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IDENTIFYING AND ANALYZING WATER RESOURCES OF ZAWITA AND ATROSH MUNICIPALITY (DUHOK CITY, IRAQ) FOR ECOTOURISM USING GIS

MASTER THESIS

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This dissertation, created by Harikar Mohammed Salih Hamid under supervision of Prof. Dr. Alaattin YUKSEL, was accepted as a Master thesis in department Soil Science and Plant Nutrition by the following committee on ...../ ..../ ….. with the vote unity.

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PREFACE

Endless thanks to **“Allah”** who enabled me to complete this work. I am grateful to the Bingöl University and the Department of Soil Science and Plant Nutrition for giving me the opportunity to complete this study.

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Every challenging study needs self-effort as well as the guidance of experienced especially those who are very close to our heart. I dedicate this thesis to my sweet and lovely mother and father whose supports, loves, encouragements and prays of days and nights helped me to be successful and receive the honor. I also would like to dedicate the study to my all hardworking and respected teachers.

Harikar Mohammed Salih HAMID

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CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

GIS	:Geographical Information System
EC	:Electrical Conductivity
Na	:Sodium
Ca	:Calcium
Mg	:Magnesium
K	:Potassium
$\mathbf{NO_3^{-1}}$	:Nitrate
$\mathbf{SO_4^{-2}}$	:Sulphate
$\mathbf{Cl^{-1}}$	:Chloride
$\mathbf{HCO_3^{-1}}$	:Bicarbonate
TA	:Total Alkalinity
TH	:Total Hardness
TDS	:Total Dissolved Solids

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ZAWİTA VE ATROSH BELEDİYELERİNDE (DUHOK ŞEHRİ, IRAK) CBS KULLANARAK EKOTURİZM İÇİN SU KAYNAKLARININ BELİRLENMESİ VE ANALİZİ

ÖZET

Irak'ın Kürdistan bölgesi de dahil olmak üzere kurak ve yarı kurak bölgelerin kırsal kesimlerinde nehirler, su kaynakları, göletler ve barajlar gibi su kaynakları başlıca turistik cazibe merkezleridir. Zawitta ve Atrosh ilçeleri, çeşitli muhteşem su kaynakları nedeniyle yerel ve bölgesel birçok turist için iyi bilinen turistik yerlerdir. Bu kaynakların su kalitesi yeterince araştırılmamıştır; bu nedenle, bu çalışma bazı nehirlerin ve göletlerin su kalitesini belirlemek ve GIS tekniklerini kullanarak su kalitesi parametrelerinin mekânsal dağılımını haritalamak için yapılmıştır. Çalışma alanı Irak'ın kuzey kesiminde ve Kürdistan Bölgesi'ndeki Duhok Valiliği'nin batı kesiminde yer almaktadır. Alan, kuzeydeki 36. 87604 ve 36.90292 N enlemleri ile 43.00163 ve 43.34493 E boylamları arasındadır. Topografya, genellikle deniz seviyesinden 606 ile 1026 m yükseklikte dağlıktır. ArcGIS yazılımı kullanılarak mekânsal su kalitesi parametrelerinin değişimi incelenmiştir. Sonuçlar, tüm su kaynaklarının alkali doğada olduğunu ve sertlik açısından da çok sert olduğunu belirmiştir. Hidro-kimyasal sonuçlar, kükürtlü su kaynakları dışındaki tüm su kaynaklarının renksiz ve kokusuz olduğunu göstermiştir. Kükürtlü su kaynakları haricindeki tüm su örneklerinde kalsiyum, magnezyum, sodyum, potasyum, klorür ve nitrat konsantrasyonları, WHO tarafından içme için izin verilen standartlarının sınırları içinde idi. Çoğu su numunesinin elektriksel iletkenliği ve toplam çözünmüş iyon konsantrasyonları orta derecede yüksek oranda mineralize olmuş, bununla birlikte kükürtlü su kaynakları ve Duhok barajı su numuneleri ise aşırı mineralize olmuş olarak sınıflandırılmıştır.

Anahtar Kelimeler: CBS, su kalitesi, kükürt kaynağı, su kaynakları, turizm.

IDENTIFYING AND ANALYZING WATER RESOURCES OF ZAWITA AND ATROSH MUNICIPALITY (DUHOK CITY, IRAQ) FOR ECOTOURISM USING GIS

ABSTRACT

Water resources such as rivers, springs, ponds, and dams are the main centers of tourism attractions in rural parts of arid and semi-arid regions including the Kurdistan region of Iraq. Zawitta and Atrosh districts are the well-known touristic destinations for many local and regional tourists due to the various magnificent water resources. Water quality of these resources have not been sufficiently investigated; therefore, this study was conducted to determine the water quality of some springs and ponds and map the spatial distribution of water quality parameters using GIS techniques. The study area is located in the northern part of Iraq and in the western part of the Duhok governorate in the Kurdistan Region. The area is situated between the 36. 87604 and 36.90292 N latitudes north and 43.00163 and 43.34493 E longitudes. The topography is generally mountainous with an elevation between 606 and 1026 m above sea level. The spatial variations of water quality parameters have been examined by using the ArcGIS software. The results revealed* that all water sources were alkaline in nature and also considered very hard in terms of hardness. The hydro-chemical results indicated that all water resources except sulfur springs were colorless and odorless. The concentrations of calcium, magnesium, sodium, potassium, chloride, and nitrate in all water samples, except sulfur springs were within the permissible limits of WHO standards for drinking. Electrical conductivity and total dissolved ion concentrations of most water samples were classified as moderately to highly mineralized, while water samples of sulfur spring and Duhok dam were classified as excessively mineralized.

Keywords: GIS, water quality, sulfur spring, water resources, tourism.

1. INTRODUCTION

Tourism is the largest and fastest growing industry worldwide in the new global economy. Ecotourism is the most common and rapid growing type of tourism which basically depends on the natural environment (Tran and Do, 2011). Ceballos-Lascuráin, (1987) who introduced the term of ecotourism first defined the ecotourism as visiting the protected and unpolluted parts of the nature with the aims of particularly enjoying, investigating the animals and plants and exploring the culture. Four basic principles of tourism have been identified as responsibility to increase the satisfaction of tourists, respect to host cultures, maximize the benefits of local people, and decrease the environmental effects (Hetzer, 1965). The characteristics of ecological tourism (EcoTourism) was identified by Fennell (1998). Miller (1978) who was another pioneer on EcoTourism and developed a road-based ecotours. Studies of Miller (1978) concentrated on the national park planning for ecological development in Latin America in connection with the environment in Canada. Five concepts, from functional standpoint have been presented for ecotourism. The concepts of ecotourism were education, protection of natural areas, participation of local people, high quality in tourism and increasing the economic benefits of the stakeholders (Ross and Wall, 1999).

The definition of environmental sustainability in EcoTourism includes a historical documentation and the preservation of natural areas (Goodland, 1995). The sustainability is a dynamic characteristic of a system and a related to the self-maintenance of the system. The sustainability refers maintaining long term value of environmental resources with the involvement of human. Goldemberg (2000) stated that the definition of environmental sustainability should concentrate on the degradation and current use rate of of natural resources which can be sustained for the future. Sustainable development is geared into the improvement of life quality in all societies and this can be maintained by strongly implemented environmental policies. Sustainable development provides all demands of present withoutcomprising the needs of future generations. Human population cannot be sustained by the long-term degradation of environment (WCED, 1987).

The development in computer technology enabled to easily analyze the large spatial data on water resources issues (Tsihrintzis *et al.,*., 1996). Geographic information Systems (GIS) become a fundamental tool to analyze the spatial data variability (Leipnik *et al.,*., 1993). The critical step in GIS applications for water resources is data gathering from the field (Kovas, 1991). Data gathering can be separated into two tasks: (i) controlling the ground for the geographic position and scaling the relationships within the study area, and (ii) to obtain the locations and specific characteristics in the field attribution (retaining walls, manholes, water valves and among others). All aforementioned studies can be complemented by photogrammetric location techniques (Kovas, 1991).

The most attractive section of innovative tourism is ecotourism which can provide local development and contribute conserving the natural resource if managed properly. In this context, the ecotourism become a rapid growing sector with an estimated growth rate of annual 20-34% since 1990 (Society, 2006). Moreover, ecotourism depends on the theory of sustainable development and principles of ecology which aims to resources conservation e.g. maintain the resources of sustainable uses, and biodiversity. Therefore, ecotourism will provide ecological experience for tourists and ecological conservation along with providing economic benefit to local community (Wanyonyi *et al.,*., 2016).

Zawita area in Duhok governorate is a well-known place attracting tourists due to availability of several beautiful natural landscapes and pleasant weather particularly during summer season. The availability of water resources (springs, rivers and small dams) in Zawita area has not sufficiently recognized by tourists from other parts of Iraq or from other countries. Therefore, identifying the available water resources using GIS toll is of great importance to introduce the ecotourism potential of the region. This will help tourists to reach the attractive touristic destinations in the region easily. The potential of Zawitta area for ecotourism has not been explored, despite the existence of many water resources available for ecotourism purposes. Moreover, the quality of these resources (suitability for drinking or swimming) also is not known. Therefore, this study was aimed to examine the availability of water resources and investigate the quality for ecotourism purposes. The main objectives of this study are to identify the water resources on a map that could enhance eco-touristic attraction in the study area, to examine the quality of water resources, and to determine the spatial variation of water quality parameters in the study area.

2. LITERATURE REVIEW

2.1. General Applications of Geographic Information System (GIS)

Arc GIS software is a universal, inserted, scalable system intended to fulfill the requirements board range of GIS employers. The software comprises of a suite of combined applications of Arc Map, Arc Catalog and Arc Toolbox. Mapping, data management and analysis of geographic information can be easily performed by utilizing the application of software (ESRI, 1991). The ArcView supplies universal mapping and analysis tools, along with simple editing and geographic requirements. The Arc Editor TM comprises the whole employment of the ArcView, for the addition of advanced editing ability. The Arc Info TM range the functionality to comprise advanced editing. Most parts of the thesis have been accomplished by using Arc Map, Arc Catalog, Arc Toolbox, Spatial analyst, and Geo statistical application. Short descriptions of these tools have been given below (ESRI, 1991). The Arc Map is the major implementation in ArcGIS desktop which is the GIS implementations utilized for whole map-based tasks comprising map analysis, editing and cartography. The Arc Catalog is the instrument for browsing, finding of geographic information, quick viewing data set and organization of GIS data holding. The Arc Tool box is a simple implementation comprising numerous GIS tools applied for geo processing. The spatial analyst tool supplies a wide range of storage special modelling and analysis characteristics that let to produce map and resolve cell-based raster datum. Various tasks such as deriving knowledge on data, determining appropriate locations, recognizing special connection and estimating the collected cost of travel from one location to another can be achieved by utilizing the spatial analyst tools. The geo statistical analyst (GSA) is a tool to make a continued surface spare measurement possessed at sample points. The GSA helps to predict values for surface utilizing different interpolation techniques such as inverse distance, spline, kriging, etc., and includes tools to explore datum and to test statistical error.

2.2. Water Resources as a Basic Component of Ecotourism

One of the most significant current discussion in ecotourism activities is the natural water resources (UNWTO, 2003; Lehmann, 2009). United Nations World Tourism Organization (UNWTO) recently recognized the freshwater as one of the most sensitive and limited natural assets for the tourism sector. The report clearly documented that consumption of water resources in tourism activities is almost double compared to the local residents of a region (UNEP, 2009). According to the United Nations Environment Program (UNEP), the average consumption of a tourist in Spain consumes approximately 440 L day^{-1} which is much higher than the water used by a person in Spanish (Choi and Sirakaya, 2006). In general, the amounts of water used by a tourist water reported ranging between 300 and 850 liters in a day (De Stefano, 2004) or almost six times higher than a local resident (Narasaiah, 2005).

The natural water resources are important in attracting tourists to a region. However, the tourism industry may create water shortages, degradation of water supplies and local environment, and increased waste water (De Stefano, 2004). The shortage of available water in some of the touristic locations increased the establishment of recycling facilities for waste water and desalination units for sea or ground water and water storages (Jamieson *et al.*,., 2003).

2.3. Importance of Natural Water Resource in Ecotourism

Recent developments indicated that water resources are invaluable natural assets for the sustainability of tourism industry (Lehmann, 2009; Brebbia and Pineda, 2010). Water has several pivotal roles for different tourism sector. Different uses of water identified by various researchers at a destination level have been illustrated in Figure 2.1 (Gössling, 2001; Tourism Victoria, 2003, 2004, 2007 and 2008; Hadwen *et al.*,., 2006). The figure shows the difference between prodigal use of water and prudent consumption of water. The careful consumption of water resources helps to protect the quantity and quality of water despite the use in tourism industry.

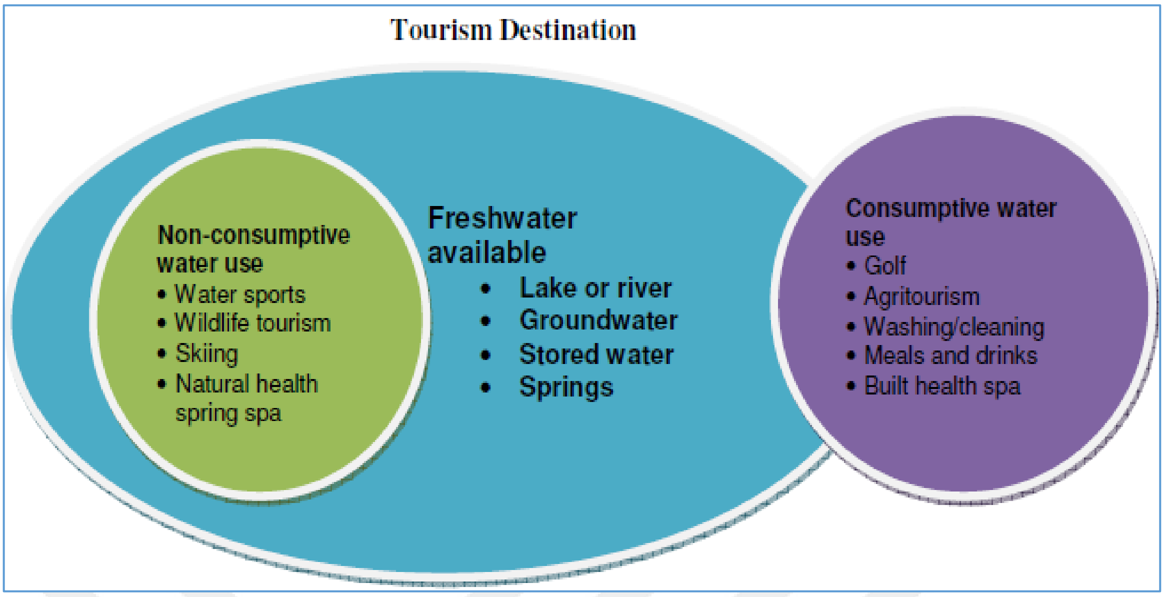

Figure 2.1. Wasteful (consumptive) and prudent (non-consumptive) water use (Lehmann 2009)

Benjamin Franklin stated that people will understand the values of water resources “when the wells run dry” (Roddick and Briggs, 2004). Importance of water has been thoroughly investigated and several reports have been published (Linsky, 2004; Young, 2005; King and Mazzotta, 2008), however, studies on evaluation of water resources for tourism are not sufficient (Linsky, 2004; Young, 2005). Linsky (2004) indicated that the real value of water is very closely associated with the way water is consumed. Besides the importance of water for tourism, data for the amount of water used in tourism sector compared to other sectors and the amount of water used is important. Especially in regions where tourism is an indispensable element for the regional economy, it seems quite easy to determine the proportion of water used. However, in the regions where tourism is not the only driving force, these evaluations are necessary because the ratio of water used in tourism compared to other sectors is important (Lehmann, 2009). In this context, the bottom-up approach used in the measurement of carbon dioxide emissions in tourism can be considered as an appropriate approach that can be used in water-related assessments (Becken and Petterson, 2008). The preferred bottom-up analysis approach in the industry can be combined with the top-down analysis approach with the help of the integrated economic-environmental accounting approach. The new applied approach to be obtained can be transferred to the studies related to the evaluation of the valuing of water in tourism and can be easily applied in the current study.

2.4. Water Quality

The water quality term is used to express the combination of various physical, chemical, biological and radiological properties of water (Nancy, 2009). According to Winter-Nelson (1997), water quality is a measure of the state of water considering the needs or intended use of one or more species or any human being. Generally, the quality of a water is judged by comparing the determined properties of a treated water or a natural water source with a set of reference values.

2.5. Indicators of Drinking Water Quality

2.5.1. Physical Indicators

Any measurable property, such as color, whose value defines the state of a physical system is considered a physical property (Burgin, 2016). Any change in the physical properties of a system or a substance can be used to identify and evaluate changes that occur over a period of time. The observable properties are often defined as the physical properties of a system or a substance. The physical properties defined as physical quantities are not modal properties.

The majority of intensive and comprehensive properties are defined as physical properties. The size or dimensions of the system does not affect the density of the feature, but the comprehensive feature is closely related to the size and dimensions of the system. Such definitions may apply when the system or substance is divided into smaller pieces and does not interfere with some physical or chemical processes.

Properties can be classified in different ways according to their nature. An example of this is that the isotropic properties do not change by observation and that the anisotropic properties change due to spatial variability.

In some cases, it can be difficult to determine whether a property is tangible or not. It consists of reflective properties of a surface which is perceived as color although it is seen and measured, and interpretation of the light used to illuminate the surface. In this context, many of the physical properties due to some of the features that are seen or measured are actually called supervenient.

Physical properties are quite different from chemical properties that determine how a material will behave in a chemical reaction. Some of the well-known and widely investigated chemical properties of water resources are temperature, electrical conductivity (EC), total suspended solids (TSS), transparency or turbidity, total dissolved solids (TDS), odor, color and taste of water.

2.5.2. Chemical Indicators of Water Quality

Properties resulting from a chemical reaction are known as chemical properties (Cengage Learning, 2009). Chemical properties cannot be identified only by looking or touching, as in physical properties. The properties of the basic building blocks that make up the material determine the chemical properties of a material. When a substance undergoes a chemical reaction for various reasons, significant changes will occur in the properties of the substance and the changes will be referred to as chemical change. However, catalytic properties are also considered chemical properties.

Chemical properties totally differ from physical properties, which can be defined without changing the structure of a substance. Chemical quality indicators for water resources are pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), dissolved oxygen (DO), total hardness (TH) and electrical conductivity (EC).

2.5.3. Biological Quality Indicators of Natural Water Resources

Biology is the basic science that examines living or fossil organisms, life processes of living organisms and all physico-chemical aspects of life. Biology has been divided into various branches and sub-branches since the beginning due to the vastness of its subject, depending on the living groups it has studied, the way of approaching the subject, and the handling of life processes at the level of organ, tissue, cell or cell components (Anonymous, 2019). A second approach to the branching of biology is to define the researches on the structural and functional characteristics of living organisms as separate study areas. Morphology, which examines the structural features of all living things, whether animals or plants, is one of the major branches of biology; it is a traditional tendency to divide this branch into morphology of plant and animal (Harold *et al.*,., 2015).

2.5.4. Quality of Natural Water Resources in Ecotourism

With the goal of ecotourism for the last 10 years, the restoration of water bodies has accelerated and the number of studies on water quality has increased (Brebbia and Pineda, 2010; Pineda and Berbbia, 2012). Instead, the result is a significant proportion of pollutants focused in the dot world. The main objective of the studies nowadays is to reduce pollution, which is currently aimed at city, forest, agriculture and landscaping (Pineda and Berbbia, 2012).

One of the most valuable assets that human being can obtain without any energy and effort in our ecosystem is the natural water resources (Islam and Mamun, 2015). Water resources make up almost 70% of the world's mass and are the most indispensable natural resource for the diverse needs of all living creatures (Mamun, 2015).

Wastewater due to the industrialization, increasing fertilizer and pesticide use in agriculture have caused the pollution of natural water resources to a dangerous level (Islam and Mamun, 2015). While the pollution of water resources adversely affects aquatic organisms, the use of polluted waters causes significant human deaths in many parts of the world (Mamun, 2015). Real-time reliable data on water quality is needed to protect water resources, to clean contaminated waters and to regularly control the water quality. Because, it is inevitable that clean water reaches for the control of epidemics and for a healthy life. In order to control epidemics and ensure the sustainability of a healthy life, clean water is needed. A natural pollution may occur in the waters originating from its natural source due to the decomposition of organisms, bathing, and disintegration of aquatic organisms. Natural waters may also contain various heavy metals in few cases (Mamun, 2015). However, the presence and quantity of toxic elements in some waters is a product of purely human pollution. Many countries use a common data set consisting of various parameters such as pH, alkalinity, dissolved oxygen and salinity in the assessment of drinking and surface water pollution (Mamun, 2015). Achieving these standards is considered as the guarantee of cleanliness of the waters. Although expensive, the range of these criteria should be set daily. In this case, the use of kits will be both more practical and less costly. Collecting and analyzing samples in the laboratory is both time-consuming and expensive. Therefore, there is a need to develop automated, real-time water quality measurement systems that will generate instant data on the quality of natural water resources. For instance, the principle of the things interne which will remotely sense, evaluate and inform water quality data in real time using GIS (Mamun, 2015) is a main basic of wireless network of sensor.

The main aim of RS and GIS water monitoring system was to measure the chemical and physical parameters of coastal places to improve the frequency and reliability of the data collection, as well as, to make tasks of stock holders simple which will improve the management and performance of staff. The developed sensor systems enable automatic measurements at different locations by making it possible to perform the analyzes defined in the previously planned range. In addition, it is possible to access data obtained from sensors via GIS system at certain centers (Islam and Mamun, 2015).

2.6. Application of GIS in Evaluating the Natural Water Resources

The projects of the natural water resources are obtained from overlapping and objectives of time conflict (Patil1 and Gosain, 2003). These kinds of innovative projects are sizes range variation from the biggest projects with the area of million hectares to the smallest projects at the local level implementation (Patill and Gosain, 2003). Consequently, all projects there are often have a proper coordination that is necessary for sustainable ensure collectives. In this context, the watershed management and development are the answers accepted while it requires a framework which enable to process of planning. They include all the stockholder compulsory at various scales and levels. In this circumstance, the unified framework of hydrology is fundamental for cause and effect evaluation of proposed action within the basins of drainage (Elshafei *et al.*,., 2014). On the other hand, the water with poor management is also has a large concern for storage sites unavailability as well as scarcity of water. By way of illustration, the water conventional management and planning is basically concentrated on blue water (reservoirs, lakes, rivers, water in streams and rivers). There is a required need of rainfall incorporate in arid and semi-arid basins that naturally infiltrate into the soil and vise-versa to the atmosphere in the evapotranspiration form (Lyon, 2003). Resent applications of GIS are existence including groundwater modeling, groundwater and surface hydrologic, sewer system and water supply modelling, nonpoint source pollution and storm water modelling for Agricultural and urban areas (Tsihrintzis *et al.*,. 1996).

Soil characteristics, slope and slope components, land use, vegetation, climate and spatial variability of human influence have significant influence on hydrological processes. Hydrological processes are the most important agents that affect the amount of pollutants transported by surface runoff or infiltration of pollutants to the groundwater. Therefore, the contamination ratio of water resources in a region and the amount of pollutants added can vary greatly depending on the spatial variability of the influencing factors (Vieux, 1991).

The process scale or modelled system are larger than the elements used in the processes of spatial distribution models. The content of information of the output model is higher than a combined model though achieving at lower cost. In this area, the technique of GIS is able to manipulate both output and input required parameters by distribution of modelling process. The application and illustrated of the GIS, INFO/ARC and the finite solution element to the equation of kinematic wave was reported by Vieux (1991). The application of GIS mostly used to analyze the spatial variable process terrain in a small watershed system using irregular triangular Network on TIN (Vieux, 1991). The TINs are used to obtain surface slope of the land in a finite solution element of overland flow which is a basic sub affecting process on non-point source, water quantity and quality.

2.7. Application of GIS in Tourism Planning

The success of any tourism business is closely related to tourism planning, development, research and tourism marketing (Jovanovic, 2016; Njegus, 2008). GIS applications contribute to the planning and management of tourism by using geographical information together with the other relevant media information. The GIS in the tourism industry provides various functional satiation maps and digital map base for printed maps. In addition, digital files for internet mapping and for mobile mapping can be provided by the GIS. Attractions map of an area and interactive maps of a region can also be created using GIS technology.

Today, GIS technologies are used to a great extent in the development of modern tourism applications and interactive maps. GIS technology allows users to use a common database while enabling large-scale visualization and querying. However, the integration of tourism-related data with GIS data is currently a challenge.

Table 2.1. Definitions of GIS

<table>
<tr><th colspan="2">Properties of GIS</th><th>GIS Analytical Functions</th></tr>
<tr><td>A process</td><td>A system for capturing, storing, checking, manipulating, analyzing and displaying data, which are spatially referenced to the earth.</td><td rowspan="2">Presentation and thematic
Mapping
Data query
Spatial query
Data base integration
Route finding</td></tr>
<tr><td>A toolbox</td><td>Containing tools for collecting, storing, retrieving, transforming and displaying spatial data.</td></tr>
<tr><td>A database</td><td>Spatially referenced entities</td><td rowspan="3">Point in polygon analysis
Overlays
Buffering
Visualization and 3-D modeling</td></tr>
<tr><td>An application</td><td>Cadastral information system, marketing information system, planning information system, etc.</td></tr>
<tr><td>A decision support system</td><td>Integrating spatial data within a problem-solving environment</td></tr>
</table>

The GIS primarily employs the spatial and attribute data. The known geographical coordinates on the world constitute spatial geographical data. The known coordinates usually consist of coordinates specified in the grid system or degrees of latitude and longitude. Many organizations use precise address information, such as location names, addresses, postcodes and road numbers, in geographic data. Exact spatial sources can often be encoded into precise spatial references. Technological development in computer software and hardware has led to the development of various systems such as easy to use search, query, presentation and analytic functions.

Table 2.2. Data elements in Geographical Information System

Data elements	Description
Geographical or spatial data	Aspects of a location: ƒ ▪ Explicitly - using a standard geographical frame of reference such as latitude and longitude ƒ ▪ Implicitly – using surrogate spatial references such as road number/location name
The attribute data	Statistical and non-location data associated with a spatial entity

Tourism planning includes various natural, cultural and man-made attractions; services like accommodation, shopping centers, banks, hospitals and post offices; and all transport facilities such as both financial infrastructure and transport services. This process is also called as the infrastructure of tourism. However, tourism planning should primarily involve the collection and processing of spatial data. Because, for a good tourism planning, the locations and the relationships between them should be defined and analyzed spatially. In this context, GIS is used to define the geometric structure of the elements of tourism infrastructure such as size, shape, properties and topology related to theme. In addition, GIS can store and analyze both object data such as visitor centers and site data and height.

3. MATERIALS AND METHODS

3.1. Study Area

Thirteen different locations were selected in Zawitta-Atrosh natural area, Duhok Governorates. The field surveys and data collections were done during 2017-2018 throughout Zawitta and Atrosh municipalities. The study area is located 16 km northeast of Duhok and on the main road between Duhok and Erbil. Geographically, the study area is located (36° 54' 23" N.; 43° 10' 18" E.). While, Atrosh municipality in Sheikan district, it is located 60 km South east of Duhok, Geographically, the study area is located (36° 51' 48" N.; 43° 27' 1" E.) and is one of the oldest towns in Duhok Province. A total of 13 water resources were selected from Zawitta-Atrosh natural area, the sampling points were as follows: 8 springs, 3 ponds, 1 dam and 1 river. (Table 3.1) (Figure 3.1).

Table 3.1. Sites, locations and geographical positions

Sample ID	water resource	Source name	Location	X	Y	Alt (m)
D1	Pond	Bihere pond	Atrosh municipality	36.96378	43.25164	1012
D2	Pond	Bablo pond	Zawitta municipality	36.8849	43.12776	872
D3	Dam	Duhok Dam	Zawitta municipality	36.88439	43.00782	606
D4	Pond	Bedule pond	Zawitta municipality	36.84708	43.25589	611
R1	River	Bedule River	Zawitta municipality	36.86636	43.23548	623
S1	Spring	Benarinke spring	Atrosh municipality	36.88805	43.24107	663
S2	Spring	Gabirkekanizerke	Atrosh municipality	36.94198	43.28349	890
S3	sulfur spring	Xirabiya SS	Atrosh municipality	36.94308	43.21152	883
S4	Spring	Zawita spring	Zawitta municipality	36.90659	43.17203	1026
S5	Sulfur spring	Garmava SS	Zawitta municipality	36.90292	43.00163	608
S6	Spring	Bedul spring	Zawitta municipality	36.86613	43.22459	652
S7	Spring	Qiyamate spring1	Atrosh municipality	36.87681	43.34601	783
S8	Spring	Qiyamate spring2	Atrosh municipality	36.87604	43.34493	777

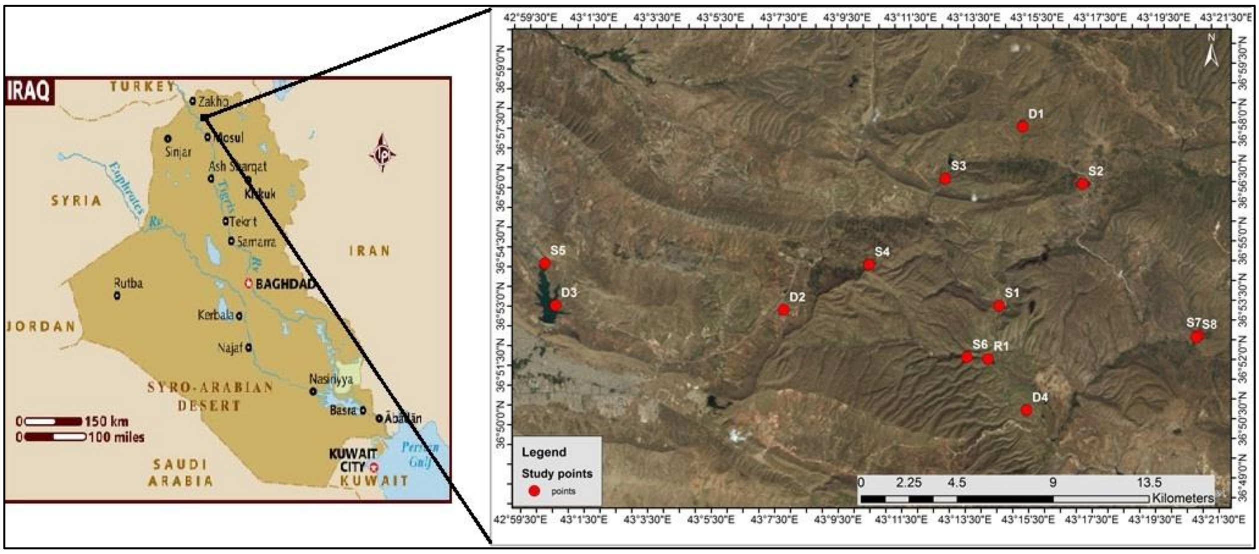

Figure 3.1. Study Area Map between Duhok, Zawitta and Atrosh triangle

3.2. Collection of Water Samples

For the purpose of water quality analyses, 13 groundwater samples are collected from the wells during the autumn 2018. The samples are collected in two main periods during the autumn: the first one is during 5 and 6 October, 2018, which is the driest period and the second is during 25 and 26 November, 2018, which is a relatively wet period. For more accuracy of the analyzed data n some wells, often more than one sample is taken. Water samples are collected in a clean polyethylene bottle from Duhok lake dam, springs, pond and river during 2018 at thirteen sites.

In order to analyze different physiochemical parameters, the samples were taken three times to insure preventing pollution then filled in clean labeled polyethylene bottles and putted in container with temperature less than 4^{o}C; All samples were then loaded to chemical laboratory of Duhok environmental directorate immediately for analyzing.

3.3. Laboratory and Data Analysis

After water samples were collected from different locations of Duhok governorate, all samples were taken to the laboratory for the water quality analysis. Water samples were analyzed for total hardness (TH) by titration with ethylene di-amine tetra acidic acid

(EDTA) using 0.01 M ammonium-ammonium chloride (NH_3 + NH_4Cl), pH buffer 10, and erochrom Black T indicator.

The temperature, EC, pH and TDS of water samples were measured by a portable multi-meter (Trans ISO 9002). Potassium and sodium concentrations of water samples were determined by a digital flame photometry (Model WAG TECH). Calcium, magnesium, chlorine, sulfate and nitrate concentrations were analyzed by using an Atomic Dionex DX500 ion chromatography system.

3.4. The Software Used in Data

Ms-word and Ms-Excel (2007) were used to type and tabulate data, solve equations perform calculations, and construct diagrams. Image editing was performed by using Adobe Photoshop 10.0 (2007). ArcMap 10.2 (2008) was used for mapping of water quality parameters. Map Info professional 5.0 (1998) was used for map preparation of geological, hydrogeological and hydrological cover conditions.

3.5. Climate Data

Several attempts have been made to characterize the bioclimatic zone of the Mediterranean n Region including the Kurdistan Region of Iraq (Daget *et al*., 1997; Roumieux *et al*., 2010). Recently, (Youssef *et al*., 2019).have classified the bioclimatic categories of the Kurdistan Region and mainly qualified it as an accentuated continental Mediterranean climate. Moreover, the climate of the Zawitta and Atrosh district is mostly semi-arid with fresh winter and warm dry summers. The annual precipitation ranges between 400 and 700 mm and the rainfall occur mostly in the late winter and early spring (from December to March). The temperature is contrasted with average minimum during January (7.5 C°) and average maximum during august (up to 40 C°) (Directorate of Meteorology of Duhok 2014). This accentuated continental Mediterranean bioclimate is mainly due to its geographical position between Mediterranean, Irano-Anatolian, Caucasian and Mesopotamian semi-arid region (Youssef *et al*., 2019).

3.6. Descriptions of Sampling Locations

3.6.1. Bihere Pond (D1)

Bihere pond is located between Xirabiya and Gabirke villages and GPS coordinates are 36.963777 N, 43.251636 E and the altitude is 1012 m. The pond water is mainly used for irrigation by the villagers, and due to the pond's location and the agricultural activities nearby the area is a very suitable for tourism and picnics. Unfortunately, the road to the pond is 3rd grade, which prevents the tourists from going there and enjoying the nature, also the pond water isn't suitable for drinking and the only suitable usage is for irrigation.

Figure 3.2. A general view from Bihere pond

3.6.2. Bablo Pond (D2)

Bablo pond is located near Zawita district, and the GPS coordinates are 36.884898 N, 43.12776 E, and the altitude is 872 m. The pond water is mainly used for tourist usage, and due to the pond's location and the facilities built nearby the pond, that area is one of the most visited tourist locations in Duhok Governorate. Since the pond and the surroundings are private property and are being taken care of properly, they are very attractive for tourists from Duhok city and Iraq in general.

Figure 3.3. A general view of Bablo Pond

3.6.3. Duhok Dam (D3)

Duhok dam is located to the North of Duhok city center, and the GPS coordinates are 36.884392 N, 43.007824 E and the altitude is 606 m. The dam water is mainly used for irrigation, and due to the dam’s location and the agricultural activities and facilities nearby, the area surrounding the dam became one of the most visited locations in Duhok city, the dam water used to be used for drinking but after being polluted by different factors, it’s mainly used for irrigation and site seeing.

Figure 3.4. General view of the Duhok Dam

3.6.4. Bedule pond (D4)

Bedula pond is located at the South-East of Atrish district, Its GPS coordination are (36.847081, 43.255887, altitude: 611m). The pond water is mainly used for irrigation by the villagers, unfortunately the road to the pond area isn't suitable for vehicles so people need to walk for more than 1km to get to the pond, which prevents the tourists from going there and enjoying the nature and beauty of the area.

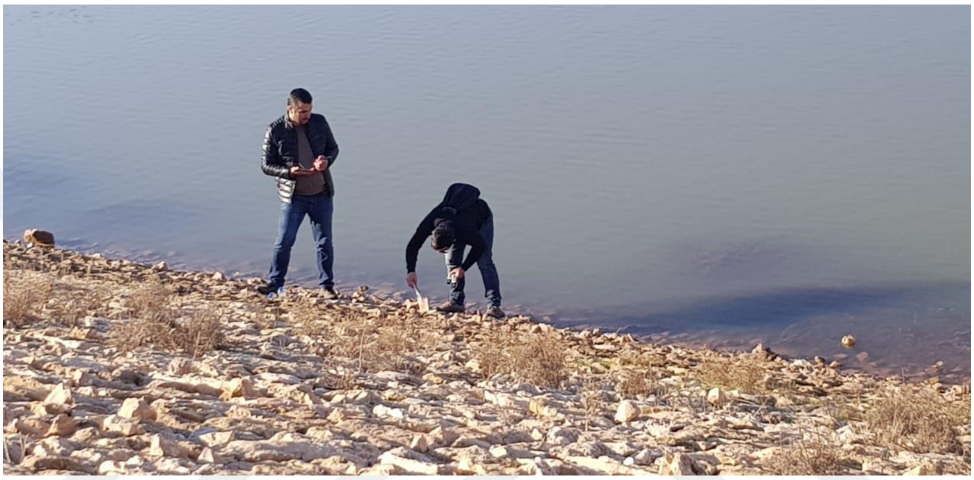

Figure 3.5. A general view of Bedule Pond

3.6.5. Bedule River (R1)

Bedule River is located at the South-East of Atrish district, and the GPS coordinates are 36.866363 N, 43.235479 E and the altitude is 623m. The river water is mainly used for tourism purposes, unfortunately the road to the river area isn't suitable for vehicles so people need to walk for 10 minutes to get to the river, and due to the huge amount of garbage and food remains that tourists leave behind them, and since no one is cleaning the river and the surroundings, the number of tourists is decreasing.

Figure 3.6. A general view of Bedule River

3.6.6. Benarinke Spring (S1)

Benarinke spring is located at the South-East of Atrish district and the GPS coordinates are 36.888048 N, 43.241068 E and the altitude is 663 m. The spring water is used for drinking and irrigation by the villagers, due to the landscape and surrounding area it's one of the most beautiful locations, but the spring water is being wasted without a pond or a gathering area to encourage tourists to visit it and benefit the village from the tourism activity, the spring is close to the main road but it's left uncared for.

Figure 3.7. A General View of Benarinke Spring

3.6.7. Gabirke Spring (S2)

It's located to the West of Atrosh district, Its GPS coordination are (36.941979, 43.283492, altitude: 890m). The spring water is used for irrigation and treatment by the villagers and tourists, due to the water's nature and the richness of minerals, the spring is considered one of the traditional treatment locations for locals and visitors, especially for treating yellowing of the skin (jaundice). The spring is far from the main road and the villagers have built a pond to save the water from being wasted, to have water year-round for the people's usage whenever they come for treatment.

Figure 3.8. A General View of Gabirke Spring

3.6.8. Xirabiya Sulphur Spring (S3)

The Xirabiya Sulphur Spring is located to the South-West of Atrosh district, Its GPS coordination are (36.943081, 43.211523, altitude: 883m). The spring water is used for dermatology treatment by the villagers and tourists, due to the water's nature and the richness of minerals especially SO4, the spring is considered traditionally a treatment for dermatology for locals and visitors. The spring is situated in a very hard to get location, and is hard to find due to the lack of signs and indications.

Figure 3.9. A general view of Xirabiya sulfur spring

3.6.9. Zawita Spring (S4)

Zawita spring is located at the South-East of Zawita district. The GPS coordinates are 36.906586 N, 43.00163 E and the altitude is 1026m. The spring is permanent situated in the middle of a natural pine forest near Zawita district. There are two 3rd grade roads leading to the spring, since the roads are constructed with soil and gravel, the access is restricted to the summer. The nearby villagers collect the spring water using bottles for drinking, and they state that the taste of water is very nice. They have also constructed a traditional irrigation channel system, the main crops in this area are: Grapes, Mulberry, Almonds, and some vegetables, etc. The stream reaches down the hill and the tourists go there for the pine trees' shade and the cool spring water.

Figure 3.10. A general view of Zawita spring

3.6.10. Garmava Sulphur Spring (S5)

Garmaya Sulphur Spring is located in valley in the middle of the triangle of the three villages of Garmava, Bajlor and Piromara. The Harmaya Sulphure Spring is situated at the North-West of Duhok district and the GPS coordination are 36.902917 N, 43.00163 E, altitude 608 m. The spring is considered hot with richness of elements and minerals, so it’s beneficial for dermatology treatment, and it’s very famous that people from Basra city come to get treatment, and some have spent more than a week to get their treatment (water). The spring is open and the location is well known to the villagers there, there are no safety measures taken around the spring which may lead to some accidents.

Figure 3.11. A general view of Garmava sulfur spring

3.6.11. Bedule Spring (S6)

Bedule spring is located at the South-East of Atrosh district and GPS coordinates are 36.866134 N, 43.224593 E and the altitude is 652m. The spring is located at the top of Bedule valley, the spring stream reaches to Bedule River as the main source. The villagers and tourists use the water for drinking since it’s situated in natural filter; Due to the pollution caused by the tourists’ garbage the stream water isn’t suitable for drinking so people need to get to the top of the spring to get clean water.

Figure 3.12. A general view of Bedule spring

3.6.12. Qiyamate Spring1 (S7)

Qiyamate spring is located at the North-West of Atrosh district and GPS coordination are 36.876808 N, 43.346013 E, and altitude is 783m. The spring is located at the top of Atrosh valley, the spring stream reaches to Atrosh, and people have constructed cabins and other facilities to host tourists. The number of daily tourists especially in the summer weekends reaches very high that in some days people can't find a place to stay in. The spring and stream cover a big area that is well developed.

Figure 3.13. A general view of Qiyamate spring 1

3.6.13. Qiyamate Spring2 (S8)

Qiyamate spring is located at the North-West of Atrish district. The GPS coordinates are 36.876036 N and 43.344927 E and the altitude is 777 m. The spring is located at the top of Atrosh valley, the spring is smaller than Qiyamate spring1, and mainly used for drinking. There are water pipes that provide fresh water that the tourists and locals can use for drinking and ablution, and there is specified area for prayers. Safety measures are taken to protect the spring from pollution and the people from accidentally falling in the spring.

Figure 3.14. A general view of Qiyamate spring 2

4. RESULTS AND DISCUSSION

The physico-chemical water quality parameters and major ion concentrations of 13 water samples collected from different parts of the study area were given in Table 4.1. The values of the water analysis results were compared with the drinking water standards published by the World Health Organization (WHO). The suitability of the sampled water sources as drinking water was evaluated with this comparison. All-natural spring waters contain certain amounts of dissolved salts. The concentration of dissolved salts in water is essential to determine the suitability of water for the various uses such as drinking and irrigation. Since the amount of soluble salt concentration has a significant effect on the physical and chemical structure of the plant and soil, water containing high dissolved salts is not suitable for drinking and irrigation.

Table 4.1. Physico-chemical characteristics of water samples

Sample ID	D1	D2	D3	D4	R1	S1	S2	S3	S4	S5	S6	S7	S8
TUR (NTU)	1.0	1.0	1.2	1.2	2.5	0.4	0.5	0.7	0.8	2.2	0.3	0.5	0.7
T ºC	16.9	16.8	23.6	16.0	12.8	20.7	14.6	18.8	18.4	31.4	17.9	18.8	19.2
pH	8.5	8.6	8.2	8.5	8.4	8.1	8.0	7.7	7.9	7.2	7.9	8.1	7.7
EC (µS cm^{-1})	551.3	477.7	1019.4	460.6	823.3	497.0	891.8	840.6	537.5	2056.4	734.0	548.2	600.6
TDS (mg l^{-1})	352.8	305.7	652.4	294.8	526.9	318.1	570.8	538.0	344.0	1316.1	478.0	350.8	384.4
T.H (mg l^{-1})	312.0	252.0	556.0	236.0	432.0	376.0	584.0	504.0	328.0	924.0	396.0	380.0	368.0
Ca (mg l^{-1})	60.8	43.2	124.8	41.6	80.0	75.2	124.8	120.0	68.8	272.0	71.0	78.4	86.4
Mg(mg l^{-1})	39.0	35.1	59.5	32.2	56.6	45.9	66.4	49.8	38.1	59.5	76.0	44.9	37.1
Na(mg l^{-1})	14.0	15.8	54.8	26.1	25.9	2.6	10.4	11.2	2.8	109.0	69.0	5.0	3.6
K(mg l^{-1})	2.0	2.2	4.1	6.0	1.8	0.3	0.7	0.6	0.7	9.3	6.7	0.5	0.4
TA(mg l^{-1})	162.0	172.0	158.0	166.0	252.0	244.0	374.0	402.0	254.0	262.0	276.0	240.0	290.0
HCO_3(mg l^{-1})	197.6	209.8	192.8	202.5	307.4	297.7	456.3	490.4	309.9	319.6	336.7	292.8	353.8
SO_4(mg l^{-1})	48.0	60.0	292.3	70.6	102.3	10.2	96.4	101.0	27.9	601.8	18.0	25.6	24.1
Cl (mg l^{-1})	18.0	28.0	72.0	15.0	36.0	12.0	16.0	24.0	10.0	228.0	12.0	14.0	16.0
NO_3 (mg l^{-1})	1.4	4.1	1.0	2.9	5.8	7.4	0.6	0.9	3.4	41.8	18.6	1.8	1.6

4.1. Colour, Odour and Taste of Water Samples

As a general principle, pure water is known to be colorless, odorless and tasteless. However, some inorganic substances such as dissolved organic matter and dissolved iron and manganese compounds, which are caused by the decomposition of algae and humic compounds in nature, cause discoloration of water resources (Pierce *et al*., 1998; Al-Manharawi and Hafiz, 1997). The odor that occurs in any water source is related to the reduction of dissolved oxygen content in water, the presence of components such as organic pollutants, phenol and hydrogen sulfide. The taste of water is related to the concentration of total soluble solids (TDS), carbonate content, decreasing oxygen content and increasing microorganism population and activity. Odor, color and taste are subjective characteristics that can be defined by human experience. Based on the maximum degree of dilution, a quantitative determination method was developed based on the distinction between odorless water and odor. However, there are no improved method or a device has been introduced for measuring the taste (Todd, 1980).

Water samples have been collected from springs, rivers, ponds and dams located at 13 different locations of the study area. T water samples of the study area were colorless, odorless and tasteless except for S3 and S5 sulfur springs. These two springs had strong smell of and hydrogen sulfide (H_2S) and not recommended to be consumed.

4.2. Temperature of the Water Sources

Temperature is an important quality parameter as it can affect many other properties and cause them to change significantly. The temperature of the water affects the speed and severity of the geochemical and chemical phenomena in the water, leading to a change in the chemistry of the water (Saether and Caritat, 1997). In addition, temperature is considered a quality criterion that must be determined because it determines the fate of many components and chemical pollutants that have a significant effect on taste (WHO, 2006). Temperatures of water samples were presented in Table 4.1 and Figure 4.1. The spatial variation of temperature values of water samples was depicted in Figure 4.2. No abnormal temperature value was recorded, except of S5 which had higher temperature

(31.4 ^{0} C) compared to the other water samples due to the nature of this sulfur spring. The temperature in S5 is almost stable around the year (Mohammed and Bamerni, 2019).

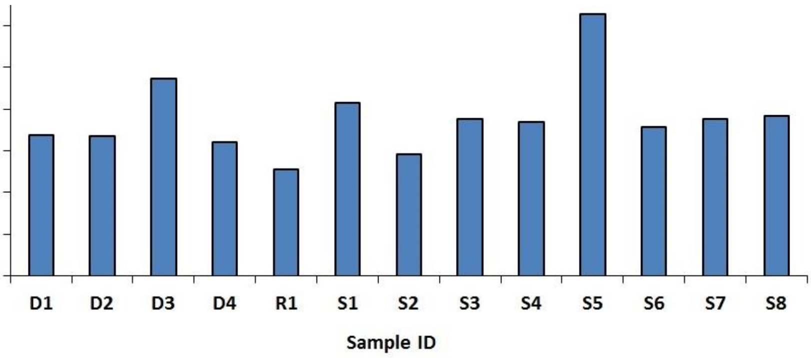

Figure 4.1. Temperatures of water samples

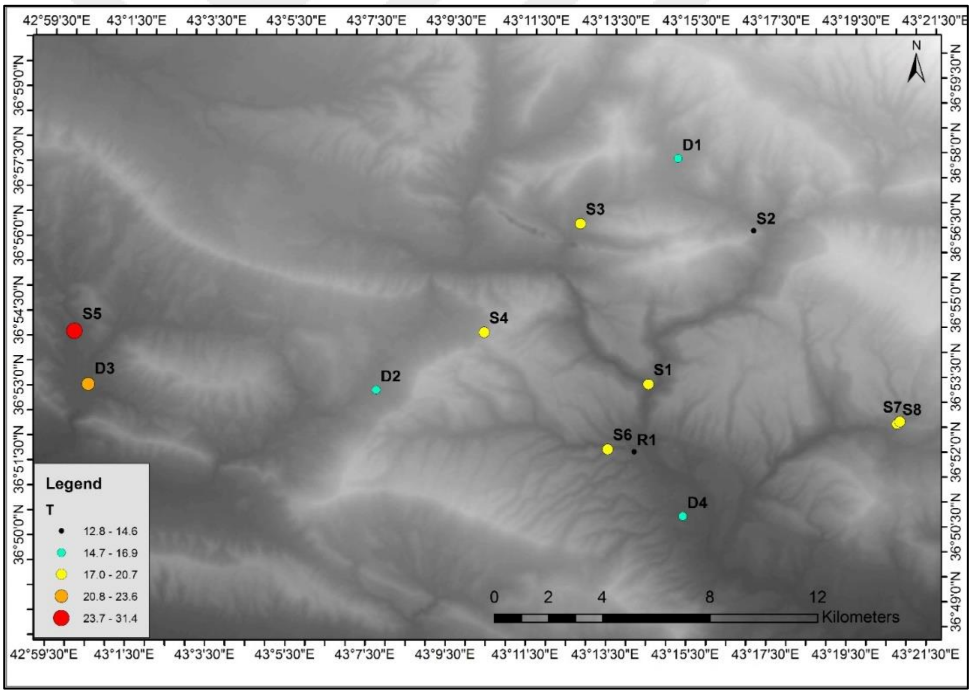

Figure 4.2. Temporal variation of water temperature values within the study area

4.3. Concentration of Hydrogen Ions (pH)

The pH is defined as the negative logarithm of hydrogen ion activity (WHO, 1996). The pH value indicates the acidity or alkalinity of water samples under normal condition of temperature and pressure. The vast majority of reactions in solid / liquid and gas systems are controlled by the pH of the environment (Mazor, 1990; Langmuir, 1997). The bicarbonate and carbonate concentrations of natural water are the major determinants of the water pH (Collins, 1975). The pH values lower than 6.5 and higher than 8.5 may cause severe damages to mucous membrane present in eyes, nose and most part of the living organisms (WHO, 2008).

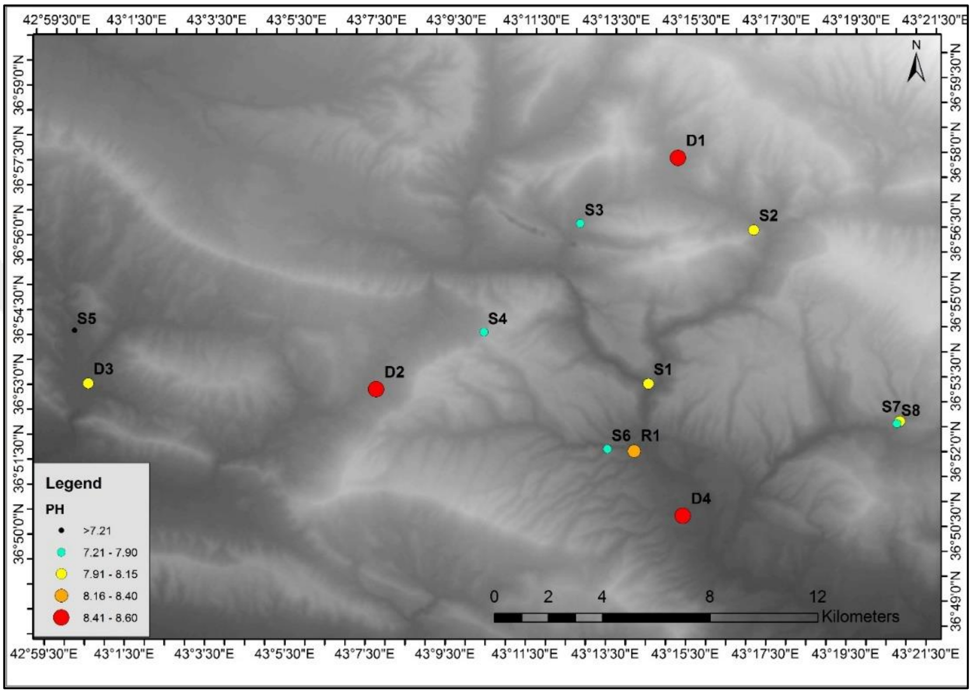

Figure 4.3. The temporal variation of pH values in study area

pH values of water samples ranged between 7.2 and 8.6 (Table 4.1) which indicated that the water resources in study area except D2 are generally slightly alkaline in nature and are within the permissible limits of drinking water (WHO, 2008). The pH value of D2 (8.6) is slightly over the permissible range. The spatial distribution of water pH in study area were given in Figure 4.3.

4.4. Electrical Conductivity (EC) of Water Samples

Electrical conductivity is an indicator of water's ability to conduct electrical current depending on the total amount of salt and is expressed as µS cm^{-1} (Todd, 2005). Since it gives direct information about the total concentration of ions dissolved in water, it is accepted as an important parameter in water quality evaluations. High EC is an indication that water is contaminated with inorganic pollutants. The high EC values measured in natural spring waters can be attributed to the high salt concentration that is mixed with water due to the various geochemical reactions (Hem, 1991; Mazor, 1990). The groundwater temperature, content, type and concentration of ions are the factors that determine the EC value of groundwater. The EC measurements in laboratory are performed at 25 °C, therefore, the measured values are indicative of the type and concentration of components in water (Walton, 1970). However, EC readings do not indicate which types of ions or compounds are present in water. The variation in the EC value of water gives important information about the change of water quality over time (Al-Manmi, 2008). High EC value of water can cause gastrointestinal irritation in humans. The type I (EC <1500 µS cm^{-1}) according to the classification of the world health organization is used for permissible water. In the same classification, type II (EC>15000 and <3000 µS cm^{-1}) indicates non-permissible waters and type III (EC>3000 µS cm^{-1}) indicates the hazardous water class.

The EC values of water samples were presented in Table 4.1 and Figure 4.4. Spatial variation of water samples within the study area was shown in Figure 4.5. The EC ranged from 460.6 to 2056.4 µS cm^{-1} and only one sample water (S5) was higher than the allowable permissible limits (1500 µS cm^{-1}) indicated by WHO (2008). The classification of mineralization ratio in relation to electrical conductivity of water defined by Detay (1997) has been shown in Table 4.2. According to this classification, water samples of the most locations were considered to be moderately to highly mineralized water, whereas water samples (D3 and S5) that were taken from sulphur spring and Duhok dam were classified as excessively mineralized water.

Table 4.2. Relationship between conductivity of water and mineralization ratio (After Detay 1997)

EC (µS cm^{-1})	**Mineralization**
< 100	Very weakly mineralized (granite terrains)
100 – 200	Weakly mineralized
200 – 400	Slightly mineralized (limestone terrains)
400 – 600	Moderately mineralized
600 – 1000	Highly mineralized
1000 <	Excessively mineralized

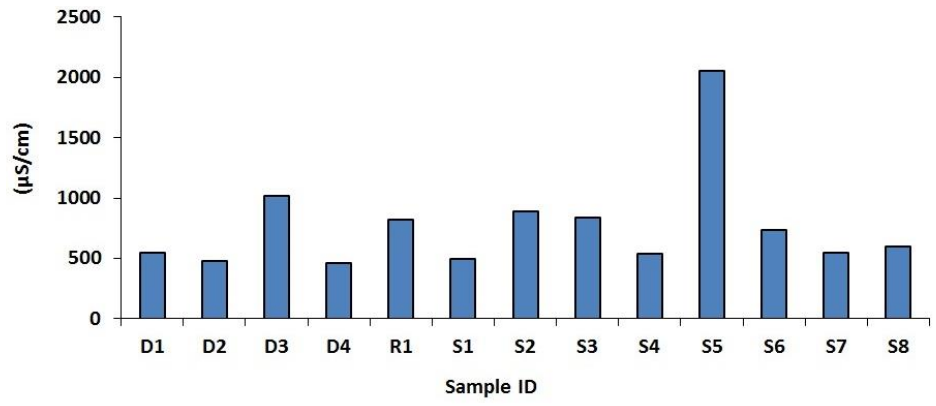

Figure 4.4. Electrical conductivity of water samples

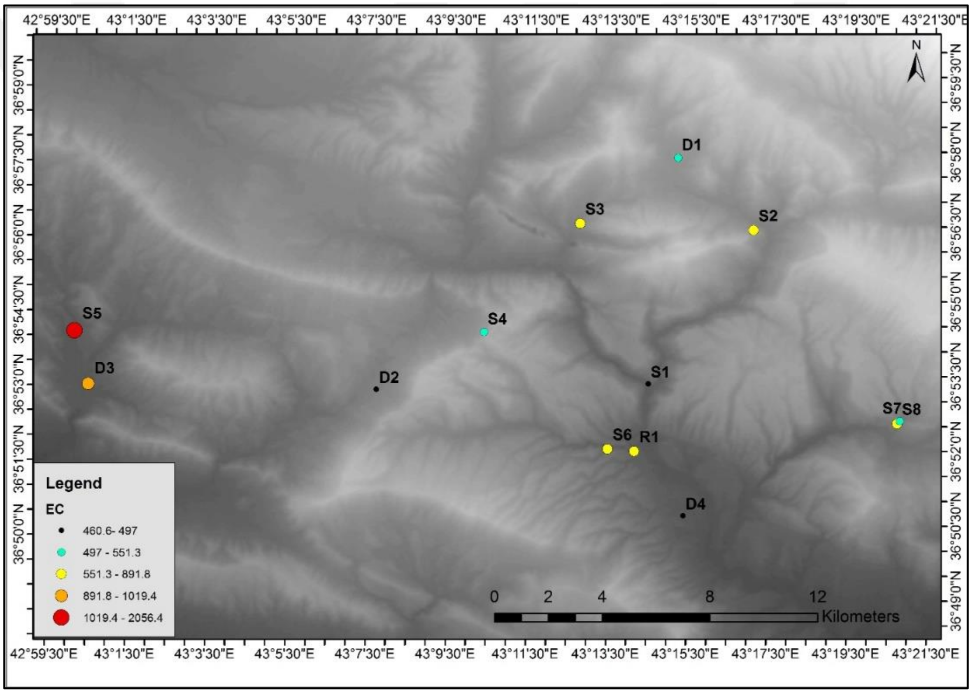

Figure 4.5. Temporal variation of electrical conductivity

4.5. Total Dissolved Solid (TDS) Concentration of Water Samples

Total dissolved salt (TDS) constitutes all ionized or non-ionized dissolved solids in water, but does not include colloidal materials, suspended sediment and dissolved gasses. The TDS sometimes is called as salinity (WHO, 1996). Inorganic salts in water and a small amount of water-soluble organic matter determine the TDS of water. Albu *et al*., (1997), which reports a relationship between TDS and EC, has shown that the TDS value can be estimated by multiplying the EC by factor of 0.64.

A classification system based on TDS values is used to determine the suitability of water resources for different uses (Table 4.3 and Figure 4.6) (Davis and De Wiest, 1966). Spatial distribution of TDS values of water samples was presented in Figure 4.7. The TDS values was between 294.8 and 1316.1 mg l^{-1} (Table 4.1). According to this classification, 8 water samples (D1, D2, D4, S1, S4, S6, S7, and S8) were desirable for drinking purposes, 4 water samples (D3, R1, S2, and S3) were permissible for drinking, and one sample (S5) was only useful for irrigation.

Table 4.3. Classification of water sources according to TDS values

TDS	Classification	Number of samples
< 500	Recommendable for drinking	8
500 – 1000	Allowable for drinking	4
1000 - 3000	Convenient for irrigation	1
> 3000	Inappropriate for drinking and irrigation	0
Total		13

Consumption of water with high TDS value as drinking water causes various damages. High TDS values is reported to cause diarrhea and even long-term consumption causes kidney stone formation (Shankar *et al*., 2008; Garg *et al*., 2009).

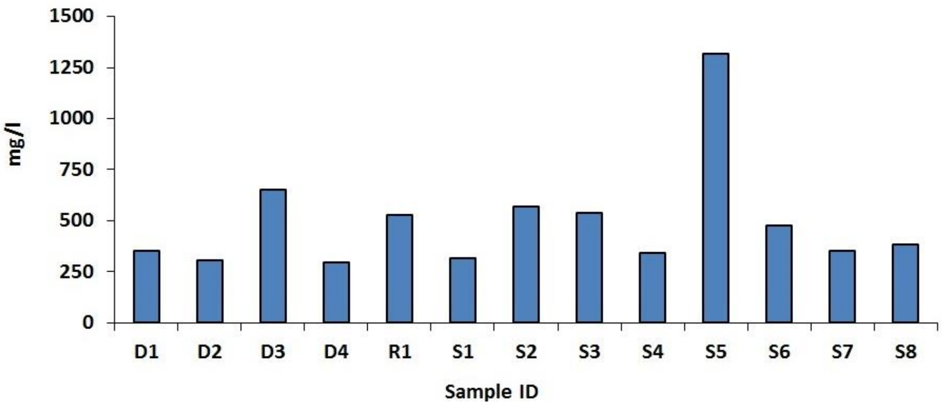

Figure 4.6. The concentration of total dissolved solids of water samples

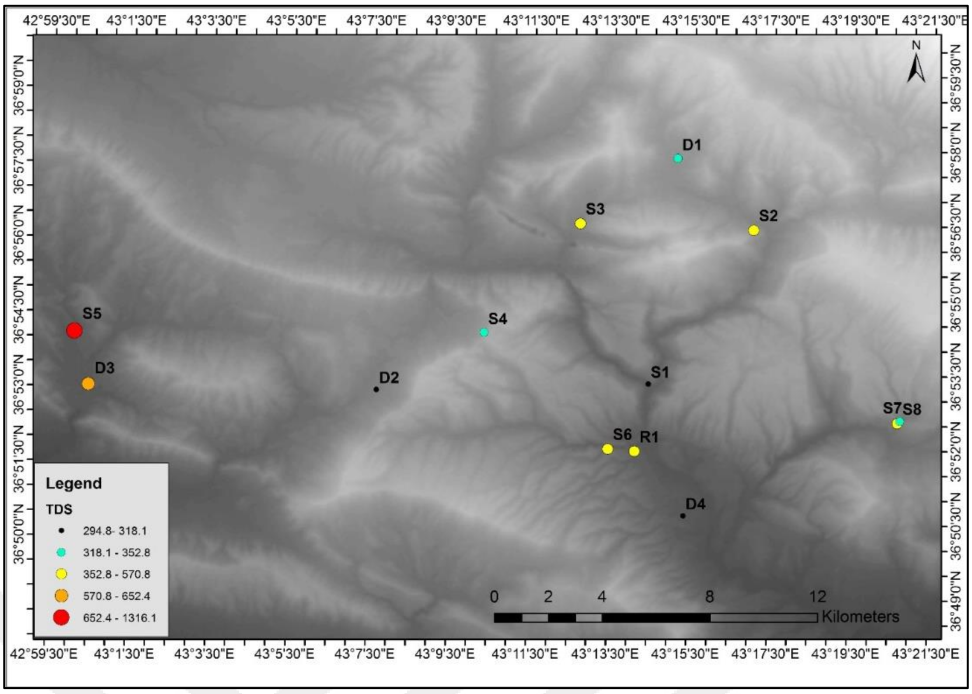

Figure 4.7. Spatial distribution of total dissolved solids of water samples

4.6. Total Alkalinity (TA) of Water Samples

Alkalinity is defined as the capacity of water to neutralize acidity. Total alkalinity (TA) is also an indicator of the buffering capacity of water. The main constituents in water that cause alkalinity are bicarbonate ions [HCO^{3-}], carbonate ions [$CO3^{2-}$] and hydroxide ions [OH−]. TA values of water samples collected in the study area ranged from 158 to 402 mg l-1 (Table 4.1, Figure 4.8). The TA value is an indicator of HCO^{3-} and $CO3^{2-}$ ions concentrations in water. Spatial distribution of TA values in the study area was shown in Figure 4.9. The acceptable limit value for the concentration of bicarbonate ion that assists digestion in the human body is reported to be 350 mg 1^{-1}. It is known to have a wide variety of effects, such as buffering lactic acid, reducing the acidity of dietary components, and preventing decay in tooth cavities. The results of the water analysis show that the bicarbonate concentration of the waters other than S2 and S3 samples exceeds the desirable limit value of 350 mg l^{-1}.

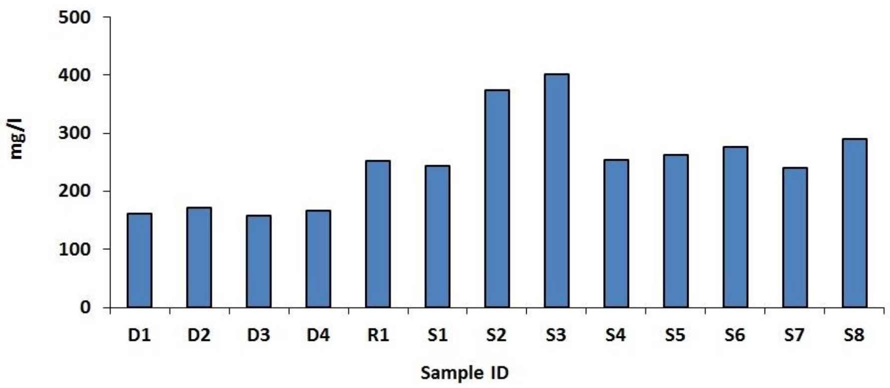

Figure 4.8. Total alkalinity values of water samples

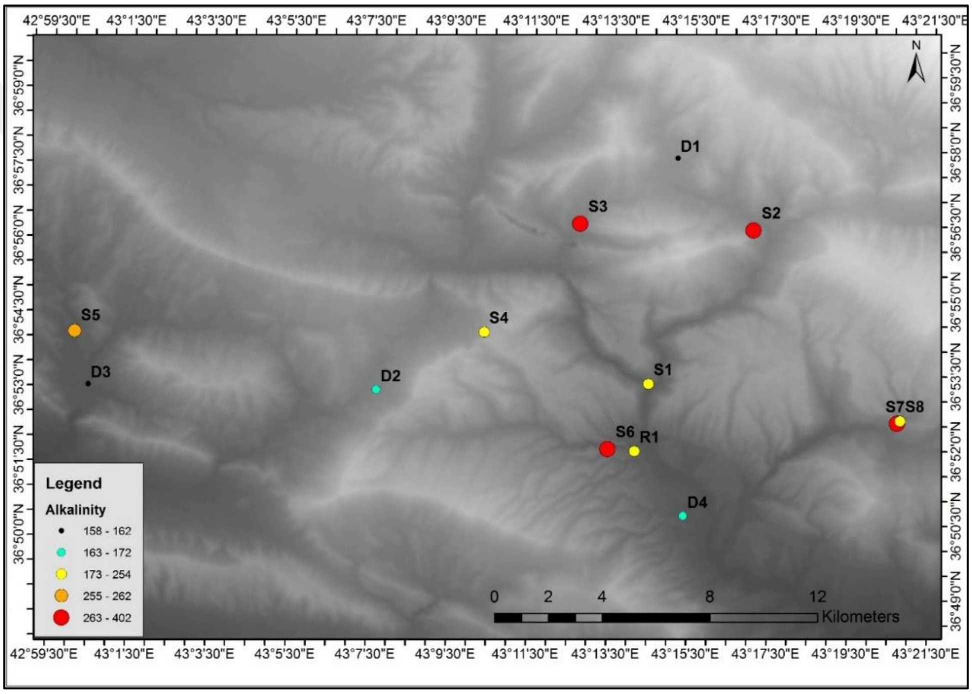

Figure 4.9. Spatial distribution of total alkalinity values within the study area

4.7. Total Hardness (TH) Values of Water Samples

Total hardness (TH), an important parameter of water quality, is an indication of the presence of calcium and magnesium, the most divalent metallic cations present in water. Calcium and magnesium ions, which cause hardness of water, react with soap and some anions in water, causing the formation of precipitates (Faure, 1998). Hardness is an indication of the ability of these two ions to form a precipitate or soap scum when reacting with soap (Hunter *et al*., 2004).

The main cause of the hardness in water is the solutions of carbon dioxide released by microorganisms in the soil together with percolations water (Todd, 1980). Two harness types have been defined. The first type of hardness is called temporary hardness, which is caused by reaction between Ca^{2+} and HCO_3^- and can be removed by heating. This type of hardness sometimes is also called carbonate hardness. The second type of harness is called permanent hardness (non-carbonate), which is produced by reaction between Ca^{2+} and Mg^{2+} with SO_4^{2-}, Cl^- and NO_3^-. The second type of harness cannot be removed (Rodiar, 1974).

Hamner (1986) reported that the hardness of the waters is higher in the areas where the geology is dominated by limestone. Al-Manharawi and Hafiz (1997) reported that the increase in the hardness of the water has healthy effects and that the increase of the hardness of the water will cause the precipitation of salt in the vessels and cause the real stone formation. However, the increase in water hardness can cause various problems in industrial use. Corrosion in heaters and coolers is one of these harmful effects.

Water hardness is also expressed as an equivalent amount of calcium carbonate concentration due to important factors such as pH and alkalinity (Ljungberg, 2004; WHO, 2006). Hardness of a water can be determined as follows;

$$\text{Hardness} = 2.49\,[\text{Ca} + 2\text{ mg/l}] \;+\; 4.11\,[\text{Mg} + 2\text{ mg/l}] \quad (1)$$

The TH values of water samples in the study area were given in Table 4.1 and Figure 4.10. Spatial distribution was shown in Figure 4.11. The TH values of water samples ranged between 236 and 924 mg l^{-1}. According to Boyd (2000) classification of water hardness, only two samples (D2 and D4) considered moderately hard, whereas the rest samples were classified very hard (Table 4.4). The geological structure and climate of a region are the most important factors determining the total hardness of the waters (Kannan and Joseph, 2010).

Table 4.4. Classifications of water hardness

TH (mg l^{-1} $CaCO_3$)	Type
< 50	Soft
50 – 150	Moderately hard
150 – 300	hard
> 300	Very hard

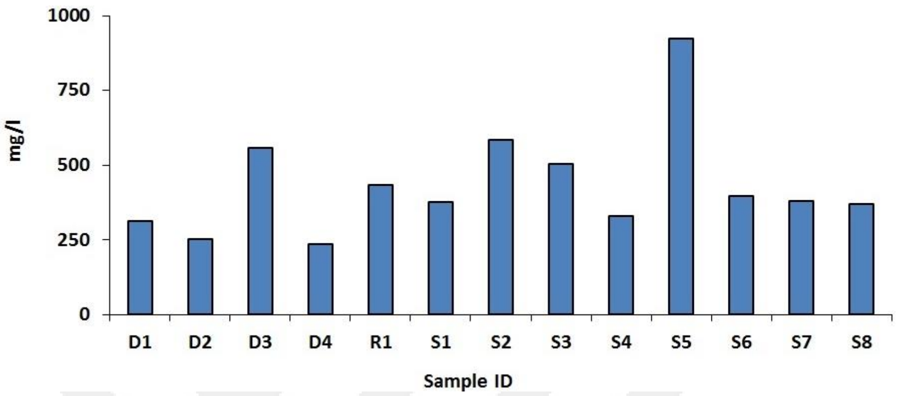

Figure 4.10. Total hardness values of water samples

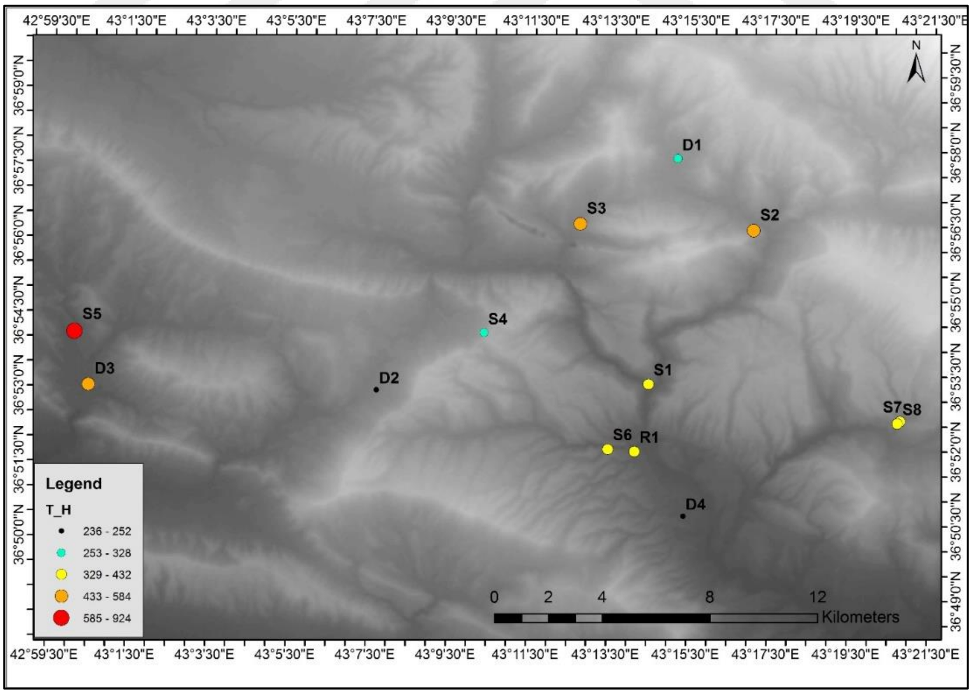

Figure 4.11. Spatial distribution of total hardness values within the study area

4.8. Turbidity

Turbidity, an expression of the clarity of water, increases with the increase in the amount of suspended solids in the water. The turbidity of the rivers results from the presence of sediments added by erosion (US EPA, 1997). Water body with low turbidity values is generally described as clean water. The turbidity of a water is commonly measured in Nephelometric Turbidity Units (NTU). Waters with NTU values less than 5 are often perceived as acceptable. The distribution of NTU values in the study area was shown in Table 4.1, Figure 4.12 and Figure 4.13. Turbidity values of water samples ranged between 0.3 and 2.5 NTU. The highest NTU values were 2.2 and 2.5 recorded in R1 (river) and S5 (Sulphur spring) water sources, respectively.

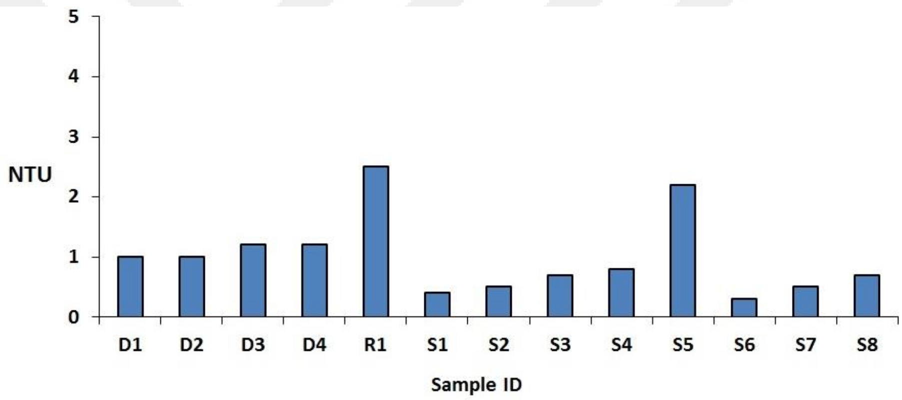

Figure 4.12. Turbidity values of water samples

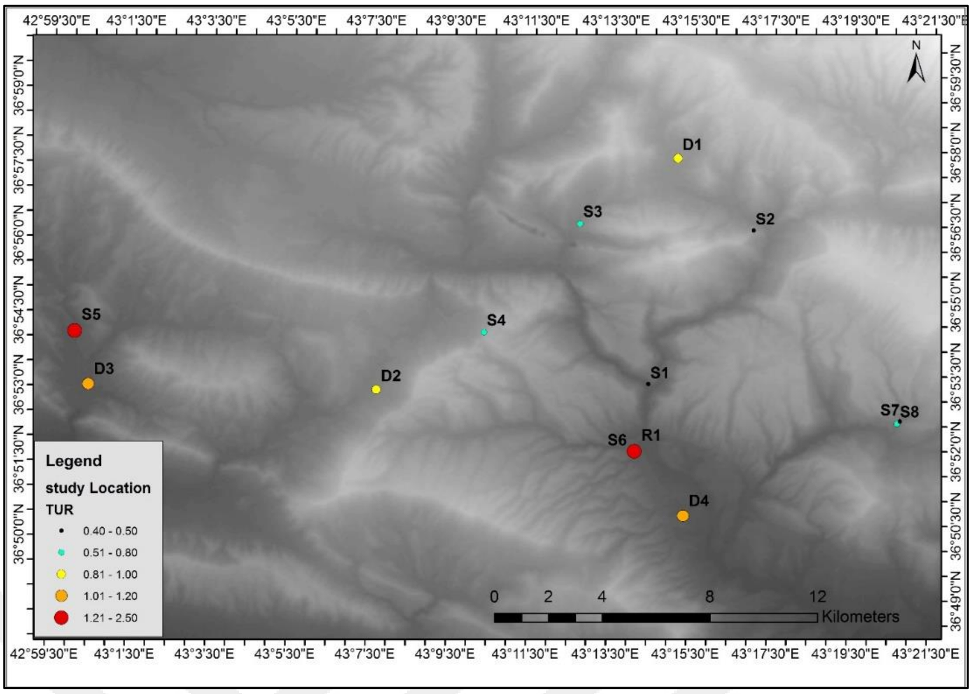

Figure 4.13. Spatial distribution of turbidity values within the study area

4.9. Major Cations

4.9.1. Calcium (Ca^{2+}) Concentration of Water Samples

Calcium, mostly found in sedimentary rocks, is the most common alkaline earth metal found in water. The main source of calcium is derived from chemical weathering of rocks in minerals containing this ion such as sedimentary rock, limestone, dolomite, gypsum, aragonite, feldspar, amphibole and pyroxene (Hem, 1985). Iraqi waters are rich in calcium, which can be attributed to the existence of sedimentary rocks (Rezoska, 1980; Mohammed and Bamerni, 2019).

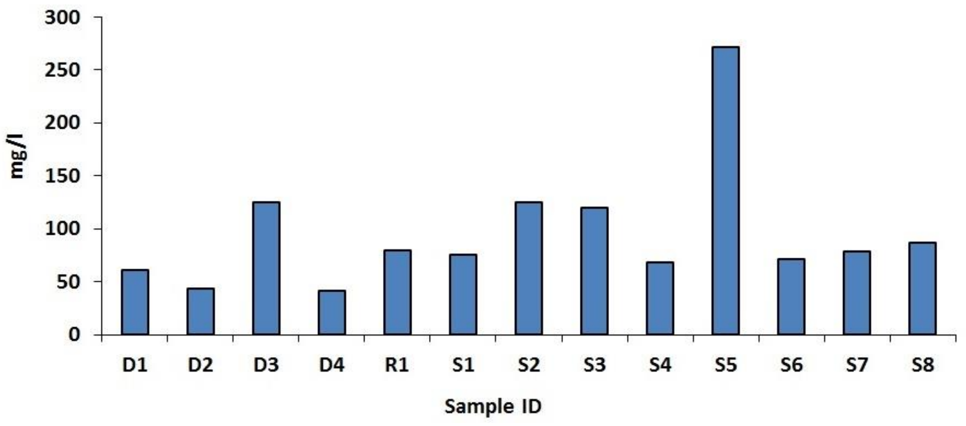

Figure 4.14. Concentration of calcium ions in water samples

The Ca^{2+} concentrations of water samples were shown in Table 4.1 and Figure 4.14. Spatial distribution of Ca^{2+} ion in study area were presented in Figure 4.15. The concentrations of Ca^{2+} ions ranged from 41.6 and 272 mg L^{-1} with only one sample (S5) above the limits of WHO (2008) standard. Calcium in waters of the study area might have derived from the weathering of carbonate and evaporate minerals (Rezoska, 1980).

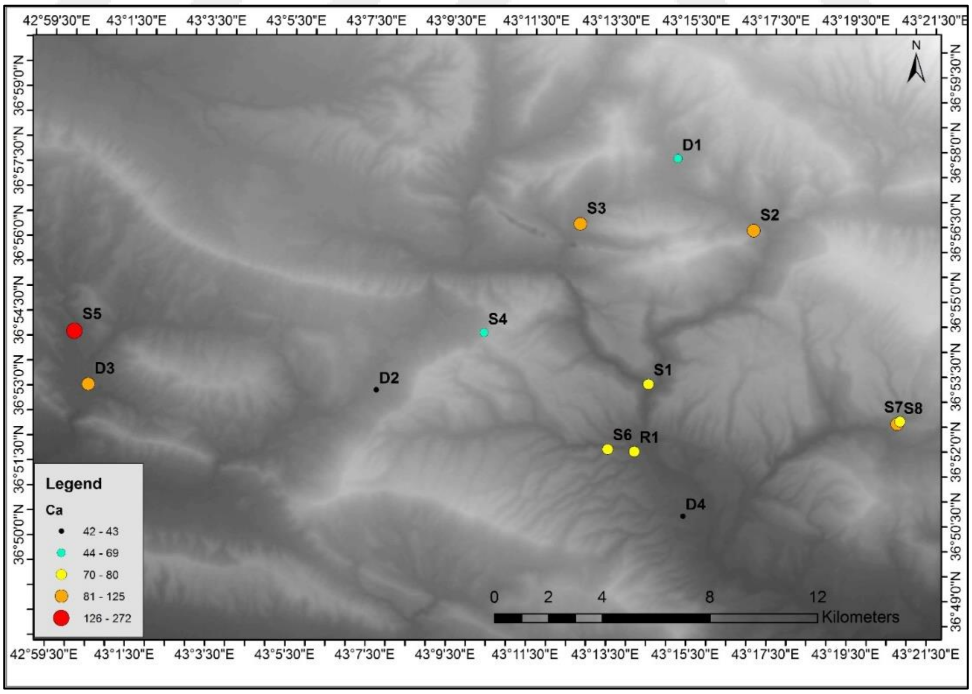

Figure 4.15. Spatial distribution of calcium ions within the study area

4.9.2. Magnesium (Mg^{2+}) Concentration of Water Samples

Along with calcium, the most common alkali element in natural water sources is magnesium. Magnesium constitutes 2.1% by weight of the earth's crust. The most abundant minerals in the earth's crust are dolomite and clay minerals (Collins, 1975). The fertilizers and municipal wastewaters are also the source of Mg^{2+} in water resources. The quantity of magnesium is less than calcium in natural water because of the solubility of dolomite, which is slower than calcite and limestone (Al-Manmi, 2002).

The Mg^{2+} concentration of water samples was shown in Table 4.1 and Figure 4.16 and spatial distribution was presented in Figure 4.17. The content of Mg was between 32.2 and 76 mg/l, which is below the allowable limit of 150 mg/l for drinking water (WHO, 2008). The importance of Mg, which is also present in water, in the activation of the cells involved in enzyme activation is very vital (Garg *et al*., 2009). The geochemistry of the rock types in the study area may have an influence on the concentration of Mg in water samples.

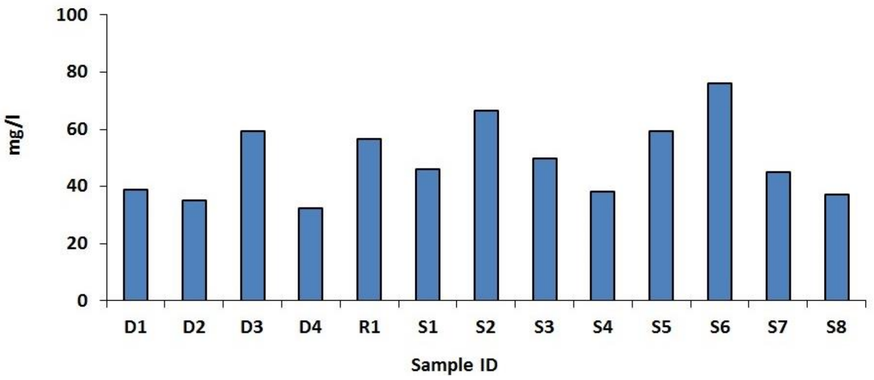

Figure 4.16. Concentration of magnesium ions in water samples

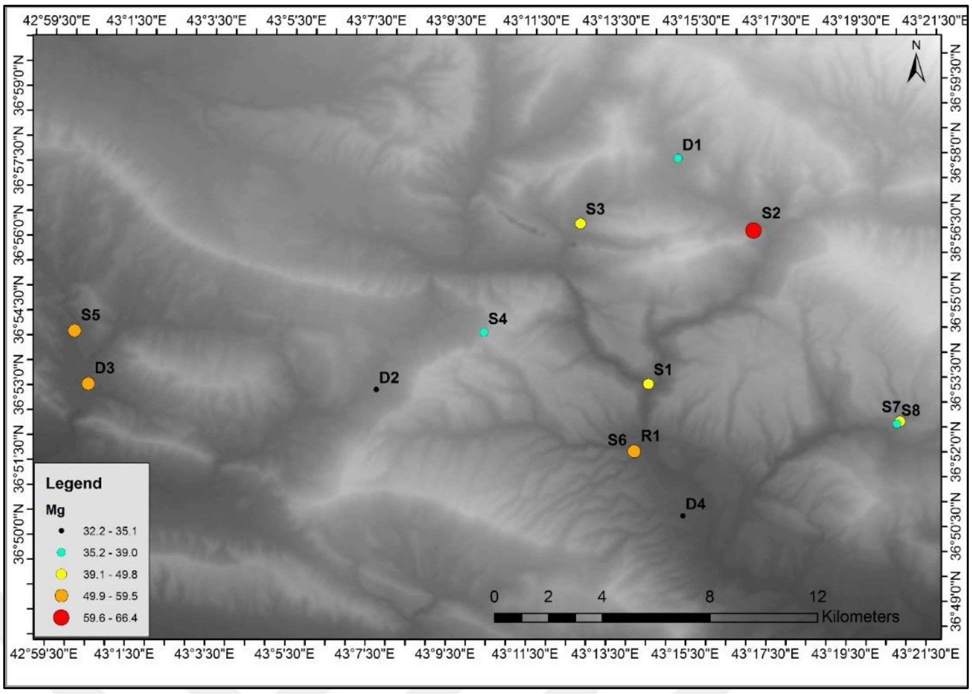

Figure 4.17. Spatial distribution of magnesium ions within the study area

4.9.3. Sodium (Na^+) Concentration of Water Samples

Sodium, which is less abundant than calcium and magnesium, is the most abundant element in the alkali metal group of the periodic table. The main source of sodium concentration in natural waters is the sodium ions released during the weathering of feldspar minerals. Dissolution of halite is the most important source of sodium ion in arid regions. It is reported that a significant amount of sodium ion is released during the decomposition of clay minerals (Davis and DeWiest, 1966). Although the sodium concentration of magmatic rocks is higher than potassium, the concentration of sodium in sediments is lower than potassium (Faure, 1998). Due to the human effect, a significant amount of sodium is added to groundwater and groundwater.

The Na^+ concentrations of water samples were given in Table 4.1 and Figure 4.18, and spatial distribution was shown in Figure 4.19. The Na^+ concentration of water samples ranged between 2.6 and 109 mg l^{-1}. The variation in Na^+ concentration may be related to geological formation and the nature of resources. The highest Na^+ concentration was recorded in Sulphur spring (S5). However, for aesthetic reason, none of the samples was higher than the permissible value of 200 mg/l (WHO, 2008).

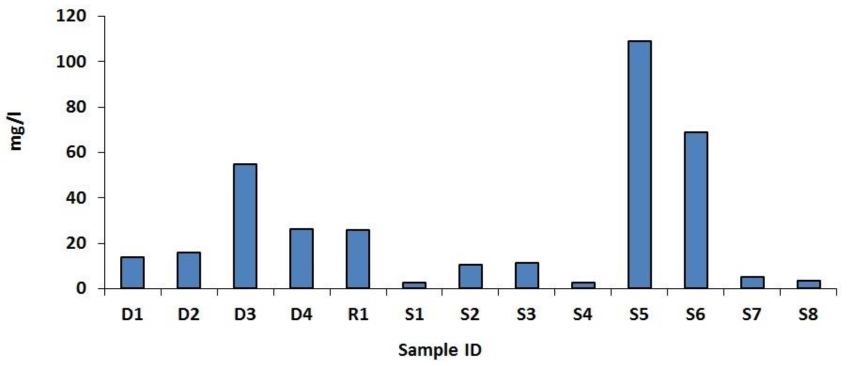

Figure 4.18. The concentration of sodium ions in water samples

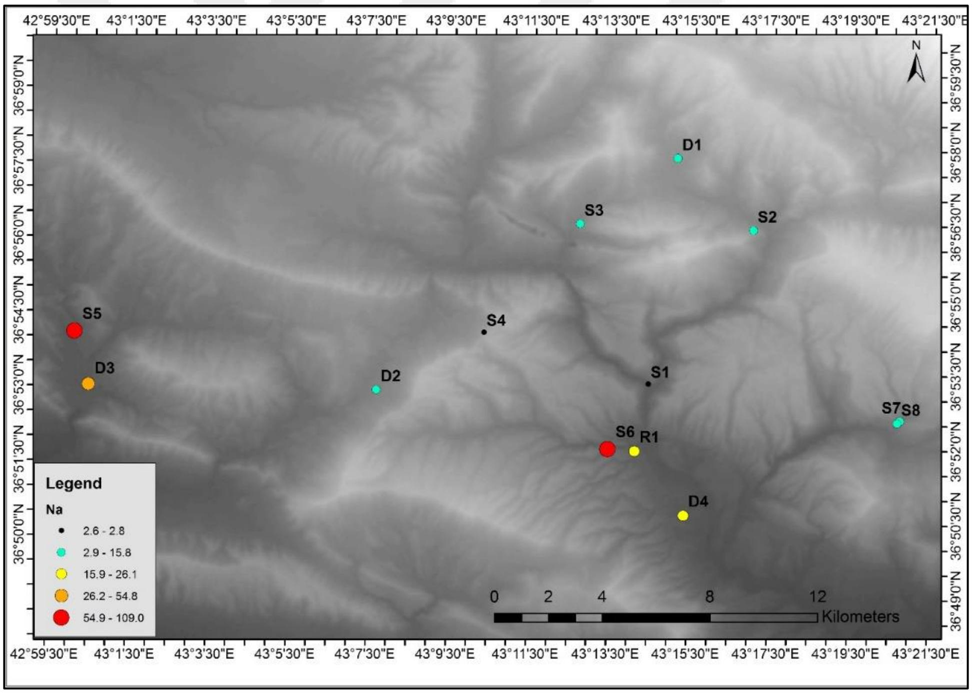

Figure 4.19. Spatial distribution of sodium ions within the study area

4.9.4. Potassium (K^+) Concentration of Water Samples

Potassium at higher concentrations in sedimentary rocks compared to sodium is found at lower concentrations in magmatic rocks. Potassium, which is commonly found in minerals such as feldspar and orthoclase in magmatic and metamorphic rocks, is released into the environment by decomposition of these minerals.

The concentration of potassium in natural waters, which is almost similar to sodium in the earth's crust, is only one-tenth of sodium (Faure, 1998). The main reasons for lower concentration in water are the reintroduction of potassium released by decomposition into some minerals and the more difficult decomposition of potassium-containing minerals compared to sodium-containing ones (Shwani, 2008). The (K^+) concentrations and distribution of water samples were presented in Table 4.1, Figure 4.20 and Figure 4.21, respectively. Potassium concentration of water samples ranged from 0.3 to 9.3 mg l^{-1} which are below the permissible drinking water standard of 12 mg l^{-1} (WHO, 2008).

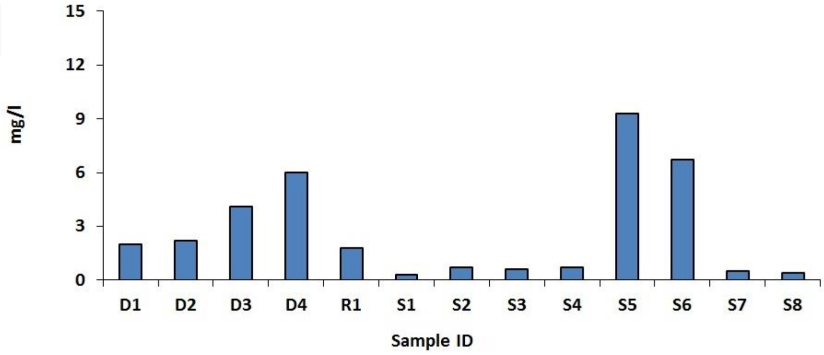

Figure 4.20. The concentration of potassium ion in water samples

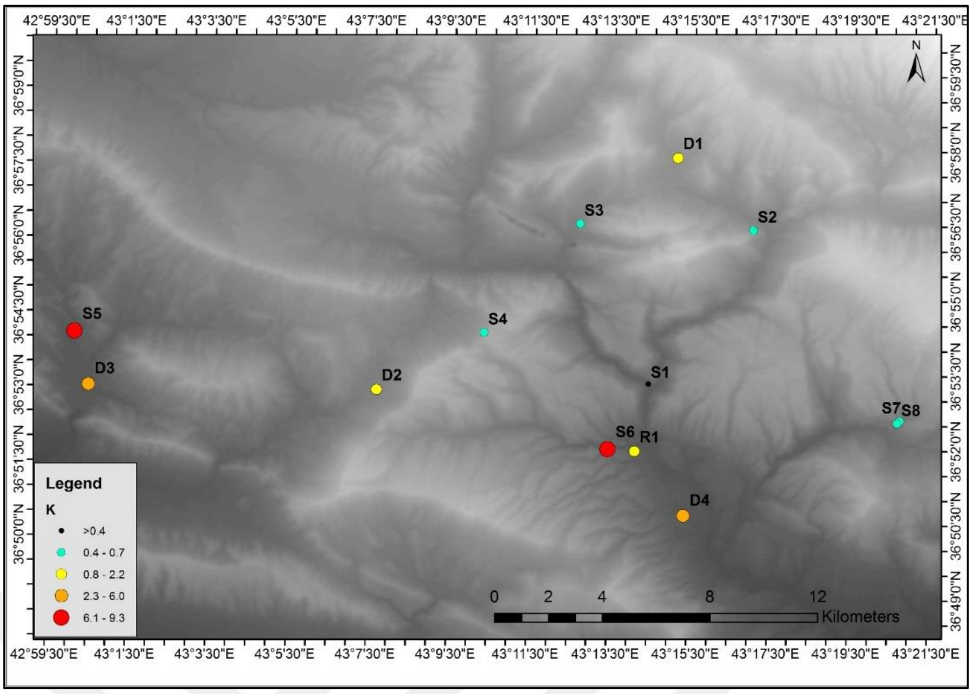

Figure 4.21. Spatial distribution of potassium ions within the study area

4.10. Major Anions

4.10.1. Bicarbonate (HCO_3^-) Concentrations of Water Samples

The main sources of bicarbonate ions in natural waters are carbon dioxide in soil and atmosphere, dissolution of rocks and minerals containing carbonates (Langmuir, 1997) and decomposition products of silicate minerals. Bicarbonate is the source of water alkalinity which is the capacity of water to neutralize H^+ ions capacity (Kiely, 1997). The HCO_3^- concentrations of water samples were presented in Table 4.1 and Figure 4.22, and the spatial distribution of HCO_3^- was shown in Figure 4.23.

The concentration of HCO_3^- ranged between 192.8 and 490.4 mgl^{-1}. Dissolving through rainwater of limestone and dolomite, precipitation, and groundwater movement were the main reasons for high HCO_3^- level in the area of interest.

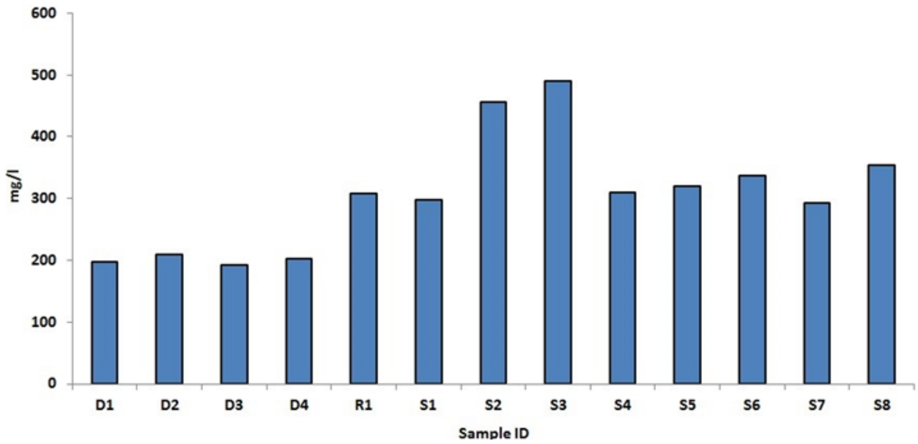

Figure 4.22. The concentration of bicarbonate ions in water samples

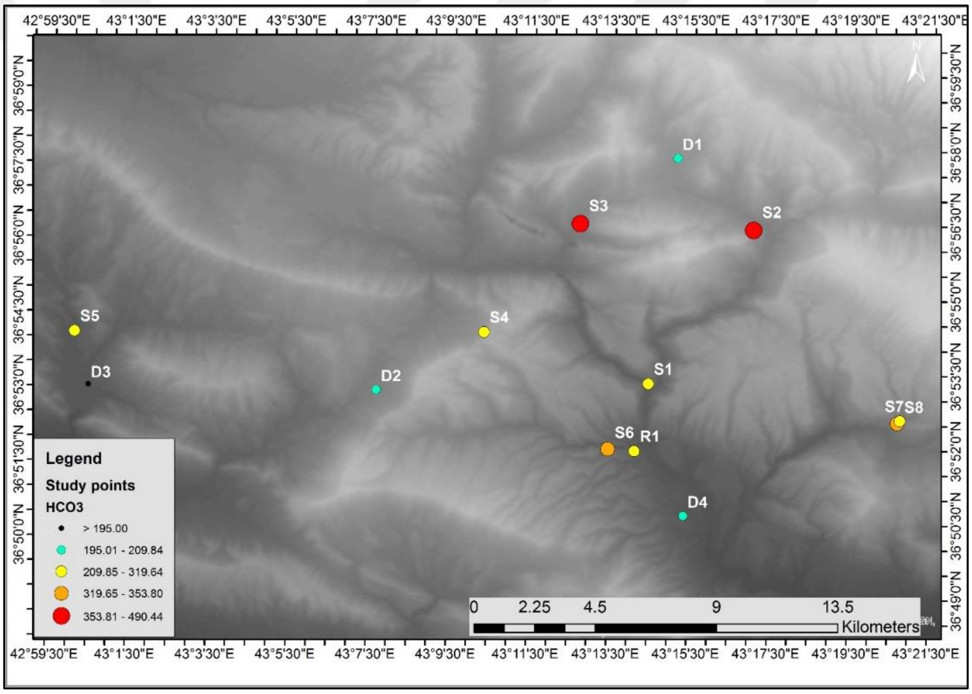

Figure 4.23. Spatial distribution of bicarbonate ions within the study area

4.10.2. Sulphate (SO_4^{2-}) Concentrations of Water Samples

The natural sources of sulfate ions are of the geological structures mainly from dissolution of evaporated rocks (the gypsum and anhydrite), or may be resulted from inorganic fertilizers, detergents, pesticides and tannin (Appelo and Postma, 1999; WHO, 2006). Increased sulphate concentration in water can lead to a significant change in taste of water. In addition, diarrhea may occur in those who are not accustomed to water with a high sulfate content. The SO_4^{2-} concentration of water samples were given in Table 4.1 and Figure 4.24, and spatial variation was shown in Figure 4.25.

Large spatial variation of the SO_4^{2-} concentration can be noticed and the values ranged between 10.2 and 601.8 mg/l. The highest level of SO_4^{2-} was recorded in the sulfur spring (S5) which is mainly used for therapeutic purposes (skin diseases, rheumatism, etc.) by local and regional people (Mizzouri, 2007). For potable reason, only two of the samples (D3 and S5) had values exceeding the guideline of 250 mg/l prescribed by WHO (2008). The main sources of SO_4^{2-} in D3 (Duhok dam) is the sulfate springs around the dam including S5.

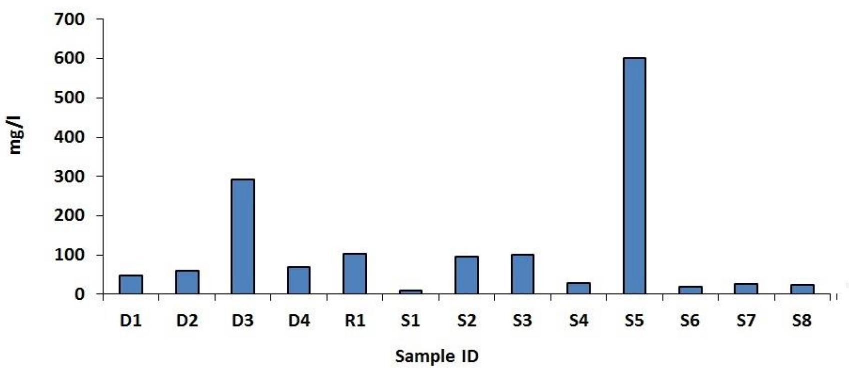

Figure 4.24. Concentration of sulfate ions in water samples

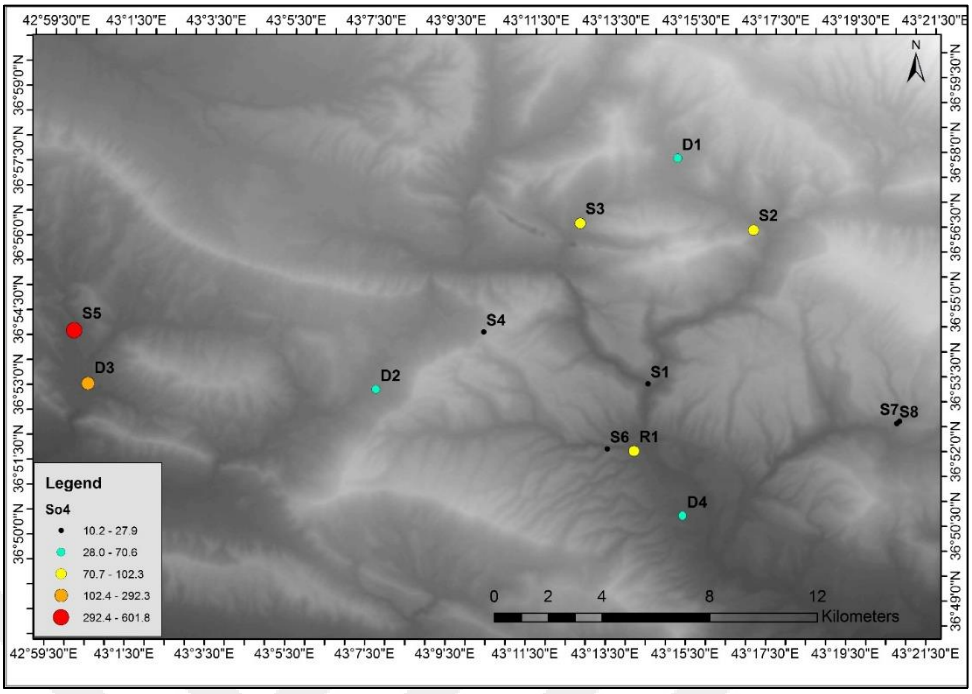

Figure 4.25. Spatial distribution of sulfate ions within the study area

Limestone minerals may produce level of sulfate up to 800 mg/l (Kiely, 1997). The high sulfate content of water samples is mainly due to characteristics of the geological formation. Quaternary and cretaceous aquifers within the study area produce several sulfur springs which containing large quantities of sulfate and released to the Duhok dam (Mizzouri, 2007).

4.10.3. Chloride (Cl^-) Concentration of Water Samples

The majority of chlorine ions in the water resources are caused by the decomposition of chlorine trapped in marine sediments, weathering of halite and similar minerals, transport from the atmosphere to the earth surface with rain and snow, and finally as a dry fallout in the arid regions (Pelmuleni *et al.*, 2002). In addition, anthropogenic activities could also increase the level of chloride in water (Drever, 1997).

Increasing chloride concentration in drinking water leads to salty taste of water. In addition, diarrhea may occur in a person drinking high chlorine content (Bhardwaj and Singh, 2011). The chloride concentration of water in the study area varied from 10 to 228 mg/L (Table 4.1 and Figure 4.26). The threshold concentration of Cl^- for drinking water has been reported as 200 mg/l (WHO, 2008). The chloride concentrations of water samples were lower than the threshold value except the sulfur spring S5 which is not suitable for drinking purposes.

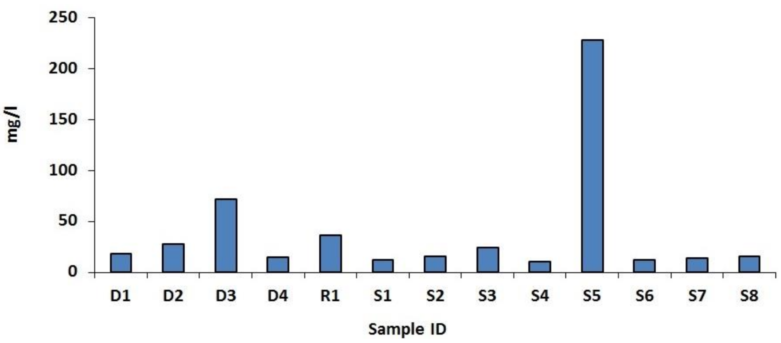

Figure 4.26. The concentration of chloride ions in water samples

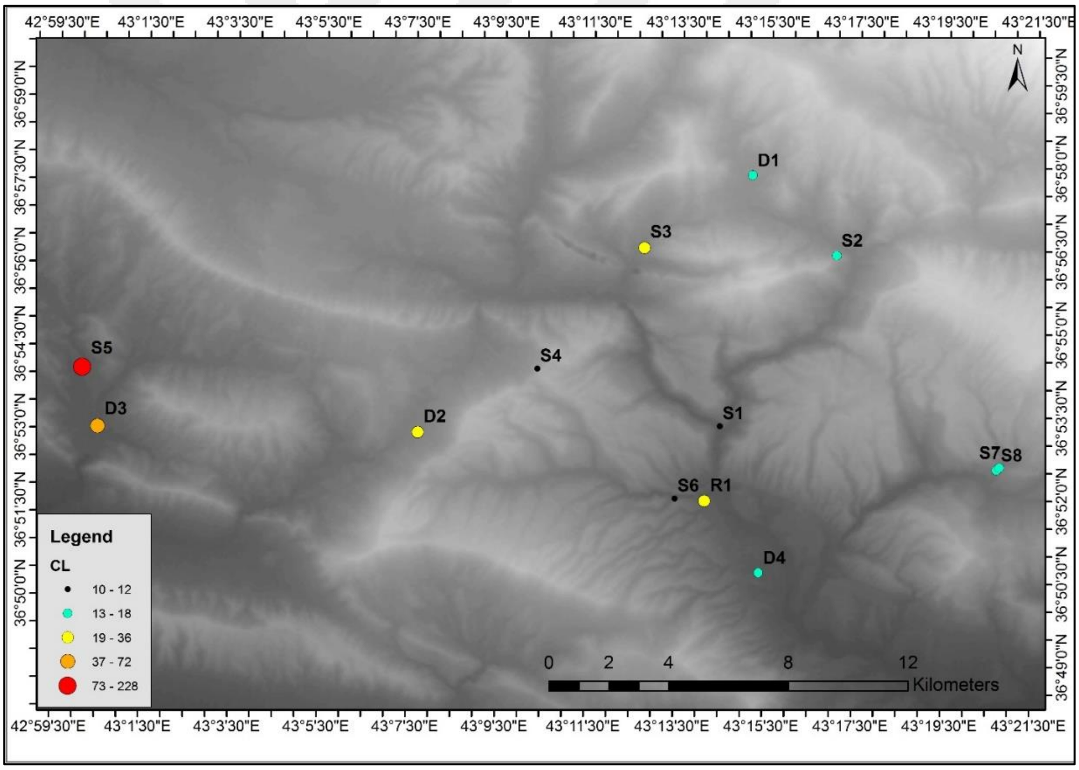

Figure 4.27. Spatial distribution of chloride ions within the study area

The distribution of Cl^{-} in the area of interest was shown in Figure 4.27. The primary source of chloride in the study area is from the geological formation and secondary are from fertilizers and anthropogenic activities.

4.10.4. Nitrate (NO_3^-) Concentration of Water Samples

Nitrate, an essential nutrient for plants, is an important component of the nitrogen cycle. Nitrate is added to surface and subsurface waters, especially with excessive application of nitrogenous fertilizers, oxidation of nitrogen sources in human and animal feces (WHO, 2011). Nitrate, which is normally less than 1 mg l^{-1} in natural conditions, can reach higher concentrations due to the excessive use of inorganic fertilizers and animal wastes. Although it is an important nutrient for plants, increasing nitrate concentration in water can cause significant water quality problems. High nitrate concentration may lead to increased plant density in water and eutrophication over time (GOWA, 2009). Higher concentration of NO_3^- causes decreasing oxygen bearing capacity of the blood called "blue-baby syndrome" (Jain *et al*., 2010; Tank and Chandel, 2010).

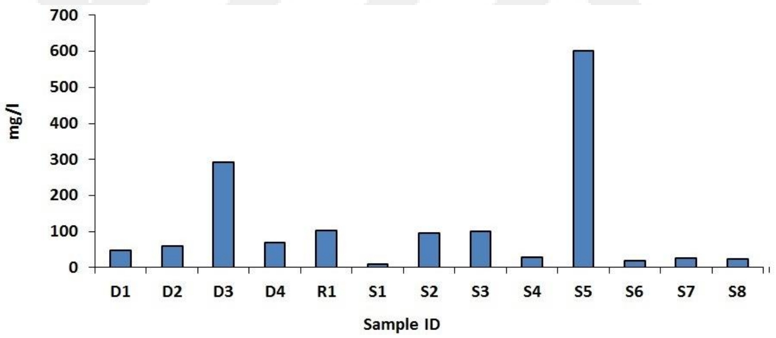

Figure 4.28. Concentration of nitrate ions in water samples

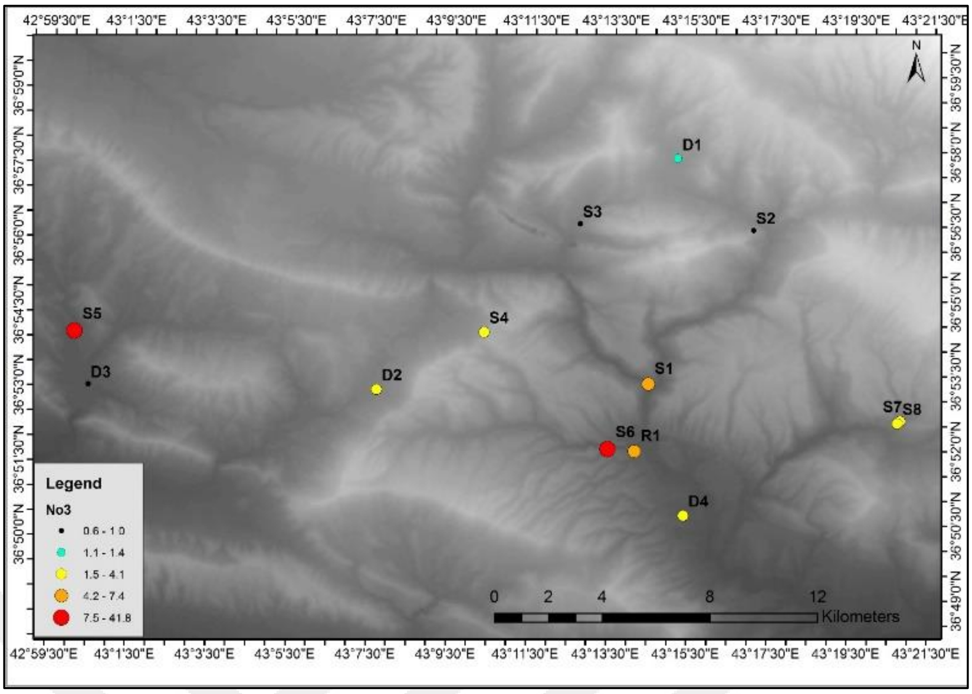

Figure 4.29. Spatial distribution of nitrate ions within the study area

Nitrate concentrations of water samples in the study area ranged from 0.6 to 41.8 mg l^{-1} (Table 4.1 and Figure 4.28). High nitrate concentrations in groundwater have been reported in many parts of Duhok governorate due to the intensive use of nitrogenous fertilizers (Mizzouri, 2007; Mohammed and Bamerni, 2019). Nitrate concentrations of all water samples were within the permissible limit of 50 mg/l (WHO, 2008). Spatial distribution map of nitrate concentration within the study area was shown in Figure 4.29.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The water quality of 13 different water sources has been assessed with respect to the suitability for human consumption. Following conclusion have been derived from the data discussed above;

1. Climatologically, the area of interest in characterized by semi-arid climate and its very suitable for touristic various activities.

2. GIS technique has been successfully used and demonstrated for evaluation of water quality of the study area. The Arc Map model has been found very suitable in the mapping of water quality parameters and showing good or bad quality based on concentration of studied parameters.

3. The analytical results of water samples for physicochemical parameter were compared to WHO standards for drinking water quality, it brought into light that pH values of the water samples are slightly alkaline. Water samples of the most locations were considered to be moderately to highly mineralized water based on EC and TDS, whereas two water samples that were taken from sulphur spring and Duhok dam were classified as excessively mineralized water. Most of the water samples were classified under the very hard water.

4. The results of cations and anions in water samples inferred that most of the water samples are good for drinking purposes as per WHO standards. Calcium ion was the dominate cation and bicarbonate water the dominate anion, therefore, the calcium-bicarbonate water type was the predominate type.

Sulfur springs contained sufficient amounts of sulfate and other minerals that could be favorable to therapeutic practices.

5. Each of the studied water resources considered good for touristic activities such as swimming, relaxation, therapeutic purposes, and most of the sources considered safe drinking based on water quality parameter analysis.

5.2. Recommendations

The recommendations of the study can bu summarized as follows;

1. GIS is a useful technique to prepare digital thematic layers and maps. The spatial distribution maps prepared are very important outputs in order to have a general knowledge about the distribution of water quality parameters in the regional sense. For this reason, spatial distribution maps should be utilized in the determination of pollutants and contamination points along with the parameters. In addition, spatial distribution maps will contribute to increase their effectiveness in the solutions to the identified problems.

2. In order to determine the suitability of water sources for drinking, some microbiological analyzes with trace elements including heavy metals are also required.

3. In order to avoid major problems in water resources in the future, it is very important that the physical and chemical water quality parameters are made at regular intervals. Therefore, water quality assessments should be repeated at regular intervals.

4. Labeling the water resources in touristic locations for their drinkability and therapeutic usefulness.

5. In areas where industry and agriculture are intensive, the contamination of pollutants into water resources should be monitored for early detection of human-induced pollution. Measures to prevent contamination should be taken before contamination occurs.

6. Promoting water-based tourism, particularly for therapeutic purposes, in the studied area is vital.

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