T.R.
VAN YUZUNCU YIL UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCE
DEPARTMENT OF GEOLOGICAL ENGINEERING

EVALUATION OF GROUNDWATER VULNERABILITY OF ERBİL CENTRAL SUB-BASIN BY DRASTIC METHOD (IRAQ)

M.Sc. THESIS

PREPARED BY: Razhan Qadir Smail SMAIL
SUPERVISOR: Assoc. Prof. Dr. Erkan DİŞLİ

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THESIS STATEMENT

All information existing in this thesis was obtained according to the proper comportments and academic rules structure. Not all statement and information belongs to me. This work is prepared in agreement with the rules of cited to the source of information.

Razhan Qadir Smail SMAIL

ABSTRACT

EVALUATION OF GROUNDWATER VULNERABILITY OF ERBİL CENTRAL SUB-BASIN BY DRASTIC METHOD (IRAQ)

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M.Sc. Thesis, Department of Geological Engineering
Thesis Supervisor: Assoc.Prof.Dr. Erkan DİŞLİ
February 2022, 93 Pages

Erbil Central Sub-Basin is located in the southwestern part of Erbil governorate, northern Iraq. Groundwater plays an important role in drinking, industrial activities, domestic purposes, and agricultural activities in the studied area. This study aims to evaluate groundwater vulnerability to pollution by using the standard DRASTIC model. According to this model, the studied area was divided into four vulnerability index zones, including very low, low, moderate, and high coverage areas (1.8%, 18.7%, 45.9%, and 33.6%), respectively. To acquire more reliable results, the standard DRASTIC model was modified in two different ways. The first modification is based on the modified of standard weight values by using single parameter sensitivity analysis (SPSA). According to this modification, the studied area was divided into four zones of vulnerability intensity, including very low, low, moderate, and high with coverage areas of (1.6%, 18.3%, 42.3%, and 37.8%), respectively. The second modification is based on the effect of land use land cover (LULC) on the vulnerability system of the studied area. Only four classes of land use can be identified from (LULC) map including, agricultural land, barren land, urban area, and vegetation land. According to the modified DRASTIC_LULC, the studied area was divided into four zones of vulnerability classes, including; low, moderate, high, and very high with coverage areas of (0.1%, 7.6%, 83.6%, and 8.7%), respectively. The accuracy of vulnerability mapping of the standard and modified DRASTIC models was validated by Pearson's correlation coefficient between vulnerability index value and both the NO_3 and TDS in groundwater. As a result, the validation confirms that the modified DRASTIC based on LULC can be considered as a realistic approach with better model validation accuracy.

Keywords: Aquifer vulnerability, DRASTIC, Erbil Central Sub-Basin, Groundwater, Pollution.

ÖZET

ERBİL (IRAK) ALT HAVZASININ YERALTI SUYU KİRLENEBİLİRLİĞİNİN DRASTİC YÖNTEMİ İLE DEĞERLENDİRİLMESİ

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Tez Danışmanı: Doç.Dr. Erkan DİŞLİ
Şubat, 2022, 93 Sayfa

Erbil Merkez Alt Havzası, Irak'ın kuzeyindeki Erbil vilayetinin güneybatı kesiminde yer almaktadır. Çalışma alanında yeraltı suları içme, endüstriyel faaliyetler, evsel amaçlar ve tarımsal faaliyetlerde önemli bir rol oynamaktadır. Bu çalışma kapsamında, alt havza genelinde bulunan kirleticilerin yeraltısularını etkileme dereceleri dolayısıyla akifer birimlerin kirleticilere karşı duyarlılıkları Coğrafi Bilgi Sistemi (CBS) tabanlı olarak DRASTIC yöntem kullanılarak belirlenmiştir. Bu modele göre, çalışma alanı, çok düşük, düşük, orta ve yüksek kapsama alanları (%1.8, %18.7, %45.9 ve %33.6) olmak üzere bir akifer duraylılığının endeksinin dört bölgesine ayrılmıştır. Daha doğru sonuçlar elde etmek için standart DRASTIC'in iki farklı modifikasyonu uygulanmıştır. İlk modifikasyonda, tek parametreli duyarlılık analizi (SPSA) ile değiştirilmiş ağırlık değerlerine dayanmaktadır. Modifed DRASTIC_ağırlık, çok düşük, düşük, orta ve yüksek kapsama alanları (%1.6, %18.3, %42.3 ve %37.8) dahil olmak üzere bir güvenlik açığı endeksinin dört bölgesine bölünmüştür. İkinci modifikasyonda ise, çalışma alanının arazi kullanım arazi örtüsüne (Arazi_Kullanımı; LULC) dayanmaktadır. LULC haritasından tarım arazisi, çorak arazi, kentsel alan ve bitki arazisi olmak üzere sadece dört darklı arazi kullanımı sınıfı tanımlanabilir. Modified DRASTIC_LULC yönteminde düşük, orta, yüksek ve çok yüksek kapsama alanı (sırasıyla %0.1, %7.6, %83.6 ve %8.7) olmak üzere akifer duraylılığının endeksinin dört bölgesine bölünmüştür. Standart DRASTIC ve modifiye edilmiş modelleri doğrulamak için NO_3 ve TDS parametreleri kullanılmış ve sonuç olarak yeraltı sularının kirliliğe karşı akifer duraylılığının değerlendirilmesinde değiştirilmiş DRASTIC_LULC haritasını önerilmiştir.

Anahtar kelimeler: Akifer Duyarlılık, DRASTİC, Erbil Merkezi Alt Havzası Yeraltı Suyu, Kirlilik.

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SYMBOLS AND ABBREVIATIONS

Some symbols and abbreviations used in this study are presented below, along with descriptions.

Abbreviations	**Description**
AVI	Application of Aquifer Vulnerability Index
BOD	Biological Oxygen Demand
CGLS	Copernicus Global Land Service
CN	Curve Number
COD	Chemical Oxygen Demand
DVI	DRASTIC vulnerability Index
EC	Electrical Conductivity
EPA	Environmental Protection Agency
FAO	Food and Agricultrue Organization
fAPAR	Fraction of Absorbed Photosynthetically Active Radiation
GIS	Geographical Information System
GOD	Groundwater occurrence, overall aquifer class and depth of groundwater table
GQI	Groundwater Quality Index
IDW	Inverse Distance Weight
IQWS	Iraqi Quality of Water Standards
LCCS	Land Cover Classification System
LULC	Land Use Land Cover
MCE	Multi Criteria Elevation
NDVI	Normalized Difference Vegetation Index
PCA	Principal Components Analysis
pH	Potential of Hydrogen
RMSE	Root Mean Square Error

Abbreviations	Description
SCS	Soil Conservation Service
SPSA	Single Parameter Sensitivity Analysis
TDS	Total Dissolved Solids
UTM	Universal Transverse Mercator
WHO	World Health Organization

1. INTRODUCTION

In the world, especially in semi-arid regions, both agriculture and drinking water supplies are mainly or generally provided from fresh surface water (lakes, ponds, streams, etc.) and groundwater sources (well and springs) (Dişli, 2017, 2018, 2020). However, over the past the last 100 years, due to rapid population and unplanned/urbanization growth, social and economic developments, and changes in climatic conditions on a local or regional scale, the sustainability of freshwater resources in terms of quality and quantity is at great risk due to pollution (Dişli 2017). The arid and semi-arid regions in the world are mainly dependent on groundwater due to scanty both quality and quantity of surface water sources or their unsuitability, as well as the relatively low susceptibility to pollution compared to surface waters and their large storage capacity (Thirumaivasan et al., 2003; Zghibi et al., 2016). Groundwater, which is one of the most important sources of freshwater from natural sources due to the lower possibility of contamination from the surface origin, is frequently used to describe the pores as fully saturated soils and geological formations below the water table (Freeze and Cherry, 1979; Bera et al., 2021). Groundwater resources are not only the sustainability and basic need for human existence but also a vital input for all development activities such as agriculture and industry. More than one-third population of the world receives drinking water from groundwater, and most of the 700 million people worldwide who currently do not have adequate water resources will have to rely on groundwater in the future due to changes in climatic conditions. However, groundwater resources meet more than 40% of the irrigation water demand and provide about a quarter of all industrial supplies (International Association of Hydrogeologists 2020). Groundwater pollution is caused by a different of nonpoint (diffuse) and point sources, including land-use activities, urbanization, a lack of proper sewage, large-scale intensive agriculture, and a large volume of poorly discharged domestic and industrial wastewater. These factors can seriously degrade groundwater resources, both in quality and quantity, to their sustainable characteristics, now and for the future (Polemio et al., 2009). The basic concept of groundwater vulnerability can be defined as that some land areas are more vulnerable to groundwater pollution than others (Piscopo, 2001). In the last century, especially in regions where arid-semi-arid climatic conditions are adequate, the overexploitation of groundwater causes a rapid decrease in the groundwater table, and therefore the reduction in the groundwater table affects the quality and quantity of groundwater available for domestic, industrial, and agricultural applications (Biswas et al., 2020; Bera et al, 2021). Therefore, determining the parameters that cause groundwater contamination and preventing it is an essential process in the management and vulnerability assessment for effective groundwater resources (Zghibi et al., 2016).

The groundwater pollution assessment process first divides a geographic region into sub-areas based on different hydrogeological parameters in terms of their vulnerability to groundwater pollution, then effective groundwater protection measures are achieved in sensitive areas prone to pollution (Zghibi et al., 2016). Vulnerability assessment and vulnerability maps may be used as a significant estimation tool for decision-makers regarding the current status of groundwater quality in aquifer systems and their distribution of pollution-sensitive areas (Bera et al., 2021). Groundwater vulnerability describes the tendency or probability of groundwater contamination depending on natural conditions (rock-water interaction, etc.) and human activities ((agricultural and industrial activities, etc.). Also. reflects the sensitivity of groundwater to changes in natural conditions and human activities (Wu et al., 2018). Many studies have been reported on groundwater vulnerability assessment in different climatic regions of the world, especially in the semi-arid regions (Djoudi et al., 2019; Arya et al., 2020; Meng et al., 2020) and arid regions (Ghazavi and Ebrahimi, 2015; Heiß et al., 2020, Bera et al., 2021).

Since its first introduction in 1968, three different aquifer vulnerability assessment methods have been developed, namely Overlay and Index Methods, Process-Based Methods, and Statistical Methods (Thirumaivasan et al., 2003). The DRASTIC model, which falls under the category of overlay and index, is known as one of the most widely used and preferred models in the vulnerability assessment of groundwater resources on a regional scale (Khosravi et al., 2018). The DRASTIC model was originally developed as an easy-to-use tool that includes various hydrogeological settings based on vulnerability index and is much easier to use in the aquifer vulnerability assessment process. The DRASTIC vulnerability index (DVI) is often useful at a regional scale to give priority areas as high, medium, and low vulnerability regions that can be tracked by detailed on-site field studies (Thirumaivasan et al., 2003). In general, groundwater vulnerability is divided into two different classes, intrinsic (natural) and specific (integrated) vulnerability. The intrinsic vulnerability may be described as the ease of movement with which a pollutant formed as a result of anthropogenic activities taking into account the geological, hydrological, hydrogeological, and hydrogeochemical properties of the studied area, reach and spreads in groundwater as a result of different processes (infiltration, etc.) from the ground surface (Vrba and Zoporozec, 1994; Zghibi et al., 2016). Specific vulnerability is used to describe the groundwater vulnerability to specific pollutants, taking into account the physicochemical characteristics of the contaminant causing groundwater pollution and their relationship to various components of intrinsic vulnerability (Gogu and Dassargues, 2000; Ghazavi and Ebrahim, 2015).

The present area is the Erbil Central Sub-Basin located in the northern part of Iraq, and Erbil city is within this sub-basin. Groundwater in the study area plays an important role in drinking, domestic purposes, industrial and agricultural activities. In Erbil central sub-basin, there is a significant increase in demand for water. At the same time, there are many challenges facing groundwater supplies such as land use activities, rapid urbanization, rapid and extensive population, oil refineries, intensive agricultural, large amounts of domestic and industrial effluents poorly discharged, leakage from sewer pipes, improper septic tanks and cesspools, and disposal sites. There are two open wastewater channels in the study area used in a rural area for irrigation on both sides of the channels. Furthermore, most areas in the Erbil Central Sub-Basin are used for agricultural purposes. Concerning agriculture, the key pollutants include pesticides and organic fertilizers (Boy Roura, 2013). Beginning in the late 1970s, the occurrences of nitrates, bacteria, and pesticides in groundwater have exhibited a significant increase in concentration, suggesting research on the subsurface fate of pollutants (Abdullah, 2018). Thus, to protect and management of groundwater resources, groundwater vulnerability assessment and mapping of the study area has become a necessity. Vulnerability assessment is a useful tool for identifying areas that are more likely to be contaminated as a result of human activities (Jaseela et al., 2016). There are many models used for groundwater vulnerability mapping. In this study, the DRASTIC model was used, and ArcGIS 10.2 software has been provided to be used DRASTIC for obtaining maps

Many researchers carried out the validation process of their proposed model with the negatively charged nitrate concentration due to its high solubility in water and concluded that it spreads from various points (sewage from cesspools etc.) and non-point sources (agricultural activities etc.) (Singha et al., 2019). In addition except for nitrate, other physicochemical parameters such as pH, COD, BOD5, iron (Fe), TDS, salinity become completely soluble in the system when comes in with water (Mogaji 2018).

In Iraq, many researchers study the DRASTIC model to assess the vulnerability of groundwater. Iraq faces poor water quality due to population growth, the impact of three wars, climate change, poor land use planning, and encroachment on fragile ecosystems (World Bank, 2017). Al-Madhlom et al, (2016) assess Groundwater Vulnerability in Northern Babylon Governorate. Al-Abadi and Al-Shamma'a (2017) assess intrinsic groundwater vulnerability in the northeastern Missan governorate. Al-Mallah and Al-Qurnawi1 (2018) delineate Intrinsic vulnerability for the Quaternary aquifer in Baghdad. Abdullah (2018) studies both standard and modified DRASTIC index models by GIS software to evaluate the potential vulnerability of groundwater contamination in the Halabja Saidsadiq Basin. Al-Hayali et al (2020) identify vulnerable zones for groundwater in the Shwan Sub-Basin.

2. LITERATURE REVIEW

The vulnerabilities of groundwater have been studied in the world by many researchers:

Javadi et al. (2011), have produced a groundwater vulnerability map to present pollution in the agricultural areas for Astaneh aquifer in Iran. The authors have modified the DRASTIC model by using Nitrate measurements.

Gupta (2014), produced a groundwater vulnerability map by applying the DRASTIC model in Jabalpur District of Madhya Pradesh in India.

Khodabakhshi et al. (2015) evaluated groundwater vulnerability for Sefid-Dasht in Iran using a DRASTIC model. The authors compared vulnerability maps in their study with the groundwater quality index (GQI).

Agyemang (2017), has studied vulnerability assessment of groundwater to evaluate Nitrate NO_3 contamination in Buncombe County, North Carolina by applying the DRASTIC model and Geostatistical analysis.

Gheisari (2017), who assessed the groundwater vulnerability for the Shahrekord plain in the southwestern region of Iran by using a GIS-based DRASTIC model, and then validated nitrate values that is compared to the generated DRASTIC index, in order to assess the efficacy of the DRASTIC model for the selected area.

Ahmed et al. (2018), have produced a map for the groundwater pollution risk by using the modified DRASTIC model in part of the Hail region of Saudi Arabia. The DRASTIC model was compared with the GOD and AVI vulnerability model and the model validation was done with NO_3, SO_4, and Cl concentrations. The maps obtained as a result of the model were used to evaluate the areas with potential contamination risk to groundwater resources.

Other provincial studies that have been conducted around the study area are directly or indirectly belong to hydrogeological and hydrological conditions. The following studies are listed below:

The oldest study is performed by the Parson company (1955) which includes regional geology and hydrogeological condition of the Erbil basin. The author has estimated recharge, water balance, and water chemistry.

Haddad et al. (1974), have studied the groundwater resources of Erbil plain. Based on groundwater fluctuations. In addition, the authors have produced a groundwater model to calculate the annual recharge and used Darcy's low to calculate the possible groundwater inflow as recharge into the basin.

Hydrogeological conditions of the central part of the Erbil basin have been studied by Hassan (1981). The author has conducted the characteristics and properties of the aquifer system in the study area and calculated water balance by using different models. Moreover, according to the citation, the author has indicated that the water types in the area are two groups: bicarbonate and sulfate, anion, and salinity.

Jawad and Hussien (1988), have designed groundwater monitoring for Erbil hydrogeological basin by using statical analysis of piezometric fluctuation. The authors also determined the fluctuation of groundwater.

Geochemistry of the groundwater in Erbil city is performed by Habib et al. (1990). This research is mainly related to the assessment of groundwater quality. The researchers also collected some samples to evaluate the hydrochemistry of the water sample and determine the availability of the wells for human consumption.

The hydrogeological conditions of Erbil City have been studied by Hassan (1998), and study urban hydrology is related to the groundwater pollution in the Plio-Pleistocene aquifer of Erbil City by using hydrochemical and numerical modeling to calculate the water supply capacity from the groundwater resources. Meanwhile, estimation of the water balance components depends on the hydro-meteorological approach and water balance approach.

Through the FAO United Nations initiative, Stevanovic and Markovic (2004), have studied the regional geology and hydrogeology of the governorates of Erbil, Sulaimaniyah and Dohuk.

Lak (2007) has conducted an environmental study of the Arab-Kand wastewater channel in Erbil city. The author has identified that the sewage water is unsuitable for human consumption but suitable for building and industrial and suitable for irrigation and agriculture depending on the plant type and tolerance salinity. It is also suitable for livestock purposes, but in some locations of the study area is not suitable for this purpose due to having a large number of bacteria and trace metals in the water.

Bapeer (2008) has studied the hydrological and geotechnical of Quaternary Sediments in the Middle Part of Erbil Plain. The study shows most of Erbil Plain is covered by Quaternary deposits. However, the study area is classified into three zones according to soil infiltration rate.

The principal components analysis (PCA) technique is used by Al-Tamir (2008) to process the physical, chemical, and biological data for many wells to identify the sources of pollution of the groundwater in Erbil city. In this study, a correlation matrix is used in data analysis to identify the relationships of each parameter with the others. Moreover, the results were indicated the three factors that responsible for groundwater quality variation. At the end of the study, the result referred to rock dissolution, human activities, and agricultural wastes.

Ghaib (2009) has assessed the Erbil aquifers by using Geo-Electrical investigation. Although, the study takes three lines of direction to measure the suitable areas for drilling wells to give considerable amounts of fresh water with the possibility of the presence of some artesian or even flow wells.

Qazwini et al. (2009), have studied the hydrochemical evaluation of the Erbil city aquifer. Twenty wells have been taken as a sample to identify the quality and origin of water for municipal use. However, the type of water was classified according to (Schoeller and Sulin) classifications. The results of this study concluded that the water in the study area is suitable for all kinds of human uses.

Hameed (2013) has studied water harvesting in the Erbil-Governorate. The study focused on detecting suitable locations for water harvesting by using (GIS) and multi_criteria evaluation (MCE). The author has suggested some micro and macro catchments based on data such as; soil texture, topography, rainfall data, land use/landcover, and drainage network. The results of the study were indicated that 36% of the total area of the region suitable sites for rainwater harvesting. The author has also suggested six suitable sites for constructing small and medium dams.

Dizayee (2014) has studied the degradation and sustainability of groundwater in the Erbil basin. The results were presented that the variations of geological basins control the quantities of water. According to the geological and geographical position of the central and southern parts of the basin, which are considered as a suitable location for groundwater accumulation. The author also presented the declination of groundwater levels based on recharge. This study is shown that the central part of the basin is the most effective by drought and illegal wells.

Wali and Alwan (2015) have studied groundwater management by assessing aquifer vulnerability to contamination by the DRASTIC model in Erbil city. The study results indicate three zones low, moderate, and high of the area according to vulnerability contamination.

Al- Kubaisi et al. (2019), have estimated the water balance for the central basin of Erbil Plain and have studied that the climate region of the study is moist-humid to moist.

Mawlood (2019) has studied groundwater conditions and the sustainability of aquifers in the Erbil Basin. The author concluded that there is an irresponsible use of groundwater, and the groundwater table has been found to decrease around 1.24 m annually.

3. MATERIALS AND METHODS

3.1.Materials

3.1.1. Aim of the study

A lot of hazardous activities could be possible contaminant factors to the groundwater by infiltration, which includes expansion of the city, rapid urbanization, rapid growth population, oil refineries, agricultural activities, a large amount of domestic and industrial effluents poorly discharged, leakage from sewer pipes, improper septic tanks and cesspools, and disposal sites. The main aim of the present thesis work is to evaluate groundwater vulnerability of the Erbil Central Sub-Basin based on DRASTIC model combined with a geographic information system (GIS) and discuss the spatial distribution of some parameters (pH, TDS, EC, and NO_3) in groundwater. The results obtained from this research will assist policy makers and planners in preparing plans for groundwater management in terms of water quality soon future.

3.1.2. Study area description

The DRASTIC index was applied to the study area is located in the Erbil Central Sub-Basin (Figure 3.1.a), which covers a surface area of approximately 1624.5 km^2 with generally part of the alluvial plain. The study area is located in the southwestern part of Erbil Governorate, Northern Iraq, which has an elevation ranging from 202 to 1076 m above mean sea level (Figure 3.1b). Geographically, it is situated between coordinates of 365934.38 to 434693.52 north latitudes and 3968625.96 to 4014122.61 east longitudes of Universal Transverse Mercator (UTM) projection. Some hills and mountains bounded the area, Sharabout and Kasnazan hills are in the north and northeastern parts, to the southeast by Bestana hills, to the northwest by Dameer Dagh hills, while Khurmala Mountain forms the southwestern boundary. The majority of the study part is agricultural land and the usability of fertilizers and pesticides are common practices. Most of the wells drilled for agricultural purposes are located in this sub-basin, which causes a real possibility of groundwater contamination by fertilizers used for agricultural purposes (Internal Report Directorate of Groundwater-Kurdistan Region, 2012).

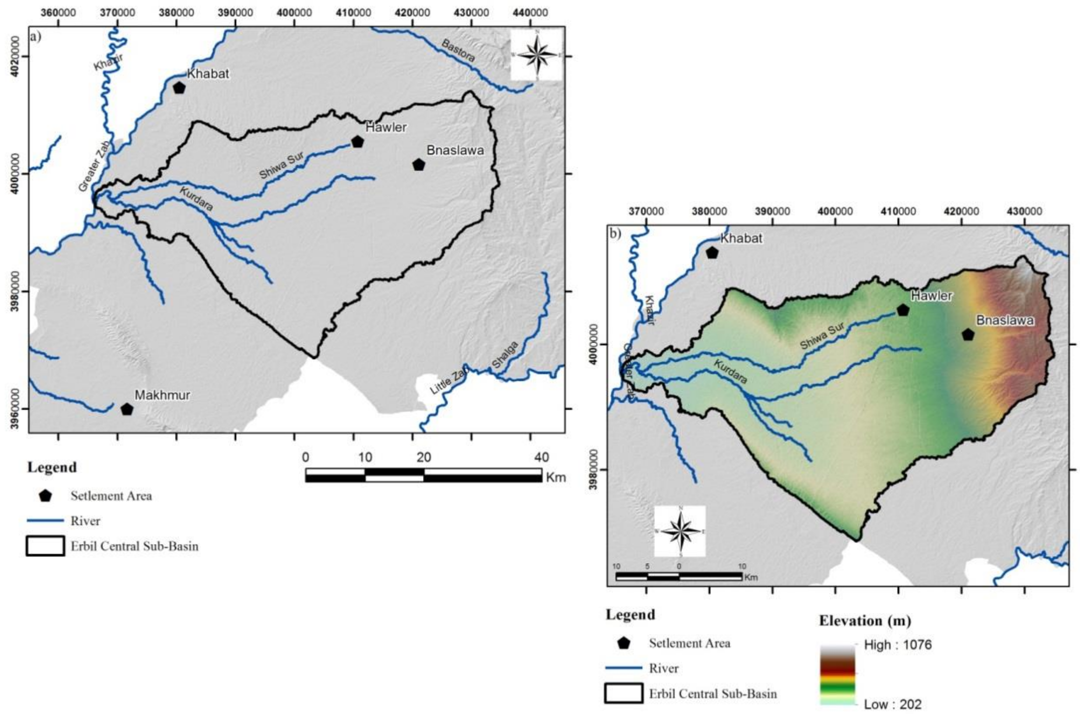

Figure 3.1. (a) Location maps of the study area (b) Topographic map of the study area.

3.1.3. Climate

The climate in the study area belongs to the Mediterranean type, which is characterized by hot summers and cold winters. Rainfall is seasonal occurs during late autumn, winter, and early spring months, and there is no rainfall during summer. The site and topography of the location significantly affect the amount of rainfall, precipitation increase from the southwest to the northeast (Stevanovic et al., 2001).

The available climate obtained from (General Directorate of Meteorology and Seismology) in the study area in Hawler station during (2005-2019) is rainfall and temperature. According to the Hawler Meteorology Station in Erbil city (Figure 3.2), the average annual rainfall between 2005 and 2019 was 400.9 mm/year. The maximum amount of rainfall was 733.6 mm/year in 2018, and the minimum amount of rainfall was 260.4 mm/year in 2010. The highest average monthly rainfall is in March (67.1 mm/month), and the lowest average monthly rainfall is in July (0 mm/month) (Figure 3.3). The minimum monthly average temperature was 8.9°C in January, while the maximum monthly average temperature was 35.07°C in July, and the mean temperature was 22.09°C (Figure 3.4).

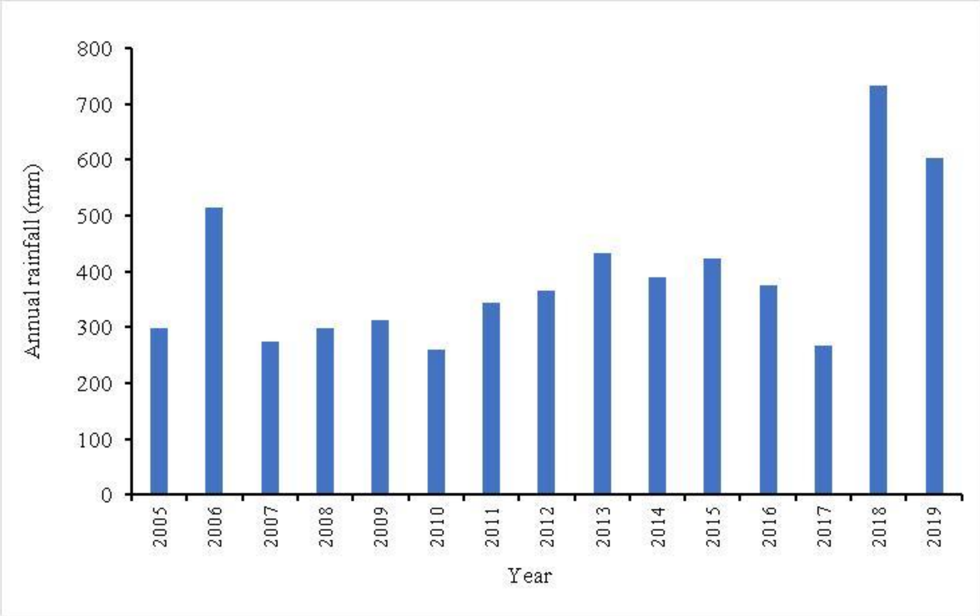

Figure 3.2. Annual rainfall of Hawler Meteorology Station during 2005-2019.

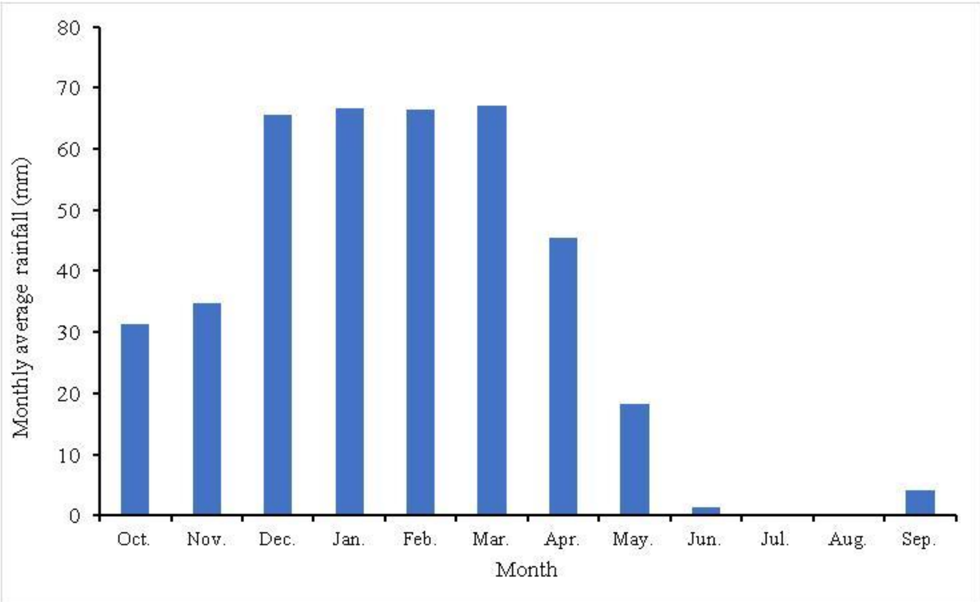

Figure 3.3. Monthly average rainfall data of Hawler Meteorology Station during 2005-2019.

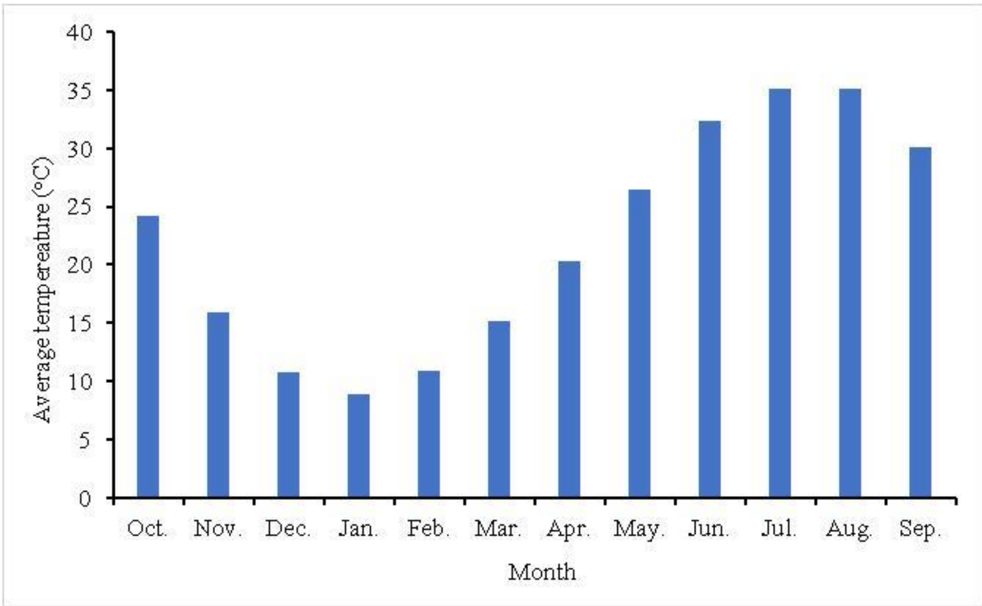

Figure 3.4. Monthly average temperature data of Hawler Meteorology Station during 2005-2019.

3.2. Geological Setting

3.2.1. Stratigraphy of the study area

The exposed geological units in the study area is Bakhtiari Formation, which overcame the Quaternary deposits, which extend from Pliocene to Pleistocene-Holocene. Most of the study area is covered by quaternary sediments (Figure 3.5). These geological units are shown in (see Figure 3.5) and briefly described below from the oldest to the youngest.

3.2.2.1. Bakhtiari formation

This formation is Pliocene in age. Busk and Mayo described the Bakhtiari Formation from Iran in 1918. The term was also introduced in Iraq, and the formation was there usually divided into lower and upper parts both considered as independent formations. The boundary between the two Bakhtiari Formations is clearly diachronous (Bellen, 1959). The contact between Lower Bakhtiari and Upper Bakhtiari is considered to be at the base of the first conglomerate series (Parson, 1955). The formation was laid down in a fluvial-lacustrine environment, in a strongly sinking foredeep, and might be considered as a typical fresh water molasse (Buday, 1980). According to primary variations and erosion, the thickness of the Bakhtiari Formation is very variable. Maximum thickness is up to 2500-3000 m (Al-Naqib, 1960).

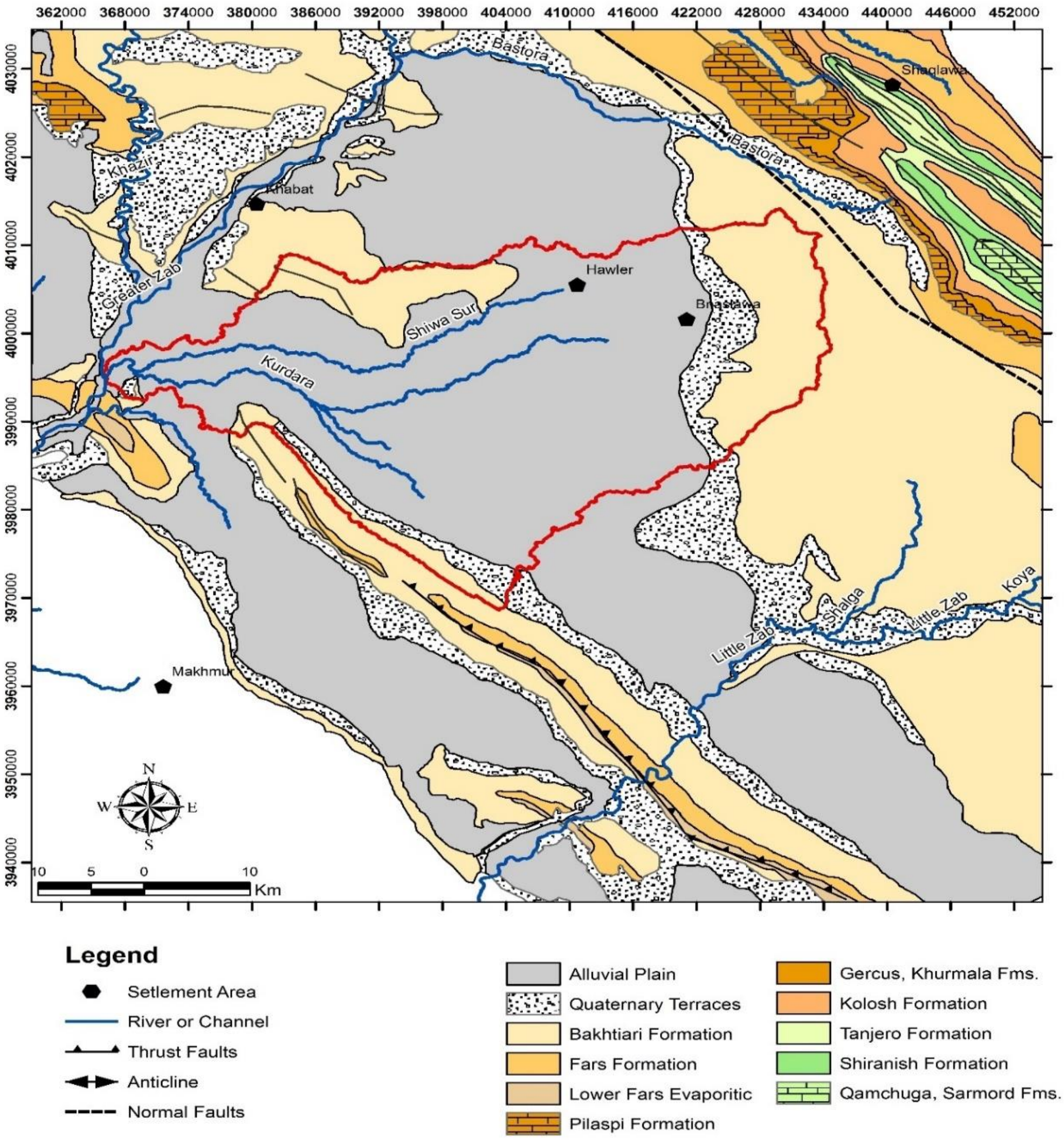

Figure 3.5. Geological map of the study area (modified from Grazic et al., 2019).

Lower Bakhtiari sediments are typically post-orogenic molasses sediments that have developed due to rapid erosion of the Tauros-Zagros mountains and deposition in troughs (Buday and Jassim, 1987). The Lower Bakhtiari is characterized by sedimentary cycles, increasing in size from red mudstone, sandstone and gravel to form conglomerate masses (Jassim and Goff, 2006). The upper Bakhtiari consists of variable units of conglomerate (different colors and grain sizes), clay, sandstone, and gravel

(Buday and Jassim, 1987). This formation is the most permeable and porous unit and is regarded as one of the best water-bearing formations (Alsalim, 1980). At the Erbil Basin, this formation is overlain by the older alluvium. This formation is existing in the northeast, northwest, and southeastern parts of the study area.

3.2.2.2. Pleistocene units and alluvium

The study site is dominated by Quaternary deposits and covers about 78.9% of the area. Quaternary deposits filling the synclines comprise mainly of a mixture of gravel, sand, silt, and clay (Jassim and Goff, 2006). The deposition and stratigraphic sequence of the Quaternary sediments depend on the climatic oscillations, resulting in periodically repeated accumulation and erosion phases. Besides, especially in the mountainous areas of Iraq, the general uplift had played an important role too. Due to alternating phases of accumulation and erosion, no continuous stratigraphic sequence of Quaternary can be supposed (Buday, 1980). These deposits are divided according to Youkhana and Sissakian (1986) into River terraces (Pleistocene), Slope deposits (Pleistocene-Holocene), Polygenic deposits (Pleistocene-Holocene), and Flood plain (Holocene).

3.2.2. Tectonic setting

The Erbil Central Sub-Basin is a part of the Unstable Shelf Zone (Figure 3.6) that was affected by the Alpine orogeny in Mesozoic in Chamchamal-Butma sub-zone of the Foothill Zone (Buday and Jassim, 1987). Chamchamal-Butma sub-zone is the NE unit of the Foothill Zone, has very conspicuous long and deep synclines with thick Pliocene molasses dominated by a conglomerate and the strata are essentially horizontal (Jassim and Goff, 2006). Erbil plain is considered to be among these plains as a broad syncline between two main anticlinal structures, Pirmam from east and Khurmala-Avana from the west (Hassan, 1998). The inner parts of the synclines contain Quaternary deposits, referred to here as the polygenetic synclinal fill (Jassim and Goff, 2006).

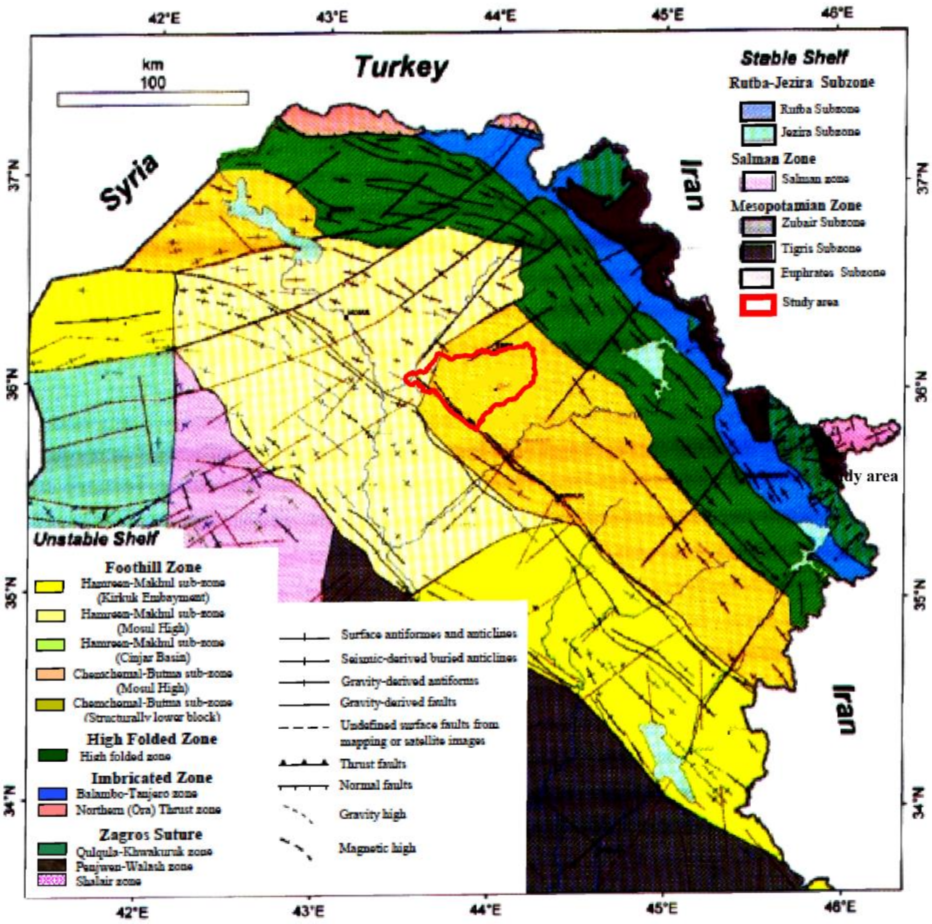

Figure 3.6. Tectonic map of the study area (modified from Buday and Jassim, 1987).

3.3. Hydrogeological Setting

The Erbil plain is divided into three sub-basins Kapran sub-basin in the north, the Central sub-basin, and Bashtapa sub-basin in the south (Hassan, 1981). It is bordered naturally by two rivers, on the northwest by Greater Zab and the southeast by Lesser Zab. The position of the study area (Erbil Central Sub-Basin) between both the Kapran and Bashtaba sub-basins (Figure 3.7).

The Bakhtiari formation and alluvium deposits are generally covered in this Erbil Central Sub-Basin. The exposures of Bakhtiari formation are found in the high land of the study area. An intergranular aquifer is the main aquifer in the study area, with medium to high production (Stevanovic and Markovic, 2004). The larger part of this aquifer is generally unconfined, semiconfined conditions are frequently found where there is a thick clay layer in the Bakhtiari formation (Jawad and Hussien, 1988).

According to (Stevanovic and Markovic, 2004) partly confined conditions found in the Bakhtiari formation, were covered by younger sediments. Bakhtiari formation and the overlying deposits are hydraulically connected and from the same aquifer system. The permeability of this aquifer is variable both in horizontal and vertical directions. The thickness of this aquifer is over 1000 meters (SETEC, 2011). Groundwater moves from the east to the west side of the study area, so it flows in the same direction as regional groundwater flows (Hassan, 1998).

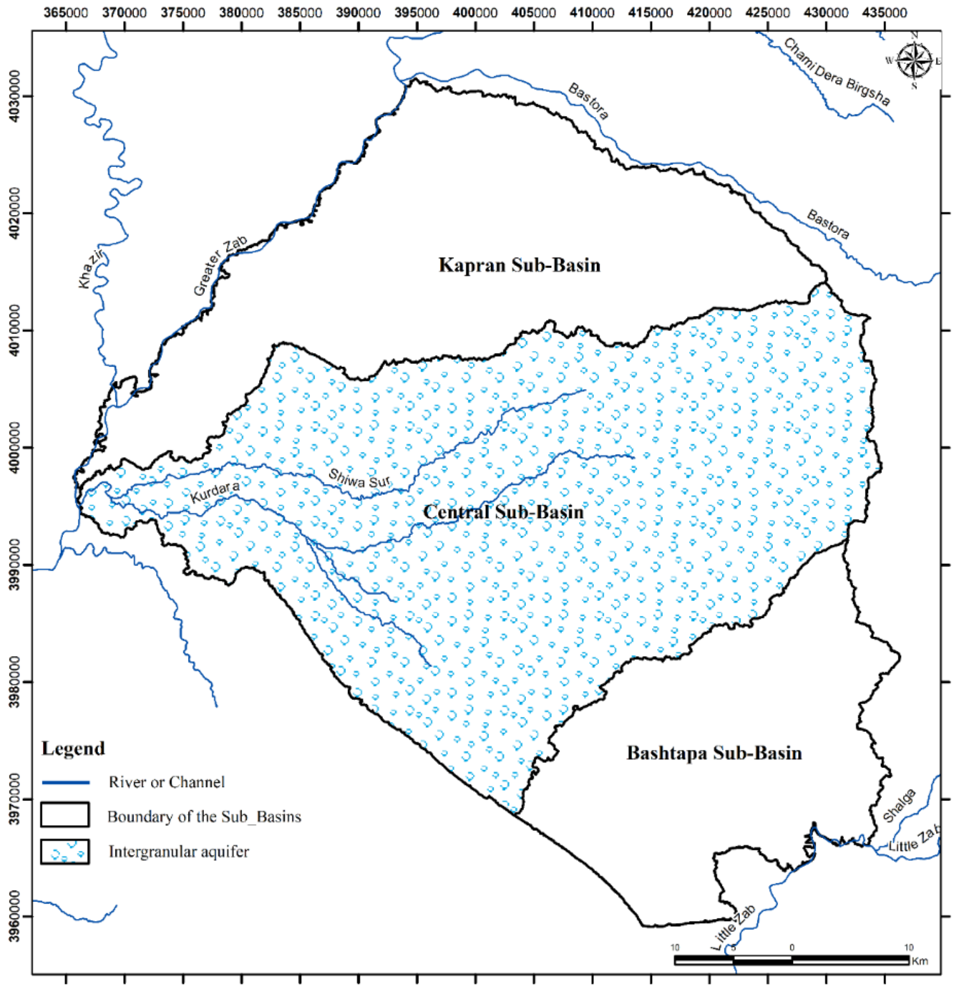

Figure 3.7. Hydrogeological map of the Erbil Central Sub-Basin.

3.4. Groundwater Quality

The quality of groundwater comprises the physical, chemical, and biological qualities of groundwater. Mineral ions are naturally present in groundwater, which slowly dissolves from soil particles, sediments, and rocks as the water moves along mineral surfaces in the pores or fractures of the unsaturated zone and the aquifer (Harter, 2003). A contaminant that has been released into the environment may transfer within an aquifer in the same manner that groundwater moves to depending on the physical, chemical, and biological properties of groundwater. Moreover, groundwater can become contaminated from natural sources or several types of human activities (USEPA, 1991). Groundwater contamination can affect health hazards, disruption or imbalance in the ecosystem, and scarcity (Talabi, 2019). Physicochemical parameters (pH, TDS, EC and NO_3) concentration for the wet season were selected as a groundwater quality parameters of the study area.

3.4.1. Hydrogen potential (pH)

pH value in water sources is defined according to the concentration of H^+ ions in the solution. In general, the hydrogen concentration (pH) is explicitly the strength of water that usually indicates acidic or alkaline material found in groundwater (Adimalla and Qian, 2019). As it is known, pH is one of the important water quality parameters in both surface and groundwater sources that determines the suitability of water resources for human use, agricultural activities, industrial applications, and aquatic ecosystem functioning (Sharma et al. 2018, Mebarki et al., 2021). In addition, its high range can possibly impart a bitter taste to drinking water (Khan et al.,2018). The pH value of water provides very important information in many types of geochemical balance or solubility calculations (Hem 1985).

3.4.2. Total dissolved solids (TDS)

Total dissolved solids (TDS) can be defined as the different types of minerals present in water in the dissolved form. TDS is an important parameter to determine the suitability of groundwater for any purpose (Sreenivasa and Asode, 2016). In natural water, sources of TDS mainly consist of a small number of inorganic salts mainly calcium, magnesium, potassium, sodium, bicarbonates, chlorides, silica, sulfates, and small amounts of organic matter that are dissolved in water (Kumar et al., 2017, Adimalla and Qian, 2019).

3.4.3. Electrical conductivity (EC)

Electrical conductivity (EC) is a vital parameter in groundwater quality evaluations for drinking and irrigation, since it is linked to the concentration of charged particles in the water (Tutmez et al., 2006). Electrical conductivity is the ability of a substance to conduct an electrical current at a standard temperature of 25^{o}C, measured in micro-Siemen's per centimeter (μS/cm) (Todd, 2007).

3.4.4. Nitrate (NO_3)

Nitrate contamination in groundwater is one of the main problems in many parts of the world, arising from both nonpoint (diffuse) like chemical fertilizers and point -sources such as cesspools or septic tanks and sewage systems (Zhou, 2015, Zhang et al., 2019). The elevated nitrogenous materials in groundwater are not of geological origin, but are mainly anthropogenic due to the contact of the soil covered with nitrate fertilizers, animal waste, domestic waste, human and cesspool leakage (Adimalla and Qian, 2019). Plants do not always use all the nitrate in (chemical) fertilizers or all the nitrate produced by the decomposition of organic matter. Therefore, if the nitrate supply is more than the amount plants use, nitrate can accumulate in the soil. With high nitrogen inputs to increase crop yields, nitrogen efficiency use may decrease and increase the possibility of nitrate leaching to the groundwater. Point sources can result in extremely high nitrate concentration has been reported in localized areas (Zhou, 2015). Livestock confinement, leaky septic or sewer systems, and areas of chemical or manure storage are caused by point sources (Haller et al, 2013).

3.5. Methods

In this study, a DRASTIC model applied in a GIS environment was used to evaluate the vulnerability of the aquifer system, which consists of the Pliocene aged Bakhtiary Formation and the Quaternary aged alluvial and terraces aquifer systems in the Erbil Central Sub-basin. DRASTIC is a popular method used in aquifer vulnerability assessment and was originally developed by the US Environmental Protection Agency (APA). For this model, the hydrogeological parameters of the aquifer system in the study area were used to evaluate the vulnerability of the aquifer. Table 3.1 represents all required data used for groundwater vulnerability mapping.

Table 3.1. Sources of data for DRASTIC Model.

Data Type	Sources
Depth to water table	Groundwater Directorate of Erbil and Directorate of Surrounding Water-Erbil
Net Recharge	General directorate of meteorology and seismology
Aquifer Media	Groundwater Directorate of Erbil and Directorate of Surrounding Water-Erbil
Soil Media	Soil Map by FAO 2001
Topography Map	DEM (30 m pixel size)
Impact of Vadose Zone	Groundwater Directorate of Erbil and Directorate of Surrounding Water-Erbil
Hydraulic conductivity	Groundwater Directorate of Erbil and Directorate of Surrounding Water-Erbil

For the study area, selected 148 wells locations for depth measurement of the groundwater level (Figure 3.8a). Physicochemical parameters (pH, TDS, EC and NO_3) concentration of groundwater quality sample for (64) wells for the wet season were selected from different locations for the study purposes (Table 3.2, Figure 3.8b), which were obtained and analyzed by (General Directorate of Water and Sewerage Quality Assurance and Public Health Laboratory Management) for study purposes (Table 3.3).

Table 3.2. Properties of sampling location in the study area.

Location Name	Location Code	Sampling Date	Coordinat (UTM)	
			X	Y
Daratu 9	QD9	04-Apr-21	416365	3997917
Rzgary 5	QR5	04-Apr-21	409453	4002463
Hawleri new 11	QHN11	05-Apr-21	417706	4007081
Betwata 3	QB3	05-Apr-21	416576	4006918
18 shubat	QSH18	05-Apr-21	413410	4001728
Shadi 9	QSH9	06-Apr-21	407438	4002026
Roshanbiri 2	QR2	07-Apr-21	413970	3999051
Bakhtiary 4	QB4	07-Apr-21	409096	4007439
Tayrawa 4	QT4	08-Apr-21	410952	4005884
Yarimj Village	QY	11-Apr-21	392848	3999842

Table 3.2. Properties of sampling location in the study area (continued)

Bnperz 1	QB	11-Apr-21	396217	4000848
Nawroz 2	QN2	11-Apr-21	407831	4003831
Hasarok 8	QH8	11-Apr-21	415324	4004607
Jmka village	QJ	12-Apr-21	395880	4000190
Zhyan 3	QZH3	12-Apr-21	411770	3999012
Gulan 1	QG1	12-Apr-21	414542	4006416
Ankawa 24	QA24	13-Apr-21	409561	4009536
Roshanbiri 19	QR19	13-Apr-21	414071	3998694
Mantikawa 2	QM2	18-Apr-21	412136	4001938
Rasti 6	QR6	19-Apr-21	411585	3999639
Badawa 3	QBD3	19-Apr-21	413799	4002795
Qushtapa No. 1	QQC	21-Apr-21	413430	3982721
Pungina	QP	21-Apr-21	426738	3999453
Grdishi sarw	QGS	22-Apr-21	430732	3998966
Chamrga	QCH	23-Apr-21	431146	3995894
Helawa	QH	25-Apr-21	390949	3984379
sarkarez 1	QSK1	25-Apr-21	407175	3999122
Nawroz 8	QN8	25-Apr-21	408062	4003642
Mastawa	QM	26-Apr-21	393518	3989951
Alyawa	QA	27-Apr-21	393328	3985151
Zagros 3	QZ3	27-Apr-21	417817	4002631
Tandura	QT	28-Apr-21	395413	3993026
Kani qrzhala 4	QKQ4	28-Apr-21	397092	4007280
Braim lak	QBL	02-May-21	411045	3988181
Goska	QG	02-May-21	407990	3987139
Sarbasti 9	QS9	02-May-21	406295	4006205
Safin 1	QS1	02-May-21	415097	4009946
Nazmawa 1	QN1	02-May-21	406000	3997304
Tobzawa 1	QT1	03-May-21	410123	3997770
Quchabilbas 2	QQ	03-May-21	408915	3990225
Eskan 2	QE2	03-May-21	412465	4003840
Kurdistan 11	QK11	03-May-21	408276	4002287
Zanko 12	QZ12	04-May-21	413659	4001189
Ankawa 22	QA22	04-May-21	409869	4009322
Ronaky 1	QR1	04-May-21	412079	4003060
Bnaslawa 27	QB27	05-May-21	420474	4001083
Sharawany 1	QSH1	05-May-21	414620	4001820
Brayati 7	QB7	05-May-21	412902	4006487
shadi 6	QSH6	06-May-21	407957	4001460
Harim 3	QH3	09-May-21	412830	4004349
Qushtapa No.3	QQ3	12-May-21	413005	3984720
Bnaslwa No.14	QB14	17-May-21	419825	4001681
Rapareen 5	QR5	17-May-21	413404	4007693

Table 3.2. Properties of sampling location in the study area (continued)

Bnaslawa No.36	QB36	18-May-21	419571	4001622
Bnsalwa 43b	QB43	21-May-21	422234	4002675
Kasnazan No.44	QK44	23-May-21	423391	4006385
Badawa 12	QB12	23-May-21	414298	4002858
Zanko 4	QZ4	23-May-21	413000	4002262
Kasnazan No. 45	QK45	24-May-21	422698	4005729
Kasnazan No. 11	QKW11	25-May-21	422211	4006732
Nogharan No.1	QNW1	26-May-21	384746	4004434
Daratu 11	QD11	26-May-21	416657	3997167
Hana city 2	QH2	30-May-21	415656	4005212
Khanzad 2	QK2	31-May-21	412476	4006936

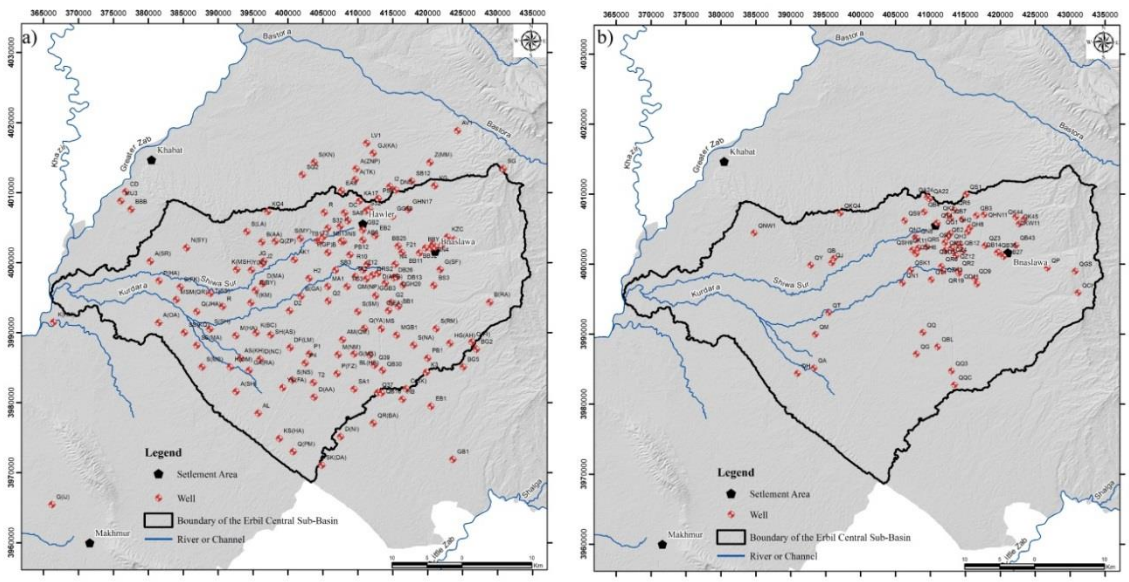

Figure 3.8. Location map of the study area a) wells for the water level b) wells for the water quality.

Table 3.3. Analysis methods used in water quality parameter tests.

No.	Parameters	Procedures
1	pH	PH meter
2	EC	Portable EC-meter
3	Nitrate (NO_3)	Spectrophotometer
4	TDS	TDS meter Portable

3.6. Data Analysis

Within the scope of the thesis study, spatial analysis of various physicochemical parameters measured/analyzed in different locations in the field was carried out using ArcGIS 10.2 software. An inverse distance-weighting (IDW) interpolation method is an algorithm used to spatially interpolate the data and/or estimate values between measurements. The IDW technique calculates a value for each grid node by examining surrounding sample points within a user-defined search radius. In this method, all data points are used in the interpolation process and the node value is computed by the inverse of the distance from observation to an estimate by averaging the weighted sum of all points (Prasanth et al., 2012).

During the GIS analysis, several methods were used, including (1) converting the hardcopy map information into a digital format after georeferencing and digitizing the various layers of data required, (2)creating a depth to the water table map from well log water depth records, existing shallow location information as well as the depth of wells, (3)development of a net recharge map from precipitation and land use/soil information (4)preparing aquifer map from a geological description of the groundwater aquifer composition (5)preparing soil media map (6)topography (slope) map from contour and elevation data (7)creating impact of vadose zone from the geological description of the unsaturated zone obtained from the borehole data (8)creating hydraulic conductivity map from well log records (9)assignment of sensitivity rating values mapped attribute values and (10)combining or overlaying individual characteristic maps to create the final cumulative susceptibility/vulnerability maps and modified maps.

3.6.1. Standard DRASTIC model

Within the scope of this thesis, the GIS-based DRASTIC model, which is a widely used approach for evaluating groundwater vulnerability in the Erbil Sub-Basin has been used. DRASTIC, an empirical method, was first developed by Aller et al. (1987) for the US Environmental protection agency (EPA) to evaluate the groundwater contamination potential systematically using hydrogeological parameters and also to demonstrate its applicability in any hydrologic setting (Stigter et al. 2006). The model is based on certain assumptions, and these assumptions are: (1) aquifer pollution originates from the surface origin, that is, from surface sources, (2) pollutants have sufficient mobility to mix with the recharge water in a porous medium to reach the water table during transport with the recharge water, and (3) in the porous media where pollutants and water are present, the hydraulic conductivity values of both fluids have similar properties (Aller et al. 1987, Bera et al., 2021). The DRASTIC Index uses the following seven different parameters, including geological, hydrogeological, hydrological factors, and data availability that affects and control pollutant movement into, from, and outside of an area (Abdullah et al. 2016): these are Depth to water (D), net Recharge (R), Aquifer media (A), Soil media (S), Topography (slope) (T), Impact of vadose zone (I), and hydraulic Conductivity (C). Each of the seven parameters in the DRASTIC model is assigned a value rating from 1 to 10 based on their relative importance of data values within each factor in estimating groundwater vulnerability. Then, each of these parameters has a relative weight of 1 to 5 assigned based on their relative importance in the process of influencing the pollution potential in groundwater. In addition, each hydrogeological parameter in the DRASTIC model is divided into some ranges in the aquifer system or different ranges according to the media type. According to the range, these parameters are ranked and weighted depending on their dominance ratio or their ability to affect groundwater. The grading differs from one area to another depending on the type of aquifer that makes up the hydrogeological system in the study area, recharge density and extraction, soil type, and depth of the water table. Due to these differences in soil and aquifer properties, ratings for a particular soil type are determined by experts (Nahin et al., 2020). Factors D, R, S, T, and C are assigned a value per range. However, factors I and A were assigned a "typical" rating and a "variable" rating, respectively (Zghibi et al.,2016). The DRASTIC index (D_i) is calculated using the rating and weight of each factor according to the equation below (3.1):

$$D_i = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \tag{3.1}$$

where D, R, A, S, T, I, and C represent the seven hydrogeological parameters as defined earlier and the subscripts r and w are the corresponding ratings and weight coefficients, respectively. A numerical value between 1 and 5, called a parametric weight, is assigned to each parameter meter, reflecting its degree of impact. Finally, by calculating the parameters in Eq. (3.1) according to their ratings and weightings, the study area will be divided into vulnerability zones (Zghibi et al., 2016). Weights of the seven parameters for the DRASTIC Index are given below (Table 3.4). A complete flow chart of the methodology is shown in Figure 3.9. Each parameter in the DRASTIC model has a fixed weight that shows the relative effect of the parameter in transporting pollutants to groundwater. The parameter ratings in the DRASTIC model have a variable effect, allowing the user to calibrate the model to suit the given characteristics of the region (Rahman 2008).

Table 3.4. Weight settings for DRASTIC hydrogeologic parameters (Aller et al., 1987).

Depth to Water		Net Recharge		Aquifer Media		Soil Media		Topography		Impact of Vadose Zone		Hydraulic Conductivity	
Range (m)	Rating	Range (mm/year)	Rating	Range	Rating	Range	Rating	Range %	Rating	Range	Rating	Range (m/day)	Rating
0-1.5	10	<50	1	Massive Shale	2	Thin or Absent	10	0 – 2	10	Confining Layer	1	<4	1
1.5-4.5	9	50-100	3	Metamorphic/Igneous	3	Gravel	10	2-6	9	Silt/Clay	3	4-12	2
4.5-9	7	100-175	6	Weathered Metamorphic/Igneous	4	Sand	9	6-12	5	Shale	3	12-29	4
9-15	5	175-250	8	Glacial Till	5	Peat	8	12-18	3	Limestone	6	29-41	6
15-21.5	3	>250	9	Bedded Sandstone, Limestone, Shale Sequences	6	Shrinking and/or Aggregated Clay	7	> 18	1	Sandstone	6	41-82	8
21.5-30	2	-	-	Massive Sandstone	6	Sandy Loam	6	-	-	Bedded Limestone, Sandstone, Shale	6	>82	10
>30	1	-	-	Massive Limestone	6	Loam	5	-	-	Sand and Gravel with significant Silt and Clay	6	-	-
-	-	-	-	Sand and Gravel	8	Silty Loam	4	-	-	Metamorphic/ Igneous	4	-	-
-	-	-	-	Basalt	9	Clay Loam	3	-	-	Sand and Gravel	8	-	-
-	-	-	-	Karst Limestone	10	Muck	2	-	-	Basalt	9	-	-
-	-	-	-	-	-	Nonshrinking and Nonaggregated Clay	1	-	-	Karst Limestone	10	-	-
Drastic weight: 5		Drastic weight: 4		Drastic weight: 3		Drastic weight: 2		Drastic weight: 1		Drastic weight: 5		Drastic weight: 3	

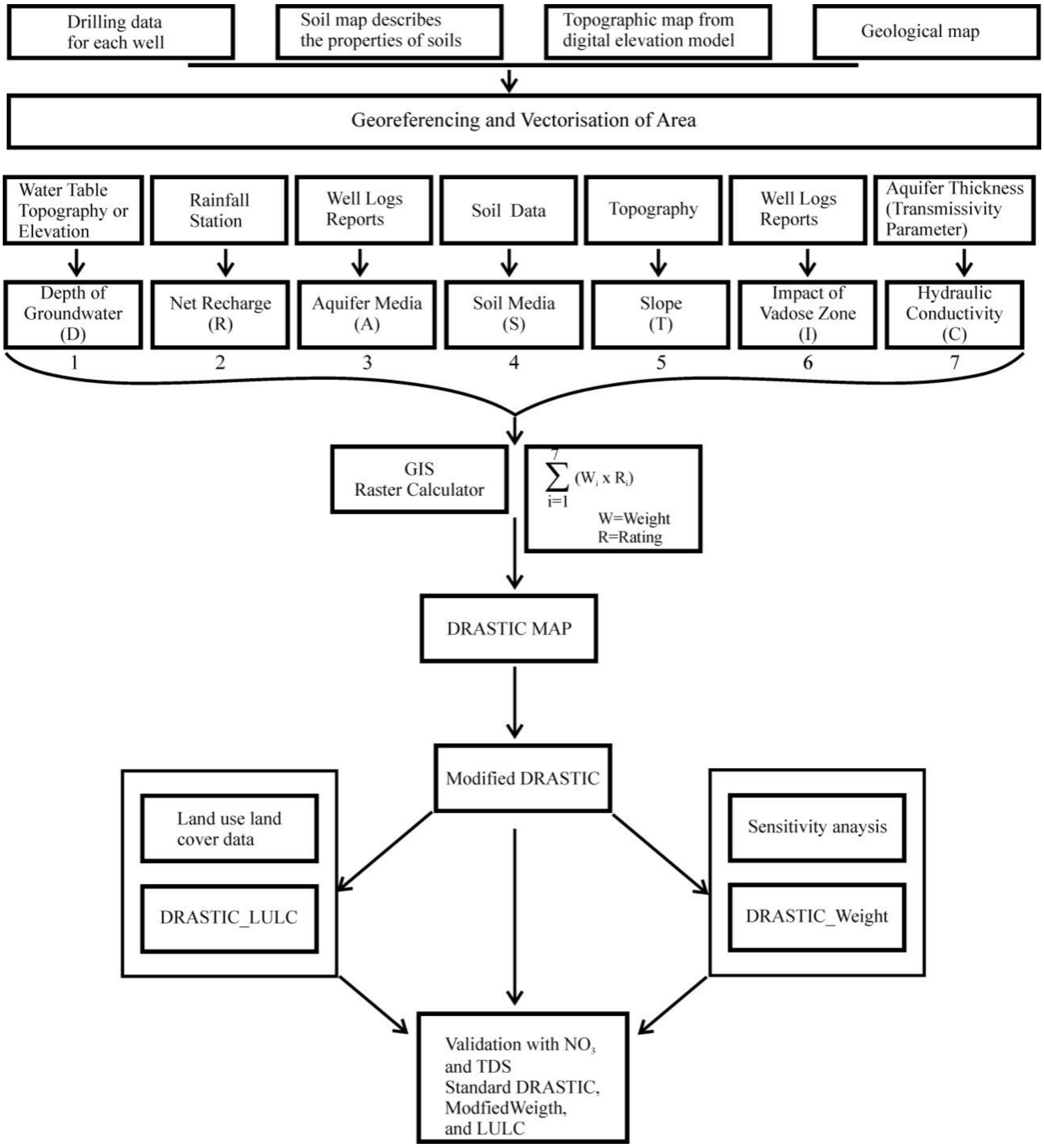

Figure 3.9. Flow chart of the methodology for groundwater vulnerability analysis and pollution risk mapping using a DRASTIC model in GIS (modified from Zghibi et al., 2016 and Singha et al., 2019).

3.6.1.1. Depth to the Water Table (D)

In the DRASTIC index model, one of the most important parmeters in the groundwater vulnerability assessment process is the depth to the water. The depth of the water table, which is defined as the distance between the ground surfaces and the water table, plays an important role in the infiltration of contaminants in aquifers because the thicker the soil surface may require more time in the process of accessing groundwater for a contaminant to pass through the soil layers before reaching the aquifer-saturated zone (Ahada and Suthar, 2018; Muhammad et al.2015, Siarkos, 2021). The duration of contact time between the percolating contaminant and sub-surface materials (air, minerals, water) in the vadose region determines to what extent the contaminants undergo chemical and biological reactions such as dispersion, diffusion, reactivity, oxidation, and effective surface area of the aquifer framework material or sorption, which cause natural attenuation during transport process (Saha and Alam, 2014).

In general, deeper aquifers are at lower risk from surface contamination than shallow aquifers because the greater the depth from the surface to the groundwater level, the lower the probability of contamination of groundwater, and shallow aquifers require a longer time and larger barriers required to reach deeper aquifers. Lower water table depth plays an active role in reducing the duration of various chemical and biological reactions, including dispersion, natural attenuation, oxidation, and sorption, which are effective in the transport of pollutants in porous media (Ahada and Suthar, 2018). In addition, thicker and highly permeable sand, gravel, and gravel materials placed between the land surface and the aquifer provide a higher chance of contaminants leaching. The weight of this parameter is assigned 5 in the DRASTIC model. In this study, 18 years of data were measured from 148 wells at different locations of the study area, which were obtained from 2002 to 2020 (Groundwater Directorate of Erbil and Directorate of Surrounding Water-Erbil) has been regarded to measure the depth to the water table. These data were interpolated by the IDW (Inverse Distance Weighted) method, which is the most popular known technique in the field of soil science to create the depth to water table layer in raster format using power 2 due to the lower root mean square error (RMSE) to construct the depth to water table map.

3.6.1.2. Net Recharge (R)

Water from precipitation and various other artificial sources available migrate down to the underground and reaches the soil and groundwater table. This amount of infiltrated water per unit area of soil is defined as net recharge. Generally varies depending on various factors such as soil type, slope, permeability, precipitation, land cover, amount of that infiltrates into the groundwater table. This parameter is important in determining groundwater vulnerability. Because with recharge water, the pollutants infiltrate underground from the surface and may move laterally within the aquifer or vertically to the water table (Nahin et al., 2020, Bera et al., 2021). Therefore, a higher net recharge indicates higher vulnerability to contamination and therefore has a higher ranking. The weight of this parameter is assigned 4 in the DRASTIC model.

The net recharge value of the study area was calculated at the meteorological data for the period (2005 -2019) based on the following equations (3.2 and 3.3):

$$W_s = R_s + R_e \tag{3.2}$$

$$R_e = W_s - R_s \tag{3.3}$$

Where W_S is the water surplus (excess water) (mm), R_s is the surface runoff (mm), R_e is the recharge (mm). W_S is calculated based on the water balance equations as follow (3.4,5,6,7 and 8):

$$P = R_s + I + A_{ET} \tag{3.4}$$

$$R_s + I = W_s \tag{3.5}$$

$$I = R_e + R_i \tag{3.6}$$

$$W_s = P - P_{ET} \quad P > P_{ET} \tag{3.7}$$

$$W_D = P_{ET} - P \quad P < P_{ET} \tag{3.8}$$

Where P is the accumulated average monthly rainfall (mm), I is the infiltration (mm), A_{ET} is the actual evapotranspiration (mm), R_i is soil moisture (mm), W_D is the water deficit (mm), P_{ET} is the potential evapotranspiration (mm) estimated by Thornthwaite equation, P is calculated from the average total annual rainfall for the mentioned period which is about 400.9 mm/year (Table 3.5). The evaporation from groundwater is not provided due to deep of the groundwater table from the ground surface of the study area. Therefore, soil moisture is consumed by evaporation from the soil or plant (Hassan, 1981).

P_{ET} value is calculated by Thornthwaite method (1948) and used to calculate W_S and A_{ET} by the following equation (3.9 - 3.12):

$$P_{ET} = 16 \left(\frac{10\,t}{J}\right)^{a} L_a \qquad \text{mm per month} \tag{3.9}$$

$$J = \sum_{n=1}^{12} j \qquad \text{for each month} \tag{3.10}$$

$$j = \left(\frac{t}{5}\right)^{1.514} \tag{3.11}$$

$$a = (675x10^{-9})\,J^3 - (771x10^{-7})\,J^2 + (179x10^{-4})J + 0.492 \tag{3.12}$$

$P > P_{ET}$ then $P_{ET} = A_{ET}$

$P<P_{ET}$ then $P = A_{ET}$

Where, La is the monthly correction constant function of latitude, j is the monthly temperature parameter (°C), J is thermal index imposed by the local normal climatic temperature regime (°C), t is the mean monthly temperature (°C), a is exponent being a function of *J*. Based on above the equations AET and WS are calculated and the value are equal to 184.69 mm and 216.21 mm, respectively (see Table 3.5).

Table 3.5. Water budget values for the period (2005-2019) by Thornthwaite method

Parameter	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Total
P	31.30	34.70	65.60	66.50	66.40	67.10	45.40	18.30	1.40	0	0.10	4.10	400.90
P_{ET}	102.66	30.23	10.19	5.60	10.86	27.22	70.60	158.50	283.23	351.59	330.40	197.88	1578.96
$P-P_{ET}$	-71.36	4.47	55.41	60.90	55.54	39.88	-25.20	-140.20	-281.83	-351.59	-330.30	-193.78	-
A_{ET}	31.30	30.23	10.19	5.60	10.86	27.22	45.40	18.30	1.40	0	0.10	4.10	184.69
W_D	71.36	0	0	0	0	0	25.20	140.20	281.83	351.59	330.30	193.78	1394.27
W_S	0.00	4.47	55.41	60.90	55.54	39.88	0	0	0	0	0	0	216.21

Total runoff (Rs) is calculated according to the Soil Conservation Service method (SCS) (Soil Conservation Service, 1972) to determine the total runoff for the study area. Based on the curve numbers (CN) (Figure 3.10) 32 and 30 are used for the Bakhtiari Formation and recent deposits (both Alluvial Plain and Quaternary Terraces) respectively (Al-Kubaisi and Rasheed, 2017), and 83 is used for the urban area (Hameed, 2013) and then using the following equation (3.13 and 14):

$$Q = {(P-0.2S)^2}/{(P+0.8S)} \quad \text{for } P>0.2S, \quad \text{else } Q=0 \tag{3.13}$$

$$S = (25400/CN) - 254 \tag{3.14}$$

Where Q is the accumulated runoff excess in (mm), S is the potential water retention, including the initial abstraction, which is assumed to be (0.2S). As a result, the annual runoff of this basin is about 8.90 mm (Table 3.6) and the annual net recharge for the entire basin is equal to 207.32 mm (Table 3.7).

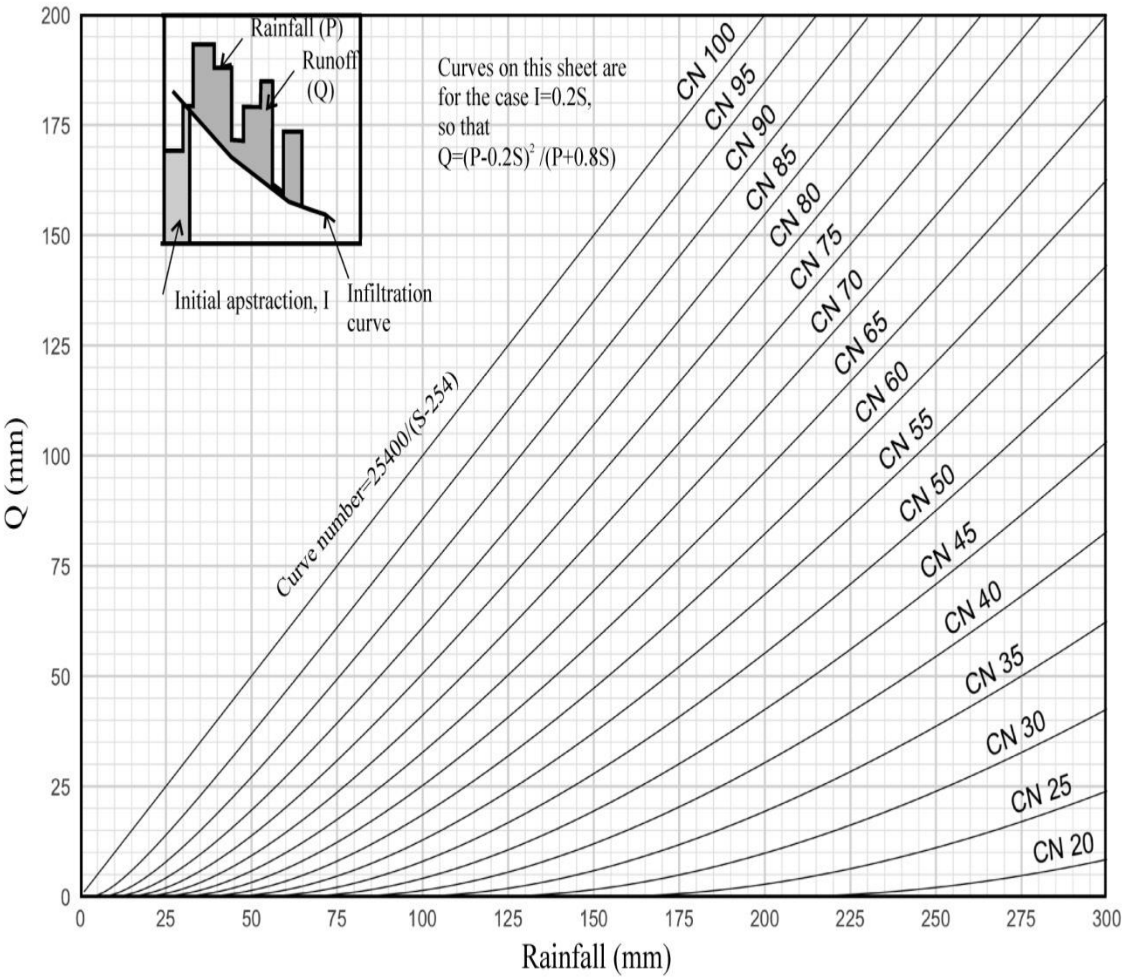

Figure 3.10. Graphical relation between rainfall and runoff (SCS-CN method) (modified USDA, 2004).

Table 3.6. Monthly runoff for the study area based on SCS method.

Month	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Total			
P	31.3	34.7	65.6	66.5	66.4	67.1	45.4	18.3	1.4	0	0.1	4.1	400.9			
W_S	0	4.47	55.41	60.9	55.54	39.88	0	0	0	0	0	0	216.21			
CN	Runoff in (mm)												Enclosed area (km^2)	Volume ($x10^6$ m^3)	Runoff in (mm)	Runoff in %
83	0	7.7	28.4	29.1	29	29.6	0	0	0	0	0	0	116.5	14.4	123.8	30.9
32	0	0	0	0	0	0	0	0	0	0	0	0	341	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	1167	0	0	0
													1624.5	14.4		
T.Runoff $x10^6$ (m^3)	0	0.9	3.31	3.39	3.38	3.44	0	0	0	0	0	0				14.4
T.Runoff (mm)	0	0.55	2.04	2.09	2.08	2.12	0	0	0	0	0	0				8.9

Table 3.7. Estimated amount of net recharge of the study area based on SCS.

Month	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Total				
P	31.3	34.7	65.6	66.5	66.4	67.1	45.4	18.3	1.4	0	0.1	4.1	400.9				
W_S	0	4.47	55.41	60.9	55.54	39.88	0	0	0	0	0	0	216.2				
R_s	0	0.55	2.04	2.09	2.08	2.12	0	0	0	0	0	0	8.9				
CN	Net Recharge in (mm)												Enclosed area (km^2)	Volume (x 10^6 m^3)	Net Recharge (mm)	Net Recharge %	DRASTIC Rating
83	0	0	27	31.79	26.51	10.32	0	0	0	0	0	0	116.5	11.14	95.62	24	3
32	0	4.47	55.41	60.9	55.54	39.88	0	0	0	0	0	0	341	73.72	216.2	54	8
30	0	4.47	55.41	60.9	55.54	39.88	0	0	0	0	0	0	1167	252.31	216.2	54	8
													1624.5	337.17			
Net Recharge x10^6 (m^3)	0	6.74	86.7	95.54	86.84	61.34	0	0	0	0	0	0				337.17	
Net Recharge (mm)	0	4.12	53.30	58.80	53.40	37.70	0	0	0	0	0	0				207.32	

3.6.1.3. Aquifer media (A)

The aquifer media parameter refers to the nature of the geologic formation, which consists of the unconsolidated (sand and gravel in case of alluvium) and consolidated rock (secondary porosities; fracture/joint), in which groundwater water is stored in the pores it contains (Rahman, 2008; Saha and Alam, 2014; Zghibi et al., 2016) and for aquifer remediation processes. Aquifer media control the natural flow of groundwater, the route and the path length of contaminants, and regulate the type of pollution depending on the function of the water table located within the subsurface, geological formations of groundwater, and hydraulic conductivities. Aquifer media with large grain size, high porosity, fracture or interconnections series are characterized by higher permeability and lower attenuation process, while consequently providing a preferential path to the contamination flow, with a greater risk for contamination (Ahada and Surthar, 2018). As water seeps inwards, absorption, cation exchange, filtration, and other processes occur in the aquifer media. For this reason, the transport of pollutants in the aquifer media varies depending on the thickness and permeability of the formation. The greater thickness of the geological formation with lower permeability is classified with a lower risk of contamination as higher dissolution and dilution of contaminants (Bera et al., 2021). This parameter is assigned a weight of 3 in the DRASTIC model.

3.6.1.4. Soil media (S)

Soil is considered the uppermost weathered portion above the vadose zone that averages a depth of 1.8 m or less from the surface. Soil actively operates on the quantity of recharge that can penetrate the ground, and hence on the ability of a contaminant to move vertically into the vadose zone. Moreover, where the soil zone is fairly thick, the attenuation processes of filtration, biodegradation, sorption, and volatilization may be quite significant. The process of attenuation occurs depending on the thickness and content of soil media (Aller et al., 1987). Soils that are porous and permeable tend to transmit water and certain types of contaminants with relative ease to an aquifer below (USEPA 1991). The finer the soil particle, the lesser possibility of infiltration, and the coarser the soil particle, the greater possibility of infiltration as well. The soil is an important factor in measuring groundwater vulnerability (Sarkar, 2021). In general, the pollution potential of soil is mainly affected by the type of clay present and the grain size of the soil. Thus, the less the clay shrinks and swells, and the smaller grain size indicates less amount of pollution potential (Aller et al., 1987). This parameter is assigned a weight of 2 in the DRASTIC model.

3.6.1.5. Topography (T)

The topography is the physical structure of land surface containing slope and slope variability that directly controls the precipitation pattern distribution, surface water movement, and runoff infiltration in the study area, and indirectly affects the infiltration of pollutants from the soil surface or the retention time on the soil surface (Aller et al., 1987; Meng, et al., 2020). If the slope is steep, more runoff will be generated and hence groundwater contamination risk will be below. However, flat areas tend to hold water for a long period, as a result increasing the potential for migration of contaminants (Ouedraogo et al., 2016). The topography map of the study area was constructed from a digital elevation model (DEM) with a pixel size of 30m which was obtained from (Ministry of Planning/ statistical Office). The weight of this parameter is assigned 1 in the DRASTIC model.

3.6.1.6. Impact of vadose zone (I)

The unsaturated or discontinuously saturated region above the water table, lying between the soil layer and the water table, is defined as the vadose zone (Aller et al., 1987; Tiwari et al., 2016). The impact of the vadose region on the transport process of groundwater pollution varies depending on the aquifer media environment and the physical properties of the land surface (Ahada and Suthar, 2018; Barbulescu, 2020). Biodegradation, neutralization, mechanical filtration, chemical reaction, volatilization, and dispersion are all possible processes within the vadose zone. The media of the vadose zone controls the length of the path and routing thus affecting the time available for attenuation and the quantity of material encountered (Aller et al., 1987). Consequently, the vadose zone media by acting as a passageway determines the number of contaminants moving to the water table and their attenuation (Bera, 2021). In the DRASTIC model, this parameter is assigned a weight of 5.

3.6.1.7. Hydraulic conductivity (C)

Hydraulic conductivity is an important parameter that affects the mobility rate of groundwater into the saturation zone under a given hydraulic gradient. It thus determines the amount of pollutants moving downwards and shows the movement of pollutant-rich groundwater into the aquifer from high peak to low peak (Subramani et al., 2005, Bera et al., 2021). The amount and interconnection of void space within the aquifer that occurs as a consequence of intergranular porosity, fracturing, and bedding planes control hydraulic conductivity. The high hydraulic conductivity values represent high contamination risk (Aller et al., 1987). This parameter is assigned a weight of 3 in the DRASTIC model.

The scaled values based on pumping tests data have been used to assess the hydraulic conductivity. Accordingly, 86 wells were selected for calculating the transmissivity by pumping test, (AQTESOL 4.0) software was used for pumping test data analyses to estimate the transmissivity of the aquifer, and then hydraulic conductivity was calculated based on the following equation (3.15).

$$K = Tb^{-1} \tag{3.15}$$

where K is the hydraulic conductivity of the aquifer (md^{-1}), T is the transmissivity ($m^2\ d^{-1}$) and b is the thickness of the aquifer (m).

3.6.2. Modification of DRASTIC model

3.6.2.1. Weight modification using single parameter sensitivity analysis (SPSA)

Sensitivity analysis is widely used in groundwater vulnerability analysis as it provides important information on the effect of the ratings and weights values assigned to each parameter, and guides decision-makers in the process of assessing the importance of subjectivity (Edet, 2014, Kazakis and Voudouris, 2015). There are two types of sensitivity analysis: map/layer removal sensitivity analysis and single parameter sensitivity analysis (Yang et al., 2017). The map removal sensitivity measure is used to describe the sensitivity of the suitability map (vulnerability map) towards removing one or more maps from the suitability analysis (Babiker et al., 2005) In this study, the single parameter sensitivity analysis (SPSA) method, which was first introduced by Napolitano and Fabbri (1996), was used to achieve more appropriate results. Single parameter sensitivity (SPSA) analysis allows determining the effective weights of each DRASTIC parameter in the final vulnerability index and allows a comparison between the theoretical weights assigned to each parameter of the DRASTIC model and its corresponding effective weight (Babiker et al., 2005, Sidibe and Xueyu, 2018). The effective weight (W_{pi}) is obtained using the following equation (3.16):

$$W_{pi} = \frac{(P_{Ri} P_{wi})}{V_i} 100\% \quad (3.16)$$

Where W_{pi} is the effective weight for each unique condition subarea *i*, V_i is the overall vulnerability index, P_{Ri} and P_{wi} are denote the rating and weight of each parameter P assigned to subarea *i*, respectively. A high to very high rating is given if a spatial variation is considered for the whole study area. This suggests a probability of coverage for an entire portion of the study area in the process of associating category high with a very high rating. In addition, It should also be noted here that the effective weight being greater than the theoretical weight corresponds to a situation where the effective weight will have more importance on the model results (Kumar and Krishna 2019).

3.6.2.2. Modified DRASTIC model based on LULC

Land use land cover (LULC) map is rated and weighted as an additional parameter and merged into the standard DRASTIC model. This combination is named the modified DRASTIC model with LULC. Based on (Secunda et al., 1998), the LULC rating map is rated and weighted to develop the modified DRASTIC map (Table 3.8).

Table 3.8. Rate and weight for LULC classes (Secunda et al., 1998).

Classes	Rate	Weight
Barren land and Vegetation	5	5
Urban area and agricultural land	8	

In order to modify the original standard DRASTIC map, it is superimposed over the LULC index map based on equation (3.17) (Secunda et al., 1998).

$$MD(i) = DI + (LULC\ Index) \tag{3.17}$$

Where MD(i) is the modified DRASTIC Model, DI is the standard index, and the LULC index (rating.weights).

Barren land and vegetation area are assigned a probability rating value of 5, which contains almost the same concentration of low nitrogen (Abdulla et al., 2015). Moreover, agricultural land and urban area are assigned a probability rating value of 8 because chemical contaminant concentrations, like nitrogen from anthropogenic activity in urban and agricultural lands, are higher than in all other land use areas (Secunda et al., 1998).

3.6.3. Land use and land cover

Land use and land cover (LULC) map are essential environmental parameters to identify the effect of human activities and natural processes (Meyer et al., 1992). LULC is a short term of land use and land cover; each term has its own distinct meaning; Land cover covers (LC) refers to the surface cover of the earth such as water, snow, forest, grassland, and bare soil; while land use (LU) indicates how the land cover is modified into use, for example, agricultural land, built-up land, etc. (Cihlar et al., 2001). Moreover, in this study, the LULC map is a useful tool used as an additional parameter to modify the standard DRASTIC model to confirm the accuracy of vulnerability for pollution because LULC dynamics have an impact on the quality and quantity of groundwater resources (Ahmad et al., 2021).

Land Cover Classification makes use of the decadal reflectance time series and seasonal phenology information from the Crop Calendar. The Level 1 land cover products were derived from the Global Land Service of Copernicus, the Earth Observation Program of the European Commission. This product was generated from MODIS data, using the Copernicus training data and operational workflow, modified to account for differences in spatial resolution and the delivered land cover classes. In addition, irrigated areas are identified by applying a water deficit index that takes into consideration seasonal cumulated values of precipitation and actual evapotranspiration.

The global CGLS-100m land cover map for 2015 served as a base layer for both Level 1 and 2, whereas the cropland class was further divided into irrigated, rainfed and fallow, on an annual basis. The classification applied is based on the Land Cover Classification System (LCCS) that was developed by FAO. Data component developed through collaboration with the FRAME Consortium. More information can be found at: http://www.fao.org/in-action/remote-sensing-for-water-productivity/en/ Until December 2019 the base input layers (NDVI, albedo, and fAPAR) for the Level 2 (100m) products were derived from the Proba-V satellite. Proba-V was decommissioned in June 2020. From January 2020 onwards the base input layers of NDVI, albedo, and fAPAR for level 2 are derived from the Copernicus Sentinel-2 mission. The LULC map of Erbil central sub-basin as shown in (Figure 3.11) that only four classes can be identified.

LULC map of the study area shows that a major part of the area is used for agricultural activity with an area of 1359 km^2 or 83.6% of the total study area. The second major area is designated as vegetation land coverering 130 km^2 or 8% of the whole study area. Additionally, the remaining classes of the area are categorized as urban area and barren land covering an area of 116.5 and 19 km^2 or 7.2% and 1.2 %, respectively of the total study area (Table 3.9).

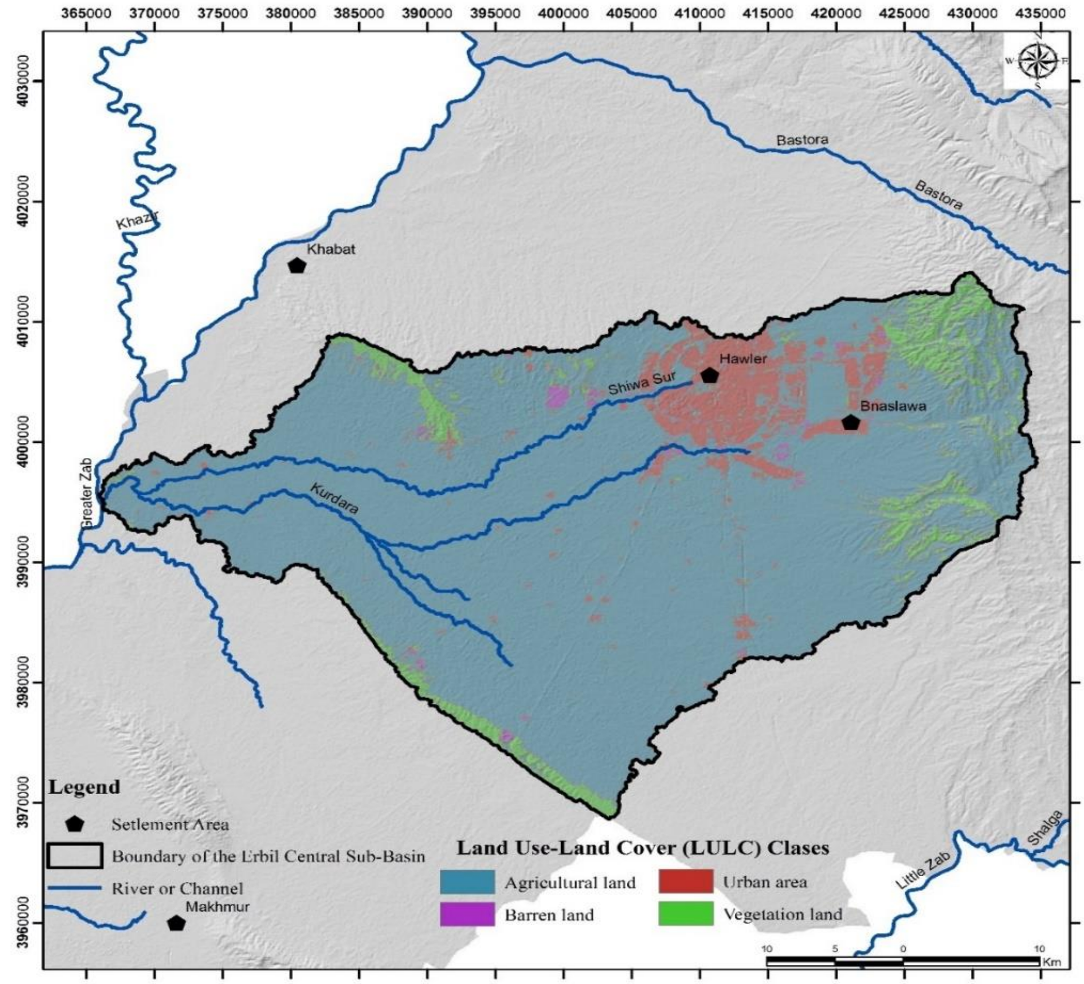

Figure 3.11. Land use land cover (LULC) map of the study area.

Table 3.9. LULC Classes Type in the study area

Classes	Area (km^2)	Area (%)
Agriculture land	1359.0	83.6
Vegetation land	130.0	8.0
Urban area	116.5	7.2
Barren land	19.0	1.2

3.6.4. Geostatistical modeling

Geostatistical modeling is a useful tool in the process of determining spatial and temporal changes in groundwater hydrochemical parameters in hydrogeological systems (Ahada and Suthar, 2018). The Inverse Distance Weighted (IDW) method, which is an interpolation method is widely recognized as the basic method in most systems. In the

IDW method, it is assumed substantially that the rate of correlations and similarities between the neighborhood of each rendering cell is proportional to the distance between them that can be defined as a distance reverse function of every sample data point from neighboring points. (Achilleos 2011, Setianto and Triandini , 2013). It should be noted that the definition of the neighboring radius and the related power due to the distance inverse function is often seen as important problems in this method (Setianto and Triandini, 2013). This method will be used when there are sufficient sample points (at least 14 points) with a suitable distribution at local scale levels. The main factor affecting the accuracy of the inverse distance interpolator is the value of p, defined as the power parameter (Burrough and McDonnell, 1998).The general IDW prediction equation (3.18) is (http://www.udaconsulting.com/sites/ default/files/2018-09/Spatial_Interpolation_UDA.pdf):

$$Z(u_0) = \sum_{i=1}^{N} w_i \, Z(u_i) \qquad (3.18)$$

Where, $Z(u_0)$ is the value being predicted for the target location; N is the number of measured data points in the search window; wi are the weights assigned to each measured point, and Z(ui) is the observed value at location ui. ui=(xi,yi.)

One of the biggest advantages of the Inverse Distance Method is that it is very simple and easy to use. It is generally applicable to a wide variety of data, as the method usually gives reasonable results and does not exceed the range of meaningful significant values (Caruso et al., 1998).

3.6.4.1. Correlation analysis

Correlation is defined as a bivariate statistical method that measures the degree of dependence of one cluster on another or how strong the relationship between two variables. Correlation coefficient (r) values can take values close to -1 and/or close to +1, where -1 indicates a perfect negative relationship, +1 indicates a perfect positive relationship, and correlation coefficient values going towards 0 indicate that there is weak or no relationship between the variables. Parameters showing r>0.75 are considered to be strongly correlated, whereas if the r value is between 0.5 and 0.75, and

0.30-0.50, the two parameters have a moderate and weak correlation, respectively (Liu et al., 2003). The linear regression coefficient (r) is used to calculate the linear correlation coefficient and the slope-intercept method for the regression line (3.19).

$$r = \frac{n(\sum xy) - (\sum x)(\sum y)}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \tag{3.19}$$

where n number of variables measured for each sample

∑XY the sum of variables

x first variable measured

y second variable measured

4. RESULTS AND DISCUSSION

Spatial maps of pH, TDS, EC, NO_3, and GIS-based DRASTIC model maps were performed using the inverse distance weighted (IDW) interpolation method of ArcGIS's spatial analysis module (version 10.2). As a result, pH, EC, TDS, and NO_3 were evaluated according to drinking water quality standards recommended by the World Health Organization and Iraqi Central Organization for Standardization and Quality Control Standards (WHO 2006; IQWS 2010). All of the parameters, which used in the vulnerability indices were organized in raster with a regular grid of 25 ×25 m resolution. The vulnerability map of DRASTIC is based on a weighted combination of seven DRASTIC parameter maps in GIS.

4.1. Groundwater Quality in the Study Area

The results of NO_3 concentration of the well water samples which were collected from the study are and field measurements such as pH, TDS and EC, are presented in (Table 4.1.) The physicochemical parameters of the well water samples were compared to the standards for drinking water limits indicated by WHO (2011) and IQWS (2010) guideline values (Table 4.2).

Table 4.1. Physicochemical parameters in the water samples from the 64 sites.

Location Name	Location Code	Sampling Date	Coordinat (UTM)		pH	EC (µS/cm)	TDS (mg/L)	NO_3 (mg/L)
			X	Y				
Daratu 9	QD9	04.Nis.21	416365	3997917	7.20	255.00	163.20	21.00
Rzgary 5	QR5	04.Nis.21	409453	4002463	7.40	262.00	167.68	38.00
Hawleri new 11	QHN11	05.Nis.21	417706	4007081	7.60	193.00	123.52	19.00
Betwata 3	QB3	05.Nis.21	416576	4006918	7.60	238.00	152.32	14.00
18 shubat	QSH18	05.Nis.21	413410	4001728	7.60	351.00	176.00	19.00
Shadi 9	QSH9	06.Nis.21	407438	4002026	7.50	199.00	127.36	19.00
Roshanbiri 2	QR2	07.Nis.21	413970	3999051	7.70	217.00	138.88	18.00
Bakhtiary 4	QB4	07.Nis.21	409096	4007439	8.00	428.00	214.00	22.00
Tayrawa 4	QT4	08.Nis.21	410952	4005884	7.90	552.00	276.00	43.00
Yarimj Village	QY	11.Nis.21	392848	3999842	7.50	322.00	206.08	70.00
Bnperz 1	QB	11.Nis.21	396217	4000848	7.70	244.00	156.16	39.00
Nawroz 2	QN2	11.Nis.21	407831	4003831	7.00	407.00	260.48	79.00
Hasarok 8	QH8	11.Nis.21	415324	4004607	7.50	477.00	239.00	17.00

Table 4.1. Physicochemical parameters in the water samples from the 64 sites (continued).

Jmka village	QJ	12.Nis.21	395880	4000190	7.30	378.00	241.92	74.00
Zhyan 3	QZH3	12.Nis.21	411770	3999012	7.50	211.00	135.04	28.00
Gulan 1	QG1	12.Nis.21	414542	4006416	7.90	332.00	166.00	5.70
Ankawa 24	QA24	13.Nis.21	409561	4009536	7.30	279.00	178.56	21.00
Roshanbiri 19	QR19	13.Nis.21	414071	3998694	7.70	178.00	89.00	23.00
Mantikawa 2	QM2	18.Nis.21	412136	4001938	7.50	258.00	165.12	40.00
Rasti 6	QR6	19.Nis.21	411585	3999639	7.71	203.00	129.92	17.00
Badawa 3	QBD3	19.Nis.21	413799	4002795	7.60	321.00	161.00	19.00
Qushtapa No. 1	QQC	21.Nis.21	413430	3982721	8.20	480.00	240.00	5.00
Pungina	QP	21.Nis.21	426738	3999453	7.60	237.00	151.68	37.00
Grdishi sarw	QGS	22.Nis.21	430732	3998966	7.90	300.00	192.00	38.00
Chamrga	QCH	23.Nis.21	431146	3995894	7.70	260.00	166.40	37.00
Helawa	QH	25.Nis.21	390949	3984379	7.70	1146.00	573.00	42.00
sarkarez 1	QSK1	25.Nis.21	407175	3999122	7.40	596.00	298.00	31.00
Nawroz 8	QN8	25.Nis.21	408062	4003642	7.60	732.00	366.00	60.00
Mastawa	QM	26.Nis.21	393518	3989951	7.60	1072.00	536.00	30.00
Alyawa	QA	27.Nis.21	393328	3985151	7.80	3200.00	1600.00	28.00
Zagros 3	QZ3	27.Nis.21	417817	4002631	7.70	451.00	226.00	17.00
Tandura	QT	28.Nis.21	395413	3993026	7.40	841.00	421.00	24.00
Kani qrzhala 4	QKQ4	28.Nis.21	397092	4007280	8.20	839.00	420.00	28.00
Braim lak	QBL	02.May.21	411045	3988181	7.80	218.00	139.52	22.00
Goska	QG	02.May.21	407990	3987139	7.90	217.00	138.88	22.00
Sarbasti 9	QS9	02.May.21	406295	4006205	7.30	292.00	186.88	30.00
Safin 1	QS1	02.May.21	415097	4009946	7.80	277.00	177.28	18.00
Nazmawa 1	QN1	02.May.21	406000	3997304	7.90	822.00	411.00	19.00
Tobzawa 1	QT1	03.May.21	410123	3997770	8.20	517.00	259.00	19.00
Quchabilbas 2	QQ	03.May.21	408915	3990225	7.90	336.00	215.04	24.00
Eskan 2	QE2	03.May.21	412465	4003840	7.40	463.00	232.00	45.00
Kurdistan 11	QK11	03.May.21	408276	4002287	7.50	705.00	353.00	58.00
Zanko 12	QZ12	04.May.21	413659	4001189	7.70	384.00	192.00	18.00
Ankawa 22	QA22	04.May.21	409869	4009322	8.00	584.00	292.00	35.00
Ronaky 1	QR1	04.May.21	412079	4003060	7.80	436.00	218.00	25.00
Bnaslawa 27	QB27	05.May.21	420474	4001083	7.40	240.00	153.60	60.00
Sharawany 1	QSH1	05.May.21	414620	4001820	7.70	184.00	117.76	25.00
Brayati 7	QB7	05.May.21	412902	4006487	8.10	518.00	259.00	33.00
shadi 6	QSH6	06.May.21	407957	4001460	7.90	408.00	204.00	19.00
Harim 3	QH3	09.May.21	412830	4004349	7.41	259.00	165.76	66.00
Qushtapa No.3	QQ3	12.May.21	413005	3984720	7.60	323.00	206.72	19.00
Bnaslwa No.14	QB14	17.May.21	419825	4001681	7.60	210.00	134.40	23.00
Rapareen 5	QR5	17.May.21	413404	4007693	7.30	273.00	174.72	48.00
Bnaslawa No.36	QB36	18.May.21	419571	4001622	7.80	270.00	172.80	31.00
Bnsalwa 43b	QB43	21.May.21	422234	4002675	8.00	435.00	218.00	30.00
Kasnazan No.44	QK44	23.May.21	423391	4006385	7.80	159.00	101.76	10.00
Badawa 12	QB12	23.May.21	414298	4002858	7.50	156.00	99.84	14.00

Table 4.1. Physicochemical parameters in the water samples from the 64 sites (continued).

Zanko 4	QZ4	23.May.21	413000	4002262	7.40	190.00	121.60	39.00
Kasnazan No. 45	QK45	24.May.21	422698	4005729	7.70	159.00	101.76	15.00
Kasnazan No. 11	QKW11	25.May.21	422211	4006732	7.50	295.00	188.80	38.00
Nogharan No.1	QNW1	26.May.21	384746	4004434	7.70	326.00	208.64	38.00
Daratu 11	QD11	26.May.21	416657	3997167	7.90	381.00	191.00	14.00
Hana city 2	QH2	30.May.21	415656	4005212	7.60	175.00	112.00	21.00
Khanzad 2	QK2	31.May.21	412476	4006936	7.20	375.00	240.00	38.00
Average					7.65	422.59	231.94	30.29
Minimum					7.00	156.00	89.00	5.00
Maximum					8.20	3200.00	1600.00	79.00

Table 4.2. Drinking water quality standards of WHO (2011) and IQWS (2010) guidelines.

Water quality parameters	Unit	WHO(2011)	IQWS(2010)
pH	-	6.5-8.5	6.5-8.5
EC	µs/cm	1500	2000
TDS	mg/L	1000	500-1500
NO_3	mg/L	50	50

According to Table 4.1, the pH values measured in all well sampling sites was within the range of 7 to 8.20 with an average value of 7.65 (see Table 4.1), indicating that slightly alkaline in the groundwater in the Erbil Central Sub-Basin. Only a few groundwater samples have pH levels less than 7.5 (8.96 %). IQWS (2010) and WHO (2011) prescribed the desirable range of pH in the water for drinking purposes is between 6.5 and 8.5 (see Table 4.2). The alkalinity of groundwater in the study area indicates that dissolution occurs due to physicochemical interactions between soil and rainwater, and therefore gives alkaline properties to groundwater (Ehya and Marbouti, 2016). All measured pH values lie within the permissible limits as per WHO (2011) and IQWS (2010) drinking water standards. The spatial distribution map of pH values in the study area was created based on the IDW method and is shown in Figure 4.1a. The interpolation map of the pH indicates that the maximum value of pH was recorded at some parts in Hawler (Erbil) well of (Bakhtiary 4 (QB4); Brayati 7 (QB7); Kani qrzhala4 (QKQ4); Ankawa22 (QA22); Tobzawa1 (QT1)), some wells (Qushtapa No. 1 (QQC)) situated at the south-wester and (Bnaslawa 43b (QB43)) situated at the east part of the Erbil Central Sub-Basin. It may be due to water mineralization probably coming from dissolved sedimentary minerals in the presence of alluvial aquifers that dominate in the sub-basin and are followed by anthropogenic activities like domestic waste from humans or household activity.

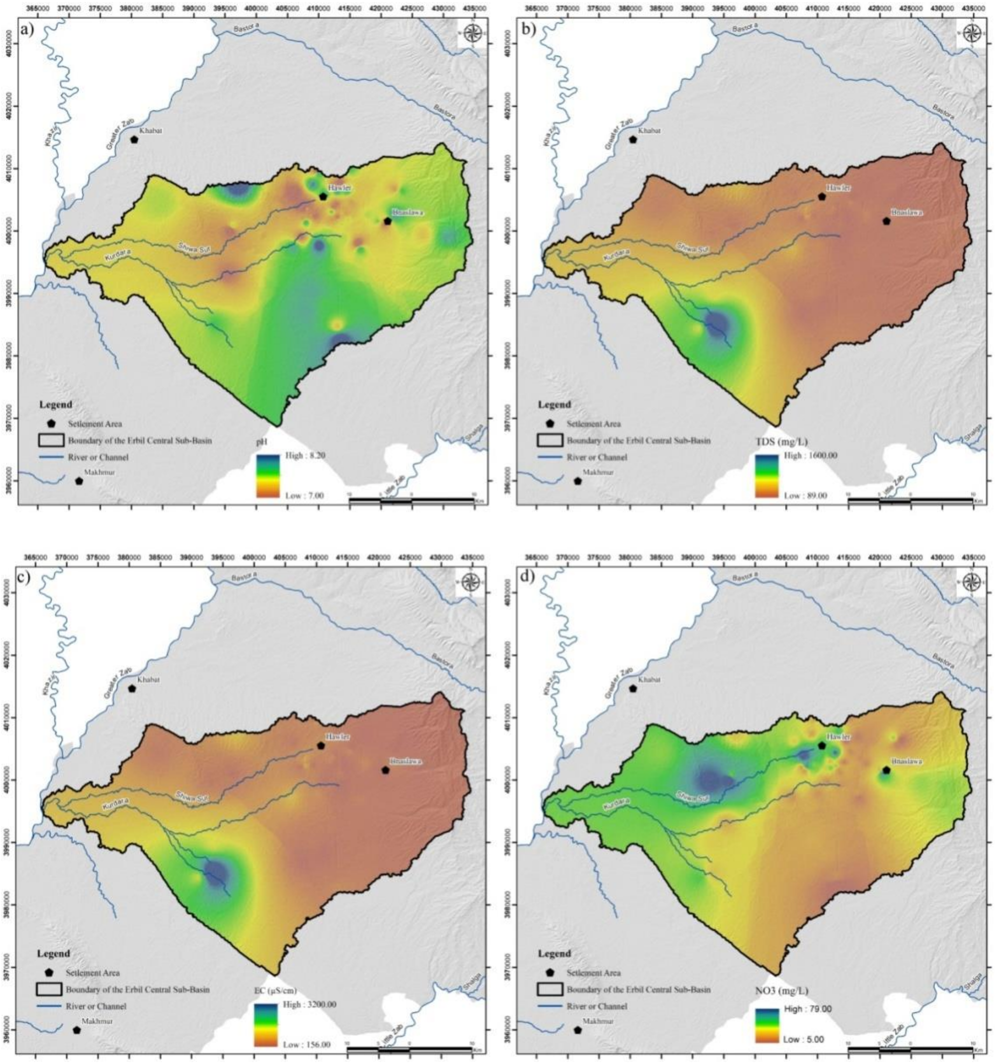

Figure 4.1. Spatial distribution maps of (a)pH, (b)EC, (c)TDS, and (d)NO_3.

The TDS values of all well water samples were observed in the ranges of 89.00 and 1600 mg/L with an average value of 231.94 mg/L (see Table 4.1, Figure 4.1b). The low TDS (89.00-421.00 mg/L) measured in well water samples located in the Erbil Central Sub-Basin generally shows the effect of rock-water interaction with respect to the recharge water. Furthermore, high TDS levels were observed in the study area ranging from 536.00 to 1600 mg/L; the occurrence of high TDS levels is due to the influence of anthropogenic sources such as domestic sewage, cesspools tanks, agricultural and industrial activities. TDS values of all well water samples except a sample from Well QA (Alyawa) in the study area are generally found below the maximum allowable value prescribed by WHO (2011) and IQWS (2010) which are 1000 and 1500 mg/L, respectively (see Table 4.2). However, 95.31% and 4.69% of the water samples fall in desirable (<500 mg/l) and permissible (500–1000 mg/l) categories, respectively. According to the guidelines of Freeze and Cherry (1979), TDS concentration indicates 98.44% of the well water samples were found to be below the <1000 mg/L (freshwater), and 1.56% of samples were found to be in the brackish water (1000-10000 mg/L) range for drinking (Table 4.3). In addition, Davis and Dewiest (1966) proposed four different categories for drinking and irrigation qualities of waters based on TDS concentrations (Table 4.4). As per Davis and De Wiest (1966) classification, the results as indicated in Table 4.4 show that 95.31% of the well water samples were found to be in the desirable for drinking (<500 mg/L), 3.13% were found to be in the permissible (500–1000 mg/L) range for drinking and 1.56 % of the samples were in the useful for irrigation (<3000 mg/L).

Table 4.3. Classification of water samples based on TDS (mg/L) (Freeze and Cherry,1979)

Range	Water Type	Groundwater (Well)	
		Number of samples	% of samples
<1000	Freshwater	63	98.44
1000-10000	Brackish Water	1	1.56
10000-100000	Saline Water	-	-
>100000	Brine Water	-	-

Table 4.4. Classification of water samples based on TDS (mg/L) (Davis and De Wiest,1966)

Range	Water Type	Groundwater (Well)	
		Number of samples	% of samples
<500	Desirable for drinking	61	95.31
500-1000	Permissible for drinking	2	3.13
<3000	Useful for irrigation	1	1.56
>3000	Unfit for drinking and irrigation	-	-

In the study area, EC values of groundwater were in the range of 156.00-3200 µS/cm with corresponding averages of 422.59 µS/cm at 25 ^{o}C for well water samples, respectively (see Table 4.1, Figure 4.1.c). Although 98.44% of the well water samples fall in permissible (1500 mg/L) categories prescribed by WHO (2011) and IQWS (2010) a guideline limit for drinking water (see Table 4.2). In addition, EC is classified as type I, if the salts enrichment are low ($EC < 1500$ µS/cm); type II, if the salts enrichment is medium (EC:1500 to 3000 µS/cm); and type III, if the salts enrichment are high ($EC > 3000$ µS/cm) (Rao et al., 2002; Adimalla 2019). According to this classification, 98.44% of samples area classified as type I, and only 1.56% of the samples are classified as type II.

The spatial variation maps of TDS and EC concentration as shown in Figures 4b and 4c indicate that samples in the southwest have high TDS and EC values. Higher EC and TDS content in groundwater sources may be attributed to the lower movement velocity, longer residence time of groundwater in the subsurface for water-rock interaction, and a larger interfacial area between phases (Singh et al. 2008). As seen in the spatial distributions of the EC values of the well water samples in Erbil Central Sub-Basin, it is seen that in general, high anthropogenic activities are more dominant than the geochemical processes prevailing in the region. The local anthropogenic activities could include discharges from intensive and long-term agricultural activities (such as fertigation and chemigation) as well as discharges from industrial and domestic waste (Laar et al., 2011).

NO_3 concentration in the well water samples of the Erbil Central Sub-Basin varied from 5.0 to 89.00 mg/L in well water samples from all sites, with an average value of 30.29 mg/L (see Table 4.1 and Figure 4.1d). According to WHO (2011) and IQWS (2010) permissible limit of nitrate concentration for drinking water is 50 mg/l (see Table 4.2).The analysis results show that NO_3 exceeded the desired limit (50 mg/L) in approximately 10.94% of the well water samples in the Erbil Central Sub-Basin. Furthermore, the spatial distribution of NO_3 concentration indicates that high nitrate concentrations are commonly found in sediments and agricultural areas (Figure 4.1d). The source of higher concentration of NO_3 concentration in the groundwater of the Erbil Central Sub-Basin is mainly non-lithological sources such as industrial activities, cesspool or septic tanks, and huge applications of nitrogen fertilizers (Tawfeeq, 2021).

4.2. DRASCTIC Parameters

4.2.1. Depth to the Water Table (D)

The depth to the water table in the Erbil Central Sub-Basin is in the range of 9.0 m (min. depth) and 171.0 m (max. depth), respectively (Figure 4.2a). In the Sub-basin, the deepest levels are located at Hawler and Bnaslawa settlements, and the shallowest levels are located in the west. Within the scope of the study, the depth to the water table is divided into 7 classes and the ratings given according to these depths were as per following; 10 (9.002-25 m), 9 (25.01-40 m), 7 (40.01-70 m), 5 (70.01-90 m), 3 (90.01-110 m), 2 (110.01-130 m) and 1 (130.01-171 m) (Table 4.5). While the water level is deeper towards the Bnaslawa settlement, it is shallow in the western parts (see Figure 4.2b). Therefore, the deepest water table, with a rating value of (1), has been observed in northeastern, southeastern, and small parts of north and south of the study area, meaning that groundwater is safer in terms of potential contamination.

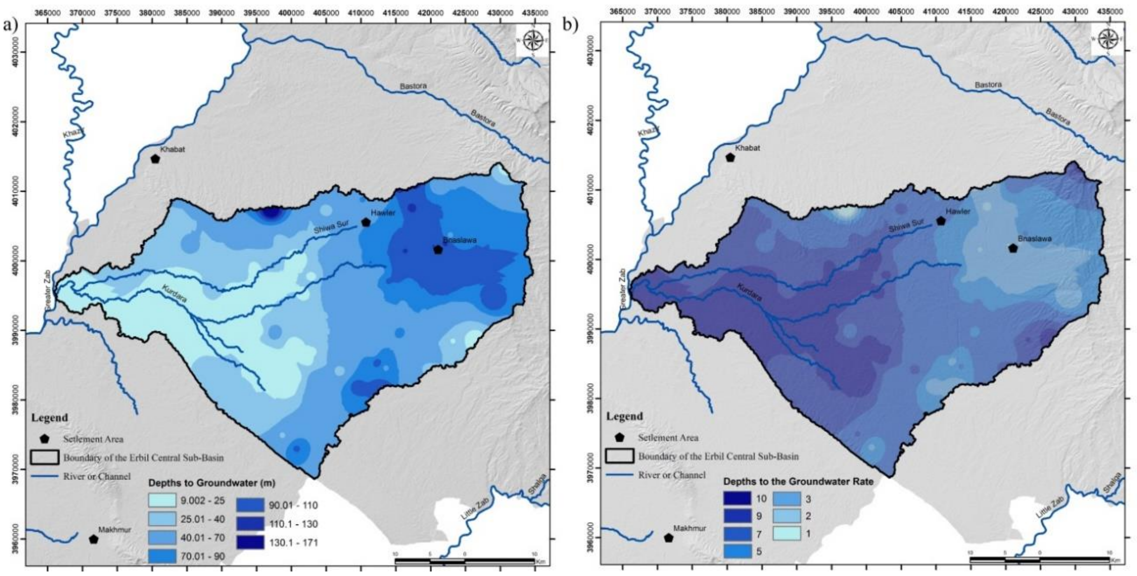

Figure 4.2. (a) Depth water level map (b)Depth to water table rating map of the Erbil Central Sub-Basin.

Table 4.5. Assigned weights for DRASTIC hydrogeologic factors (modified Aller et al. 1987; Barres-Lallemand, 1994)

Parameters	Index	Ranges/classes	Rating (r)	Relative weight	Total weight (rating x realtive weigting)	Index (D)
Depth of water (m)	D	9.01-25 25.01-40 40.01-70 70.01-90 90.01-110 110.01-130 130 01-171	10 9 7 5 3 2 1	5	50 45 35 25 15 10 5	50 45 35 25 15 10 5
Net recharge (mm)	R	50-100 175-250	3 8	4	12 32	12 32
Aquifer media	A	Bedded of sandstone, and conglomerate Sand and gravel	6 8	3	18 24	18 24
Soil media	S	Rock outcrop Silty loam Clay loam	10 4 3	2	20 8 6	20 8 6
Topography (% slope)	T	0 - 2 2 - 6 6 - 12 12 - 18 >18	10 9 5 3 1	1	10 9 5 3 1	10 9 5 3 1
Impact of vadose zone	I	Clay, silt, sand and gravel Gravel, clay and sand Gravel and sand	5 6 8	5	25 30 40	25 30 40
Hydraulic conductivity (m/day)	C	$7.42x10^{-4}$-$5x10^{-2}$ $5.1x10^{-2}$-$1x10^{-1}$ $1.1x10^{-1}$-$2x10^{-1}$ $2.1x10^{-1}$-$6.2x10^{-1}$	2 4 6 8	3	6 12 18 24	6 12 18 24

4.2.2. Net Recharge (R)

The net recharge of the Erbil Central Sub-Basin is 95.62 and 216.2 mm/year (Figure 4.3a, see Table 3.7). The net recharge is divided into two categories (50-100) and (175-250) mm/year assigned a rating of 3 and 8, respectively (see Table 4.5, Figure 4.3b). The value of 3 corresponds to a small part scattered over (7.2%) of the whole study area, including the city center and districts, due to most of these areas being are covered by asphalt and concrete and prevent infiltrating of water reach the groundwater aquifer. Rating 8 has been observed in most parts of the study area (92.8%), a recent deposit and Bakhtiari Formation, which are classified as in intergranular aquifer as a good pass way for reaching rainy water to groundwater aquifer. And lead groundwater to be under threat of pollution in these regions compared with the lower net recharge rating value.

4.2.3. Aquifer Media (A)

The aquifer map is generated from the geological description of the groundwater aquifer composition of the study area (Figure 4.4a) and was classified according to the DRASTIC rating (see Table 4.5). The aquifer media is classified into two classes; the rating 6 has been assigned to interbedded of sandstone and conglomerate which is represented Bakhtiari Formation covered (21.1%) in the eastern, northwestern, and southwestern of the study area. While, most parts of the study area characterized by sand and gravel interbedded represented by recent deposit, which assigned rating 8 covered (78.9%) of the entire study area (Figure 4.4b).

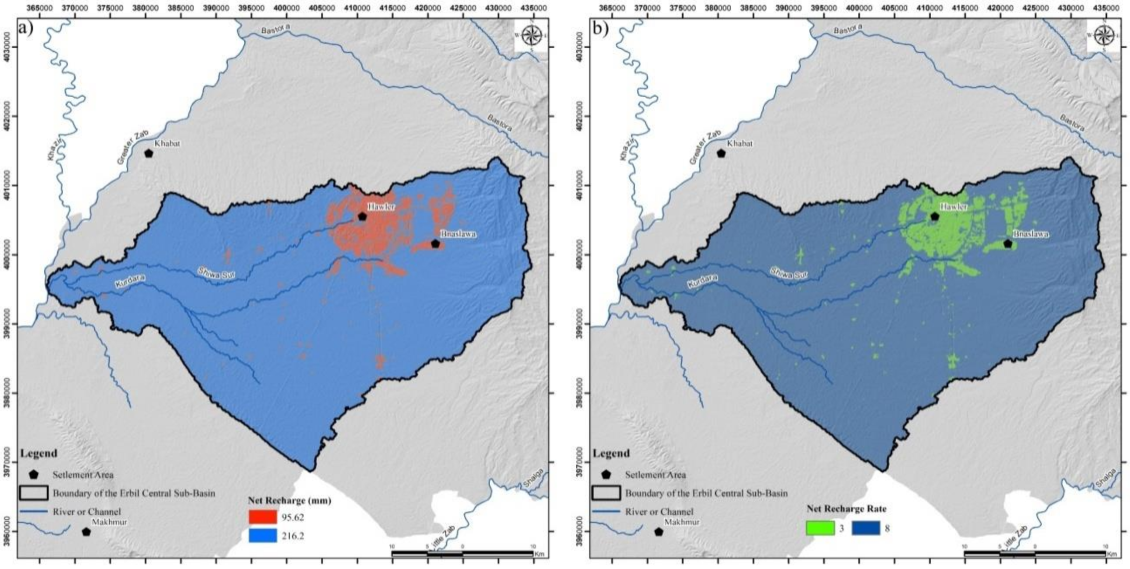

Figure 4.3. a) Net recharge map b) Net recharge rating map of the Erbil Central Sub-Basin.

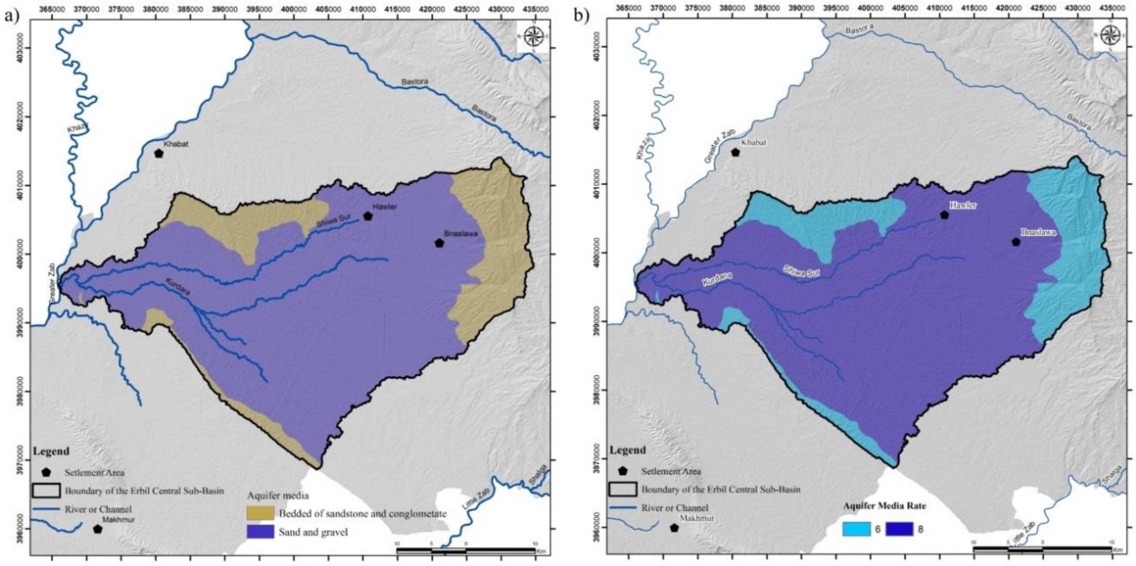

Figure 4.4. a)Aquifer media map b)Aquifer media rating map of the Erbil Central Sub-Basin.

4.2.4. Soil media (S)

Three media types of soil were prevalent in the study area. Each soil type was classified according to DRASTIC rating value ranging (see Table 4.5 and Figure 4.5a). Clay loam covered (75.1%) of the area assigned a rating value of 3. The rating value 4 represents silty loam and is situated in the eastern, northwestern, and southwestern parts covered (23.2%) of the study area. While rating value of 10 represented by rock outcrop that covered (1.7%) in the northeastern and northwestern parts of the study area. The resulting map was suitable to be used for the soil media vulnerability feature map (Figure 4.5b).

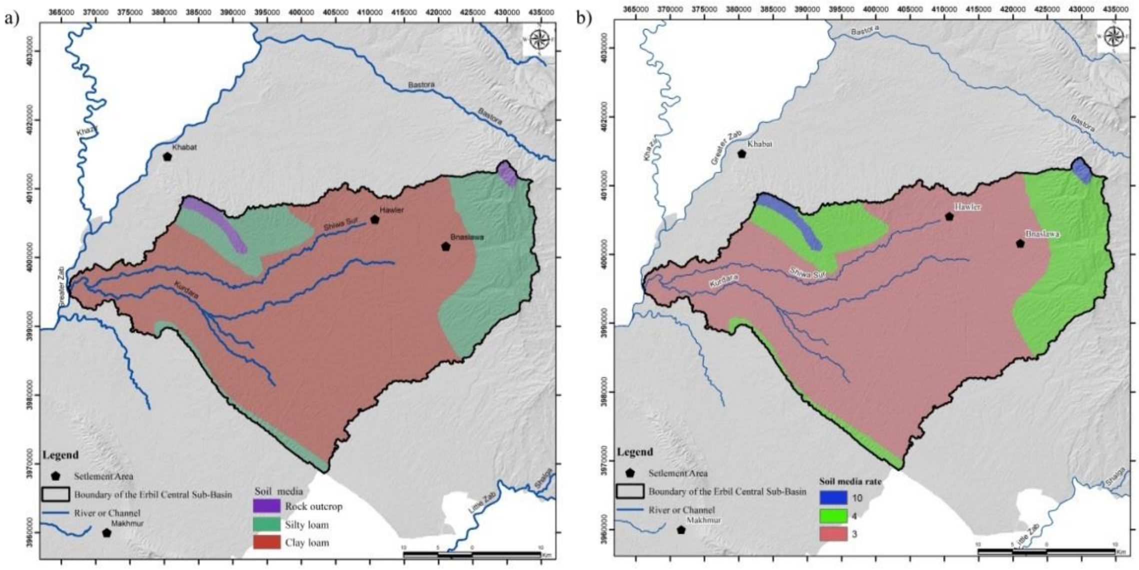

Figure 4.5. a) Soil media b) Soil media rating map of the Erbil Central Sub-Basin.

4.2.5. Topography (T)

The characteristic of the slope was provided from the 30 m-elevation digital elevation model (DEM). It was extracted as a percentage from (DEM) with a pixel size of 25 using the Spatial analyst tool in Arc GIS 10.02 (Figure 4.6a). The slope in the Erbil Central Sub-Basin varies from 0% to 56.16 % and has been divided into 5 classes. A very flat area with 0-2% is given the highest rank of 10. Others 2-6%, 6-12%, 12-18% and >18% slopes are rated 9, 5, 3, and 1, respectively (see Table 4.5, Figure 4.6b). Areas with a low slope varying nearly level to very gentle % (0-6%) value in the central sub-basin generally indicate a longer residence time to retain pollutant-rich water, which helps pollutant-rich water to higher infiltrate. Especially in the eastern side (Bnaslawa) of the central sub-basin, the slope is highly steep varying between 6.01% and 56.16%, the risk of contamination is less vulnerable in these regions having a high rate of runoff and a low rate of infiltration. On the other hand, the risk of contamination is higher in the lower basin as the valley fill, agricultural and industrial areas have a gentle slope.

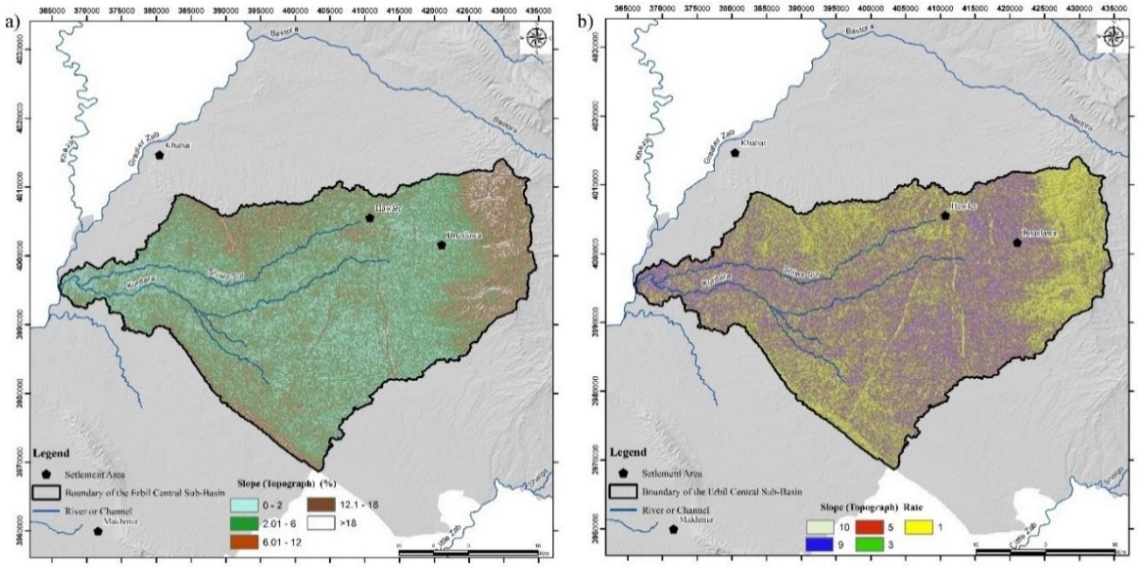

Figure 4.6. a)The spatial distribution of slope percentage map b)Topography rating map of the Erbil Central Sub-Basin.

4.2.6. Impact of vadose zone (I)

The impact of the vadose zone of the study area was classified according to the DRASTIC rating (see Table 4.5). The impact of the vadose zone was prepared based on the geological description of the unsaturated zone obtained from the well log data. The impact of the vadose zone has been divided into three categories; (clay, silt, sand and gravel), (gravel, clay and sand) in the eastern, northwestern, and southwestern part, (gravel and sand) in the eastern and southwestern part, covering areas of 71.3%, 21.1%, and 7.6%, respectively (Figure 4.7a). The constructed map with organized different rate values of the vadose zone is 5, 6, and 8, respectively (Figure 4.7b).

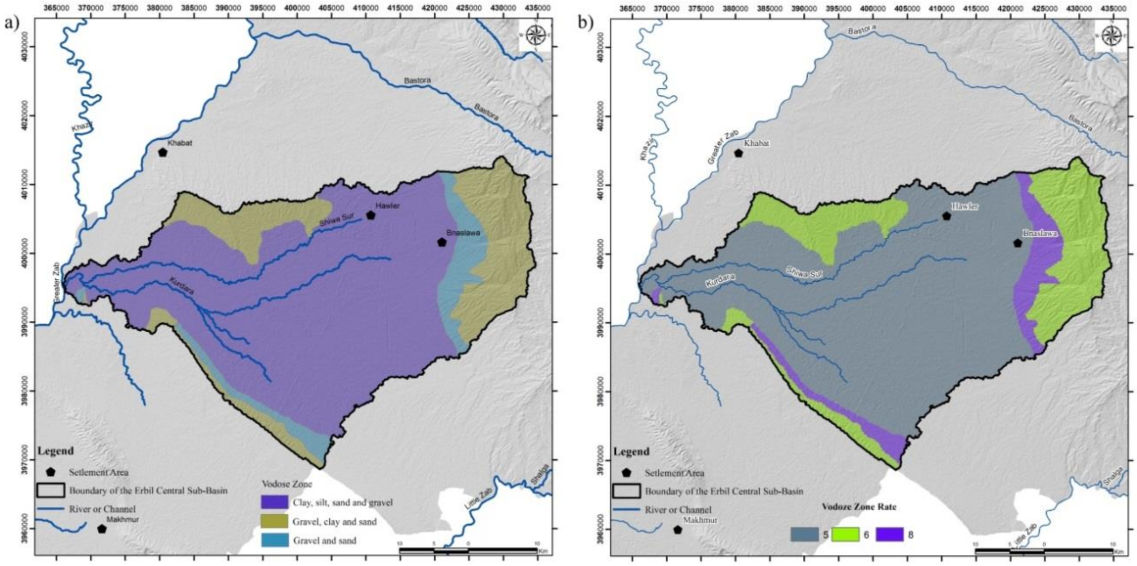

Figure 4.7. a) Impact of the vadoze zone map b) Impact vadose zone rating map of the Erbil Central Sub-Basin.

4.2.7. Hydraulic conductivity (C)

Groundwater aquifer in the study areas have hydraulic conductivity values ranging from ($7.42x10^{-4}$) to ($6.2\ x10^{-1}$) m/day classified into four classes ($7.42x10^{-4}$-$5x10^{-2}$), ($5.1x10^{-2}$-$1x10^{-1}$), ($1.1x10^{-1}$-$2x10^{-1}$) and ($2.1x10^{-1}$-$6.2x10^{-1}$) (Figure 4.8a), and assigned a rating value of (2, 4, 6 and 8) respectively (Figure 4.8b) based on standard DRASTIC rating value (see Table 4.5). (42.2%) of the study area bearing hydraulic conductivity varies from $7.42x10^{-4}$ to $5x10^{-2}$ m/day. The eastern regions, especially Bnaslawa, indicate relatively lower hydraulic conductivity values, ranging from $7.42x10^{-4}$ to $5x10^{-2}$ m/day. Therefore, the risk of contamination in these regions is lower than in other regions. Otherwise, hydraulic conductivity is relatively higher in the western and central catchment areas, ranging from $1.1x10^{-1}$ to $6.2x10^{-1}$m/day, so the contamination risk is higher in these areas.

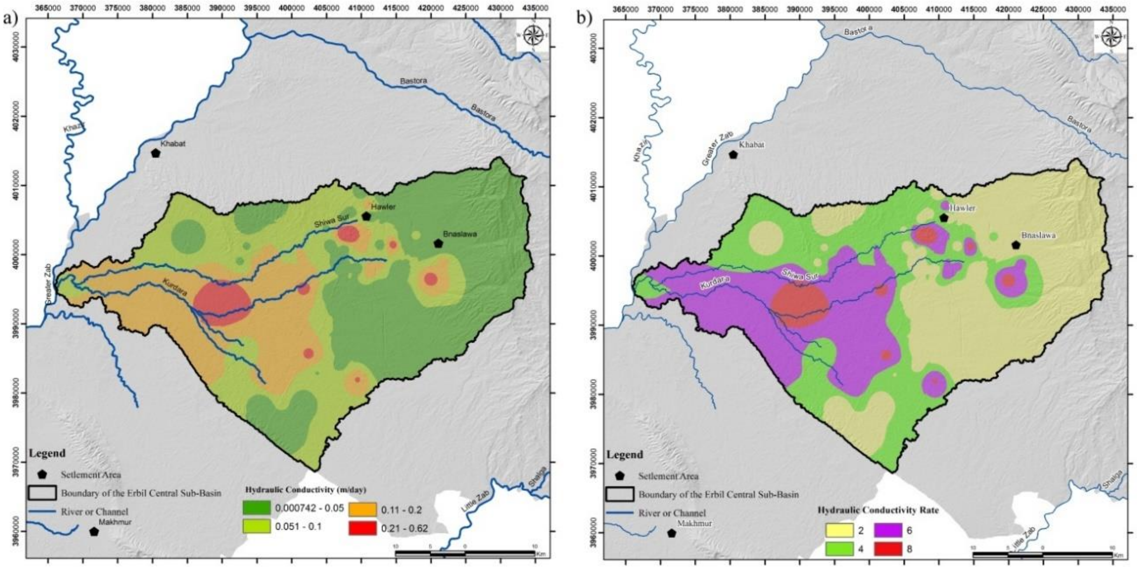

Figure 4.8. a)The spatial distribution of hydraulic conductivity map b)Hydraulic conductivity rating map of the Erbil Central Sub-Basin.

4.3. DRASTIC Vulnerability Index Map

The groundwater vulnerability of the Erbil Central Sub-Basin has been generated using the DRASTIC vulnerability index (DVI) was calculated after integrating seven different data layers using the ARGIS 10.2 program according to Equation (3.1). All relevant input layers are further subdivided to assign ratings according to their relative importance to groundwater pollution. As a result of the calculations, it was determined that the DRASTIC index values (Figure 4.9) varied between 80-182. This range was classified into four vulnerability classes according to Aller et al. (1987) and Foster et al. (2002): (1) very low (<100), (2) low (100-125), (3) moderate (125-150), (4) high (150-200) and very high (>200) (Tabe 4.6). These classes indicate the relative pollution potential in the selected area.

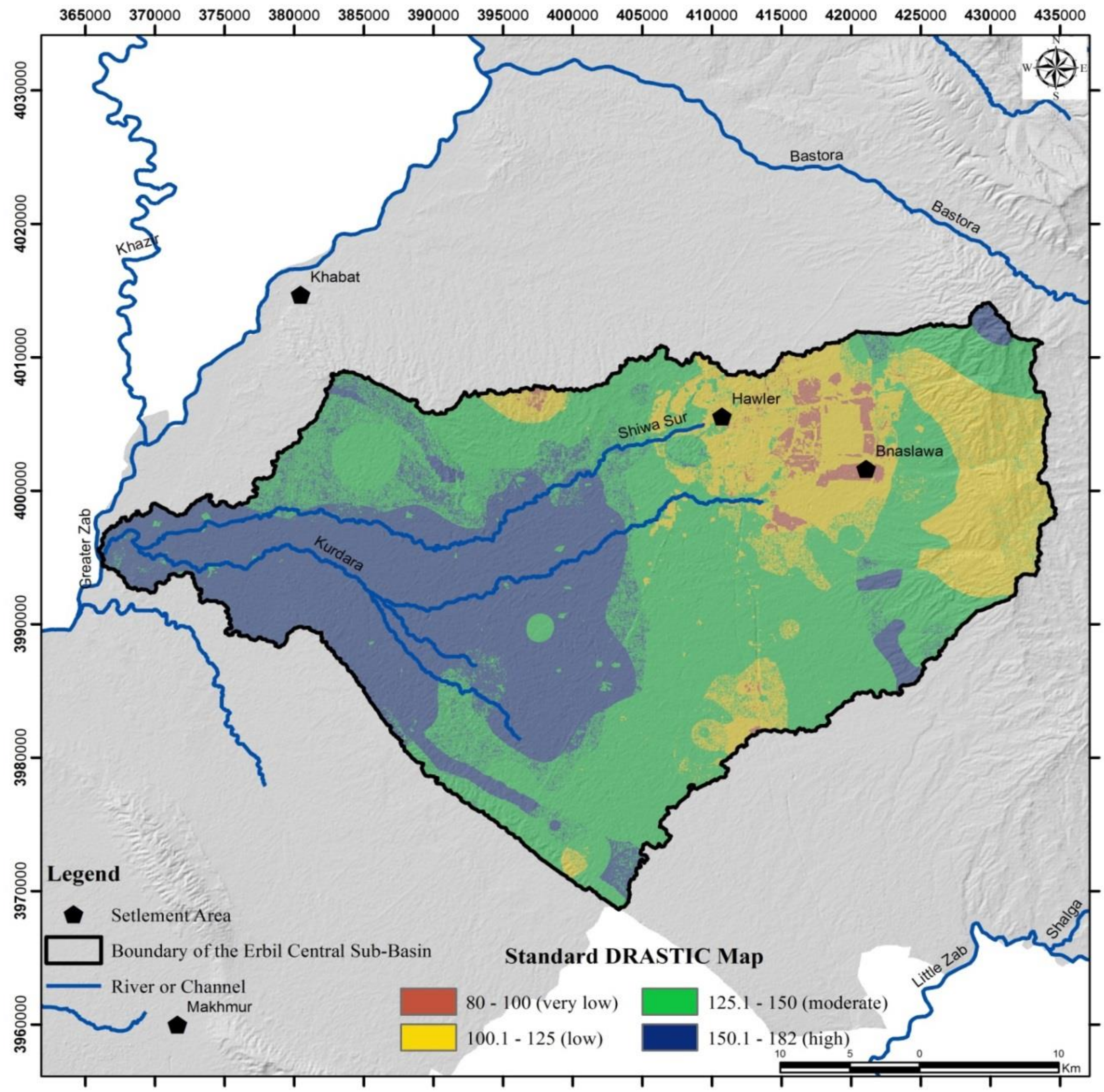

Figure 4.9. Vulnerability maps of standard DRASTIC model of the Erbil Central Sub-Basin.

DRASTIC vulnerable map (see Figure 4.9) indicates that approximately 332.7 km^2 (20.5%) of the total area lies between very low to low risk of pollution zone, while the remaining approximately 1291.8 km^2 (79.5%) is occupied by moderate risk to high risk of pollution zone. The fact that a large area exhibits a moderate to high vulnerability zone in the study area may be due to its high recharge potential as the area experiences abundant rainfall (i.e., 400.9 mm per year on average), flat slope (topography), water depth, hydraulic conductivity, relatively porous aquifer media, vadose zone, groundwater and surface water flow directions. As seen in the DRASTIC index vulnerability (DVI) map (see Figure 4.9), especially the western and southwestern portion which covers an area of 546.2 km^2 (33.6 %) of the total area (see Figure 4.9

and Table 4.6), is exposed to high pollution risk (blue color zone). Because the depth to water in this region is shallow and varies between 9.002-25 m. The main soil type of this zone is clayey loam skeleton and the main aquifer type is sand and gravel. Therefore, depending on the high hydraulic conductivity range, the groundwater infiltration rate is also high. The map identifies that eastern, south-southeastern, north part and some areas in the west part of the sub-basin area which constitute approximately an area of 745.6 km^2 or (45.9%) of the total area, are moderately vulnerable to groundwater contamination (green color zone). These regions are characterized by relatively shallow depth to water varying between 25.1 to 70 m, the aquifer media consists of sand and gravel, almost flat to very soft slope % (0-6%), and moderate to high hydraulic conductivity varying $5.1x10^{-2}$ to $6.2x10^{-1}$ m/day. Furthermore, high and moderate vulnerability zones have been seriously polluted by both wastewater discharge from wastewater channels and infiltration of the agricultural area resulting in high NO_3 concentrations in the groundwater (Tawffeq, 2021). In general, an increasing trend is observed in the DVI score from east to west of the study area, there are several very low/low contamination zones between them, with DVI scores ranging from 80 to 125.

The eastern hilly areas of the study area reveal very low to low vulnerability to groundwater pollution. A small portion (20.5%) of the total area is changing between low and very low vulnerable to pollution. The total area of low vulnerability (yellow color zone) is 303.9 km^2 (18.7%). Whereas, the total area of very low (red color zone) is 28.8 km^2 (1.8%) (see Table 4.6). The Hawler and Bnaslawa regions and surrounding elevated regions generally displayed low to very low aquifer vulnerability. These regions are characterized by a low hydraulic conductivity ranging between $7.42x10^{-4}$-$1x10^{-1}$ m/day and deeper groundwater depth ranging between 90-171 m. In addition, land cover generally consists of urban and built-up areas, open plots, and barren land, which have the highest runoff due to impervious surface areas. Therefore, contaminants percolating with recharge water through the vadose zone take longer to reach the groundwater table, resulting in a lower risk of contamination.

Table 4.6.Vulnerability class definition (modified Aller et al. 1987 and Foster et al., 2002)

Vulnerability class	DRASTIC index clases	Area (km^2)	Area (%)	Corresponding definition
Very Low	<100	28.8	1.8	existing confining beds with no significant vertical groundwater flow (leakage)
Low	100-125	303.9	18.7	only when conservative pollutants are continuously and widely discharged or leached are they vulnerable to conservative pollutants in the long term.
Moderate	125-150	745.6	45.9	it is vulnerable to some contaminants, but only if it is continuously discharged or leached.
High	150-200	546.2	33.6	in many pollution scenarios, many pollutants (except those that are strongly absorbed or easily transformed) are vulnerable.
Very High	>200	-	-	in various pollution scenarios, it is vulnerable to the majority of water pollutants, with a rapid impact.

4.4. Result of Weight Modification Using Single Parameter Sensitivity Analysis (SPSA)

Based on the standard DRASTIC map and then modified the weight by using (SPSA) the new effective weight of seven parameters was achieved and shows some difference from the theoretical weights (Table 4.7). According to the SPSA (see Table 4.7), the average effective weight values of the parameters varied between 4% to 23.7%, indicating that these seven parameters do not differ greatly. The depth to water exhibited the highest effective weight, followed by vadose zone media, net recharge, aquifer media, hydraulic conductivity, and according to Table 4.7 both the depth to water and vadose zone parameters have exceeded the theoretical weights determined by DRASTIC by 21.7%, with an effective weight of 23.7% and 22.6%, respectively, and the actual weights, that is the effective weights, are higher than the theoretical weights, shows the result that the two most effective factors in the DRASTIC calculation, that is the most sensitive in assessing vulnerability. The theoretical weight determined by the

DRASTIC model is less than the average effective weight of the other parameters except net recharge, soil media, topography and hydraulic conductivity.

The effective weight (15.1%) of aquifer media also exceeded its theoretical weight of 13.0%. Moreover, net recharge, soil media, topography and hydraulic conductivity have shown lower effective weight 15.8%, 8.2%, 4% and 10.8%, respectively than the theoretical weight 17.4%, 8.7%, 4.3% and 13%, respectively (see Table 4.7). There is no significant difference in the modified DRASTIC_weight map when compared to the standard DRASTIC vulnerability map.

Table 4.7.Statistical summary of the single parameter sensitivity analysis (SPSA).

Parameters	Theoretical weight	Theoretical weight (%)	Effective weight (%)			Average modified weigh
			Minimum	Average	Maximum	
D	5	21.7	6.8	23.7	25.0	5.4
R	4	17.4	16.4	15.8	16.0	3.6
A	3	13.0	24.7	15.1	12.0	3.5
S	2	8.7	8.2	8.2	10.0	1.9
T	1	4.3	1.4	4.0	5.0	0.9
I	5	21.7	34.2	22.6	20.0	5.2
C	3	13.0	8.2	10.8	12.0	2.5

The modified DRASTIC using SPSA index value between (81-184) has been divided into four classes including: very low, low, moderate, and high with 1.6%, 18.3%, 42.3%, and 37.8%, respectively (Table 4.8 and Figure 4.10). This difference was made due to the specific ground of the study area. The low average effective weight of topography indicates it has the least importance in groundwater vulnerability. As a result, the importance of the seven indexes, especially the depth to water and the impact of the vadose zone, as well the aquifer media, emphasized the importance of obtaining accurate, detailed, and representative information about these factors.

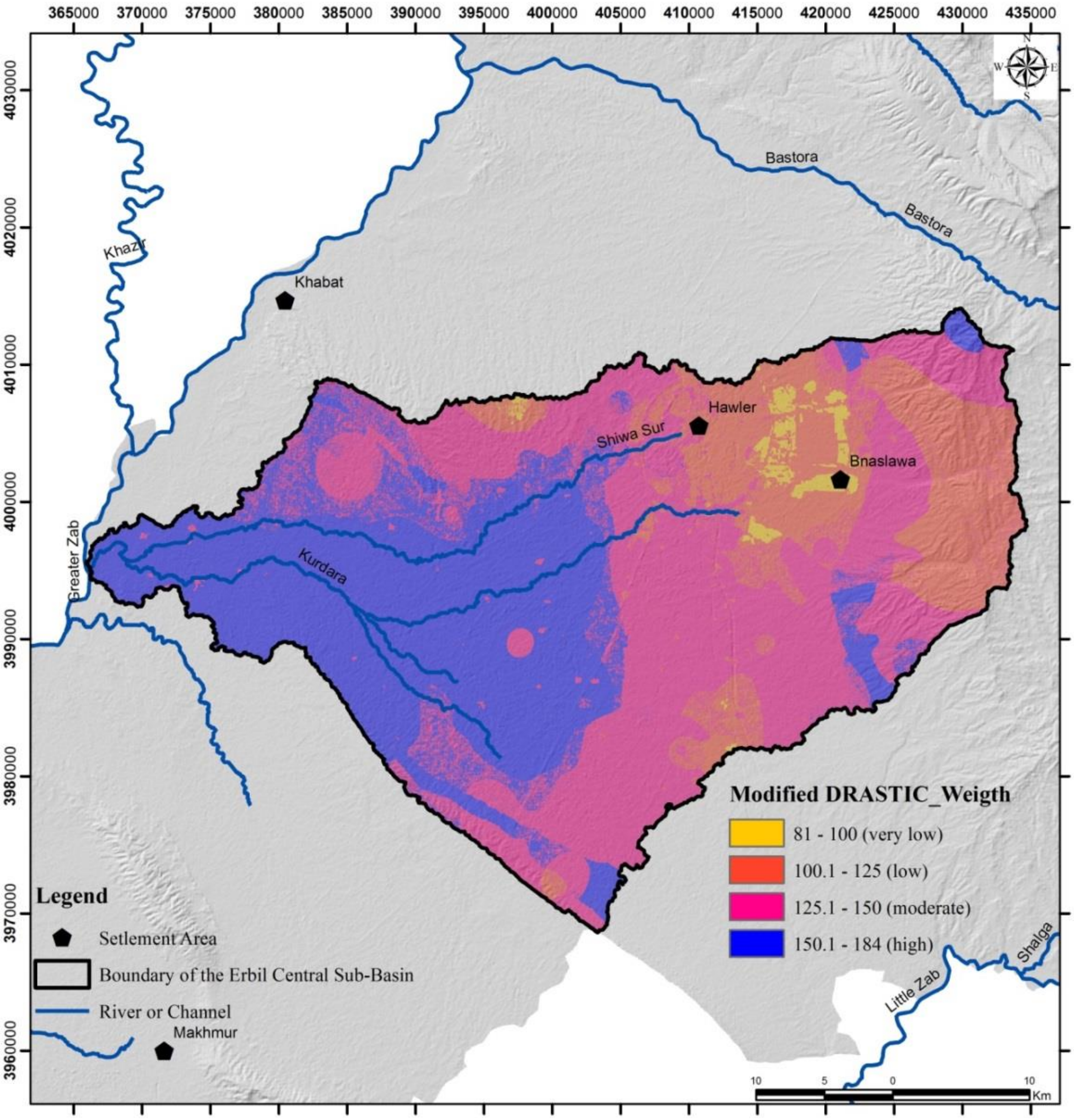

Figure 4.10. Vulnerability maps of modified DRASTIC_weight model of the Erbil Central Sub-Basin.

Table 4.8. Modified DRASTIC_weight index value of classes of the stduy area

Vulnerability class	Drastic Index	Area (km^2)	Area (%)
Very low	81-100	25.9	1.6
Low	> 100 - 125	296.7	18.3
Moderate	> 125 - 150	687.5	42.3
High	> 150 - 200	614.4	37.8
Very high	> 200	-	-

4.5. Result of Modified DRASTIC Based on LULC

The LULC map of Erbil central sub-basin (see Figure 3.11) shows that only four classes can be identified. As mentioned in (Table 4.9) barren land and vegetation area are assigned a probability rating value of 5 covers 9.2% of the study area. While, agricultural land and urban area are assigned a probability rating value of 8 covers most part of the study area with 90.8% (Figure 4.11).

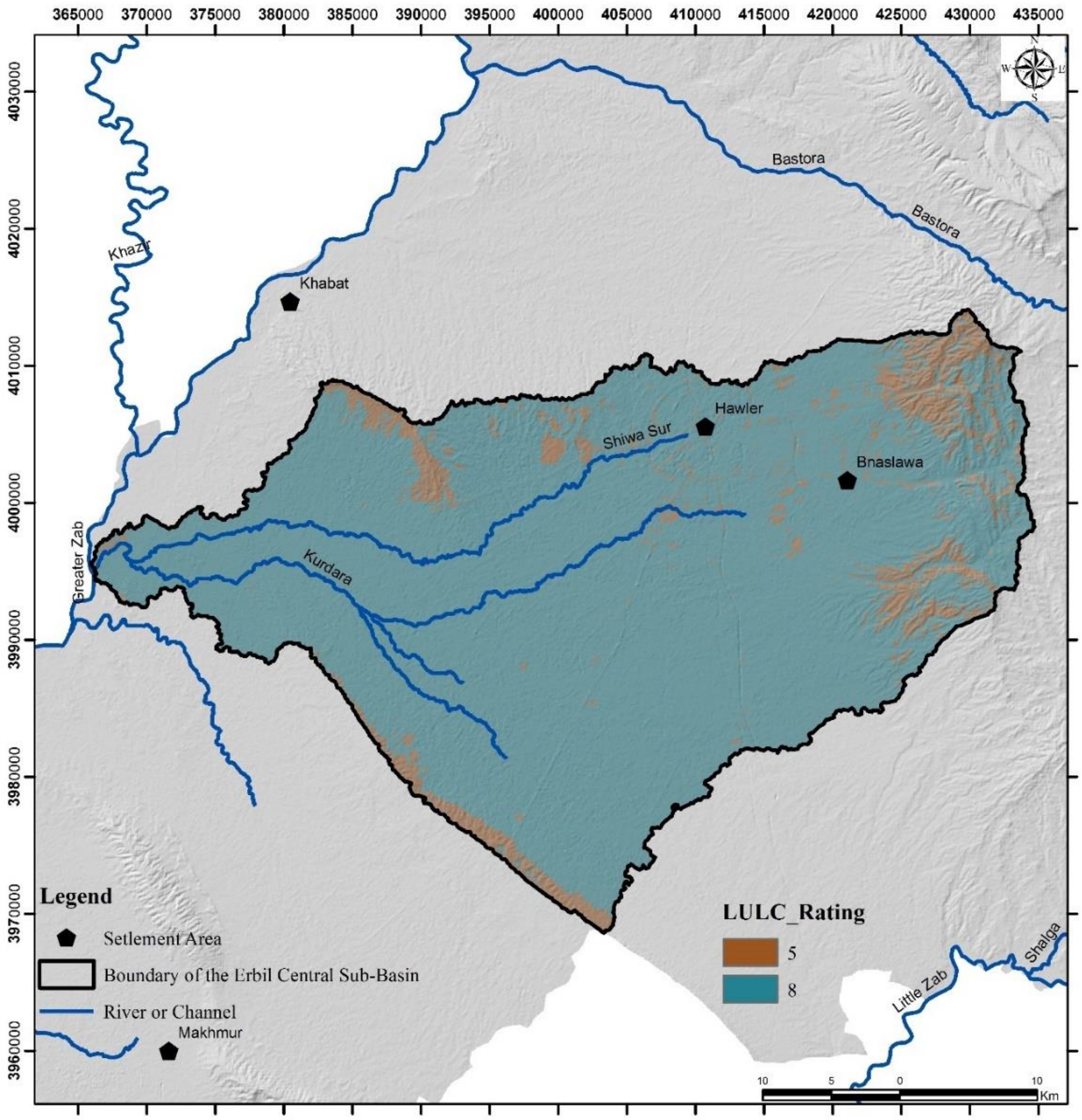

Figure 4.11. LULC rating map of the Erbil Central Sub-Basin.

Table 4.9.Rate and weight for LULC classes (Secunda et al., 1998)

Classes	Rate	Area %
Barren land and Vegetation	5	9.2
Urban area and agricultural land	8	90.8
Weight = 5		

Moreover, the LULC rating map is transformed into a raster grid and multiplied by the weight of the parameters (Lw=5) to generate a LULC index map (Figure 4.12). The index map is classified into two classes (25 and 40), which cover (9.2% and 90.8%) of the study area, respectively.

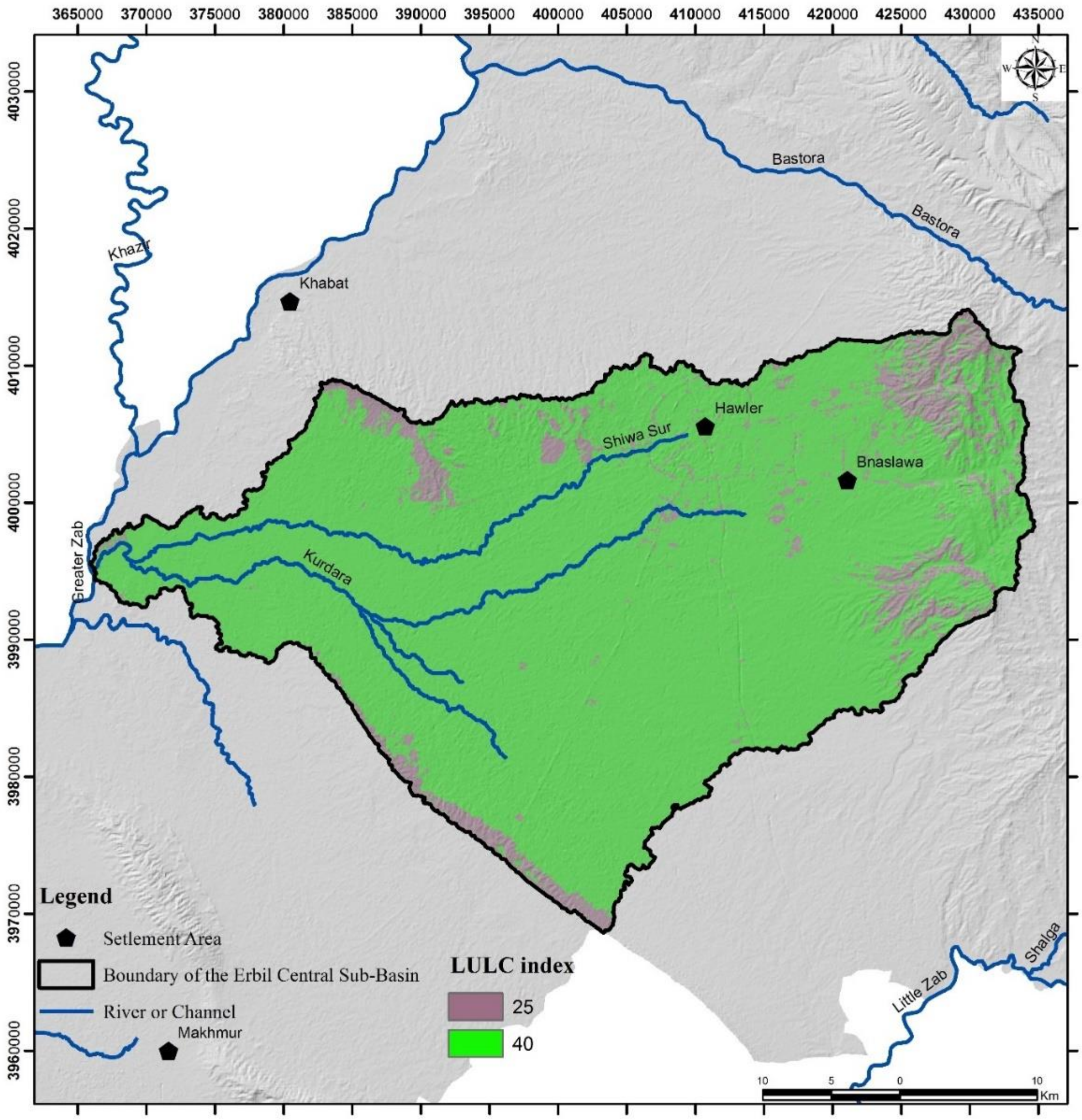

Figure 4.12. LULC index map of the Erbil Central Sub-Basin.

Figure (4.13) shows the modified DRASTIC index based on the LULC index map. The range of index values between (105-222) has been classified into four classes including low to very high, 83.6% of the study area under high vulnerable zone with index values ranging >150-200. The area with 8.7% under very high vulnerable zone with index ranging values >200-222. While low and moderate area comprise 0.1% and 7.6%, respectively, with index values (>100-125) and (>125-150), respectively (Table 4.10).

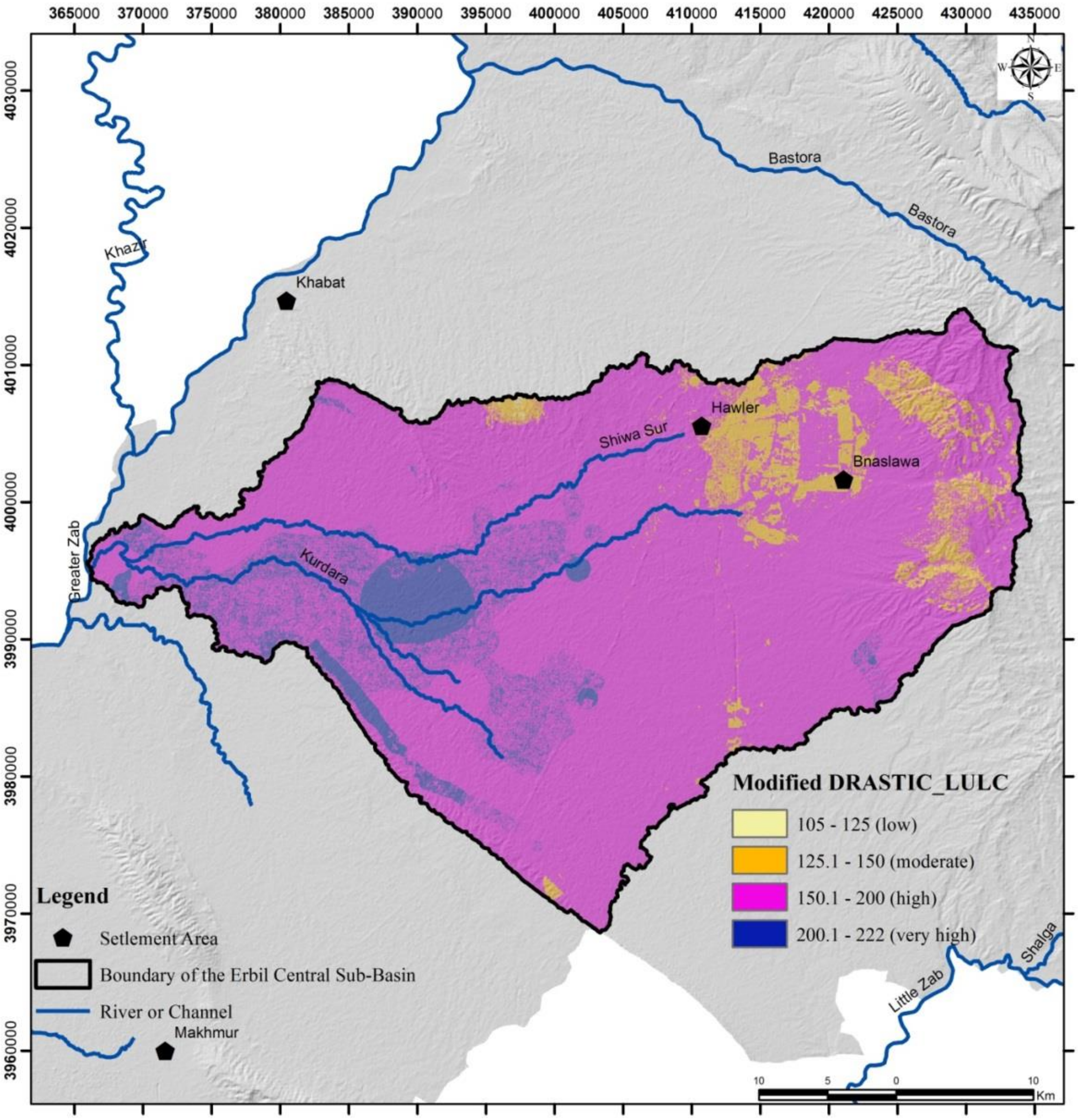

Figure 4.13. Vulnerability maps of modified DRASTIC_LULC model of the Erbil Central Sub-Basin.

Table 4.10.Modified DRASTIC_LULC index value of classes of the study area.

Vulnerability class	Drastic Index	Area (km^2)	Area (%)
Very low	>100	-	-
Low	> 100 - 125	1.4	0.1
Moderate	> 125 - 150	124.1	7.6
High	> 150 - 200	1357.3	83.6
Very high	> 200 - 214	141.7	8.7

As seen in (Figure 4.13), the modified DRASTIC_LULC map is considerably different when compared to the standard DRASTIC model. Additionally, urban area, vegetation, and barren land have caused rise up low vulnerability zone to moderate and high vulnerability zones. The main part of the very low vulnerability zone disappeared and was converted to low and moderate vulnerability zone due to the effect of the urban area. As well agricultural area has led to converting moderate vulnerability zone to high or very high vulnerability zone.

4.6. Comparison of the vulnerability classes of models

Table 4.11 and Figure 4.14 represent the comparison of results from the standard DRASTIC model, DRASTIC_weight modified and modified DRASTIC_ LULC. The values of standard DRASTIC and modified DRASTIC_weight are divided into four classes and the index values reach their peak of moderate class as first and high class as second highest vulnerability index range values. In addition, modified DRASTIC_LULC has been divided into four classes and the index value reaches its peak of high class as the highest vulnerability index range value. The variation is apparently because of specific ground conditions and the impact of LULC on the study area.

Table 4.11.Comparison between vulnerability classes area of each model

Vulnerability classes	Index range	Standard DRASTIC (%)	DRASTIC-weight modified (%)	Modified DRASTIC_LULC (%)
Very low	<100	1.8	1.6	-
Low	>100-125	18.7	18.3	0.1
Moderate	>125-150	45.9	42.3	7.6
High	>150-200	33.6	37.8	83.6
Very high	>200	-	-	8.7

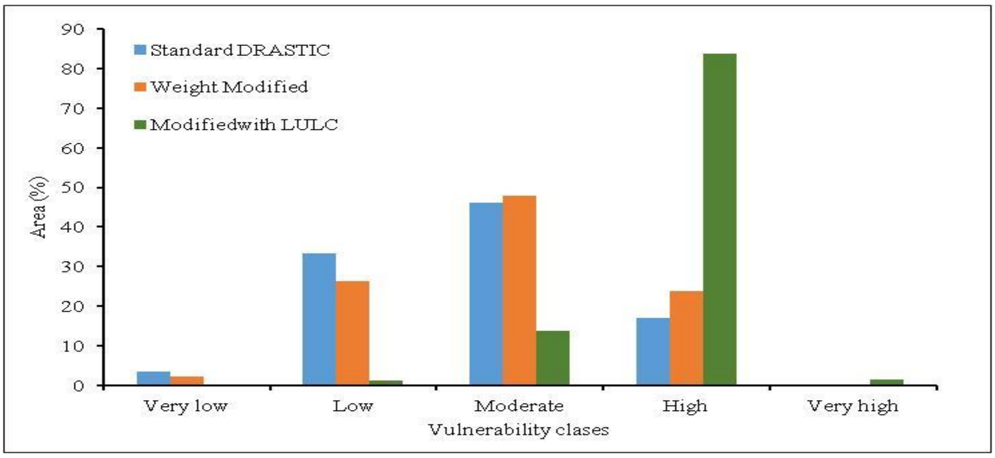

Figure 4.14. Comparison between vulnerability classes of models.

4.7. Models Validation

The spatial distribution map of NO_3 concentration and TDS has been selected to validate all applied models in the studied area. This approach is used to examine the similarity of the spatial pattern of variability of these maps by taking a common section (Figure 4.15) in different models (Abdullah, 2018). The results show a better match between the patterns of the NO_3 and TDS of groundwater and models (Figure 4.16,17 and 18). The correlation coefficient between the NO_3, TDS, and DRASTIC models was calculated by using the Pearson correlation matrix. The correlation coefficient (r) obtained between NO_3 and (standard DRASTIC, modified DRASTIC_weight and modified DRASTIC_LULC) are 0.67, 0.65, and 0.68, respectively (Figure 4.19, 20, 21). While, the correlation coefficient obtained between TDS and (standard DRASTIC, modified DRASTIC_ weight and modified DRASTIC_LULC) are 0.78, 0.79, and 0.79, respectively (see Figure 4.19, 20, 21). the correlation coefficient of TDS generally remained constant (r = 0.79) after modification. The results show a better match between the pattern of NO_3 value and modified DRASTIC_LULC. Therefore, it can be stated that modified DRASTIC_LULC is an ideal model for assessing groundwater vulnerability.

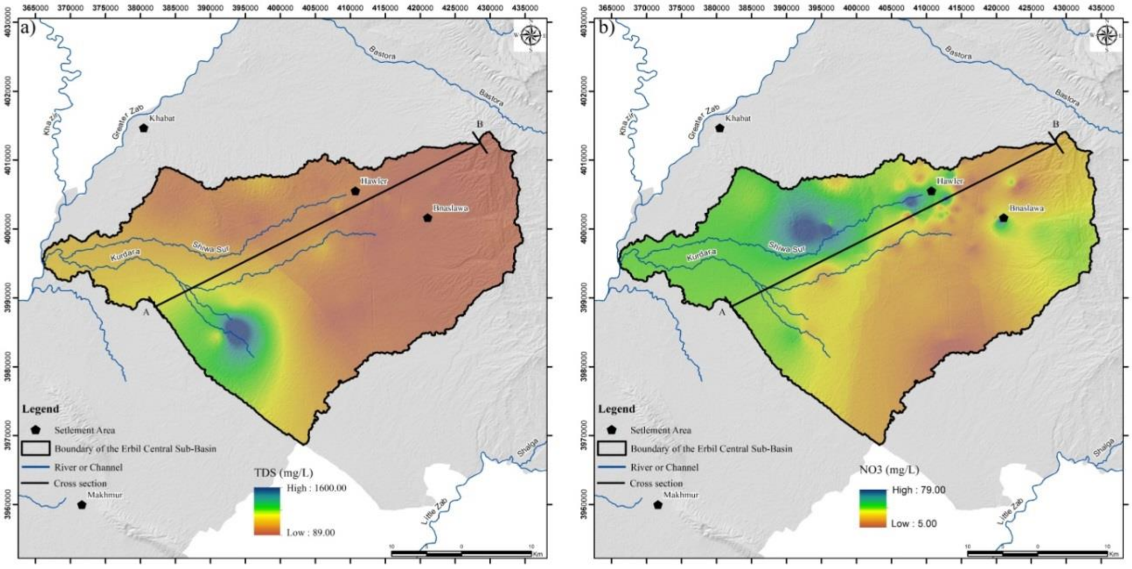

Figure 4.15. Location of cross section a)TDS and b)NO_3.

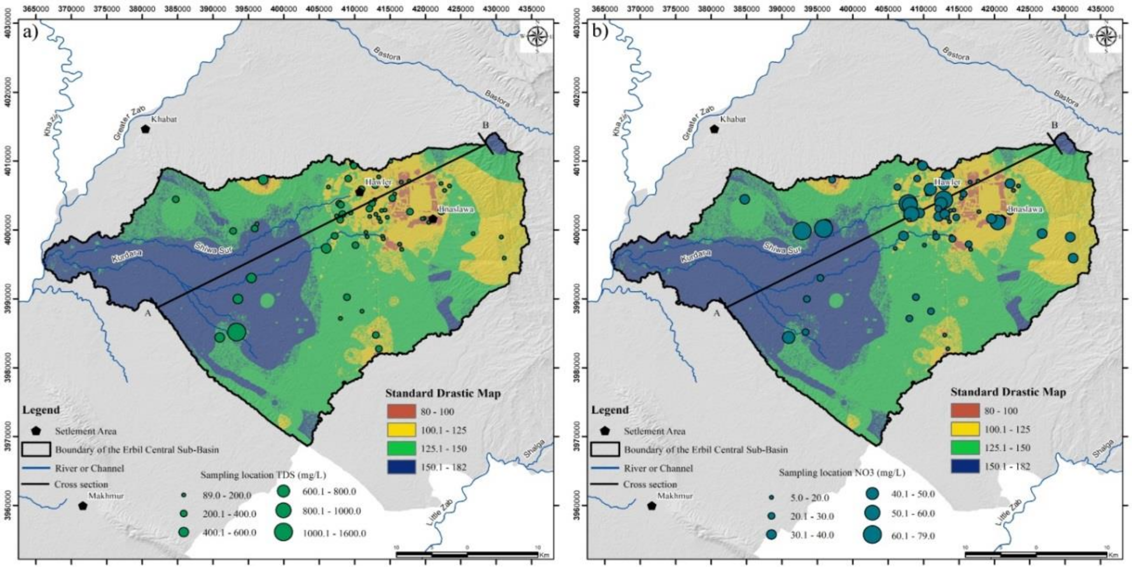

Figure 4.16. a) NO_3 concentration sample map b)TDS sample map for validation of vulnerability standard DRASTIC model.

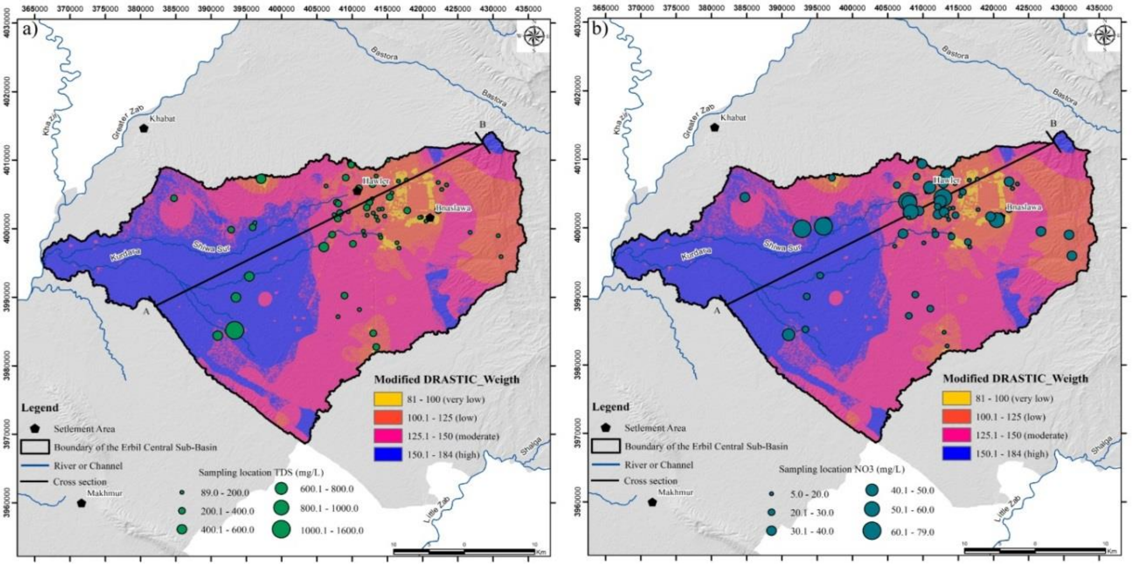

Figure 4.17. a)NO_3 concentration sample map b)TDS map for validation of vulnerability modified DRASTIC_Weight model.

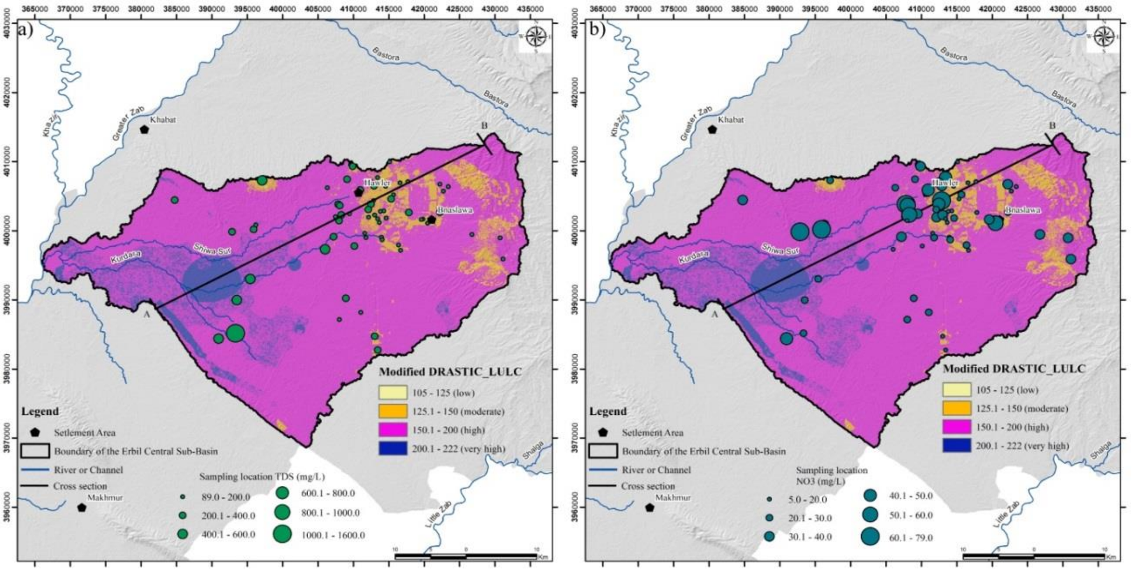

Figure 4.18. a)NO_3 concentration sample map b)TDS map for validation of vulnerability modified DRASTIC_LULC model.

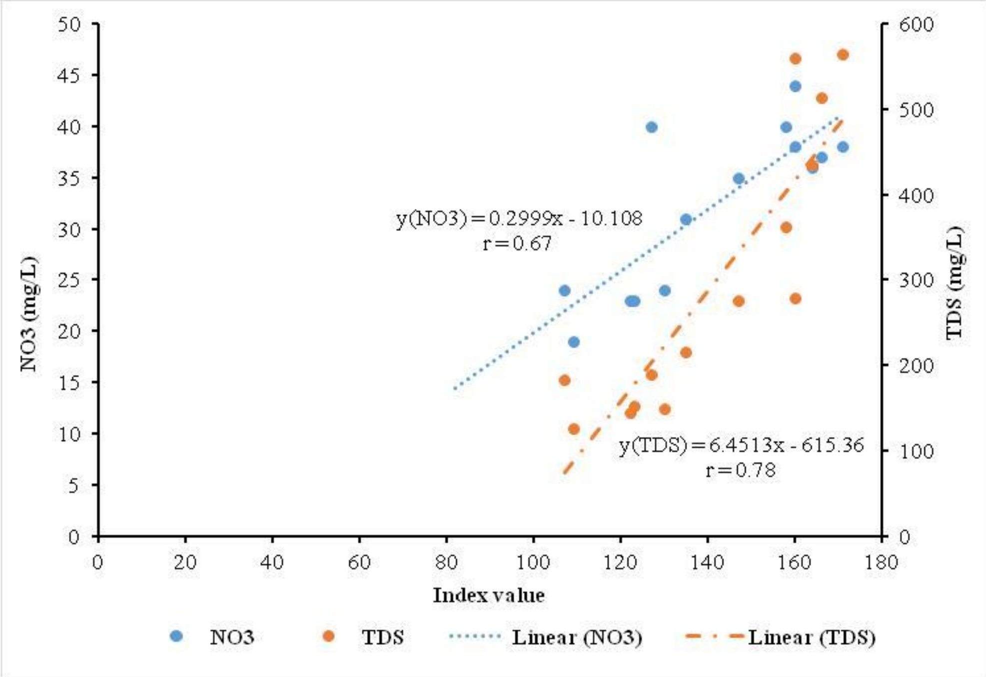

Figure 4.19 Correlation between NO_3, TDS concentration, and Standard DRASTIC model model.

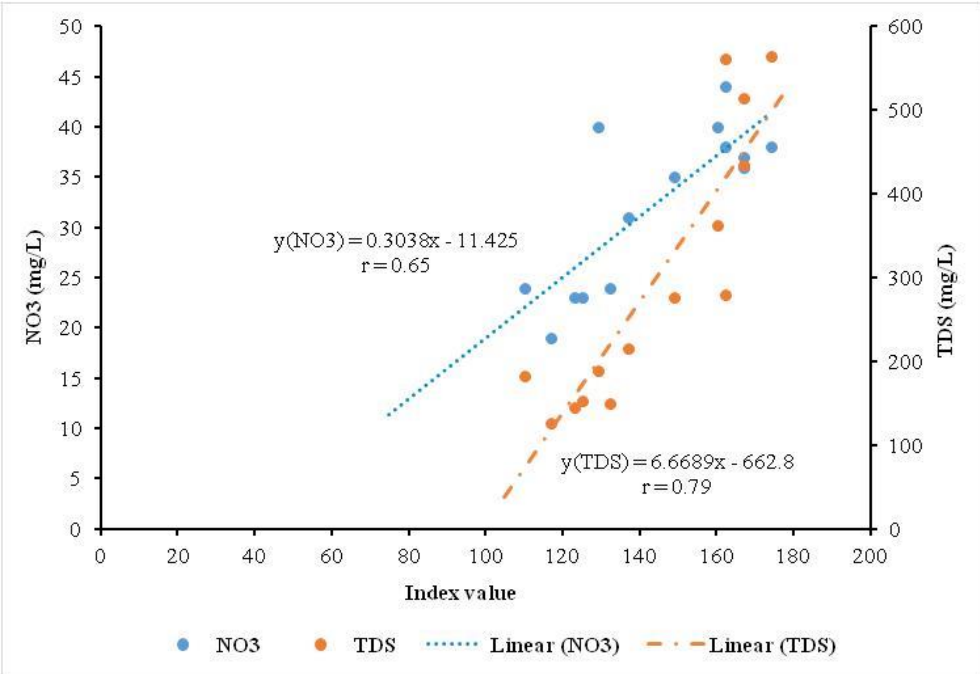

Figure 4.20. Correlation between NO_3, TDS concentration, and modified DRASTIC_Weight model.

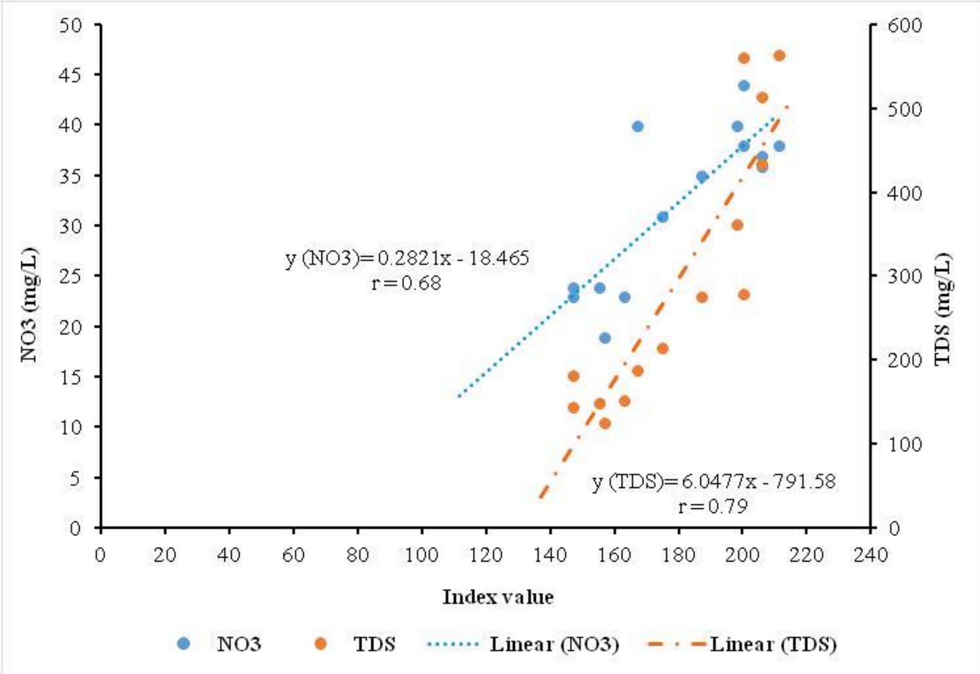

Figure 4.21.Correlation between NO_3, TDS concentration, and modified DRASTIC_LULC model.

5. CONCLUSIONS

The Erbil Central Sub-Basin has been chosen as a study area due to anthropogenic activities, and groundwater is a major source for the study are. The results of this study are required to provide a clearer appreciation of the action required to protect the quality of groundwater from deterioration. To determine the quality of groundwater 64 wells for the wet season were collected for the study area. The pH values measured in all well sampling sites were within the range of 7 to 8.20 with an average value of 7.65, indicating that slightly alkaline in the groundwater in the Erbil Central Sub-Basin, and only a few groundwater samples have pH levels less than 7.5 (8.96 %). IQWS (2010) and WHO (2011) prescribed the desirable range of pH in the water for drinking purposes is between 6.5 and 8.5. The low TDS (89.00-421.00 mg/L) measured in well waters located in the Erbil Central Sub-Basin generally shows the effect of rock-water interaction with respect to the recharge water. Furthermore, high TDS levels were observed in the study area ranging from 536.00 to 1600 mg/L; the occurrence of high TDS levels is due to the influence of anthropogenic sources such as domestic sewage, cesspools tanks, agricultural and industrial activities. In addition, EC values of groundwater were in the range of 156.00-3200 μS/cm with corresponding averages of 422.59 μS/cm at 25 ^oC for well water samples, respectively. According to guideline limit for drinking water prescribed by WHO (2011) and IQWS (2010) 98.44% of the well water samples fall in permissible (1500 mg/L) categories. NO_3 concentration in the well water samples varied from 5.0 to 89.0 mg/L with an average 30.29 mg/L. The analysis results show that the NO_3 exceeded the desired limit (50 mg/L) based on prescribed by WHO (2011) and IQWS (2010) guideline limit for drinking water.

In order to evaluate the groundwater vulnerability of the study area, the GIS-based DRASTIC model was applied and the seven parameters in the DRASTIC model were taken into account. The DRASTIC vulnerability index (DVI) values ranged from 80 to 182 and the study area has been classified into four classes comprising from very low to high vulnerability intensity. The moderate vulnerability zone covers a major part bout 45.9% of whole the study area. While, very low, low and high vulnerability zone cover an area of 1.8%, %18.7 and 33.6%, respectively. These classes represent the relative pollution potential in the study area.

In addition, to obtain more accurate results, it is necessary to modify the standard DRASTIC model based on the specific hydrogeological characteristic of groundwater aquifers in the study area. In this study, two approaches has been applied to modify the standard model. The first attempt, the standard weight value of each parameter in the DRASTIC model was modified by applying the single parameter sensitivity analysis (SPSA) to calculate the effective weight of each parameter. The SPSA showed that the depth to water, aquifer media and impact zone parameters significantly impact the vulnerability system in the study area. The modified of DRASTIC_weight vulnerability index values ranged from 81 to 184 with four vulnerability classes very low, low, moderate and high. Most part of the area comes under a moderate vulnerability zone, which covers about 42.3% of the study area. While very low, low and high vulnerability zones cover 1.6%, 18.3% and 37.8% of the total study area, respectively. In the second attempt, the standard DRASTIC model was modified based on the effect of the LULC map of the study area. LULC map is one of the significant parameters reflecting anthropogenic impact and it is used as an additional parameter to modify the standard DRASTIC model. LULC map of the study area shows that four classes can be identified, including vegetation, barren land, urban area and agricultural land. According to this modification, the vulnerability index values ranged from 105 to 222 and the study area was classified into four classes of vulnerability comprising from low to very high. High vulnerability zone covers a major part about 83.6% of the whole study area. Whereas, low, moderate and very high areas comprise 0.1%, 7.6%, and %8.7, respecively.

The study indicates that the standard DRASTIC based on pollutant source information not improve the correlation between the TDS and the groundwater contamination risk index for all modified DRASTIC models but improved the correlation between NO_3 and the groundwater pollution risk index. While the correlation coefficient of NO_3 increased significantly (r is from 65% to 68%), the correlation coefficient of TDS generally remained constant (r =0.79) after modifications. The result of linear correlation between NO_3 and each model indicates, that the modıfıed DRASTIC_LULC (r =68%) is an ideal model in the process for assessing groundwater vulnerability.

Recommendation

Based on the current study, the following points should be taken into account:

1- There are many types of contaminations required to be dealt with based on the source of pollution. Moreover, the study area subjected to leakage from oil refinery, landfills, septic tanks and cesspool, Irrigation, and Industry wastes should be treated before entering the environment.
2- There is a huge lack of data from groundwater quality in Erbil Central Sub_Basin, especially the wells data should distribute and represent the actual behavior of the location.
3- The polluted water due to irrigation is required to be treated and reused.
4- All the related data of the water supply system should be managed and organized as a dataset and must include wells coordination.
5- It is advisable to conduct the application of groundwater vulnerability to contamination for the other basins.
6- It is highly recommended to the related authorities to manage surface and groundwater systems better.

The hydrogeological and geology of the basins need to be further investigated to present the actual behavior of the study area.

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EXTENDED TURKISH SUMMARY
(GENİŞLETİLMİŞ TÜRKÇE ÖZET)

ERBİL (IRAK) ALT HAVZASININ YERALTI SUYU KİRLENEBİLİRLİĞİNİN DRASTİC YÖNTEMİ İLE DEĞERLENDİRİLMESİ

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Erbil Merkez Alt Havzası, Irak'ın kuzeyindeki Erbil vilayetinin güneybatı kesiminde yer almakta olup yeraltısuları içme, endüstriyel faaliyetler, evsel amaçlar ve tarımsal faaliyetlerde önemli bir rol oynamaktadır. Alt havza genelinde akifer birimlerin kirleticilere karşı duyarlılıkları Coğrafi Bilgi Sistemi (CBS) tabanlı olarak DRASTIC yöntem kullanılarak belirlenmiştir. Bu modele göre, çalışma alanı, çok düşük, düşük, orta ve yüksek kapsama alanları (%1.8, %18.7, %45.9 ve %33.6) olmak üzere bir akifer duraylılığının endeksinin dört bölgesine ayrılmıştır. Daha doğru sonuçlar elde etmek için standart DRASTIC'in iki farklı modifikasyonu uygulanmıştır. İlk modifikasyonda, tek parametreli duyarlılık analizi (SPSA) ile değiştirilmiş ağırlık değerlerine dayanmaktadır. Değiştirilen DRASTIC_ağırlık, çok düşük, düşük, orta ve yüksek kapsama alanları (%1.6, %18.3, %42.3 ve %37.8) dahil olmak üzere bir güvenlik açığı endeksinin dört bölgesine bölünmüştür. İkinci modifikasyonda ise, arazi kullanım- arazi örtüsüne (Arazi_Kullanımı; LULC) dayanmaktadır. LULC haritasından tarım arazisi, çorak arazi, kentsel alan ve bitki arazisi olmak üzere sadece dört darklı arazi kullanımı sınıfı tanımlanabilir. DeğiştirilenDRASTIC_LULC yönteminde düşük, orta, yüksek ve çok yüksek kapsama alanı (sırasıyla %0.1, %7.6, %83.6 ve %8.7) olmak üzere akifer duraylılığının endeksinin dört bölgesine bölünmüştür. Standart DRASTIC ve modifiye edilmiş modelleri doğrulamak için NO_3 ve TDS parametreleri kullanılmış ve sonuç olarak yeraltı sularının kirliliğe karşı akifer duraylılığının değerlendirilmesinde değiştirilmiş DRASTIC_LULC haritasını önerilmiştir.

Anahtar kelimeler: Akifer Duyarlılık, DRASTIC, Erbil Merkezi Alt Havzası, Yeraltı Suyu, Kirlilik.

1. GİRİŞ

Dünyada özellikle yarı kurak bölgelerde hem tarım hem de içme suyu temini büyük ölçüde veya genel olarak tatlı yüzey sularından (göller, göletler, akarsular vb.) ve yeraltı suyu kaynaklarından (kuyu ve pınarlar) sağlanmaktadır (Dişli, 2017, 2018). , 2020). Ancak son 100 yılda, hızlı nüfus ve plansız/şehirleşme artışı, sosyal ve ekonomik gelişmeler, yerel veya bölgesel ölçekte iklim koşullarındaki değişiklikler nedeniyle tatlı su kaynaklarının nitelik ve nicelik açısından sürdürülebilirliği büyük risk altındadır (Dişli 2017). Dünyadaki kurak ve yarı kurak bölgeler, yüzey su kaynaklarının hem nitelik hem de nicelik olarak yetersiz olması veya uygun olmaması ve özellikle ayrıca yeraltısuyu kaynaklarının kirliliğe karşı yüzey sularına göre nispeten düşük duyarlılıkları ve geniş depolama kapasiteleri nedeniyle ile yeraltı suyuna bağımlıdır (Thirumaivasan). Yüzey kaynaklı kirlenme olasılığının daha düşük olması nedeniyle en önemli tatlı su kaynaklarından biri olan yeraltı suları, genellikle su tablasının altındaki gözenekleri tamamen doymuş topraklar ve jeolojik oluşumlarıdaki suyu tanımlamak için kullanılır (Freeze ve Cherry, 1979).Yeraltısuyu kaynakları sadece sürdürülebilirlik ve insan varlığının temel ihtiyacı değil, aynı zamanda tarım ve sanayi gibi tüm kalkınma faaliyetleri için hayati bir girdidir. Dünya nüfusunun üçte birinden fazlası içme suyunu yeraltı sularından temin etmekte olup şu anda dünya çapında yeterli su kaynaklarına sahip olmayan 700 milyon insanın çoğu, iklim koşullarındaki değişiklikler nedeniyle gelecekte yeraltı suyuna güvenmek zorunda kalacaktır. Bununla birlikte, yeraltı suyu kaynakları, sulama suyu talebinin %40'ından fazlasını karşılamakta ve tüm endüstriyel kaynakların su ihtiyacının yaklaşık dörtte birini sağllamaktadır (Uluslararası Hidrojeologlar Birliği 2020). Yeraltı suyu kirliliğine, arazi kullanımı faaliyetleri, kentleşme, uygun kanalizasyon eksikliği, büyük ölçekli yoğun tarım ve büyük miktarda yetersiz deşarj edilen evsel ve endüstriyel atık su dahil olmak üzere farklı yaygın ve noktasal kaynaklar neden olmaktadır.Bu kaynaklar, yeraltı suyu kaynaklarını hem nitelik hem de nicelik olarak şimdi ve gelecekte sürdürülebilir özelliklerine ciddi şekilde bozabilir (Polemio ve diğerleri, 2009). Yeraltı suyu hassasiyetinin temel kavramı, bazı kara alanlarının diğerlerine göre yeraltı suyu kirliliğine karşı daha savunmasız olması olarak tanımlanabilir (Piscopo, 2001).

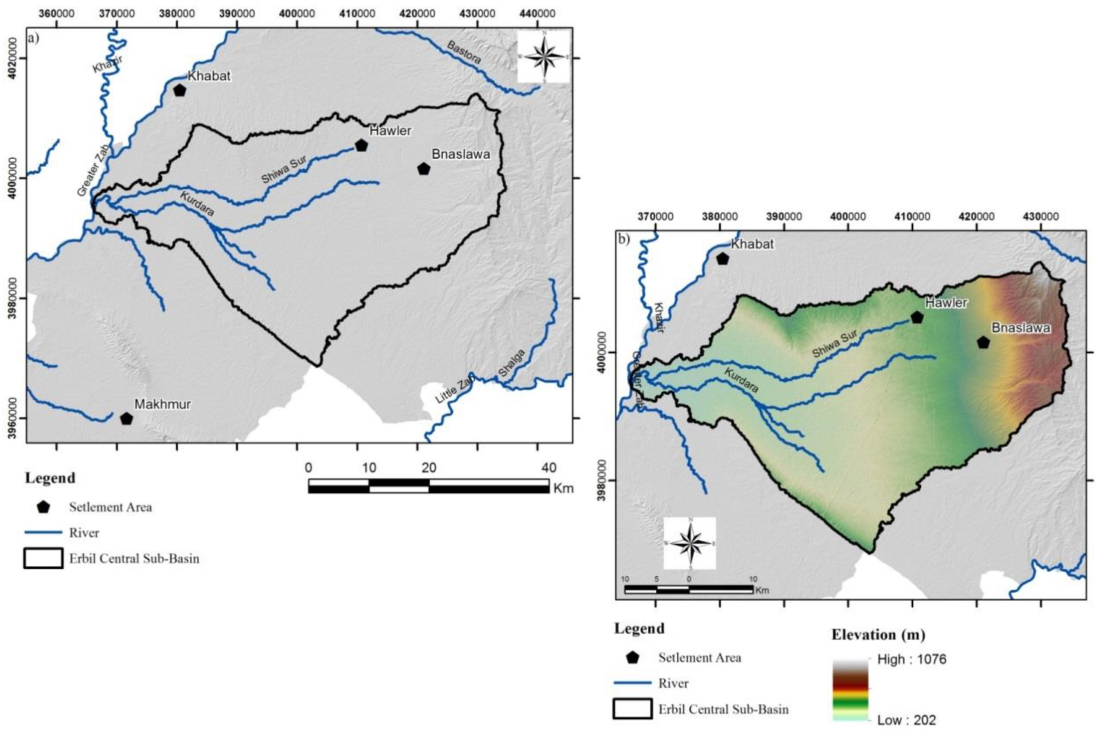
1968'deki ilk tanıtılmasından bu yana, üç farklı akifer kirlenebilirlik değerlendirme yöntemi geliştirilmiş olup bu yöntemler bindirme ve indeks yöntemleri, süreç tabanlı yöntemler ve istatistiksel yöntemlerdir (Thirumaivasan ve diğerleri, 2003). Bindirme ve indeks kategorisine giren DRASTIC modeli, bölgesel ölçekte yeraltısu kaynaklarının kirlenebilirlik değerlendirmesinde en yaygın kullanılan ve tercih edilen modellerden biri olarak bilinmektedir (Khosravi vd., 2018).DRASTIC modeli, başlangıçta, kirlenebilirliğe karşı duyarlılığı endeksine dayalı çeşitli hidrojeolojik ayarları içeren ve akifer kirlenebilirliğe indekslerinin değerlendirme sürecinde kullanımı çok daha kolay olan bir araç olarak geliştirilmiştir.

1.2. Çalışmanın Amacı

Erbil Merkezi alt havzası genelinde hızlı kentleşme, hızlı nüfus artışı, petrol rafinerileri, tarımsal faaliyetler, büyük miktarda evsel ve endüstriyel atıkların düzensiz şekilde boşaltılması, kanalizasyondan sızıntı gibi birçok tehlikeli kirletici unusrlar yeraltı suyuna sızmasından dolayı yeralatısuyu kaynaklarında kirlenmeye neden olmaktadır. Bu tez çalışma kapsamında, alt havza genelinde bulunan kirleticilerin yeraltısularını etkileme dereceleri dolayısıyla akifer birimlerin kirleticilere karşı duyarlılıkları Coğrafi Bilgi Sistemi (CBS) tabanlı olarak DRASTIC yöntem kullanılarak belirlemek ve sonuçları NO_3 ve TDS parametrelerin mekansal dağılımını ile karşılaştırmaktadır. Bu araştırmadan elde edilen sonuçlar, politika yapıcılara ve planlayıcılara yakın gelecekte su kalitesi açısından yeraltı suyu yönetimi planları hazırlamada yardımcı olacaktır.

1.3. Çalışma Alanının Konumu

DRASTIC indeksinin uygulandığı çalışma alanı, genel olarak alüvyon ovasının bir parçası olan ve yaklaşık 1624.5 km^2'lik bir alanı kaplayan Erbil Merkez Alt Havzası'nda (Şekil 1.1.a) yer almaktadır. Çalışma alanı, ortalama deniz seviyesinden yüksekliği 202 ile 1076 m arasında değişmektedir (Şekil 1.1b). Coğrafi olarak, UTM projeksiyonuna göre 365934.38 ile 434693.52 kuzey enlemleri ile 3968625.96 ile 4014122.61 doğu boylamları arasında yer almaktadır.



Şekil 1.1.a)Çalışma alanının yer bulduru haritası b)Çalışma alanının topoğrafik haritası

2. MATERYAL VE METHOD

2.1. Materyal

Çalışmaalanı genelinde yeraltısuyu seviyesini belirlemek amacı ile n 148 kuyu yeri seçilmiş ve bu kuyulardan 64 tanesi ise mevcut su kalitesine ait bazı parametreleri (pH, TDS, EC ve NO_3) belirlemek amacı örnekleme alımında kullanılmıştır. Alınan örneklemeler Erbil(Irak) de yer alan "Su ve Kanalizasyon Kalite Güvence ve Halk Sağlığı Laboratuvar Müdürlüğü" tarafından analiz edilmiştir.

2.2. Method

DRASTIC sistem hidrojeolojik yerleşim terimleri, DRASTIC oran diye anılan hidrojeolojik parametrelerin bağıl derecelenmesi ile ilgili şema olmak üzere ikiye ayrılır. DRASTIC indeksi Yeraltısuyu olan Derinlik (D), Net Beslenme (R), Akifer Ortamı (A), Toprak Ortamı (S), Topografya (eğim) (T), Vadoz Bölgenin Etkisi (I) ve

Hidrolik İletkenlik (C) olmak üzere yedi farklı parametreyi kullanır (Abdullah et al. 2016) . DRASTIC oranda, kirliliğe etkiyen her bir faktör kendi içinde derecelere göre sınıflandırılır. DRASTIC modelindeki yedi faktörün her birine, yeraltı suyu hassasiyetini tahmin etmede her bir faktör içindeki veri değerlerinin göreli önemine bağlı olarak 1 ila 10 arasında bir değer atanır ve ardından bu faktörlerin her birinin göreceli ağırlığı 1 ila 5 arasında değişen ağırlıklı oranlara göre ölçeklendirilir. DRASTIC İndeks aşağıda yer alan eşitlik kullanılarak hesaplanmaktadır (2.1)

$$D_i = D_r D_w + R_r R_w + A_r A_w + S_r S_w + T_r T_w + I_r I_w + C_r C_w \tag{2.1}$$

Burada; r: her parametrenin oran katsayısını, w ise ağırlık katsayısını göstermektedir . Son olarak, Yukarıda yer alan eşitlikte yer alan parametreler hesaplanarak sıralamalarına ve ağırlıklarına göre, çalışma alanı düşük (mavi rengin tonları), orta (yeşil rengin tonları) ve yüksek (kırmızı rengin tonları) renklerde hassas bölgelere ayrılır (Zghibi et al., 2016).DRASTIC modelindeki her parametrenin, kirleticilerin yeraltı suyuna taşınmasında parametrenin göreli etkisini gösteren sabit bir ağırlığı vardır (Rahman 2008).

2.1. DRASTIC Modelinin Modifikasyonu

2.1.1. Tek parametre duyarlılık analizi (SPSA) kullanılarak ağırlık modifikasyonu (DRASTIC_Weight)

Duyarlılık analizi, her bir parametreye atanan derecelendirme ve ağırlık değerlerinin etkisi hakkında önemli bilgiler sağladığı ve öznelliğin önemini değerlendirme sürecinde karar vericilere rehberlik ettiği için yeraltı suyu duraylılık analizinde yaygın olarak kullanılmaktadır (Edet, 2014; Kazakis ve Voudouris, 2015). İki tür duyarlılık analizi vardır: harita/katman kaldırma duyarlılık analizi ve tek parametreli duyarlılık analizi (Yang ve diğerleri, 2017). Harita kaldırma hassasiyet analizi, uygunluk haritasının uygunluk analizinden bir veya daha fazla haritanın çıkarılmasına yönelik hassasiyetini tanımlamak için kullanılır (Babiker vd., 2005). Bu çalışmada, tek parametreli duraylılık analizi (SPSA) yöntemi kullanılmıştır. Tek parametre duyarlılığı (SPSA) analizi, nihai güvenlik açığı endeksindeki her bir

DRASTIC parametresinin etkin ağırlıklarının belirlenmesine ve DRASTIC modelinin her bir parametresine atanan teorik ağırlıklar ile buna karşılık gelen etkin ağırlık arasında bir karşılaştırma yapılmasına olanak sağlamaktadır.

2.1.2. Arazi kullanımı-arazi örtüsüne (LULC) dayalı modife edilmiş DRASTIC modeli (DRASTIC_LULC)

Arazi kullanımı arazi örtüsü (LULC) haritası, ek bir parametre olarak derecelendirilir ve ağırlıklandırılır ve standart DRASTIC modeline birleştirilir. Bu kombinasyon, LULC ile değiştirilmiş DRASTIC modeli olarak adlandırılır.

3. TARTIŞMA VE SONUÇ

Erbil Merkez Alt Havzası antropojenik faaliyetler nedeniyle çalışma alanı olarak seçilmiştir ve yeraltı suları çalışma için önemli bir kaynaktır. Bu çalışmanın sonuçlarının, yeraltı suyunun kalitesini bozulmadan korumak için gereken eylemin daha net bir şekilde anlaşılmasını sağlaması gerekmektedir. Kuvaterner yaşlı Alüvyon çökeller, Pleistosen yaşlı teraslar ve Pliyosen yaşlı Bakhtiari Formasyonu, Erbil-Merkez Alt havzası genelinde ana akiferler olarak kabul edilmektedir. Yeraltı suyunun kalitesini belirlemek için alt havza sınırları içerisinde yer alan 64 kuyudan yağışlı sezonda örnekleme yapılmıştır. Kuyu sularında pH değerleri 7 ila 8.20 aralığında değişmekte olup, ortalama değeri 7.65 olarak bulunmuştur. Bu durum Erbil Merkez Alt Havzası'ndaki yeraltı suyunun hafif alkali olduğunu ve pH değerlerinin IQWS (2010) ve WHO (2011) içme suyu kalitesi için tanımlanan aralık olan 6.5 ile 8.5 arasında olduğunu belirlemiştir. Erbil Merkez Alt Havzasında yer alan kuyu sularında ölçülen düşük TDS (89.00-421.00 mg/L) genellikle kayaç-su etkileşiminin etkisini göstermektedir. Ayrıca, çalışma alanında 536.00 ila 1600 mg/L arasında değişen yüksek TDS seviyeleri ise evsel atık su, fosseptik tankları, tarımsal ve endüstriyel faaliyetler gibi antropojenik kaynakların etkisinden kaynaklanmaktadır. Ayrıca yeraltı suyunun EC değerleri 25 ^{o}C'de 156.00-3200 µS/cm aralığında değişim göstermektedir. Analiz edilen tüm kuyu suyu numunelerinin EC değerleri IQWS (2010) tarafından belirtilen izin verilen maksimum limit dahilinde olmasına rağmen, alanın %98.44'ü WHO (2011) içme suyu standartında tanımlanan limit değerlerinin içerisinde yer aldığı belirlenmiştir.

Çalışma, kirletici kaynak bilgilerine dayanan standart DRASTIC'in, diğer modife DRASTIC modelleri için TDS ile yeraltı suyu kirlenme risk indeksi arasındaki korelasyonu iyileştirmediğini, ancak NO_3 ile yeraltı suyu kirliliği risk indeksi arasındaki korelasyonu iyileştirdiğini göstermektedir. NO_3'ün korelasyon katsayısı önemli ölçüde artarken (r =65%- 68%), TDS'nin korelasyon katsayısı modifikasyonlardan sonra genellikle sabit kalmıştır (r:0.79).NO_3 ile her model arasındaki doğrusal korelasyonun sonucu, modife edilmiş DRASTIC_LULC'nin (r = 68%) yeraltı suyu kirlenebilirliği değerlendirme sürecinde ideal bir model olduğunu göstermektedir.

CURRICULUM VITAE

She studied in University Salahadeen and graduated BSc / Geology in 2008. She started her MSc. Program of Engineering in Institute of Science of Van Yuzuncu Yıl University in Van /Turkey, in September 2019.

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