FRSAT ABDULLAH ABABAKR

GEOSTATISTICAL ANALYSIS OF GROUND WATER QAULITY (CASE STUDY ERBIL, IRAQ)

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A THESIS SUBMITTED TO THE GRADUATE SCHOOL OF APPLIED SCIENCES OF NEAR EAST UNIVERSITY

By
FRSAT ABDULLAH ABABAKR

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

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Approval of Director of Graduate School of Applied Sciences

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I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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To my family...

ABSTRACT

Assessment of groundwater quality is necessary to warranty sustainable safe use of water. A groundwater quality map serves as a deterrent mechanism which provides an insight of likely environmental health predicaments by determining if the water is safe for use in drinking, domestic, irrigation, and industrial purposes. The aim of the research is to map and evaluate the groundwater quality in Erbil City. Based on the thirteen groundwater parameters Such as Potential of Hydrogen (PH), Electrical Conductivity (E.C), Calcium, Magnesium, Turbidity, Sodium, Total Dissolved Solids, Potassium, Total Hardness, Nitrate, Chlorine, Sulfate, water quality index (WQI) was calculated for 61 wells from 2015 to 2018 for wet and dry seasons by using Horton (1965) method which was called Weight Arithmetic Water Quality Index (WAWQI), the WQI percentages for each well was calculated. After calculating the WQI in order to generate maps for the WQI parameters, geo-statistical analyst tool in geographical information system (GIS) was used, two methods have been tested then groundwater quality maps were processed to get WQI map. The methods including (Kriging, and Inverse distance weighted (IDW), for determination of the most suitable method Root Mean Square Error (RMSE) was used between the methods, from the results it can be concluded, kriging method had more considerable accuracy than IDW method. Furthermore, the kriging method increases prediction accuracy and had less RMSE. Final results show that the water quality in 2018 was decreased compare to the previous years due to the increase in the number of wells that were not very satisfactory for drinking purposes without some level of treatment. The WQI was increased from 1.64 % to 11.47%. Untreated domestic and industrial wastewater causes groundwater pollution which was the main reason for a decrease in the water quality of Erbil city. The number of population increase requires the city to be developed continuously, but a plan should be established to control the spread and hazards of pollution.

***Keywords*:** Geographical information system; geostatistics; groundwater; inverse distance weighted; water quality index; kriging

ÖZET

Yeraltı suyu kalitesi ve kontrolü suyun sürdürülebilir güvenli kullanımı için gereklidir. Bu sebeple yeraltı suyu kalite haritasının hazırlanması, suyun içme, evsel, sulama ve endüstriyel amaçlı kullanımı için güvenli olup olmadığının belirlenmesi ve olası çevresel sağlık sorunlarına karşı bir güvenlik mekanizması oluşturması açısından önemlidir. Bu araştırmanın amacı Erbil şehrindeki yeraltı suyu kalitesi haritasını çıkarmak ve değerlendirmektir. Bu amaçla bölgedeki 61 kuyuya ait on üç parametre; Hidrojen Potansiyeli (HP), Elektriksel İletkenlik (EI), Kalsiyum, Magnezyum, Bulanıklık, Sodyum, Çözünmüş Katılar, Potasyum, Toplam Sertlik, Nitrat, Klor, Sülfat, Su Kalitesi Endeksi (SKE), ilgili departmanlardan temin edilmiştir. Daha sonra Ağırlıklı Aritmetik Su Kalitesi Endeksi Yöntemi (AASKE-Horton Yöntemi) ile yağışlı ve kurak mevsimlere ait SKE yüzdeleri hesaplanmıştır. Kriging Enterpolasyon ve IDW metotları kullanılarak elde edilen sonuçlar Coğrafi Bilgi Sistemine (CBS) işlenmiştir. RSME kontrol parametresi kullanılarak elde edilen sonuçlar değerlendirilmiş ve Kriging metodunun IDW Yöntemine göre üstünlük sağladığı gözlenmiştir. Ayrıca, 2018 yılında alınan örneklerde su kalitesinin önceki yıllara göre bozulma gösterdiği gözlemlenmiştir. Bunun sebebi içme suyu olarak açılan yeni kuyuların çokluğu ve evsel ve endüstriyel atık sularının yeterli derecede arıtılamamasıdır. Sonuçlar incelendiğinde, SKE %1.64'ten %11.47' ye yükselmesi bunu desteklemektedir. Sürekli nüfus artışı dikkate alındığında su kalitesinin daha da kötüleşmesini engellemek amacıyla iyi bir planlamanın yapılması gerektiği aşikardır.

Anahtar Kelimeler: Yeraltı suyu; jeoistatistik; Coğrafi Bilgi Sistemi; kriging; ters mesafe ağırlıklı; su Kalitesi Endeksi

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LIST OF ABBREVIATIONS

ASE:	Average Standard Error
Ca^{+2}:	Calcium
EC:	Electrical Conductivity
EWD:	Erbil Water Directorate
GIS:	Geographical Information System
IDW:	Inverse Distance Weighting
K^{+1}:	Potassium
ME:	Mean Error
Mg^{+2}:	Magnesium
MSE:	Mean Square Error
Na^{+1}:	Sodium
No_3^{-1}:	Nitrate
PH:	Potential of Hydrogen
RMSE:	Root Mean Square Error
RMSS:	Root Mean Square Standardized
So_4^{-2}:	Sulfate
TDS:	Total Dissolved Solid
WAWQI:	Weight Arithmetic Water Quality Index
WHO:	World Health Organization
WQI:	Water Quality Index
W:	Well

CHAPTER 1

INTRODUCTION

1.1 Overview

There are three main sources of water through which people in Iraq get access to drinking water and these are; springs, wells, and lakes. These three sources of water can thus be said to be Iraq's surface and groundwater sources of water supply and they play an important role in the hydrologic system. Though there are many uses to which the hydrologic system can be put to, Munna (2015) outlined that it is mainly used to provide a better understanding of temporal and spatial changes associated with water movement and storage.

Meanwhile, there has been a lot of developments taking place in Erbil region which is one of the biggest provinces in Iraq after Mosul, Basra, and Bagdad. These developments started in the period 2003 and ever since that time, the city of Erbil has been undergoing through a lot of expansion and development. As it stands, the Erbil region is considered to be the fastest developing region in Northern Iraq. The major challenge is that such expansion and developments are associated with huge changes in lifestyles, high demand for recreational facilities, an increase in economic activities and high population growth. All these challenges tend to press a huge demand on the city's capacity to sustainably manage water resources and provide adequate water to people. This can be supported by similar thoughts which proved that there has been an increase in cases of ground and surface water pollution caused by untreated sewage water in Erbil.

It is in this regard that there are challenges in providing quality water to residents in Erbil. Moreover, this problem is being made worse by the fact that water supply in Erbil is mainly drawn from the Ifraz Water project and groundwater wells which all in all account for an approximated to be at least 30% of Erbil's daily water supply of 530,000 m3 (Erbil Water Directorate, n.d). However, this has resulted in an over-exploitation of aquifers and a notable daily decline in groundwater levels. As a result, it water supply problems are more likely to increase in the future as the capacity of water wells to meet rising drinking water continues to decline. Thus, a lot of work needs to be done to pump more water but this will potentially cause an increase in energy consumption and financial costs. The other significant problem that is affecting groundwater quality is wastewater. The major advantage of using groundwater is that its supply is naturally refilled through rainfall.

Any water that is found in open spaces below the earth's surface is known as groundwater. Nabi (2004) established that groundwater can be found in open spaces that are in different strata of geological materials like limestone, sandstone, silt, and sand. Toma (2006) undertook a study that supports this argument and established that much of the water supply in Erbil comes from groundwater and that there are a lot of drilled groundwater wells in Erbil. This has been of good concern because it is an important source of drinking water. Also, the water from such wells serves a lot of important uses. However, Toma (2013) contends that the composition of the recharge water tends to affect the quality of groundwater. Arguments from the study by Toma are based on ideas which state that the interaction between the soil and the water can affect the quality of water.

There are also changes in water quality that are caused when a saturated zone comes into contact with rocks and soil-gas. The use of groundwater in Northern Iraq dates back from the year 7000 B.C., and most of the springs and underground burrows which are known as Kahreez in the Kurdish language provided water for animal husbandry, irrigation, as a strategic point of advantage during the war and other uses. Though the benefits of underground water include economic and social benefits, it is important not to overlook the importance of having high water quality. This is because in some cases, high water quality is more desirable as opposed to high water quantity. Yet the quality of such water resources may be of equal importance to its quantity if not exceeding it. Having a lot of wells across the city has an important implication on the quality of waters supplied from these wells. That is, the quality of water supplied from the walls varies according to the location of the well. Some wells can have high-quality water while others can have poor quality water. Such variation in water quality can either be as a result of human activities, changes in geographical stratification caused by percolation of agricultural activities, geological formation, interacting with each other.

1.2 Water Quality Index

Abbasi and Abbasi (2012) consider the Water Quality Index (WQI) as a way that is used to generally examine the quality of water using a set of parameters and express it in an understandable manner such as numerical form like numbers. The importance of the WQI is highlighted in a study by Ewaid and Abed (2017) which established that the WQI provides a detailed analysis of water quality obtained from wells. They also further outlined that the WQI can be used to examine the impact of pollution. This is because the WQI is made up of a combination of variables and attach a numerical figure to it as a way of reflecting the quality of water. Ewaid (2016) contends that decision makers have benefited a lot from the WQI as evidenced by its uses in quite a number of instances and places such as Asian, African and European countries.

Having weighted parameters determines the extent to which that variable will affect the index. However, there has been a series of improvements made to improve the WQI by Horton (1965). The major improvements which involve the use of more weights to a parameter were done by Brown in 1970. But other improvements were also made to previous WQIs and this led to the development of indexes such as the Oregon Water Quality Index (OWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), National Sanitation Foundation Water Quality Index (NSFWQI), and Weight Arithmetic Water Quality Index (WAWQI) etc.

The main distinguishing feature between these indexes is that they vary according to the nature of water quality and the assigned weights of the selective place. Water quality indices are meant to conveniently and efficiently describe changes and patterns in water quality as well as temporal and spatial and temporal changes in water quality irrespective of the level of concentrations. The period under study is from 2015 to 2018 wet and dry seasons. This study uses WAWQI and a set of parameters that include Sulfate, Nitrate, Chlorine, Potassium, Sodium, Magnesium, Calcium, Total Hardness, Total Alkalinity, Total Dissolved Solid, Electrical Conductivity, and Potential of Hydrogen.

1.3 Geographical Information System

Spatial information on water resources is effectively analyzed and presented into a meaning form using a geo-statistical approach and Geographical Information System (GIS). The GIS has associated distribution maps that help to establish the GWQI by applying the water quality index system. Balakrishnan et al. (2013) outlined that in the examination of groundwater, the GIS is used for a lot of things such as using spatial data to estimate groundwater quality evaluation models, to model solute transport and leaching, and groundwater flow modeling, determining the extent to which the water is contaminated, for processing site inventory data, and analyzing sites to determine if they are suitable for the development of a well. Hence, this reinforces the importance of using GIS methods to test and enhance the effective use of risk evaluation programs targeted at assessing groundwater contamination risk.

A groundwater quality map serves as a deterrent mechanism which provides an insight of likely environmental health predicaments by determining if the water is safe for use either for irrigation or drinking purposes. In as much as water quantity is important, groundwater quality is correspondingly important particularly in areas that rely on groundwater as the principal source of water. This is mainly accomplished by using mapping techniques to determine the spatial changes in groundwater quality. With regards to the foregoing viewpoints on the value of GIS in groundwater quality mapping in assessing contamination levels of groundwater, this study, therefore, seeks to undertake a groundwater quality mapping in Erbil city, Iraq.

1.4 Statement of the Problem

The importance of having access to safe water is attached to a number of important social, economic and health aspects. For instance, UNICEF (2008) contends that having access to safe water is not restricted to safeguarding good health, but is also part of people's human rights. UNICEF, further states that more than hundreds of millions of people do not have access to safe water. As a result, the deterioration in water quality is one of the major environmental concerns nowadays. One of the major problems posing severe threats to people's health is the contamination of ground and surface water. Hence, there is a need to conduct water quality assessment tests especially in Erbil which uses groundwater for various uses. Another of key issues causing an increase in the demand for quality water is the increased rate of urbanization in cities which is accompanied by high population growth. In most cases, housing and planning standards in these areas are very poor. UNEP (2013) asserts that such areas are also associated with uncontrolled commercial and industrial activities and sewerage leakages which result in the contamination of groundwater. UNEP (2016) also reinforces these ideas and established that informally settled people relying on groundwater are prone to health risks as a result of an increase in groundwater contamination activities. UNICEF (2008) went on established that the annual death of 3.4 million is indorsed to poor sanitation and nonexistence of safe water. There are also concerns that more than one billion people still do not have access to clean water (UNICEF, 2016). The challenge is that it is difficult to purify groundwater once it is contaminated. In most cases, it is a daunting task to deal with the various pollutants of groundwater. Hence, researchers like Chauhan and Singh (2010) recommend that it is of paramount importance to come up with methods and ways of protecting groundwater quality.

With regards to the Erbil, the need to have the desired water quantity and quality can be met by first conducting an assessment of the condition of the water. Such an assessment will start from the source up to the final users and establish factors affecting the provision of the increased water supply of high-quality. This study will thus map the water quality in Erbil on a spatial scale by using ArcGIS software to determine the extent to which it is suitable for drinking. The established water quality results will then be examined to see if they match the World Health Organization drinking water standards.

1.5 Objectives of the Study

1.5.1 General objective

The main purpose of the study is to conduct a groundwater quality evaluation mapping of physicochemical data from wells in the city of Erbil using GIS.

1.5.2 Specific objectives

- To determine if the groundwater quality used in Erbil matches the established 2011 World Health Organization drinking water quality standards.
- To examine the temporal and spatial distribution of groundwater quality variables in relation to Sulfate (So4-2), Nitrate (No3-1), Chlorine (Cl-1), Potassium(K+1), Sodium (Na+1), Magnesium (Mg+2), Calcium (Ca+2), Total Hardness, Total Alkalinity, Total Dissolved Solid, Electrical Conductivity (E.C), Potential of Hydrogen (PH) and Potential of Hydrogen (PH).
- To develop a groundwater quality zone map for the city of Erbil.
- To develop and map each Water Quality Index (WQ) parameters.

1.6 Significance of the Study

Much of the water that is used in Erbil, Iraq is from groundwater sources and also used for various purposes. However, chances are very high that the water in these wells is more likely to vary. This is because of the differences in their geographical locations. Hence, there is a need to map both the quantity and quality of water provided by these wells. The major advantage of using results produced hazard and vulnerability maps is that they are so simple and any person can easily understand. Also, in this study, the spatial frequency of the various sound planning decisions. Physical-chemical in the groundwater will be represented with various color legends. As a result, town planners and local authorities will be in a position to use the results to make good groundwater quality management decisions. This also serves as a powerful tool which can be used to improve groundwater management and sustainability in Erbil.

1.7. Thesis Organization

The flow of the thesis is like this; Chapter 1 provides an introduction to the situation of groundwater usage, WQI, and GIS. As well as the problem statement, and has the contributions of the thesis work.

Chapter 2, is consist of a literature review of some previous studies for Iraq and other countries

Chapter 3, contains a detailed methodology on which we have worked on and the explanation of the proposed approaches. It also has the study area, hydrogeological formation, the climate of the area of study were also discussed.

In chapter 4, discussed the results of WQI for wet and dry seasons separately and generated map for all parameters of WQI. As well as compare the methods used for the mapping process. This chapter also concludes the best result among all results.

Chapter 5, consists of conclusions and recommendations for future work.

CHAPTER 2

LITERATURE REVIEW

2.1 Previous Studies for Iraq

Thair et al. (2017) used 45 groundwater samples to produce spatial variation maps of the city of Al-Samawa in Iraq which offer details of the city's groundwater quality. The emphasis was to examine the geological and non-geological causes of water pollution in relation to NO3-, HCO3-, SO42-, Cl1-, Ca2+, Mg2+, Na+, and K+ conditions. A high proportion of the samples (87%) were considered to be safe for drinking while about 94% were regarded as unsafe when the tests were done in relation to the water's Na% and sodium adsorption ratio. This was done in comparison to the WHO 2011 and Iraq water standards. 10 samples were considered to be unstable of quality while 35 samples were considered to be of poor quality for both irrigation and drinking purposes. Thus, Iraq was considered to be having a poor WQI and the implication of the research was that GIS can effectively be used for groundwater quality and spatial information mapping.

Kadhim (2018) studied seasonal variations in water quality of 25 wells in Dhi-Qar district with regards to the level of EC, PH, sulfates, Chloride, and TDS. The tests were carried out using ArcGIS and all the samples were established to be having quality properties that match the WHO standards, in addition, it was noted that the water properties of these samples made it suitable for use for different activities such as irrigation, drinking and concrete mixing.

Hamdan et al. (2018) used a WQI to determine the pollution levels of 37 locations in Iraq based on their EC, TSS, Tur, TDS, NO3-2, COD, BOD5, PO4-3, and pH properties. The results showed that the WQI of these sites was very low because of high sewage pollution and industrial effluent levels. This proves that sewage pollution and industrial effluent are key water contamination issues that need to be addressed in societies that rely on the use of groundwater.

Hamdan et al. (2017) also did another study that uses Map Algebra and ArcGIS to analyze the chemical properties of water collected from 42 wells in Iraq. The findings led to the conclusion that the suitability of the water to be used for drinking varied a lot with the distance from the river bed. As a result, areas that are far from the riverbed were noted as having a high WQI that matches WHO standards. The WQI of Areas that areas as close as 11.94Km to the riverbed were observed to be unstable. These findings also match findings made from other studies by Wilcox (1955), Ayers and Westcot (1985). This greatly shows that rivers play an important part in influencing water quality levels.

Hussain et al. (2014) studied the WQI of 39 locations in Iraq using GIS during the 2013 dry and wet seasons. The tests were done to examine the water properties with respect of SAR, Na+, Cl-, Mg+2, EC, and pH level. It was noted that though groundwater remains vulnerable to contamination, most of the regions in Iraq had high WQI which made it safe and usable for a lot of things, especially for irrigation activities.

Ewaid et al. (2017) did an evaluation of the Al-Gharraf River from the period 2015 to 2016 by looking at their EC, TSS, TDS, PO4-3, NO3-2, COD, BOD5 and pH properties. The water's turbidity was not examined and in such a scenario, the results exhibited that the water can be declared to be safe for drinking. However, the inclusion of water turbidity made the water to be classified as not fit for drinking.

Douaa et al. (2018) also used the GIS to determine the WQI with regards to EC, Tur, TSS, TDS, PO4-3, NO3-2, COD, BOD5 and pH properties of 37 locations lying along river beds in Basrah governorate. It was reported that all the sites had bad or low WQIs and this led to the idea that not all areas along the river bed have better or high WQIs. The reason behind the low WQI was established to be pollution and this reinforces the fact that pollution remains a huge problem affecting water quality.

Ali et al. (2012) utilized the GIS and a DRASTIC approach to examine the Vulnerability of groundwater in Kuwaik and Uloblagh to pollution. The findings illustrated that water pollution levels vary according to a number of factors and that one of the notable factors is human activity. As a result, it was noted that human activity affects the WQI. That is, there is a low WQI in areas that have a lot of human activities and vice versa. This is true especially considering that the South Western part of Iraq has a few people residing there.

Toma et al. (2013) did an assessment of Erbil's WQI using Mg+2, Ca+2, NO3, Hardness, Alkalinity, pH, TDS and EC standards. The water quality was noted to vary with changes in locations around Erbil and areas such as Badawa 13, Ronaki 1, Ankawa 9, and Azadi 8 had high WQIs as compared to other areas such as Rezgari No. 1. This, therefore, shows that locations are also another essential aspect to look at when examining the WQI of any area.

Babir et al. (2016) chemically and physically analyzed 39 water samples collected from Erbil governorate to examine the water's Tur, TDS, EC, pH, and temperature. The study was done in line with the 2004 WHO and Iraq standards. The samples were observed to be suitable for both irrigation and drinking purposes as observed by their sodium adsorption ratio.

Jadoon et al. (2015) did a study that focused on Ainkawa, Bakhtari wells and three areas of Ifraz in Erbil to examine their drinking water properties using a total of 32 house samples. The samples were analyzed in relation to pure alkalinity, total hardness, conductivity, and turbidity. All the findings showed that the water in Erbil is suitable for drinking. In overall, the water quality in Iraq can thus be said to suitable for drinking.

2.2 Previous Studies for Other Countries

Okoye et al. (2016) generated the spatial variability map of in Awka, Nigeria using the GIS to determine the groundwater WQI. The findings showed that the entire Awka region's water is suitable for drinking. The findings are relatively different from those that were established by Venkatesh and others. Venkatesh et al. (2018) used the Inverse Distance Weighted spatial interpolation to assess 9 water quality variables and compute the WQI. The findings indicated that about 78% of the water is not suitable for drinking.

Şener et al. (2017) did a study that was aimed at looking at the WQI of water in Isparta Province between October 2011 and May 2012. The results were analyzed based on the Turkish and WHO drinking water guidelines. The reported findings showed that the WQIs of the province varied from one location to the other. That is, some areas in the province had poor WQI while others had a high WQI. Such variations were considered to be as a result of pollution activities and recommendations were given to deal with the problem of pollution.

Shams et al. (2014) employed the Wilcox and zoning approach using the GIS to analyze the WQI of Khorramrood River from the first 6 months of 2012. The tests were done with regards to sodium, magnesium, calcium, fecal coliform, nitrate and phosphate content of the water. The findings provide support to the idea that the WQI varies with location. Meaning that other locations have got a better WQI as compared to other areas.

Gorai et al. (2013) did a quantitative analysis of 65 samples collected from different areas in Ranchi to evaluate the WQI. A WQI model was estimated based on the collected turbidity, alkalinity, total hardness, TDS, and pH values. The developed models had low error values which indicated that they had a high probability to offer reliable estimates. As a result, it was noted that the WQI varies with location and as usual, some locations were not to be having high WQIs as compared to others and such variations were attributed to increased pollution levels.

Venkatesa et al. (2018) did a study on water quality determinants in India through the application of GIS on 15 variables which provide an indication of chemical and physical determinants. The study established that the water quality was either good, bad or moderate and offered suggestions on how to preserve water quality. It was contended that better human practices and regulation strategies are needed to avoid water contamination problems.

Al-Omran et al. (2017) focused their study on Saudi Arabia and used ArcGIS to test groundwater samples amounting to 180. The NO3- and EC dS m-1 of the water were determined using the kriging approach and this also included normalizing the collected data and then estimating a WQ model. The results went on to support the idea that water quality levels vary with respect to the location of the water body or source. This is what a lot of studies have established but the issue of human activities contribute to much of the pollution cannot be ruled out.

Eslami et al. (2013) used interpolation methods to examine spatial changes in WQ measured by SO4, EC, TDS, and SAR in Mianab plain. After having tested the parameters with a variogram, the GIS results showed that water contamination levels were relatively higher on one side of the plain as compared to the other. The results also established that the contamination levels were so high and that there is a huge need to contain them. The proposed strategies and measures aimed at regulating human activities.

Sarukkalige (2012) applied kriging interpolation and geostatistical measures to determine changes in water quality in Australia. The study was based on the need to examine how spatial variations in WQ were related to differences geographical locations of the same region between years 2005-2011. The study did find differences in WQ across Australia and outlined that it was evident that pollution was compromising WQ and that a lot of industrial and commercial activities were contributing to the increased contamination levels. The study was highly considered pivotal for groundwater policy and decision making.

Uyan et al. (2013) focused on determining factors behind groundwater depletion period (1999-2008) using a sample of 58 wells located in different areas. The kriging method and a GIS method were used for analyzing the data and established the spatial map. The findings revealed that there are notable changes in groundwater levels and that groundwater depletion was increasing getting higher. A 15% difference was noted to exist between the different areas that were examined and possible seismic effects were also established to take place due to increased drilling activities. This, therefore, shows that increased water pollution levels have severe effects not only on drinking and irrigation but also on a number of activities. Hence, the need to address water contamination is always needed at all times.

Shomar et al. (2010) also used a GIS to map possible changes in WQI along the Gaza Strip. The obtained findings proved strong evidence of the existence of differences in WQI. The results were similar to what was established by Marko et al. (2013) who used the same approach in Saudi Arabia. The study by Marko, however, focused on looking at TDS, salinity, conductivity, Cl-, Mg2+, and Na+ water characteristics. Both studies showed that there are significant variations in WQIs across the examined areas and pointed out that there is a significant increase in water contamination levels. As a result, much of the water was considered not to be safe for drinking and other activities such as irrigation. Furthermore, the findings showed that the WQ in these areas was not in line with the WHO standards. With problems of water provision increasing at a high level, it was suggested that it was important to prevent groundwater contamination.

Samin et al. (2012) did a study that was relatively similar to these studies but differed in terms of the number of parameters examined. Samin focused on EC, Cl- and SAR water properties and used a kriging approach to examine the data. The results also showed that there is a significant difference in water properties. Meaning that the water was the WQI varied a lot across the examined areas.

Khan (2010) did a study that uses the WQI to assess the water quality in Pakistan based on the water's Sulfate, Nitrates, EC, Dissolved Oxygen and pH values. The findings revealed that water contamination is a huge problem in Pakistan and that measures were needed to control water contamination. Increased water contamination problems were established to be posing huge health problems. Prior to that, Ramakrishnalah et al. (2008) had also used a WQI in Tumkur Taluk but focused on the examination of 12 water variables which included fluorides, manganese, iron, nitrate, and chlorine levels. The findings had shown that water contamination levels were a common feature and that it was now difficult to consume water without first checking if it safe for drinking. The study suggested that water treatment is done prior to any form of consumption. Saeedi et al. (2010) followed with another study that uses GWQI to test samples collected from 163 wells in Iran using 8 model parameters. This resulted in the development of a series of indices which provided a clear indication of the GWQIs. The indices showed huge variations in WQ and that pure and high-quality water was found to be having a lot of minerals while poor quality water was established to be having a lot of acidic components. These studies were supported by another study that was done by Varol et al. (2014) using a total of 56 water samples. The findings did not rule out the fact that GWQ was being affected by human activities but went on to establish that agricultural activities were affecting GWQ. This was also supported by findings made by Shah et al. (2017) who also used a similar approach but focused on the period 2005-2008 and applied it to the Sabarmati river. The study also established that there are growing concerns over water contamination as a result of urban runoff, unprotected river sites, proper sanitation, industrial and sewage effluent discharges.

CHAPTER 3

STUDY AREA AND METHODOLOGY

3.1 Description of the Study Area.

The study is centered on the city of Erbil which is located in the northern parts of Iraq. The area is composed of a mountainous area and the other area which has plains and valleys. The geographical location of the city of Erbil is shown in figure 3.1 and can be noted to be found at longitudes $44^{o}20^{'}$E and $43^{o}20$ and latitudes $37^{o}30^{'}$N and $35^{o}40$. The locations of the wells are also depicted by the green dots on the right-hand side of the map.

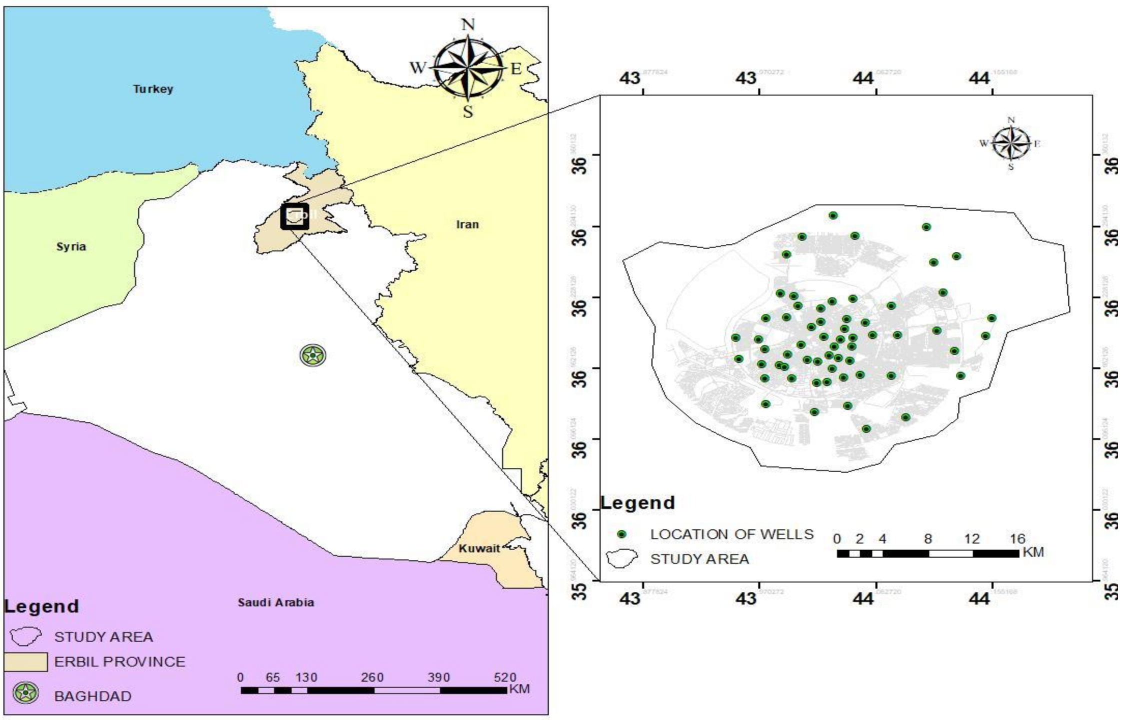

Figure 3. 1: Map of study area and location of wells

3.2 Population Size

It was estimated in 2017 that the city of Erbil had a total population of 1,542,421 people which comprised of 690,989 male and 851,432 female individuals (Erbil City Government Report, 2017). The population densities vary across the different parts of the city. For instance, Choman accounts for 2.7%, Makhmur 3.7%, Shaqlawa 11.1%, and Erbil city 59% of the entire population. The rest varies according to other cities located around Erbil. 24% of Erbil's population resides in the rural areas as opposed to 76% of the population which resides in the city. However, all the cities are similar in terms of their climatic and hydrogeological characteristics.

3.3 Climate

Generally, the climate condition of Erbil is considered to be of a Mediterranean climate type with an average rainfall which falls between 600 to 800 mm per year. But the climatic conditions do somehow differ a bit. This is because the Southern part is cold and gets snowy especially in winter while the northern part is relatively warmer (Hameed, 2013). It is cold and snowy in the winter and temperatures can reach as low as 7.9 °C, and hot and dry in summer. There are also a lot of different topographic features that can be found in Erbil and these features will influence the distribution of wells in Erbil. Also, some wells will be noted to be having more underground water as opposed to other areas especially the rocky or mountainous parts of Erbil (Hameed, 2013). The most important feature is that rainfall distribution patterns are relatively different between the northern and southern parts (see figure 3.2). The Southern part receives an average annual rainfall of 1,200 mm while the Northern gets an annual average of about 200 mm/year (UNDP, 2016).

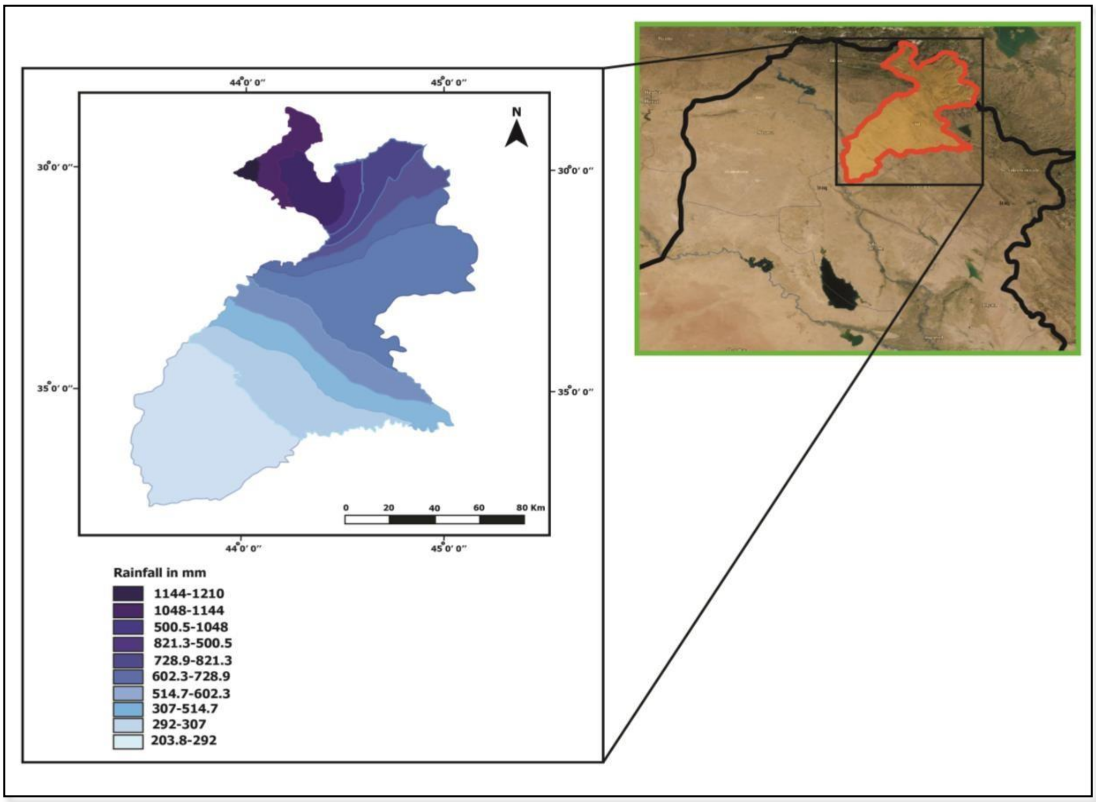

Figure 3. 2: Spatial distribution of average yearly rainfall in the study area

3.4 Water Resources and Supply

In terms of water supply, it can be said that Erbil has sufficient water supplies to meet daily demands (Hameed, 2013). However, there is a problem of growing water demand almost on a daily basis. This is more likely to pose challenges of straining existing water supplies. It was established that 530,000 m3 of water are consumed daily in Erbil (Erbil Water Directorate, n.d). The main sources of Erbil's water supply are the Ifraz Water Project which supplies about 70% of Erbil's daily water needs and the rest is wells situated in and around Erbil. Alternatively, the water sources can be classified as follows:

- Gravity streams
- Confined aquifer.
- Shallow aquifer system

- Deep aquifer system
- Springs and, deep and shallow wells (Groundwater resources).
- Artificial dams, lakes, streams, and rivers (Surface water resources).

3.4.1 Groundwater resources in Erbil city

Due to the idea that groundwater is a huge notable source of water for all the industrial, recreational and agricultural activities in Erbil. Hence, it is important to have the right water quantity and quality. Gardi (2017) outlook that some of the challenges faced by people are as a result of the pollution of groundwater. It must be noted that pollution affects the ability the future of wells to provide water. As a result, efforts will, therefore, be needed to additionally pump in the future. But the problem is that, pumping water results in additional costs and an increase in energy consumption. Hence, the problem of water contamination can also be noted to affect other economic sectors. The good part is that groundwater is naturally provided especially during rainy days and seasons.

3.5 Groundwater Quality and Sources of Pollution

UNICEF (2008) highlighted that the pollution of groundwater quality poses a lot of serious problem among others, the challenge of having to purify it. This is groundwater is so difficult to purify it. Also, the purification process takes more time to do. Gardi (2017) also contends that water purification especially groundwater purification is so expensive to do. On the other hand, UNEP, 2016 highlighted that the contamination of groundwater is mainly a result of increased human activities. It is believed that humans are responsible for the release of high sewage volumes into rivers and dams as well as underground (UNICEF, 2008). Human activities are not limited to the increased sewage bursting but also include a series of industrial activities undertaken by humans either as a means of production or consumption. Also, poor agricultural practices are also an important factor to consider. This is because agricultural practices are associated with increased or poor leaching of chemicals. Thus, poor waste and chemical management, and dumping practices can be said to be possible causes of water pollution in Erbil.

It is along these factors that any possible discoveries in water contamination will possibly be explained. Water contamination can be assessed based on:

- Its turbidity, taste, smell, color, and temperature (physical features).
- pH, chemicals, metals, and minerals (chemical content)
- Helminths, protozoa, viruses, and bacteria. (Microbiological)

As showed in table 3.1 the major sources of chemicals polluting groundwater are pesticides, water treatment, human dwellings and industrial, agricultural activities induced and natural chemicals (WHO, 2011).

Table 3. 1: Sources of chemical contamination

Source of Chemicals	**Examples**	**Common Chemicals**
Naturally occurring	Rocks and soils	Arsenic, chromium, fluoride, iron, manganese, sodium, sulfate, uranium
Agricultural activities	Manure, fertilizer, intensive animal practices, pesticides	Ammonia, nitrate, nitrite
Industrial sources and human dwellings	Mining, manufacturing and processing industries, sewage solid waste, urban runoff, fuel leakages	Nitrate, ammonia, cadmium, cyanide, copper, lead, nickel, mercury
Water treatment	Water treatment chemicals, piping materials	Aluminum, chlorine, iodine, silver
Pesticides used in water for public Health	Larvicides used to control insect vectors of disease	Organophosphorus compounds (e.g., chlorpyrifos, diazinon, malathion) and carbamates (e.g., aldicarb, carbaryl, carbofuran, ox amyl)

3.6 Groundwater Quality of Erbil City

Drinking water must be first tested before one consumes it but this can only be done after testing to check if the water quality is of the right quality. As a result, the quality of the water has to be evaluated from both the source up to the final point of consumption. Jadoon, 2015 featured that variety in groundwater quality, in Erbil, can be clarified by numerous components contribute and these incorporate, human exercises, farming exercises and geological formation, and so forth. The contamination of groundwater is often a big challenge to handle and this is why it is always important to prevent toxins from entering the water at all costs.

3.6.1 Sources of Groundwater pollution in Erbil city

UNEP (2013) established that water contamination remains a major world issue and that its causes are diverse. One of the notable causes of water contamination is human activities such as farming and much chemicals used in farming often infiltrate the soil and pollute groundwater. Tamru et al. (2013) highlighted that this problem is mainly because most farming activities are not controlled. Wildlife, agriculture livestock, septic system, and sewage have caused bacteria and viruses to be a common feature of water contaminants in Erbil. It is also reported by Mus'ab (2014) that radioactive and industrial materials are also a common element of water contaminants. Also, in Erbil, dissolution of materials has been a contributing factor to GW pollution and it was noted that about 30% of the changes in WQ is as a result of $MgCl2$ and $CaCl2$. Generally, the major sources of water pollution in Erbil city are explained below:

I. **Government & private Institutions** EWD (2015) highlights that a lot of institutions in Erbil are situated far away from sewage terminals and chances of these institution contaminating water bodies are very high.

II. **Effect of Industry on Degradation of Water Quality**: There are a lot of industrial activities that take place in Erbil and these activities generate a lot of physical and soluble waste materials that can easily contaminate both ground and surface water. UNESCO (2016) established that only about 10% of industries in

Iraq are engaging in safe practices that do not contaminate water bodies. This implies that 90% of industries are easily contaminating existing open streams and water bodies by releasing sewage and other chemical products into the water and on the land. UNESCO (2016) further states that this is due to a lack of sound rules and laws that govern waste management practices in Erbil. This can be evidenced by reports which showed that about 40 of the 118 registered industries have solid waste discharges (UNESCO, 2016).

III. **Poor solid waste management**: Which results in increased pollution levels and much of it is a result of uncollected waste which continuously piles up (EWD, 2015).

3.7 Geology and Hydrogeology of Iraq and Northern Part of Iraq

3.7.1 Tectonic Framework of Iraq and northern part of Iraq

Jassim and Goff (2006) outlined that the Zagros Belt in Northern Iraq is part of a geologically Tertiary orogen. Jassim and Goff believed that this has resulted as a result of a collision between Eurasian and Arabian plates. Figure 3.3 shows that Part of this region is table while the other is unstable and is composed of 4 tectonic elements tectonic elements (Suture Zone, Imbricate Zone, High Folded Zone and Low Folded Zone (Al-Juboury, 2012).

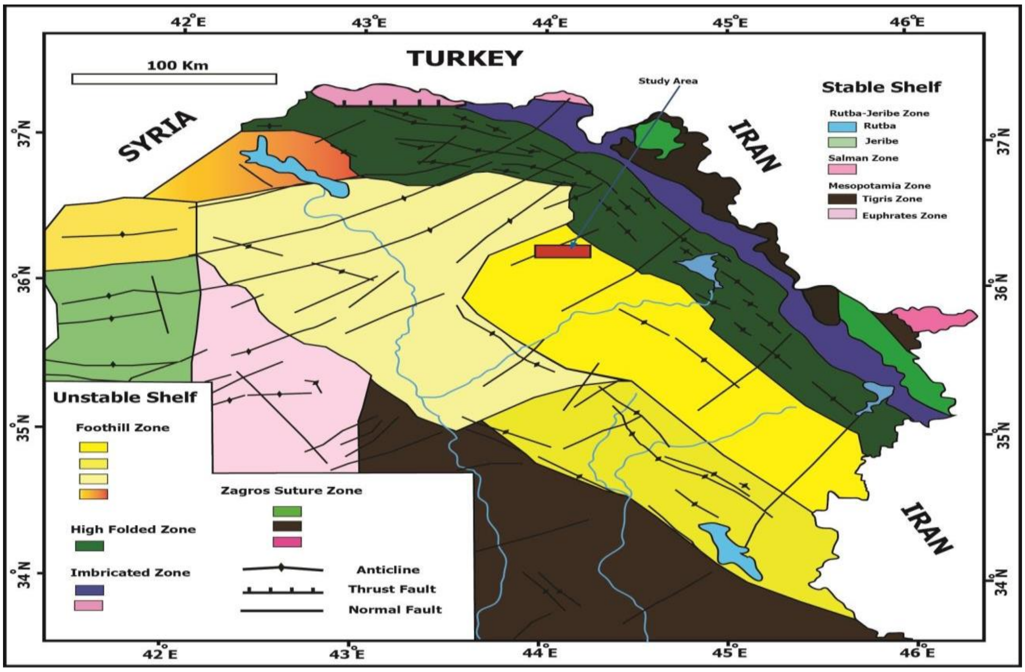

Figure 3. 3: Tectonic map of the northern part of Iraq

The Erbil Basin area lies in the Low Folded Zone of Northern Iraq in areas have a wavelength which is between (5-10) km (Bapeer et al., 2010). In this area, the Kirkuk anticlinal and the Permam Dagh anticline set geographical boundaries of the basin. Their formations are increasing getting bigger and shallow at the NNE (Figure 3.4).

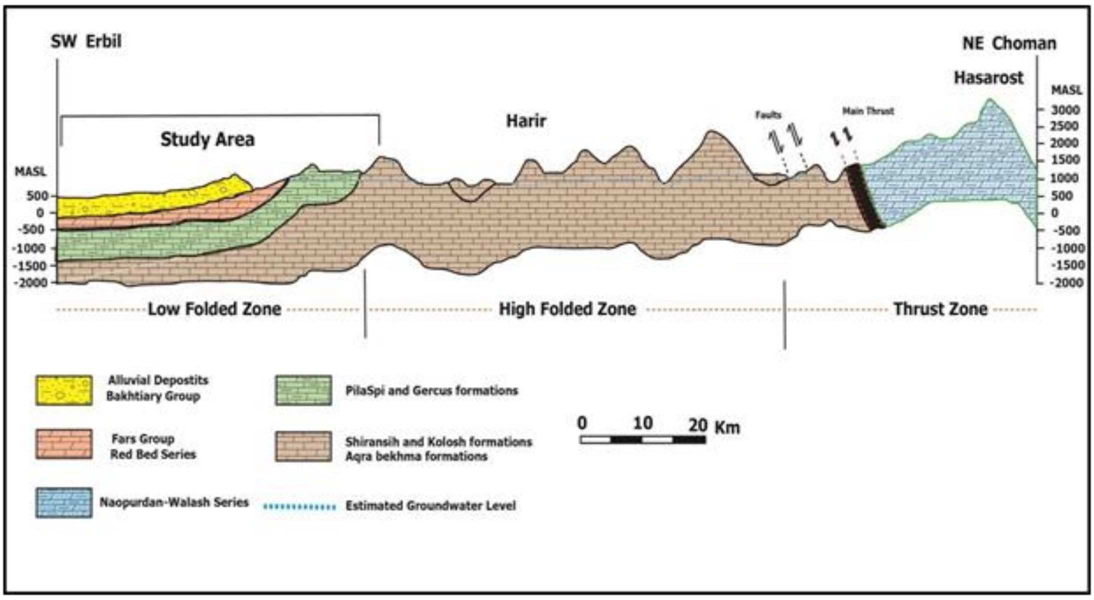

Figure 3. 4: Regional hydrogeological cross section

3.7.2 Erbil Basin

The Dashty Hawler Basin or the Erbil Basin is the largest groundwater reservoir Erbil Province which is 800 meters deep and stretches for about 3,200 km^2. Ahmed (2009) contends high WQ is obtained from this basin in large quantities which makes it possible to serve other nearby communities. This is because it is so close to the surface and thus few or fewer costs can be incurred in trying to access underground water from this basin. The Kurdistan Region Groundwater Report (2012) states that there are however harmful ions and soluble salts that are found in water from this basin which can pose serious threats to people's health. Figure 3.5 shows that Erbil Basin is divided into three sub-basins (Bashtapa, Kapran and the central basin). These basins are demarcated by subsurface structures.

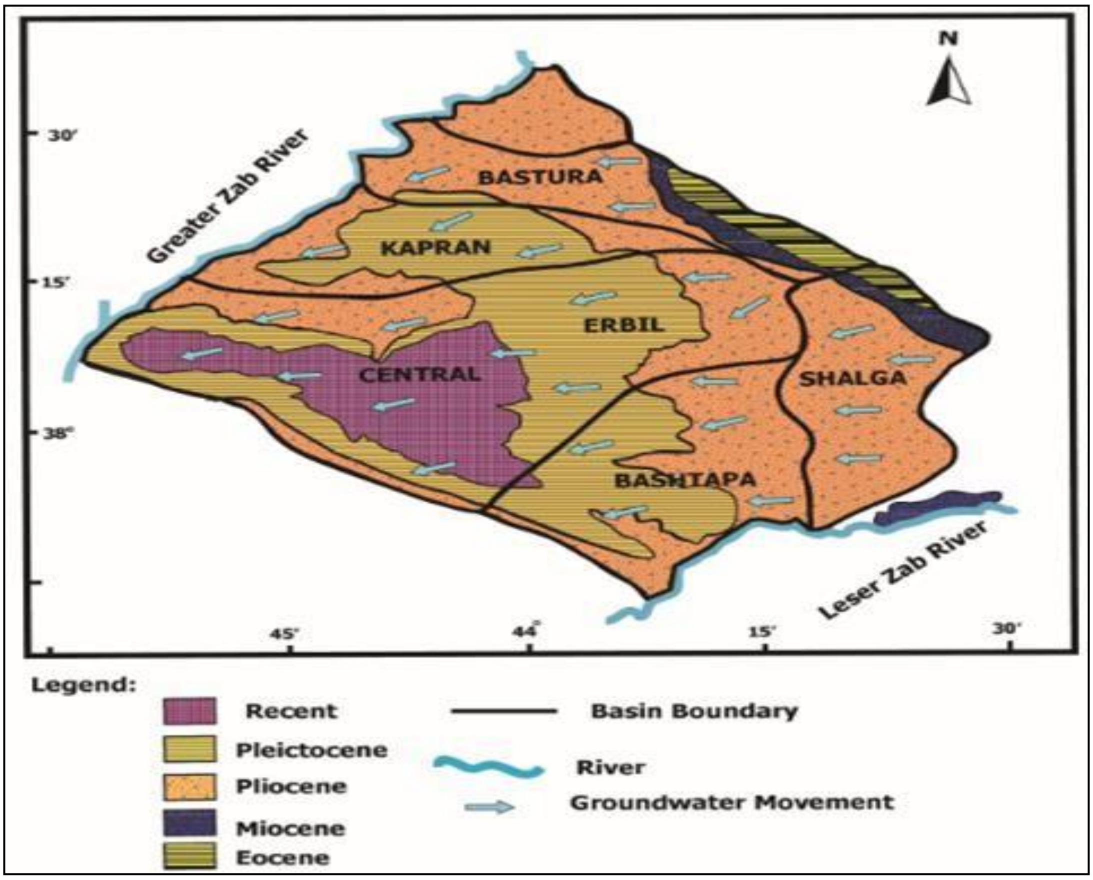

Figure 3. 5: Geological map of Erbil Basin with the sub-basins labeled

3.7.3 Soils

The northeast part of Erbil is mountainous as compared to the northern part and has shallows soils. Shallow soil in the northern part does not have good texture while that in the southern part is considered to be way better for agricultural activities and other man-made activities (Hameed, 2013). Figure 3.6 provides an outline of the soil types in Erbil Province.

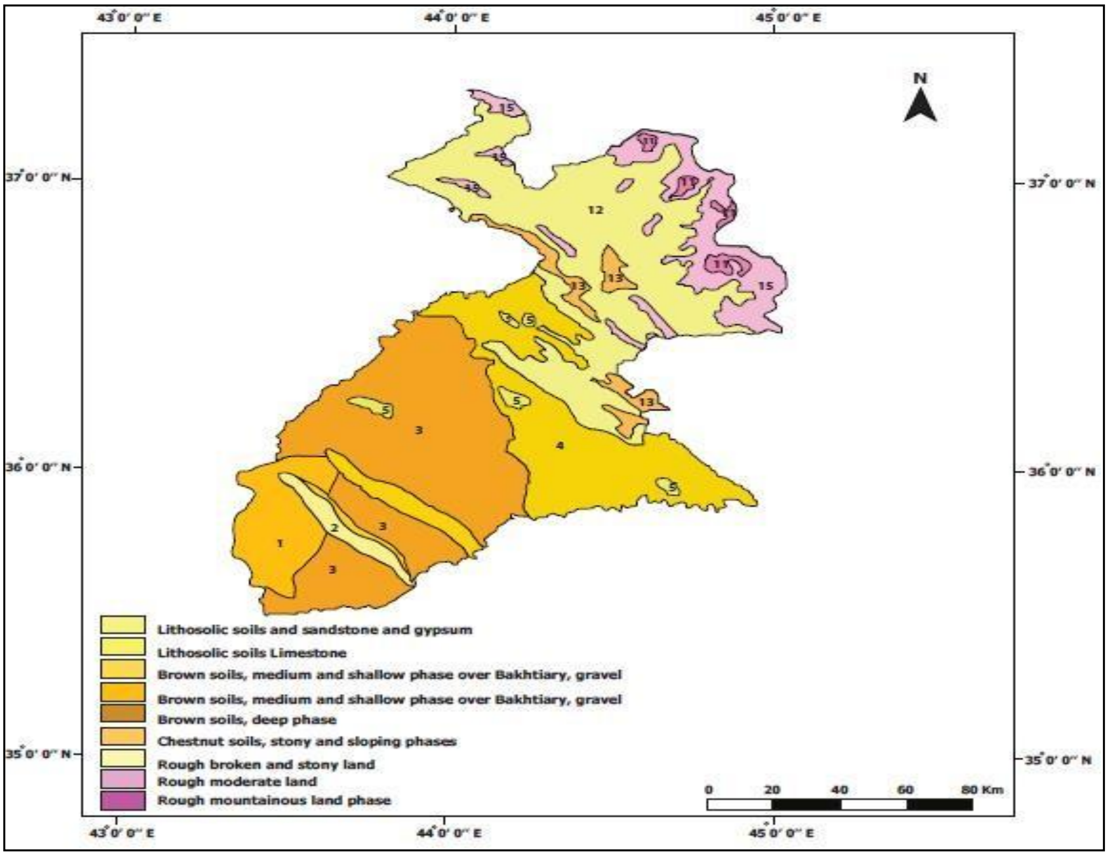

Figure 3. 6: Soil types in the Erbil Province

3.8 Methodology

3.8.1 Sources of data

The period under study is 1st January 2015, 2016, 2017, 2018's wet season and 1st January 2015, 2016, 2017, 2018's cold season. Sampled data of 61 wells was retrieved from Erbil water directorate. The data was collected with regards to WQ variables such as Sulfate, Nitrate, Chlorine, Potassium, Sodium, Magnesium, Calcium, Total Hardness, TDS, EC, pH, and turbidity.

3.8.2 Calculation of the water quality index

As noted, pollution levels are determined using the WQI. In this study, the WQI was estimated based on Sulfate, Nitrate, Chlorine, Potassium, Sodium, Magnesium, Calcium, Total Hardness, TDS, EC, pH, and turbidity for all the 61 wells in Erbil. This was accomplished by using recommendations made by Cude (2001) to assign weights to the WQI which results in the establishment of a weighted WQI as shown below.

$$WQI = \Sigma\, qn\, Wn / \Sigma\, Wn \qquad (3.1)$$

Where:
qn = quality rating of nth water quality parameters.
Wn = Unit weight of nth water quality parameter.

The nth water quality variable is assigned a weight Wn and the WQ variables are denoted by qn which is determined by incorporating the standard permissible value (Sn) Ideal value (Vid) and the estimated value will thus be (Vn) as shown below;

$$qn = [\ (Vn - Vid) / (Sn - Vid)\ ] \times 100 \qquad (3.2)$$

Where:
Vn = Estimated value of nth water quality parameter at a given sample location.

Vid = Ideal value for nthe parameter in pure water. (Vid for pH = 7 and 0 for all other parameters)

Sn = Standard permissible value of nthe water quality parameter.

Equation (3) was used to obtain the unit weight (Wn).

$$Wn = k / Sn \tag{3.3}$$

Equation (4) was used to determine the constant of proportionality (k).

$$k = [1 / (\Sigma\ 1/ Sn=1, 2\ .n)] \tag{3.4}$$

Existing types of WQ were obtained from a study by Shweta et al. (2013) and both are in line with the WHO 2011 standards as depicted in Table 3.

Table 3. 2: The WQI categories corresponding status

No	WQI	STATUS	POSSIBLE USAGE
1	0 – 25	Excellent	Drinking, Irrigation, and Industrial
2	25 – 50	Good	Domestic, Irrigation and Industrial
3	51 -75	Fair	Irrigation and Industrial
4	76 – 100	Poor	Irrigation
5	101 -150	Very Poor	Restricted use for Irrigation
6	Above 150	Unfit for Drinking	Proper treatment required before use.

3.8.3 Guidelines for water quality parameters

WHO (2011) established that water must be safe for use bet it for bathing, cleaning, cooking or drinking. Hence, attempts are always made to ensure that the water is safe for use. As a result, WQ standards were developed so as to ensure that WQ is of the required standards to allow effective and safe use by people. These standards, however, can vary from one country to the other. These standards also help to establish rules and laws that govern the use of water and prohibit water contamination activities. Table 3.2 provides details of the WHO WQ standards.

Table 3. 3: Drinking water quality standards of WHO

water quality Parameters	WHO standards
Turbidity (NTU)	5
pH	6.5-8.5
EC (µS/cm)	1500
TDS (mg/l)	1000
Total Alkalinity (mg/l)	250
T.H as CaCO3 (mg/l)	500
Ca +2 (mg/l)	75-200
Mg +2 (mg/l)	30-150
Na + (mg/l)	200-400
K+ (mg/l)	12
Cl- (mg/l)	200-400
NO3- (mg/l)	10-45
So4-2 (mg/l)	200-400

3.8.4 Preparation of well location point feature

Point feature was developed using the detailed location of the study area and data on WQ was obtained from secondary sources. The Arc Map was developed using a combination of spatial and secondary data and this was used to produce Erbil’s WQ spatial distribution maps.

3.8.5 Log transformation

The collected data was transformed into logarithms so as to make it easy to interpret the obtained findings. Also, transforming data into logarithms helps in dealing with the problem of outliers and heteroscedasticity which may affect the effective use of the Kriging approach. The transformation process will also aid in ensuring that the data remains normally distributed over the course of time.

3.8.6 Geostatistical approach

A GIS software was used to determine Erbil's spatial distribution of GWQ variables. The use of GIS dates back to the year 1979 when it was used to involve the use of models to estimate the spatial features of a geographical area (McNeely et al., 1979).

This includes the use of the semivariogram which shows the relationship between the semivariogram value and the lag distance. Nayanaka et al. (2010) outlined that the semivariogram can also be used to determine how two or more parameters are correlated together and a high value indicates a high level of co-movement. On the other hand, it can be determined as follows:

$$\gamma (h) = \frac{1}{2n(h)} \sum_{i=1}^{n(h)} [z(xi) - z(xi + h)]2 \qquad (3.5)$$

The semivariogram models (Spherical, Exponential, and Gaussian) were tested for each parameter data set. Prediction performances were assessed by cross-validation. Cross-validation allows determination of which model provides the best predictions. According to Berktay and Nas (2008), for a model that provides accurate predictions, the standardized mean error should be close to 0, the root mean square error and average standard error should be as small as possible (this is useful when comparing models), and the root mean square standardized error should be close to 1.

In this research two methods are used for mapping groundwater quality parameters and three methods are used to generate a map for groundwater quality index, methods are:

1. **Kriging**

Semi-variogram provides a base upon which the Kriging approach is based on. The correlation between the variables is an indication of the changes in the variables' variance and is denoted γ(h) using the following formula:

$$2\gamma\ (h) = 1/\ n \sum in{=}1[Z(xi + h) - Z\ (xi)] \qquad (3.6)$$

The distance is denoted by h, while point xi+h and xi values are given by Z(xi+h) and Z(xi). It is possible to determine the sill, effect radius and nugget effect using the parameters of the variogram. Hasanipak (2008) denoted that the estimation process can be done once the theoretical model has also been established and mathematical expressions have been applied. Also, the best unbiased linear estimator can be determined from the Kriging estimation which attempts to determine the weighted values of Z(xi).

2. **Inverse Distance Weighted**

   The IDW is used to determine the values of unknown parameters and is an inverse of closer points and the distance of the parameters. The computation of IDW of a sample (*i*) is done assigning weights (λi) to the parameter values Z (xi) at given xi points using the following expression:

$$Z^*(xi) = \sum \lambda i.Z(xi) \qquad (3.7)$$

   The performance of the model can be assessed using the root mean square error (RMSE) which is a function of the Z*(xi) and can be using the following expression:

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(z(xi) - Z^*(xi))^{2}} \qquad (3.8)$$

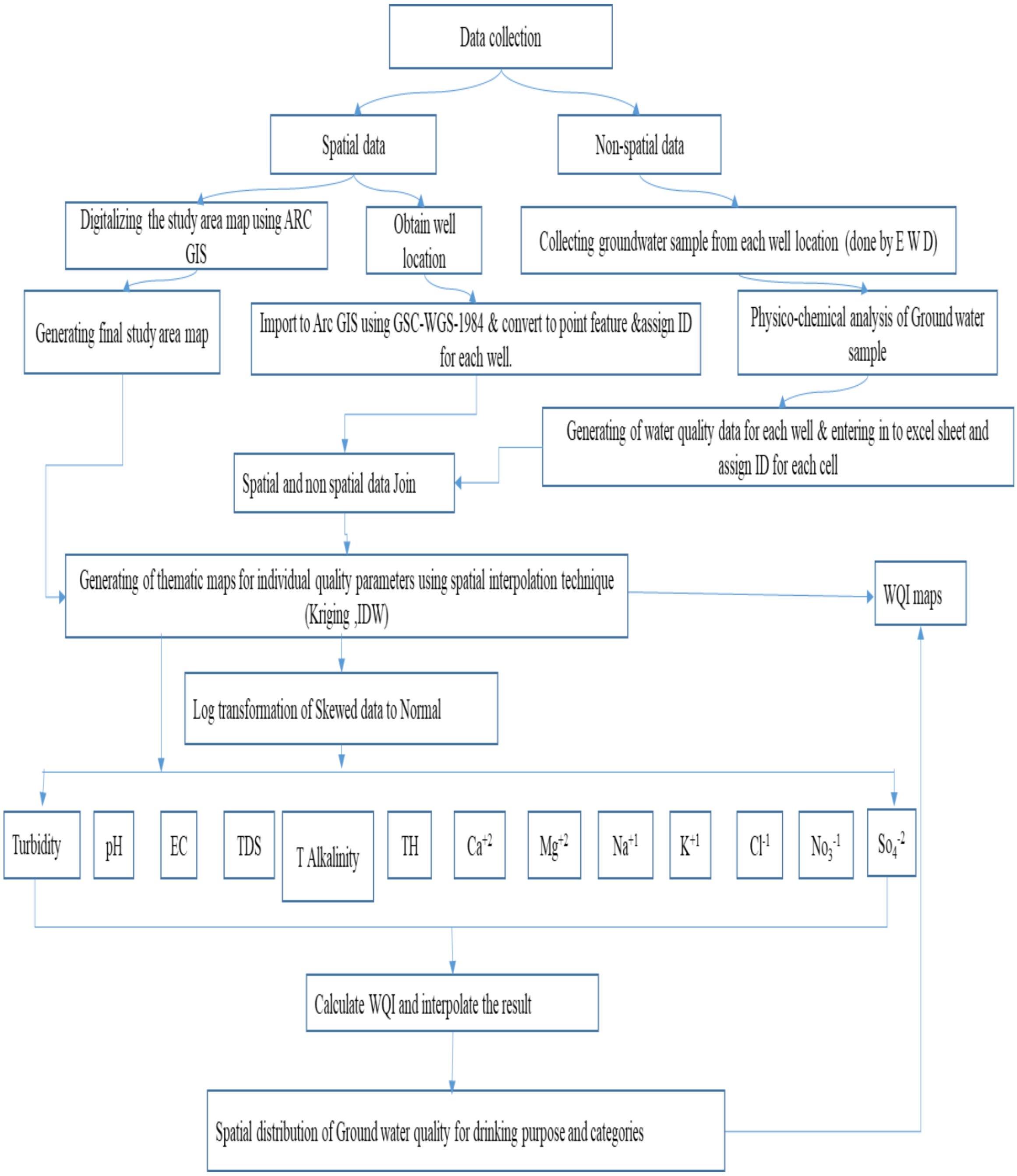

Figure 3. 7: Flowchart of the methodology

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Statistical Analysis of GWQ Parameters

The water quality parameters of the city of Erbil presented in table 4.1 and 4.2 for the wet and dry seasons. Turbidity concentration for the wet season varied from a minimum of 0.4 to a maximum15.9 with a mean and standard deviation of 3.04 to 3.07 respectively. Also, skewness and kurtosis were calculated to determine the distribution of data. If the distribution of data showed high skewness, it means the data was not normally distributed, it should be transformed using a log transform application. The values of skewness and kurtosis for turbidity were established to be 1.817 and 3.17 respectively. The values of turbidity concentration for the dry season decreased from 0.2 to 8.1 with a mean and standard deviation of 1.6 to 1.61 respectively. The values of skewness and kurtosis increased and this means that the data for dry seasons was not normally distributed. The value of min, max, mean, standard deviation, skewness, and kurtosis for all other parameters for the wet season showed in table 4.1 and for dry season showed in table 4.2.

Table 4. 1: Examination of the GWQ parameters (wet)

NO	parameters	Min	Max	Mean	Std	Skewness	Kurtosis
1	Turbidity (NTU)	0.4	15.9	3.0492	3.07	1.817	13.17
2	pH	7.2	8.2	7.82	0.23	-0.42	3.5
3	EC (μS/cm)	427	783	559.57	87.2	0.46	2.3
4	TDS (mg/l)	213.5	391.5	279.79	43.6	0.46	2.3
5	T.A (mg/l)	194	370	256.52	41.51	0.7	2.76
6	T.H as CaCO3 (mg/l)	194	480	321.87	55.38	0.68	3.76
7	Ca +2 (mg/l)	49	120	80.6	13.74	0.72	3.87
8	Mg +2 (mg/l)	18.28	48.72	29.07	5.57	1.09	4.93
9	Na + (mg/l)	11	61	35.75	14.33	-0.11	1.67
10	K+ (mg/l)	0.8	20.4	3.84	10.45	4.37	20.98
11	Cl- (mg/l)	14	55	25.27	7.87	1.22	5.62
12	NO3- (mg/l)	6.5	66.5	32.59	15.25	0.48	2.48
13	So4-2 (mg/l)	20	157	49.62	28.84	2.33	8.61

Table 4. 2: Examination of the GWQ parameters (dry)

NO	parameters	Min	Max	Mean	Std	Skewness	Kurtosis
1	Turbidity (NTU)	0.2	8.1	1.6	1.61	2.35	8.43
2	pH	7.1	8.3	7.67	0.27	-0.08	2.27
3	EC (μS/cm)	409	958	644	128.73	-0.07	2.44
4	TDS (mg/l)	207.5	479	323.16	61.21	0.03	2.62
5	T.A (mg/l)	180	390	278.54	43.63	-0.08	2.49
6	T.H as CaCO3 (mg/l)	187	570	364.92	88.26	0.29	2.54
7	Ca +2 (mg/l)	47	143	92.93	21.98	0.18	2.5
8	Mg +2 (mg/l)	16.7	65.94	33.5	9.01	0.79	4.36
9	Na + (mg/l)	12	96	34.88	17.16	1.19	4.62
10	K+ (mg/l)	0.8	6.2	1.61	0.9	3.19	15.4
11	Cl- (mg/l)	17	200	42.65	24.61	4.33	28.54
12	NO3- (mg/l)	3	78	32.81	20.15	0.42	2.15
13	So4-2 (mg/l)	19	116	53.11	21.27	0.53	3.06

Temporal analysis for chemical and physical of GWQ parameters presented in figure 4.1, 4.2, 4.3, and 4.4. Figure 4.1 shows that electrical conductivity, total dissolved solids, total alkalinity, and total hardness values increased from 2015 to 2017 for the dry and wet seasons but the figures of the 2018 wet season declined. The electrical conductivity was below the value of 1500 μS/cm specified by the WHO. The EC value ranged from a minimum of 427 μS/cm to a maximum of 783 μS/cm for the wet season but for the dry season, the range changed from 409 μS/cm to 958 μS/cm. Also, total dissolved solid was below the value of 1000 mg/l for both seasons. Total alkalinity was within the specified value 250 mg/l (WHO) in all seasons except in two seasons (2017 dry, 2018 wet) was higher than the specified level. Total hardness was also within the 500 mg/l limit in wet seasons for all years but was higher in the 2017 dry season than the specified value.

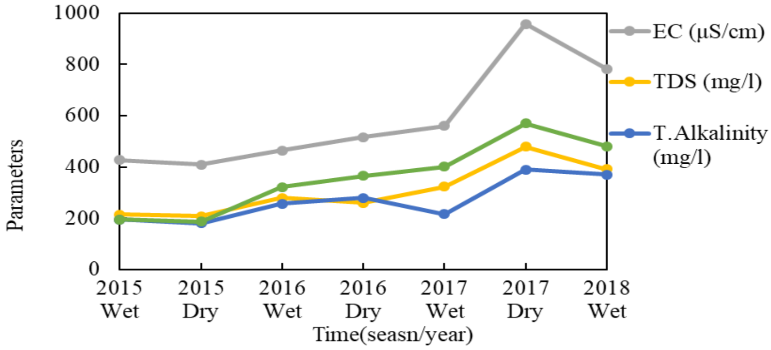

Figure 4. 1: Variation of groundwater physical parameters

Figure 4.2 shows the groundwater physical parameters of turbidity (NTU) and PH. As seen from the graph the values of PH parameter were within the 6.5-8.5 limit which has been established by the WHO for all years and seasons. From the same figure, it can be said the turbidity concentration parameter was below the 5-limit specified by the WHO from 2015 up to the 2017 wet seasons. In overall, the turbidity parameter increased in the 2017 dry season and 2018 wet season.

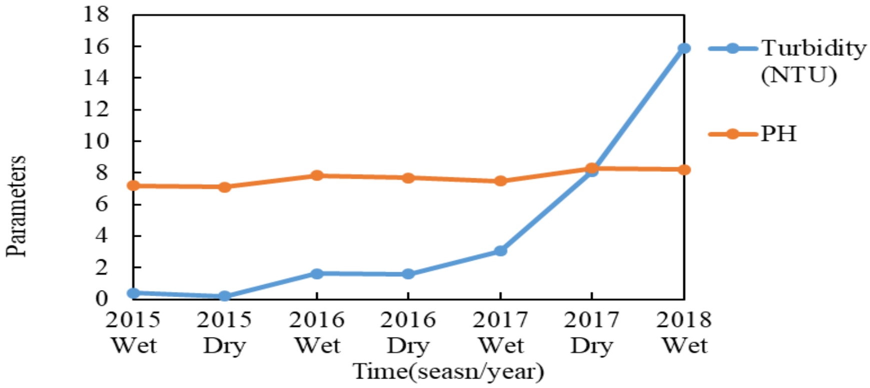

Figure 4. 2: Variation of groundwater physical parameters

Figure 4.3 exhibits the groundwater cation parameters of potassium, calcium, magnesium, and sodium. As it seen from the graph the values of Na^+, Mg^+2 and Ca^+2 parameters lied within the limit (75-200) mg/l, (30-150) mg/l, and (200-400) mg/l respectively which had been specified by (WHO) for all years and seasons. From the same figure, it could be said that the K+ concentration parameter was below the 12mg/l limit specified by the WHO from 2015 up to the 2017 dry season. Meanwhile, on the other hand, the K+2 parameter increased in the 2018 wet season.

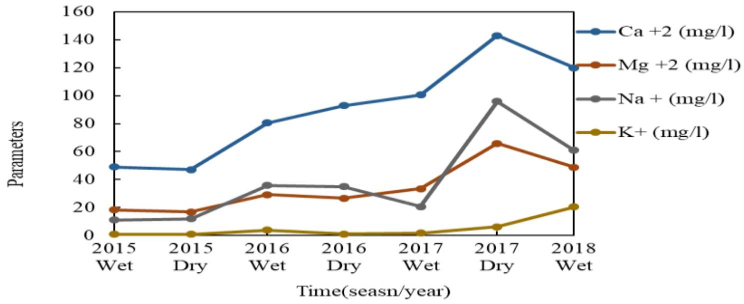

Figure 4. 3: variation of groundwater Cation parameters

Figure 4.4 shows the groundwater anion parameters of chlorine, nitrate, and sulfate. As it seen from the graph, the values of Cl- and So4-2 parameters were within the 200-400mg/l limit which had been specified by the WHO for all years and seasons. From the same figure, it can be said that the No3- concentration parameter was below the 10-45 mg/l range specified by the WHO from 2015 up to the 2017 wet season. Also, the No3- parameter increased in the 2017 and 2018 wet seasons.

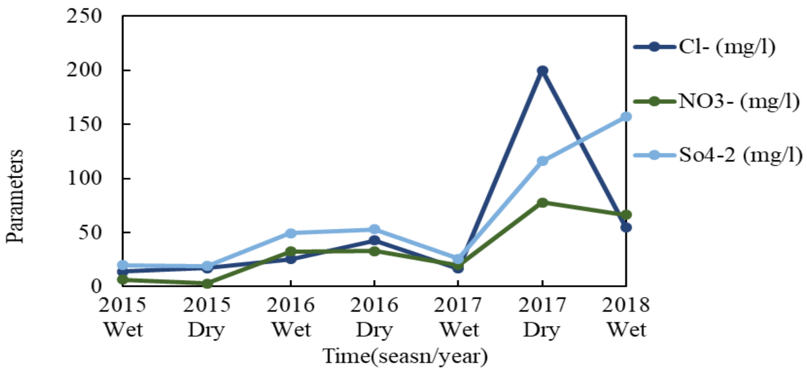

Figure 4. 4: Variation of Groundwater anion parameters

4.2 Calculation of Groundwater Quality Index (GWQI)

An assessment of the study area's water quality was done by calculating the WQI. The concentration of various physical and chemical parameters of GWQ of the dry and wet seasons from 2015 to 2018 and were presented in appendix one. The WQI of the dry and wet seasons was determined by using water quality parameters and the drinking water standard of the WHO (2011). According to Shweta et al. (2013), the water quality index value had been classified into six classes. If the WQI is greater than 150, 101-150, 76-100, 51-75, 25-50, and less than 25, and it meant that it was unsuitable, very poor, poor, fair, good and excellent for drinking respectively.

Table 4. 3: WQI range and status

NO	WQI	Status	Possible Usage
1	0 – 25	Excellent	Drinking, Irrigation, and Industrial
2	25 – 50	Good	Domestic, Irrigation and Industrial
3	51 -75	Fair	Irrigation and Industrial
4	76 – 100	Poor	Irrigation
5	101 -150	Very Poor	Restricted use for Irrigation
6	Above 150	Unfit for Drinking	Proper treatment required before use

Thirteen Parameters were used such as Turbidity, Ca+2, PH, E.C, total hardness, total dissolved solids, So4-2, K+1, No3-1, Mg+2, Na+1, Cl-1, to calculate the water quality index by using the Horton (1965) method. After calculated the results of the WQI and the number of wells corresponding to each status of the study area during wet and dry seasons were summarized and presented in table 4.4 up to 4.7.

The WQI in wet seasons (2015) in table 4.4 showed that 20 wells had excellent status, 18 wells had good status, 4 well had fair status, 13 wells had poor status, 6 wells had very poor status and one well had unfit water status but in dry season the excellent status increased to 23, the good status decreased to 8 the fair status increased to 18 the poor statues decreased to 5, very poor and unfit statuses were the same in both seasons.

Table 4. 4: WQI results of the 2015 dry and wet seasons

Status	Representing Wet Season	Representing Dry Season
Excellent	W(3,5,6,12,13,14,15,16,17,26, 28,29,30,35,36,37,46,50,52)	W(3,4,6,7,8,14,15,23,24,25,28,29,30,32, 33,43,44,45,46,49,50,52,53)
Good	W(1,2,4,8,23,24,25,27,32,33,3 4,43,44,45,47,49,51,53)	W(1,2,5,13,18,27,34,39)
Fair	W(7,10,18,55)	W(9,10,11,12,17,21,22,26,31,35,36,40,4 2,47,51,54,60,61)
Poor	W(9,11,20,21,22,31,38,39,42, 48,59,60,61)	W(16,19,20,41,48)
Very poor	W(19,40,41,54,56,57)	W(37,38,55,56,57,59)
Unfit	W(58)	W(58)

The 2016 wet seasons' WQI (table 4.5) showed that 20 wells had excellent status, 12 wells had good status, 13 well had fair status 10 wells had poor status, 7 wells had very poor status and one well had an unfit water status but in dry season the excellent status increased to 24, the good status decreased to 7, the fair status decreased to 12, the poor statues decreased to 8, very poor status increased to 10 and there is no well had unfit status.

Table 4. 5: WQI results of the 2016 dry and wet seasons

Status	Representing Wet Season	Representing Dry Season
Excellent	W(1,4,5,11,20,21,22,23,25,28,31,32,40,41,43,46,47,49,51,52)	W(2,4,5,6,8,11,19,20,22,23,25,28,30,31,32,41,42,43,45,47,48,51,52,53)
Good	W(1,2,6,8,26,29,30,42,45,48,50,53)	W(1,9,16,21,40,46,49)
Fair	W(1,3,7,9,10,13,14,16,18,24,39,54,61)	W(3,7,12,13,18,26,29,44,50,54,60,61)
Poor	W(12,15,17,33,34,35,37,44,55,60)	W(10,14,17,24,27,34,37,39)
Very poor	W(19,27,36,38,56,57,59)	W(15,33,35,36,38,55,56,57,58,59)
Unfit	W(58)	-

The WQI of the 2017 wet seasons table 4.6 shows that 21 wells had excellent status, 7 wells had good status, 11 well had fair status 12 wells had poor status, 6 wells had very poor status and 4 wells had unfit water status but in dry season the excellent status increased to 24, the good status decreased to 2 the fair status decreased to 7 the poor statues decreased to 4, very poor status also decreased to 4 and there was no well have unfit status. The WQI of the 2018 wet seasons (table 4.7) showed that 22 wells had excellent status, 6 wells had a good status, 15 well had fair status 8 wells had poor status, 3 wells had very poor status and 7 well had unfit water status.

Table 4. 6: WQI results of the 2017 dry and wet seasons

Status	Representing Wet Season	Representing Dry Season
Excellent	W(1,2,6,7,8,10,12,13,22,23,26,28,29,31,34,43,44,46,48,53,54)	W(1,2,4,5,6,8,10,12,13,22,23,26,28,29,31,32,34,43,44,46,48,50,53,54)
Good	W(4,5,9,24,32,42,50)	W(7,9)
Fair	W(11,16,18,20,21,30,35,41,45,51,56)	W(21,24,30,35,42,45,49)
Poor	W(14,17,25,33,36,38,39,40,47,49,52,57)	W(33,36,41,47)
Very poor	W(3,15,27,37,55,61)	W(25,27,37,39,40)
Unfit	W(19,58,59,60)	-

Table 4. 7: WQI results of the 2018 wet season

Status	Representing Wet Season
Excellent	W(1,4,7,8,9,10,13,14,22,24,26,28,29,31,34,42,43,44,46,48,53,54)
Good	W(11,12,25,32,35,50)
Fair	W(2,3,5,6,16,18,21,30,33,39,40,41,45,47,51)
Poor	W(17,20,27,36,37,38,49,52)
Very poor	W(15,59,60)
Unfit	W(19,23,55,56,57,58,61)

4.3 Temporal Analysis of Groundwater Quality Index

The final result showed that the water quality index for wet season value ranged from 14.34 to 172.28, 13.27 to 154.88, 14.93 to 177.62, and 13.24 to 198.22 for 2015,2016,2017,2018 respectively, and for dry season value ranged from 17 to 163, 16 to 144, and 12 to 143 for 2015, 2016, and 2017 respectively.

Figure (4.5 and 4.6) showed the water quality of Erbil city declined from 2015 to 2018, since increased the WQI in some wells. In 2015 only one well had the value of WQI unfitted for drinking but in 2018 the number of wells which were not suitable for drinking increased to seven.

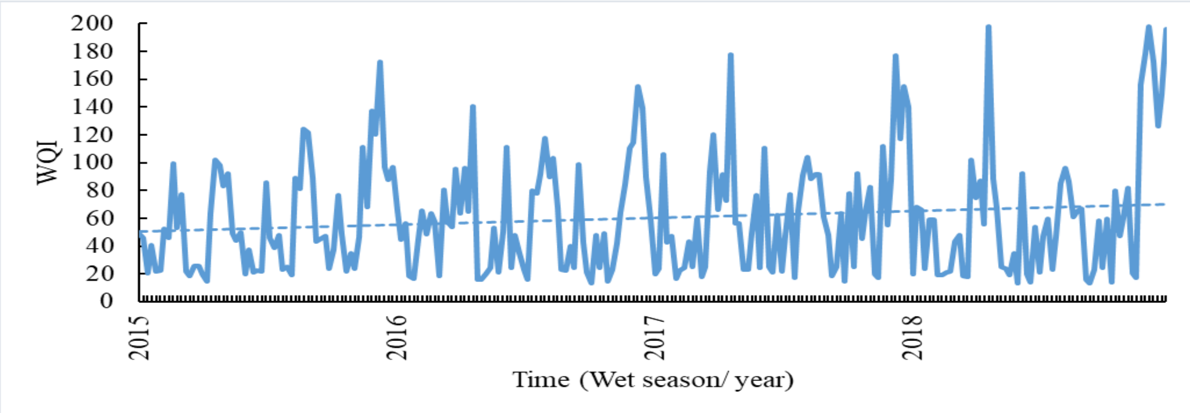

Figure 4. 5: Changes in the wet seasons' WQI

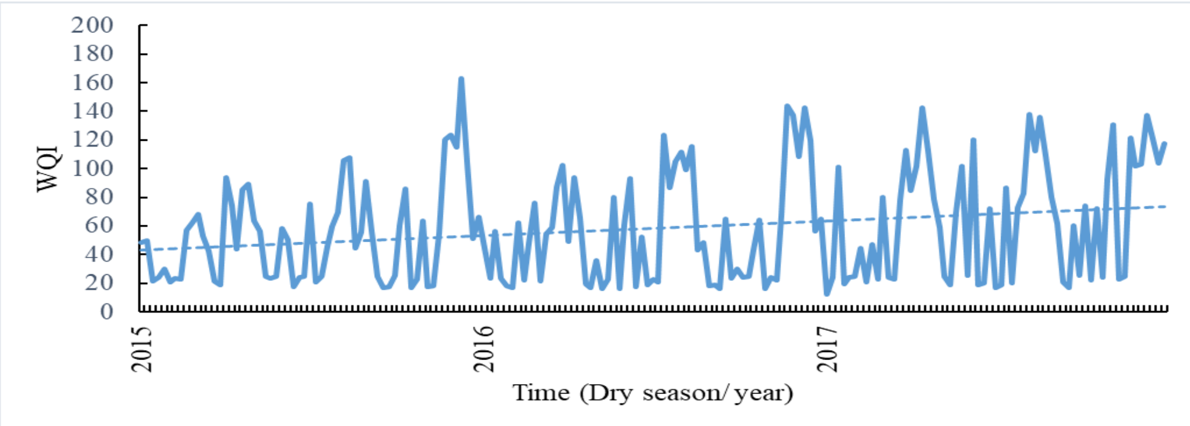

Figure 4. 6: Changes in the dry seasons' WQI

Figure 4.7 up to 4.10 showed the results of different WQI at different locations (wells). Figure 4.7 depicted changes in the 2015 wet and dry seasons' WQI. As seen from the graph the quality of water was higher in the dry season, and the water quality index varied for different wells, well number 58 had the highest value of WQI among other wells for both wet and dry season, it means that the water status in the well was unsuitable for drinking purpose it needed proper treatment before use.

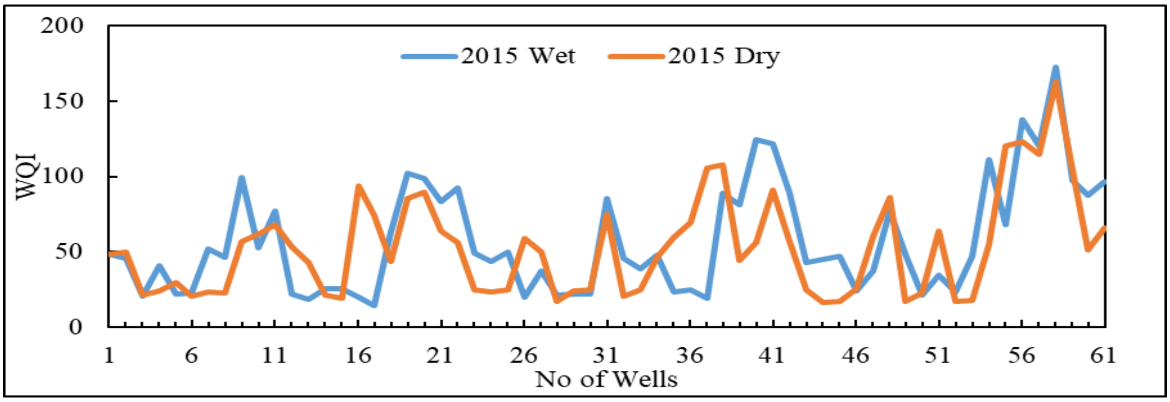

Figure 4. 7: Changes in the WQI of wells during the 2015 wet and dry seasons

Figure 4.8 exhibits changes in the WQI of the 2016 wet and dry seasons. As seen from the graph the quality of water was higher in the dry season, and the water quality index varied for different wells, well number 58 had the highest value of WQI among other wells for wet, it means that the water status in the well was unsuitable for drinking purpose it needed proper treatment before use, but for dry season there were some wells that have very poor status of WQI, it needed Restricted use for Irrigation and there was no well that had the unsuitable for drinking purpose status.

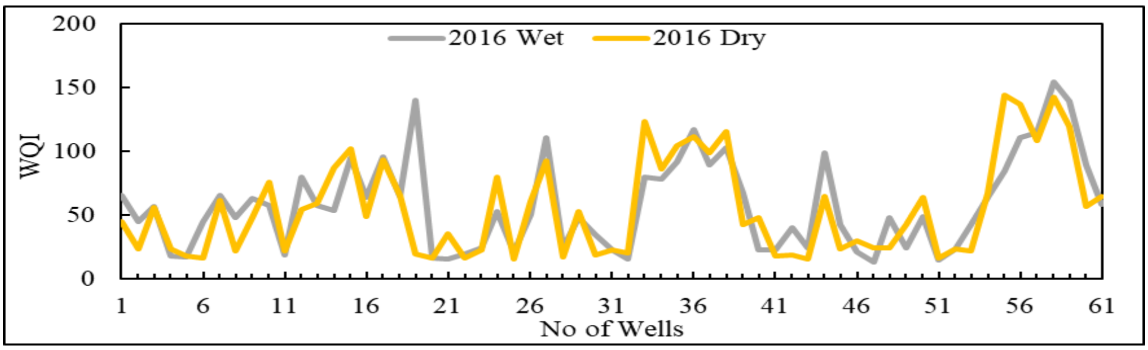

Figure 4. 8: Changes in the WQI of wells during the 2016 wet and dry seasons

Figure 4.9 exhibited changes in the WQI of the 2017 wet and dry seasons, as it seen from the graph the quality of water was higher in the dry season, and the water quality index varied for different wells, wells number(19,58,59 and 60) had the highest value of WQI among other wells for wet season, it means that the water status in the wells unsuitable for drinking purpose it needed proper treatment before used, but for dry season there were some wells that had very poor status of WQI, it needed Restricted use for Irrigation and there was no well that had the unsuitable for drinking purpose status.

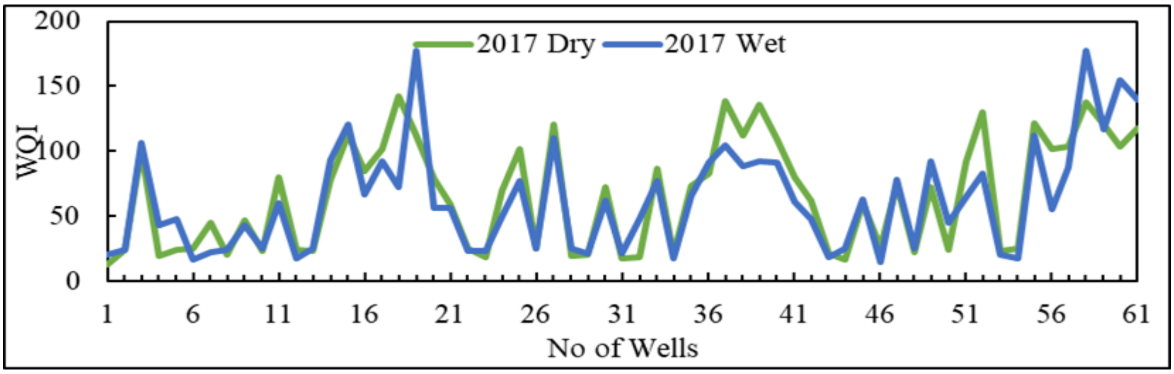

Figure 4. 9: Changes in the WQI of wells during the 2017 wet and dry seasons

Figure 4.10 exhibited changes in the WQI of the 2018 wet season and the WQI varied for different wells, wells number (19, 23, 55,56,57,58 and 61) had the highest value of WQI among other wells for the season. As it seen from the graph the quality of water was lowest in 2018 wet season among the other years and seasons, it means that the water status in the wells was unsuitable for drinking purpose increased compared to the other years and seasons proper treatment was required before use.

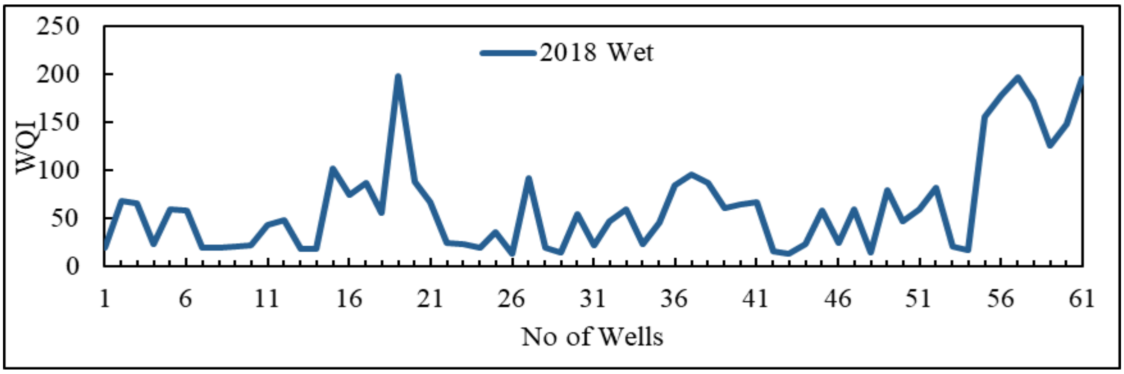

Figure 4. 10: Changes in the WQI of wells during the 2018 wet season

4.4 Geostatistical Analysis

Data normalization was done prior to the determination of the semivariograms using ArcGIS Geostatistical Analyst. Kriging and Inverse distance weighted (IDW) were applied in this computation for groundwater parameters and WQI parameters were used for WQI parameter. For finding the most suitable method between kriging and IDW, RMSE was used to the groundwater parameters and WQI of the dry and wet seasons. The results in table 4.8 up to 4.11 showed that the suitable method varied for mapping each groundwater parameters of the dry and wet seasons. Based on RMSE for the wet season out of 13 parameters 10 parameters were found the minimum RMSE and Kriging methods were more suitable. 6 of them required transformation before applying the method but the others no need transformation. Whereas 3 parameters were found the minimum RMSE and IDW method is more suitable and no need transformation for mapping the groundwater parameters as shown in the table (4.8 and 4.9).

Table 4. 8: RMSE of the wet season semivariogram models (Original)

Model on original data				
parameters	**Kriging**			**IDW**
	Spherical	**Exponential**	**Gaussian**	
Turbidity(NTU)	3.244	3.254	**3.239**	3.332
pH	**0.242**	0.243	0.244	0.247
EC (µS/cm)	79.625	79.322	79.721	**79.124**
TDS (mg/l)	39.812	39.661	39.86	**39.562**
T.A (mg/l)	44.347	44.216	44.681	**43.264**
T.H (mg/l)	59.278	59.946	58.691	58.363
Ca +2 (mg/l)	14.754	14.953	14.602	14.474
Mg +2 (mg/l)	5.726	5.708	5.814	5.849
Na + (mg/l)	**15.058**	15.192	15.47	15.155
K+ (mg/l)	11.171	11.206	11.28	11.586
Cl- (mg/l)	8.488	8.344	8.486	8.47
NO3- (mg/l)	15.509	15.509	15.509	15.98
So4-2 (mg/l)	27.669	28.329	**27.33**	29.245

*Boldface numbers indicate the minimum RMSE

Table 4. 9: RMSE of the wet season semivariogram models (Transformation)

Model on transformed data				
Parameters	**Kriging**			**IDW**
	Spherical	**Exponential**	**Gaussian**	
Turbidity (NTU)	3.305	3.302	3.285	3.332
pH	0.242	0.244	0.244	0.247
EC (µS/cm)	83.273	82.943	83.112	79.124
TDS (mg/l)	41.636	41.472	41.556	39.562
T.A (mg/l)	45.129	44.18	45.33	43.264
T.H as CaCO3 (mg/l)	58.66	59.21	**58.078**	58.363
Ca +2 (mg/l)	14.603	14.738	**14.448**	14.474
Mg +2 (mg/l)	5.803	**5.675**	5.802	5.849
Na + (mg/l)	15.421	15.692	16.036	15.155
K+ (mg/l)	10.571	**10.555**	10.562	11.586
Cl- (mg/l)	8.299	**8.063**	8.306	8.47
NO3- (mg/l)	15.656	**15.382**	15.629	15.98
So4-2 (mg/l)	27.98	28.423	27.649	29.245

*Boldface numbers indicate the minimum RMSE

Table 4.10 showed minimum RMSE for the dry season out of 13 parameters 10 parameters were found with the minimum RMSE 10 parameters were found the minimum RMSE and Kriging method was more suitable 7 of them required transformation before applying the methods but the others did not need transformation. Whereas 3 parameters were found with the minimum RMSE and IDW method was more suitable and there was no need transformation of mapping the groundwater parameters.

As shown in the table (4.12 and 4.13) Different methods were used to evaluate semivariogram models among Spherical, Exponential and Gaussian Based on ME, RMSE, RMSS, MSE, and ASE for varied parameters.

Table 4. 10: RMSE of the dry season semivariogram models (original)

Model on original data				
Parameters	**Kriging**			**IDW**
	Spherical	**Exponential**	**Gaussian**	
Turbidity (NTU)	1.762	1.738	1.771	1.764
pH	0.294	**0.293**	0.293	0.294
EC (µS/cm)	128.804	129.447	128.266	**127.844**
TDS (mg/l)	63.89	63.822	63.976	**63.058**
T.A (mg/l)	44.809	44.689	44.288	**44.274**
T.H as CaCO3 (mg/l)	92.372	**93.217**	92.318	92.919
Ca +2 (mg/l)	**23.308**	23.423	23.503	23.701
Mg +2 (mg/l)	9.788	9.858	9.823	9.711
Na + (mg/l)	18.093	17.694	18.129	18.592
K+ (mg/l)	0.992	0.987	1.017	0.958
Cl- (mg/l)	29.303	28.55	29.59	26.126
NO3- (mg/l)	21.677	21.677	21.677	19.853
So4-2 (mg/l)	21.677	21.677	21.677	20.963

*Boldface numbers indicate the minimum RMSE

Table 4. 11: RMSE of the dry season semivariogram models (Transformation)

Model on transformed data				
parameters	**Kriging**			**IDW**
	Spherical	**Exponential**	**Gaussian**	
Turbidity (NTU)	1.655	1.666	**1.653**	1.764
pH	0.3	0.298	0.299	0.294
EC (µS/cm)	130.461	130.37	129.935	127.844
TDS (mg/l)	64.312	64.389	64.367	63.758
T.A (mg/l)	44.868	45.066	44.341	44.274
T.H as CaCO3 (mg/l)	92.762	94.305	94.132	92.919
Ca +2 (mg/l)	23.413	23.485	23.588	23.701
Mg +2 (mg/l)	9.869	**9.708**	9.838	9.711
Na + (mg/l)	**17.414**	17.414	17.414	18.592
K+ (mg/l)	0.966	**0.946**	0.983	0.958
Cl- (mg/l)	26.452	**26.021**	26.499	26.126
NO3- (mg/l)	20.531	**19.43**	20.387	19.853
So4-2 (mg/l)	20.531	20.43	**20.387**	20.963

For wet season the Kriging method with Gaussian model was appropriated to be used for these parameters Turbidity, Total Hardness, Calcium (Ca^{+2}) and sulfate, at the same time, the Kriging method with exponential model was fit to be utilized for these parameters Magnesium (Mg^{+2}), Potassium (K^{+1}), Chlorine (Cl^{-1}) and Nitrate (No_3^{-1}), also PH and Sodium (Na^{+1}) fitted to be used with Spherical model. The kriging method with Exponential model was suitable to be used for Sulfate (So_4^{-2}), for other three parameters (E.C, TDS, Total alkalinity) IDW method were applied since the method had minimum RMSE for these three parameters.

Table 4. 12: best semivariogram model map production features of the wet season

Parameters	Method	Model	ME	RMSE	MSE	RMSS	ASE
Turbidity (NTU)	Kriging	Gaussian	-0.021	3.239	-0.005	0.849	3.898
pH	Kriging	Spherical	-0.001	0.242	-0.007	1.065	0.222
EC (µS/cm)	IDW	-	-1.451	79.124	-	-	-
TDS (mg/l)	IDW	-	-0.725	39.562	-	-	-
T.A (mg/l)	IDW	-	-1.234	43.264	-	-	-
T.H (mg/l)	Kriging	Gaussian	0.855	58.078	-0.007	1.002	58.674
Ca +2 (mg/l)	Kriging	Gaussian	0.201	14.448	-0.008	1.004	14.563
Mg +2 (mg/l)	Kriging	Exponential	0.129	5.675	0.009	1.026	5.532
Na + (mg/l)	Kriging	Spherical	-0.044	15.058	-0.007	1.006	14.816
K+ (mg/l)	Kriging	Exponential	-1.471	10.555	-0.757	0.945	4.945
Cl- (mg/l)	Kriging	Exponential	-0.12	8.063	-0.03	0.948	8.4506
NO3- (mg/l)	Kriging	Exponential	0.79	15.382	0	0.862	20.309
So4-2 (mg/l)	Kriging	Gaussian	0.119	27.33	0.004	1.098	25.33

For dry season the Kriging method with Gaussian model was suitable to be used for these parameters Turbidity, sulfate at the same time, the Kriging method with the exponential model was fitted to be utilized for these parameters PH, Total Hardness, Na^{+1}, Ca^{+2}, No_3^{-1}, Cl^{-1}, K^{+1}, and Mg^{+2} also fitted to be used with the Spherical model. The kriging method with Exponential model was suitable to be used for Sulfate (So_4^{-2}), for other three parameters (E.C, TDS, Total alkalinity) IDW method were applied since the method has minimum RMSE for these three parameters.

Table 4. 13: best semivariogram model map production features of the dry season

Parameters	**Method**	**Model**	**ME**	**RMSE**	**MSE**	**RMSS**	**ASE**
Turbidity(NTU)	Kriging	Gaussian	-0.043	1.653	-0.079	1.175	1.691
pH	Kriging	Exponential	0.931	0.293	0.013	0.746	28.82
EC (μS/cm)	IDW	-	-3.583	127.844	-	-	-
TDS (mg/l)	IDW	-	-3.583	63.058	-	-	-
T.A (mg/l)	IDW	-	-2.019	44.274	-	-	-
T.H (mg/l)	Kriging	Exponential	1.038	93.217	0.008	0.98	95.705
Ca +2 (mg/l)	Kriging	Spherical	0.707	23.308	0.026	0.962	24.645
Mg +2 (mg/l)	Kriging	Exponential	0.169	9.708	-0.012	0.962	10.236
Na + (mg/l)	Kriging	Spherical	0.562	17.414	0.011	0.949	18.958
K+ (mg/l)	Kriging	Exponential	-0.044	0.946	-0.14	1.035	0.6671
Cl- (mg/l)	Kriging	Exponential	-1.222	26.021	-0.141	1.084	17.142
NO3- (mg/l)	Kriging	Exponential	0.931	19.43	0.013	0.746	28.82
So4-2 (mg/l)	Kriging	Gaussian	0.933	20.387	0.014	0.744	28.765

4.5 Spatial Distribution of Groundwater Parameters

GWQ maps were essential in evaluating the feasibility of utilizing the water for various used. The attribute and spatial data were used for the generation of spatial variation maps of main water quality parameters like Turbidity, pH, E.C, TDS, Sulfate, Magnesium, Total Hardness, Sodium, Chlorine, Nitrate, Potassium, Calcium Based on these spatial variation maps of main water quality parameters, GWQ map of the area of study was prepared using GIS. This GWQ map benefits to knowing the existing groundwater status of the study area. The distribution of groundwater parameters spatially showed in figure 4.6 up to 4.18.

4.5.1 Turbidity

Turbidity levels in groundwater varied from 0.4 NTU to 16 NTU for the wet season and from 0.2 NTU to 6.1 NTU for the dry season. According to WHO (2011) turbidity for drinking consumption should not be more than 5 NTU. Figure 4.11 showed that the spatial distribution map of turbidity for the wet season was increasing to the central part of the study areas but for the dry season was increasing to the northwest.

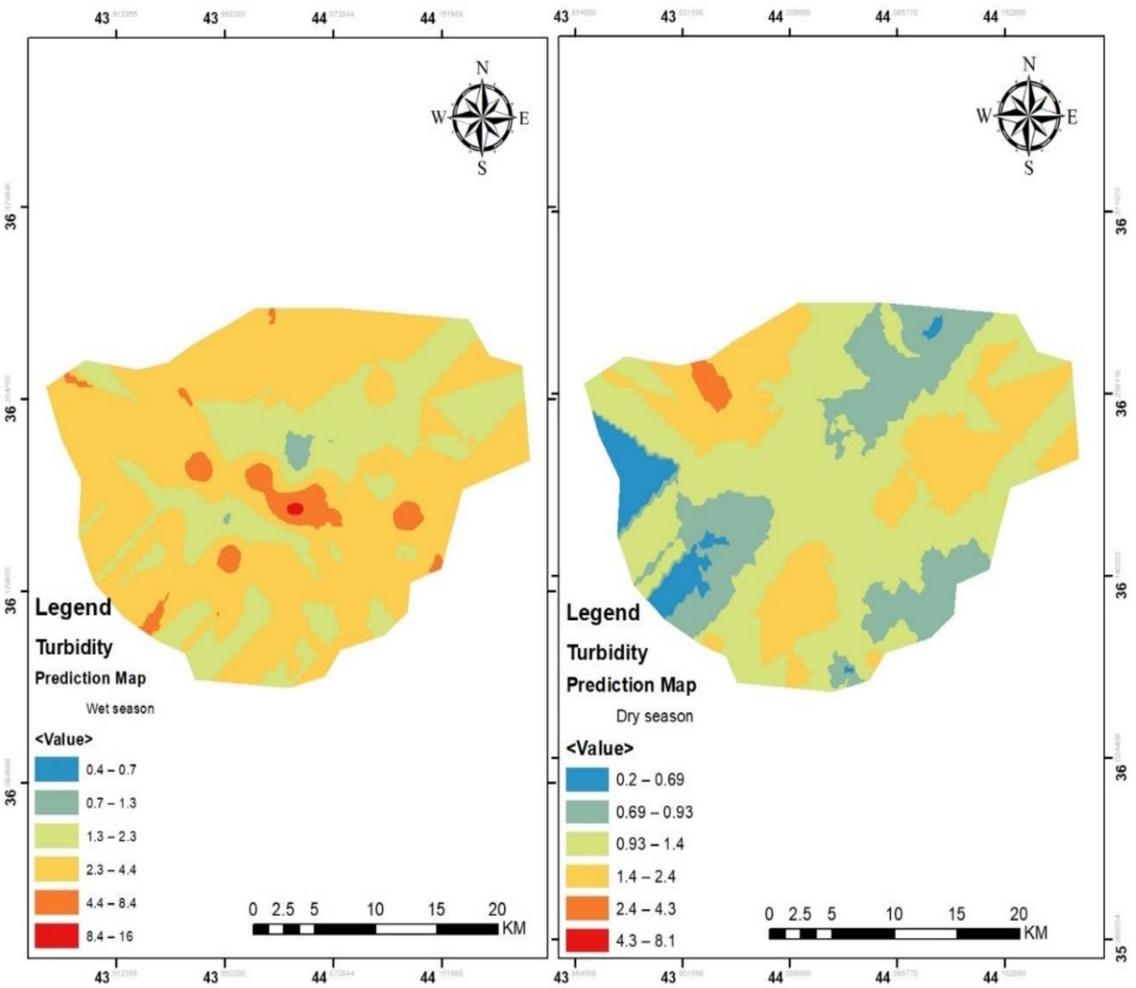

Figure 4. 11 : Spatial variability map of groundwater quality of turbidity

4.5.2 Potential of hydrogen

The PH levels in the groundwater of study area ranged from a minimum value 7.2 to a maximum value of 8.2 for wet season and a minimum value 7.1 to a minimum value of 8.3 for the dry season respectively. No health guideline value was suggested for the PH level. While PH mostly had no direct effect on users, the WHO suggested that contaminant level of PH in drinking water should be between 6.5-8.5mg/l. The PH levels in all of the analyzed samples were found to be within the suggested 6.5-8.5mg/l range. The spatial distribution of PH concentrations was shown in the figure. 4.12. It was shown that the PH concentration increased to the southern part of the study area for wet season and the small value of PH concentrations occur in the east for the dry season.

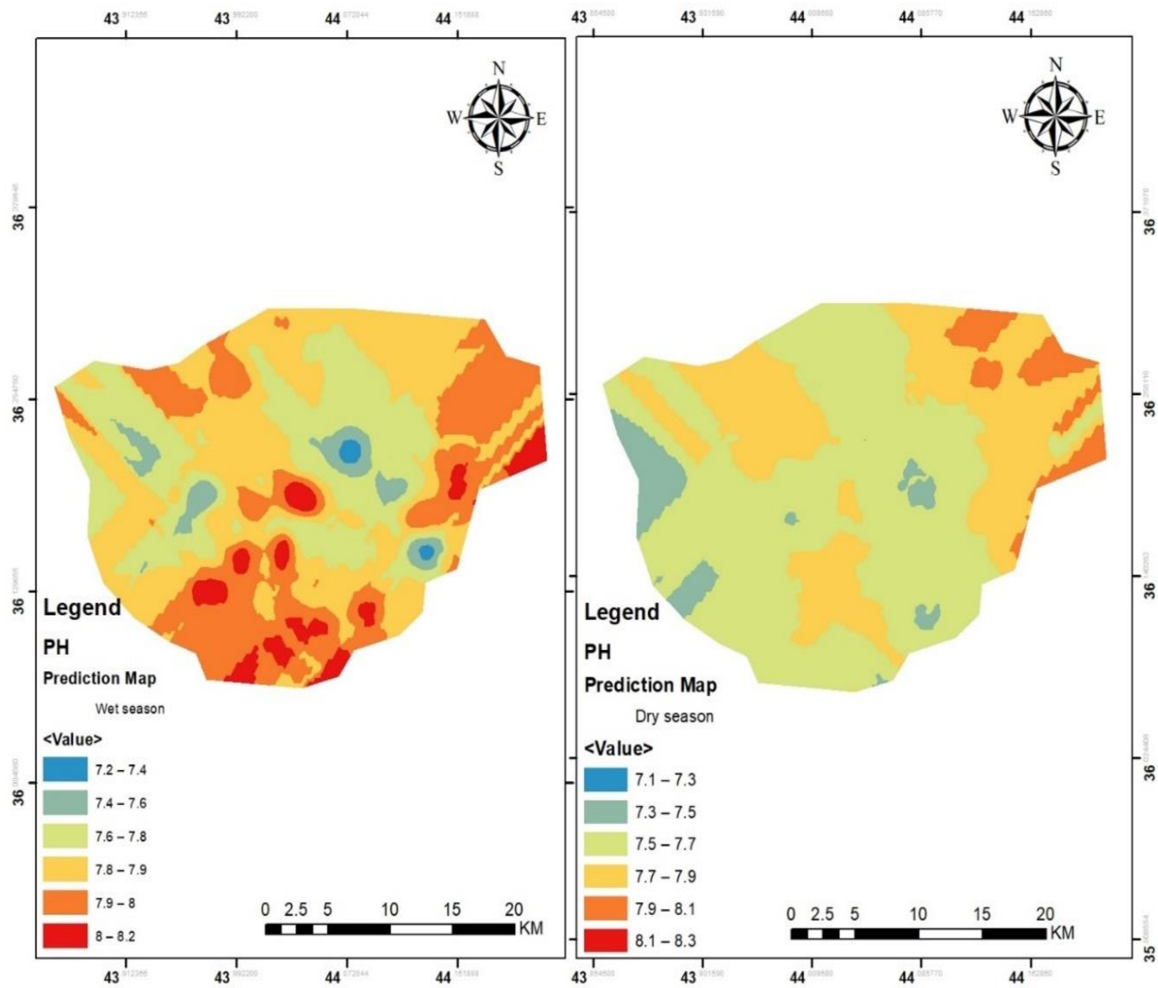

Figure 4. 12: Spatial variability map of groundwater quality of PH

4.5.3 Electrical conductivity

The electrical conductivity in study area varied from a minimum of 430 μS/cm to a maximum of 780 μS/cm for the wet season and from a minimum 410 μS/cm to maximum 960 μS/cm, respectively. Electrical conductivity (EC) was a parameter correlated to total dissolved solids (TDS). Effendi (2003) established that 1,500 μS/cm was suitable for drinking purpose but the electrical conductivity of the seawater can reach 10000 μS/cm while 20–1,500μS/cm related to natural water. The spatial distribution of EC concentrations in figure 4.13 showed that they were increasing towards the center part of the study area for both seasons wet and dry, and all wells have EC concentration below 1500 μS/cm.

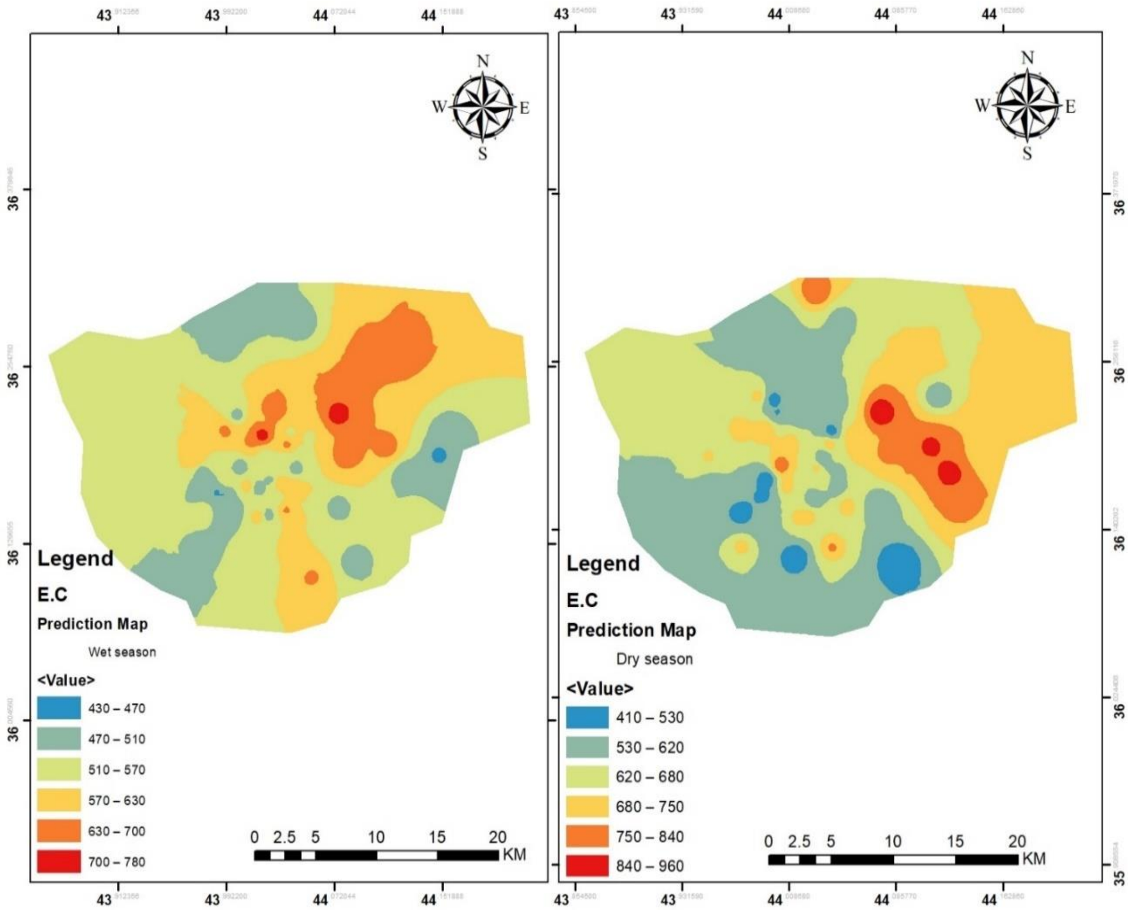

Figure 4. 13: Spatial variability map of groundwater quality of EC

4.5.4 Total dissolved solid

TDS is an amount of materials that dissolved in water and can include organic ions, Na^{+1}, Ca^{+2}, No_3^{-1}, Cl^{-1}, K^{+1}, Mg^{+2}, So_4^{-2} and other ions (UNICEF, 2008). The TDS varied in the study area of this research from 210 mg/l to 480 mg/l and from 210 mg/l to 390 mg/l for the dry and wet seasons respectively. According to the WHO guideline, 1,000 mg/l was set for TDS with regards to taste. The spatial variation map for TDS for this study was prepared into six class ranges are presented in figure 4.14 which depicted that the concentrations of TDS increased towards the central part during both dry and wet seasons. All wells had TDS concentration below 1000 mg/l.

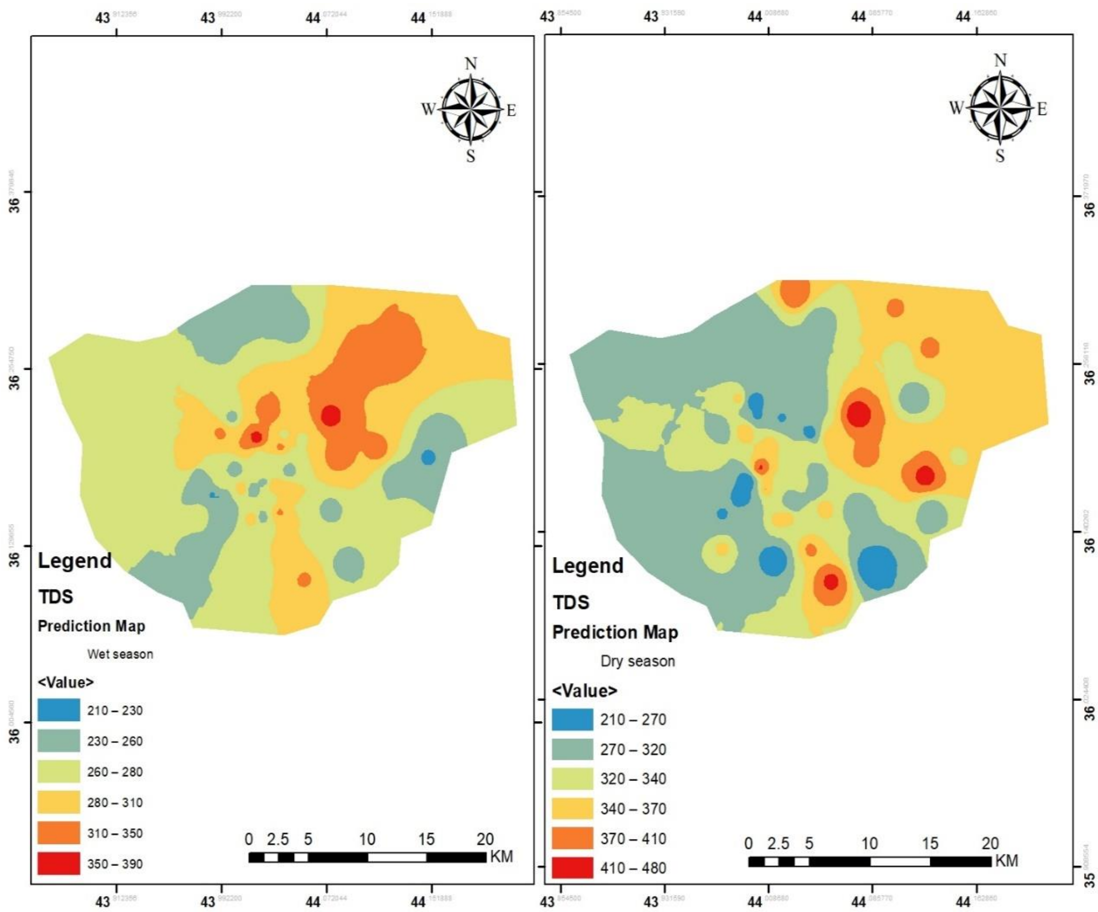

Figure 4. 14: Spatial variability map of groundwater quality of TDS

4.5.5 Total alkalinity

The total alkalinity levels in study area varied from 180 mg/l to 390 mg/l and from 190 mg/l to 370 mg/l for both dry and wet seasons respectively. The map showed that the concentration levels of some samples were found to be of the desired standard of 200 mg/L (WHO, 2011) while the levels in remaining other samples exceeded the desirable limit. The spatial distribution map of total alkalinity in figure 4.15 showed that the concentration was increased to the direction of the southeast and the city center of the study area for wet and dry seasons.

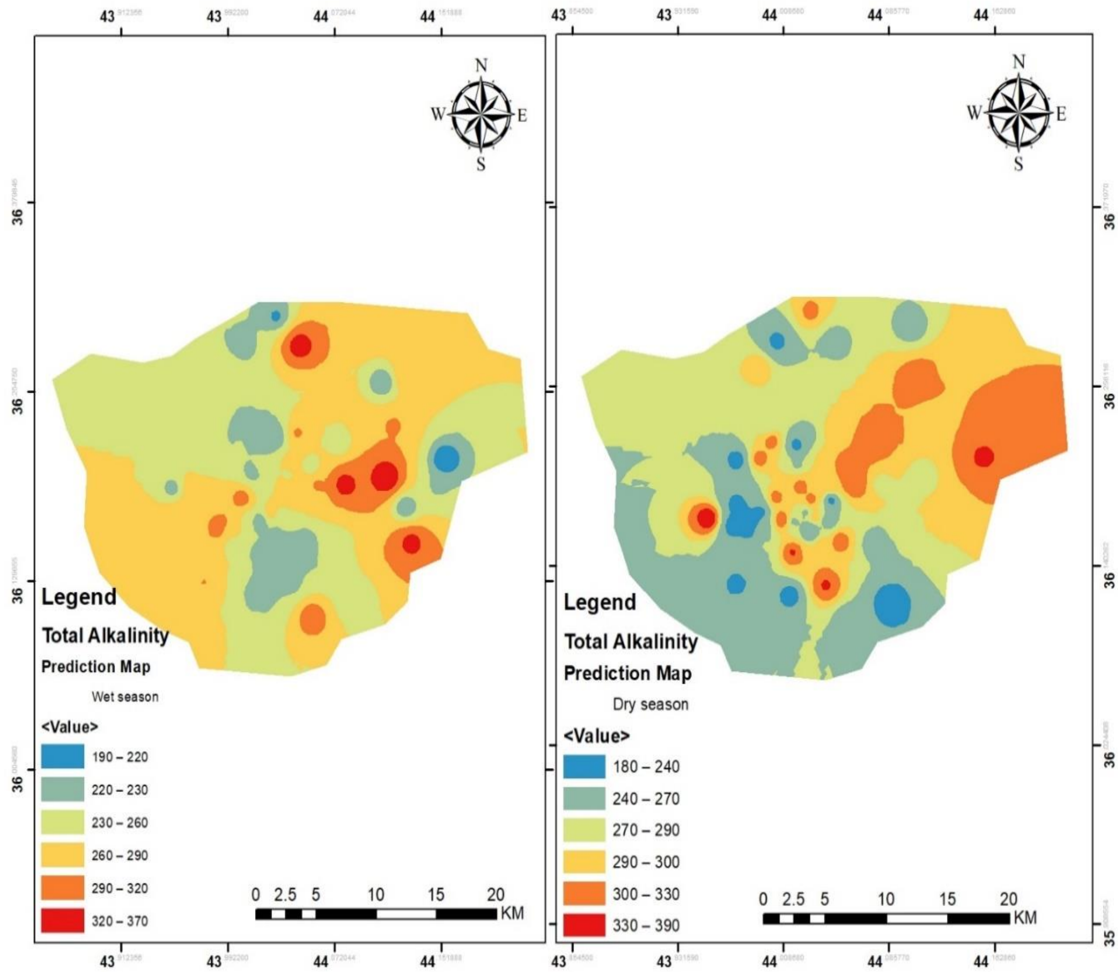

Figure 4. 15: Spatial variability map of groundwater quality of T. Alkalinity

4.5.6 Total hardness

Sulfates, chlorides, hardness, magnesium nitrates, calcium bicarbonates, and carbonates in water caused an increase in total hardness. An evaluation of the hardness distribution the spatial variation map for the total hardness of Erbil presented in figure 4.16 below. The hardness concentration in the groundwater of the study area was ranged from 190 mg/l to 480 mg/l and from 190 mg/l to 570 mg/l, respectively. Nitrate concentration in the groundwater for drinking, must not surpassed to 500 mg/l. From the map, it was observed that total hardness tends increased towards the center of the area. Some wells for the wet season were above the suggested value all other wells for the dry season had concentration below 500 mg/l.

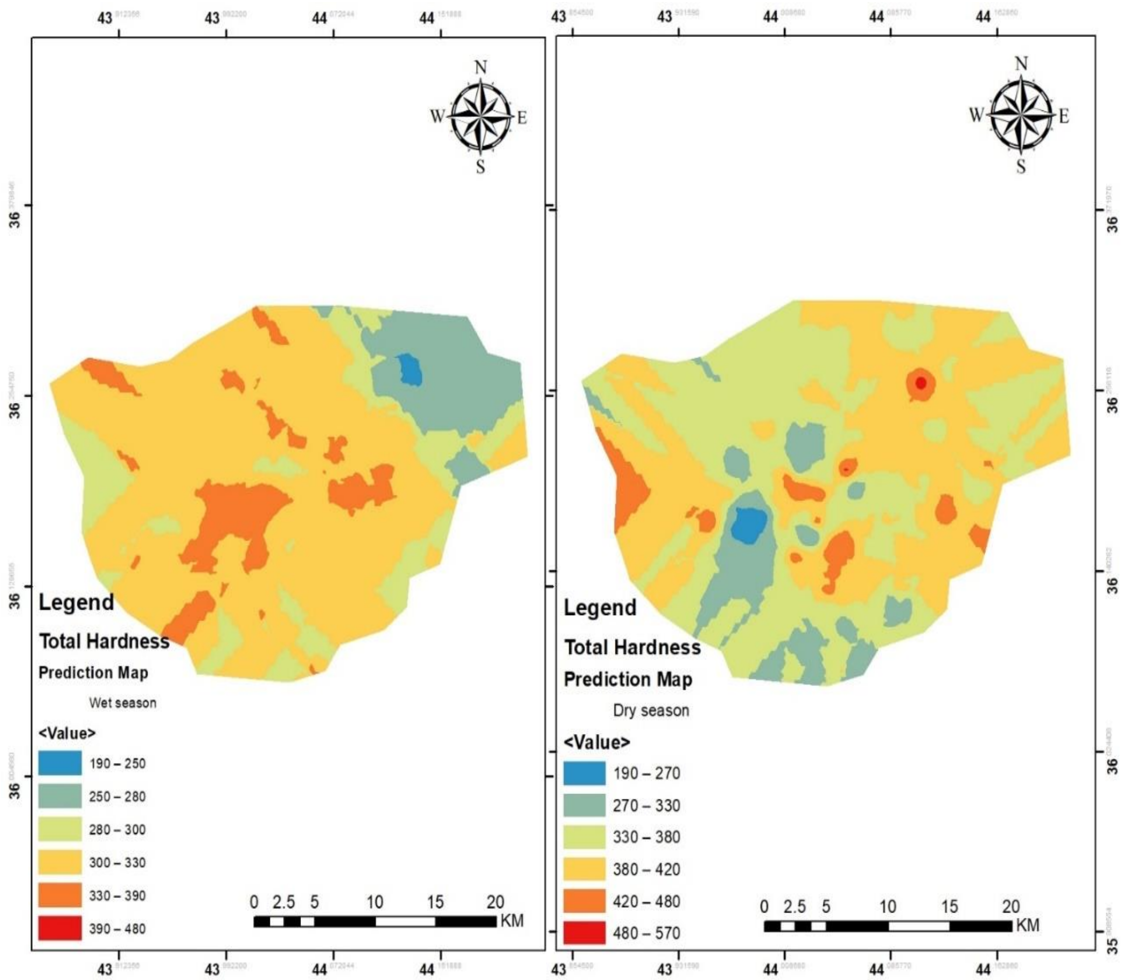

Figure 4. 16: Spatial variability map of groundwater quality of T.H

4.5.7 Calcium

The presence of limestone, dolomite, and gypsum minerals were the main cause of occurs Ca^{+2} in wastewater, industrial water, and water treatment. The process also donated calcium to groundwater and surface water. Leaching of calcium increased from soils as a result of acidic rainwater. The calcium in groundwater of the area of study varied from a minimum of 49 to a maximum of 120 mg/l and a minimum of 47 to a maximum of 140 mg/l for both dry and wet seasons respectively. Effendi (2003) exposed that 400 mg/l and 30–100 mg/l were respective standards for water that was nearby the sea and carbonate rocks while natural water had less than 15 mg/l of calcium. Also, the WHO (2011) posited that a 75 mg/l lower Ca+2 concentration limit was suitable for drinking water purposes. Figure 4.17 depicted that a high calcium concentration was noted to be in the middle of the dry and wet seasons. There were some wells which have calcium concentration above 75 mg/l, other wells had calcium concentration that did not surpass 75 mg/l.

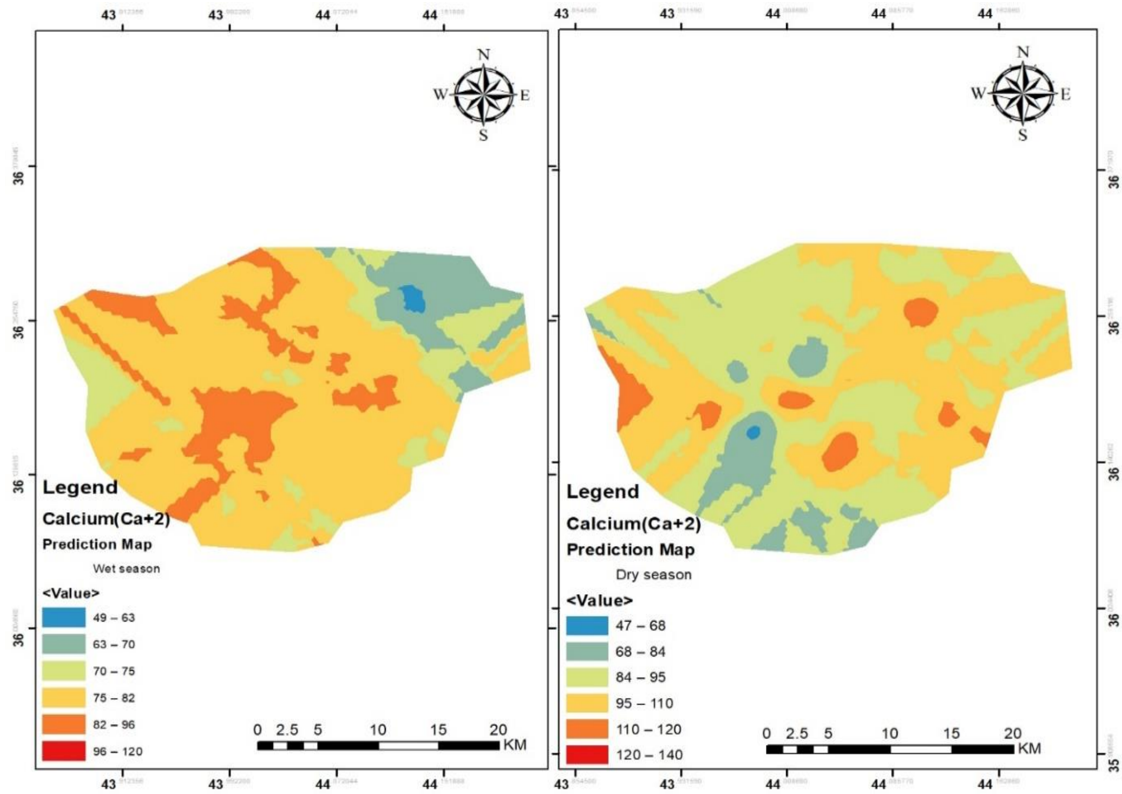

Figure 4. 17: Spatial variability map of groundwater quality of Ca^{+2}

4.5.8 Magnesium

As noted by Perk (2006), water hardness was mainly as a result of the presence of calcium and magnesium and their respective concentrations were from 17 mg/l to 66 mg/l and from 17 mg/l to 49 mg/l respectively. However, the magnesium concentration should not be more 30 mg/l for drinking purposes. Figure 4.18 showed that the concentration tended to decreased as one approaches the eastern part of the wet season but for the dry season the parameter was decreased towards the center, some wells in the wet season above the suggested level but all the wells for the dry season have magnesium concentration were below 50 mg/l.

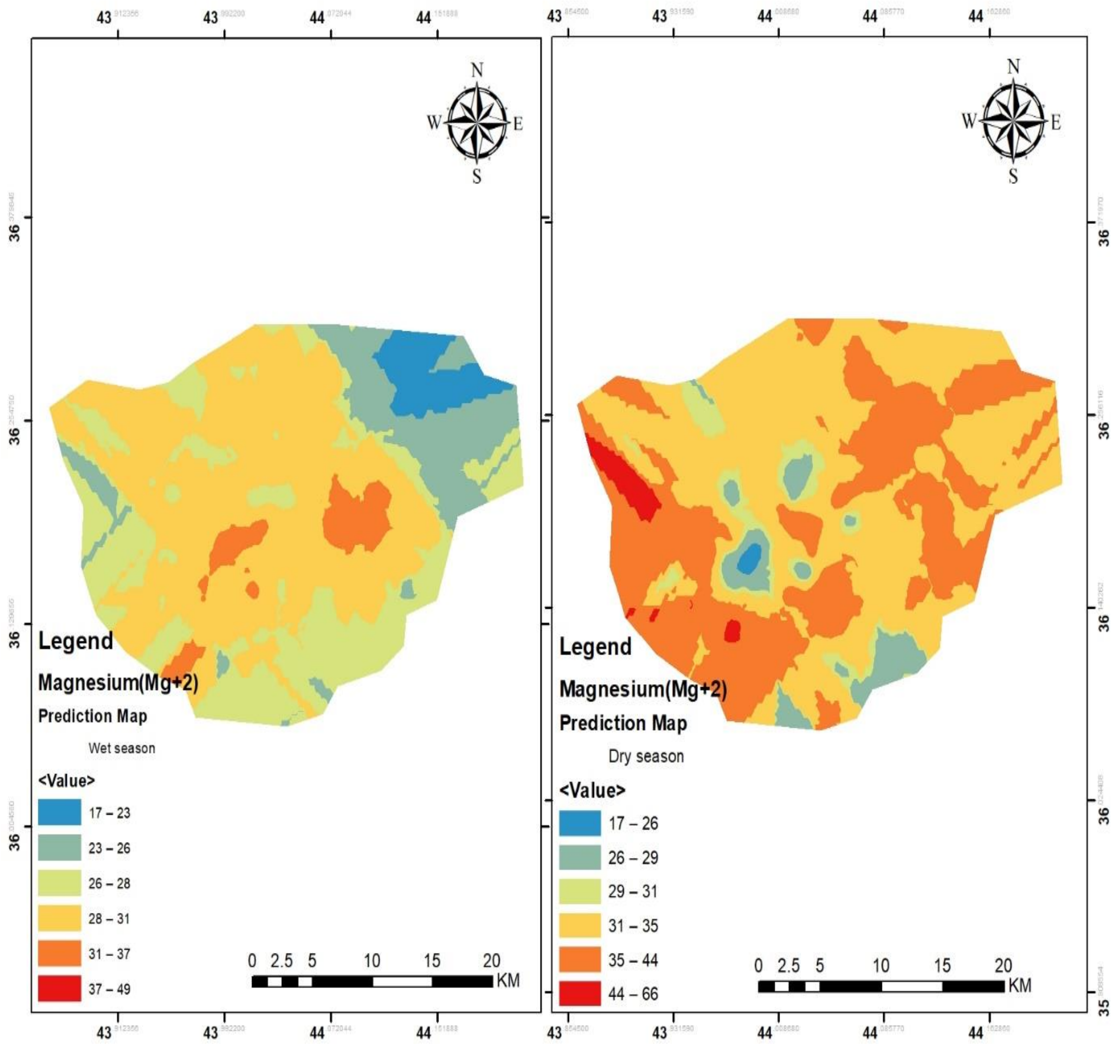

Figure 4. 18: Spatial variability map of groundwater quality of Mg^{+2}

4.5.9 Sodium

Na^{+1} concentrations level in groundwater of study area ranged from 12 mg/l to 96 mg/l and from 11 mg/l to 61 mg/l for dry and wet seasons respectively. Maximum contaminant levels for Na+1 in drinking water were suggested as to be 200 mg/l by WHO. Na+1 concentrations in all the analyzed samples were found to be of the required standard (200 mg/l) for dry and wet seasons. Spatial distribution map in figure 4.19 showed that Na+1 increased to the direction of southern and central part of the study area for wet season and the concentration was increased to the northern part for the dry season.

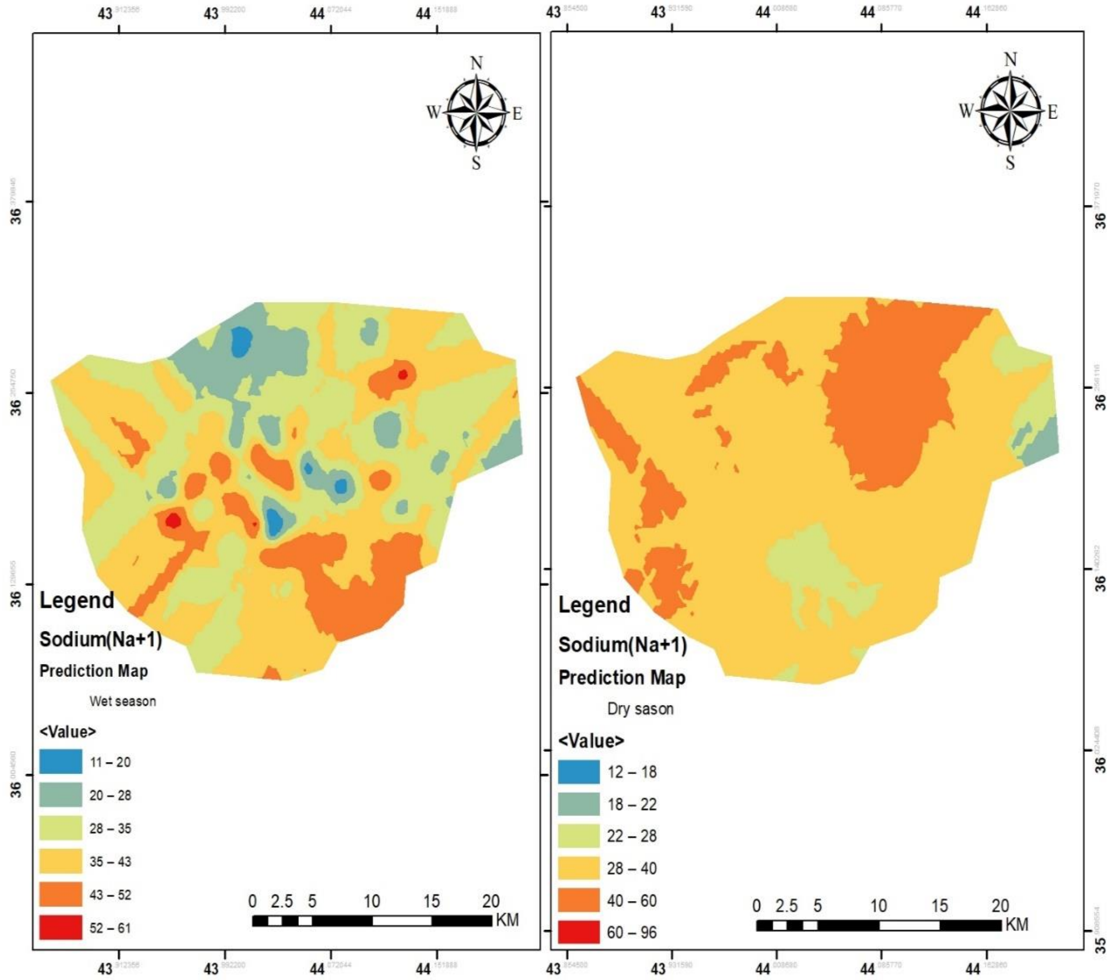

Figure 4. 19: Spatial variability map of groundwater quality of Na^{+1}

4.5.10 Potassium

Potassium levels in groundwater of the study area ranged from 0.8 mg/L to 6.2 mg/l and from 0.8 mg/L to 60 mg/l for dry and wet seasons respectively. The maximum contaminant level for Na+1 in drinking water was suggested as to be 12 mg/l by WHO. Concentrations in all the analyzed samples were found to be within the desirable 12 mg/l limit for the dry season but K+1 concentration for wet season in some wells had the value desirable limit (12 mg/l). The spatial distribution map in figure 4.20 showed that K+1 decreased to the direction of northern east for wet season and the parameter was also decreased towards the middle part of the area.

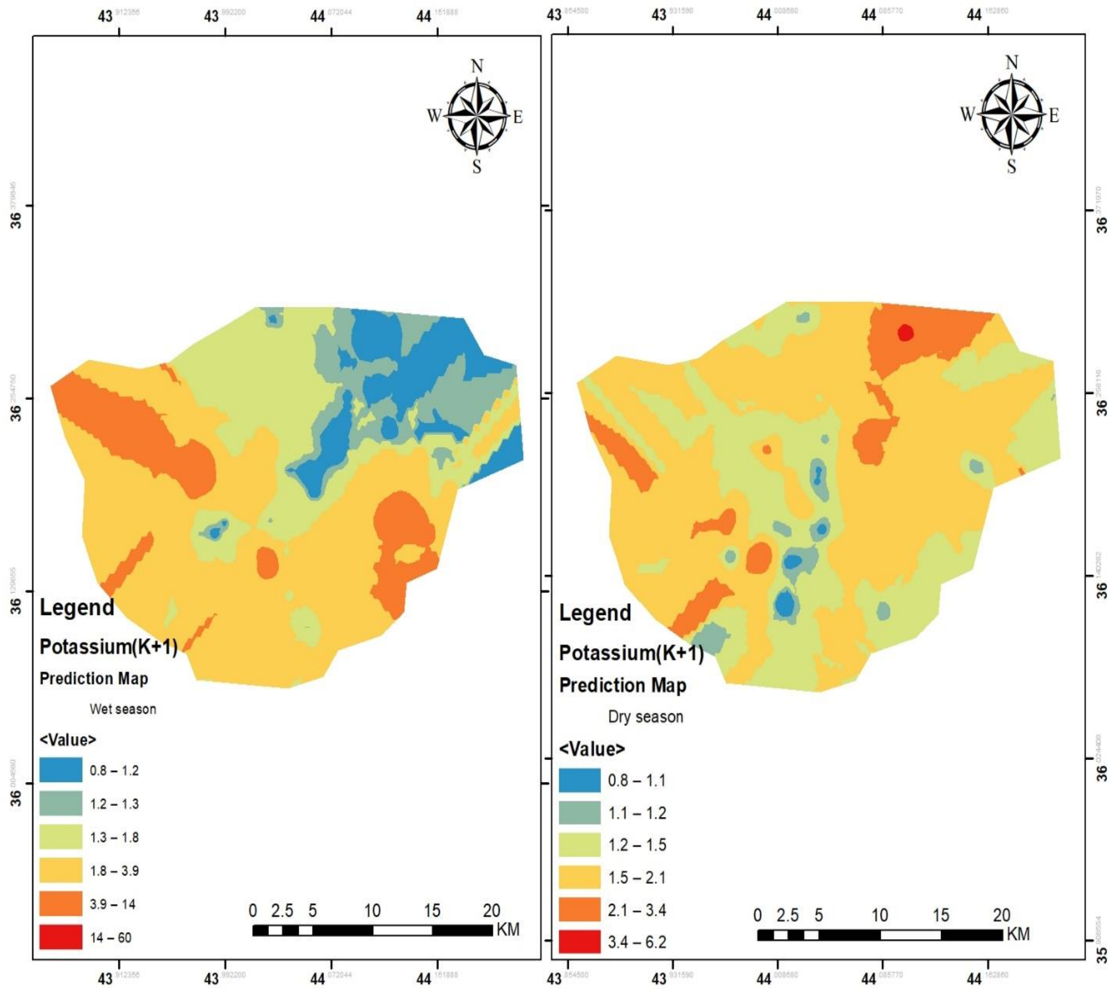

Figure 4. 20: Spatial variability map of groundwater quality of K^{+1}

4.5.11 Chlorine

Both the dry and wet seasons must had chlorine concentration levels of 14 to 55 mg/l respectively. But the occurrence of weathering can trigger a huge release of chlorides into the water and too much of it can cause the water to be too salty (Effendi, 2003). Hence, a 200 mg/l standard was set for all drinking water uses. A 200 mg/l chlorine concentration limit was discovered to be prevalent in all wells. Figure 4.21 depicted that the concentration decreased toward the northern part of the area.

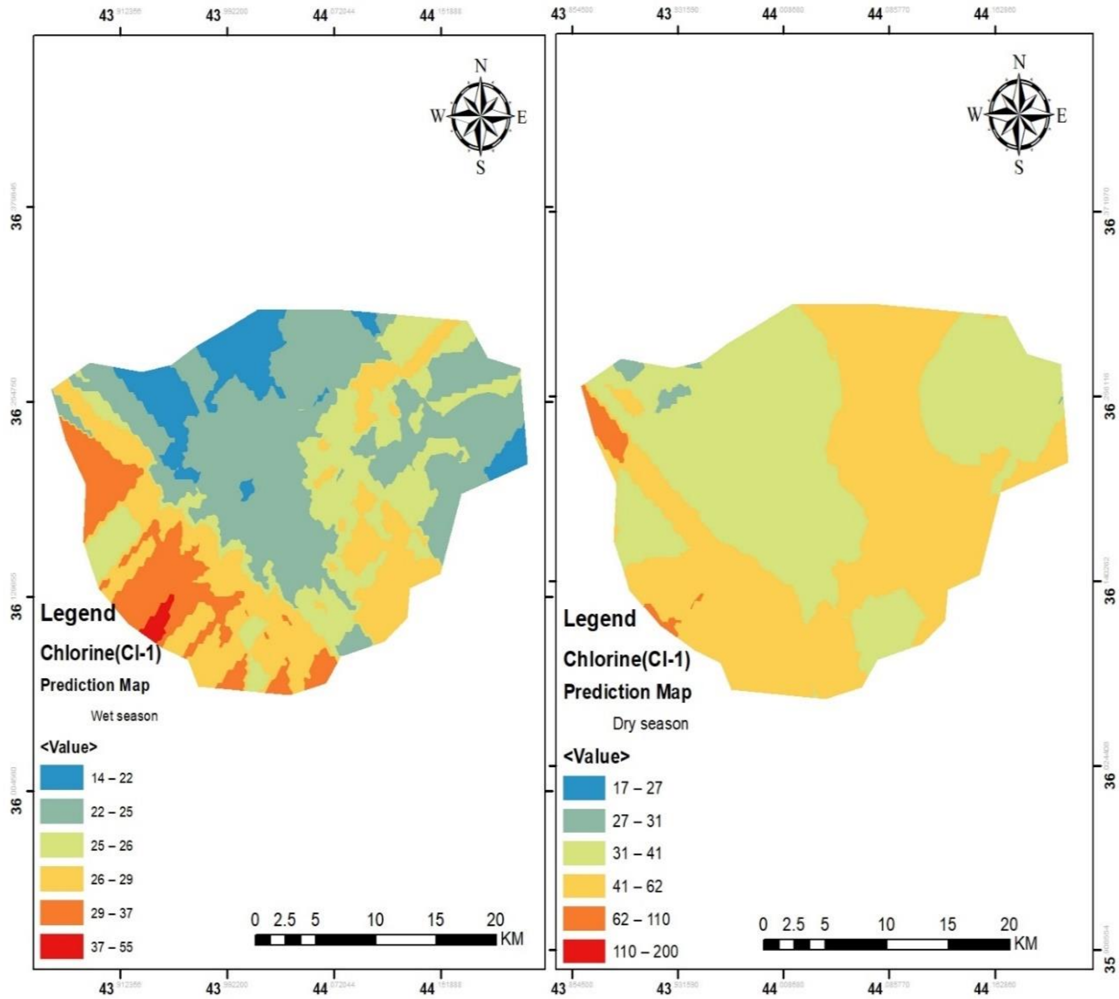

Figure 4. 21: Spatial variability map of groundwater quality for Cl^{-1}

4.5.12 Nitrate

Nitrate levels should be within the 19 to 120 mg/l and 6.5 to 66.5 mg/l limits for dry and wet seasons. But, high concentration levels of 1000 mg/l can be observed in areas with severe agricultural activities due to a high release of fertilizer compounds into the water. As a result, drinking water must had a concentrate of not more than 45 mg/l (WHO, 2011). Figure 4.22 depicted that several wells had severe nitrate concentrations, and this possessed health problems. However, both the dry and wet seasons were characterized by declining nitrate concentration towards the western part.

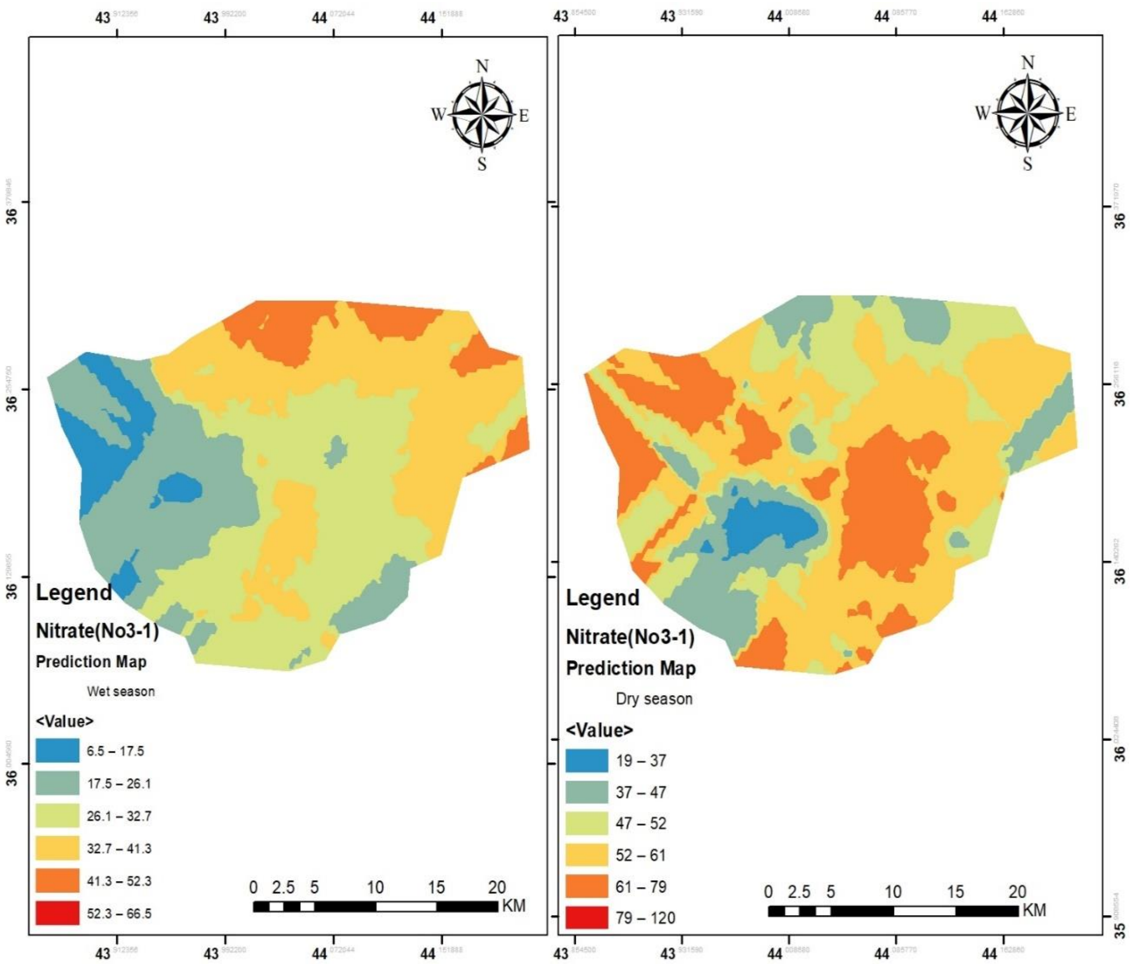

Figure 4. 22: Spatial variability map of groundwater quality of No_3^{-1}

4.5.13 Sulfate

The WHO (2011) asserted that the presence of anhydrite and gypsum results in the formation of sulfates and this also includes activities such as industrial discharge and the burning of fossil fuels. UNICEF (2008) asserted that any level that was higher above 400 mg/l renders the water unsafed for drinking. All the parameters were also noted to conform to the 250 mg/L standard. In this study, dry and wet seasons were not to be having concentration levels of 19 to 120 mg/l and 20 to 160 mg/l respectively as depicted in figure 4.23.

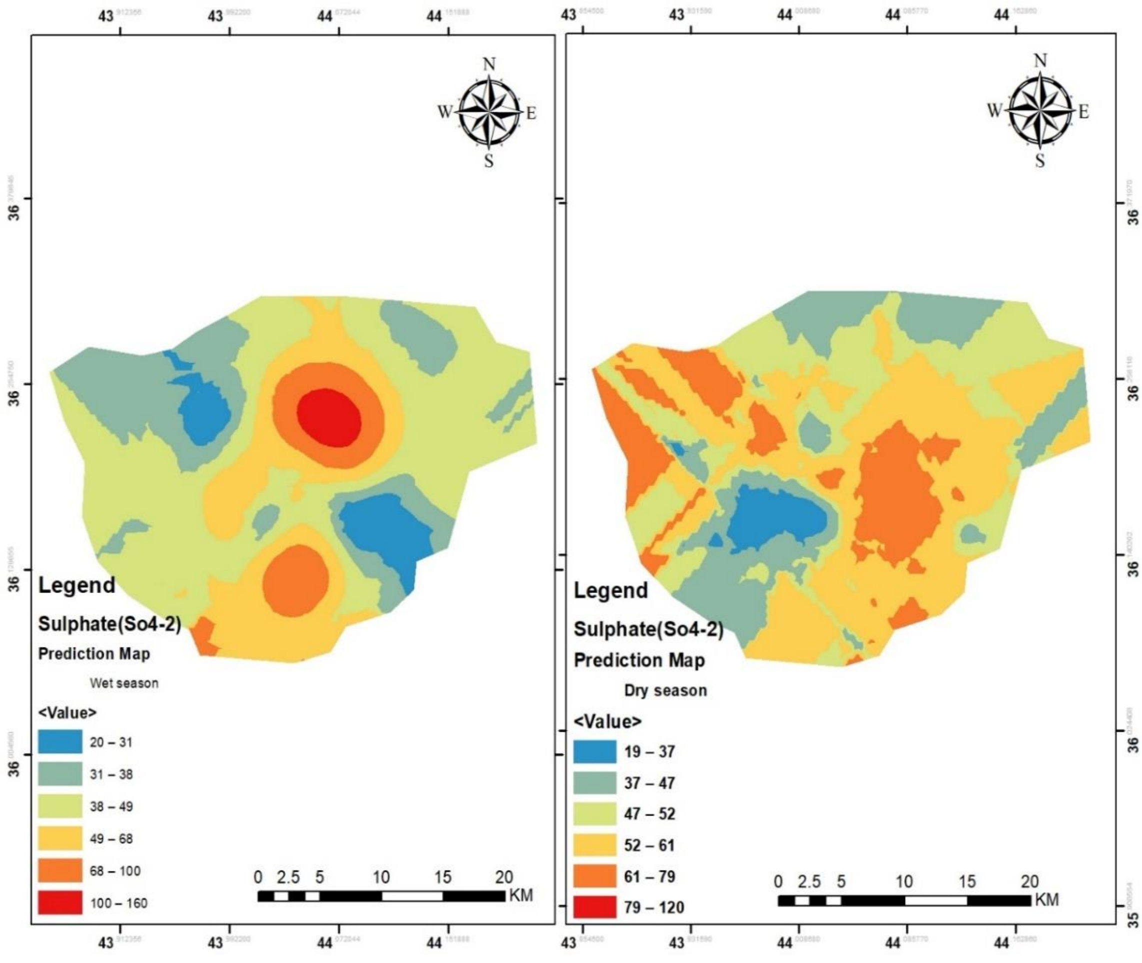

Figure 4. 23: Spatial variability map of groundwater quality of So_4^{-2}

4.6 Groundwater Quality Index Map

The GWQI was estimated from thirteen parameters of water quality parameters. Then groundwater quality maps were processed to get the output map (WQI map) using geostatistical methods in GIS. Kriging and IDW were tested in this process. The RMSE was used to determine the most suitable method between Kriging and IDW.

The results in table 4.14 and 4.15 showed that the suitable method varied from mapping each WQI in different seasons based on the RMSE and out of the seven parameters, six parameters were found to be having a minimum RMSE. The Kriging method was more suitable for mapping the parameters and one of them had a minimum RMSE without log transformation whereas five parameters were found to be having a minimum RMSE with log transformation. The IDW method was more suitable with the other one parameter which had minimum RMSE.

Table 4. 14: RMSE for semivariogram models based on original data

WQI(Year)	Season	Kriging			IDW
		Spherical	Exponential	Gaussian	
2015	wet	36.143	36.143	**36.140**	37.922
	dry	34.014	34.014	34.014	34.804
2016	wet	36.882	36.882	36.882	36.583
	dry	34.079	34.402	34.372	35.815
2017	wet	42.692	42.692	42.692	41.652
	dry	41.232	41.181	41.165	**40.330**
2018	wet	54.316	54.390	54.250	55.234

**Boldface numbers indicate the minimum RMSE

Table 4. 15: RMSE for semivariogram models based on transformed data

WQI(Year)	Season	Kriging			IDW
		Spherical	Exponential	Gaussian	
2015	wet	36.185	36.175	36.194	37.922
	dry	33.681	33.681	**33.679**	34.804
2016	wet	35.733	36.508	**35.736**	36.583
	dry	**32.029**	33.133	32.115	35.815
2017	wet	40.671	40.483	**40.476**	41.652
	dry	41.931	41.801	41.982	**40.330**
2018	wet	54.066	53.900	**54.018**	55.234

**Boldface numbers indicate the minimum RMSE

Figure 4.24 shows the experimental semivariogram for each theoretical model such as spherical, exponential and Gaussian were generated. As shown in the table (4.16) Different methods were used to evaluate semivariogram models among Spherical, Exponential and Gaussian Based on ME, RMSE, MSE, RMSS, and ASE for varied WQI to generate the map. The kriging method with Gaussian model was appropriate to be used for all period except the period of 2016 dry season it was suitable for the spherical model. But the exponential model had a large RMSE so it was not applied for generating the map.

Table 4. 16: The most fitted semivariogram model characteristics for map generation

WQI(Year)	Season	Method	Model	ME	RMSE	MSE	RMSS	ASE
2015	wet	Kriging	Gaussian	0.85	36.14	0.02	0.98	37.1
	dry	Kriging	Gaussian	0.52	33.68	-0.01	0.86	40.91
2016	wet	Kriging	Gaussian	0.24	35.74	-0.01	0.77	48.29
	dry	Kriging	Spherical	1.1	32.03	0.01	0.74	51.41
2017	wet	Kriging	Gaussian	1.36	40.48	-0.03	0.8	60.31
	dry	IDW	-	0.33	40.33	-	-	-
2018	wet	Kriging	Gaussian	1.33	54.02	-0.07	0.86	78.12

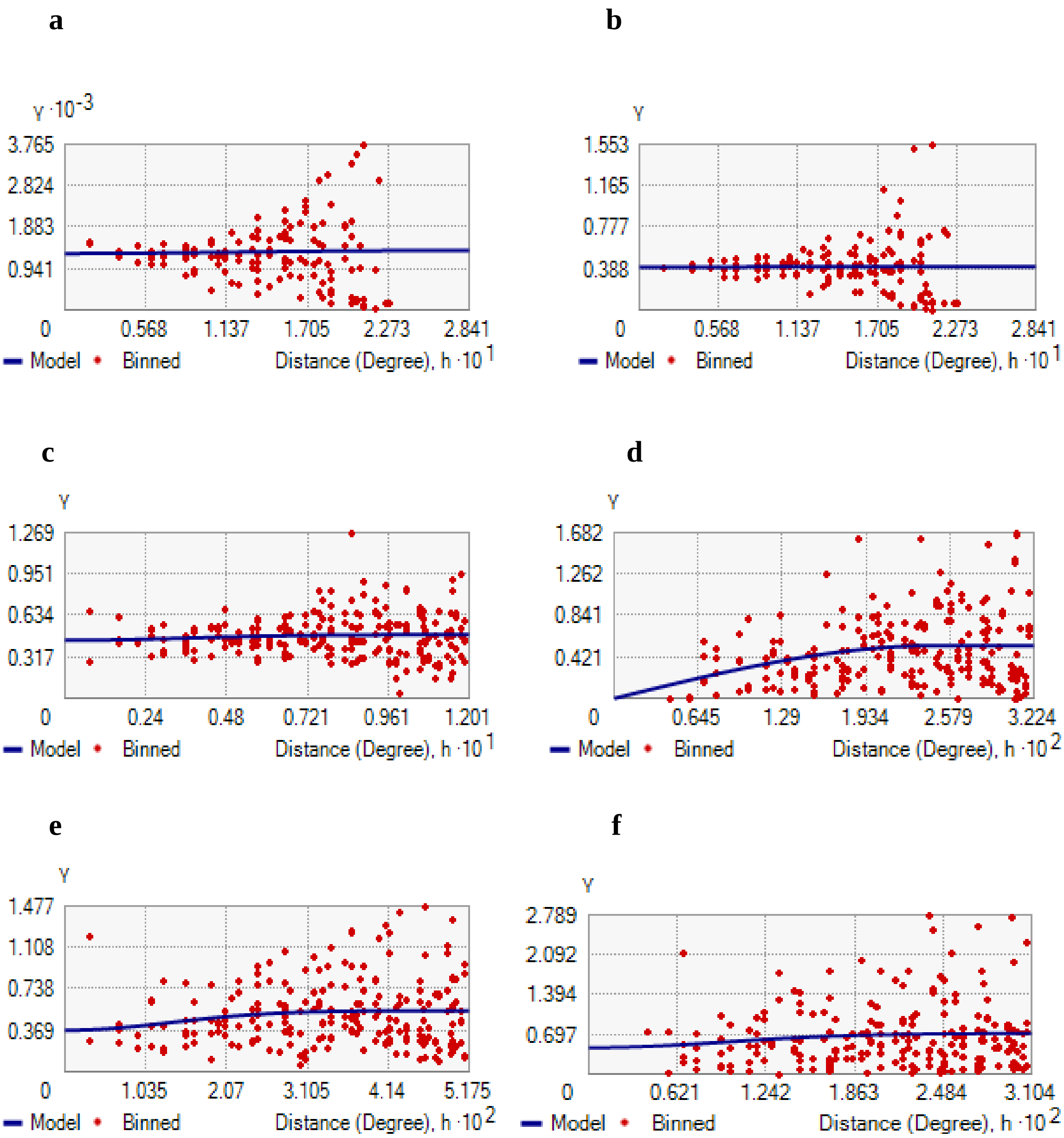

Figure 4. 24: Fitting semivariogram models for the water quality index, **a** Gaussian, **b** Gaussian, **c** Gaussian, **d** spherical, **e** Gaussian, **f** Gaussian

4.6.1 Groundwater quality index map in 2015 wet season

The water quality index was classified into six classes that describe the quality of groundwater in the studied region. These six classes were: excellent, good, fair, poor, very poor, unfit for drinking ranges class of the groundwater quality index of WQI map, figure 4.25 showed that the GWQI in the period of 2015 wet season the below map at the western part of the city, exhibited good and excellent water On the other hand, the northeast of the map had the maximum values of water quality index which mean the quality of water was very poor and improper for drinking. The water quality index of the middle of the study location in the demonstrated map below was fair and poor. As could be observed from the map the overall quality of water was approximately fair and good so that the water could be used for the purpose of irrigation, domestic, and industrial.

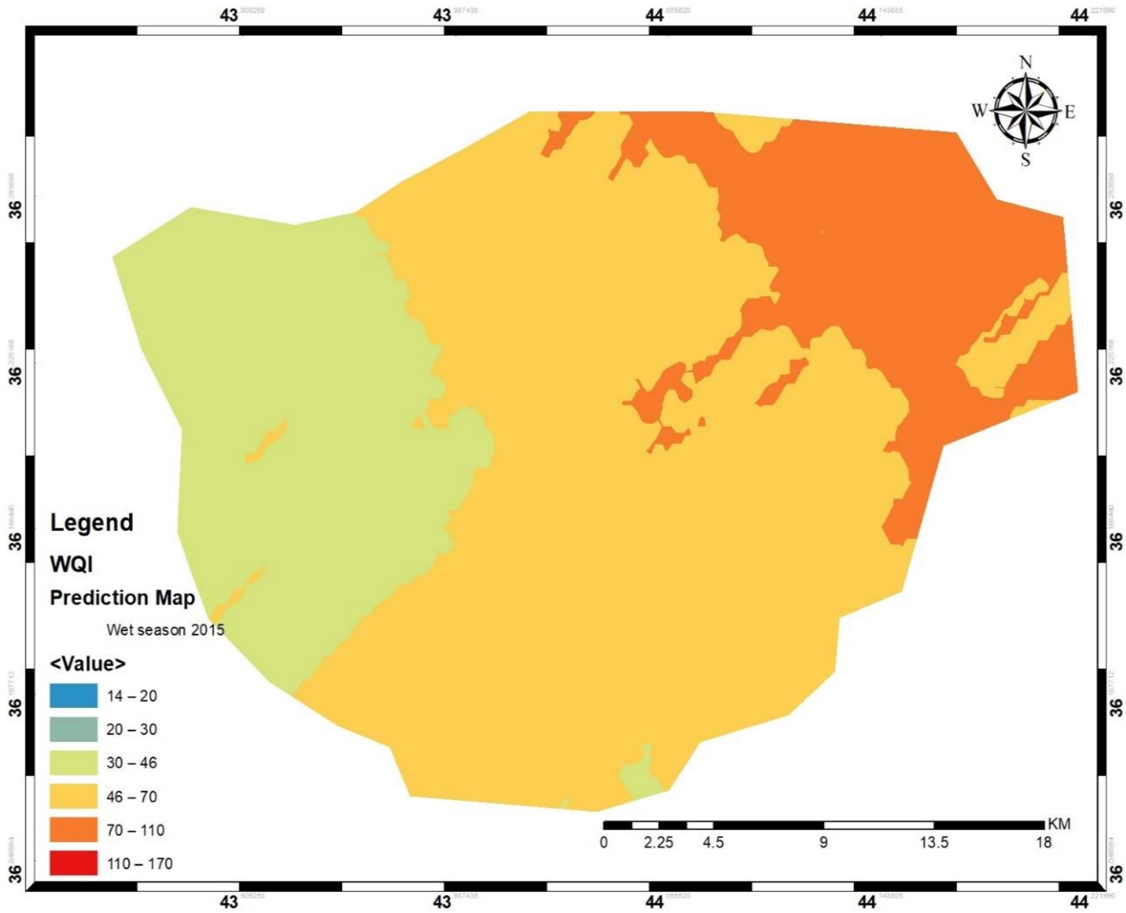

Figure 4. 25: Spatial distribution of groundwater quality index for wet season 2015

4.6.2 Groundwater quality index map in 2015 dry season

The groundwater quality index in the period of 2015 dry season showed in figure 4.26, exhibits good and excellent water, in the other hand the northern part of the map had the maximum values of water quality index which mean the quality of water was very poor and improper for drinking. The water quality index of the south to the east and center of the city in the demonstrated map below was fair and poor. As can be observed from the map the overall quality of water was approximately fair and good so that the water could be used for the purpose of irrigation, domestic, and industrial.

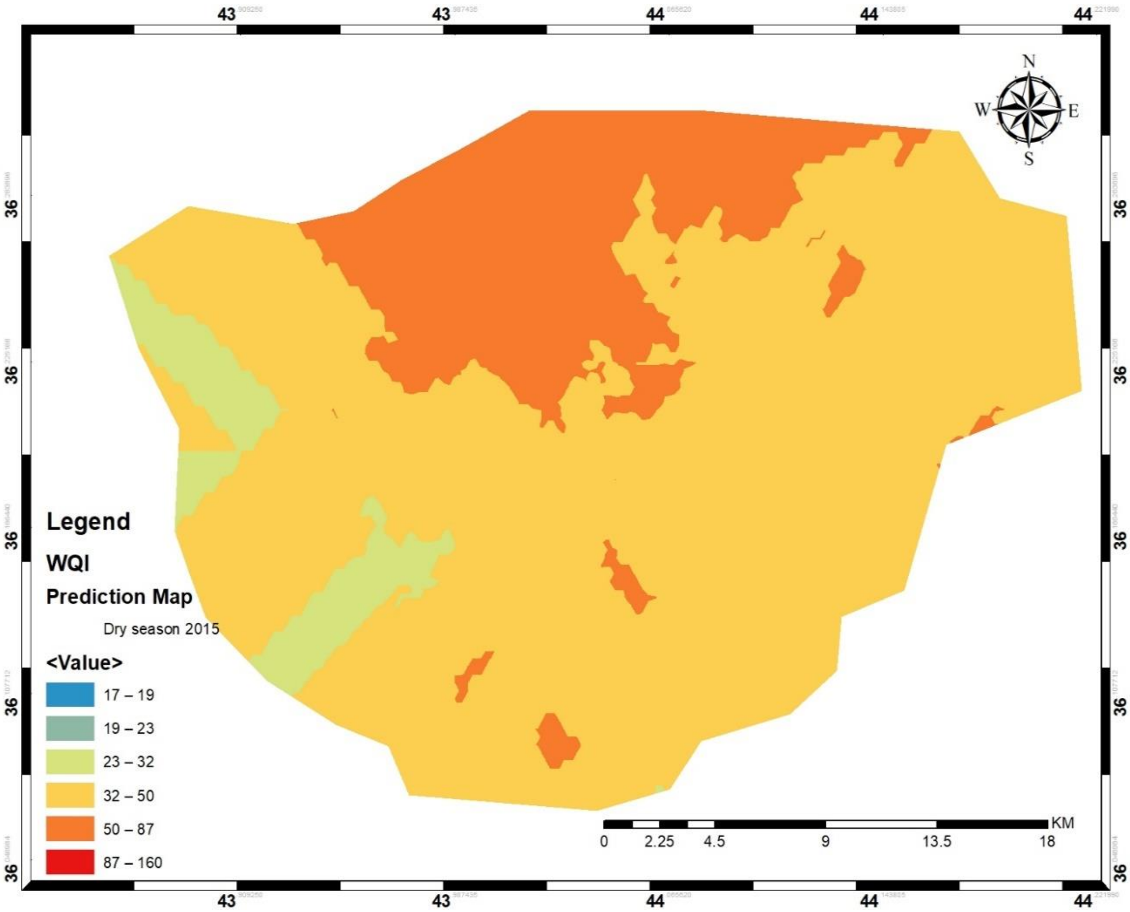

Figure 4. 26: Spatial distribution of groundwater quality index for dry season 2015

4.6.3 Groundwater quality index map in 2016 wet season

The groundwater quality index in the period of 2016 wet season showed in figure 4.27, reveals good and excellent water. On the other hand, the north and northwest and central part of the map had the maximum values of water quality index which mean the quality of water was very poor and unfitted for drinking. The water quality index of most parts of the city in the demonstrated map below was fair and poor. As can be observed from the map the overall quality of water was approximately fair and good so that the water could be used for the purpose of irrigation, domestic, and industrial.

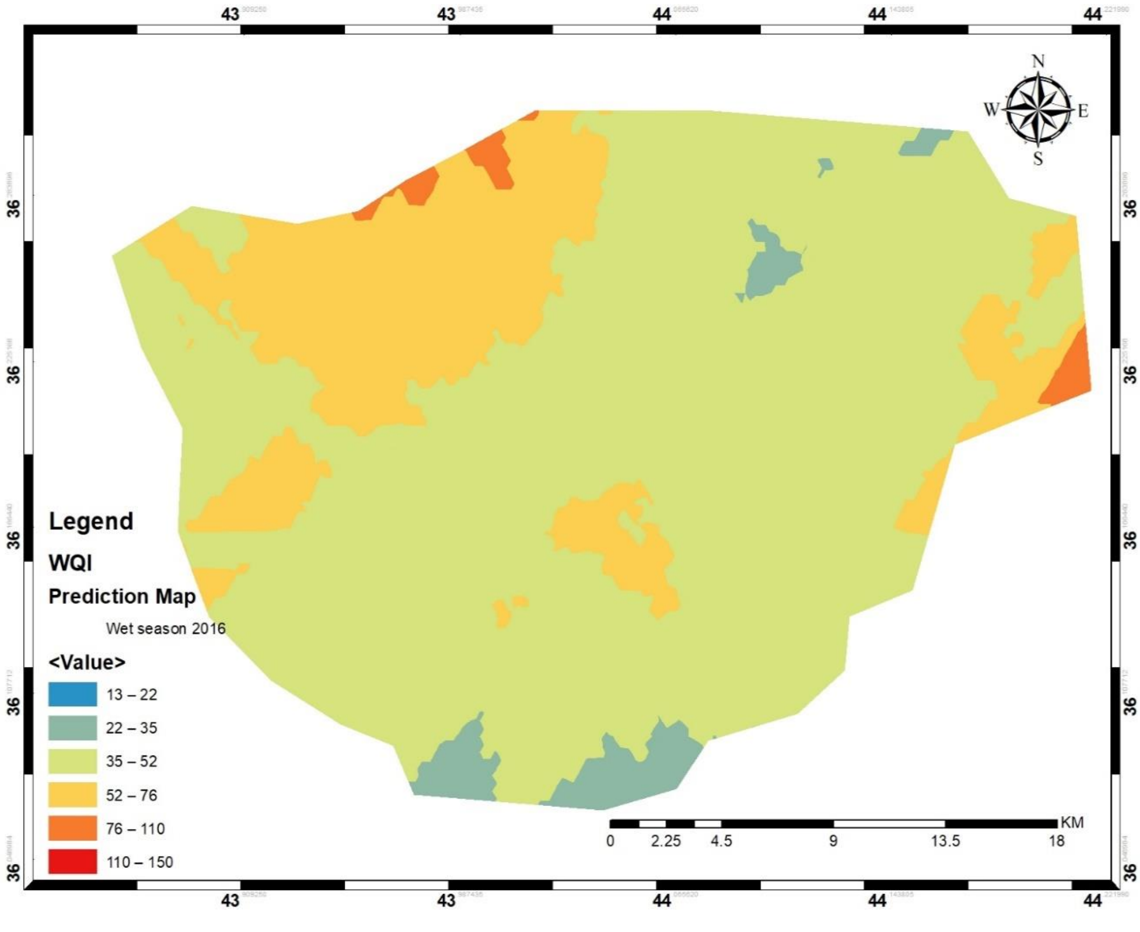

Figure 4. 27: Spatial distribution of groundwater quality index for wet season 2016

4.6.4 Groundwater quality index map in 2016 dry season

The groundwater quality index in the period of 2016 dry season showed in figure 4.28 in the western and central part of the city exhibited good and excellent water. On the other hand, the north, small part of center of the map had the maximum values of water quality index which mean the quality of water was very poor and unfitted for drinking. The water quality index was distributed to all directions of the city as showed in the given map below was fair and good. As can be observed from the map the overall quality of water is approximately fair and good so that the water could be used for the purpose of irrigation, domestic, and industrial.

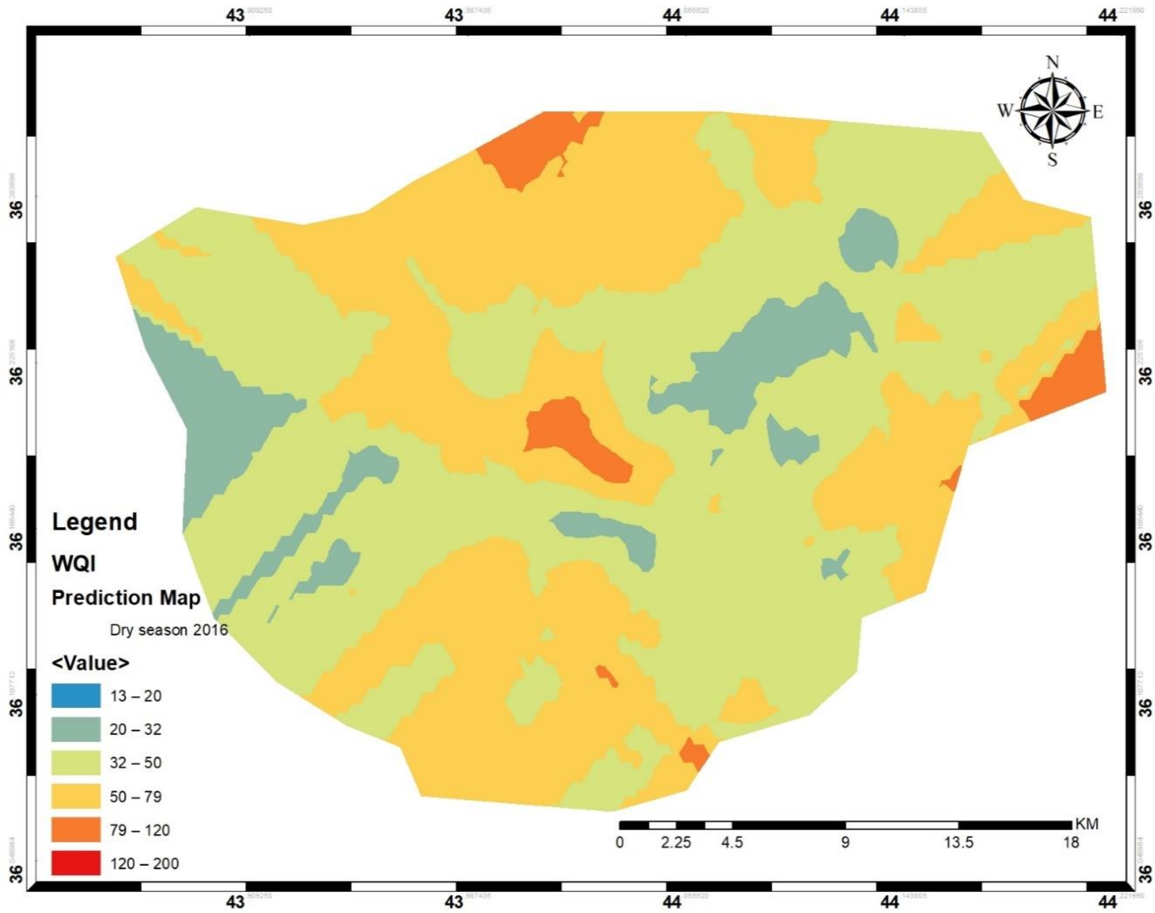

Figure 4. 28: Spatial distribution of groundwater quality index for dry season 2016

4.6.5 Groundwater quality index map in 2017 wet season

The groundwater quality index in the period of 2017 wet season showed in figure 4.29 in the western a part of the city exhibited good and excellent water, in the other hand the east and north, and a small area of the central part had the maximum values of water quality index which mean the quality of water was very poor and unfitted for drinking. The water quality index was distributed to all directions of the city in the demonstrated map below was fair and good. As can be observed from the map the overall quality of water was approximately fair and good so that the water could be used for the purpose of irrigation, domestic, and industrial.

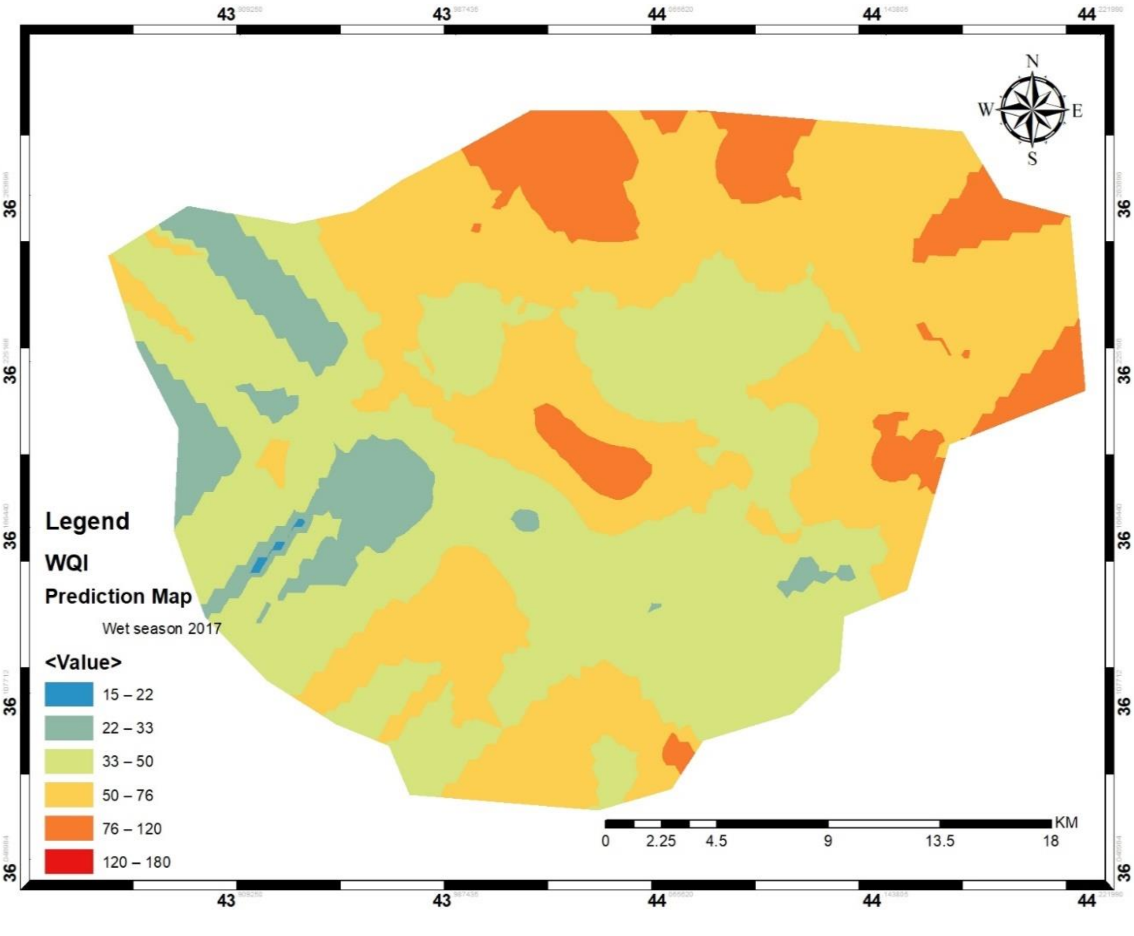

Figure 4. 29: Spatial distribution of groundwater quality index for wet season 2017

4.6.6 Groundwater quality index map in 2017 dry season

The groundwater quality index in the period of 2017 dry season shown in figure 4 in the western and central part of the city exhibited good and excellent water, in the other hand the north, small part of center of the map had the maximum values of water quality index which mean the quality of water was very poor and unfitted for drinking. The water quality index was distributed to all directions of the city in the given map below was fair and good. As can be observed from the map the overall quality of water was approximately fair and good so that the water could be used for the purpose of irrigation, domestic, and industrial.

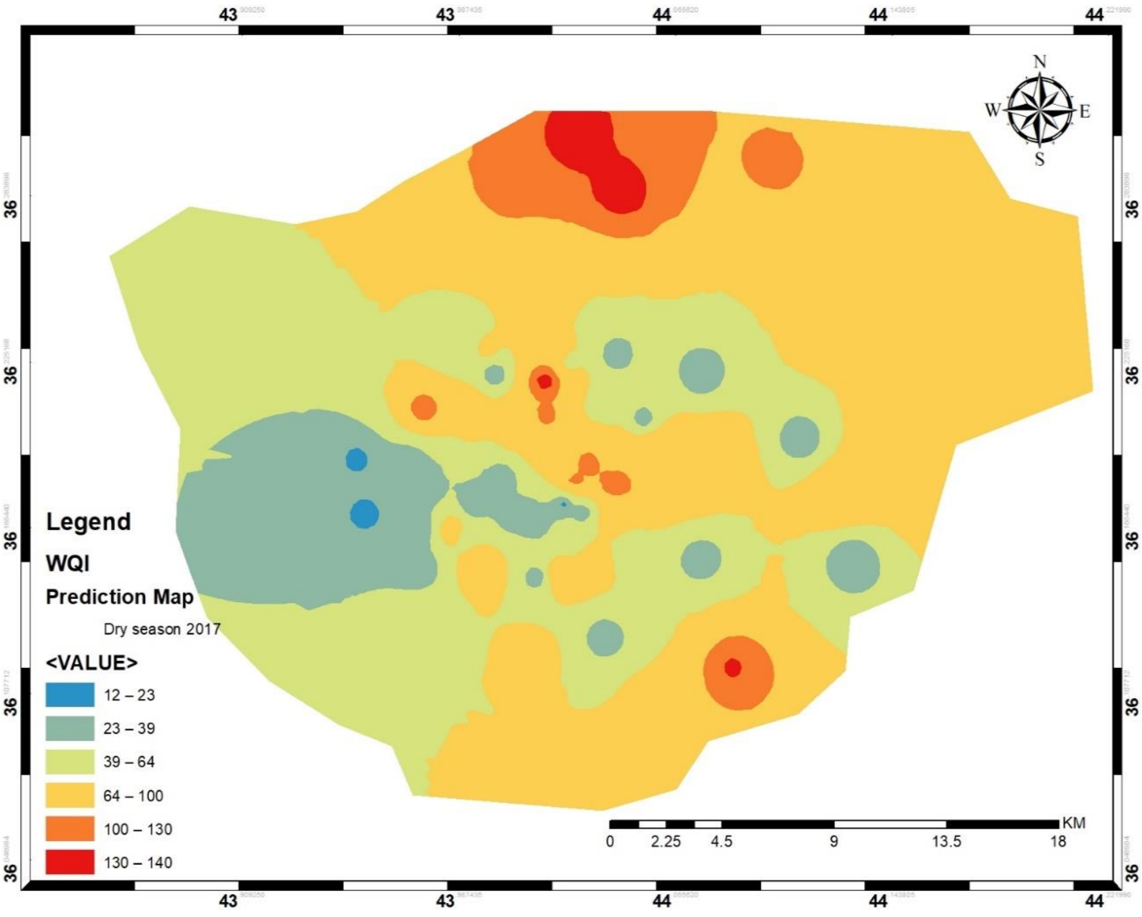

Figure 4. 30: Spatial distribution of groundwater quality index for dry season 2017

4.6.7 Groundwater quality index map in 2018 wet season

The groundwater quality index in last period of this study is 2018 wet season showed in figure 4.31 in the below map, showed that the southern and central part of the city exhibited good and excellent water, in the other hand the quality of water was declined in this period compared to the previous year most part of the map had the maximum values of water quality index which mean the quality of water was very poor and unfitted for drinking. The water quality index was distributed to all directions of the city in the given map below was fair and good. As can be observed from the map, the overall quality of water was approximately fair and good so the water could be used for the purpose of irrigation, domestic, and industrial.

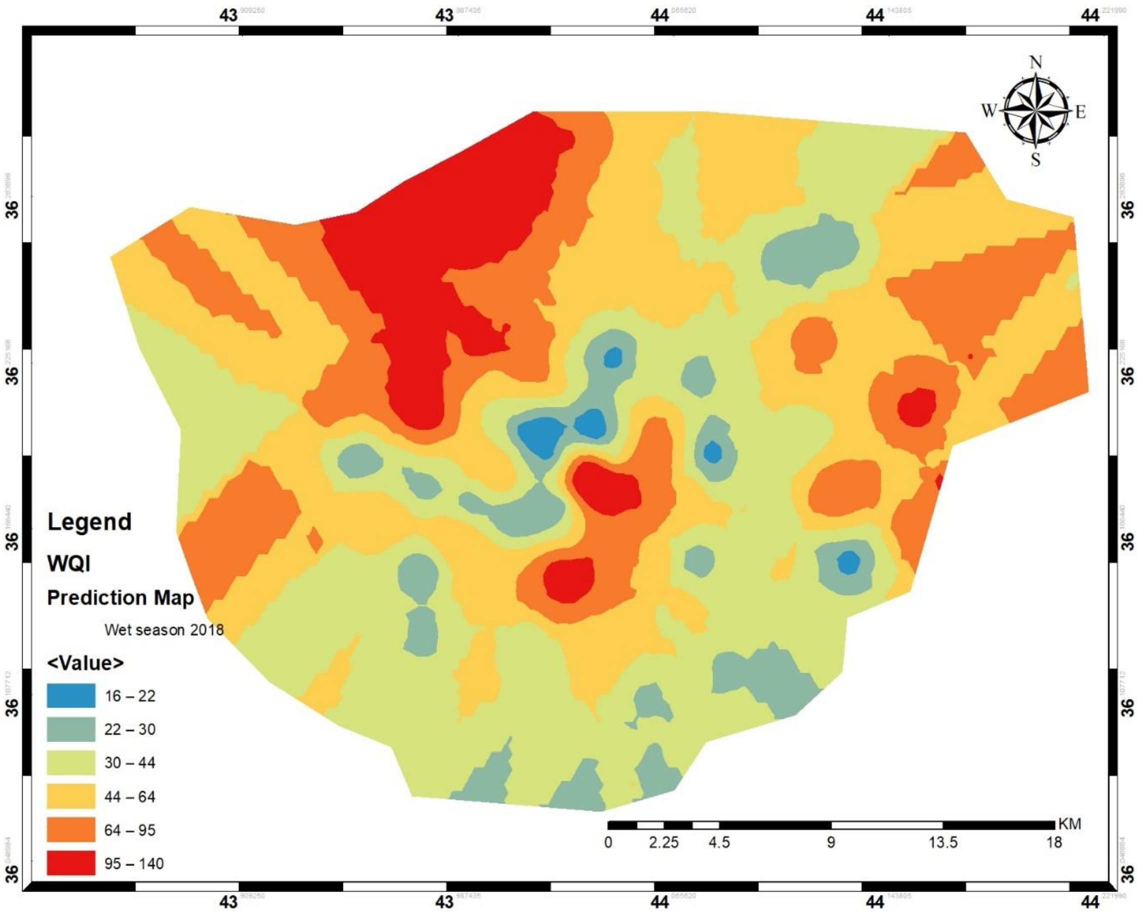

Figure 4. 31: Spatial distribution of groundwater quality index for dry season 2018

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The primary aim of the research is to map and evaluate the GWQ in the city of Erbil. By utilizing GIS and geostatistical approaches so as to establish spatial distribution of groundwater quality parameters. Such approaches have effectively revealed its potency in GWQ mapping of the city of Erbil. The present study had been undertaken to analyze the spatial variation of major GQW estimators such as potential of hydrogen, electrical conductivity, calcium, magnesium, turbidity, sodium, total dissolved solids, potassium, total hardness, nitrate, chlorine, and sulfate using GIS approach. Kriging and Inverse distance weighted were applied in this computation for groundwater parameters for determination of the most suitable method between kriging and IDW, root means square error was used to the groundwater parameters for wet and dry seasons. The results showed that the Kriging method was more suitable and had an accurate prediction than the IDW method for mapping groundwater parameters.

The WQI was calculated based on the thirteen groundwater parameters using Horton (1965) method which was called Weight Arithmetic Water Quality Index, the percentages of the WQI were computed for each well. The water quality ratings basis of an index value variation of WQI well samples showed that the WQI for wet the 2015 season that 31.14% of the wells were excellent, 29.5% were good, 6.56% were fair, 21.31% were poor, 9.83% were very poor, 1.64% were unfit for drinking. The WQI for 2015 dry season wells depicted that 37.7% of the wells were excellent, 13.11% were good, 29.5% were fair, 8.2% were poor, 9.83% were very poor, and 1.64% were unfit for drinking. The WQI for the 2016 wet season depicted that 31.14% of the wells were excellent, 18.03% were good, 21.31% were fair, 16.39% were poor, 11.47% were very poor, 1.64% were unfit for drinking, The WQI for the 2016 dry season depicted that 39.34% of the wells were excellent, 11.47% were good, 19.67% were fair, 13.11% were poor, 16.39% were very poor, 0.0% were unfit for drinking, The WQI for the 2017 wet season depicted that 34.42% of the wells were excellent, 11.47% were good, 18.03% were fair, 19.67% were poor, 9.83% were very poor, 6.55% were unfit for drinking. The WQI for the 2017 dry season depicted that 39.34% of the wells were excellent, 3.27% were good, 11.47% were fair, 14.75% were poor, 31.14% were very poor, and 0.0% were unfit for drinking. Final period WQI for the 2018 wet season depicted that 36.06% of the samples were excellent, 1.64% were good, 24.59% were fair, 13.11% were poor, 4.91% were very poor, and 11.47% were unfit for drinking. The water quality in 2018 decreased as compared to the previous years due to an increased in the number of wells that were not suitable for drinking purposes without some level of treatment. The water quality index increased from 1.64 % to 11.47%. Untreated domestic and industrial wastewater caused groundwater pollution which was the main reason of a decrease in the water quality in the city of Erbil. High cased of population require the city to be developed continuously, but a plan should be established to control the spread and hazards pollution.

After calculating water quality index in order to generate maps for the parameters, two methods had been used then groundwater quality maps were processed to get the map of WQI. The methods including the Kriging, and Inverse distance weighted to determine the most suitable method in terms of RMSE. The results showed that the kriging method was considerably accurate than the IDW method. Furthermore, the Kriging was established to be having lower RMSE which increased its prediction accuracy as compared to the IDW.

5.2 Recommendations

In order to properly manage water quality in a good manner the following recommendations are presented.

1. The use of GIS computer programs and their applications are highly proposed to be used in the mapping of any groundwater situation of a city.

2. The effect of the degree of pollution and anthropogenic of the city of Erbil on the groundwater still remain unknown. So further studies are required on polluted chemicals with high accurate instruments.

3. The quality of water is affected by groundwater table level and this study determined that the water quality in Erbil city has decreased. Hence, it is highly recommended to work and monitor the groundwater table level of the city. As the ground table decreases, the possibility of a deterioration in the quality of water also decreases. As a result, it is highly recommended to monitor the groundwater table continuously along with its quality. Nowadays, a majority of countries around the world have faced a decrease in the groundwater table. The main reason of this decrease is due to improper uses of water, an increase the number of wells and a decrease in annual rainfall. As such, a decrease in the groundwater table level causes the quality of water to deteriorate.

4. The methods used in this study depend on one parameter so it is better to use another method to obtain more accurate prediction maps, so Cokriging method is highly recommended to be used between two parameters which are WQI and groundwater table. Then the results of Cokriging method can be compared with the methods that are used in this study and the most suitable method can be chosen in the future works.

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APPENDIX 1
DATA

In this thesis has used ArcGIS 4.5 2016 for mapping the groundwater quality parameters and WQI. The computer has used was core i7 and has ram of 6 Gigabytes.

The physical parameters that used for statistical analyzes and mapping (Wet)

FID	Turbidity (NTU)	PH	EC (µS/cm)	TDS (mg/l)	TA (mg/l)	TH (mg/l)
1	1	7.7	441	220.5	278	306
2	2.5	7.9	470	235	246	294
3	2.1	7.9	459	229.5	324	435
4	0.5	7.7	553	276.5	285	462
5	1.5	7.7	583	291.5	283	426
6	0.5	7.8	626	313	245	311
7	1.5	7.7	465	232.5	280	288
8	2.1	7.7	466	233	204	345
9	1.3	8.1	500	250	230	312
10	1.2	7.8	610	305	226	480
11	0.8	7.8	536	268	221	288
12	2.9	7.8	589	294.5	228	300
13	1.1	7.7	631	315.5	225	297
14	0.5	7.5	647	323.5	237	266
15	7.4	7.9	583	291.5	269	333
16	2.7	7.9	658	329	234	284
17	5	7.8	651	325.5	221	290
18	1.5	7.8	620	310	221	330
19	9.8	7.9	783	391.5	250	243
20	4.5	7.7	649	324.5	217	290
21	1.4	7.8	699	349.5	194	336
22	0.6	7.6	615	307.5	293	388
23	1.1	7.2	753	376.5	231	366
24	0.8	7.7	611	305.5	289	343
25	1.9	7.7	703	351.5	350	373
26	0.8	7.7	552	276	234	290
27	8.7	7.8	568	284	291	289
28	0.5	7.8	559	279.5	221	338
29	0.6	7.8	463	231.5	235	350
30	3.5	7.9	500	250	221	442
31	0.5	7.7	486	243	278	361

32	0.7	7.7	547	273.5	272	238
33	2.9	8.1	474	237	197	286
34	0.5	7.8	565	282.5	269	296
35	2.6	7.8	539	269.5	210	300
36	5.3	8.1	469	234.5	244	367
37	5.5	7.9	498	249	213	363
38	1.6	7.7	485	242.5	225	265
39	2.4	7.7	470	235	345	335
40	3.4	7.9	625	312.5	280	268
41	4.7	7.8	702	351	210	232
42	0.4	7.8	643	321.5	288	194
43	0.5	7.2	524	262	337	270
44	4.2	7.5	569	284.5	280	260
45	3.3	8.2	490	245	286	287
46	0.7	7.2	677	338.5	295	343
47	1.5	8.1	641	320.5	315	318
48	0.6	7.5	671	335.5	370	382
49	4.3	8.2	516	258	300	344
50	1.5	8.1	467	233.5	315	394
51	1	8.1	664	332	248	298
52	4.6	8.2	483	241.5	236	310
53	1.2	7.6	475	237.5	242	305
54	1.1	7.7	564	282	209	324
55	9.2	7.8	570	285	230	315
56	6.3	8.2	471	235.5	215	303
57	8.5	8.1	450	225	210	308
58	15.9	8.1	455	227.5	287	341
59	6.3	8.2	518	259	293	351
60	5	8.1	456	228	230	327
61	9.5	8.2	427	213.5	236	254

The cation parameters that used for statistical analyzes and mapping (Wet)

FID	Ca +2 (mg/l)	Mg +2 (mg/l)	Na + (mg/l)	K+ (mg/l)
1	77	27.36	42	1.1
2	74	26.16	22	0.9
3	109	39	43	0.9
4	116	41.28	43	0.9
5	107	38.04	44	1.6
6	78	27.84	44	1.4
7	72	25.92	39	1.4
8	86	31.2	55	1.7
9	78	28.08	14	1.4
10	120	43.2	40	2.2
11	72	25.92	35	1.6
12	75	27	32	1.3
13	74	26.88	18	1.3
14	67	23.64	22	1.4
15	83	30.12	25	1
16	71	25.56	52	1.2
17	73	25.8	51	1.1
18	83	29.4	52	1.9
19	61	21.72	52	2
20	73	25.8	25	1.9
21	84	30.24	17	1.9
22	97	34.92	46	1.3
23	92	32.64	43	0.8
24	86	30.72	11	1
25	86	48.72	12	1.5
26	73	25.8	15	0.8
27	73	25.8	26	0.9
28	85	30.12	16	1.4
29	88	31.2	23	1.4
30	111	39.48	29	2.9
31	90	32.64	14	1.1
32	60	21.12	46	1
33	72	25.44	22	1
34	74	26.64	45	1.3
35	75	27	25	0.9
36	92	32.88	23	1.7
37	91	32.52	30	1.1
38	67	23.4	13	1.3
39	84	30	19	1.3
40	67	24.12	22	0.9

41	58	20.88	52	1
42	49	17.28	57	1.1
43	68	24	55	2.3
44	65	23.4	61	3.5
45	72	25.68	28	2.1
46	86	30.72	54	5
47	80	28.32	43	1.1
48	96	34.08	53	2.1
49	86	30.96	43	1.9
50	99	35.16	50	2.4
51	75	26.52	56	1.4
52	78	27.6	46	2.6
53	76	27.6	52	1.5
54	81	29.16	49	2.2
55	79	28.2	41	44
56	77	26.52	49	60
57	77	27.72	24	42
58	85	30.84	35	1.2
59	88	31.44	36	1.3
60	82	29.28	27	1.1
61	64	22.56	23	1.2

The anion data that used for statistical analyzes and mapping (Wet)

FID	Cl- (mg/l)	NO3- (mg/l)	So4-2 (mg/l)
1	34	24	41.25
2	18	16.5	32
3	29	44.5	102
4	16	12.5	108
5	28	18.5	33.75
6	23	19.5	31
7	16	21	20.5
8	20	14.5	44
9	24	42.5	22
10	18	20.5	33
11	30	33	50.5
12	17	25	157
13	17	20	32
14	17	44	68
15	14	43.5	70
16	28	28	57
17	25	42.5	47
18	18	29	51
19	18	63	56
20	17	30	70
21	19	35.5	67
22	36	40.5	140
23	17	18	155.8
24	35	19.5	48.5
25	25	23	46
26	26	16.5	70
27	30	36.5	57
28	20	6.5	53
29	29	13	32
30	31	16.5	42
31	25	38	33.5
32	28	20.5	31
33	16	31	40
34	24	32.5	23
35	26	32.5	30
36	17	34.5	35
37	14	43	40
38	23	50	37
39	26	40	46
40	24	45	36
41	23	39.5	46

42	29	44	33
43	30	17	26
44	55	30	37
45	35	23	50
46	30	7.5	38
47	31	33.5	58
48	30	32.5	36
49	27	32	29
50	31	16	34
51	22	21.5	42
52	27	29.5	38.5
53	25	13.5	20
54	22	49.5	43.5
55	16	44.5	20
56	38	61.5	35
57	25	66.5	32
58	34	58.5	57
59	22	65	55
60	23	55.5	53
61	49	63.5	55

The physical parameters that used for statistical analyzes and mapping (Dry)

FID	Turbidity (NTU)	PH	EC (µS/cm)	TDS (mg/l)	TA (mg/l)	TH (mg/l)
0	1	7.8	594	297	210	236
1	0.4	7.4	603	301.5	219	260
2	1.9	7.7	532	266	180	220
3	0.3	7.1	415	207.5	225	210
4	0.4	7.4	434	264.5	248	300
5	0.6	7.3	756	378	336	420
6	0.6	7.9	467	233.5	262	272
7	1	7.4	636	318	260	331
8	2.7	8	423	211.5	207	187
9	3.5	7.9	727	363.5	344	473
10	4.5	7.9	422	211	215	300
11	1.1	7.6	764	382	342	455
12	0.7	7.6	713	356.5	300	469
13	1.5	7.7	545	278	243	329
14	1.1	7.8	715	357.5	316	380
15	1.3	7.5	758	379	319	389
16	0.6	7.6	656	328	300	420
17	1.7	7.5	529	264.5	215	270
18	8.1	7.5	632	316	259	270
19	0.5	7.5	748	374	285	460
20	0.9	7.9	527	263.5	256	285
21	0.9	7.3	582	291	291	343
22	0.5	7.6	958	479	331	427
23	2.1	7.3	548	274	285	327
24	7.2	7.2	779	389.5	276	326
25	1.5	7.8	743	371.5	320	520
26	0.7	7.7	750	375	340	256
27	0.4	7.2	696	348	283	430
28	0.4	7.9	520	260	319	344
29	0.9	7.7	675	337.5	317	500
30	4.1	7.7	672	336	260	350
31	0.2	7.5	451	225.5	300	338
32	4.6	7.9	717	358.5	343	430
33	2	7.7	714	357	289	389

34	1.1	8.1	479	239.5	270	418
35	3.7	7.9	534	267	301	340
36	2.1	7.4	819	409.5	308	415
37	1.4	7.4	598	299	228	343
38	0.6	7.7	584	292	258	341
39	0.5	7.9	651	374	254	314
40	1.1	7.9	748	329.5	324	559
41	0.8	8.2	659	379	300	353
42	0.3	7.6	758	291.5	285	430
43	0.8	7.8	583	273.5	390	518
44	0.7	7.3	711	355.5	229	315
45	0.9	7.8	703	351.5	240	421
46	1.2	8	614	432	250	305
47	1.7	7.3	864	359.5	269	356
48	0.9	7.3	719	337.5	304	386
49	0.9	7.6	850	425	315	398
50	1.1	8	753	347.5	290	338
51	0.8	7.2	409	208.5	210	283
52	1	7.5	506	283	250	350
53	1.1	7.8	737	368.5	323	570
54	6.1	8.1	720	299.5	215	235
55	2.2	7.8	720	360	300	415
56	1.6	8.3	884	442	290	506
57	1.3	7.8	568	264.5	216	332
58	1.3	8	423	325.5	304	493
59	1	7.9	672	336	302	330
60	1.8	7.9	617	308.5	271	280

The cation parameters that used for statistical analyzes a mapping (Dry)

FID	Ca +2 (mg/l)	Mg +2 (mg/l)	Na + (mg/l)	K+ (mg/l)
0	59	21.2	50	2.2
1	113	40.68	60	2.5
2	55	19.8	41.3	1.6
3	53	18.6	33.7	1.2
4	75	27	20	0.8
5	105	37.8	29.5	1.1
6	68	24.48	32	1.3
7	83	29.64	16	1.1
8	47	16.7	18	1.3
9	118	42.72	12	0.9
10	75	27	21	0.8
11	114	40.8	26	1.3
12	117	42.36	19	1.2
13	82	29.76	16	0.9
14	95	34.2	63	2.3
15	99	33.96	21	1.1
16	105	37.8	20	1.1
17	68	24	15	1.1
18	68	24	28.8	1.6
19	115	41.4	39.8	1.4
20	71	25.8	20	1.3
21	86	30.72	31	1.1
22	107	38.3	96	2.7
23	83	28.68	48	2.4
24	82	29.04	23	1.7
25	130	46.8	28	1.6
26	65	22.44	40	1.7
27	108	38.4	41	1.8
28	86	30.96	79	2.7
29	125	45	41	1.7
30	88	31.2	43	1.4
31	85	30.12	23	1
32	108	38.4	16	0.9
33	97	35.2	32	1.3

34	105	37.3	36	1.1
35	92	30.6	45	2.1
36	104	37.2	21	1
37	86	30.72	40.2	1.3
38	85	30.84	40	1.7
39	79	27.96	63	5.1
40	140	50.16	31	1.4
41	88	31.92	30	1.4
42	108	38.4	38	1.2
43	130	46.32	31	2.2
44	79	65.94	62	2.3
45	105	38.04	15	1.4
46	76	27.6	45	2.1
47	89	32.04	50	1.8
48	97	34.44	27	1.1
49	120	30.12	63	1.1
50	89	30.12	67	1
51	77	21.72	13	1
52	88	31.2	37	1.6
53	143	51	40	1.9
54	59	21	37	1.2
55	104	37.2	26	1
56	126	45.84	34	1.5
57	83	29.88	31.6	1.2
58	123	44.52	13	1.3
59	83	29.4	22	2.3
60	76	27.1	27	6.2

The anion parameters that used for statistical analyzes a mapping (Dry)

FID	Cl- (mg/l)	NO3- (mg/l)	So4-2 (mg/l)
0	40	15	30
1	48	19	35
2	32	42	39
3	17	9	32
4	28	10	23
5	43	7	24
6	27	23	20
7	29	8	19
8	22	20	22
9	41	21	45
10	17	20	49
11	54	19	53
12	36	22	51
13	34	35	60
14	63	55	116
15	23	43	78
16	40	44	43
17	30	66	22
18	37	54	48
19	45	43	44
20	31	25	55
21	41	20	65
22	55	3	70
23	44	30	55
24	45	21	58
25	56	22	68
26	40	60	83
27	45	3	81
28	54	18	82
29	36	23	80
30	41	18	31
31	48	3.5	30
32	36	39	53
33	39	31	102
34	24	54	44

35	31	39	45
36	53	66	41
37	28	56	36
38	37	68	50
39	76	51	38
40	50	37	50
41	18	21	47
42	57	3	25
43	54	21	47
44	200	23	65
45	17	11	23
46	58	25	76
47	31	34	65
48	22	30	43
49	35	23	55
50	64	34	87
51	22	67	56
52	50	4	76
53	50	24	87
54	30	71	65
55	50	66	49
56	64	54	80
57	25	78	47
58	28	56	67
59	50	50	56
60	61	44	54