water level measured in the observation wells, the quantity or discharge of the aquifer, the water quality of the water bearing stratum, the hydraulic permeability of the aquifer, etc. The sustainable use of groundwater resource is the properly management of groundwater related phenomenon for the wise use of the resource. By knowing the depth of ground water level in a certain area, one might be able to observe how depleted the aquifer system is. At the same time, by monitoring the quality of the water, it is possible to adopt mechanisms to mitigate or take actions. The other parameter for the indication of groundwater quantity and also for groundwater pollution is the permeability of the groundwater aquifer. The higher the permeability of the aquifer, the higher the yield will be so that it may be used to locate relative potential areas with the help of other parameters like aquifer thickness, the hydro geological make up of the area, and the depth to the static water table, etc. There are ranges of values for which we say the aquifer is a good one based on the factors considered.

Spatial patterns of hydrological processes are a rich source of variability which in some instances is quite obvious to the observer, as in the case of spatial patterns of a seasonal snow cover; and in other instances is hidden from the eye and very difficult to identify by even the most sophisticated measurement techniques, as is the case with patterns of subsurface preferential flow paths. Part of the richness comes from the diversity in the spatial arrangement of hydrologically relevant variables. It is important to understand this arrangement to design measurement strategies adequately, to interpret the data correctly, to build and/or apply a model of catchment dynamics, and ultimately to use these data in predictions of the hydrological behaviour of catchments. There is a wide spectrum of ''measurement techniques'' (in a general sense) available for exploring these complex patterns, ranging from traditional stream gauging to remote sensing. Ideally, a measurement technique should be designed to take into account the type of natural variability one would expect to encounter. Depending on the nature of the hydrological variability, certain measurement techniques will be more suitable than others (Grayson and Bloschl, 2000).

Although there are perennial rivers and other intermittent streams in Kobo valley, the use of the groundwater resources is found to be crucial for the development of irrigation agriculture in the project area. This is because of the available land resource for irrigation in the project area is vast and could not be covered with the existing surface water resource (Feasibility Study Report of KGVDP, Volume II: Hydrology,1999).

Irrigation water increases crop yields and quality in semi arid areas like Kobo, in the Northern part of Ethiopia. Irrigation is essential especially during periods of erratic rainfall and drought. Since there is a degradation of the groundwater, which is the main source of irrigation in the area, the irrigation water efficiency has to be increased as much as possible (Adane, 2014). From the above statement, it is evident that management of those resources is vital to make the inflow and outflow proportional to sustain future expansion and sustainability.

The groundwater table in Kobo-Girana is supplied by recharge from the areal rainfall and lateral recharge from the surrounding mountains. This makes the area higher groundwater potential. In the country, this is the only project significantly benefited from groundwater irrigation. According to hydro geological investigation report by Metaferia Consulting Engineers (2009), a certain portion of the groundwater potential of the valley is the reserved groundwater. Therefore caution is needed to sustain use of the available groundwater.

There is large amount of irrigable land but the current irrigated area is very small for different reasons. Farmers and regional government are trying to drill more deep wells to cover the whole irrigable land in the valley (Endalamaw, 2009).

Finding groundwater, in basins such as Kobo Girana, is not the problem. Just dig and you will eventually find it. The real challenge faced by the exploration hydro geologist is to site and design high yield wells (Ferriz and Bizuneh, 2003). And identification of areas with high aquifer permeability might be helpful as a supplementary source in the geological investigation of future borehole spots.

Due to the volcanic geological formation of the area and the surroundings, the ground water aquifer consists of different hydrogeochemicals. The quality of the groundwater may also be deteriorated due to pumping from wells. In addition to this, the chemicals used as fertilizer in the irrigation system can percolate down to the aquifer.

Geostatistical techniques play a vital role in sustainable management of groundwater system by estimating the model input parameters at regular points from their measurements at

random locations (Kitanidis, 1997). Geostatistics offers a variety of tools including interpolation, integration and differentiation of hydro geologic parameters to produce the prediction surface and other derived characteristics from measurements at known locations.
In this work, Geostatistcs techniques are going to be used as a modelling tool for analysing the spatial variation of different groundwater parameters in Kobo Valley Development Project. This study is beneficial to know the groundwater system for better utilization and management of the resources.

1.1 Statement of the problem

Kobo Girana Basin is one of the areas in Ethiopia with significant reserved groundwater potential. Yet, the area has suffered from erratic rainfall and is of a drought prone. The source of water for irrigation and domestic purpose is the reserved groundwater. With increasing number of population and demand for agricultural products, the sustainable use of this resource is paramount. It is has been reported that in some areas due to the application of chemicals like fertilizers, weed removal and the geological makeup of the area (the interaction between the rock and the water), the water quality is being threatened (Metaferia Consulting).

The other challenging problem to the hydro geologist was spotting the high yielding aquifer parts in the area with less cost. This is due to the fact that the area has a complex geological formation.
Due to the above problems, Geostatistical methods of prediction for hydro geochemical properties (groundwater quality) and the better groundwater potential sites based on the aquifer properties are proposed to be done for controlling and managing the groundwater system by informing the outcome to the respected body or organization.

1.2 Objectives of the study

The objectives of the research are:

- To study the spatial variability of hydro geochemical properties (groundwater quality) of the study area
- To study the vulnerability of the area to pollution.
- To study the groundwater potential for spotting high yielding aquifers sites for future development.
- To provide recommendations to project managers based on the achieved results.

1.3 Research Questions

The following research questions can be drawn

- How is the distribution of hydro geochemical properties of the aquifer system?
- Which part of the study area has more potential to pollution?
- Where are the probable high yielding aquifer spots?

1.4 Methodological framework

In order to achieve the objectives stated in section 1.2, a certain methodological framework is followed. Geostatistical (Ordinary, Universal and Bayesian Kriging) and Inverse Distance Weighting methods are used to develop the best possible maps of several groundwater quality and aquifer parameters. Each parameter is evaluated against the four prediction methods to get the best possible spatial distribution using the cross validation. Up on getting the best possible spatial distribution of each groundwater quality parameters, the Water Quality Index (WQI) map is developed. The weighted arithmetic mean method is used to obtain the water quality index map. For assessing the vulnerability of the study area for pollution, GOD rating system that uses aquifer parameters as inputs is used. Furthermore, the groundwater potential map of the study area which can be used to spot the drilling sites for future development is made using weighted overlay analysis.

1.5 Thesis organization

The thesis work is organized in to six chapters. The first chapter is an introduction part. It consists of statement of the problem, objective of the study, research and the summary of the methods. The second chapter is about literature review. It consists of works done by other researchers on similar topics and theoretical view of the science behind the groundwater parameters. The third chapter is about the study area. It deals with the geology, the hydrogeology, climate and rainfall, and drainage system. The fourth chapter deals with data and methodology. It consists of both the data sets used and the general methodology followed. The fifth chapter deals with results and discussions. It consists of the predicted water quality surfaces and their relation with the standard guidelines set for irrigation purposes. In addition, the water quality index, pollution vulnerability and aquifer potential sites are discussed. The last chapter is about conclusions and recommendations.

2. Literature Review

2.1 General

In applied statistical modelling (including regression and time-series) least squares or linear estimation is the most widely used approach. The Advanced adoption of such methods is well suited to the solution of estimation problems involving quantities that vary in space. Examples of such quantities are conductivity, hydraulic head, and solute concentration. This approach is known as the theory of regionalized variables or simply geostatistics. It was popularized in mining engineering in 1970s and now it is used in all fields of earth science and engineering particularly in the hydrologic and environmental fields. Geostatistics is well accepted among practitioners because it is a down-to-earth approach to solve problems encountered in practice using statistical concepts that were previously considered recondite (Kitanidis, 1997).

An important distinction between geostatistical and conventional mapping of environmental variables is that the geostatistical prediction is based on application of quantitative, statistical techniques. Unlike the traditional approaches to mapping, which rely on the use of empirical knowledge, in the case of geostatistical mapping we completely rely on the actual measurements and (semi-)automated algorithms. Although this sounds as if the spatial prediction is done purely by a computer program, the analysts have many options to choose whether to use linear or non-linear models, whether to consider spatial position or not, whether to transform or use the original data, whether to consider multicolinearity effects or not. So it is also an expert-based system in a way (Hengl, 2007). It typically comprises of the following five steps:

1. design the sampling and data processing,
2. collect field data and do laboratory analysis,
3. analyse the points data and estimate the model,
4. implement the model and evaluate its performance,
5. Produce and distribute the output geoinformation.

The natural resource inventories need to be regularly updated or improved in detail, which means that after step (5), we often need to consider collection of new samples or additional samples that are then used to update an existing GIS layer (Hengl, 2007). For this proposed study, works related to spatial variability of groundwater parameters, vulnerability assessment and groundwater potential are reviewed.

There are no studies with their particular aim addressing the objectives given in section 1.2 in Kobo Valley Development Project. Adane (2014) has done a work on Ground water Modelling and Optimization of Irrigation Water Use Efficiency to Sustain Irrigation in Kobo

Valley. The objective of his study was to quantify the recharge and abstraction of groundwater.

The other study was done by Endalamaw in 2009.He has done a work on optimum utilization of groundwater in Kobo valley. The work mainly focuses on quantifying annual recharge and status of the groundwater table using water balance equations under different scenarios of pumping and recommends that the groundwater should be managed for sustainability.

Gundogdu and Guney (2007) made spatial analysis of groundwater level using Universal Kriging. In this study, they were trying to find the best empirical semivariogram models that matched with the experimental models. They found out that the rational quadratic empirical semivariogram is the best fitted model.

Sahoo and Jha (2014) have done Analysis of Spatial Variation of Groundwater Depths Using Geostatistical Modelling. Groundwater depth data of 24 observation wells in the study area for 15 year period (1997-2011) were considered for the analysis. Ordinary kriging method was considered to evaluate the accuracy of the selected variograms in the estimation of the groundwater depths. The analysis of results indicated that geostatistics can reveal stochastic structure of groundwater level variations in space. Spatial analysis showed a significant groundwater fluctuation in the study area. The exponential model was found to be the best-fit geostatistical model for the study area, which were used for developing contour maps of pre- and post-monsoon groundwater depth.

Ahmadi and Sedghamiz (2007) analyzed the spatial and temporal variation of the groundwater level using Universal and Ordinary Kriging methods on 39 peizometric wells for a duration of 12 years. The years considered are 1993 and 2004.Variaogram models were developed and the prediction performances were checked with cross-validation. Both Ordinary and Universal Kriging methods yield good results with very small errors.

Moradi et al. (2012) conducted a study on Geostatistics approaches for Investigation of aquifer Hydraulic Conductivity in Shahrekord Plain, Iran. The purpose of this study is the investigation of spatial changes of hydraulic conductivity. Kriging, Inverse Distance Weighting method (IDW), Local Polynomial Interpolation and Global Polynomial Interpolation methods were used for interpolation. Well hydraulic Conductivity data were considered. Ordinary Kriging was found to be the best method of interpolation.

Verma & Chakraborty (2014) conducted a study to analyze the spatial variability of groundwater depth and quality in Haridwar district,India using geostatistic technique. They used Ordinary Kriging. It was observed in their study that the semi-variogram parameters fitted well in the spherical for water depth and in the exponential model for the water quality (electrical conductivity).

Patriarche (2005) made a geostatsitical estimation of hydraulic conductivity at the Carrizo aquifer,Texas. Two different approaches were used to determine the hydraulic conductivity of the area. The first is an indirect method where hydraulic conductivity (K) is determined from Transmitivity (T). The other approach is a direct method where hydraulic conductivity can be kriged. Simple Kriging, Ordinary Kriging, Kriging with an external drift and Co-Kriging were used for the prediction of the surfaces under different sclaes of the area (model,country and Texas domains). Prediction performances were assesed through cross validation.In the small model domain area for the indirect method, simple kriging gave better results. For larger regional scales for the same indirect method,Co-Kriging gave better reults. For the direct approach, the best prediciton performance was obtained using Kriging with an external drift.

The above sample works confirm that geostatistical methods can be used in the prediction of environmental variables like water quality, hydraulic permeability, transmissivity, groundwater depth, etc.

2.2 Groundwater for irrigation purpose

Irrigation water whether derived from springs, diverted from streams, or pumped from wells, contain appreciable quantities of chemical substances in solution that may reduce crop yield and deteriorate soil fertility. In addition to the dissolved salts, which has been the major problem for centuries, irrigation water always carry substances derived from its natural environment or from the waste products of man's activities (domestic and industrial effluents). These substances may vary in a wide range, but mainly consist of dirt and suspended solids resulting into the emitters' blockages in micro-irrigation systems and bacteria populations and coliforms harmful to the plants, humans and animals (Ayers, 1976).

The most damaging effects of poor-quality irrigation water are excessive accumulation of soluble salts and/or sodium in soil. Highly soluble salts in the soil make soil moisture more difficult for plants to extract, and crops become water stressed even when the soil is moist. When excessive sodium accumulates in the soil, it causes clay and humus particles to float into and plug up large soil pores. This plugging action reduces water movement into and through the soil, thus crop roots do not get enough water even though water may be standing on the soil surface (Zhang,1990).

Groundwater quality comprises the physical, chemical and biological qualities of groundwater. Temperature, turbidity, colour, taste and odour make up the list of physical

water quality parameters. Since most groundwater is colourless, odourless and without specific taste, we are typically more concerned with its chemical qualities (Harter, 2003).
The lists of dissolved solids in natural ground water may be classified as major constituent, secondary constituent and trace constituents and are given in the Table 2.1 below.

	Major(1-1000 mg/l)	Secondary(0.01-10 mg/l)	Trace(0.0001-0.1 mg/l)	Trace(less than 0.0001 mg/l)
Cations	Sodium	Potassium	Antimony	Beryllium
	Calcium	Iron	Aluminium	Bismuth
	Magnesium	Strontium	Arsenic	Cerium
			Barium	Cesium
Anions	Bicarbonate	Carbonate	Bromide	Gallium
	Sulphate	Nitrate	Cadmium	Gold
	Chloride	Fluoride	Chromium	Indium
	Silica	Boron	Cobalt	Lanthanum
			Copper	Niobium
			Germanium	Platinum
			Iodide	Radium
			Lead	Ruthenium
			Lithium	Scandium
			Manganese	Silver
			Molybdenum	Thallium
			Nickel	Thorium
			Phosphate	Thin
			Rubidium	Tungsten
			Selenium	Ytterbium
			Titanium	Yttrium
			Zinc	Zirconium

Table 2.1 Major, Secondary and Trace constituents of Groundwater (Source: Harter, 2003)

Mostly the groundwater quality is measured by analysing the chemicals that are in it. To measure it, indices or chemical concentrations like total dissolved solids, electric conductivity, sodium concentration, calcium concentration, bicarbonates, sulphate, chloride and other trace chemicals need to be found out by making analysis of the water in the laboratory. Generally, use of poor quality irrigation water cann creat four types of problems.These problems are grouped in to: water infiltration rate, alkalanity, specific ion toxicity and miscellaneous (Ayers and Westcot, 1994).

The salinity hazard can be estimated by measuring the electrical conductivity (EC) directly or the Total Dissolved Solid (TDS). Electrical conductance, or conductivity, is the ability of a substance to conduct an electric current. The presence of charged ionic species in solution makes the solution conductive. According to Ayers and Westcot (1994), EC (µS/cm) values less than 750, 750-3000 and greater than 3000 are categorized as none, medium, and severe salinity hazard respectively. With regards to TDS (mg/l), values less than 450, 450-2000 and greater than 2000 are grouped as none, medium and severe respectivley.

Beside the potential dangers from high salinity, sodium hazard sometime exists. The two principal effect of sodium are a reduction in soil permeability and a hardening of the soil. Both effect are caused by the replacement of calcium and magnesium ions by sodium ions on the soil clays and colloids. The extent of this replacement can be estimated by sodium adsorption ratio (SAR) which is expressed by the following given in Eq.2.1.

$$SAR = \frac{Na_{meq/l}}{\sqrt{\frac{Ca_{meq/l} + Mg_{meq/l}}{2}}} \quad \text{.......................Eq.2.1}$$

Toxicity problems occur if certain (constituents) ions in the water are taken up by the plant and accumulate to concentrations high enough to cause crop damage or reduced yields.The ion toxicity may come from sodium (Na), chloride (Cl), Boron (B), Sulphate (SO4) and etc (Ayers and Westcot, 1994).

Marko and et al (2013) studied Geostatistical analysis using GIS for mapping groundwater quality (case study in the recharge area of Wadi Usfan, Western Saudi Arabia). In their study; Ordinary kriging method was applied to map the spatial distribution of the groundwater chemistry. And they came up with the conclusion that most of the groundwater is not suitable for drinking purposes based on the guidelines set for the purpose.

Rawat and et al. (2012) made a research entitled Spatial Variability of Ground Water Quality in Mathura District (Uttar Pradesh, India) with Geostatistical Method. In this study, kriging methods were used for predicting spatial distribution of some groundwater quality parameters such as: Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, TDS, EC, F^{-}, $HCO3^{-}$, $NO3^{-}$, Cl^{-}, SO_4^{2-} and PO_4^{2-}.

Tizro, et al (2014) made a case study in the semi-arid of Iran on the spatial variability of groundwater quality parameter. In this study spatial analysis was used to interpret some of the chemicals in the groundwater samples from the aquifer. For this purpose they used samples from 61 wells in order to analyse the quality of the water. Finally maps showing the distribution of the different chemicals on the study area are plotted. The spatial analyses were made using Kriging, Co-Kriging and IDW methods. The results obtained by these methods were compared by the Root Mean Square Error (RMSE) and Mean Absolute Error (MAE). They obtained that Co-Kriging is the best method of prediction the groundwater quality in this study area.

Hassen (2014) conducted a study on the geostatistical analysis of groundwater quality in Tehsil Sheikhupura region, Pakistan for better understanding of the distribution of each chemical element. The goestatistical analysis of the chemicals was performed and spatial distribution of maps was developed by Ordinary Kriging. The chemical concentrations were compared against the guidelines of WHO for drinking water.

Nas (2009) studied the groundwater quality for the purpose of drinking water. The Geostatistical Analyst extension module of ArcGIS was used in the study for exploratory data analysis, semivariogram, cross validation, mapping the spatial distribution of pH, electrical conductivity, Cl^-, SO_4^-, hardness, and NO_3^- concentrations. The Ordinary Kriging method was used to produce the spatial patterns of these chemical concentrations. The result showed there is high concentration of the chemicals on the north east part of the study area.
Anomohanran and Chapele (2012) made a study that evaluated the effectiveness of kriging interpolation technique for estimating permeability or hydraulic conductivity distribution by using 39 well data. The permeability obtained in the kriging method was compared with other empirical models and the error is found to be small ranging from 0.6 to 2.4%.

2.3 Effects of soluble salts on plants

The application of irrigation water to the soil introduces salts into the root zone. Plant roots take in water but absorb very little salt from the soil solution. Similarly, water evaporates from the soil surface but salts remain behind. Both processes result in the gradual accumulation of salts in the root zone. This situation may affect the plants in two ways: a) by creating salinity hazards and water deficiency; and b) by causing toxicity and other problems (Phocaides, 2000).

2.3.1 Salinity hazards and water Deficiency

The build-up of salinity in the root zone increases the osmotic pressure of the soil solution and causes a reduction in both the rate of water absorption by the plants and the soil water availability. Thus, a continuous water deficiency may exist even though the field is heavily irrigated. Plant wilting symptoms may not become apparent, but growth and yield are depressed. Under such circumstances it is not possible to maintain good crop development conditions and obtain high yields. Instead, plant growth is delayed and there is a considerable reduction in yield. Seed germination is also affected by the presence of salts. It is usually delayed and in some cases does not occur. The level of salinity build-up depends on both the concentration and the composition of salts in the water. Chloride is highly soluble and remains in the soil solution, while sulphate and bicarbonate combine with calcium and magnesium, where present, to form calcium sulphate and calcium carbonate, which are sparingly soluble compounds (Phocaides, 2000).

2.3.2 Toxicity hazards

Many fruit trees and other cultivations are susceptible to injury from salt toxicity. Chloride, sodium and boron are absorbed by the roots and transported to the leaves where they accumulate. In harmful amounts, they result in leaf burn and leaf necrosis. Moreover, direct contact during sprinkling of water drops with high chloride content may cause leaf burn in high evaporation conditions. To some extent, bicarbonate is also toxic. Other symptoms of toxicity include premature leaf drop, reduced growth and reduced yield. In most cases, plants do not show clear toxicity problems until it is too late to remedy the situation. Chloride and sodium ions are both present in the solution. Thus, it is difficult to determine whether the damage caused is due to the one or to the other. Chloride ions in high concentrations are known to be harmful to citrus and many woody and leafy field crops. Chloride content exceeding 10 meq/litre may cause severe problems to crops. The effect of sodium toxicity is not very clear. However, it has been found that it may cause some direct or indirect damage to many plants (Phocaides, 2000).

2.4 Effects of soluble salts on soil

2.4.1 Sodium hazard

A soil permeability problem occurs with high sodium content in the irrigation water. Sodium has a larger concentration than any other cation in saline water, its salts being very soluble. Positively charged, it is attracted by negatively charged soil particles, replacing the dominant calcium and magnesium cations. The replacement of the calcium ions with sodium ions causes the dispersion of the soil aggregates and the deterioration of its structure, thus rendering the soil impermeable to water and air. The increase in the concentration of exchangeable sodium may cause an increase in the soil pH to above 8.5 and reduce the availability of some micronutrients, e.g. iron and phosphorus.

The sodium problem is reduced if the amount of calcium plus magnesium is high compared with the amount of sodium. This relation is called the sodium adsorption ratio (SAR). The use of water with a high SAR value and low to moderate salinity may be hazardous and reduce the soil infiltration rate (Phocaides, 2000).

2.4.2 Residual sodium carbonate (RSC)

This is defined as the difference in milequivalents per litre between the bicarbonate ions and those of calcium and magnesium. Calcium and magnesium may react with bicarbonate and precipitate as carbonates. The relative sodium concentration in the exchangeable complex increases resulting in the dispersion of soil. When the RSC value is lower than 1.25 meq/litre, the water is considered good quality, while if the RSC value exceeds 2.5 meq/litre, the water is considered harmful (Phocaides, 2000).

2.5 Water Quality Indices

2.5.1 General

Groundwater quality parameters include the Sodium Adsorption Ratio (SAR), Total Dissolved Solids (TDS), Electric Conductivity (EC), Sodium (Na^+), Calcium (Ca^{++}), Chloride (Cl^-), Sulphate (SO_4^{2-}), Bicarbonate (HCO_3^-) ,Magnesium(Mg^{++}) etc. In water quality analysis using geostatistical methods, it is possible to make spatial analysis for each parameter and compare the values with the guidelines for irrigation purpose. It is expected that some of the parameters are within the guidelines and some are out of the guidelines. In such a case, it might be a bit difficult to report to the public or to a layman in such a way that they can get the clear picture of the pollution. Water Quality Index helps in aggregating all the parameters considered and gives a single map of the area in question.

WQI is a mathematical instrument used to transform large quantities of water quality data into a single number which represents the water quality level while eliminating the subjective assessments of water quality and biases of individual water quality experts. Basically a WQI attempts to provide a mechanism for presenting a cumulatively derived, numerical expression defining a certain level of water quality (Miller et al., 1986).

Water Quality Indices can be classified in to two groups: objective or subjective. Objective methods are those which are not using subjective inferences. The indices obtained by subjective methods are often called statistical indices. In the subjective methods, the weights and ratings are entirely subjective and are drawn out of questionnaire analysis inquiring the opinion of experts. The advantage of objective over subjective is its unbiasedness (Ott, 1978).

A general water quality index approach can be described in three steps: parameter selection, determination of quality function for the parameters considered and aggregation with mathematical expression.However, a huge number of water quality indices viz. Weight Arithmetic Water Quality Index (WAWQI), National Sanitation Foundation Water Quality Index, Canadian Council of Ministers of the Environment Water Quality Index, Oregon Water Quality Index etc. have been formulated by several national and international organizations (Tyagi et.al, 2013).

2.5.2 Arithmetic Water Quality Index

This water quality index is an index originally proposed by Horton in 1965 and also called as the weighted arithmetic mean method. Many researchers like Brown et.al, 1970 and many more have used this index in their research work. Recently, Omran (2012), Ambica (2014), Chowdhurry et.al (2012) used the Weighted Arithmetic Mean method to assess the water quality index.

2.6 Groundwater Vulnerability to Pollution

2.6.1 General

Groundwater vulnerability index is the measure of the aquifer pollution potential based on some hydro geological, morphological and hydrographical parameters. It is not possible for directly measuring the groundwater vulnerability as of the water quality parameters in assessing the quality of water for a specific use.

Different methods are proposed by different researchers for assessing the vulnerability of groundwater for pollution. Parametric System method is one of them. This parameter system method intern has Matrix System (MS), Rating System (RS) and Point Count System Models (PCSM).And they are based on Overlay and Index method.

Ground water vulnerability assessment has the ability to delineate areas, which are more likely than others to become polluted as a result of anthropogenic activities at or near the land surface (Vrba and Zaporozec, 1994).

For all parametric system methods the procedure is almost the same. The system definition depends on the selection of those parameters considered to be representative for groundwater vulnerability assessment. Each parameter has a defined natural range divided into discrete hierarchical intervals. To all intervals are assigned specific values reflecting the relative degree of sensitivity to contamination (Gogu and Dassargues, 2000).

Rating Systems (RS) methods provide a fixed range of values for any parameter considered to be necessary and adequate to assess the vulnerability. This range is properly and subjectively, divided according to the variation interval of each parameter. The sum of rating points gives the required evaluation for any point or area. The final numerical score is divided into intervals expressing a relative vulnerability degree. The rating systems are based upon the assumption of a generic contaminant. Examples are GOD system, AVI method and ISIS method. Point Count System Models (PCSM) or Parameter Weighting and Rating Methods are also a rating parameters system. Additionally, a multiplier identified as a weight i assigned to each parameter to correctly reflects the relationship between the parameters. Rating parameters for each interval are multiplied accordingly with the weight factor and the results are added to obtain the final score. This score provides a relative measure of vulnerability degree of one area compared to other areas and the higher the score, the greater the sensitivity of the area. One of the most difficult aspects of these methods with chosen weighting factors and rating parameters remains distinguishing different classes of vulnerability (high, moderate, low etc.), on basis of the final numerical score. Examples are DRASTIC, SINTACS and EPIK methods (Gogu and Dassargues, 2000).

2.6.2 GOD Rating System

GOD rating system is an empirical method for assessing the vulnerability of the aquifer system. It only needs three parameters in order to get the result and it is simple. When there is a limitation in the data for using other methods like DRASTIC and others, this method is a good choice. The three parameters considered are Groundwater occurrence (G), Overlying aquifer litho logy (O) and Depth to the groundwater table (D). The ratings for each of the parameters and their classes are given by the GOD chart.

The vulnerability index is obtained by multiplying the groundwater occurrence ratings with the ratings of the overlaying aquifer litho logy and again with the ratings of the depth to the groundwater level. The index values are between 0 and 1. The higher the values, the more vulnerable the area is for pollution. The GOD Rating flow chart is shown in the Annex V.

2.6.3 DRASTIC Method

This method considers the following factors in order to determine the vulnerability of the aquifer pollution. Depth to Water(D), Recharge(R), Aquifer Media(A),Soil Media(S),Topography(T), Impact of the Vadose Zone(I) and Hydraulic Conductivity (C) of the Aquifer. These factors are arranged to for the acronym DRASTIC for ease of reference.
A numerical ranking system to assess groundwater pollution potential in hydro geologic settings has been devised using the DRASTIC factors. The system contains three significant parts: weights, ranges and ratings. The weights are between 1 to 5 and individual parameters are assigned fixed values based on their influence. So, these weights are constant and cannot be changed. Then each parameter is classified in to certain ranges according to their impact on pollution potential. The range of each DRASTIC factor is rated between 1 to 10 (Aller et.al, 1985).

The equation for DRASTIC method is:

$D_rD_w+R_rR_w+A_rA_w+S_rS_w+T_rT_w+I_rI_w+C_rC_w$=Pollution Potential ....Eq. 2.2

Where r=rating

w=weight

2.7 Groundwater Potential of the Aquifer

Groundwater potential sites are sites which have the appropriate conditions for yielding good quantity of water in the aquifer system . Different aquifer parameters like the thickness, hydraulic permeabilitity , geology of the overlaying aquifer and the depth to the static water table are some of the factors that might influence the existance of a good quantity of water in groundwater basin.

The type and number of themes used for the assessment of groundwater resources by geoinformatics techniques varies considerably from one study to another. In most studies, local experience has been used for assigning weights to different thematic layers and their features (Hutti et. al, 2011).

Amah et. al (2012) used some of the aquifer parameters to spot the good aquifer potential areas in Calabar coastal aquifer. They used litho logy, aquifer thickness, hydraulic conductivity or transmissivity, static water level and storativity to plot the final aquifer potential maps of the area.

Apart from this, Alridha et. al (2013) used the hydraulic conductivity, transmissivity and storativity parameters to delineate the most productive groundwater aquifer sites in Iraqi.
Patil and Mohite(2013), Zende et. al (2012) have also done works related to the identification and zoning of groundwater potential sites using weighted overlay analysis.

3. Study Area

3.1 General

The Kobo valley is part of the Kobo Girana Valley Development Project in the North Eastern Amhara regional state, North Wollo Administrative Zone. The Kobo System and valley inter-mountain plain is between UTM 1300000 m - 1360000 m north, and UTM 540000 m-582000 m east. The valley plain has an elongation in north-south direction. The valley is surrounded by Zoble Mountain in the east, the western escapement of the mainland in the west, Raya Valley in the North and volcanic ridges in the South. The study area is shown in the Figure 3.1 below. The Kobo catchment covers parts of three woredas, Kobo, Guba Lafto and Gidan. The valley is bounded by Zobil mountain ranges in the East & the North-Eastern escarpment in the West. The northern ridge of Girana valley namely Guba ridge and the Alamata Woreda bound the valley in the South and North respectively. The sub-basin is divided into Waja-Golelsha , Hormat-Golina and Kobo-Gerbi groundwater basins by undulating surfaces and volcanic inselbergs and intrusion lying in the east-west direction following the Kobo-Zobel road along Gara Lencha–Mendefera stretch.

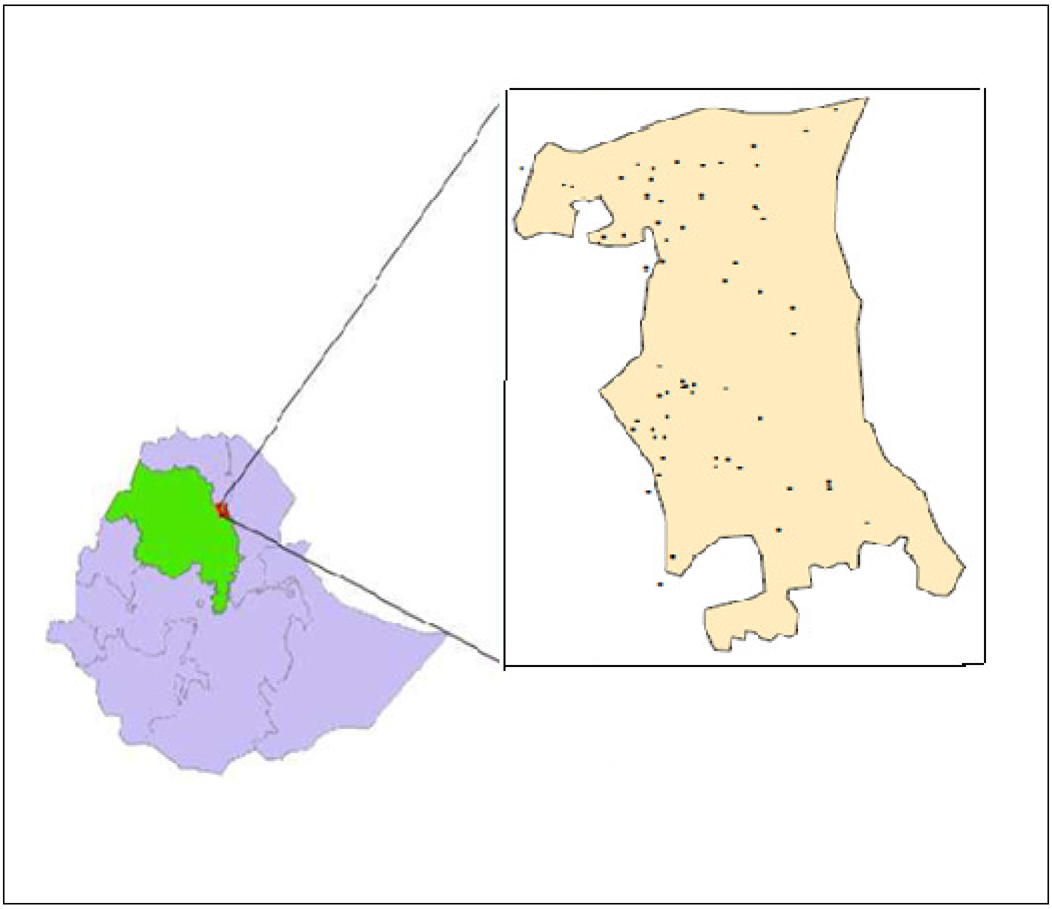

Figure 3.1 Location of the study area(Metaferia Consulting Engineers,2009)

3.2 Regional Geology and Hydrogeology

3.2.1 General Geology

The geology of north and central Ethiopia, which also includes the current study area, is dominated by Tertiary volcanic strata underlain by Mesozoic sedimentary rocks. The dominant outcrops on the mountains are fissural basalts with silica varieties. The first geologist in Ethiopia, Branford, 1869 classified the northern Ethiopia volcanic into Ashange and Magdala group. Two Volcanic successions occurred in the period of Paleocene to Miocene, recognized as the Ashangi and Magdala groups.

3.2.1.1 Geology of the Kobo-Girana Valley

3.2.1.1.1 Mesozoic Sedimentary Rocks

The geological map of the Kobo-Girana Valley (Co-SAERAR, 1997) shows sandstone unit outcropping near Hara swamp extending to the north and east beyond the boundary of the project area. The sandstone is reported to be characterized by flat topped hills affected with numerous north-south trending faults. This rock unit is composed of horizontal beds of white to pink, medium grained, friable sandstone frequently conglomeratic and with intercalations of limestone or marl.

Weathered aphanitic basalt was observed on top of a faulted block of sandstone. Because of its stratigraphic position and due to the existence of a basalt outcrop on top of it, this sandstone unit is taken as belonging to the upper sandstone formation of the Mesozoic sedimentary sequence. The geology and structural map of Kobo-Girana valley is shown in Figure 3.2.

3.2.1.1.2 Igneous Rock

The volcanic rocks outcrop on the western and eastern ridges and as erosion remnants at the valley floor. The volcanic rocks of the valley and its surrounding are the Trapean Series especially the Ashangi Group volcanics. These Ashangi Group consists predominantly the thick basalt flow of trachytes and rhyolites interbedded with pyroclastics erupted from fissures. According to Co-SAERAR, 1997, the maximum thickness of this group occurs near Korem upto 1200m. In the upper part, the Ashangi Group becomes more tuffaceous and contains interbeds of lacustrine deposits and some acid volcanics. The basalt rock outcrop in the area includes, olivine, porphyritic and amygdaloidal basalt.

Acidic pyroclasts are found in the north-eastern boundary of the area forming part of the Zobul Mountains. It consists of tilted beds of ignimbrite and agglomerates with sedimentary (shale) intercalation at the upper part. The ignimbrite is composed of well stratified layers of tuff showing flow banding. Acid volcanic agglomerate contains large fragments of volcanic particles and quartz embedded in acidic tuff.

The Magdela Group volcanic succession is reported to outcrop in Wuchale as Rhyolite overlying the basalt unit. It is characterized by greenish gray, fine grained and compact rock.

Intrusion of granite and syneite outcrop in the volcanic succession in the areas like Garalencha and Keigara close to the Zobul ridge. It forms an isolated ridge upstanding above the surrounding low lying area, showing mineralogical variations between granite and syenite. It consists of feldspar and varying amounts of quartz and some mafic minerals.

The type and age of these granite intrusions may be similar to those of the Tertiary alkaline massifs occurring on the edge of the Afar Depression and elsewhere.

3.2.1.1.3 Quaternary Sediments

The quaternary sediments are all unconsolidated deposits which filled in the graben bounded by the western and eastern volcanic ridges. The source of the sediment is mainly the western ridge from which most of the streams are flowing eastwards into the valley floor. The erosion/transportation from the escarpments and deposition of sediments in the valley flooring is a continuous process to the present as witnessed in the field.

The thickness of the sediment in the valley floor varies from place to place owing to the morphology of the deposition basin, the probable shifting of flow channels and the tectonic disturbance that has affected topography of the bed rock.

According to the report of KGVDP feasibility study, the thickness of the sediments in the valley varies from place to place due to differential faulting that affected the graben-floor. The maximum thickness reported to exceed 350 m with the general west to east increase of the thickness. The report further elaborated the deposits in the valley to be lacustrine, alluvial and colluvial.

The lacustrine sediments are composed mainly of alternations of sandy, silty and clayey layers. The existences of a number of swamps in the area are evidences for the presence of clay horizons underlying these swampy areas.

The alluvial deposits are composed of boulders, cobbles, pebbles, gravel, sand and silt. While the deposition of the larger materials like boulders, cobbles, and pebbles is restricted to the western part of the graben-floor, the fine materials reach furthest extremes of the area following flood plains of streams.

The colluvial deposits are confined to the foot-hill areas in the grabens and are composed of poorly sorted sediments of all sizes.

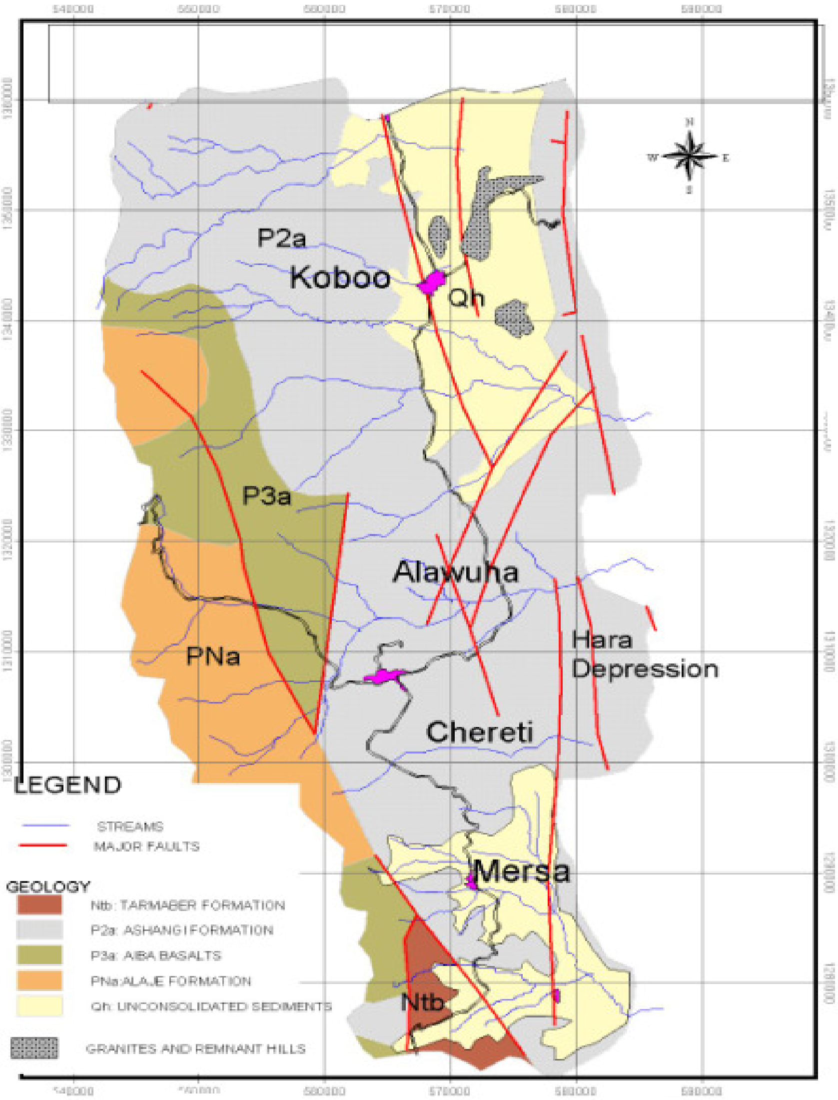

Figure 3.2 Geology and Structural Map of Kobo-Girana valley:source geological map of Ethiopia,1996.

3.2.1.2 Geology of Kobo Valley

The geology of the specific study area (Kobo Valley) is made up of four types of rock materials.These includes granite,lacustrine, trachite and unconsolidated sediment.The majority of the area is made up of unconsolidated sediment. The Geology of the Kobo Valley is shown in Figure 3.3 below.

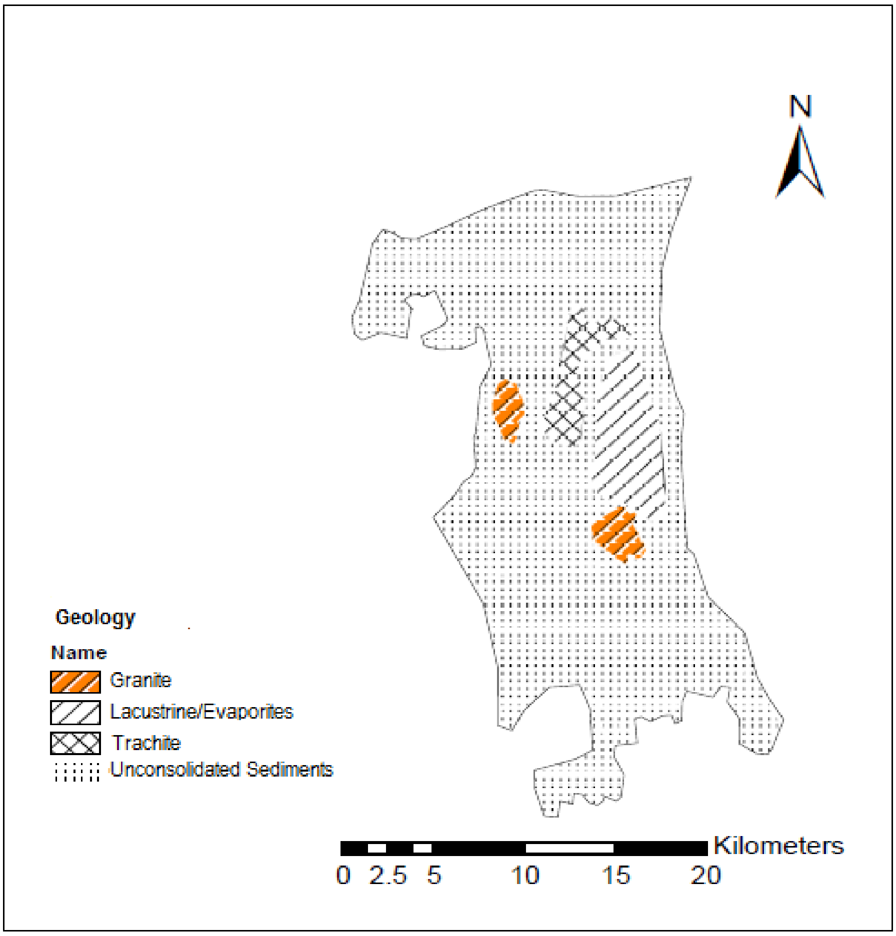

Figure 3.3 Geology of Kobo Valley (Source: Metaferia Engineering,2009)

3.2.2 General Hydrogeology

3.2.2.1 Hydrogeology of Ethiopia

Ethiopia has a complicated hydrogeological environment and complex groundwater regime. Until recently, many experts believed that extensive aquifers usable for large-scale exploitation of groundwater were unlikely to exist. This claim, which was almost a consensus, has recently been disputed due to a paradigm shift in methodology. There are indications that some aquifers in the count have large deposits of groundwater (Moges, 2012).

From the standpoint of groundwater development, the rocks of the Precambrian metamorphic complexes are notoriously problematic. Fractured-rock aquifers exist within them, but in their shallow reaches can only produce very modest amounts of water, often barely sufficient to satisfy the drinking needs of small settlements. The deeper reaches of these aquifers could have higher yields, but exploration and deep drilling will be expensive and time consuming. The Mesozoic sequence is much more promising in terms of groundwater development. The Tertiary flood basalts can be major sources of groundwater, which under some circumstances are easy to tap (Ferriz and Bizuneh, 2003).

3.2.2.2 Hydrogeology of The Study Area

3.2.2.2.1 General

The valley and plain area are comprised of several low lying depositional areas distributed in the middle of the area extended from north to south. The mountain rises from 1500m to more than 2000 m and the plain is characterized by flat topography not greater than 1500m altitude. The plain area is formed by the accumulation of sediments from the surrounding scraps in an old lake bed. River drainage in the study area originates in from the western scraps where the youthful streams have cut deep gorges through the strata they cross and flow to the east across the plain to the Afar Depression through the narrow outlets in the eastern scraps. Due to low gradient, the streams form wide flood plain, alluvial flats and swamps as they reach the plain and deposit huge quantity of sediments. The soil type, as the geologic and hydrogeology report of the project, is dominantly alluvial sediment deposit from the escarpment of mountains. The soil is rich in organic and inorganic material for the production of crops (KGVDP feasibility report, volume II, Water Resource and Engineering, Regional Geology 1996).

3.2.2.2.2 Regional Setup

The regional hydrogological set up of the project area and its surrounding can be summarized as localized graben filling unconsolidated sediment composed of clay, silt, sand, gravel, boulders and pebbles above the Ashangi group volcanics which are intern underlain by Mesozoic sedimentary rocks.

With regards to groundwater movement and storage, the unconsolidated sediments in the grabens and the sedimentary rock beneath the Ashangi Group volcanics have high potential. The Ashangi volcanics are also moderately productive for rural and small towns water supply in the region as they are good for transmission but with localized flow conduits along the fractures and thin upper fracture zones under the unconsolidated sediments. The groundwater in the Ashangi volcanics in the area can be tapped as springs or shallow wells and due to the poor geomorphologic setup for storing large amount of groundwater it is understood that the aquifers are not promising for high yields at this particular project area. Although localized in occurrence, the unconsolidated sediments are relatively thick with good hydraulic permeability and these sediments get recharge from the weathered part of Ashangi volcanics surrounding the grabens.

3.2.2.2.3 Aquifer Thickness

The aquifer thickness varies over the valley. The thickness was determined from VES and drilling data.The material is considered as an aquifer if it is composed of layers of sand, gravel, pebbles and boulder. The lithological and electrical logs and the geophysical survey data of the sub surface material below the water table in each basin is analyzed to determine the thickness of the aquifer material. The sediment in Kobo-Arequaite-Gerbi sub-basin is mainly clay that less aquifer is expected. Water is hardly transmitted to wells at the required rate.

3.2.2.2.4 Aquifer Type

According to Metaferia Consulting Engineers report (2009), the groundwater aquifer type in the Kobo Valley development project is unconfined aquifer.

3.3 Climate and Rainfall

The principal feature of rainfall in the area is seasonal, poor distribution and variable from year to year. Rainfall distribution over the area is Bimodal, characterized by a short rainy season (Belg) and the long rainy season (Meher) that occurs in February-April and July-October respectively with a short dry spell from May to June (Feasibility Study Report for KGVDP, Volume II: Hydrology; CoSAERAR, 1999).

The position of Inter-Tropical Convergence Zone (ITCZ), seasonal variations in pressure systems and air circulation, results in the seasonal distribution of rainfall over the project area. This low pressure area of convergence between tropical easterlies and equatorial westerlies causes the equatorial disturbances to take place.

The distribution of rainfall over the highland areas is modified by orographic effects and is significantly correlated with altitude. Two rainy seasons have been experienced. The main rainy season often extends from end of June through end of September and the small rainy season from end of March to middle of April. The rest of the months are generally dry. The pattern of the seasonality of rainfall in the project area is determined by computing mean monthly rainfall ratio with that of rainfall module and compare with rainfall coefficient given by Gemechu classification as shown in the Table 3.1 below. The monthly rainfall of the study area for the concurrent selected 10 years is shown in Annex A.7.

Rainfall Coefficient	<0.6	=> 0.6	0.6 to 0.9	=> 1	1.0 to 1 .9	2 to 2.9	3.0 and above
Designation	Dry	Rainy	Small Rains	Big rains	Moderate	High	Very high

Table 3.1 climate regions as per rainfall coeficient (Source: Daniel Gemechu,1977).

The mean annual rainfall of the watershed is estimated to be about 798.4 mm. As per Gemechu(1977)system of defining climatic or moisture regions, the basin is classified as dry sub-humid.

3.4 Drainage System

3.4.1 General

Kobo is a part of Kobo-Girana valley which comprises of Kobo, Girana and some part of the Raya valley. The major drainage system is associated with valley plains. The main river in the valley originates from the western mountains. The perennial rivers draining in to the valleys are the Hormat, Golina, Alawuha, Chereti and Gelana. There are also a number of intermittent streams which are draining westwards to the valley. The Kobo-Girana valley can be classified into seven major sub-basins and their respected locations are shwon in the Figure 3.4. These are the Waja-Golesha, Hormat-Golina, Kobo-Arequaite-Gerbi, Alawuha, Chireti, Gelana and the Hara sub-basins. Kobo Valley Development Project is a part of the first three sub basins, Waja-Golesha, Hormat-Golina and Kobo-Gerbi. The areal coverages of sub-basins in the Kobo-Girana valley are given in Table 3.2 below.

NAME	AREA (km^2)	PERIMETER (km)
Hormat-Golina	794.95	122.95
Kobo-Gerbi	113.62	50.88
Waja-Golesha	556.30	113.63
Girana	450.86	90.07
Alawuha	661.84	127.30
Chereti	218.19	78.78
Hara	83.51	38.62

Table 3.2 Areal Coverages of Sub-Basins in Kobo Girana valley(Source:Metaferia Consulting Engineers,2009).

3.4.2 Waja Golesha Sub Basin

The Waja-Golesha sub-basin is drained by Gobu and Waja streams which disappear in Waja plain. There is one intermittent stream named Dikala stream which starts from the western ridge of Kobo Town and flows towards the Garalencha Mendefera before it disappears in the Chobe-Golesha plain.

3.4.3 The Kobo-Gerbi Closed Sub Basin

Some intermittent streams are flowing from Zobul ridge, Gedemyu and Mendefra hills into the Arequaite-Gerbi plain-depression. No surface drainage out let is observable from this depression. Wet Season Lake at Gerbi disappears in the dry season by evaporation.

3.4.4 The Hormat Golina Sub Basin

The Hormat-Golina sub-basin constitutes the drainage systems of Hormat, Golina, Kelkeli and Weylet. Most of the flows of the rivers of this sub-basin too are lost in the plain before reaching their outlets through Golina River.

Hormat, Golina and Kelkeli are perennial rivers in general. However, during dry season, Hormat and Kelkeli lose their discharge in the plain before joining Golina that ultimately discharge through the Golina gorge to the Afar Depression. As it can be learnt from the aerial photo interpretation and from geophysical investigation, most of these rivers are fault and fracture controlled. In their upper course of the mountainous terrain, the slopes of these rivers vary from 4.2 to 6.9 %.

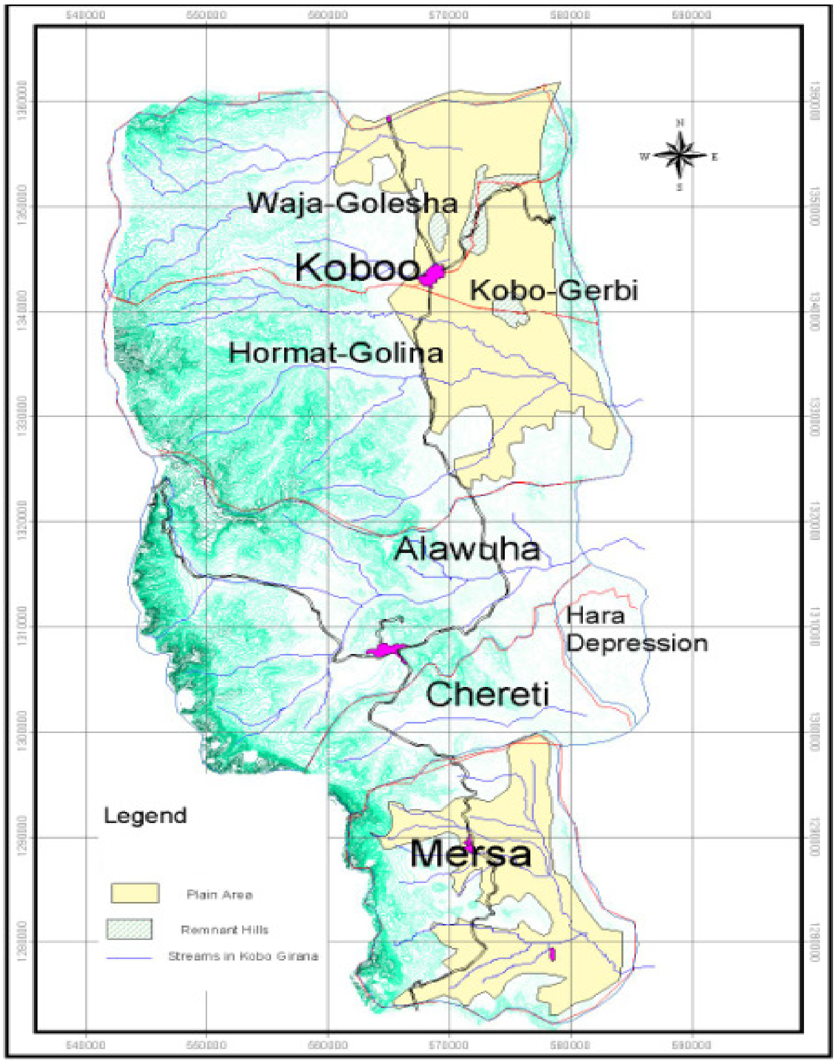

Figure 3. 4 Drainage system map of the sub-Basins in Kobo Girana Valley(Source:Metaferia Consulting Engineers, 2009).

3.4.5 Groundwater Divide Line

The groundwater divide line helps to demarcate the extents of the sub basins in the study area. According to Metaferia Consulting Engineers (2009), the groundwater divide line is given in the Figure 3.5 below.

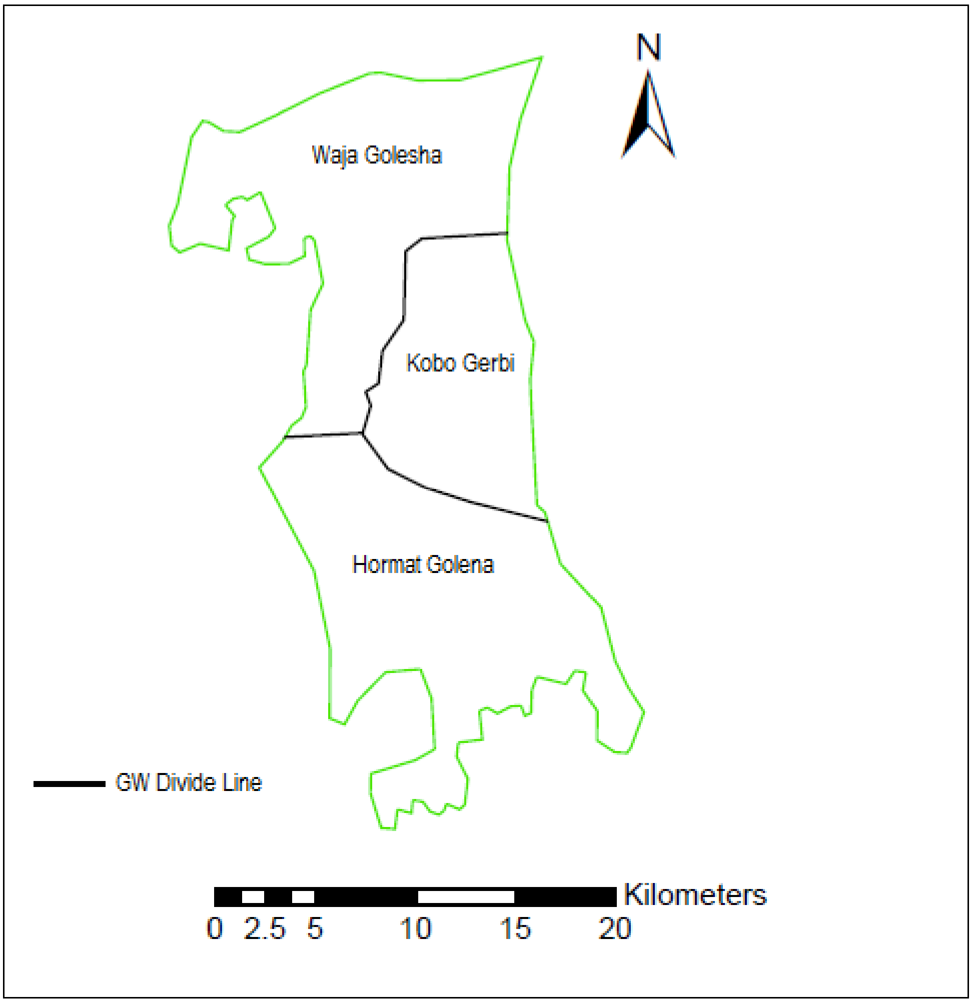

Figure 3.5 Groundwater Divide Line of Kobo Valley (Metaferia Consulting Engineers, 2009)

4. Data and Methodology

4.1 Data

In the study area there are around 100 water wells. Out of these 100 water wells 64 of them are currently functional and the study is based on these wells. In Ethiopia, controlling or monitoring the groundwater level is not done very well. Even if it is done, it is not really complete. An organized monitoring of groundwater was officially started in 2001 for few parts of the country. Kobo Girana Valley development project is one of the better monitored sites with regard to groundwater data in the country.

The main data required for this study are Geological data, Elevation of the study area, Hydro geochemical properties, aquifer thickness, sediment thickness, depth to groundwater table, and hydraulic permeability of the aquifers. The precipitation data for the Kobo area is obtained from National Meteorology Agency. The groundwater parameters are obtained from Ethiopian National Groundwater Database Association (ENGDA) under the Ministry of Water Resources. Some of the data are also obtained from Amhara Water Works Design and Supervision. The feasibility study of the Kobo Girana Valley Development Project is also a good source of data. The groundwater quality and aquifer data are shown in Annex 9 and 10 respectively. These data are collected until the year of 2009.

4.1.1 Data Preparation

Before the data are directly used for the intended purposes, they had to go through a certain procedures since they didn't meet the requirements for ArcGIS software. The hardcopy of the maps (study area and others) had to be digitized and georeferenced. After the maps were georeferenced, they were converted to shapefiles so that ArcGIS can be effectively used. The projected coordinate system is UTM 37 N which represents the study area.

The hydro geochemical and all aquifer parameters were made ready to be used in the Arc GIS software.

4.1.2 Data Cleaning

As Chapman (2005) said, error prevention is far superior to error detection and cleaning, as it is cheaper and more efficient to prevent errors than to try and find them and correct them later.

In general, data cleaning is a process used to determine inaccurate, incomplete, or unreasonable data and then improving the quality through correction of detected errors and omissions. The process may include format checks, completeness checks, reasonableness checks, limit checks, review of the data to identify outliers or other errors, and assessment of data by subject area experts (e.g. taxonomic specialists).The need for data cleaning is centred around improving the quality of data to make them "fit for use" by users through reducing errors in the data and improving their documentation and presentation (Chapman, 2005).Since we don't have a huge data in this study, data cleaning softwares were not used. The cleaning was done manually. The problems encountered are blank spaces, texts in numerical fields and big numbers. In general the data was not that noisy and it was easy to clean it.

4.1.3 Data transformation

Several methods in Geostatistical Analyst require that the data is normally distributed. When the data is skewed, it may be needed to transform the data to make it normal based on the aim we are achieving. In exploratory data analysis, the histogram and Normal QQ plot are used to explore the effect of different transformations. If the data is chosen to be transformed before creating a surface using geostatistics, the predictions will be transformed back to the original scale for the interpolated surface.

For Geostatistical analysis, based on the purpose we are thriving to achieve, data transformation or normalization may be needed. If we are just in need of surface predictions and map of prediction standard errors, the assumption of normal distribution of the data can be ignored on the classical kriging methods (ordinary, universal and Bayesian Kriging). On the other hand if the output surface is to generate quantile and probability maps, the assumption of normal distribution is necessary.

In this study, surface prediction is aimed; in order to produce the thematic maps and use them as an input for further investigations about the study area. Up on this aim (surface prediction), the assumption which uses normalization can be ignored since the classical methods of kriging don't favour it.

4.1.4 Exploratory Data Analysis

Exploratory data analysis is the process of using graphs and other methods in order to look deep in to the data. It is useful to determine the different characteristics of the data into consideration. Before doing any geostatistical applications or predictions on the data, it is mandatory to do exploratory data analysis so that one can have a clear picture on the nature of the data and it compatibility for the intended purpose. Even the selection of the interpolation methods critically depends on the results of the exploratory analysis. In this study, the main exploratory analysis done includes statistics summary, histogram, Normal QQ plot, trend analysis and Voronoi. The exploratory analysis is done using both ArcGIS and Microsoft Excel.

4.1.4.1 Summary Statistics

In descriptive statistics, summary statistics are used to summarize data observations in order to communicate the largest amount of information in a simpler way. These may include measure of location or central tendency as a form of arithmetic mean, measure of statistical dispersion as standard deviation, a measure of the shape of the distribution like skewness or kurtosis and if more than one variable is measured a measure of statistical dependence such as correlation coefficient.

	Mean	Standard Error	Median	Standard Deviation	Standard variance	Kurtosis	Skewness
SAR	1.98	0.38	1.11	3.05	9.31	40.03	5.85
TDS	766	304	432	2419	6E+06	62.4	7.88
EC	1195	398	705	3163	1E+07	61.86	7.83
Na^+	129	63.8	52.6	502	252032	60.8	7.76
Ca^{++}	72	10.8	58.4	85.9	7383	55	7.2
Cl^-	96.5	60	22.66	479	229733	62.4	7.8
SO_4^{2-}	208	156	17.4	1239	2E+06	62.5	7.89
HCO_3	394	15.2	383	121	14691	0.066	0.58
K	6.5	0.8	5.47	6.6	44.5	15.4	3.2

Table 4.1 Descriptive Statistics of groundwater parameters

The Table 4.1 shows the descriptive statistics of the nine groundwater parameters selected for this study. The summary includes the mean, standard error, median, standard deviation, variance, kurtosis and skewness.

The mean is influenced by the big number that is registered in the well TK3 which is an outlier. The standard error is also big except for SAR and Hydraulic Conductivity (K). Except for Sodium Adsorption Ratio (SAR) and Hydraulic Conductivity, all the other parameters have huge values for standard deviation and variance. Apart from this all parameters have a kurtosis value greater than 40 except from hydraulic conductivity and bicarbonate which has 15.4 and 0.066 respectively. In general, the kurtosis value is very big for the distribution to be normal.

Almost all the parameters have skewness values between 3.2 to 7.89 except for bicarbonate which has a value of 0.58. From the skewness values, it can be understood that the distribution is far from the normal distribution as the skewness value is not in the range between -0.8 to 0.8 except for the bicarbonate. For the analysis which needs the data to be normally distributed, the data should be transformed or normalized before doing the main analysis on the data set.

	SAR	TDS	Ec	Na	Ca	Cl	SO4	HCO3
SAR	1							
TDS	0.913434	1						
Ec	0.919259	0.999433	1					
Na	0.933776	0.997674	0.997843	1				
Ca	0.867027	0.974871	0.974887	0.967532	1			
Cl	0.914833	0.99918	0.998539	0.99748	0.971056	1		
SO4	0.911752	0.998821	0.998103	0.997356	0.969438	0.998684	1	
HCO3	0.065563	-0.05686	-0.04226	-0.04293	0.002902	-0.08004	-0.08857	1

Table 4.2 Correlation coefficient values of the groundwater quality parameters

The table above shows the correlation coefficient among the hydro geochemical parameters of the groundwater. It can be seen that the Sodium Adsorption Ratio (SAR) has almost a perfect correlation with TDS, Ec, Na, Ca, Mg, Cl and SO4. The correlation coefficient ranges from 86.7 to 93.3%. On the contrary, SAR has very small correlation with bicarbonate (HCO3) with a value of 6.5%.

Total Dissolved Solids (TDS) has a perfect correlation with Ec, Na^{+}, Ca^{++}, Cl^{-} and SO_4^{2-}. The correlation ranges between 97.4 to 99.9 %. Similar to SAR, TDS has a very small correlation which is -5.6%. The negative sign shows that this very small correlation is negative.
In general, it can be seen that bicarbonate (HCO_3^{-}) has very small correlation with the other groundwater chemical parameters.

4.1.4. 2 Histograms

Histogram is used to graphically show how the univariate data is distributed. A histogram is probably the most commonly used way of displaying data. Simply stated, a histogram is a bar chart with the height of the “bars” representing the frequency of each class after the data have been grouped into classes. The histogram graphically shows the centre of the data, the spread of the data, skewness of the data, presence of outlier and presence of multiple mode in the data. These features provide strong indications of the proper distributional model for the data.

The histogram is an effective graphical technique for showing both the skewness and kurtosis of data set. Skewness is a measure of symmetry. A distribution, or data set, is symmetric if it looks the same to the left and right of the centre point. Kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution. That is, data sets with high kurtosis tend to have a distinct peak near the mean, decline rather rapidly, and have heavy tails. Data sets with low kurtosis tend to have a flat top near the mean rather than a sharp peak.

In this study, Histograms are made for individual groundwater quality parameters like TDS, EC, SAR, Na, Ca, SO4, HCO3 and Cl using ArcMap software. Besides to these groundwater quality parameters, histogram is constructed for hydraulic conductivity or permeability of the aquifer. The figure showing the histogram for all parameters is given in Annex A.1.

It has been observed that, the values at bore hole TK3 are located at the extreme end of the histogram leaving other values to the left. This is an indication that the values recorded at the TK3 might be an error in the reading or just an extreme value. This might suggest that we have an outlier in the data. Apart from this, the skewness values are more than 1 or -1 in almost all of the histograms and this is an indication of the lack of normal distribution due to the presence of extreme values at well TK3. When the values at TK3 are removed, the histograms show normal distribution pattern than the previous.

When the extreme value at well TK3 is removed, the histogram shows a bell like structure on the plot for most of the groundwater parameters which is an indication of normal distribution of the data.

4.1.4.3 Normal QQ Plot

Normal QQ plot is done to asses if the data samples are whether normally distributed or not. If the data points fall on the line of the Normal QQ plot, it can be said that the data in consideration is normally distributed. Otherwise, it is not normally distributed.
For the groundwater parameters in this study, as shown in Annex II, the data points don't fall on the straight line on the Normal QQ plot. This implies that the parameters in question are not normally distributed. This may be due to the extreme big values at well TK3. This fact is also shown in the Histogram and summary statistics analysis. Once the Outlier or extreme value is removed, most of the data points fall on the straight line of the Normal QQ plot. The Normal QQ plot for the groundwater parameters is shown in Annex A.2.

4.1.4.4 Trend Analysis

Before using a specific method of interpolation, it may be necessary to find out the trend of the data set and make considerations for the trend in the data. The trend analysis tool in the ArcMap can help identify trends in the input data set. This tool provides a three dimensional perspective of the data. The locations of sample points are plotted on the X,Y plane. Above each sample point, the value is given by the height of a stick in the Z dimension. The unique feature of the trend analysis tool is that the values are then projected on to X,Z plane and the Y,Z plane as scatter plots. This can be thought of as sideways view through the three dimensional data. Polynomials are then fit through the scatter plots on the projected planes.

For this study, the trend analysis is done using the ArcMap for individual ground water parameters. It is seen that Sodium Adsorption Ratio (SAR), Sodium (Na^+), Calcium (Ca^{++}), Sulphate (SO_4^{2-}), Bicarbonate (HCO_3^-) and Hydraulic Conductivity (K) show no trend on their data. Whereas Total Dissolved Solids (TDS), Electric Conductivity (Ec), and Chloride (Cl^-) show trend towards the east direction.

4.1.4.5 Voronoi Map

A Voronoi map is one of the exploratory analysis tools in the Gesotatistical Analyst extension. It helps us to determine how much variation exists in the dataset. Some analysis tool requires the data to be stationary and values at certain distance apart should have similar difference in values. For the data to be stationary, the variation in the data should be consistent across the study area. In addition to the above benefit, Voronoi map is used to detect if the area is under sampled or oversampled. The Voronoi map reveals that the eastern part of the study area is under sampled and the contrary is observed in the south western of the study area.

4.2 Methodology

Geostatistics assume that the spatial variation of natural phenomena can be modelled by random process with spatial autocorrelation. Geostatistics techniques are used:

- To predict values at un samples locations
- To assess the uncertainty associated with predicted values
- To model spatial patterns

4.2.1 Interpolation Methods

Although Kriging (Geostatistical Methods) is the primary focus of this study, it is useful to be aware of some other common methods of spatial interpolations. These methods are explained well below.

4.2.1.1 Deterministic methods

The deterministic method of interpolation includes nearest neighbour, inverse distance weighting, splines, etc and are discussed below

4.2.1.1.1 Polygonal (Nearest Neighbour): Polygonal or proximal techniques are deterministic methods that utilize no information about the system being analysed other than the measured data points. They are relatively simple to implement in that all points in an area are set equal to one value, whether it be the value of the nearest measured point, an average of the cell and its surrounding points, or the mode of the cell and its surrounding cells. These methods are more formally called by a few names including Thiessen Polygons, Voronoi diagrams or maps, and Delaunay triangulation. The output of these methods is a set of polygons whose values change abruptly at the boundaries between them, which defines these methods as abrupt interpolators as opposed to gradual. For a two-dimensional spatial situation, the polygons are drawn by connecting neighbouring points with a line and intersecting that line with a perpendicular line. If the sampled data points are in a rectangular grid, then the resulting polygons will be of equal size and regularly spaced. If the measured data points are irregularly spaced, then the resulting predictive surface will be an irregular lattice of polygons. This type of method may be appropriate for interpolating data that are more discrete than continuous in nature (Baldridge, 2004).

4.2.1.1.2 Inverse Distance Weighting (IDW): is another set of deterministic interpolation methods based on mathematical formulas. Estimates are based on averages of the known measured points. IDW is an example of a gradual, exact, mathematical interpolator in which points closer to the measured data points receive more weight in the averaging formula. The formula can be adjusted to change the relative importance of the nearest points as opposed to those that are further away, i.e., the power. Specifying a higher power places more weight on the nearer points while a lower power increases the influence of points that are further away. Using a lower power will result in a smoother interpolated surface being generated. Other variables within the IDW formula that can be altered include the number of measured points that can be considered in the averaging, the zone of influence or search area within which measured data points will be considered, and the direction from which measured points are selected (Baldridge, 2004).

4.2.1.1.3 Splines: is another type of deterministic interpolation method. Splines are part of a family of exact interpolation models called radial basis functions (RBF). This method includes thin-plate spline, regularized and tension spline, and inverse multiquadratic spline. RBF methods seek to minimize the overall curvature of the estimated surface while passing through the measured data points. This method performs best when the surface is relatively smooth and a large number of measured data points are available. RBFs will not perform as well when there are large changes in the surface within short distances. RBF interpolation methods are local in that a subset of measured values can be used to generate each prediction, with the actual search area being flexible

4.2.1.2 Kriging: geostatistical interpolation methods are stochastic methods, with kriging being the most well-known representative of this category. Kriging methods are gradual, local, and may or may not be exact (perfectly reproduce the measured data). Also, they are not by definition set to constrain the predicted values to the range of the measured values. Similar to the IDW method, kriging calculates weights for measured points in deriving predicted values for unmeasured locations. With kriging, however, those weights are based not only on distance between points, but also the variation between measured points as a function of distance. The kriging process is composed of two parts: analysis of this spatial variation and calculation of predicted values (Baldridge, 2004).

Spatial variation is analysed using variograms, which plot the variance of paired sample measurements as a function of distance between samples. An appropriate parametric model is then typically fitted to the empirical variogram and utilized to calculate distance weights for interpolation. Kriging selects weights so that the estimates are unbiased and the estimation variance is minimized. This process is similar to regression analysis in that a continuous curve is being fitted to the data points in the variogram. Identifying the best model may involve running and evaluating a large number of models, a process made simpler by the geostatistical software packages. After a suitable variogram model has been selected, kriging creates a continuous surface for the entire study area using weights calculated based on the variogram model and the values and location of the measured points. The analyst has the ability to adjust the distance or number of measured points that are considered in making predictions for each point. A fixed search radius method will consider all measured points within a specified distance of each point being predicted, while a variable search radius method will utilize a specified number of measured points within varying distances for each prediction (Baldridge, 2004).

Because kriging employs a statistical model, there are certain assumptions that must be met. First, it is assumed that the spatial variation is homogenous across the study area and depends only on the distance between measured sites. There are different kriging methods and each has assumptions that must be met. Simple kriging assumes that there is a known constant mean, that there is no underlying trend, and that all variation is statistical. Ordinary kriging is similar except it assumes that there is an unknown constant mean that must be estimated based on the data. Universal kriging differs from the other two methods in that it assumes that there is a trend in the surface that partly explains the data's variations. This should only be utilized when it is known that there is a trend in the data.

Bayesian kriging (BK) is a geostatistical interpolation method that automates the most difficult aspects of building a valid kriging model. Other kriging methods in Geostatistical Analyst require us to manually adjust parameters in order to receive accurate results, but BK automatically calculates these parameters through a process of subsetting and simulations. Empirical Bayesian kriging also differs from other kriging methods by accounting for the error introduced by estimating the underlying semivariogram. Other kriging methods calculate the semivariogram from known data locations and use this single semivariogram to make predictions at unknown locations; this process implicitly assumes that the estimated semivariogram is the true semivariogram for the interpolation region. By not taking the uncertainty of semivariogram estimation in to account, other kriging methods underestimate the standard errors of prediction (ArcGIS Resources).

4.2.2 Variogram

4.2.2.1 General

Variogram analysis consists of the experimental variogram calculated from the data and the variogram model fitting to the data. The experimental variogram is calculated by averaging one half the differences squared of the z values over all pairs of observations with the specified separation distance and direction. Two data sets may have similarity when tested for exploratory data analysis. When we consider variograms, it might show us eventually that the data sets are quite different. In variogram analysis, it gives us distinction behaviour of the data where the exploratory data analysis couldn't give us. This is basically in terms of spatial autocorrelation. The variogram is a quantitative descriptive statistic that can be graphically represented in a manner which characterizes the spatial continuity (i.e. roughness) of a data set (Barnes, 1991).

4.2.2.2 Characteristics of the variogram

A typical semivariogram/variogram model is made up of the Sill, Range and Nugget. The sill consists of the partial sill and the nugget. They are well defined below. Figure 5.1 shows the typical semivariogram. Sill is the semi variance value at which the variogram levels off. And it can also be refereed as the amplitude of a certain component of the semivariogram. Range is the lag distance at which the semivariogram (or semivariogram component) reaches the sill value. Presumably, autocorrelation is essentially zero beyond the range.
Nugget in theory at the origin (0 lag) of the variogram should be zero. If it is significantly different from zero for lags very close to zero, then this semivariogram value is referred to as the nugget. The nugget represents variability at distances smaller than the typical sample spacing, including measurement error.

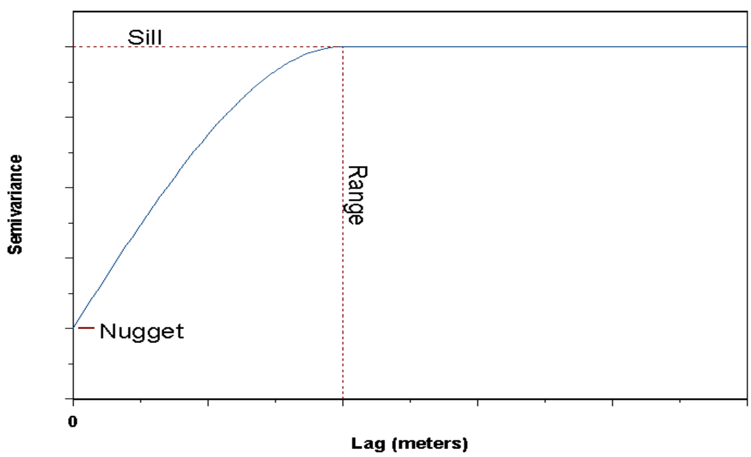

Figure 4.1 Typical Semivariogram: Source (Bohling, 2005).

4.2.2.3 Fitting Semivariogram Models

The three most commonly used variogram models are Spherical, Exponential and Gaussian. When attempting to model one of these types of variograms via trial and error visual inspections, there are some guidelines that can be applied.

In general, when visually estimating variogram, it is important to note that not all empirical variogram points are equally important when it comes to developing model variograms. Short distances are most important since they have the greatest impact on prediction and prediction errors. Long distances may be generated with fewer observation pairs due to the geometry of the spatial sampling locations, and, therefore, the variogram model fit at such distances may be more uncertain as a result. In addition, a large number of values at or near the sill will tend to dominate any automatic fitting algorithms (and, thus, the objective function). Thus, one might consider trimming some of the empirical values that are beyond the range out of the variogram modeling process.

The kriging algorithm need to access the semivariogram values for lag distance used other than the empirical variogram. More importantly, the semivariogram models used in the kriging process need to obey certain numerical properties in order for the kriging equations to be solvable (Bohling, 2005).

The common types of models are Nugget, Spherical, Exponential, Gaussian and power models. They have their own description in terms of the equation they are involved with.

The nugget model represents the discontinuity at the origin due to small-scale variation. On its own it would represent a purely random variable, with no spatial correlation. The spherical model actually reaches the specified sill value, *c*, at the specified range, *a*. The exponential and Gaussian approach the sill asymptotically, with *a* representing the practical range, the distance at which the semi variance reaches 95% of the sill value. The Gaussian model, with its parabolic behavior at the origin, represents very smoothly varying properties. (However, using the Gaussian model alone without a nugget effect can lead to numerical instabilities in the kriging process.) The spherical and exponential models exhibit linear behavior the origin, appropriate for representing properties with a higher level of short-range variability. The power model does not reach a finite sill and does not have a corresponding covariance function. Power-law semivariogram models are appropriate for properties exhibiting fractal behavior (Bohling, 2005).

4.2.2.3.1 Anisotropy

An isotropic covariance structure is one in which the magnitude of the covariance between measured data at two locations depends only on the distance between the two locations. In contrast, anisotropic covariance is a structure in which the magnitude of the covariance between the observations at two locations depends both on the distance and the direction between the locations. This directional covariance structure can be caused by underlying physical processes that evolve differentially in space, like geological make up, wind etc. When modeling to spatially interpolate, the implementation of an anisotropic covariance model might provide a better overall description of the data by putting an additional structure in the covariance component of the model. When the process Z is anisotropic (i.e. dependence between Z(s) and Z(s+h) is a function of both the magnitude and the direction of h), the variogram is no longer purely a function of distance between two spatial locations (Cressie, 1990).

Generally speaking, there are two types of anisotropy: geometric anisotropy and zonal anisotropy. Geometric anisotropy occurs when the range, but not the sill, of the variogram changes in different directions. Geometric anisotropy means that the correlation is stronger in one direction than it is in other directions.

4.2.3 General Procedure

A major benefit of the various forms of kriging (and other stochastic interpolation schemes) is that estimates of the model's prediction uncertainty can be calculated, considered in the analysis, and plotted along with the predicted surface. Such uncertainty information is an important tool in the spatial decision making process.

Before using different geostatistical interpolation techniques, exploratory spatial data analysis shall be done. This can be done with the tool of geostatistics wizard in ArcGIS. Histograms, Normal QQ plot, Voronoi map, Trend Analysis, etc. are included in the exploratory data analysis.

In order to fit the model, Semivariograms are used. Semivariograms are used to quantify the spatial autocorrelation between the data sets. Different models (Circular, Gaussian, Exponential and Spherical) can be chosen for a single interpolation method and the best model is considered. When attempting to determine what model to apply to an empirical variogram, one can get information by a visual inspection of the shape of the variogram. For example, as stated previously, Gaussian variograms tend to have an "S" shape. That is, they exhibit a gradual upward slope from distance zero, followed by a sharper upward slope toward the middle of the variogram, and finally another gradual upward slope at the end of the variogram. On the other hand, both the spherical and exponential variograms start sloping upward more sharply at distance zero. Of the two, the exponential variogram tends to have more gradual behavior. The exponential curve tends to be sharper than the Gaussian and spherical models at the beginning. The exponential curve also tends to become shallow more gradually than the spherical variogram, which tends to have the same slope until it nears the sill at which point it tends to become nearly flat (Cressie,1993).

The prediction surfaces are going to be constructed using Geostatistical Methods (Ordinary Kriging, Bayesian Kriging and Universal Kriging). Inverse Distance Weighting can also be considered for the sake of comparison.

For predicting the surfaces of hydro geochemical concentrations (water quality) and the rest parameters of the aquifer system, the same geostatistical methods shall be applied. These data are obtained from the water wells in the study area.

In order to compare the different interpolation methods and choose the better surface, Cross Validation techniques are used. The evaluation criteria is based on Mean Error (ME) values.

The General methodology consists of collection of data, preparation of experimental variograms (exploratory data analysis), fitting the theoretical models, kriging and cross validation, spatial water quality analysis, pollution vulnerability and potential aquifer site determinations.

The methodology followed is basically the same for all of the parameters that are considered in the study until map generation. Then, spatial water quality analysis, pollution vulnerability and aquifer site determinations are made out of the maps generated.

After each groundwater parameters are mapped with the best possible method, the individual results are compared against the guidelines to come up with the quality of the water for irrigation purpose. Beyond this, to make the results more understandable for public, planners and non-technical person, a single Water Quality Index (WQI) map is made out of all parameters consider for the water quality determination.

The WQI is determined by using the weighted arithmetic mean method, which is an objective type. Weights and quality ratings are given for each of the water quality parameters considered (SAR, EC, Cl^-, Na^+, Ca^{++}, SO_4^{2-}, and HCO_3^-).

The following formulas are used to calculate the weights and the ratings as given by Brown et al. 1972.

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} \mathrm{QiWi}}{\sum_{i=1}^{n} \mathrm{Wi}} \qquad \text{......................................Eq.4.1}$$

Where,

WQI= Water Quality Index

Qi= Quality rating of the i th parameter

Wi=Weightage of the ith parameter

The quality rating of the ith parameter is given by the equation below

$$Qi = \frac{\text{Vi}}{\text{Si}}*100 \text{ ....Eq.4.2}$$

Where Vi= the observed concentration of i^{th} parameter

Si= the standard/desired value of i^{th} parameter

The weightage of the i^{th} parameters is given by the equation below

$$Wi = \frac{\text{K}}{\text{Si}} \text{ ....Eq.4.3}$$

Where,

k= Proprotional constant $= \frac{1}{(\frac{1}{S1}+\frac{1}{S2}+\frac{1}{S3}...+\frac{1}{Sn})}$

Where,

S_n=desired limit of the n^{th} water quality parameter

The Groundwater Vulnerability index is made using the Rating System (RS). The rating system considered is the GOD index method. The reason for selecting this method over the other methods is the data availability. This method considers three variables or parameters (Groundwater occurrence, Overlaying aquifer lithology and Depth to groundwater table) for the computation of its index. Ratings are given following the GOD rating charts for all the ranges of individual parameters. Then, to get the index, the rating of groundwater occurrence is multiplied with the ratings of overlaying lithology and finally with the ratings of the depth to groundwater table.

For assessing the potential aquifer sites in the study area, a weighted overlay analysis is used. The layers considered for this analysis are the geology of the area, aquifer thickness, hydraulic conductivity of the aquifer and the static water level. Weight values of 1, 2 and 3 are given to the parameters or layers based on the relative importance of each of the parameters as a contributor for the suitability of potential aquifer site. Again, the ranges of each parameter are also rated as 1, 2 and 3. The values of 3, 2 and 1 represent high, medium and low rating values respectively. The resulting map in the weighted overlay of spatial analyst in Arc Map yields a suitability map with values of 1, 2 and 3.And the flow chart is shown in the Figure 4.2 below. The yellow part depicts the geostatistical method with the inclusion of exploratory data analysis.

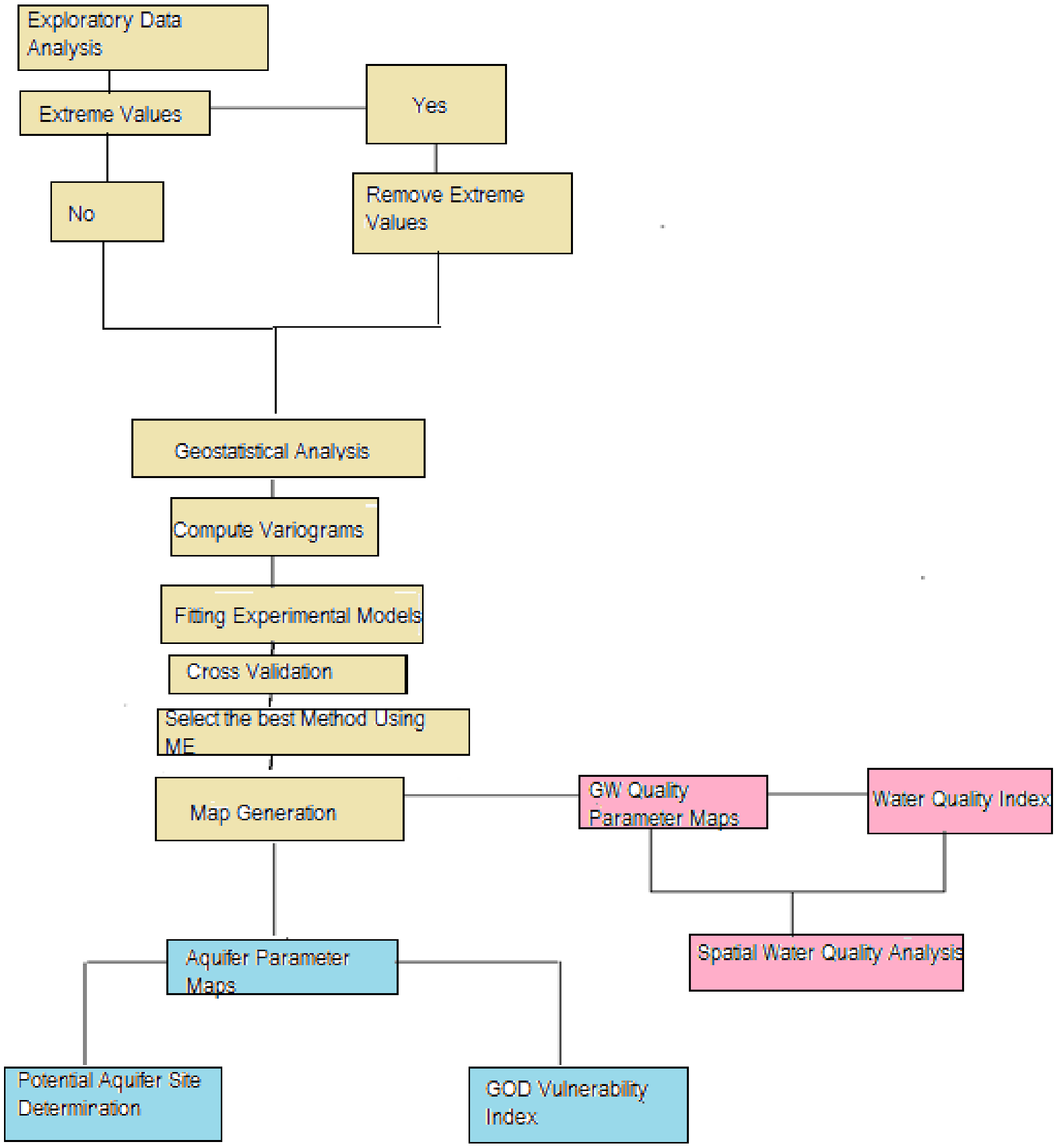

Figure 4.2 General Methodology

5. Results and Discussion

5.1 Variogram Analysis

For the sake of Geostatistical Analysis, it is necessary to replace the empirical variograms with appropriate models. The directional variogram and exploratory data analysis suggested that most of the groundwater parameters are anisotropic and they have major and minor ranges.

In this study, different variogram models were tried to fit to the experimental variogram of each groundwater parameter. The models include Spherical, Exponential, and Gaussian. Table 5.1 deatails variogram models obtained for each groundwater parameters. The variogram pictures for each parameter are presented in Annex A.8.

Parameters	Model Fitted	Range		Lag size	No. of lags	nugget	Partial Sill	Angle of spatial continuity
		Major	Minor					
SAR	Spherical	6500	4000	900	7	0	1.06	42.9
TDS	Exponential	12876	7502	1073	12	4057	14088	38.4
EC	Spherical	18284	10388	2700	10	10399	99097	177.4
Na	Exponential	23000	14000	2000	7	0	3381	134.3
Ca	Exponential	3555	1185	1331	9	28.59	401	58.9
Cl	Spherical	18000	12500	1800	10	0	1722	286.6
SO4	Spherical	10000	7000	1297	7	0	5528	25
HCO3	Exponential	18000	7500	1997	7	0	17305	286.2
K	Exponential	1000	1000	300	8	0	65	

Table 5.1 Model fits and their parameters

5.2 Groundwater Parameters Surfaces

In this study, prediction of the best possible surface of groundwater parameters using the gesotatistical methods (Universal Kriging, Ordinary Kriging and Bayesian Kriging) as well as Inverse Distance Weighting is made. Table 5.2 shows best surface prediction methods selected. The resulting surfaces are compared with the guidelines provided for the purpose of irrigation. The results are compared against irrigation water quality because of the fact that Kobo Valley Development Project is groundwater supported pressurised irrigation project. By comparing the results for each individual groundwater quality parameters against the guidelines, it is possible to come up with the effect of each one on the quality of the water in

the area. In addition to this, a single Water Quality Index (WQI) is made from the individual parameters so that it is possible to see the overall groundwater quality of the study area.
The Groundwater Pollution Index which represents the vulnerability of the area for pollution is also computed using the GOD method. The Ground water Potential Index (GWPI) which can be used as an indication of good aquifer site for future water well drilling is also computed using Weighted Overlay Method.

To assess the groundwater quality parameters, SAR (Sodium Adsorption Ratio), Total Dissolved Solids (TDS), Electrical Conductivity (EC), Sodium Concentration (Na^+), Calcium ion concentration (Ca^{++}), Chloride Concentration (Cl^-), Bicarbonate (HCO_3^-) and Sulphate (SO_4^{2-}) are considered.

Hydraulic Conductivity (K), Aquifer Thickness (H) and Static water level (h) are also mapped as they are important for assessing the aquifer potential spots in the study area. The best possible map is generated for each of the parameters using Ordinary Kriging, Universal Kriging, Bayesian Kriging and Inverse Distance Weighting Methods. The Cross Validation method is used to assess the best one among them. After many trials for each parameter, the geostatistics methods that gave minimum errors are shown in the table below. All the maps generated for each method and their cross validation results are shown in the Annex A.3 and A.4 respectively.

Groundwater Parameters	Symbol	Unit	Best method selected	Mean Error
Sodium Adsorption Ratio	SAR		Universal Kriging	0.0017
Total Dissolved Solids	TDS	mg/l	Universal Kriging	-0.016
Electrical Conductivity	EC	µS/cm	Universal Kriging	-0.073
Sodium	Na^+	mg/l	Bayesian Kriging	-0.0006
Calcium	Ca^{++}	mg/l	IDW	0.0005
Chloride	Cl^-	mg/l	Ordinary Kriging	-0.0206
Sulphate	SO_4^{2-}	mg/l	Universal Kriging	-0.004
Bicarbonate	HCO_3^-	mg/l	Universal kriging	0.024
Hydraulic Conductivity	K	m/d	Ordinary/Universal	-0.054
Aquifer Thickness	H	m	Ordinary Kriging	0.212
Static water level	h	m	Ordinary Kriging	-0.41

Table 5.2 Best surface prediction methods

From the above table, it can be seen that Inverse Distance Weighting (IDW) which is a deterministic interpolation method is found to be the best method of interpolation for the calcium concentration. This can be explained by the fact that in the variogram model fit, calcium has almost horizontal variogram fit indicating that the spatial autocorrelation between the data points is minimal.

5.2.1 Groundwater Quality Parameters

5.2.1.1 Sodium Adsorption Ratio (SAR): It expresses the relative activity of sodium ions in the exchange reactions with the soil. The ration measures the relative concentration of sodium to calcium and magnesium. It measures the infiltration problem of water in the soil.

The guideline given by Water Treatment Solution Lenntech (Bara, 2008) in the Netherlands put the SAR hazard problems in irrigation water in to three classes. These classes are given in the Table 5.3 below.

SAR Hazard Irrigation Water		
Effect	SAR	Notes
None	<3	No restriction on the use of water
Slight to Moderate	3-9	From 3-6 care should be taken for sensitive crops. From 6-8 gypsum should be used. Not sensitive crops. Soils should be sampled and tester every 1 to 2 years to determine whether the water is causing sodium increases.
Acute	> 9	Sever damage. Unsuitable

Table 5.3 Guideline of SAR for irrigation purpose (Bara, 2008).

The Standard Provided by Food and Agricultural Organization (FAO) also puts standards for Irrigation water Quality. The Standard for Sodium Adsorption Ratio (SAR) with regards to the permeability that affects the infiltration rate in to the soil falls in to three categories as well. If the SAR values are less than 6, there is no problem for most of the plants. If it is between 6 to 9, there is increasing problem. For values greater than 9, the problem is severe for most of the plants.

The two guidelines are somewhat similar on their basis of classification. The guideline given by Water Treatment Solution is a little bit conservative and it is taken in to consideration to be on the safe side.

The Figure 5.1 below shows the spatial distribution of SAR and its classification of the groundwater quality based on the guidelines set. It can be seen that most of the areas in Hormat-Golina and Waja Golesha(except for a small area where trachayte formation is found) have SAR values less than 3 and there is no restriction in the use of this water on the plants. In Kobo-Gerbi basin, there is slight to moderate and increasing problem due to the SAR measured in the area. Sensitive crops and others which cannot tolerate SAR shouldn't be recommended on this specific area. A small part of Washa Golesha is also having a slight to moderate problem. The explanation for Kobo-Gerbi having an increasing problem might be due to the fact that the geological make up of this region is of Lacustrine/Evaporite in nature. These lacustrine clay soils have deficiencies both in horizontal and vertical drainage and that makes the permeability worse with the presence of some ions. And these clay soils are active in reaction with cations like sodium and make it more difficult for the permeability. Where as in the areas where the SAR value is small and considered good as irrigation water, the geology is of unconsolidated sediment for which the permeability is far better than the other geological make of the study area. The delination of the basins is shown in Figure 3.5.

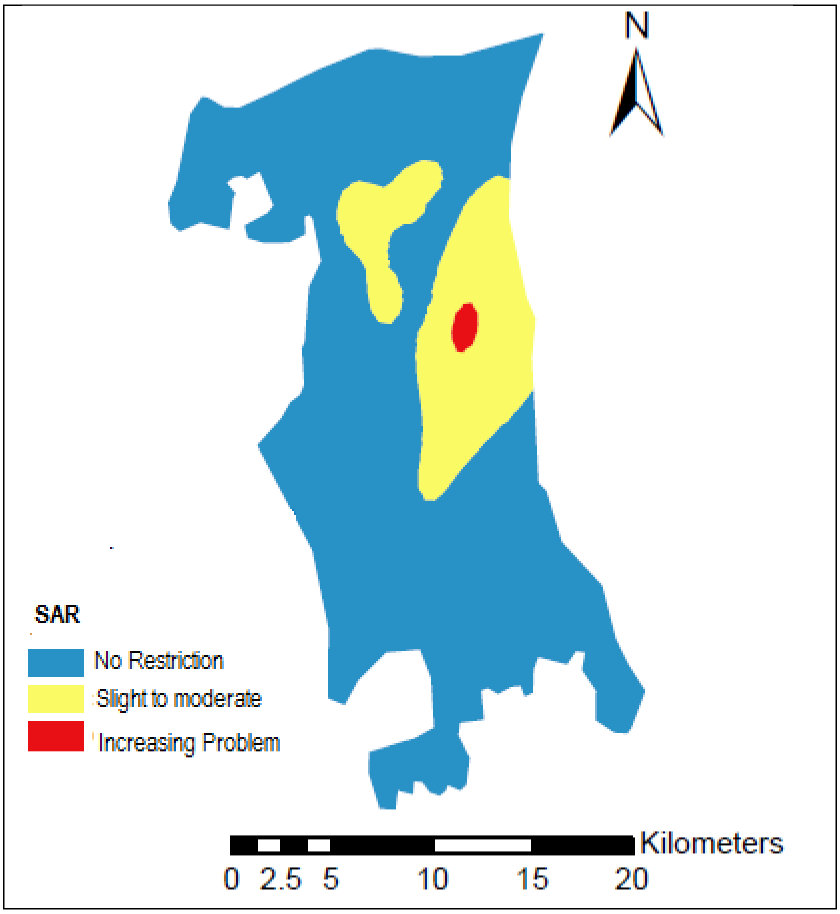

Figure 5.1 Spatial Distribution of SAR

5.2.1.2 Total Dissolved Solids (TDS)

It is used to measure the salinity of irrigation water for agricultural purposes. It can be expressed in ppm or mg/l. Salts reduce the osmotic potential of water then increases the energy needed for the plants to take over the water.

According to the salinity management guide (www.salinitymanagement.org/), the amount of Total Dissolved Solids in Irrigation water is classified in to three groups. If the amount is less than 450mg/l, then the water is generally safe for irrigation. From 450mg/l to 2000 mg/l, there is slight to moderate risk. For values greater than 2000 mg/l, there is severe risk of alkalinity. As shown in Figure 5.2, the TDS values of the study area fall under two categories. The two categories are generally safe (TDS<450 mg/l) and slightly to moderate risk (TDS between 450 to 846 mg/l). Most of the study area falls under slightly to moderate risk except for the South Western part of the region which is part of Hormat Golina sub basin and small part of Waja Golesha on its north western part.

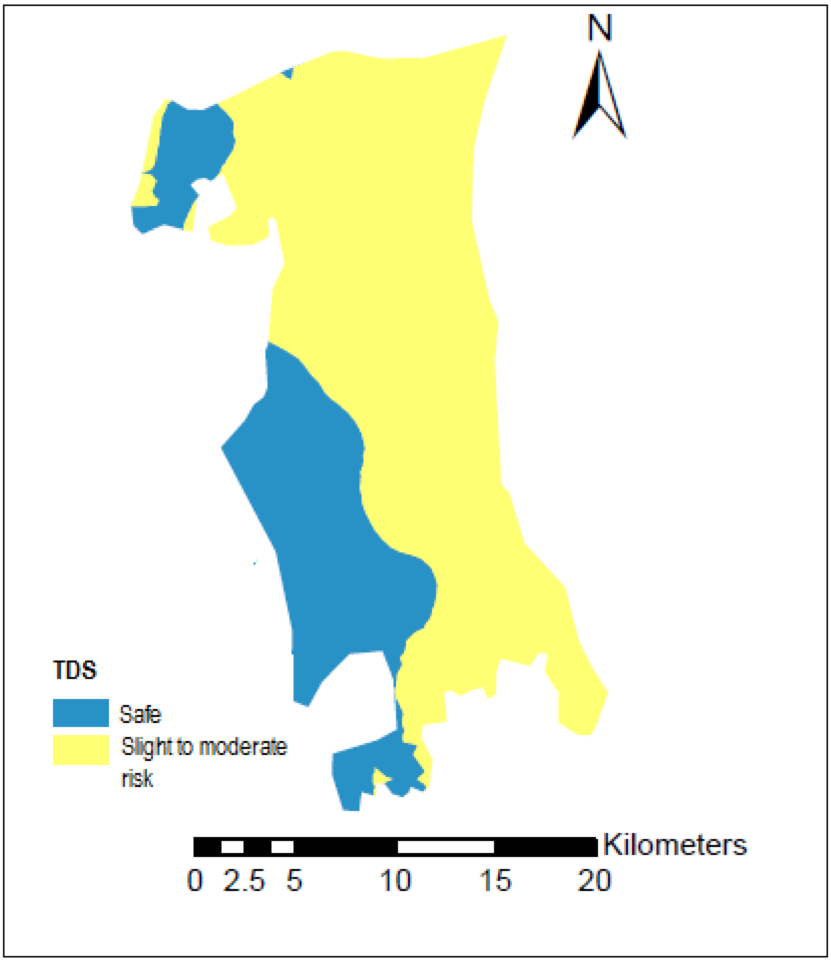

Figure 5.2 Spatial Distributions of TDS

5.2.1.3 Electrical Conductivity (EC)

Electrical Conductivity is used to assess the salinity of the irrigation water. It can be measured by microsiemens per centimetre (µS/cm). It can be affected by the presence of inorganic dissolved solids.

According to Food and Agricultural Organization of the United Nations (FAO, 1976), salinity guidelines are given in three classes based on the Electrical Conductivity (EC) of the irrigation water. If the electrical conductivity is less than 750 µS/cm, then the water has generally no problem on the alkalinity. If it is between 750 to 3000 µS/cm, then there is an increasing problem of alkalinity. For electrical conductivity greater than 3000 µS/cm, there will be severe problem of alkalinity. Figure 5.3 below shows the spatial distribution of Electrical Conductivity in the study area. The area is generally falls under no problem (less than 750 µS/cm) and increasing problem (750-1505 µS/cm) based on the guideline set. It is evident that, the spatial distribution of total dissolved solids and that of electrical conductivity almost follows the same trend. There is no problem in some portion of the Hormat-Golina sub basin due to the electrical conductivity. But there is an increasing problem both in Waja-Golasha and Kobo-Gerbi groundwater sub basins that are located in the North and Eastern part of the study area. The reason for this might be due to a slightly higher value of TDS in these specific areas as seen from the spatial distribution of total dissolved solids in Figure 5.2. Apart from this, if we see each cation and anion distributions, it is evident that the values tend to be higher on these parts

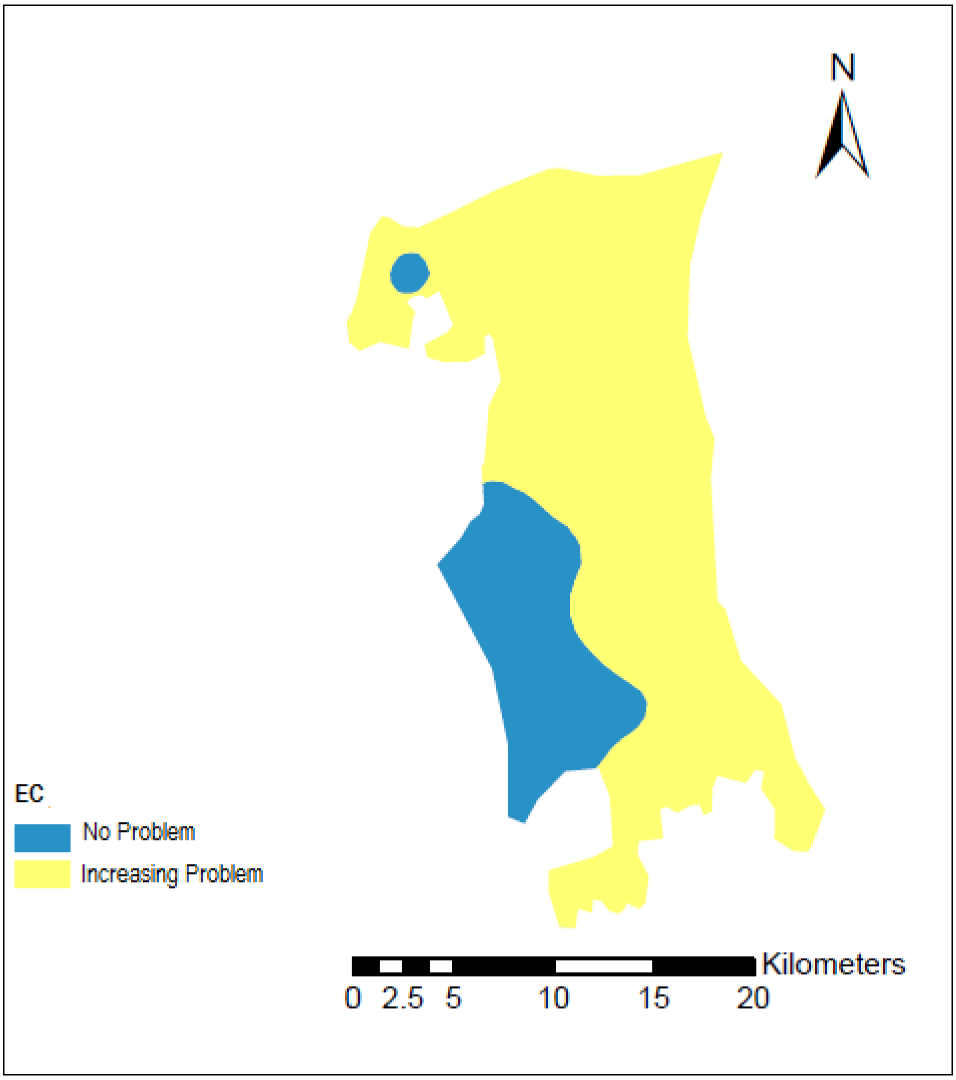

Figure 5.3 Spatial Distribution of EC

5.2.1.4 Sodium (Na^+)

Some ions are found in the water and can be toxic if their concentration is beyond the tolerable limit of the crops. Sodium is one of the positively charged ions that are found in the ground water.

FAO gave general thresholds of specific ion toxicities for agricultural crops(Ayeres,1985). According to this classification, for sprinkler irrigation, two ranges of concentrations are given. If the sodium concentration is less than 70 mg/l, there is no restriction on the use of water for irrigation. If it is greater than 70 mg/l, then the usage is restricted from slight to moderate.

The salinity management guide also gives the same standards for sprinkler irrigation as of the FAO guideline for this specific this cation.

Figure 5.4 below shows the spatial distribution of sodium ion concentration. Kobo-Gerbi groundwater sub basin has slight to moderate restriction on the use of the water for irrigation purpose. In this basin, the sodium concentration is basically between 70 – 212 mg/l. On the other hand, the south and south west part of the Hormat-Golina sub basin have concentration of less than 70 mg/l and therefore there is no restriction on the use of the water for irrigation purpose. For the part of the Hormat-Golina which is adjacent to the Kobo-Gerbi basin, the usage is restricted from slight to moderate. In Washa-Golesha, the central part of the basin is limited to slightly to moderate usage while the North Western part of it is generally safe to use.

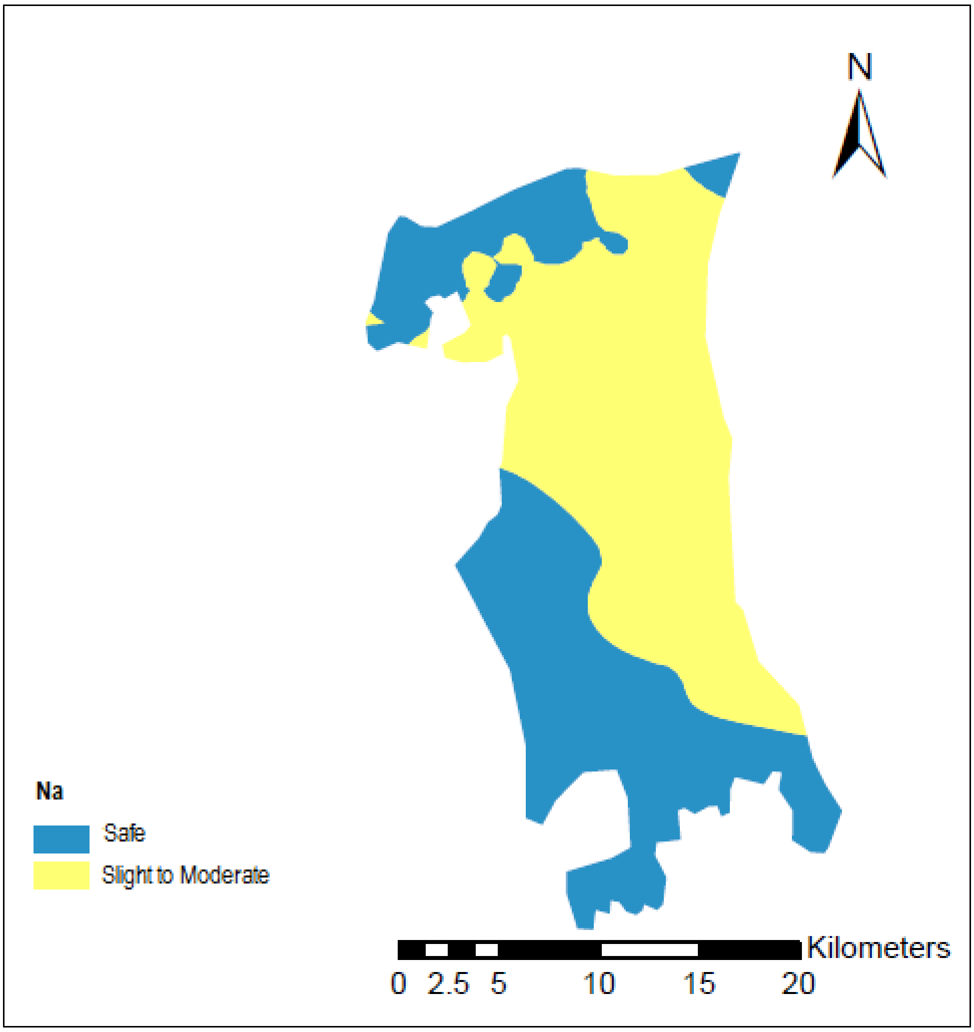

Figure 5.4 Spatial Distribution of Na

5.2.1.5 Chloride (Cl^-)

Although chloride is needed for plants in small amount, a concentration above a certain limit is a cause for toxicity. The problem is worsened when it is applied with sprinkler irrigation as that of sodium. In irrigation water, the most common toxicity is from chloride. Chloride causes leaf burn or tissue damage of the crop.

According to Mass (1990), chloride concentration in water is classified in to four groups for irrigation purpose. The Classification is shown in Table 5.4 below.

Chloride(mg/l)	Effect on crops
<70	Generally safe for all plants
70-140	Sensitive plants show injury
141-350	Moderately tolerant plants show injury
>350	Can cause severe problems

Table 5.4 guideline for chloride concentration in irrigation water (Mass, 1990)

The standard provided by FAO in 1976 recommended that chloride with a concentration of less than 4 meq/l (142mg/l) is safe, between 4-10 meq/l (142-350 mg/l) with increasing problem and beyond 10 meq/l (350mg/l) it is unsafe to use the water. But in this guideline it is noted that if sprinkler irrigation is used, excess of 3 meq/l (106mg/l) chloride concentration might cause leaf burn on sensitive crops.

Accounting the above two guidelines, it is fair to use the first one since it accounts the issues raised in FAO (1976) guideline for sprinkler irrigation and seems to be a bit conservative for sensitive crops which need protection against this commonly known toxic for plants. Figure 5.5 below shows the spatial distribution of chloride in the study area. From the figure, it is evident that the concentration of chloride increases from west to east part of the whole area. Chloride is one of the chemicals that are used to trace the movement of water in a basin or to measure the velocity of water in rivers. So based on this idea, it is possible to say that the movement of the groundwater is from west to east direction.

On the area, by comparing the resulting chloride concentrations against the guideline set above, three classifications are obtained. The first classification is the one which has a chloride concentration of less than 70 mg/l. This area is safe for almost all types of plants and covers many portions of the Waja Golesha and Hormat Golina sub basins. The other class is the one which has the values between 70 and 140 mg/l. This class is dangerous for sensitive crops. It covers some portions of the Hormat Golina and Kobo Gerbi sub basins. And very little portion of the Waja Golesha Basin. The last classification obtained is the one which has chloride concentration between 140 to 165 mg/l. This class affects moderately sensitive plants and of course sensitive plants. The water is found in Kobo Gerbi sub basin and selection of crops on this area is required.

The reason for higher values of chloride concentrations in Kobo Gerbi sub basin may be due to the geological make up of the basin. From the geology, it is seen that this basin is made of lacustrine and evaporite sediments. Evaporites are formed when dissolved chemicals are precipitated due to evaporation. The semi-arid and arid nature of the area facilitates the evaporation. Evaporites contain slyvite and halite. Slyvite has a chemical composition of KCl and halite NaCl. The two chemicals contain chloride (Boggs, 2009). Thus, evaporites might be responsible for the higher chloride concentrations in the area.

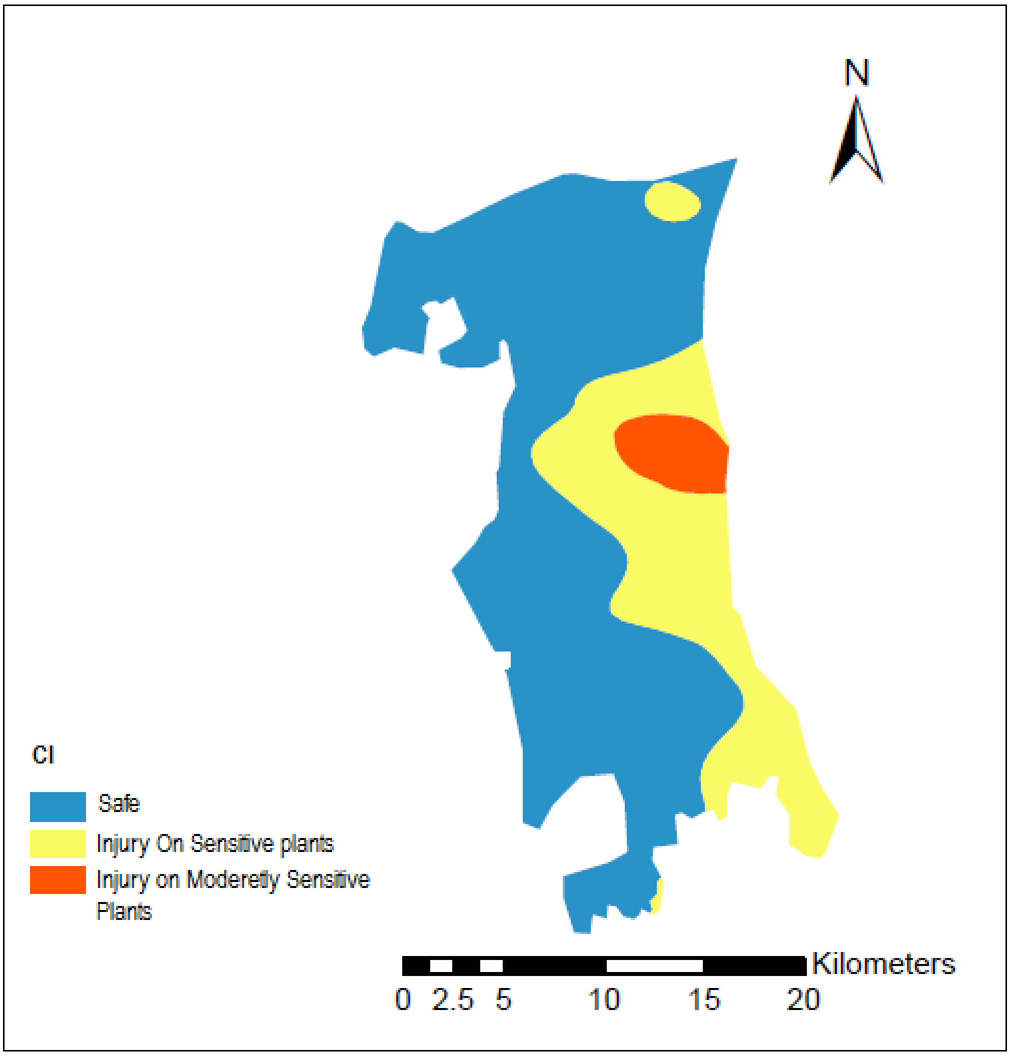

Figure 5.5 Spatial Distribution of Chloride

5.2.1.6 Calcium (Ca^{++})

The Calcium cations are generally found in all natural waters. When adequately supplied with exchangeable calcium, soils allow water to drain easily. That is why calcium in the form of gypsum is applied to improve the structure of the soil. Soil First Consulting gave irrigation water guideline for Calcium concentration in the water. The desired amount of calcium in irrigation water is up to 120 mg/l (Soil first consulting).

Figure 5.6 below shows the spatial distribution of calcium over the study area. From the figure, it is seen that the whole study area is safe against the calcium concentration and it is within the desired range i.e. less than 120mg/l being 116 the highest concentration obtained.

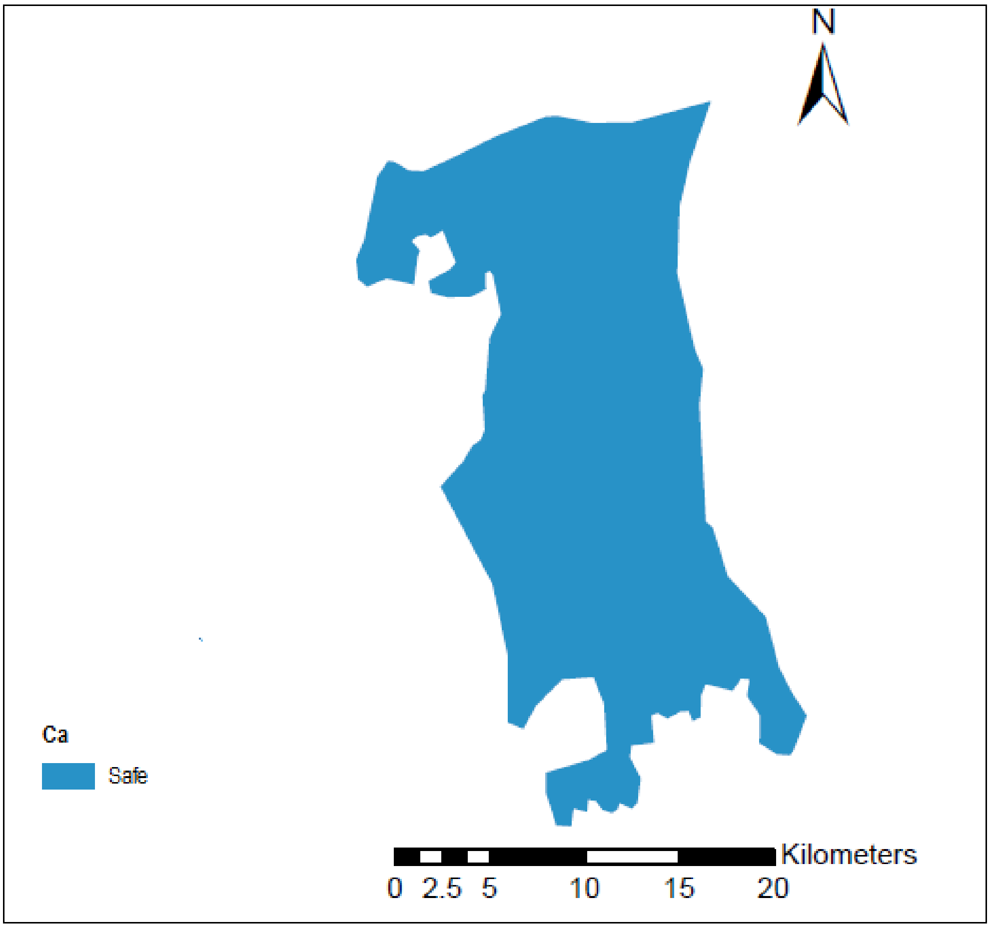

Figure 5.6 Spatial Distribution of Ca

5.2.1.7 Sulphate (SO_4^{2-})

Most corrosion problems are associated with groundwater. Especially when sprinkler irrigation systems are used, lots of metals are needed for the lay out system of the irrigation. Using bad quality of water might affect the general system due to corrosion. High sulphate in irrigation water is responsible for corrosion. Apart from the corrosion, the emitters might be clogged. In regard to the plants, Sulphate is considered as a nutrient. However, high sulphate concentration in irrigation water might increase the salinity of the soil and interferes in the up taking of nutrients by the plants. The desired concentration of sulphate for plants should be less than 400 mg/l.

According to Ayres and Westcot (1994) FAO guideline, four levels of corrosion attack by sulphate are given. If the sulphate concentration is less than 200 mg/l, the corrosion attack is none to slight. Concentration from 200 to 600 mg/l has a mild attack on the irrigation infrastructures. From 600 to 3000 mg/l concentration has a strong corrosive impact. And at last if the concentration exceeds 3000 mg/l, the corrosive impact is very strong.

Figure 5.7 below shows the spatial distribution of sulphate (SO4) in the Kobo valley irrigation development project. It can be seen that majority of the groundwater, including the whole

Hormat Golina sub basin, is good for the infrastructures against the corrosion effect. They have sulphate concentrations of less than 200 mg/l. But some areas in the Kobo-Gerbi and Waja Golesha sub basins seem to have a mild quality of water against the sulphate attack and they are shown by the yellow area in the figure. The concentration ranges from 200 to 363 mg/l. The maximum concentration of sulphate in the whole area is less than 400 mg/l and this shows that it is good for the plants.

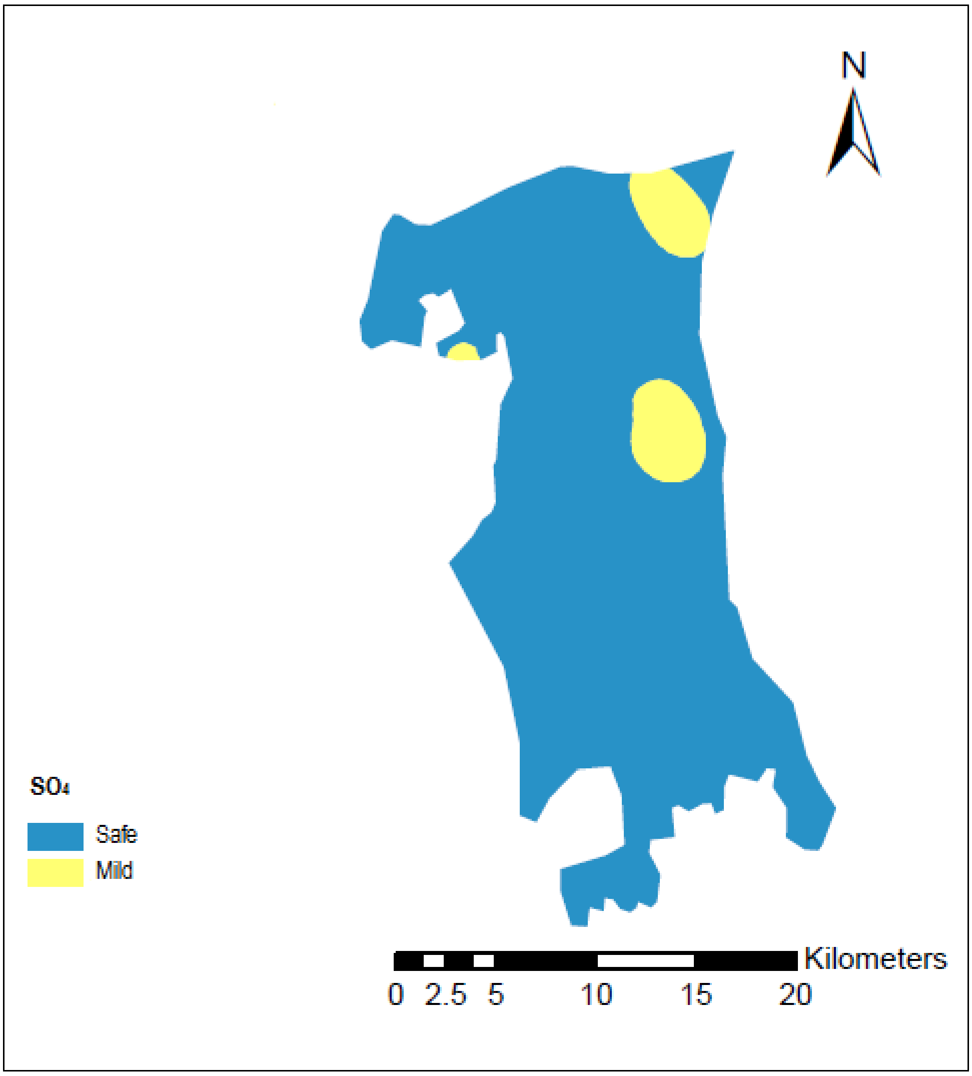

Figure 5.7 Spatial Distribution of sulphate

5.2.1.8 Bicarbonate (HCO_3^-)

According to Ayers (1976) FAO guideline for interpretation of water quality of irrigation, three classes of problem are given for overhead sprinkler irrigation with regard to the bicarbonate concentration. If the concentration of bicarbonate is less than 1.5 meq/l (91.5 mg/l), there is no problem with the irrigation water. If it is in the range of 1.5 – 8.5 meq/l (91.5 – 457.5 mg/l), there will be an increasing problem. Values beyond 8.5 meq/l (457.5 mg/l) will have severe problem up on using it as irrigation water. Figure 5.8 below shows the spatial distribution of bicarbonate distribution in the whole study area. Comparing with the standard given by FAO, the study area falls under two classes. We don't have safe areas with bicarbonate concentration. Most of the areas seem to have an increasing problem. This might be due to the application of fertilizer which can increase the carbonate amount. Besides to this, some areas in Waja Golesha sub basin have a severe problem against bicarbonate and they are shown by red colour in the Figure 5.8.

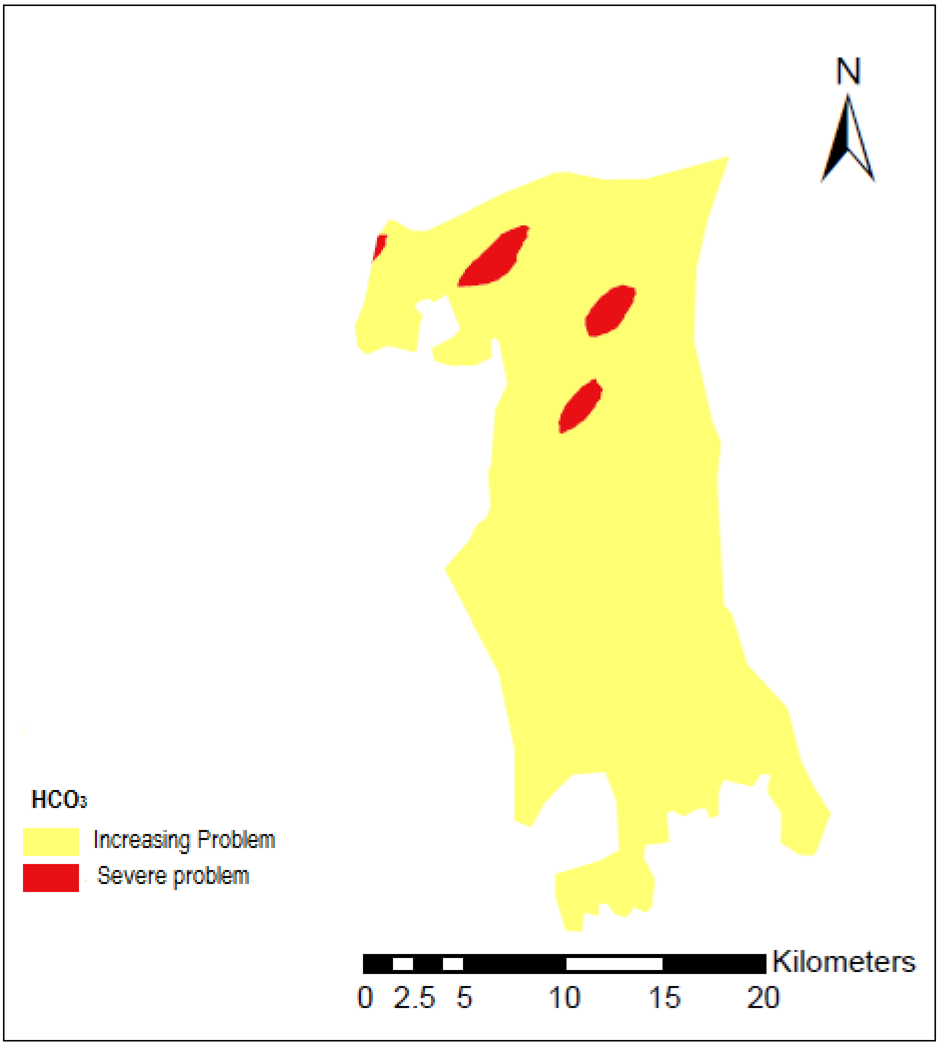

Figure 5.8 Spatial Distribution of Bicarbonate

5.2.2 Water Quality Index (WQI)

As it is seen from the above section, not all water quality parameters are safe against the requirements of the standards of irrigation water quality. Some are fine for some area and some are not. In order to make the effect of all water quality information understandable and usable by people with no encounter with the science (managers, planners and the public), water quality indexing is vital.

In this water quality index determination, an objective type of indexing is preferred over subjective one. Objective type of indexing is also called statistical index. The advantage of objective indexing over subjective one is that it is not a biased on allocating weights to the parameters considered. Besides to that, there is a lack of literature on subjectively weighting the groundwater quality parameters for the purpose of irrigation.

For getting the water quality index of the study area, the weighted arithmetic mean method is used. The maps generated for Sodium Adsorption Ratio (SAR), Electrical Conductivity(EC), Sodium(Na^{++}), Calcium(Ca^{++}), Chloride (Cl^{-}), Sulphate(SO_4^{2-}) and Bicarbonate(HCO_3^{-}) are used. These individual maps are given weights (objective weights using statistics) and quality rating based on the guidelines used. Then, all the parameters are aggregated to give a single map of water quality index using weighted sum overlay. See the methodology section for details. Using the guidelines for safe irrigation water quality parameters provided and the above formulas, the weight of the parameters are obtained. The results are summarized in Table 5.5 below.

Groundwater Quality Parameters	Desirable limits/Standards(Si)	1/Si	k	Wi
SAR	6	0.16	4.71	0.78
EC	750	0.001		0.0063
Na	70	0.014		0.067
Ca	120	0.008		0.039
Cl	70	0.014		0.067
SO4	200	0.005		0.023
HCO3	91.5	0.01		0.051

Table 5.5 weights of groundwater quality parameters

Since we have different ranges in the values of the parameters, the quality rating is incorporated within the raster when the weighted sum overlay is done. The classification of water quality index is presented in Table 5.6.

Figure 5.9 shows the aggregated weighted sum overlay map which is the water quality index map. The area in the light green represents the water quality which is safe for irrigation purpose and it has a water quality index value of less than 50. The yellow portion has a moderate effect as irrigation water shall be used with caution. It has water quality index values of 50 to 100. The red areas are the ones which cannot be used as irrigation water because of their sever effect on the plants. These areas have a water quality index of 100 to 151.

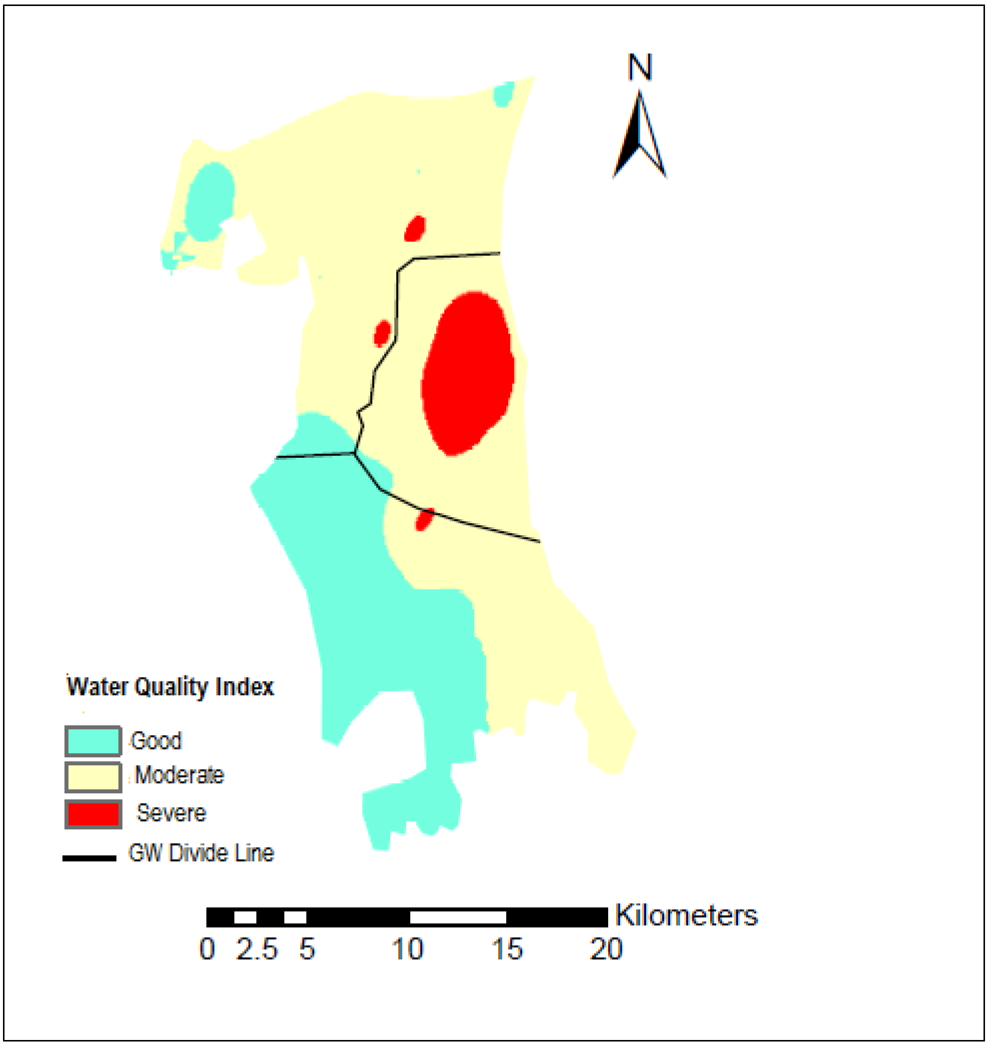

Figure 5.9 Water Quality Index map of the study area

The water quality index is classified in to three groups and the percentage area is also calculated. Table 5.6 shows the classification and percent area coverage of the water quality index values.

Water Quality Index(WQI)	Description	Area coverage (%)
<50	Good	36.9
50-100	Moderate	59.8
>100	Sever/not safe	3.3

Table 5.6 Classification of water quality index and percent area coverage

5.2.3 Ground Water Pollution Index

Ground water pollution index is a measure of the potential vulnerability of the aquifer system against the contaminants. The water quality index tells us the current contamination state using the existing measured ground water quality parameter data. The groundwater pollution index tells us how vulnerable the area is considering some factors.

Vulnerability assessment of groundwater, as used in many methods, is not a characteristic that can be directly measured in the field. It is an idea based on the fundamental concept "that some land areas are more vulnerable to groundwater contamination than others" (Vrba and Zaporozec 1994).

The GOD method is used to assess the vulnerability of the groundwater aquifer system. It is an overlay and index type. The choice of this method over the other is based on the data we have. GOD only needs three aquifer parameters to give us the vulnerability index. It is a simple method. The parameters that are considered in this method are: a) Groundwater occurrence (G), Overlaying aquifer lithology, only for unconfined aquifer (O) and Depth to the groundwater (D). Using the GOD flow chart, the ratings for the groundwater occurrence, overlaying lithology and depth to the water level are obtained for the study area. These values are between 0 and 1. The ratings are given in Table 5.7 below.

Parameters	Ranges and Rates				
G (Groundwater Occurrence)	Range	Unconfined			
	Rating	1			
O (Overlaying Aquifer Lithology)	Range	Granite	Lacustrine/ Evaporite	Trachite /fractured	Unconsolidated Sediments
	Rating	0.5	0.6	0.7	0.8
D (Depth to water)	Range	5-10	10-20	20-50	50-100
	Rating	0.8	0.7	0.6	0.5

Table 5.7 Ranges and ratings of G, O, and D parameters.

Following the GOD rating, the vulnerability index is computed first by multiplying the groundwater occurrence rating with the overlaying aquifer lithology rating and then finally with the depth to water rating. Since the rating values are between 0 and 1, the multiplication of the ratings give a value less than the two values considered. The flow chart that consists of the GOD rating system is given at the Annex A.6.

Using the spatial analyst tool in Arc Map and raster calculator functions, the final pollution potential map is created. According to the flow chart, five aquifer vulnerability classes are given and are shown in Table 5.8. The higher the index value, the higher the vulnerability of the area.

Class	0-0.1	0.1-0.3	0.3-0.5	0.5-0.7	0.7-0.1
Description	Negligible	Low	Moderate	High	Very High

Table 5.8 Vulnerability scale as of GOD rating system (Foster, 1987)

The final map reveals that the study area is having two classes, moderate and high vulnerability indices. The minimum and maximum values obtained are 0.3 and 0.65 respectively. The vulnerability index shows that the management of the groundwater quality is very necessary since the values fall under moderate to high. Figure 5.10 shows the vulnerability map of the area according to GOD rating system.

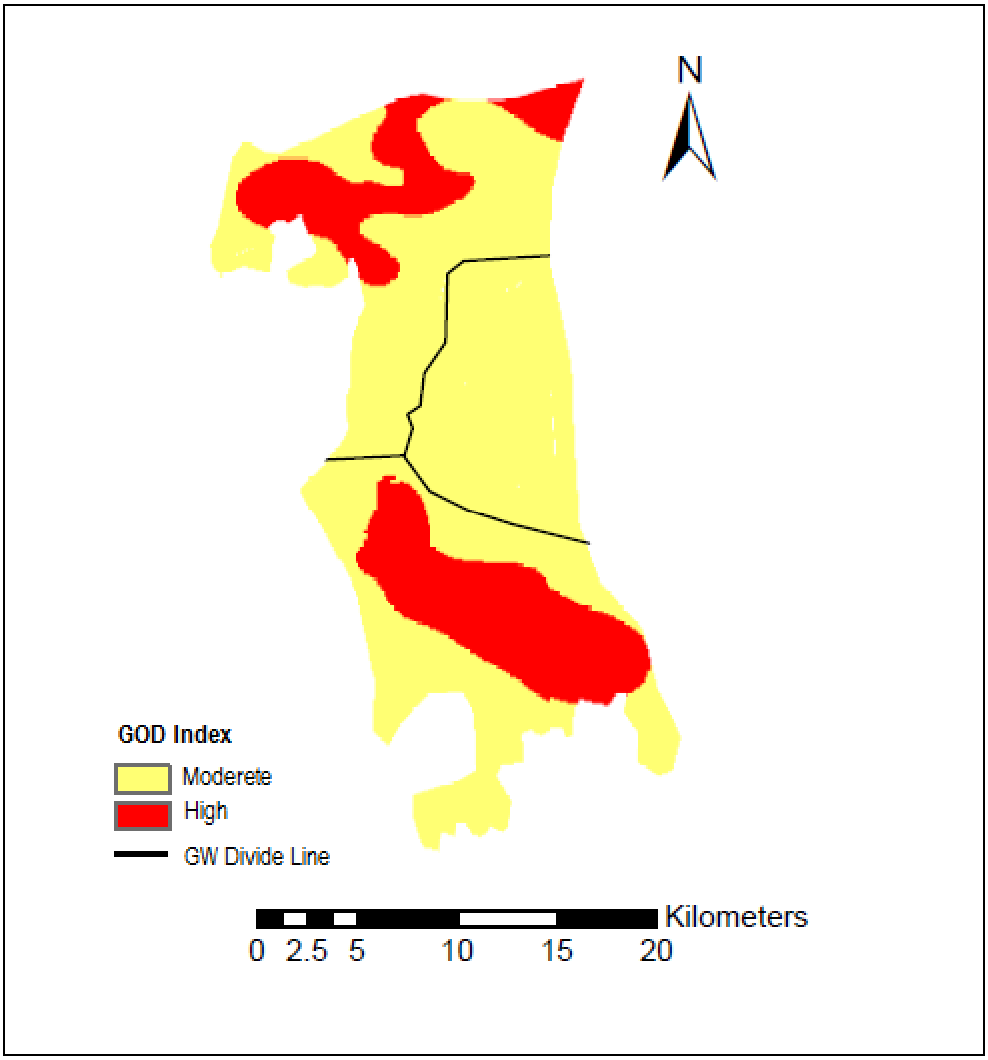

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Figure 5.10 God Vulnerability map

From the water quality index values, it is obtained that Hormat Golina has lots of areas with good water quality index than the other areas. But as we see in the above map, it has also high vulnerability index. Waja Golasha sub basin also experience high pollution risk. Attention should be given to Hormat Golina and Waja Golasha sub basins since the water quality in these areas is not yet deteriorated like that of Kobo Gerbi. In general most of the area has moderate vulnerability.

Table 5.9 below shows the area and percentage area vulnerable to pollution. 26.5 percent of the total area has high pollution vulnerability.

Condition	Area(Km^2)	Percentage (%)
Moderate	331	73.5
High	119	26.5

Table 5.9 Pollution potential percentage in the study area

5.2.4 Groundwater Potential

Groundwater potential analysis is used to assess the better aquifer sites for future water well drilling or development. In order to develop the groundwater potential map of the study area, weighted overlay analysis is used. The parameters are given weights and they are also classified in two different ranges. Then the ranges are rated up on some scales.

The parameters that are considered in determining the groundwater potential index are static water level, the aquifer thickness, the overlaying geology and the hydraulic conductivity of the aquifer. Each parameter is classified based on their effect on the groundwater availability. Then they are rated between 1-3, 1 being the worst and 3 being the best. The relative weight for each parameter is also first given based on the importance. The most important parameter has a weight of 3 and the least important one has a value of 1. These weights and ratings are obtained from literature and experts opinion on the groundwater parameters. Table 5.10 shows the weights and ratings given to the parameters. Maps of the aquifer parameters are given at Annex A.5.

The weights and the ratings given for the parameters considered in this study are shown in the following table. The ranges and weights for aquifer thickness and static water level are taken from Amah and et.al (2012). The geology rate is in compliance with the British Geological Survey: Guide to Permeability Indices given by Lewis and et.al in 2006. The Hydraulic Conductivity range is based on the Hydrogeology of Kobo valley study made by Metaferia Consulting Engineers.

<table>
<tr><th>Parameters</th><th>Weight</th><th colspan="5">Ranges and Rates</th></tr>
<tr><td rowspan="2">Geology</td><td rowspan="2">3</td><td>Range</td><td>Granite</td><td>Lacustrine</td><td>Trachite</td><td>Unconsolidated Sediment</td></tr>
<tr><td>Rate</td><td>1</td><td>1</td><td>2</td><td>3</td></tr>
<tr><td rowspan="2">Aquifer Thickness(m)</td><td rowspan="2">3</td><td>Range</td><td><20</td><td>20-50</td><td colspan="2">>50</td></tr>
<tr><td>Rate</td><td>1</td><td>2</td><td colspan="2">3</td></tr>
<tr><td rowspan="2">Hydraulic Conductivity(m/d)</td><td rowspan="2">2</td><td>Range</td><td><5</td><td>5-15</td><td colspan="2">>15</td></tr>
<tr><td>Rate</td><td>1</td><td>2</td><td colspan="2">3</td></tr>
<tr><td rowspan="2">Static water Level (m)</td><td rowspan="2">1</td><td>Range</td><td><35</td><td>35-45</td><td colspan="2">>45</td></tr>
<tr><td>Rate</td><td>3</td><td>2</td><td colspan="2">1</td></tr>
</table>

Table 5.10 Weights and rates of aquifer parameters for aquifer potential site assessment.

Figure 5.11 shows the groundwater potential map of the study area. The red colour with a value of 1 is not a good site for groundwater development in terms of getting good quantity of water. The area which is represented by number 2 is the one with a yield of moderate quantity of water. The green part of the area is the one which is good for drilling water wells or future groundwater development.

In general, from the map, Kobo Gerbi groundwater sub basin is not a good site for drilling water wells since it falls under bad to moderate in terms of the quantity of water it can give. Most of the Hormat Golina sub basin is good for groundwater development except for the few areas shown in the map. Likewise, Waja Golesha sub basin has lots of areas of aquifer with a good source of water.

Table 5.11 shows the area and the percent coverage of the individual zones (suitable, moderate and not suitable) as a good aquifer site for water well development. 73.7 percent of the total area is found to be suitable and the rest 26.3 percent of the area falls under moderate (slightly good) to not suitable for water well development.

Condition	Area(Km^2)	Percentage (%)
Suitable	332	73.7
Moderate	103	23
Not suitable	15	3.3

Table 5.11 Aquifer potential percentage in the study area

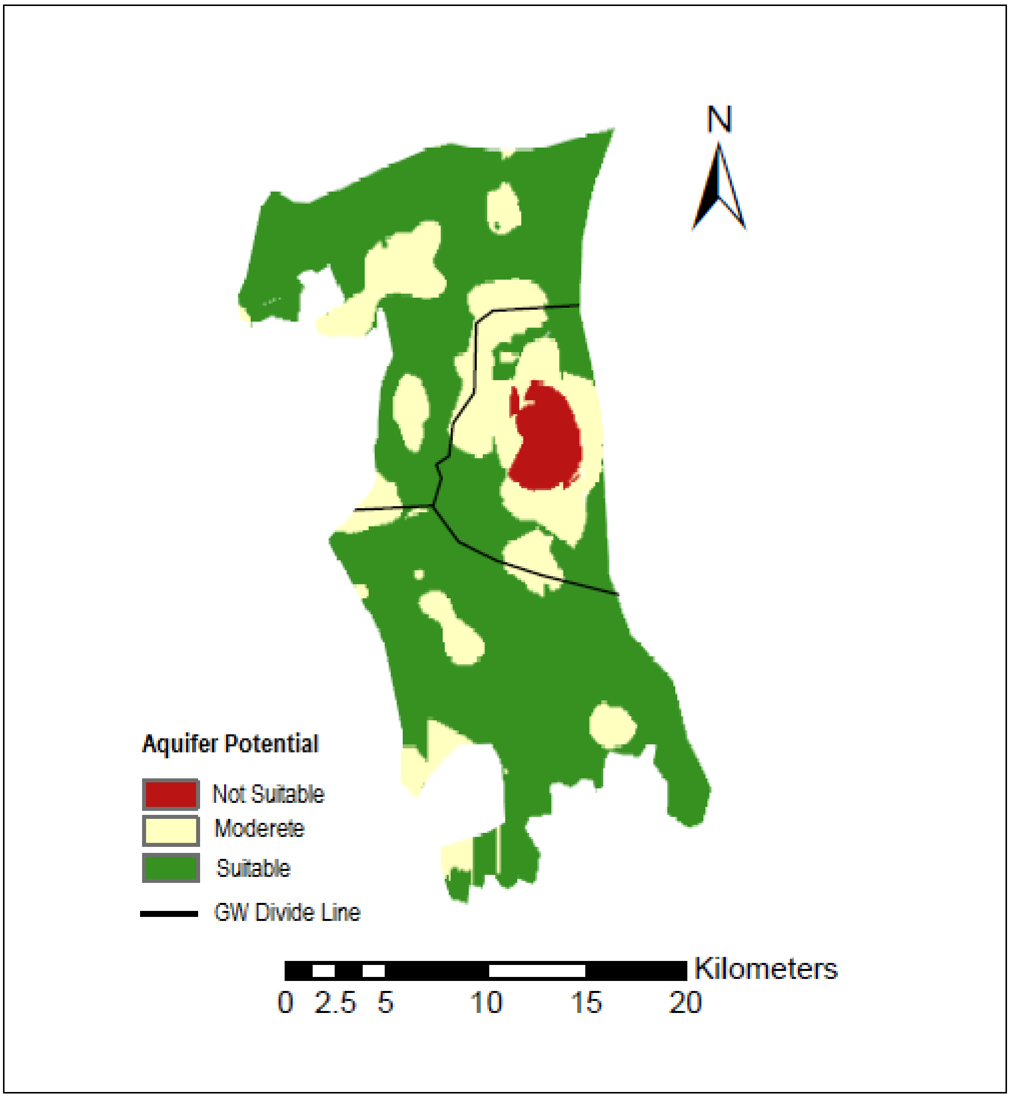

Figure 5.11 Aquifer potential map of the study area

6. Conclusions and Recommendations

6.1 Conclusion

The sustainable use of the groundwater resources in areas where the rainfall is erratic and susceptible to drought is vital. Inorder to use sustainably, the groundwater quality and the groundwater vulnerability to pollution must be known so that measures will be taken. Besides to this, it is also important to know which part of the area is good enough to yield a good quantity of water so that it will be used as a preliminary site exploration source for a hydro geologist. In this study the following conclusions are drawn:

The spatial water quality analysis of individual parameters reveals that all of them have usability ranges from safe to moderately safe except for calcium concentration which is completely safe. As of Sodium Adsorption Ratio, Chloride and Bicarbonate, the range also includes severe or increasing problems. The Water Quality Index value indicates that Kobo-Gerbi groundwater sub-basin has a severe problem as irrigation water in most of its parts. The Waja Golesha sub basin has a moderate problem. The Hormat Golena sub basin has a better water quality for irrigation purpose since it has both good and moderate classes.

The groundwater vulnerability for pollution is medium to high in the whole study area. The whole area showing medium to high vulnerability is an indication of a good warning for the wise use of the groundwater resource. Hormat Golena which has the better water quality index in most of its part is found to be highly vulnerable for pollution. Waja Golesha also shows high vulnerability. The assessment for spotting good aquifer sites implied that 73.3% of the total study area is a good potential site for future water well development. The rest 26.6% is not a target area most of which is in Kobo Gerbi sub basin.

6.2 Recommendations

Temporal groundwater depth study is used to assess whether the reserved or rechargeable groundwater storage is depleted or not. In this study area, there are very few functional groundwater monitoring wells which are not representative of the whole area and it is not possible to make geostatistical analysis like the one in this study. As a recommendation that may be applied in the future works, to assess the temporal behaviour of the groundwater depth, sufficient monitoring groundwater wells should be drilled and monitored regularly so that the temporal and spatial variability of groundwater level will be studied. In the water quality part, the areas are classified in to good or generally safe, moderate, severe or increasing problems. The planers or managers of the project should follow the FAO guidelines in order to select the crop/plant types that should and shouldn't be used under moderate or severe conditions since some plants are more resistant than the others to failure.

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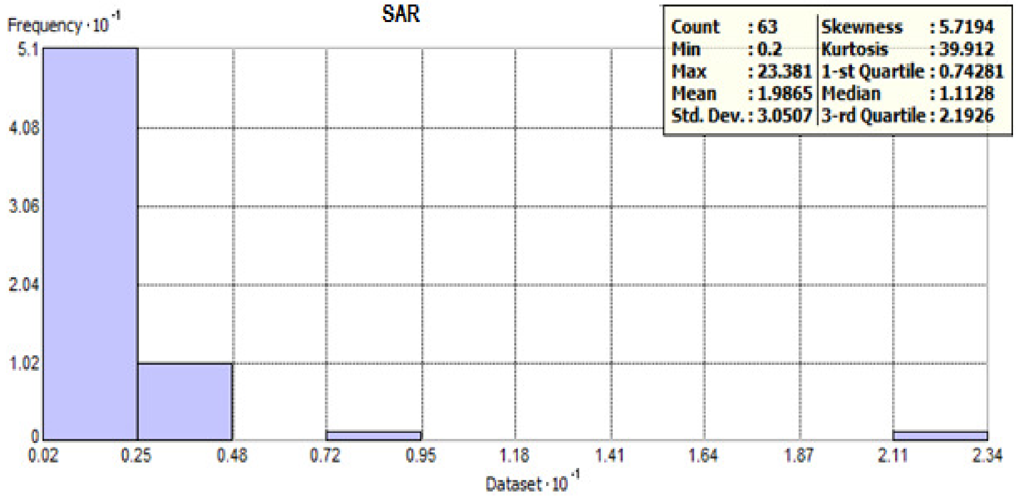
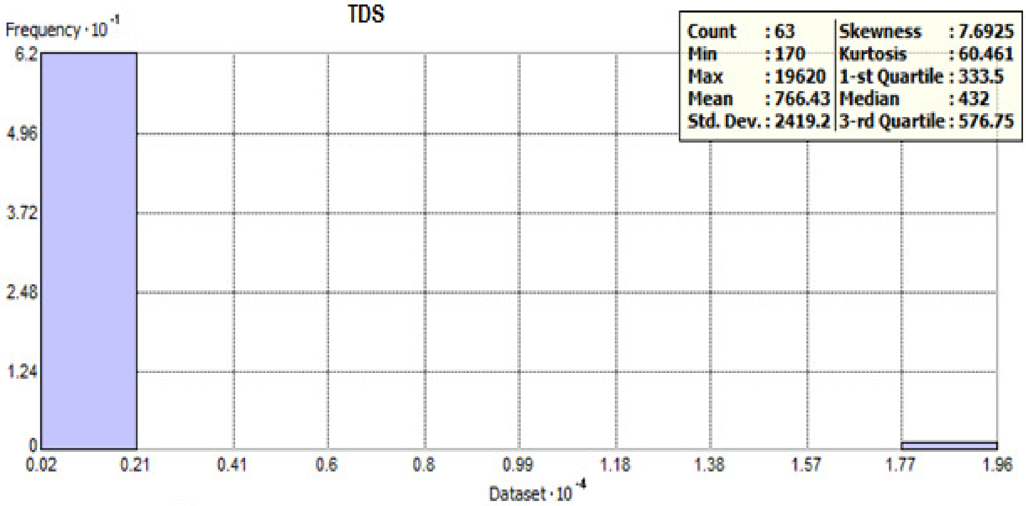
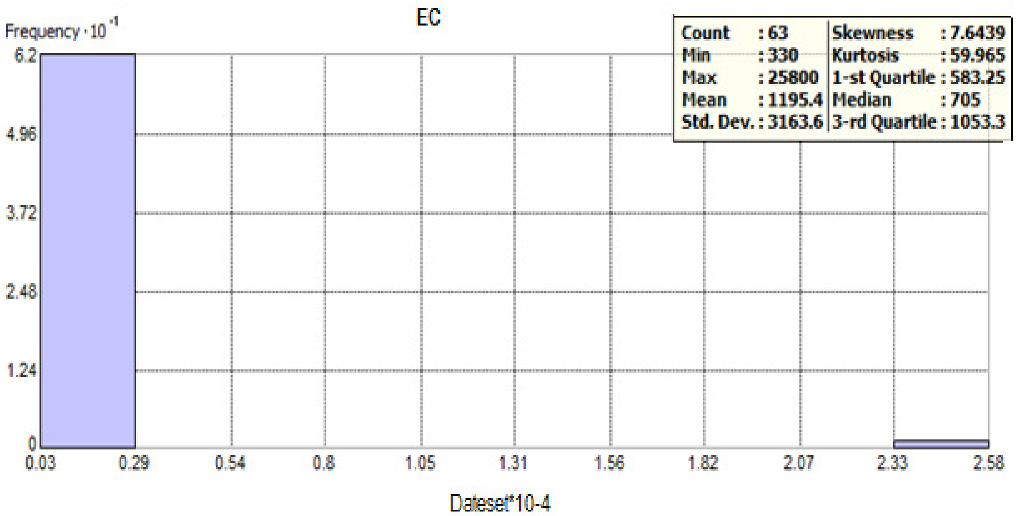
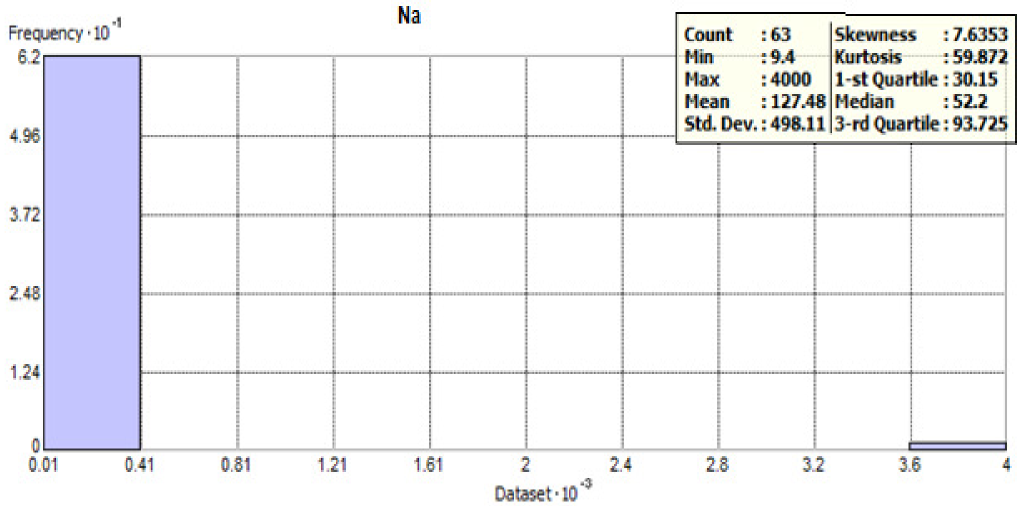
Annexes

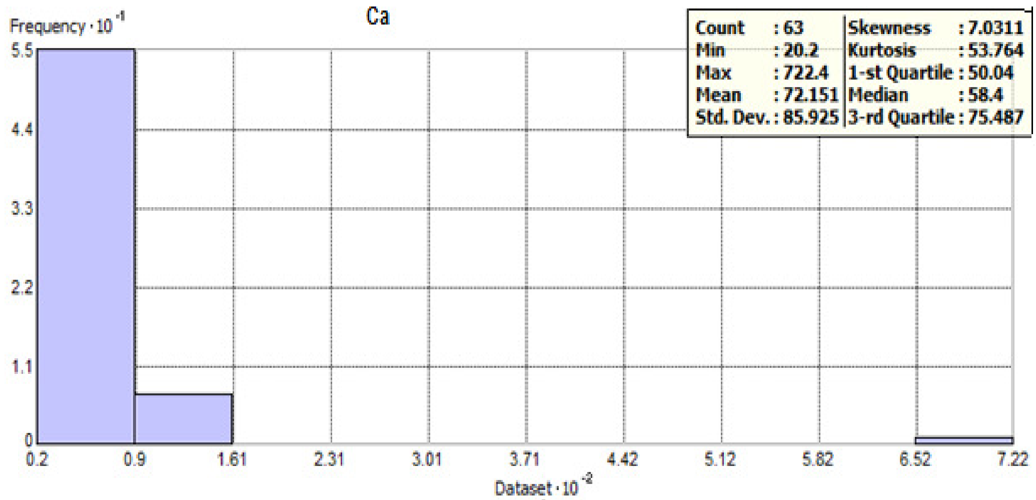
A.1 Histograms of Groundwater Parameters

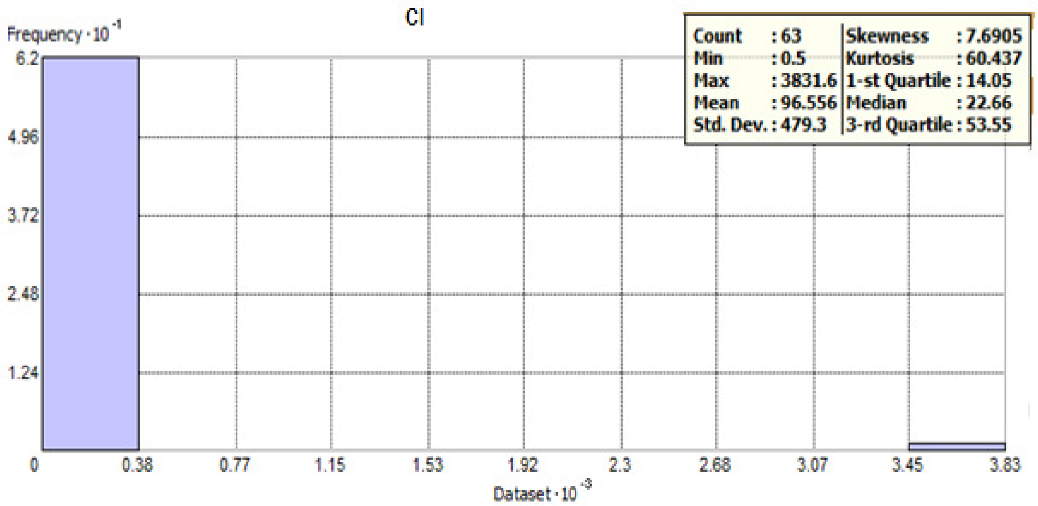


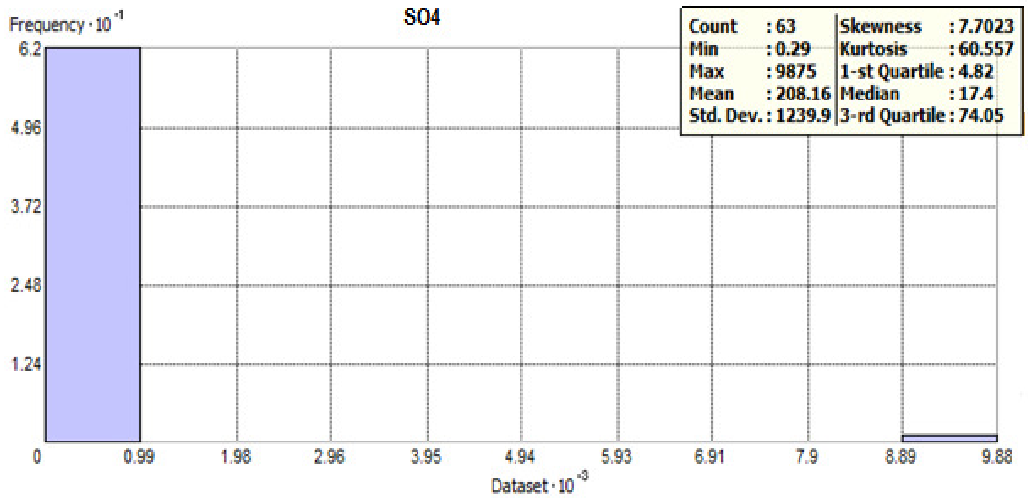


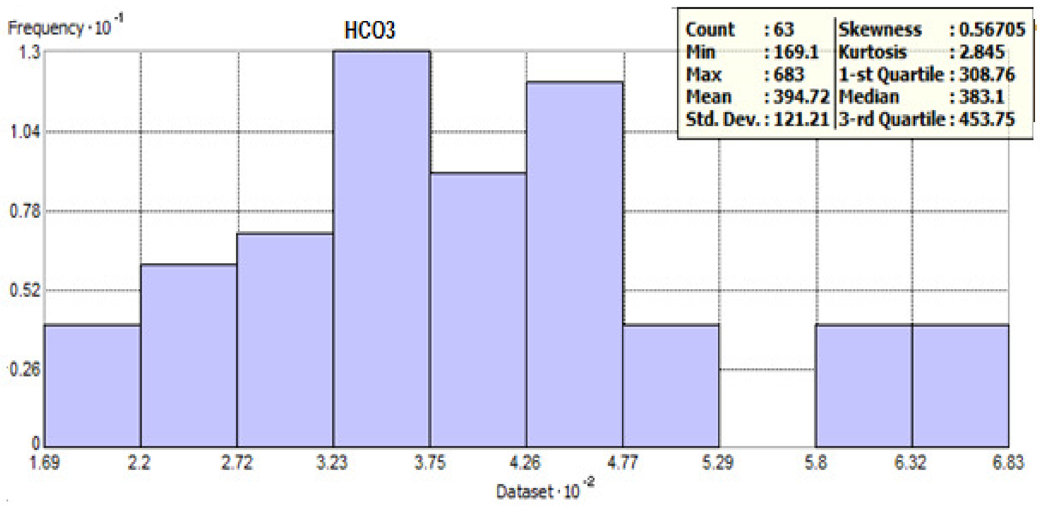



Na
Frequency · 10^-1
6.2
4.96
3.72
2.48
1.24
0
0.01 0.41 0.81 1.21 1.61 2 2.4 2.8 3.2 3.6 4
Dataset · 10^-3
Count : 63
Min : 9.4
Max : 4000
Mean : 127.48
Std. Dev. : 498.11
Skewness : 7.6353
Kurtosis : 59.872
1-st Quartile : 30.15
Median : 52.2
3-rd Quartile : 93.725

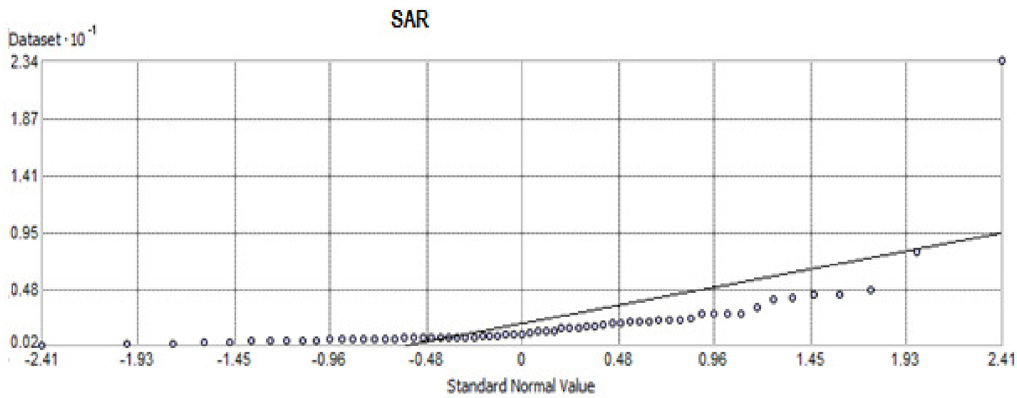

Ca
Frequency · 10^-1
5.5
4.4
3.3
2.2
1.1
0
0.2 0.9 1.61 2.31 3.01 3.71 4.42 5.12 5.82 6.52 7.22
Dataset · 10^-2
Count : 63
Min : 20.2
Max : 722.4
Mean : 72.151
Std. Dev. : 85.925
Skewness : 7.0311
Kurtosis : 53.764
1-st Quartile : 50.04
Median : 58.4
3-rd Quartile : 75.487

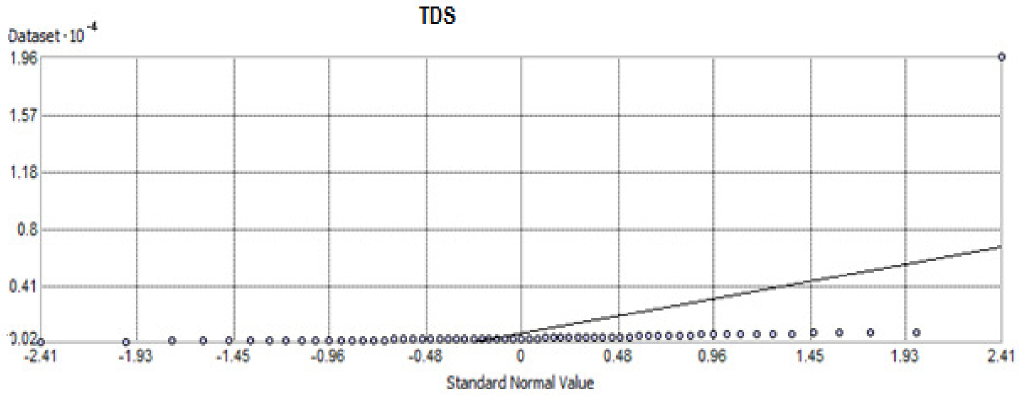

Cl
Frequency · 10^-1
6.2
4.96
3.72
2.48
1.24
0
0.38 0.77 1.15 1.53 1.92 2.3 2.68 3.07 3.45 3.83
Dataset · 10^-3
Count : 63
Min : 0.5
Max : 3831.6
Mean : 96.556
Std. Dev. : 479.3
Skewness : 7.6905
Kurtosis : 60.437
1-st Quartile : 14.05
Median : 22.66
3-rd Quartile : 53.55

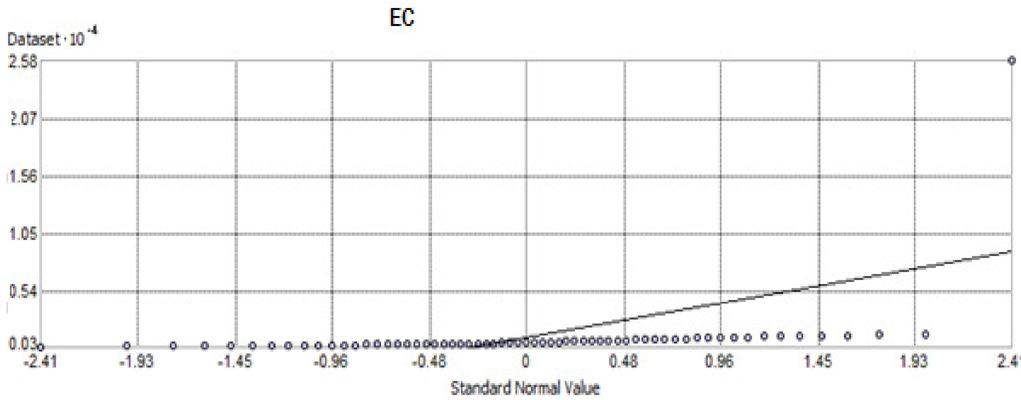


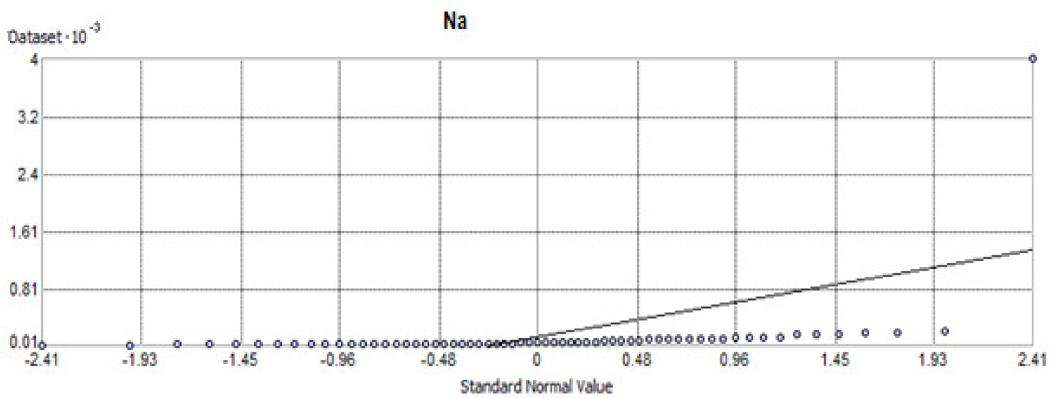


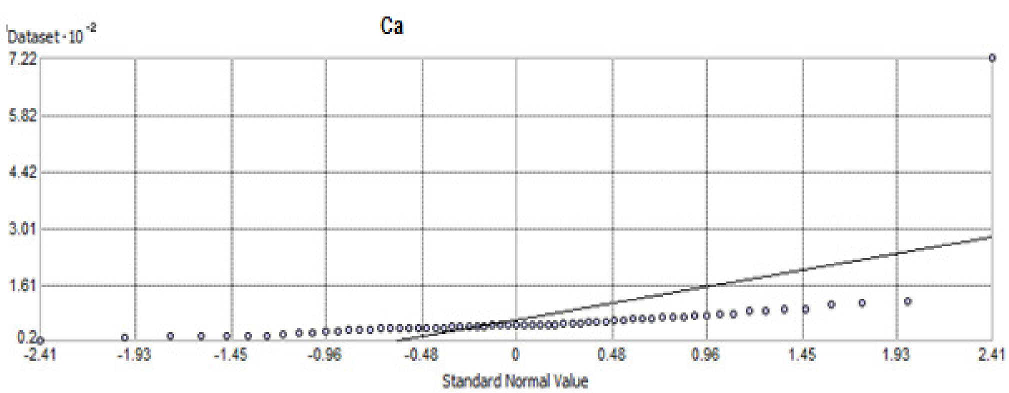
A.2 Normal QQ Plot of Groundwater Quality Parameters

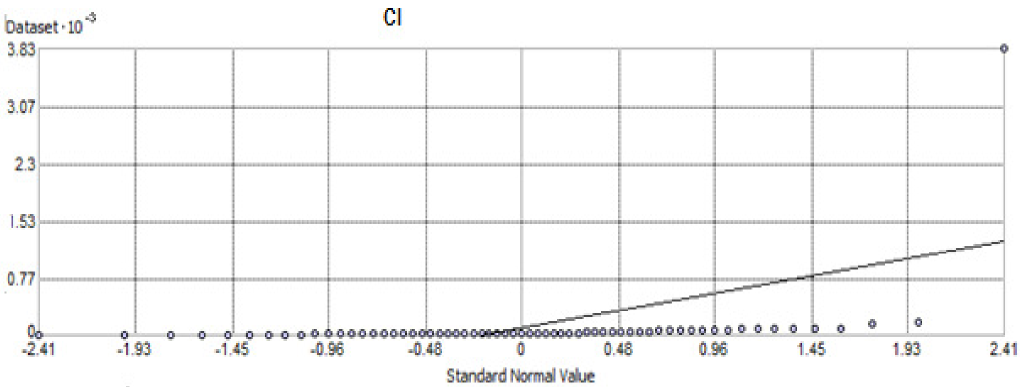


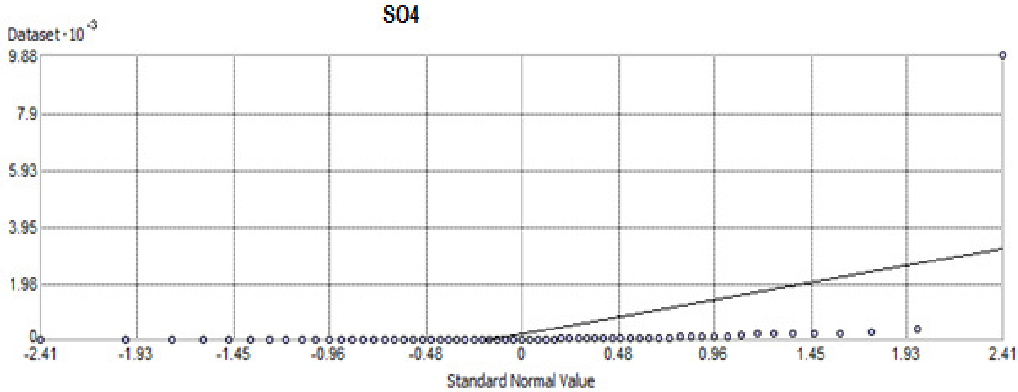

TDS
Dataset · 10^-4
1.96
1.57
1.18
0.8
0.41
0.02
-2.41
-1.93
-1.45
-0.96
-0.48
0
0.48
0.96
1.45
1.93
2.41
Standard Normal Value

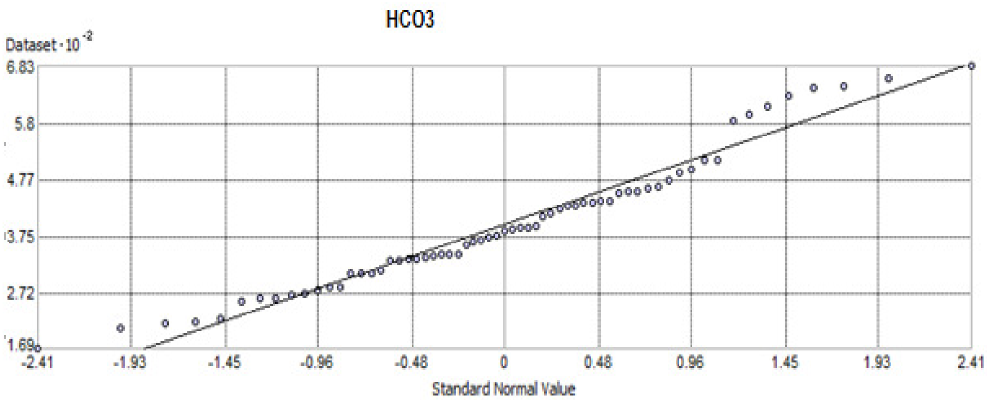

EC
Dataset · 10^-4
2.58
2.07
1.56
1.05
0.54
0.03
-2.41
-1.93
-1.45
-0.96
-0.48
0
0.48
0.96
1.45
1.93
2.41
Standard Normal Value


Na
Dataset · 10^-3
4
3.2
2.4
1.61
0.81
0.01
-2.41
-1.93
-1.45
-0.96
-0.48
0
0.48
0.96
1.45
1.93
2.41
Standard Normal Value


Ca
Dataset · 10^-2
7.22
5.82
4.42
3.01
1.61
0.2
-2.41
-1.93
-1.45
-0.96
-0.48
0
0.48
0.96
1.45
1.93
2.41
Standard Normal Value

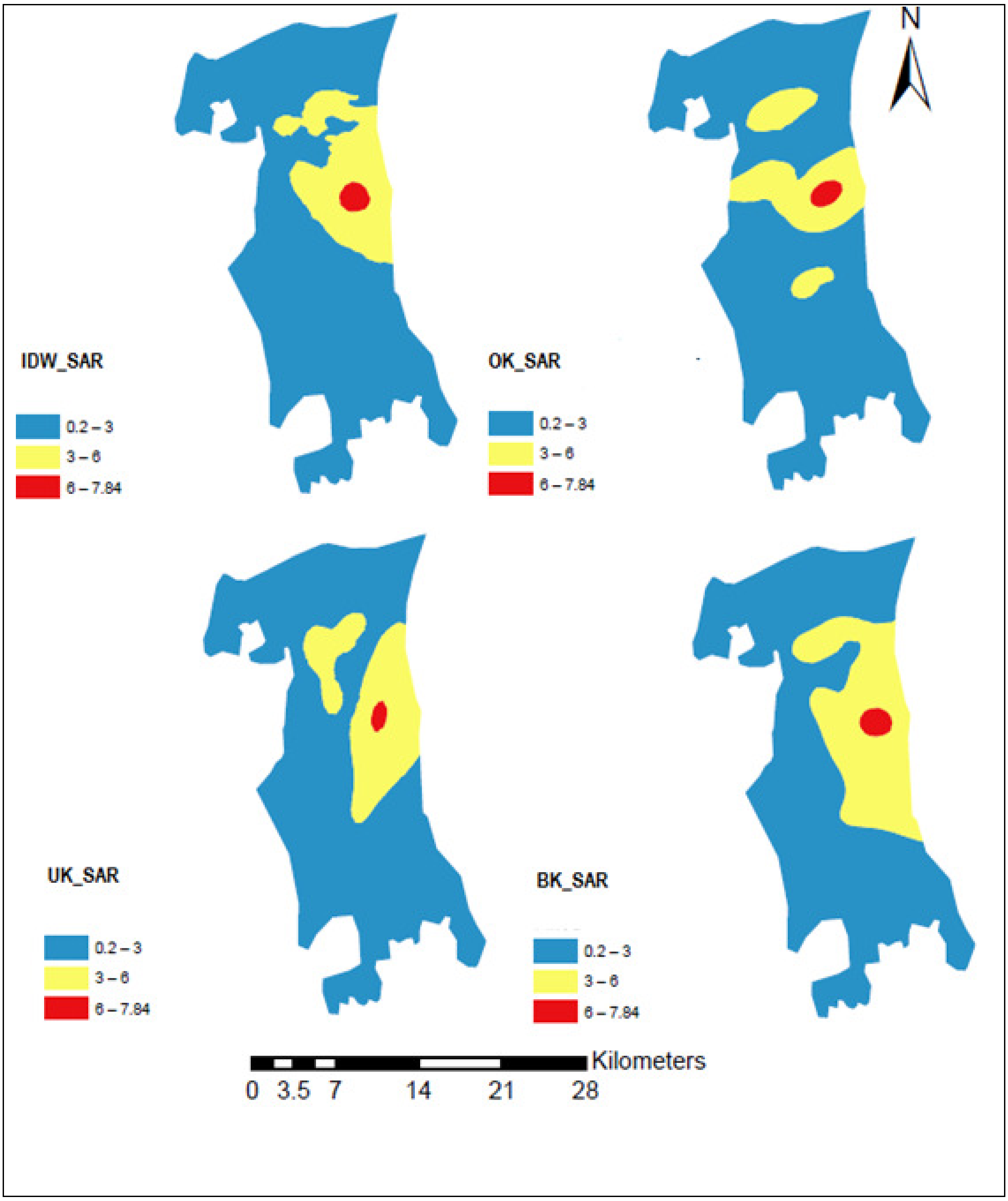

Cl
Dataset · 10^-3
3.83
3.07
2.3
1.53
0.77
0
-2.41
-1.93
-1.45
-0.96
-0.48
0
0.48
0.96
1.45
1.93
2.41
Standard Normal Value

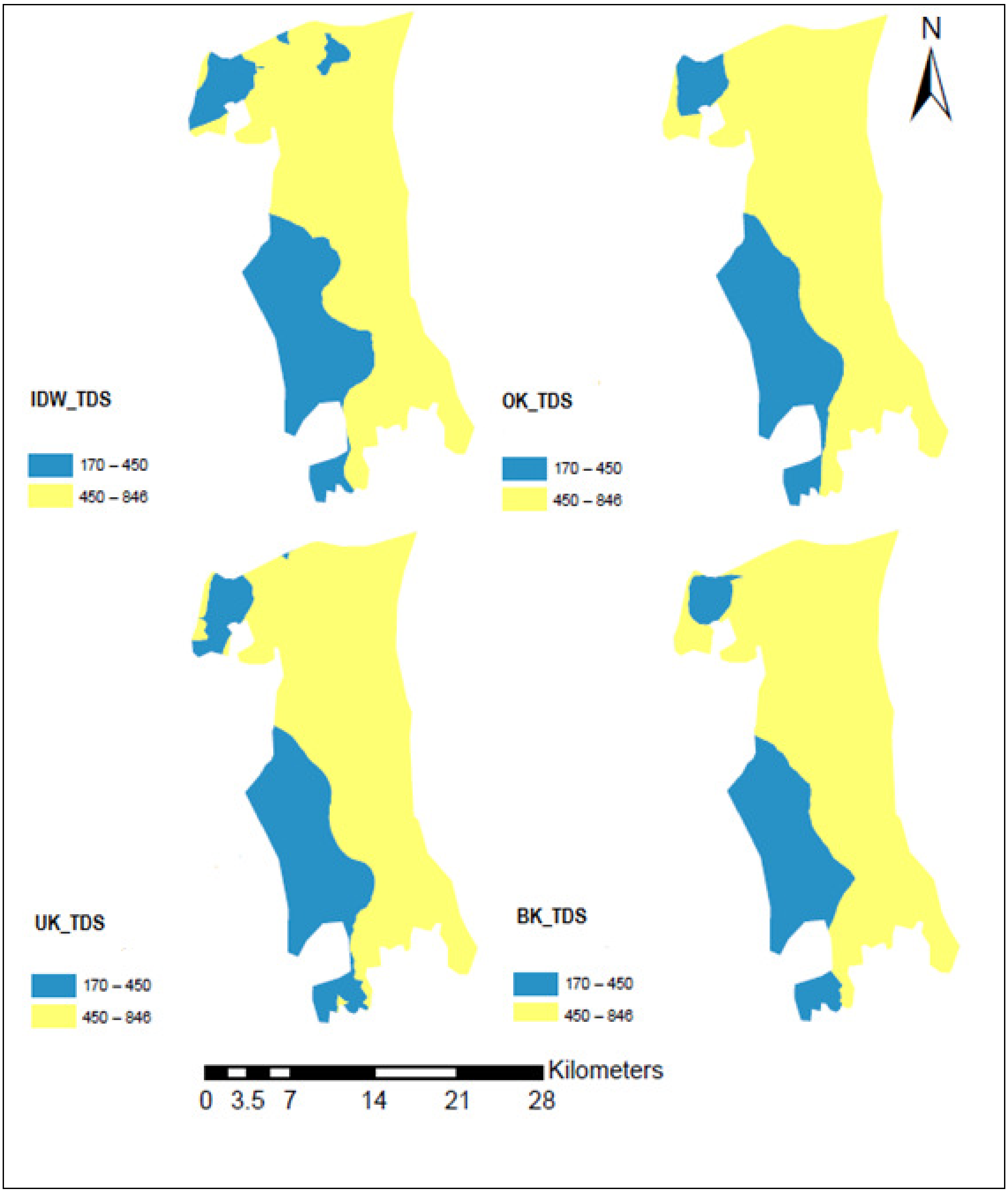

SO4
Dataset · 10^-3
9.88
7.9
5.93
3.95
1.98
0
-2.41
-1.93
-1.45
-0.96
-0.48
0
0.48
0.96
1.45
1.93
2.41
Standard Normal Value

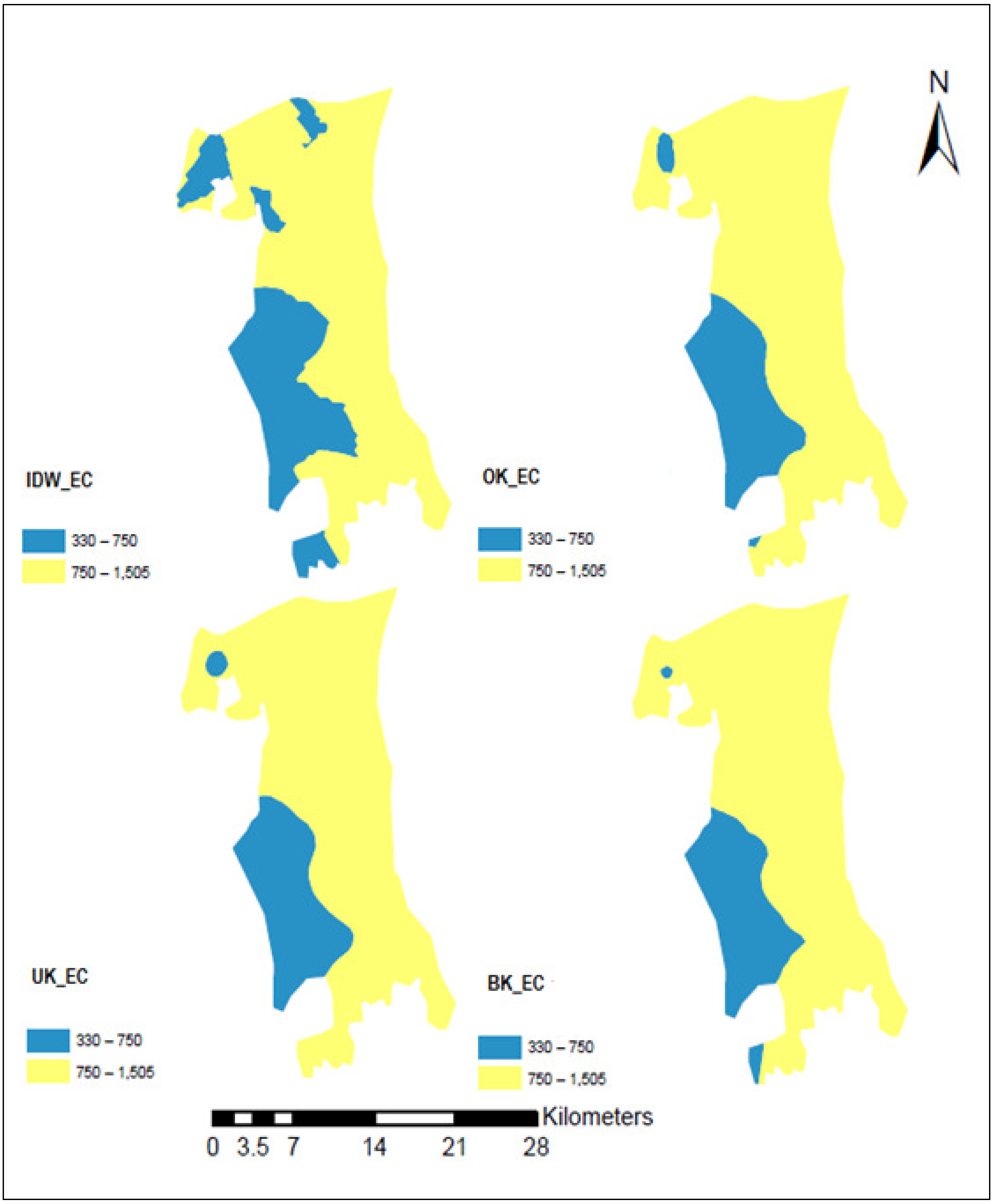

HCO3
Dataset · 10^-2
6.83
5.8
4.77
3.75
2.72
1.69
-2.41
-1.93
-1.45
-0.96
-0.48
0
0.48
0.96
1.45
1.93
2.41
Standard Normal Value

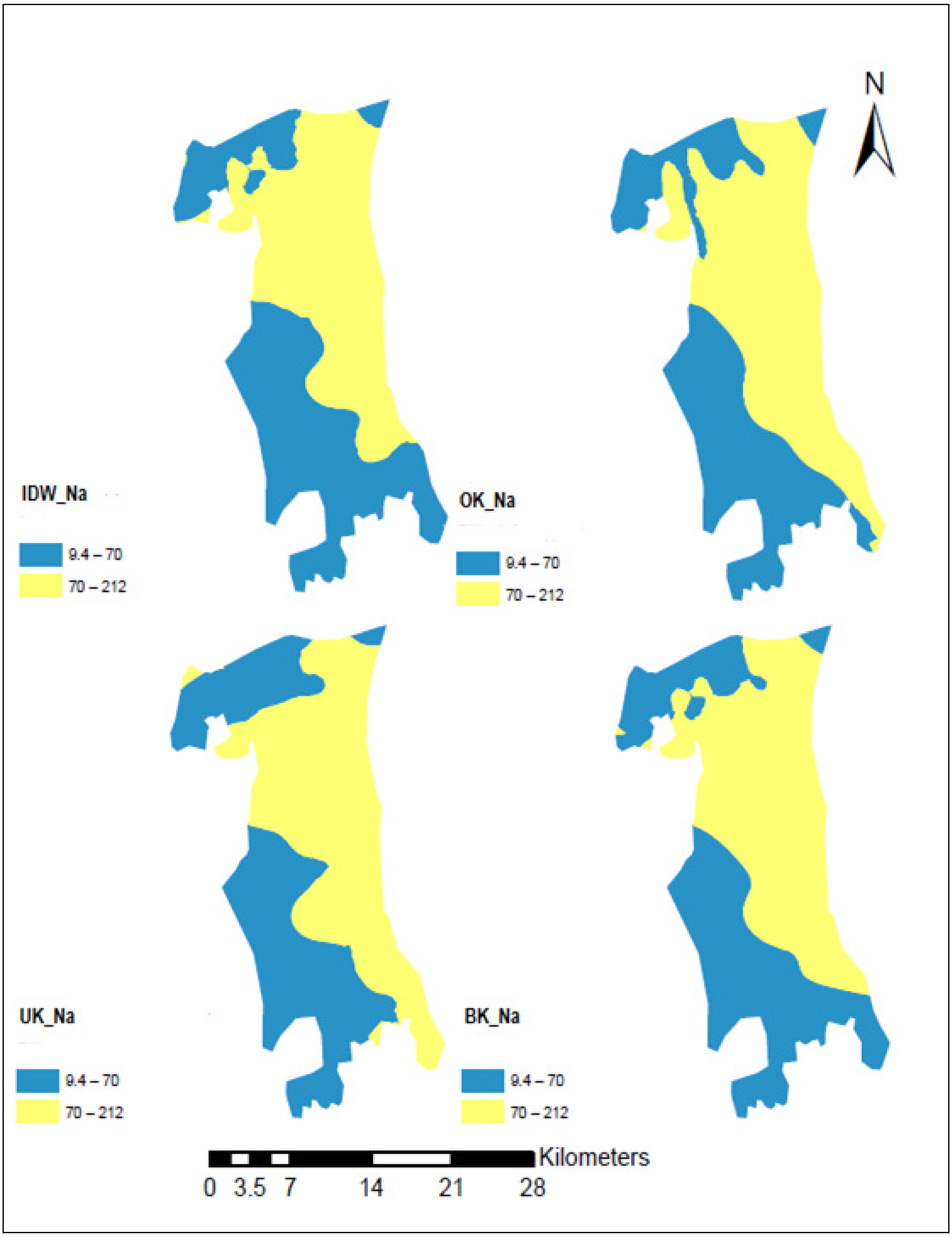
A.3 Maps generated for each prediction methods

(Values in mg/l except for EC which is meq/l)

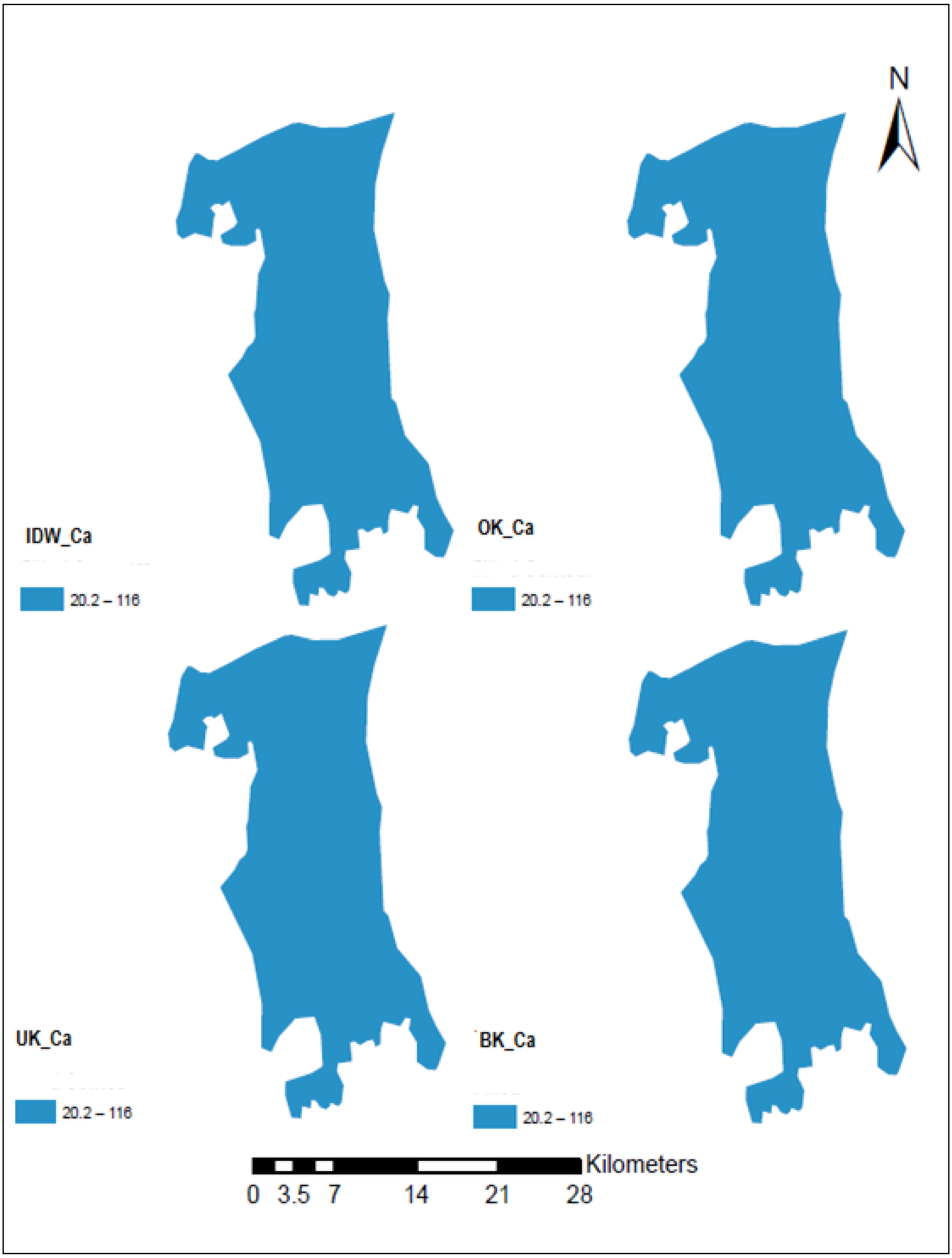



N
IDW_TDS
170 – 450
450 – 846
OK_TDS
170 – 450
450 – 846
UK_TDS
170 – 450
450 – 846
BK_TDS
170 – 450
450 – 846
Kilometers
0 3.5 7 14 21 28

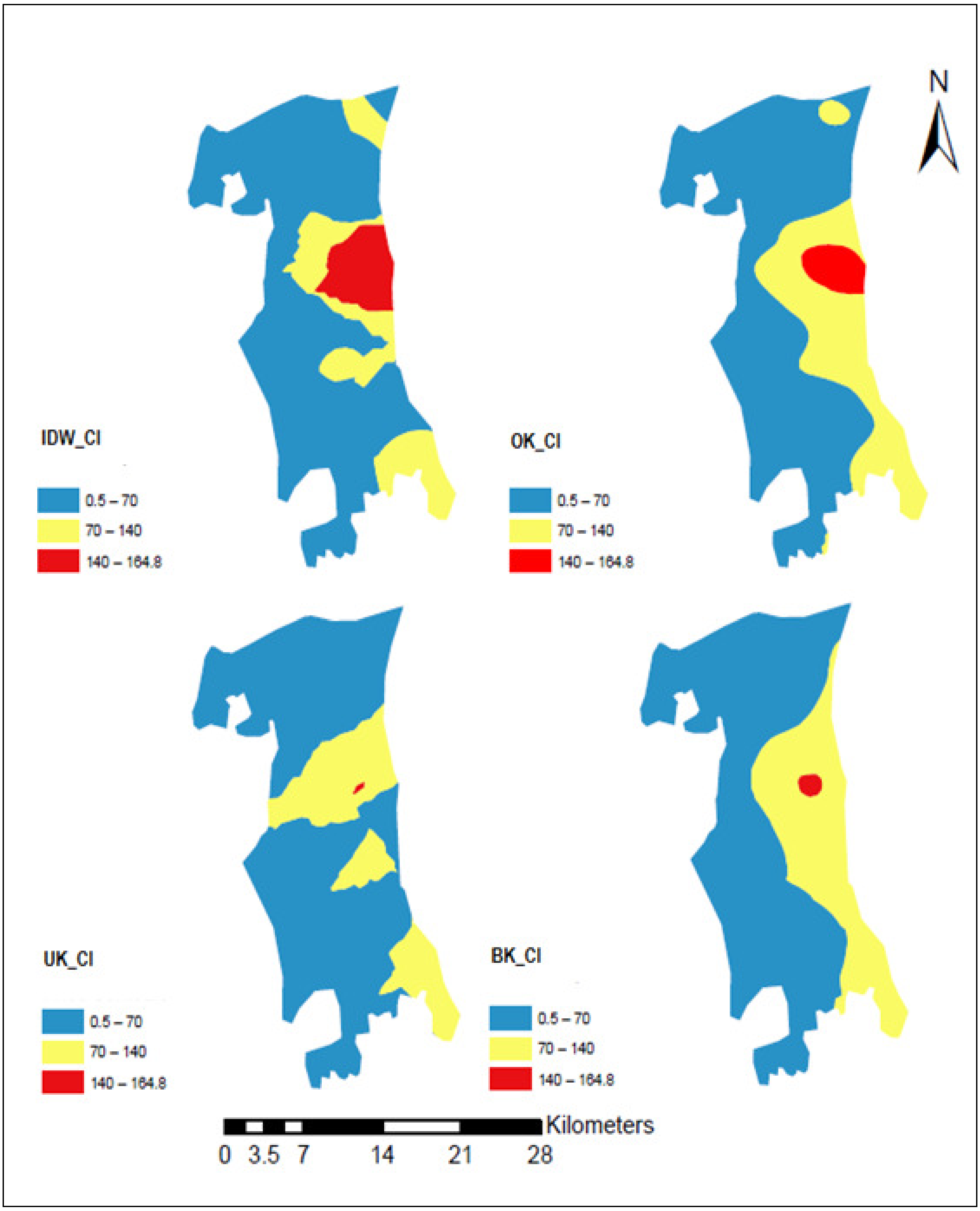

N
IDW_EC
330 – 750
750 – 1,505
OK_EC
330 – 750
750 – 1,505
UK_EC
330 – 750
750 – 1,505
BK_EC
330 – 750
750 – 1,505
Kilometers
0 3.5 7 14 21 28



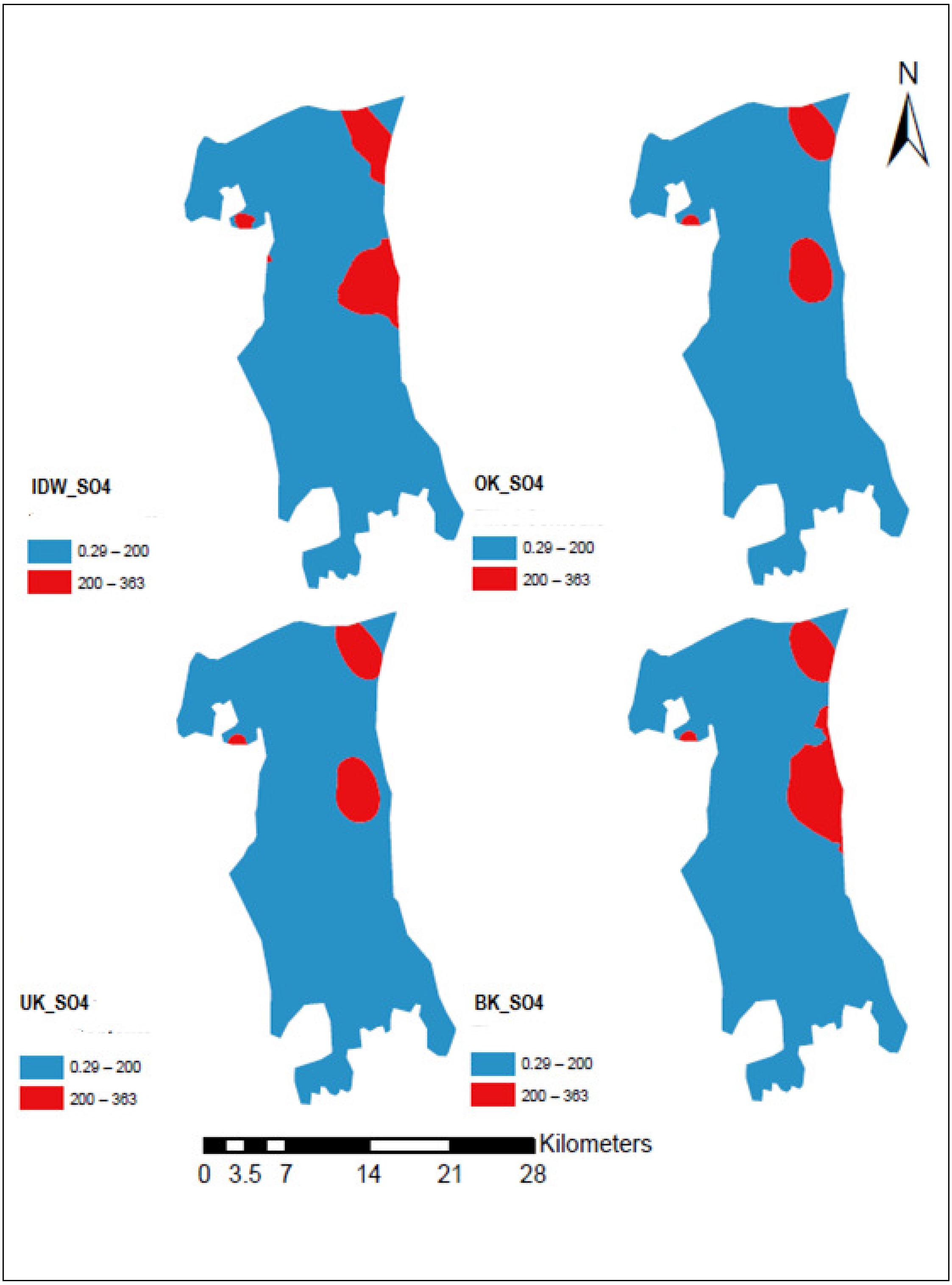
N
IDW_Na
9.4 – 70
70 – 212
OK_Na
9.4 – 70
70 – 212
UK_Na
9.4 – 70
70 – 212
BK_Na
9.4 – 70
70 – 212
Kilometers
0 3.5 7 14 21 28

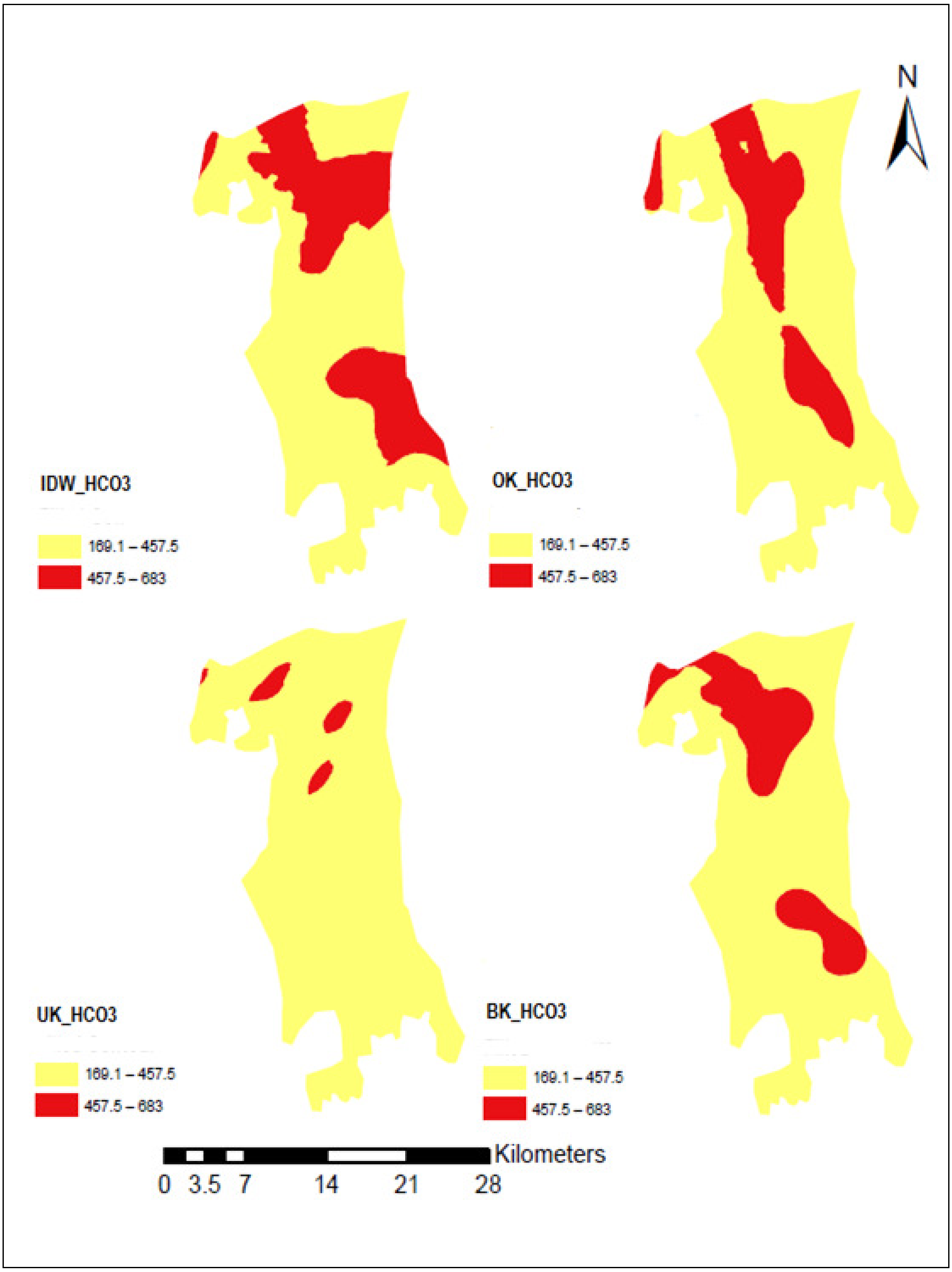


N
IDW_Ca
20.2 – 116
OK_Ca
20.2 – 116
UK_Ca
20.2 – 116
BK_Ca
20.2 – 116
Kilometers
0 3.5 7 14 21 28



N
IDW_CI
0.5 – 70
70 – 140
140 – 164.8
OK_CI
0.5 – 70
70 – 140
140 – 164.8
UK_CI
0.5 – 70
70 – 140
140 – 164.8
BK_CI
0.5 – 70
70 – 140
140 – 164.8
Kilometers
0 3.5 7 14 21 28

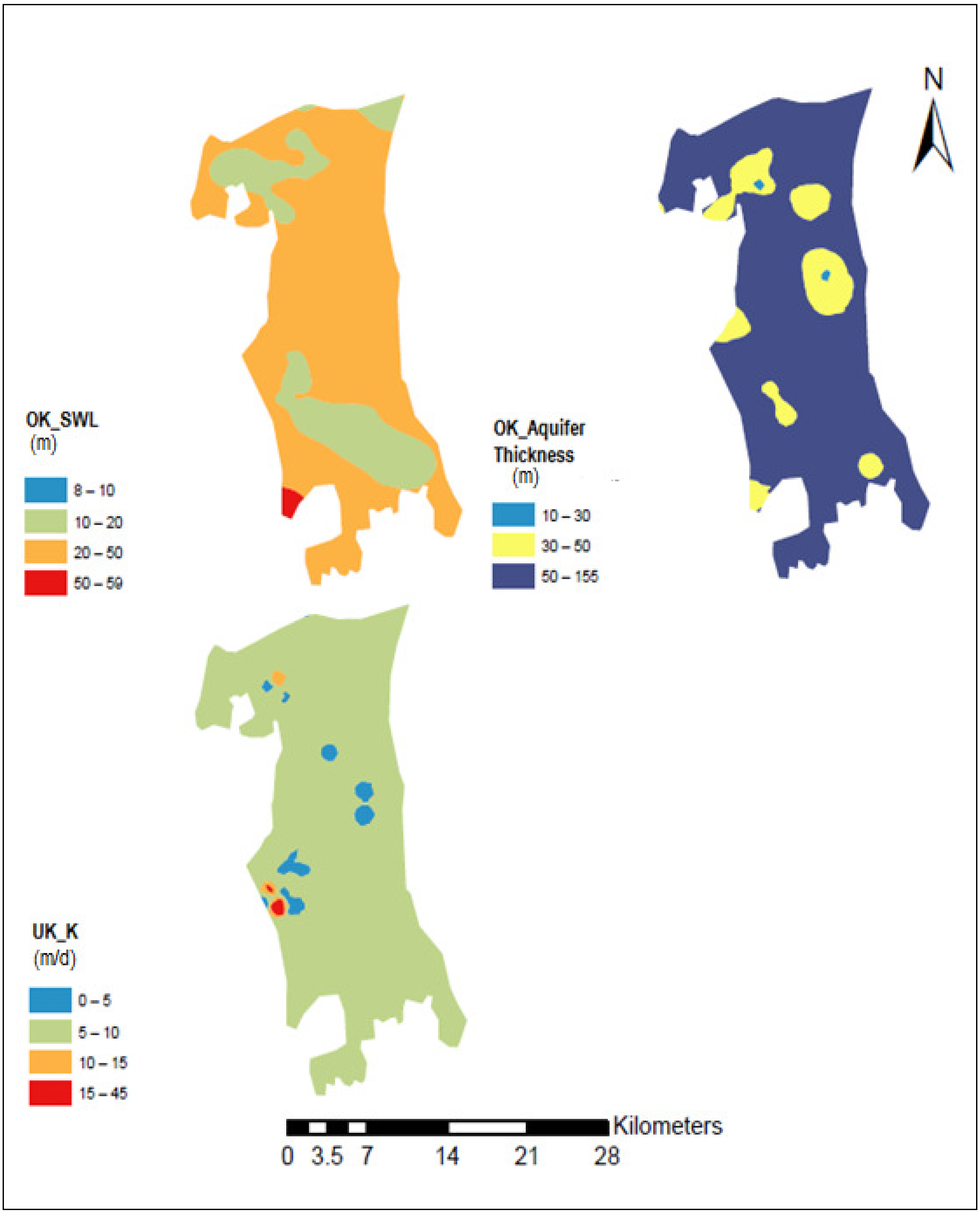

N
IDW_SO4
0.29 – 200
200 – 363
OK_SO4
0.29 – 200
200 – 363
UK_SO4
0.29 – 200
200 – 363
BK_SO4
0.29 – 200
200 – 363
Kilometers
0 3.5 7 14 21 28


N
IDW_HCO3
169.1 – 457.5
457.5 – 683
OK_HCO3
169.1 – 457.5
457.5 – 683
UK_HCO3
169.1 – 457.5
457.5 – 683
BK_HCO3
169.1 – 457.5
457.5 – 683
Kilometers
0 3.5 7 14 21 28

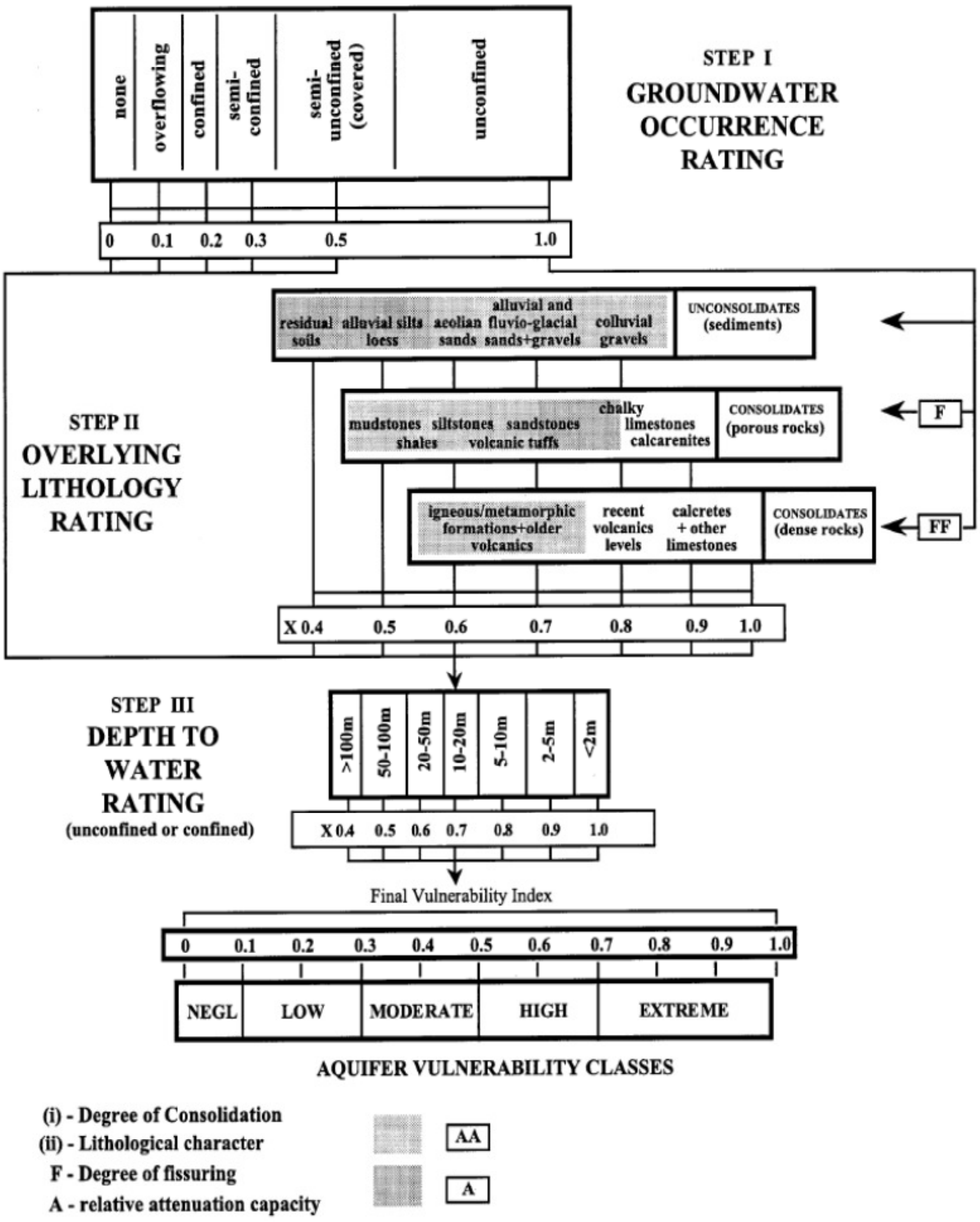
A.4 Cross Validation Results

	IDW				OK				UK				BK			
	Neigh.		Sec	ME	Neigh.		Sec	ME	Neig.		Sec	ME	Neigh.		Sec	ME
	max	Min			Max	Min			Max	Min			Max	Min		
SAR	2	1	8	0.023	25	25	1	-0.0023	25	20	8	**0.0017**	15	10	4sec45	-0.006
TDS	2	2	4 sec 45	-.0147	3	2	4sec45	-0.024	15	10	8	**-0.016**	5	1	4	-0.48
EC	2	1	1	-4.7	25	25	>>	-1.17	15	10	4sec45	**-0.073**	5	5	1	-2.56
Na	5	5	4 sec 45	.012	15	10	>>	0.00075	25	21	4	-0.021	15	10	4	**-0.0006**
Ca	15	10	>>	**.0005**	10	5	>>	0.027	25	25	8	-0.036	5	5	4	-.114
Cl	2	1	1	-0.76	25	25	8	**-0.02**	5	2	4	0.068	5	5	1	-.612
SO4	1	1	4sec45	-0.84	25	15	8	0.0089	20	14	8	**-.004**	10	5	4	0.011
HCO3	2	2	4	9.9	10	10	1	5.18	20	15	4	**0.024**	15	10	4sec45	3.05

A.5 Maps of aquifer parameters



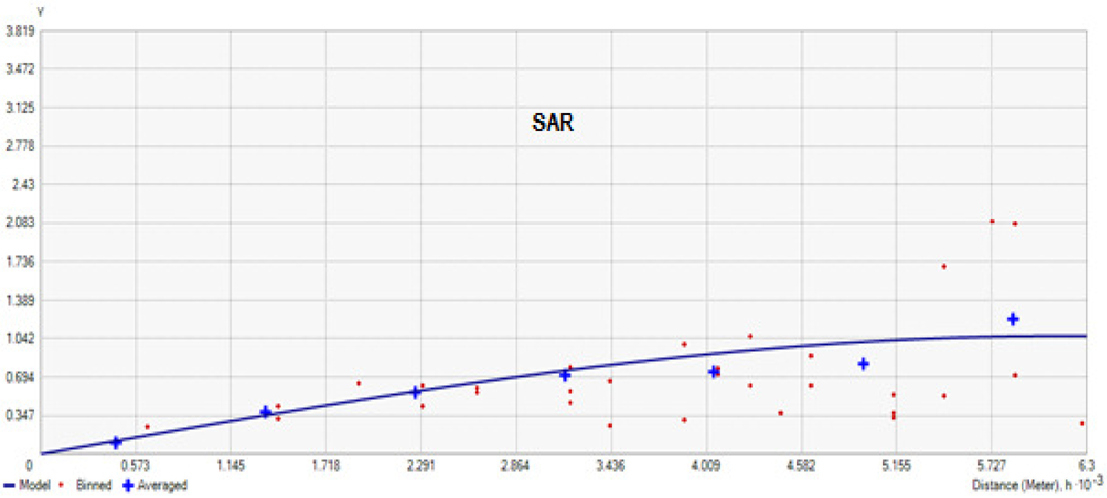
A.6 GOD Flow Chart for Vulnerability Assessment (Foster, 1987).

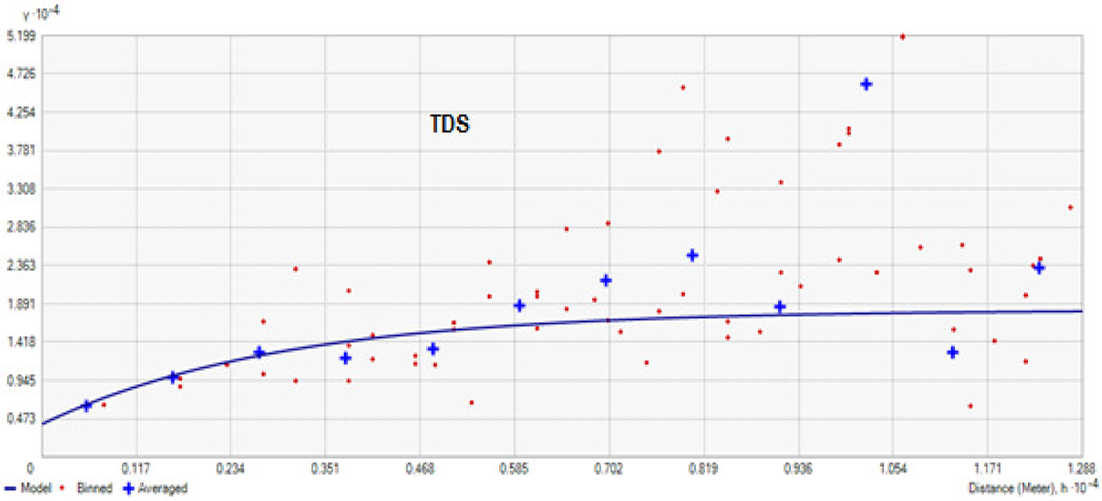


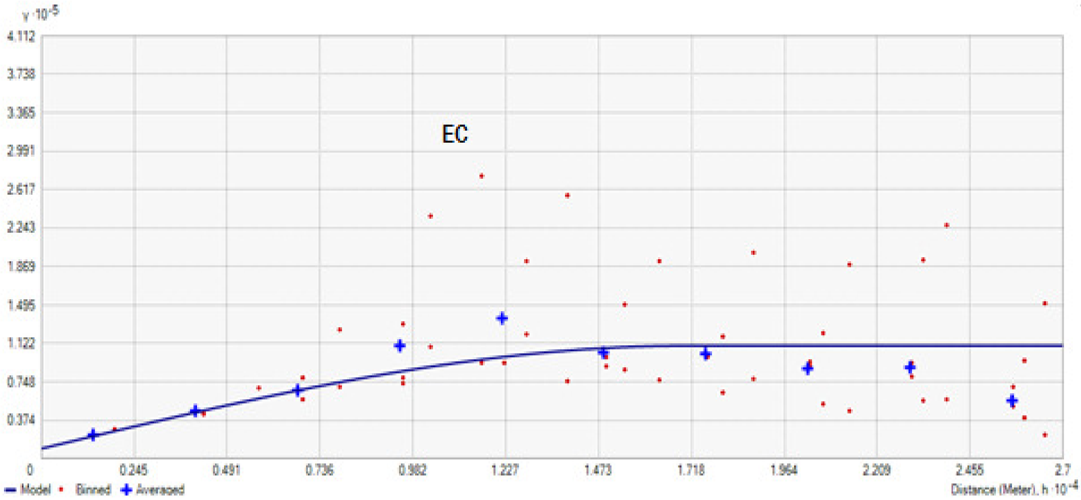
A.7 Kobo Monthly Rainfall (mm)

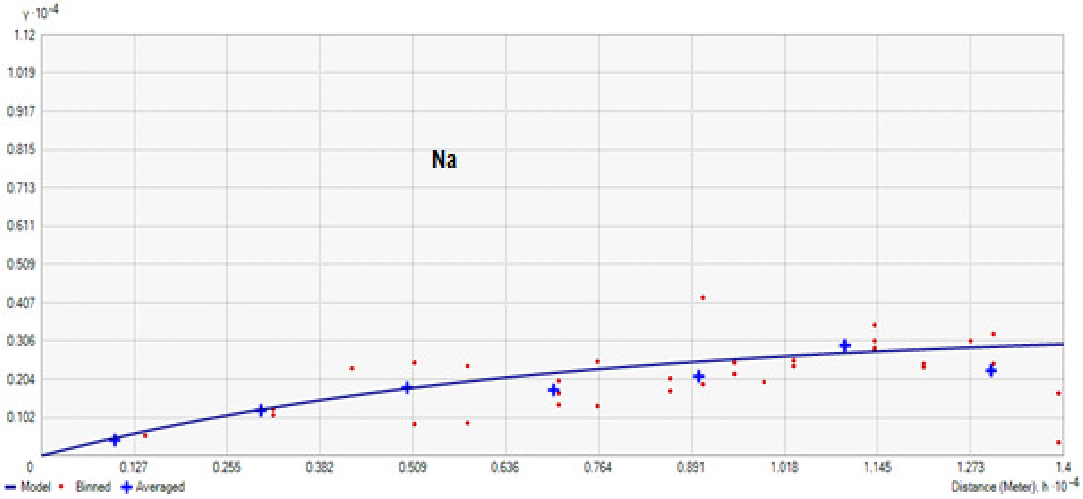
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1996	47.37	0.00	51.04	75.40	133.30	52.50	147.40	205.00	66.70	18.00	63.50	0.00
1997	0.00	0.00	42.50	57.60	47.80	51.50	110.60	94.40	37.40	169.20	49.30	0.00
1998	53.90	32.30	24.10	38.90	11.70	3.80	326.10	311.80	50.90	6.10	0.00	0.00
1999	20.30	0.00	33.50	48.20	11.70	2.20	226.30	315.90	0.00	0.00	0.00	0.00
2000	0.00	0.00	1.50	76.10	42.00	5.20	226.70	268.00	48.70	87.80	24.10	83.40
2001	0.00	0.00	70.60	13.00	27.70	8.40	187.45	220.65	30.90	9.90	5.00	1.25
2002	80.55	0.00	19.90	88.05	2.90	99.70	296.00	116.60	16.00	0.00	66.60	41.20
2003	41.20	32.70	34.80	32.80	11.00	129.30	247.50	41.80	0.00	0.00	42.80	29.90
2004	29.90	0.00	28.10	3.00	25.90	116.20	162.40	9.20	74.20	35.50	10.20	8.30
2005	8.30	0.00	34.00	125.60	2.80	125.20	190.90	23.20	8.70	64.80	0.00	0.00
Mean	28.15	6.50	34.00	55.87	31.68	59.40	212.14	160.66	33.35	39.13	26.15	16.41
St.Dev	27.46	13.70	18.53	36.82	38.92	53.83	66.43	118.47	26.83	54.72	27.08	27.74
Coef.Va	0.98	2.11	0.55	0.66	1.23	0.91	0.31	0.74	0.80	1.40	1.04	1.69
R. Coef.	0.48	0.11	0.58	0.95	0.54	1.01	3.62	2.74	0.57	0.67	0.45	0.28

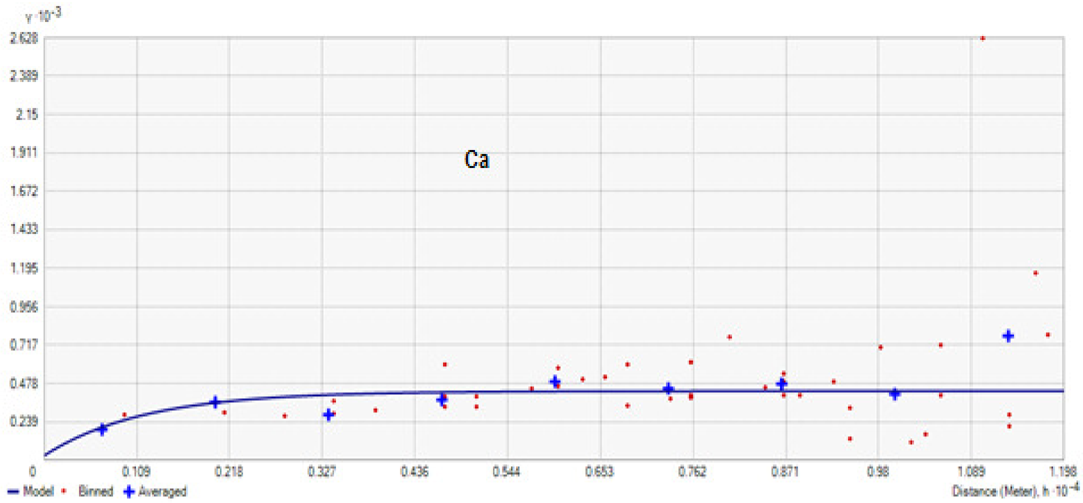
A.8 Variogram Analysis for groundwater parameters

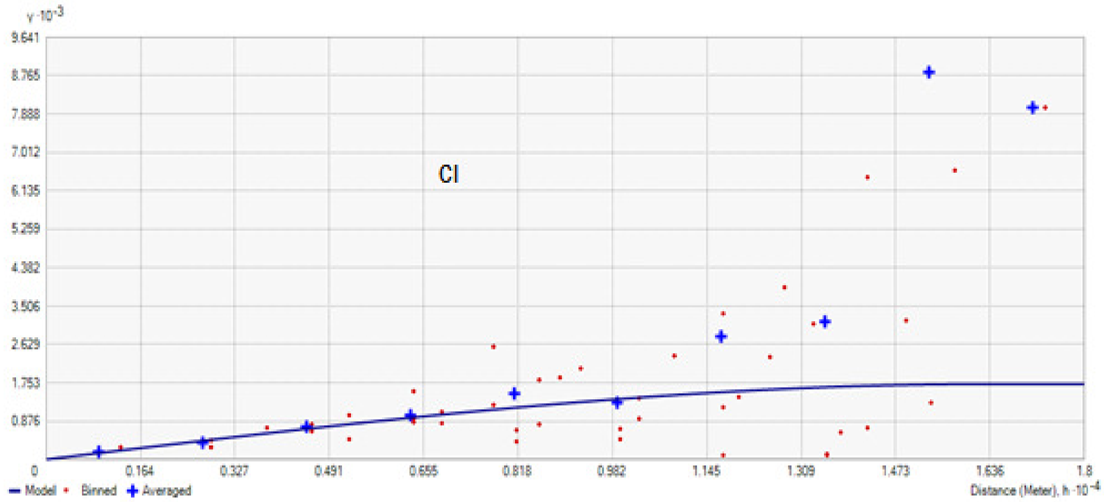


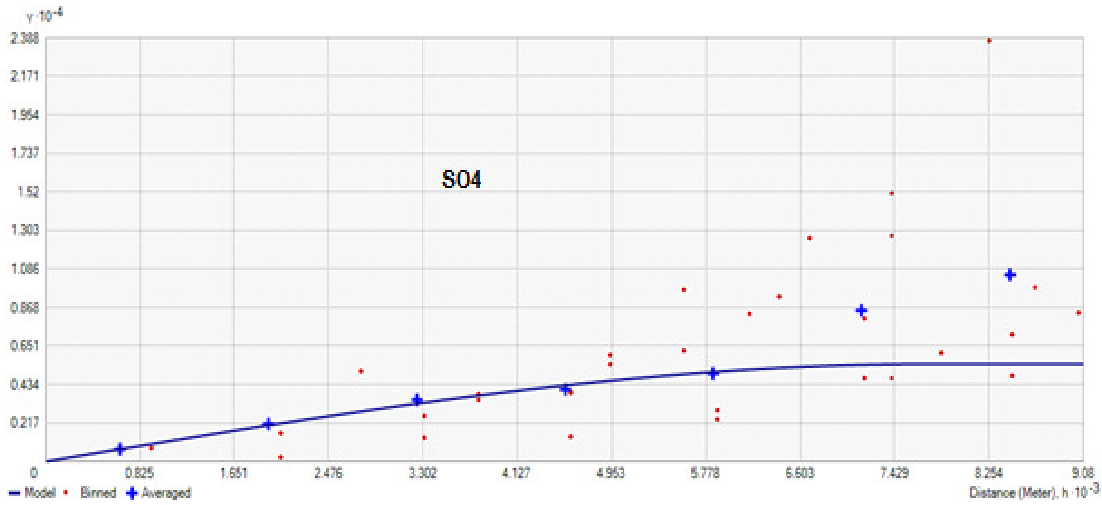


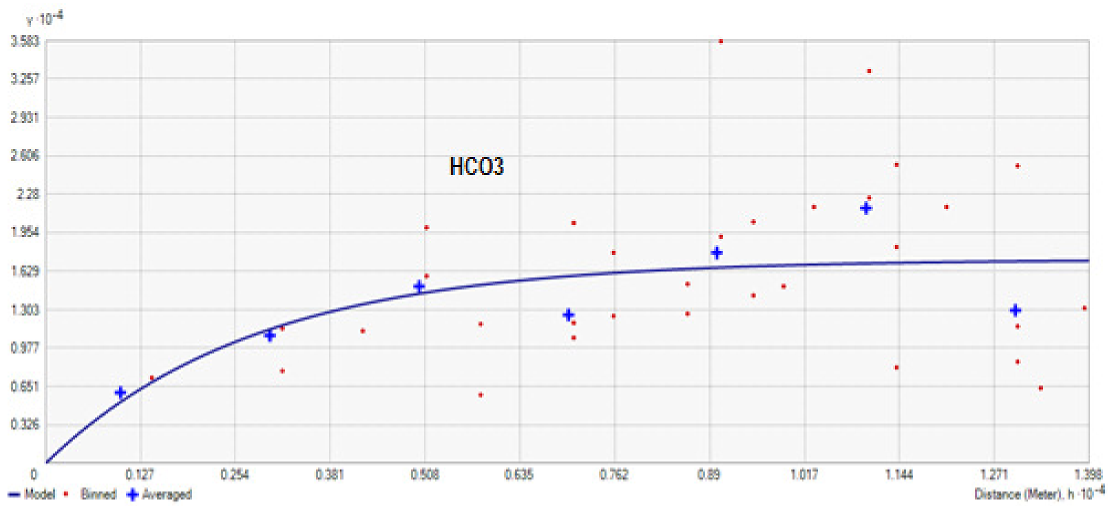

γ ·10-5
4.112
3.738
3.365
2.991
2.617
2.243
1.869
1.495
1.122
0.748
0.374
0
EC
0.245
0.491
0.736
0.982
1.227
1.473
1.718
1.964
2.209
2.455
2.7
Distance (Meter), h ·10-4
Model
Binned
Averaged

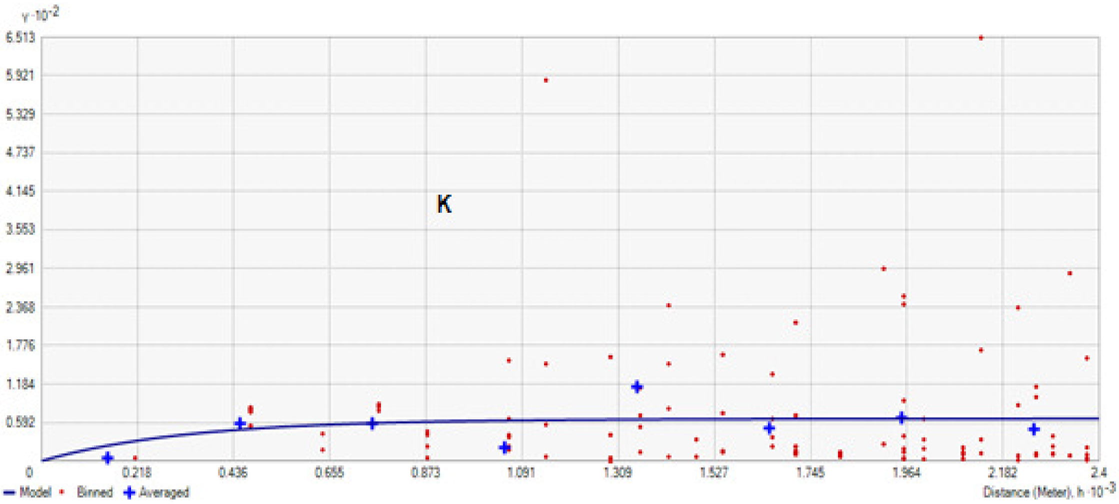

γ ·10-4
1.12
1.019
0.917
0.815
0.713
0.611
0.509
0.407
0.306
0.204
0.102
0
Na
0.127
0.255
0.382
0.509
0.636
0.764
0.891
1.018
1.145
1.273
1.4
Distance (Meter), h ·10-4
Model
Binned
Averaged


γ ·10-3
2.628
2.389
2.15
1.911
1.672
1.433
1.195
0.956
0.717
0.478
0.239
0
Ca
0.109
0.218
0.327
0.436
0.544
0.653
0.762
0.871
0.98
1.089
1.198
Distance (Meter), h ·10-4
Model
Binned
Averaged


γ ·10-3
9.641
8.765
7.888
7.012
6.135
5.259
4.382
3.506
2.629
1.753
0.876
0
Cl
0.164 0.327 0.491 0.655 0.818 0.982 1.145 1.309 1.473 1.636 1.8
Model Binned Averaged
Distance (Meter), h ·10-4


γ ·10-4
2.388
2.171
1.954
1.737
1.52
1.303
1.086
0.868
0.651
0.434
0.217
0
SO4
0.825 1.651 2.476 3.302 4.127 4.953 5.778 6.603 7.429 8.254 9.08
Model Binned Averaged
Distance (Meter), h ·10-3


γ ·10-4
3.583
3.257
2.931
2.606
2.28
1.954
1.629
1.303
0.977
0.651
0.326
0
HCO3
0.127 0.254 0.381 0.508 0.635 0.762 0.89 1.017 1.144 1.271 1.398
Model Binned Averaged
Distance (Meter), h ·10-4



γ ·10⁻²
6.513
5.921
5.329
4.737
4.145
3.553
2.961
2.368
1.776
1.184
0.592
0
K
0.218
0.436
0.655
0.873
1.091
1.309
1.527
1.745
1.964
2.182
2.4
Model
Binned
Averaged
Distance (Meter), h ·10⁻³

A.9 Water Quality Data

Well_ID	X	Y	SAR	TDS	Ec	Na	Ca	Cl	SO4	HCO3
K1	563441	1355529	0.90	302	583	34	54.4	11	4	383.1
K11	573041	1358438	2.32	383	735	77.9	48.8	43.6	75	335
K12	575819	1359490	3.26	796	1462	158	63	89	363	372
K14	569309	1352716	4.32	529	992	130	32	21	16	488
K15	573284	1354016	4.29	712	1315	186	98	84	96	641.7
K16	573112	1354230	4.71	366	705	180	28.9	28.3	90	658.8
K17	573568	1353279	2.25	483	910	95	83	0	98	463.6
K2	566912	1357164	1.32	444	842	52.2	58	24	10	409.9
K20	564878	1351600	2.13	593	1105	98	76	52.5	198	390.4
K21	565141	1352000	1.73	662	1226	80	50	54	208	390
K23	566168	1352156	2.74	597	1112	120	71.2	41	208	422
K24	567382	1349855	2.75	625	1161	112	80.8	71	218	268.4
K25	571524	1349005	4.09	683	1264	170	87.2	77	84	629.5
K26	572125	1350173	1.95	820	1505	101	100	91.1	196	512.4
K27	573429	1348241	2.75	687	1270	117	50.5	152.4	153	280.6
K3	566038	1356087	2.43	447	848	92	57.6	36	21	475.8
K34	568463	1339475	0.89	247	477	27.8	54	12	8	253.8
K35	573391	1339426	3.90	718	1325	165.6	96	86	40	646.6
K37	566652	1338642	0.00	229	444	32	52.8	14.2	0	217.2
K38	568228	1336496	0.27	294	567	9.4	58.4	14	2	261
K40	568020	1335266	0.88	222	430	25.3	50.4	13	5	206
K43	574975	1334515	0.30	311	599	10.58	60.8	18	10	266
K46	574378	1331442	0.50	463	875	20.7	80	39	20	341.6
K47	568097	1327741	0.66	321	618	23.5	58.4	45	15	222
K6	567728	1356859	2.14	565	1056	106	79.6	41	38	683
K7	560810	1356844	1.63	539	1010	77.3	65.6	38	31	610
K8	568966	1357323	1.59	390	746	57	33	11	6	415
K9	571353	1357238	2.21	372	716	74.3	37.6	27	23	365
'HG,DW1	568072	1342974	0.55	243	470	20.7	55.5	12.4	8.6	259.3
'HG,RW8	567458	1334169	0.67	170	330	21.6	42.1	15.2	6.7	213.5
'HG,SP1'	577035	1334796	1.83	573	1070	94.3	38.3	59.9	50.9	594.2
WG,SP1	577404	1360915	0.40	471	890	20.5	20.2	53.9	60.5	389.9
WG,SP2	563009	1355579	0.70	332	640	30.6	73.9	23	12.5	307.5
HG11	571055	1335915	0.84	352	542	31	46.3	8.64	4.4	340.81
HG12	572295	1335804	1.06	378	589	39	40.05	8.64	4.4	374.66
HG13	571683	1336365	0.82	394	611	32	52.5	21.12	22	329.5
HG14	571067	1336466	0.74	410	624	29	56.1	20.2	16.5	363.38
TW1	568755	1329590	0.74	438	684	30	113.6	26.8	17.4	333.1
TW2	577087	1334495	2.05	534	826	80	92.8	25.8	40.9	450.9
TW3	579090	1332043	1.27	742	1117	60	116	92.3	71.2	435.5
WG10	568148	1354589	2.14	578	941	91	73.95	64.3	31.9	511
WG11	570347	1357013	0.86	782	1223	48	86.33	64.3	58.5	581.76
WG13	573250	1357002	0.96	520	872	43.5	77.4	22.08	93.45	453.84
WG8	567608	1356024	1.05	684	1045	53	111.3	69.12	48.95	495.1
WG9	567405	1354956	1.33	428	687	53	57.85	15.4	12.65	428.9
PHG1	567688	1338578	0.65	280	446	22	50.16	12.9	9.11	275.72
PHG2	567801	1337977	0.62	322	492	23	62.16	11.33	0.38	338.18
PHG3	568356	1337982	0.67	304	466	23	58.8	6.18	0.29	312.56
PHG4	566854	1339244	1.02	300	458	31	33.6	8.24	1.76	307.44
PK1	568066	1340931	0.56	330	503	20.5	55.44	10.3	3.62	333.06
PK2	568476	1341101	0.60	338	517	22	42	7.21	6.4	329.6
PK3	568204	1350350	1.32	516	747	55	71.4	22.66	75.39	435.54
PK4	568000	1353000	1.76	374	569	60	46.2	14.42	3.81	386.8
PK5	568427	1351843	1.57	374	584	56	51.4	21.8	29.29	341.6
PK6	569299	1341890	0.75	434	674	31.3	68.88	21.63	4.47	461.16
PK7	569892	1341651	0.86	428	656	35	67.2	15.45	1.81	438.1
PK8	569814	1341065	0.83	380	584	32	58.8	19.57	4.76	358.7
PK9	569485	1341610	0.97	432	661	40	59.64	13.39	1.05	453.47
TK1	570278	1354934	2.73	460	704	91	50.4	26.78	12.9	438.1
TK2	575113	1347150	7.84	846	1296	212	30.24	164.8	280.6	169.1
TK3	575136	1345247	23.38	19620	25800	4000	722.4	3831.6	9875	307.44
TK6	571593	1341396	1.11	308	470	32.5	33.6	20.6	4.2	281.8
TK7	569334	1341467	0.84	410	627	35	63	16.48	0.86	427.85

A.10 Aquifer Data

Well ID	X	Y	K(m/d)	Elevat(m)	Q(l/s)	T(m2/d)	SWL(m)	H(m)
TK1	570275	1355009	8.17	1418	75	457.5	19.62	55.9976
PK1	568066	1340931	3.04	1491	55	280	25.54	92.1053
PK2	568476	1341101	4.06	1488	80	341	23.56	83.9901
PK3	568204	1350350	10.58	1440	70	1172.5	30.45	110.822
PK4	568000	1353000	19.43	1436	60	1126.25	8.27	57.9645
PK5	568427	1351843	0.92	1428	30	55.2	17.08	60
TK7	569334	1341467	3.99	1475	50	486.5	14.27	121.93
PK6	569299	1341890	2.61	1481	40	198	17.52	75.8621
PK7	569892	1341651	7.41	1474	40	577.5	20.34	77.9352
PK8	569814	1341065	1.43	1469	50	168	17.98	117.483
PK9	569485	1341610	8.35	1475	50	768.5	23.85	92.0359
PHG1	567688	1338578	13.53	1487	50	1245	24.35	92.0177
PHG2	567801	1337977	44.9	1479	45	3145	18.92	70.0445
PHG3	568356	1337982	4.94	1473	50	513.5	16.63	103.947
PHG4	566854	1339244	22.75	1507	45	1411.5	27.96	62.044
TWJ2	573465	1355068	0.7	1398	15	51.9	23.11	74.1429
TWJ3	569491	1357769	6.24	1433	60	624.33	16.46	100.053
TWJ4	568854	1352624	4.45	1425	60	475.5	16.38	106.854
HG-1	568171	1339140	2.3	1480	51	225	20.59	97.8261
HG-2	569552	1339024	6.2	1461	51	433	15.1	69.8387
HG3	569659	1338130	0.84	1455	20	25.06	21	29.8333
HG4	569354	1339493	7.2	1466	51	259.2	17.55	36
HG11	571055	1335915	5.52	1437	50	230.54	14.4	41.7645
HG12	572295	1335804	5.2	1417	50	218.45	16.3	42.0096
HG13	571683	1336365	5.7	1425	50	239.62	18.26	42.0386
HG14	571067	1336466	7.58	1436	50	318.24	16.66	41.9842
Zeleke1	570187	1338097	8	1452	50	276	20.4	34.5
Zeleke2	570658	1337490	7.2	1446	50	345	19.05	47.9167
WG1	563443	1355457	8.3	1505	51	1079	13.3	130
WG2	570825	1357345	1.3	1417	40	147	18.7	113.077
WG3	567035	1355424	1.34	1453	7	40.18	13	29.9851
WG4	563723	1355956	5.28	1496	52	315.36	13.16	59.7273
WG5	568109	1356681	7.1	1444	52	372.96	19.65	52.5296
WG6	569681	1357025	5.05	1429	50	181.44	25.61	35.9287
WG7	569106	1357024	8.5	1435	50	505.96	24.43	59.5247
WG8	567608	1356024	18.99	1447	50	797.76	10.19	42.0095
WG9	567405	1354956	10.28	1446	30	432	19.15	42.0233
WG11	570347	1357013	5.42	1423	50	227.81	18.7	42.0314
WG13	573250	1357002	18.86	1399	50	790.56	20.3	41.9173
TW1	568755	1329590	9	1367	7	236	58.78	26.2222
TW3	579090	1332043	5	1375	29	140	13.3	28
BH-21	574000	1361697	3.9	1393	4.2	171	19.3	43.8462
BH-46	569953	1361441	2.7	1416	5	113	17.5	41.8519
BH-59	562048	1362061	8.3	1532	4.5	435	46.3	52.4096
K1	563441	1355529	8.3	1507	6	1079	17.3	130
K3	566038	1356087	8.3	1464	6	962.8	11.1	116
K6	567728	1356859	7.5	1448		553.3	27.2	73.7733
K10	573042	1358223	3.9	1402	4	171.3	28.8	43.9231
K12	575819	1359490	1.4	1385	2	115	25	82.1429
K 13	576572	1359860	7.3	1385		578.8	14.3	79.2877
K14	569309	1354016	9	1427	3	90.4	33.2	10.0444
K17	573568	1353279	11.7	1403	5.6	202	25.8	17.265
K19	559823	1351989	9.5	1607		234.4	36.8	24.6737
K20	564878	1351600	4.1	1517	5	169	45.6	41.2195
K23	566168	1352156	9.4	1486	2.5	301	40.5	32.0213
K26	572125	1350173	0.4	1465	3	22.3	41.5	55.75
K27	573429	1348241	0.4	1434	3	18.6	46.9	46.5
K28	565976	1343340	0.44	1560		9.7	22.9	22.0455
K30	568093	1342945	8.4	1517	5	169	54.7	20.119
k31	569814	1343472	6.5	1487	4	1007	46.7	154.923
K35	573391	1339426	0.08	1414	1	7.9	29	98.75
K37	566652	1338642	0.2	1515	2.5	7.9	35.7	39.5
K38	568228	1336496	6.7	1464	4.2	1038	22.7	154.925
K42	573764	1334973	5.3	1402	4.5	424	12.3	80