

**REPUBLIC OF TURKEY  
HARRAN UNIVERSITY  
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES**

**MASTER OF SCIENCE (MSc) THESIS**



**THE EVALUATION OF WATER QUALITY FROM SOME HIGHLANDS BY  
USING DIATOM INDICES IN HIGH MOUNTAIN AREA, ERBIL IRAQ**

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**ŞANLIURFA**

**2020**

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## ÖZET

### Yüksek Lisans Tezi

## YÜKSEK DAĞLIK ALANDA DİATOM ENDEKSLERİ KULLANILARAK BAZI YAYLALARDAN SU KALİTESİ DEĞERLENDİRİLMESİ, ERBİL IRAK

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Yıl: 2020, Sayfa: 76

Bu çalışmada Erbil İlinin Choman bölgesinden 10 çalışma alanı/istasyon seçilmiştir. Su numuneleri Ekim 2018'den Mart 2019'a kadar aylık olarak alınmıştır. Elde edilen sonuçlara göre hava sıcaklığı, 0 - 33.6 °C aralığında oldukça dalgalanmalara sahip olduğunu ortaya koymuştur. Su sıcaklığı 11 – 23.7 °C arasında değişmiştir. Su analizleri sonuçları şu şekilde belirlenmiştir: pH, 7.17 - 7.98 arasında değişmiştir; EC, 143 - 979 µScm-1; arasında değişmiştir; bulanıklık 0.50 - 13.3 NTU arasında değişmiştir; Toplam alkalilik, asitlik ve sertlik sırasıyla 87 - 354.2, 0.37 - 8.28 ve 57 - 301 ppm CaCO<sub>3</sub> arasında belirlenmiştir. Choman bölgesindeki inorganik metalik olmayan özellikleri sonuçları aşağıdadır: Klor, 3.9 - 117.9 mg l-1; sülfat 36-497 ppm, ve nitrat, 0.27-1.2 ppm N-NO<sub>2</sub> ile; fosfat 0-3.56 ppm P-PO<sub>4</sub>; silis 0.23-3.93 ppm Si-SiO<sub>2</sub>-arasında değişmiştir. Öte yandan, diğer metalik katyonların sonuçları şu şekilde çıkmıştır: Ca<sup>2+</sup> 12-120 ppm, Mg<sup>2+</sup> 7 - 43 ppm. Kalsiyum bütün su kaynaklarında magnezyumdan baskındır. Kaynak suyu sahalarındaki Çözünmüş oksijen (DO) muhtevasına gelince, konsantrasyon 0.92 ile 10.5 ppm arasında değişmiştir. 1. ve 8., istasyonlar ortalama 7 ppm'den daha yüksek DO düzeyleriyle karakterize edilmiştir. Beş günlük Biyolojik Oksijen İhtiyacı (BOD<sub>5</sub>) sonuçları 1,58 - 4,14 ppm arasında değişmiştir. 2. ve 3. istasyonlar incelenen dönemde ortalama 0.77 ve 0.66 ppm değerindeki düşük BOD<sub>5</sub> seviyeleri ile karakterize edildiğinden diğer çalışma alanları arasında iyi su kalitesi olarak kabul edilmiştir. Morfolojik olarak toplam 87 diatom türü tanımlandı ve bu türler 8 takım, 10 aile ve 30 cins ile temsil edilmiştir. Naviculaceae takımı, Navicula cinsinden 10 tür ve toplamda 25 tür ile ilk sırada yer almıştır. Fragilariaceae takımı, Fragilaria cinsinden 9 ve Synedra cinsinden 6 tür olmak üzere 19 tür ile ikinci sırada yer almaktadır. Toplam diatom sayısı 23.35 ila 491.3 hücre, X 10<sup>3</sup> l-1, ilkbahar ve sonbahar olmak üzere yılda iki yükseliş/pik yaptıkları gözlenmiştir. Çalışma süresince çeşitlilik endeksinin değeri 1.09 ile 2.02 arasında değişmiş ve hiçbir zaman 1.74 değerinin altına düşmemiştir, bu da Choman bölgesindeki tüm kaynak sularının iyi ile çok iyi diatom tür çeşitliliği ve iyi su kalitesine sahip olduklarını göstermiştir.

**ANAHTAR KELİMELELER:** Su kalitesi, Diatom indeksleri, Su kaynakları, Choman, Erbil, Irak.

## ABSTRACT

MSc Thesis

### THE EVALUATION OF WATER QUALITY FROM SOME HIGHLANDS BY USING DIATOM INDICES IN HIGH MOUNTAIN AREA, ERBIL IRAQ

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Year: 2020, Page: 76

In the present study, ten spring water sites were selected in Choman district within Erbil province, Iraq. Water samples were taken monthly from October 2018 to March 2019. The results revealed a wide range of variations in air temperature, ranging from 0 to 33.6 °C. The temperature of the water ranged from 11 to 23.7 °C. The findings of the study of the spring water samples revealed the following records: The pH value was 7.17-7.98; Electrical Conductivity - EC ranged from 143 - 979  $\mu\text{S. cm}^{-1}$ ; turbidity levels was 0.50 – 13.3 Nephelometric Turbidity Unit- NTU; Alkalinity, acidity and hardness ranged 87-354.2, 0.37–8.28, and 57-301 mg  $\text{CaCO}_3\text{l}^{-1}$  respectively. Analysis of inorganic non-metallic properties revealed the following records in Choman area:  $\text{Cl}^{-}$  ranged from 3.9 – 117.9 mg  $\text{l}^{-1}$ ; sulfate and nitrate were ranged from 36-497 mg  $\text{l}^{-1}$ , 0.27-1.2 mg  $\text{N-NO}_2\text{l}^{-1}$ ;  $\text{PO}_4^{3-}$  ranged from 0-3.56 mg  $\text{P-PO}_4\text{l}^{-1}$ ;  $\text{SiO}_2$ - ranged from 0.23-3.93 mg  $\text{Si-SiO}_2\text{-l}^{-1}$ . On the other hand, results of metals revealed the following records:  $\text{Ca}^{2+}$  was ranged from 12 -120 mg  $\text{l}^{-1}$ , while  $\text{Mg}^{2+}$  ranged from 7 - 43 mg  $\text{l}^{-1}$ . Calcium dominated over magnesium in all spring sites. Regarding the DO content in spring water sites, the concentration fluctuated between 0.92 and 10.5 mg  $\text{l}^{-1}$ . Sites 1 and 8 characterized by high levels of DO with mean of greater than 7 mg  $\text{l}^{-1}$ . The results of five-day Biological Oxygen Demand (BOD5) ranged from 1.58 – 4.14 mg  $\text{l}^{-1}$ . Sites 2 and 3 characterized by low levels of BOD5 with mean value 0.77 and 0.66 mg  $\text{l}^{-1}$  during the studied period, thus they were considered as good water quality among other studied sites. Phycologically, a total of 87 diatom species was identified and represented by 8 orders, 10 families and 30 genera. Naviculaceae was placed in the first ranked order among the total identified diatoms represented by 25 species, dominated by Navicula with 10 species. Fragilariaceae with 19 species placed in the second ranked order, dominated by Fragilaria with 9 species and Synedra with 6 species. Total number of diatoms ranged from 23.35 to 491.3 cells  $\times 10^3\text{l}^{-1}$  with two annual peaks, the spring peak of growth and the autumn peak. The value of diversity index during the period of the study were ranged from 1.09 to 2.02 and never fell below the value of one with an overall mean of 1.74, which means that all spring sites in Choman district characterized good to very good diatom species diversity and indicate good water quality in the study area.

**KEY WORDS:** Water quality, Diatom indices, Water springs, Choman, Erbil, Iraq.

## ACKNOWLEDGMENTS

First of all, I thank (Allah) for his blessing, which helped me to successfully complete and pass out this report.

I'd like to thank my supervisor Assist. Prof. Dr. Göksal SEZEN throughout this project for his patience, support and guidance. My thanks and appreciation go to the Ministry of Higher Education and Scientific Research, the presidency of Salahaddin University-Erbil, the dean of Education College and the head of Department of Biology for their facilities during the research. I am also grateful to Dr. Khattab Shekhany in Ministry of Higher Education and Scientific Research and Dr. Jawher Fatah in Salahaddin University-Erbil for their facilities in Administrative matters prior to begin this study.

Furthermore I would like to address my cordial thanks for joint efforts on the field to Dr. Abdulla Aziz for his encouragement and supporting during the study. Last but not least, I convey to my family my heartfelt appreciation for their spiritual support, pleasure, compassion, tenderness and motivation. Eventually, I would like to thank all those who helped me do my work.

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## LIST OF SYMBOL AND ABBRIVATIONS

°C	Degrees Celsius
Minute	'
Degree	°
EC	Electrical conductivity
km <sup>2</sup>	Kilometre kare
km <sup>3</sup>	Cubic kilometers
l / s	Liter / second
m / s	Meters / second
m	Meter
m <sup>3</sup> / s	Cubic meters / second
m <sup>3</sup>	cubic meters
mg	Miligram
mg/l	Miligram litre (ppm)
mm / year	Milimetre / year
ppb	Parts per billion
ppm	Parts per million
Sp	Kind
Subsp	Subtype
Syn	Synonyms, same, equal
Var	Varyete
μ veyā μm	Micron or micronmeter
μg/l	Microgram liter (ppb)
μS/cm	Micro Siemens / centimeter
BOD5	Biological Oxygen Demand
DO	Dissolved Oxygen
COD	Chemical Oxygen Deman
WHO	World Health Organization
D.W	Distled Water
M a s l	Meter above sea level
GPS	Global Position Satellite
IPS	Pollution Sensevity Index

**1. INTRODUCTION**

Groundwater quality depends on the recharge water structure, the interactions between water and soil, soil-gas and rocks with unsaturated area, and the residence period and reactions within the aquifer. Significant differences in water quality can therefore be observed, particularly where rocks with different compositions and solubility exist (Bartram and Balance, 1996). In addition to this production, death and decomposition of aquatic plants and algae can influence the concentration of oxidation / reduction-sensitive nutrients, pH, carbonates, dissolved oxygen and other chemicals (Leggett et. al. 2001).

Environmental pollution has drawn great attention globally with the growing use of water resources. Accordingly, it is necessary to evaluate water quality for the preservation and regeneration of aquatic ecosystems, especially freshwaters, which are vital to drinking water supply and economic progress (Wu et al. 2019). Human activities endanger the value of natural resources throughout the globe, which is one of the major environmental issues (Çelekli et al. 2019). A major problem associated with water quality is Nutrient enrichment. Significant link between Diatoms with nutrient concentrations were exist in all aquatic biota and used in a wide range as trophic and weakness index (Charles, et al. 2019).

One of the key methods in the evaluation of water quality is to determine the environmental condition of water bodies based on physical and chemical parameters of the environment (Chen, et al. 2018). Use water's physical and chemical properties to determine water quality gives a good understanding of a water body's health, efficiency, and conservation (Tyagi et al. 2013). This form, however, provides a limited understanding of water conditions. The use of biological surveillance, on the other side, provides a direct indicator of ecological stability by using biota's reaction to shifts in environmental variables (Çelekli et al. 2019).

Because algae are good indicators of water characteristics, they are used to track

water quality. Between algae, diatoms have the benefit that they can be easily identified at species level without the need for crops and are very easy to collect and store due to their strong frustula. Many diatom species are known for their ecological requirements and therefore many diatom-based water quality indexes have been developed (Martin & Fernansez, 2012).

Diatoms are a broad phytobenthos community and can be harvested from almost all aquatic habitats at times of the year. Diatoms are a varied group of 10,000 species of algae (Round, 1991). Diatom assemblies in diverse ecosystems respond quickly and sensitively to changes in the environment and are ideal water bodies' ecological markers. The use of benthic diatoms for measurements of water quality levels is not a new subject and has been in use since the 1900s (Almeida et al., 2014).

Several physical, chemical and biological factors determine the water quality in an aquatic ecosystem. A variety of approaches for evaluating water quality data vary depending on knowledge targets, specimen volume, and sampling region scale (Alobaidy, et al., 2010). Because of short generation and wide distribution, diatom assemblages are widely used as indicators of water quality in many countries. Diatom indices are the most common tool to summarize the information provided by the diatom assemblages (Luu and Duc, 2018). Diatoms have several benefits as bio indicators: as a species they are omnipresent and their diversity spreads over most of the marine environment's environmental conditions; benthic populations incorporate water quality differences in a particular location; testing and preparation techniques are relatively straightforward and preparations can be maintained indefinitely; and with some practice, it is practical to do so (Mishra et al., 2019).

The purpose of this study is:

1. Using 10 spring water sites in Choman district, Erbil to assess the quality of ground water sources in the area.

2. The assessment will be done using the most important physical and chemical properties of water quality include pH, Electrical Conductivity-EC, Total Dissolved Solids-TDS, Turbidity, Chloride, Alkalinity, Hardness, Nitrate, Phosphorus, Dissolved oxygen, Biochemical oxygen demand.

3. The study also aimed to define the biological evaluation of water quality using diatom assemblages and diatom species ecological preferences.



## **2. LITERATURE REVIEW**

### **2.1. Phycolimnological Study in Iraq**

In Iraq from the last five decades in previous century the beginning of the ecological and phycological studies in inland waters were appeared and grew with universities and scientific research centers development, hence, from starting in 1964s onward, many papers and thesis have been published (Abdin, et.al. 1957, Al-Kaisi 1964, and 1970). However, many works have been carried out on algal and ecological studies in southern marshes such as that of Arntd and Al-Saadi (1975), Hinton and Maulood (1980), Al-Saboonchi, et.al. (1982), Al-Lami (1986), Al-Musawi, et.al. (1988), Maulood and Al-Saadi (1990), Al-Saadi and Al-Lami (1992), and Al-Saadi, et.al. (1996). Furthermore, a great number of investigations have been done on the effect of some ecological factors on algal abundance, and their distribution in Shatt Al-Arab estuaries area: Hameed (1977), Al-Saadi, et.al. (1979), Saad and Antoine (1982), Antoine and Al-Saadi (1982), and Al-Saadi and Schiewer (1993).

Finally, and as reviewed by Aziz (1997) five check lists of the algae from Iraq were published viz., firstly by Islam and Hameed (1985) involving notes on limnological and oceanographic studies in Iraq from 1947-1982 of which 610 algal taxa are presented, second check list by Hinton and Maulood (1983) including a total of 1296 species and varieties with notes on their habitats. Al-Saboonchi and Al-Saadi (1988) have made a third check list related to Shatt al-Arab River including 415 taxa. Maulood, et.al. (1993) of which 1917 taxa were thought to be recorded in Iraq. The last check list was made by Maulood et al. (2013) identified a total of 2647 algal taxa including Chlorophyceae (788), Cyanophyceae (508), Chrysophyceae (1233), Euglenophyceae (54), Charophyceae (13), Cryptophyceae (5), Pyrrophyceae (32) and Rodophyceae (13).

Phycolimnological studies of algae were performed in various inland aquatic systems including ponds, lakes, springs, and rivers during the last three decades in Iraqi

Kurdistan. Firstly Hirano (1973) based on the samples collected by Botanical Expedition to the Northern Highland of Mesopotamia in 1970, he identified 129 taxa, 86 of which belong to diatoms in 21 stations in Mesopotamia region (Iraq, Iran, Afghanistan and central Asia), of which 6 stations from Iraqi Kurdistan region.

In Iraqi Kurdistan region the second paper was published by Al-Hamed (1976) on the abundance of phytoplankton Dukan reservoir. Then, in Sulaimani province Maulood and Hinton (1978a) conducted an ecological investigation on Sarchinar spring; they stated that the water of this spring was virtually thermostatic with a fluctuation of only  $\pm 1^{\circ}\text{C}$  around the mean temperature of  $17.7^{\circ}\text{C}$ . Maulood and Hinton (1978b) studied the algal flora in thirteen sites of habitats including several springs and ponds within Sulaimani province, they identified 87 species of Cyanophyta and Chlorophyta, and also they indicated that the waters of these areas were found to be alkaline or neutral, with water temperatures often reaching  $30^{\circ}\text{C}$  during summer months.

However, Maulood and Hinton (1979) studied the algal distribution and abundance of phytoplanktonic diatoms with their seasonal variation in stenothermal Sarchinar spring in Sulaimani region, they recorded only 22 diatom species which dominated by *Cymbella affinis*, *Achnanthes amphicephala* and *Cocconeis placentula*. Also Hinton and Maulood (1979a) identified 84 taxa of fresh water diatoms in some streams and springs within Sulaimani province. A comprehensive study of chemical, physical and biological aspects of pollution in Tanjaro River was made by Khamees (1979) in Sulaimani province, he identified 59 diatom species. Ibrahim (1981) studied algal biology and occasional variations of physical and concoction properties of water in 37 springs within Sulaimani province and he identified 180 algal taxa in all springs.

Al-Nimma and Maulood (1992) performed phycological and an ecological study in seven thermal springs in Nineveh province, They found that water temperature ranged from  $18$  to  $40^{\circ}\text{C}$ , while water pH was 6.9 with conductivity between  $950$  to  $3900 \mu\text{S.cm}^{-1}$  what is more the estimation of acidity were extended from  $60$  to  $217 \text{ mg CaCO}_3\text{l}^{-1}$ ,

additionally 33 types of algal taxa have been recognized, five species were enlisted as another augmentation to the algal verdure of Iraq, the populace comprise from 66% blue-green growth, while diatoms constitute 27%, and just 3 taxa of the green growth has been distinguished here.

A limnological study was conducted by Rasheed (1994) in Erbil province on some water systems comprising stream, impoundments, springs, and kahreezes. Al-Barzingy (1995) recognized 198 taxa, belong to Cyanophyta and Chlorophyta with their seasonal variation and periodicity, in different water systems.

Aziz (1997) made an exhaustive phycolimnological study along the Rawanduze waterway in various territories including springs, streams and rivers on algal bounty, with their dissemination and periodicities. A total of 1016 taxa have been identified, comprising 483, 238, 229 and 66 species of Bacillariophyceae, Chlorophyceae, Cyanophyceae and other classes respectively.

Ali (2002) performed a phycological and ecological analysis on two wastewater canals in the province of Erbil, defining some physicochemical causes of sewage water, describing a total of 128 taxa in addition to the approximate productivity of phytoplankton through enumeration. Al-Naqishbandi (2002) conducted a limnological study on the water treatment plant in Efray within Arbil region, the results showed that bacteriologically the water not safe in Bahdinan river Since fecal coliform bacteria are present. A phycolimnological study carried out by Al-Nakshabandi (2002) on Duhok impoundment and its main watershed, he studied four springs among fourteen stations studied, he pointed out that the water in this area was alkaline and very hard, and the total hardness was dominated by calcium hardness.

Aziz (2011) recorded 1341 algal taxa from Iraqi Kurdistan Region (1978-2011). They belong to 8 divisions and 10 classes: Cyanophyceae (326 taxa, 24.51%), Chlorophyceae (358 taxa, 26.92%), Charophyceae (10 taxa, 0.75%), Englenophyceae (21

taxa, 1.58%), Xanthophyceae (30 taxa, 2.26%), Crysophyceae (7 taxa 0.53%), Bacillanophyceae (571 taxa, 42.93%), Pyrrophyceae (10 taxa, 0.75%), Cryptophyceae (3 taxa 0.23%). The works on topography, climate, ecology and limnology were also reviewed in addition to recording these taxa. It was the region's first detailed checklist.

Abdulwahid (2012) performed the first analysis of algal assemblies at six spring sites in the Sherwan Mazn sub-district, with particular reference to the occurrence, distribution and periodicity of the collected samples was investigated. In 3 divisions, a total of 42 species were identified, including 24 Bacillariophyta taxa, 13 Chlorophyta taxa and 5 Cyanophyta taxa. In all springs, the seasonality of algal flora has been increasing. *Oscillatoria*, *Lyngbya*, *Tribonema*, *Vaucheria* and *Spirogyra* were the dominant genus among non-diatoms, while *Navicula*, *Syndra*, *Gomphonema* and *Nitzschia* were among the diatoms.

In the fourth checklist of algae in Iraq, Maulood et al. (2013) identified a total of 2647 algal taxa including Cyanophyceae, Chlorophyceae, Chrysophyceae, Charophyceae, Euglenophyceae, Cryptophyceae, Rodophyceae and Pyrrophyceae with 508, 788, 1233, 13, 54, 5, 13, and 32 respectively. The checklist adds another 334 algal taxa to the algae in Iraq that was previously known. The researchers stated that the checklist will be used as a trustworthy tool for potential algae investigations and will fill the gap in the data on limnology and phycology of the entire Middle East.

Al-Hassany and Hindi (2016) investigated Epiphytic and epipellic algae in Baghdad, Iraq, Al-Dora Site / Tigris River. A quantity of 183 and 154 epiphytic and epipellic algae species were respectively identified. The diatoms, accompanied by Cyanophyceae and Chlorophyceae, were the dominant algal community. Furthermore, between two groups of algae (epiphytic and epipellic) 90 species were exchanged and identified at the site of the research.

Jalil and Alkfagi (2016) studied the ecological and biological properties of

groundwater and river in Al-falluja city-West Iraq. Six genus of algae were diagnosed. Four genus from diatoms algae class (Gomphonema sp, Navicula sp, , Cymbella sp, Fragilaria sp) and one genus from blue-green algae (Oscillatoria sp) and last genus to Euglena algae class (Euglena sp).

In Abdullah Abu-Nadjem Oasis, Al-Dewanyah, Iraq, Al-Asady (2017) researched a qualitative function on algae. On the other hand, in this analysis, about (58) algal taxa were identified, Diatoms (Bacillariophyceae) were the dominant microalgae (58.6%), accompanied by blue greens, Cyanophyceae, (20.6%), while the Chlorophyceae and Charophyceae were the lower in occurrence.

## 2.2. Phycolimnological Study in Turkey and other Countries

Coskun (2018) studied epilithic algae with physical and chemical parameters from three Elazığ Çalgan Creek stations at Fırat University between January and June 2016. The results revealed that a total of 44 taxa of epilithic algae were identified, *Euglenophyta* (1 species), *Cyanophyta* (3 species), *Chlorophyta* (6 species) and *Bacillariophyta* (34 species) were both the most frequently occurring and the most important algae in the epilithic algae community. Almeida, et al. 2014 described the potentials and constraints of the inter calibration of indices using diatoms for assessment of Mediterranean rivers. The results showed that *Achnanthes minutissimum* was the most discriminative species of good ecological status class. *Gomphonema parvulum* and *Nitzschia palea* were the most contributive to Moderate ecological status class.

Tan et al. (2015) analyzed benthic algae assemblies and water quality variables to establish a Benthic Diatom Based Biotic Integrity Index (BD-IBI) for evaluation of the upper Han River (China) aquatic environment. Teittinen, et al. 2015 examined the impact of water chemistry and catchment characteristics on stream diatom populations and evaluated the Pollution Sensitivity Index (IPS) output as a measure of stream water quality across an urban-to-rural gradient in southern Finland. Taş and Yılmaz (2015) identified a total of 113 taxa belong to five separate divisions. Diatoms had the most

diversity of species (74, 65%). *Cyanophyta* (28.25%), *Charophyta* (6.5%), *Chlorophyta* (4.4%) and *Euglenophyta* (1.1%). *Cocconeis pediculus*, *C. placentula*, *Achnantheidium minutissimum.*, *Gomphonema parvulum*, *G. truncatum*, *Cymbella affinis*, *Menisculus navicula*. In the Cimil River, *Nitzschia palea* is a widespread and dominant diatom species. Indicator species have shown that the Cimil Stream's ecological situation is not yet under heavy pressure pollution.

Dalu et al. (2016) studied the effect of land use practices on water quality and benthic diatom population structure and to check the applicability of diatom indices established in other regions of the world to a limited temperate southern African river system. Sampling was performed at eight test sites along the length of the river on four separate occasions.

Tan et al. (2017) thought about the exhibition of 14 broadly connected diatom files in evaluating natural conditions in South East Queensland (SEQ) subtropical rivers in Australia and China's upper Han River. Ateş and Ertan (2017) have established the monthly development and distribution of Pınargözü spring's epilithic algae with physical and chemical water properties. Furthermore, the relationship was evaluated between physico-chemical properties and algae. A total of 97 algae taxa, 80 of which belong to *Bacillariophyta*, 11 belong to *Cyanobacteria*, 5 belong to *Chlorophyta* and 1 belong to *Charophyta*, have been identified. In terms of the number of taxa and individuals, *Bacillariophyta* was found to be more dominant. Based on the epilithic algae and physico-chemical characteristics, Pınargözü spring water was determined to be less polluted. Çelekli et al. (2018) assessed the ecological quality of freshwater bodies in the North Aegean catchment using the trophic index Turkey (TIT), recently developed for Turkish running water assessment.

Çelekli et al. (2019) investigated the distribution of diatom species related to total phosphorus (TP) variation in eight basins to determine trophic weight and indicator values of diatom species, and development of the Trophic Index-Turkey (TIT) for the assessment

of freshwater ecological status. Diatom species such as *Clevamphora ovalis*, *Caloneis amphisbaena*, *Gyrosigma acuminatum*, *Navicula tripunctata*, and *Nitzschia umbonata* showed high trophic weight values, while *Achnanthydium minutissimum*, *Cymbella excisa*, *Didymosphenia geminata*, *Hannaea arcus*, and *Meridion circulare* had low weight trophics. Such results provide additional information on the water bodies' biotic integrity and could be used to establish the TIT for bioassessing aquatic environments, especially running water bodies. Çelekli et al. 2019 evaluated the limno-ecological condition of freshwater ecosystems in the Aras River (Turkey) basin utilizing diatometrics and multivariate evaluation according to the criteria of the European Union Water Framework Directive.

Charles et al. (2019) applied new process of identifying possible nutrient requirements and Biological Condition Gradient (BCG) using diatom assemblies are implemented. Diatom count information was first used to allocate test positions to classes of BCG deficiency (points), and then the intensity of P and N relative to the boundaries between those grades was calculated.

Wood et al. (2019) built up another biomonitoring database using the diatom network to classify the harmful effects of herbicides in rivers and cross-examined 14 waters in the Australian catchment area of the Great Barrier Reef. The new record uses the characteristics of diatom species to group diatoms as either touchy or herbicide tolerant, and measures the division of responsive taxa in an illustration.

First attempt by Celekli (2019) to evaluate the limno-ecological status of freshwater ecosystems in the Aras River (Turkey) using diatom indices and multivariate analysis in accordance with the requirements of the Water Framework Directive of the European Union. The pollution-tolerant taxa such as *Cocconeis placentula*, *Gomphonema parvulum*, *Navicula cryptocephala*, *Navicula trivialis*, and *Tryblionella angustata* characterized all sites.

### 3. MATERIAL and METHODS

#### 3.1. Description of Study Area

Erbil province is located between latitudes 35° 40' and 36° 30' N, and longitudes 43° 20' and 44° 20' E. The area is bordered by two major rivers, the Greater Zab river in the north west and the Lesser Zab river in the south east side. The sources of these two rivers are precipitation, snow melts in winter and spring sources in summer season. The two rivers flow at a much lower elevation than the general topographic level of the area, for this reason ground water is the most important source of water for irrigation and drinking water of most villages (Haddad and Smoor, 1973).

#### 3.1.2. Location and description of the studied sites

A total of 10 spring sites were selected in Choman district within Erbil governorate. The location of spring sites (Plates 1-10, Figure 1 and Table 1) were determined by using Global Positional Satellite (G.P.S.), the aftereffects of X and Y pivot were communicated in UTM framework unit which utilized in a product program (Guide Information 10.0 Expert).

Table 3.1. The location and altitude of 10 spring sites within Erbil province recorded during the studied period.

Sites	Spring local name	Latitude	Longitude	Altitude (m.a.s.l)
Site 1	Kofi Ranginan spring	36°37.698' N	44°51.691' E	1685
Site 2	Tallasew spring	36°41.536' N	44°57.779' E	1253
Site 3	Banan spring	36°44.606' N	44°62.589' E	1302
Site 4	Gorestan spring	36°45.523' N	44°63.709' E	1278
Site 5	Perdok spring	36°47.180' N	44°71.968' E	1135
Site 6	Mam Said spring	36°47.104' N	44°72.907' E	1105
Site 7	Kawarta spring	36°51.306' N	44°76.691' E	1050
Site 8	Mshkor-Qasre spring	36°55.940' N	44°82.728' E	970
Site 9	Walza-Qasre spring	36°54.929' N	44°85.569' E	1225
Site 10	Kani Dino-Qasre spring	36°57.516' N	44°88.369' E	1115



Figure 3.1. Map of Iraq showing the studied area

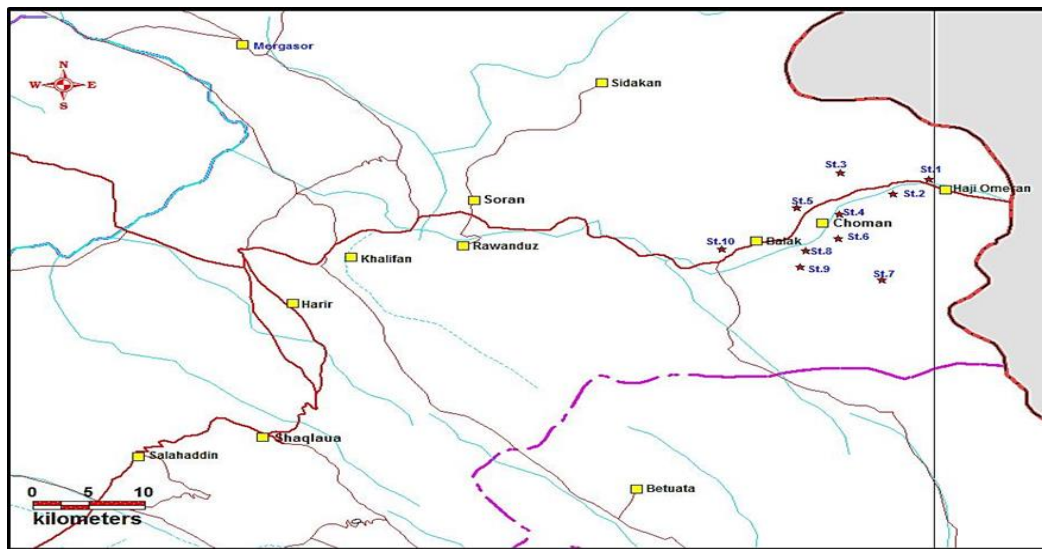


Figure 3.2. Map of the study area shows the sampling locations.

### 3.1.1.1. Kofi ranginan spring

This spring located about 3km north western of Haji Omaran district. The spring was situated in high altitude of 1685 m.a.s.l. The area is surrounded by Salix and Oak trees with grasses.



Figure 3.3. Site (1) kofi ranginan spring.

### 3.1.1.2. Tallasew spring

Situated near Haji Omaran district about 5km. to the south west on the main road from Choman town to Haji Omaran. The soil of Haji Omaran at the Iraqi Iranian border has a dark brown color and the soil is deep, the clay content exceeds 40%. The dominant tree species in the area are *Quercus aegilops*, *Q. infectoria*, and *Q. libani*, while the most common associated plant species are *Pistacia*, *Pyrus*, *Prunus*, *Crakaegus*, and *Ficus hispida*.



Figure 3.4. Site (2) tallasew spring.

#### 3.1.1.3. Banan spring

This spring situated north east about 7km of Choman district. Its located at an altitude of 1302 m.a.s.l. The soil has a dark brown color, with considerable amount of gravel (1–2 cm. in diameter). The dominant tree species in the area are *Quercus aegilops*



Figure 3.5. Site (3) banan spring.

#### 3.1.1.4. Gorestan spring

This site situated about 1 km to the east of Choman district at an altitude of 1278 m.a.s.l. The area is rich in natural pastures and oak and the common plant species are Poplar and Willow.



Figure 3.6. Site (4) gorestan spring.

#### 3.1.1.5. Perdok spring

This spring located North West about 3km from Choman district at an altitude of 1135 m.a.s.l. The soils has a dark brown color and the organic matter contents s between 3 and 5%. The common plant species in the area are Poplar, Willow, *Medicago* sp., *Trifolium* sp., and *Avena* sp.



Figure 3.7. Site (5) perdok spring.

#### 3.1.1.6. Mam said spring

This spring situated south east about 2km from Choman district at an altitude of 1105 m.a.s.l. The common plant species are *Juniperus*, *Vitus vinifera*, and *Quercus* sp.

#### 3.1.1.7. Kawarta Spring

It is situated at an altitude of 1050 m.a.s.l. The soil has a dark brown color with organic matter contents of 3-5%, and the soil depth is more than 1meter. The dominated tree species in the area are *Quercus aegilops*, *Populus nigra*, *populus alba*, and *Salix* sp.



Figure 3.8. Site (6) mam said spring.



Figure 3.9. Site (7) kawarta spring.

### 3.1.1.8. Mshkor-qasre spring

This spring is situated south west of Choman district at an altitude of 970 m.a.s.l., this spring is the main source for drinking by the villager, and the outflow is used for the purpose of irrigation. The soil has dark brown color, and the water issue from limestone and dolomitic limestone. The dominated tree species in the area are *Juniperus* sp., *Prunus* sp., *Vitis vinifera*, *Morus* sp., *Populus nigra*, *populus alba*, and *Salix* sp.



Figure 3.10. Site (8) mshkor-qasre spring.

### 3.1.1.9. Walza-qasre spring

This spring is located about 8 km south of Choman district at an altitude of 1225 m.a.s.l., the water of this spring is collected in constructed cement basin tank for the purpose of drinking and irrigation purpose by the villager. The soil color and the vegetative cover is same as the previous site.



Figure 3.11. Site (9) walza-qasre spring.

#### 3.1.1.10. Kani dino-qasre spring

It is situated about 12km to the south west of Choman district at an altitude of 1115 m.a.s.l. The soil has dark brown color, and the water issue from limestone and dolomitic limestone. The dominated tree species in the area are *Juniperus* sp., *Prunus* sp., *Vitis vinifera*, *Morus* sp., *Populus nigra*, *populus alba*, and *Salix* sp.



Figure 3.12. Site (10) kani dino-qasre spring.

### 3.2. Field operating approaches and analysis of samples, physical and chemical analysis

Water samples from 10 different sites were collected monthly intervals from October 2018 to March 2019. Water samples were taken at each spring station for physical, chemical and biological examination using a polyethylene container that was washed twice with a water test and transferred to a 5-liter polyethylene bottle that was flushed twice with a water test before it was filled

Winklar's and Amber containers for dissolved oxygen (DO) and biochemical oxygen demand for five days-BOD<sub>5</sub> were put separately underneath the water and filled to remove water bubbles, the containers stoppered and all reagents were applied to the Winklar's bottle at the field except the titration (A.P.H.A., 2012). At the same time samples of algal flora were collected at each station.

Collect your diatom sample from the side of the particle that was exposed to sunlight using the brushing and scraping tools for any residues. Preserve the sample by adding 1.0 mL of Lugol's preservative solution. The water in the sample jar should now be a light tea color. If it is not, add extra Lugol's by drop until the water is a light tea colour (A.P.H.A., 2012).

Table 3.2. Instruments and apparatus for physical-chemical measurements.

Measured parameter	Device brand	Accuracy and measuring range
Altitude	GPS, Garmin e-Map	±3m
Air and Water Temperature	Thermometer	0.05 °C, 0 – 50 °C
pH, EC & TDS	pH-meter model (HANNA)	0.01, 0 - 14
Turbidity	HACH model (2100 A, U.S.A)	0.00 – 1000 NTU
Nitrate	Nitrate-meter model (Nitrachek 404, England RH12 3JR)	0 – 100 mg l <sup>-1</sup>

**3.2.1. Elevation (m.a.s.l.)**

The elevation of each site was recorded in October 2018 by a convenient Global Positional satellite (GPS) model (GARMIN e-Map) accurate up to  $\pm 2\text{m}$  and had the option to interface with in excess of 12 satellite for real determination of sites.

**3.2.2. Temperature**

An precision glass mercury thermometer ( $0\text{--}50\text{ }^{\circ}\text{C}$ ) graduated up to  $0.1\text{ }^{\circ}\text{C}$  was used in the field to measure air and water temperatures, measurements were taken after a few minutes of temperature settling, the thermometer was rinsed after each use with distilled water as defined by Bartram and Balance (1996).

**3.2.3. Hydrogen ion concentration-pH**

Electrometric approach used a portable pH-meter device (HANNA device, Portugal) was used to assess it directly in the sites. Before each sample, the instrument was calibrated using buffer solutions of (pH= 4, 7 and 9) as defined in A.P.H.A. (2012).

**3.2.4. Electrical conductivity-EC**

The results were estimated in the field using a compact conductivity meter model (HI 9811, HANNA instruments, 2000) aligned with (0.01 M) potassium chloride arrangement before each inspection, the outcomes were communicated in  $\mu\text{S}\cdot\text{cm}^{-1}$  as depicted by (A.P.H.A., 2012).

**3.2.5. Total dissolved solids-TDS**

Measured in the field utilizing a compact T.D.S-meter model (Hello 9811, HANNA instruments, 2000), the results were expressed in  $\text{mg l}^{-1}$  (A.P.H.A., 2012).

**3.2.6. Turbidity**

It was determined by Nephelometric technique using HACH turbidimeter instrument (2100 A, U.S.A), calibrated prior to each test using standard solutions

packaged originally with the instrument., and the findings are stated as N.T.U. (A.P.H.A., 2012).

### **3.2.7. Total alkalinity**

It was resolved in the research center by Titration technique prescribed by A.P.H.A. (2012), the outcomes were communicated in mg CaCO<sub>3</sub> l<sup>-1</sup> utilizing the recipe below:

Alkalinity as mg CaCO<sub>3</sub> l<sup>-1</sup> = A\*B\*50000/ml of sample.

Where: A= ml of standard acid titrant.

B= normality of standard acid.

### **3.2.8. Total acidity**

Acidity was controlled by titration technique as portrayed by A.P.H.A. (2012), the outcomes were communicated in mg CaCO<sub>3</sub> l<sup>-1</sup> utilizing the accompanying equation:

Acidity as mg CaCO<sub>3</sub> l<sup>-1</sup> = A\*B\*50000/ml of test.

Where: A= ml of standard NaOH titrant utilized.

B = ordinariness of standard NaOH

### **3.2.9. Total hardness**

It was dictated by EDTA titrimetric technique as portrayed by A.P.H.A. (2012), utilizing Erichrom Dark T as pointer and support arrangement of pH 10, the outcomes were communicated in mg CaCO<sub>3</sub> l<sup>-1</sup> utilizing the recipe below:

Hardness as mg CaCO<sub>3</sub> l<sup>-1</sup> = A\*B\*1000/ml of test.

Where: A= ml titration for test.

B = mg CaCO<sub>3</sub> proportionate to 1ml EDTA titrant

### 3.2.10. Chloride-Cl<sup>-</sup>

It was determined by Argentometric method using silver nitrate titrant as described by A.P.H.A. (2012), the outcomes were communicated in mg Cl<sup>-</sup> l<sup>-1</sup> by condition:

$$\text{mgCl}^{-1} \text{ l}^{-1} = (A-B) * N * 35450 / \text{ml of sample.}$$

Where: A= ml titration for sample.

B= ml titration for blank.

N= normality of AgNO<sub>3</sub>.

### 3.2.11. Sulfate-SO<sub>4</sub><sup>-2</sup>

Sulfate was determined by Turbidimetric method using Barium chloride, buffer solution, and HACH turbidimeter model (2100 A, U.S.A), as described by A.P.H.A. (2012), the results were expressed as mg SO<sub>4</sub><sup>-2</sup> l<sup>-1</sup>.

### 3.2.12. Nitrate-NO<sub>3</sub>

Nitrate was determined by Nitrate-meter model (Nitrachek 404, England RH12 3JR), the results were expressed in µg-at N-NO<sub>3</sub> l<sup>-1</sup>.

### 3.2.13. Reactive phosphorus-PO<sub>4</sub><sup>-3</sup>

The procedure used sensitive Stannous Chloride Method that Molybdophosphoric acid is formed and reduced by stannous chloride to intensely colored molybdenum blue. The absorbance was estimated in 1cm cuvette cell at the wavelength 669nm. The results were expressed in µg-at P-PO<sub>4</sub> l<sup>-1</sup>.

### 3.2.14. Reactive silicate-SiO<sub>2</sub>

The method used (Molybdosilicate method) is basically taken from Mullin and Riley (1955), as depicted by Parsons, *et. al.*(1984). The absorbance was estimated in 1cm cuvette cell at the wavelength 810nm.

### 3.2.15. Calcium-Ca<sup>+2</sup>

It was controlled by EDTA titrimetric technique as depicted by A.P.H.A. (2012) utilizing murexide as marker and cradle arrangement of pH 12. The outcomes were communicated in mg Ca<sup>+2</sup> l<sup>-1</sup>, the accompanying condition was utilized:

$$\text{mg Ca}^{+2} \text{ l}^{-1} = A * B * 400.8 / \text{ml of test.}$$

Where: A= ml titrant for test.

B = mg CaCO<sub>3</sub> (1ml EDTA titrant).

### 3.2.16. Magnesium-Mg<sup>+2</sup>

Determined by subtracting the amount of EDTA used for calcium titration from the volume of EDTA used for total hardness. Results in mg Mg<sup>+2</sup> l<sup>-1</sup> are reported.

### 3.2.17. Dissolved Oxygen-DO and Biological Oxygen Demand-BOD<sub>5</sub>

Azide modification of the classical Winkler procedure (1888) as described by A.P.H.A. (2012) was used to determine Dissolved Oxygen. The outcomes were communicated in mg O<sub>2</sub> l<sup>-1</sup>. So after titration almost 1ml of sodium thiosulfate = 1mg DO l<sup>-1</sup>.

Biological oxygen Demand (BOD<sub>5</sub>) was done following five-day brooding as indicated by Bartram and Ballance (1996), utilizing the accompanying condition:

$$\text{BOD}_5 (\text{mg l}^{-1}) = \text{DO initial} - \text{DO after 5 days of incubation.}$$

## 3.3. Biological Analysis

### 3.3.1. Diatom productivity (enumeration of diatoms)

Enumeration was conducted according to a modification of membrane filtration technique of McNabb (1960), Hinton and Maulood (1979c) and applied by Aziz (1997) using Millipore filter of 25mm diameter with pore size of 0.45µm. The volume of water sifted was based on the phytoplankton quantity, the solids suspended and the silt in the

water test. The diatom was tallied by Olympus Compound Magnifying lens, the quantity of diatom cells per liter determined by the accompanying equation:

All out no. of diatoms (cell l-1) =  $(D \times \text{area of channel}) / (\text{territory of 30 fields} \times \text{liter of test sifted})$ . Where: D = All out tallies of 30 fields.

### 3.3.2. Mounting of diatoms

The methods of cleaning of diatom varies with the condition of diatoms reviewed by Patric and Riemer (1966), the most suitable method which applied in this study is that of Sullivan and Riemer (1975) using  $\text{H}_2\text{SO}_4$  and  $\text{K}_2\text{Cr}_2\text{O}_7$ , as used by Aziz (1997).

### 3.3.3. Preservation of diatoms

Lugol's solution prepared as outlined by Bony (1975) retained specimens of diatoms obtained in vials at each spring site and applied 0.7ml of solution to 100ml of sample (Bold and Whyne, 1985). In addition to this formalin solution (10 %), 3-4 drops are applied to 100 ml of specimen (Al-Nimma, 1982) for algal conservation. Saturated blue  $\text{CuSO}_4$  solution has been formulated and applies a few drops to the test for the remaining true algal color (A.P.H.A., 2012).

### 3.3.4. Identification of diatoms

Diatoms were identified after cleaning according to Huber-Pestalozzi (1942), Benson and Rushforth (1975), Patric and Riemer (1966), Weber (1971), Germain (1981), Prygiel and Coste (2000), Taylor, *et al.* (2007), Wetzel (2012) and Necchi (2016). The classification and arrangement of algal taxa were done according to Hoek, *et al.* (1997).

### 3.3.5. Species diversity

Species diversity applied to the most common diatom species during the period of the study among different sites, the diversity index of Shannon – Wiener or Shannon's index as described by Barnes *et al.* (1998) was conducted by the following formula:

$$H' = - \sum_{i=1}^k p_i \log_2 p_i$$

$$H = - \sum p_i \ln p_i$$

Where H = Shannon's diversity index.

S = Number of species in the sample.

P<sub>i</sub> = Proportion of individuals that belong to species i.

Typical values are generally between 1.5 and 3.5 in most ecological studies, and rarely the index exceeds 4.

Table 3.3. Ecological quality conditions of the seabed according to the h' (Shannon-weiner) index results obtained from the individual numbers of Benthos species (UNESCO, 2004).

Pollution class	H': Zenetos & Simbora, 2001	Ecological quality status	H': Simbora & Zenetos, 2002	Norway benthos environmental status classification
Normal / Clean	H' > 4,6	Very good	H' > 5	H' > 4
Slightly contaminated, in transit	4 < H' ≤ 4,6	Good	4 < H' ≤ 5	4 < H' ≤ 3
Moderately contaminated	3 < H' ≤ 4	Middle	3 < H' ≤ 4	3 < H' ≤ 2
Heavily soiled	1,5 < H' ≤ 3	Poor	1,5 < H' ≤ 3	2 < H' ≤ 1
Oxygen-free	0 < H' ≤ 1,5	Bad	0 < H' ≤ 1,5	H' < 1

### 3.4. Computer Software and Programs

The following programs were used

1. MapInfo Professional. Version 19.0. Released 2019. MapInfo Corp: utilized for drawing the guide of the examined zone.
2. Statistical Product and Service Solutions (IBM SPSS Statistics for Windows). Version 25. Released 2017. IBM Corp.

### 3.5. Surface Water Quality Management Regulation

This Regulation on the Amendment to the Surface Water Quality Management Regulation, determines the biological, physico-chemical and hydromorphological qualities of the surface waters and coastal and transitional waters, monitors the water quality and quantity, and the balance of the use of these waters in accordance with sustainable development goals. It has been issued with the aim of determining the procedures and principles for the measures to be taken in order to be taken into consideration, to be protected and to reach a good water condition. In line with the data obtained from the monitoring tables in Annex-6 of the Regulation, four main groups were determined using the criteria in Annex-5 Table 5 (Quality Criteria According to Classes of Continental Surface Water Resources) (T.C. Official Gazette, 2012). (Table 3.4).

Table 3.4. Quality Criteria of Continental Continental Water Resources by Classes.

Water Quality Parameters	Water Quality Classes <sup>a)</sup>			
	I	II	III	IV
General conditions				
Temperature (oC)	≤ 25	≤ 25	≤ 30	> 30
Color (m-1)	RES 436 nm: ≤ 1,5 RES 525 nm: ≤ 1,2 RES 620 nm: ≤ 0,8	RES 436 nm: 3 RES 525 nm: 2,4 RES 620 nm: 1,7	RES 436 nm: 4,3 RES 525 nm: 3,7 RES 620 nm: 2,5	RES 436 nm: >4,3 RES 525 nm: >3,7 RES 620 nm: >2,5
pH	6,5-8,5	6,5-8,5	6,0-9,0	< 6,0 veya > 9,0
Conductivity (µS / cm)	< 400	1000	3000	> 3000
(A) Oxygenation Parameters				
Dissolved oxygen (mg O <sub>2</sub> / L) (b)	> 8	6	3	< 3
Biochemical oxygen demand (BOD <sub>5</sub> ) (mg / L)	< 4	8	20	> 20
B) Nutrient Parameters				
Nitrate nitrogen (mg NO <sub>3</sub> <sup>-</sup> -N / L)	< 5	10	20	> 20
Total phosphorus (mg P / L)	< 0,03	0,16	0,65	> 0,65
C) Trace Elements (Metals) and Inorganic Pollution Parameters (d)				
Sulfur (µg S = / L)	≤ 2	≤ 2	10	> 10

(a) Purposes of use of water according to quality classes:

First Class - High quality water (The fact that all parameters are of first class water quality means “Very Good” water status);

1. Surface waters with high potential to be drinking water,
2. Water that can be used for recreational purposes, including those that require body contact, such as swimming,
3. Usable water for trout production,
4. Usable water for animal production and farm needs,

II. Class - Lightly contaminated water (Values between 1st and 2nd class water quality represent “Good” water status);

1. Surface waters with the potential to be drinking water,
2. Water that can be used for recreational purposes,
3. Water that can be used for fish production other than trout,
4. Irrigation water provided that the Mer meets the irrigation water quality criteria determined by legislation,

III. Class - Contaminated water (Values between II and III class water quality refer to “Medium” water status).

According to Klee (1991), according to the physicochemical water quality assessment, there are seven classes, four main and three intermediate classes (Table 3.5.).

Table 3.5. Klee (1991), concentration distribution of chemical parameters according to the statistical average values of different contamination steps (Gün, 2011).

Kirlenme Basamakları	Organik karbon	BOİ <sub>5</sub>	NH <sub>4</sub> -N	NO <sub>2</sub> -N	NO <sub>3</sub> -N	PO <sub>4</sub> -P	Cl <sup>-</sup>
I	1,6 1,3-2,0	1,1 0,7-1,9	0,08 0,06-0,15	0,006 0,003-0,01	1,2 0,8-1,8	0,06 0,003-0,09	8 6-14
I-II	1,9 1,4-2,4	1,8 1,2-2,8	0,11 0,09-0,21	0,013 0,008-0,033	1,7 1,0-3,9	0,08 0,04-0,21	14 8-26
II	2,3 1,8-3,1	3,2 2,1-5,8	0,16 0,11-0,30	0,03 0,018-0,055	3,0 1,9-4,7	0,19 0,09-0,38	20 12-35
II-III	2,7 2,1-3,3	6,2 4,1-7,8	0,4 0,14-0,8	0,055 0,025-0,104	3,9 2,4-6,4	0,3 0,09-0,82	34 22-55
III	3,8 2,8-6,5	9,9 5,2-11,6	0,9 0,3-2,9	0,11 0,056-0,21	4,4 2,9-7,3	1 0,48-1,35	45 28-72
III-IV	5,4 3,5-8,8	10,8 6,2-12,3	2,48 0,6-5,52	0,19 0,092-0,28	7,0 3,8-12,2	1,7 0,72-1,98	57 35-108
IV	9,4 8,7-10,5	14,2 7,9-17	12,2 2,8-28	0,28 0,06-0,45	2,6 1,5-5,2	2,48 1,1-3,0	70 29-240

## 4. RESULTS and DISCUSSION

### 4.1. Ecological study

#### 4.1.1. Air temperature

The results of the air temperature showed extremely fluctuations with significant differences ( $P < 0.05$ ) during the sampling date and the studied sites., the minimum temperature of  $0^{\circ}\text{C}$  was recorded during January and February 2019 at site 1 (Kofi Ranginan spring) in Haji Omaran, whereas the highest value of  $33.6^{\circ}\text{C}$  was observed at sites 3 (Banan spring) and 6 (Mam Said spring) during October 2018.

#### 4.1.2. Water temperature

Water temperature data revealed seasonal variations with differences ( $P < 0.05$ ) between sampling date and studied sites, the average annual temperature for all springs was  $17.8^{\circ}\text{C}$  throughout the studied period, and the minimum temperature of spring waters was  $11^{\circ}\text{C}$  in site 1 during December 2018, while the maximum water temperature of  $23.7^{\circ}\text{C}$  was recorded at site 3 during December and March 2019. The annual fluctuations of water temperature for each site show observed stabilization in temperature changes, i.e. Stenothermal, which about  $\pm 1^{\circ}\text{C}$  around the annual mean of water temperature during the period of this study. The results came in accordance with that concluded by Abdulwahid (2012).

Table 4.1. Air temperature values (°C) recorded for 10 spring stations within Erbil Province, during the studied period.

Date		Sites										Mean
		1	2	3	4	5	6	7	8	9	10	
2018	Oct.	16.8	16.2	33.6	22.1	21.0	33.6	29.4	30.5	23.1	25.2	17.5
	Nov.	8.93	12.6	20.5	16.8	16.8	12.6	8.40	14.7	14.7	17.3	14.3
	Dec.	5.25	8.40	18.9	22.1	17.9	10.5	9.45	12.6	12.6	15.8	13.3
2019	Jan.	0.00	3.15	10.5	13.7	13.7	5.3	5.25	7.88	8.40	9.45	7.72
	Feb.	0.00	2.10	11.6	14.7	13.7	11.6	10.5	9.45	10.5	11.6	9.56
	Mar.	5.25	6.30	12.6	16.8	15.8	10.5	12.6	10.5	13.7	14.7	11.9
Mean		6.04	8.1	17.9	17.7	16.5	14.0	12.6	14.3	13.8	15.7	17.5

LSD (0.05) for date of sampling=2.48

LSD (0.05) for studied sites =1.87

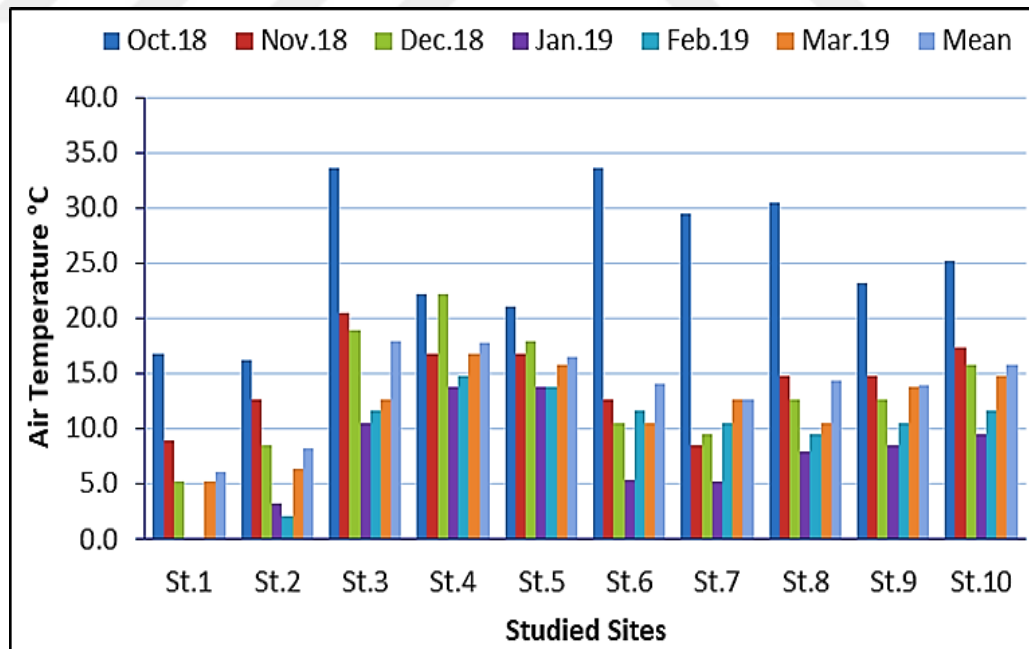


Figure 4.1. Air temperature values (°C) recorded for 10 spring stations within Erbil Province, during the studied period.

Table 4.2. Water temperature values (°C) recorded for 10 spring stations within Erbil Province, during the studied period.

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	11.6	14.3	23.1	21.5	20.9	17.6	16.5	17.6	17.6	17.6	17.8
	Nov.	11.5	14.9	23.1	21.5	21.5	16.5	15.4	18.2	19.3	17.1	17.9
	Dec.	11.0	14.3	23.7	20.9	21.5	16.5	16.0	17.6	18.7	17.1	17.7
2019	Jan.	11.4	14.3	23.1	20.4	20.9	17.1	16.0	17.1	18.2	17.6	17.6
	Feb.	11.7	14.9	23.1	20.9	20.9	17.6	16.5	17.1	18.2	16.5	17.7
	Mar.	12.1	14.9	23.7	20.9	21.5	17.6	16.5	17.6	17.6	16.5	17.9
Mean	11.6	14.6	23.3	21.0	21.2	17.1	16.1	17.5	18.2	17.1	17.8	

LSD (0.05) for date of sampling=0.56

LSD (0.05) for studied sites =0.41

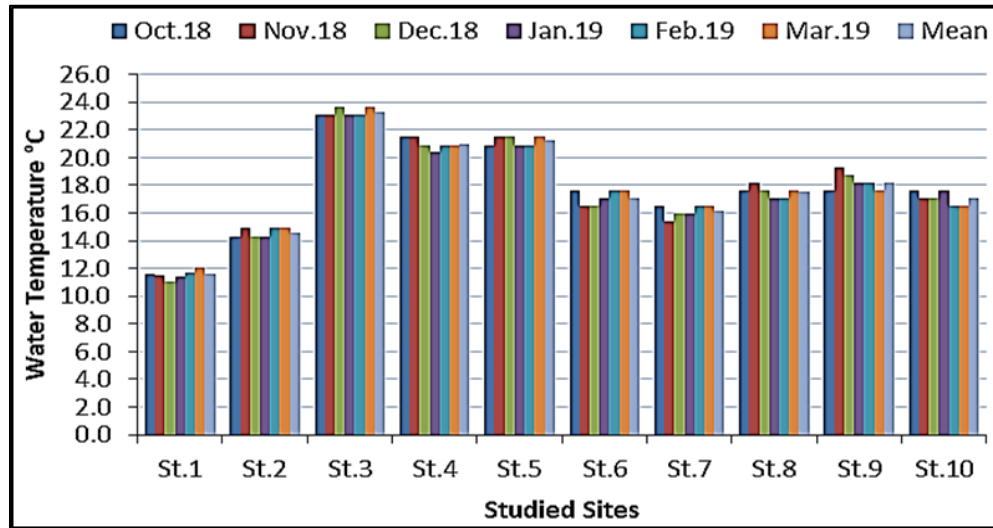


Figure 4.2. Water temperature values (°C) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.3. Hydrogen ion concentrations-pH

Water pH is the negative logarithm of the activity of hydrogen ions (WHO, 2011), and its meaning reflects the strength of water's acid or alkaline state (Sawyer and

McCarty, 1978). Generally speaking, the pH of water in the Kurdistan region was distinguished by alkaline neutrality due to the geological formation of the region, which mainly consisted of CaCO<sub>3</sub> as stated by (Rasheed, 1994, Aziz, 1997; Ganjo, 1997; and Al-Naqishbandi, 2002, Aziz, 2011 and Abdulwahid, 2012) in Arbil province, (Maulood and Hinton, 1978a; Ibrahim, 1981; and Toma, 2000) in Sulaimani province, and Al-Nakshbandi (2002) in Duhok province.

The hydrogen ion concentrations for all stations were more than 7. The minimum pH value 7.17 was recorded in site 2 and site 6 during December and October 2018., and the maximum pH values 8.18 was measured in site 10 during February 2019, whereas the overall mean for all springs was calculated 7.53 during the period of this study. The statistical analysis found that the pH levels between the sample date and the locations analyzed were significantly different ( $P < 0.05$ ). In relation to the water potability and according to guideline of WHO (1996), and USEPA ground water and drinking water standards (2004), the water pH value should be between 6.5 and 8.5 for drinking purpose, thus, the pH levels of the studied sites is in the acceptable condition as potable water.

Table 4.3. P H values recorded for 10 spring stations within Erbil province, during the studied period.

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	7.27	7.27	7.98	7.47	7.88	7.17	7.47	7.88	7.17	7.27	7.48
	Nov.	7.47	7.47	7.58	7.68	7.37	7.58	7.47	7.68	7.78	7.37	7.54
	Dec.	7.27	7.17	7.37	7.47	7.37	7.47	7.37	7.78	7.68	7.47	7.44
2019	Jan.	7.27	7.37	7.78	7.68	7.47	7.68	7.47	7.88	7.58	7.58	7.58
	Feb.	7.37	7.68	7.88	7.58	7.47	7.47	7.17	7.37	7.17	8.18	7.56
	Mar.	7.58	7.78	7.68	7.47	7.37	7.58	7.27	7.88	7.37	7.98	7.60
Mean		7.37	7.46	7.71	7.56	7.49	7.49	7.37	7.74	7.46	7.69	7.53

LSD (0.05) for date of sampling=0.15

LSD (0.05) for studied sites =0.10

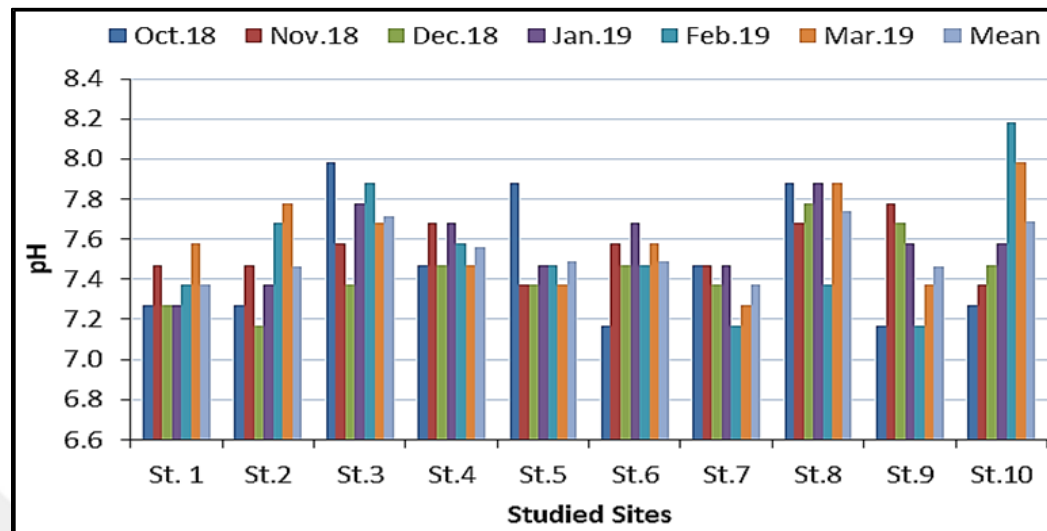


Figure 4.3. PH values recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.4. Electrical conductivity-EC

Conductivity is a mathematical representation of an aqueous solution's ability to carry an electrical current. Such capacity relies on the existence of ions, their overall amounts, their flexibility and the measuring temperature (APHA, 2012). A wide range of differences between sites and during the observed time ( $P < 0.05$ ) are identified in total ion concentrations in water samples, the minimum value of  $143 \mu\text{S}\cdot\text{cm}^{-1}$  was recorded in site 1 during October 2018, while the maximum value of  $779 \mu\text{S}\cdot\text{cm}^{-1}$  was observed in sites 6 during November 2018. On the other hand, site 1 showed lowest annual value which was not exceeded  $200 \mu\text{S}\cdot\text{cm}^{-1}$  during the whole period of this study, while site 6 recorded highest annual values and never fall below  $400 \mu\text{S}\cdot\text{cm}^{-1}$  during the period of this investigation. The maximum acceptable level of conductivity as indicated by USEPA (2018) is  $1000 \mu\text{S}\cdot\text{cm}^{-1}$ . Because all studied sites containing low levels of conductivity and never exceeded  $1000 \mu\text{S}\cdot\text{cm}^{-1}$ , therefore they were suitable for drinking.

Table 4.4. Electrical conductivity (EC) ( $\mu\text{s}\cdot\text{cm}^{-1}$ ) recorded for 10 spring stations within Erbil province, during the studied period.

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	143	304	361	390	380	437	447	380	352	485	368
	Nov.	190	380	437	447	494	779	551	532	456	618	508
	Dec.	190	380	456	409	513	669	570	608	475	570	484
2019	Jan.	190	399	437	523	523	690	618	665	485	589	512
	Feb.	190	390	456	494	523	669	532	646	532	570	500
	Mar.	190	399	456	504	513	648	542	627	513	608	501
Mean	182	375	434	461	491	649	543	576	469	573	479	

LSD (0.05) for date of sampling=83.98

LSD (0.05) for studied sites =60.23

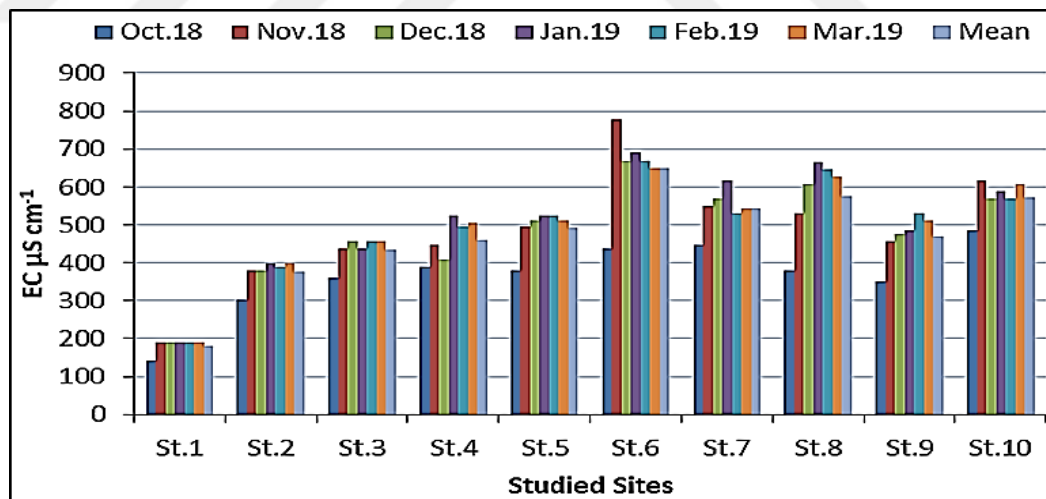


Figure 4.4. Electrical conductivity (EC) ( $\mu\text{s}\cdot\text{cm}^{-1}$ ) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.5. Total dissolved solids-TDS

Total dissolved solids are a measurement of all chemical components dissolved in water, often affected by main ion concentrations; calcium, bicarbonate, magnesium, sulfate and chloride, It is also an important indicator for the assessment of groundwater

residence time in the aquifer (Champion and Starks, 2001). The TDS of water is intimately linked to conductivity, where high levels of TDS are commonly associated with high levels of conductivity (Leggett *et. al.* 2001), as revealed in this study, maximum TDS levels recorded when the conductivity is in the peak concentrations. The cumulative tests of dissolved solids showed significant variations ( $P < 0.05$ ) between the spring locations and the time analyzed, the peak levels of TDS  $333 \text{ mg.l}^{-1}$  was recorded in site 8 during January 2019, while the minimum value of  $67 \text{ mg.l}^{-1}$  was measured in site 1 during October 2018. On the other hand, the overall mean of  $226 \text{ mg.l}^{-1}$  was recorded for all studied springs. The maximum acceptable concentration of TDS in drinking water according to the mentioned guidelines is  $500 \text{ mg.l}^{-1}$ , thus, all sites were considered as potable water.

Table 4.5. Total dissolved solids (TDS) ( $\text{mg.l}^{-1}$ ) recorded for 10 spring stations within Erbil province, during the studied period.

Date		Sites										Mean
		1	2	3	4	5	6	7	8	9	10	
2018	Oct.	67	152	171	190	190	219	219	190	171	238	181
	Nov.	86	190	219	219	247	285	276	266	228	304	232
	Dec.	95	190	228	200	257	304	285	304	238	285	238
2019	Jan.	95	200	219	257	257	314	304	333	238	295	251
	Feb.	95	190	276	247	257	304	266	323	266	285	251
	Mar.	95	200	228	247	26	295	266	314	51	304	202
Mean		89	187	223	226	205	287	269	288	199	285	226

LSD (0.05) for date of sampling=43.22

LSD (0.05) for studied sites=34.42

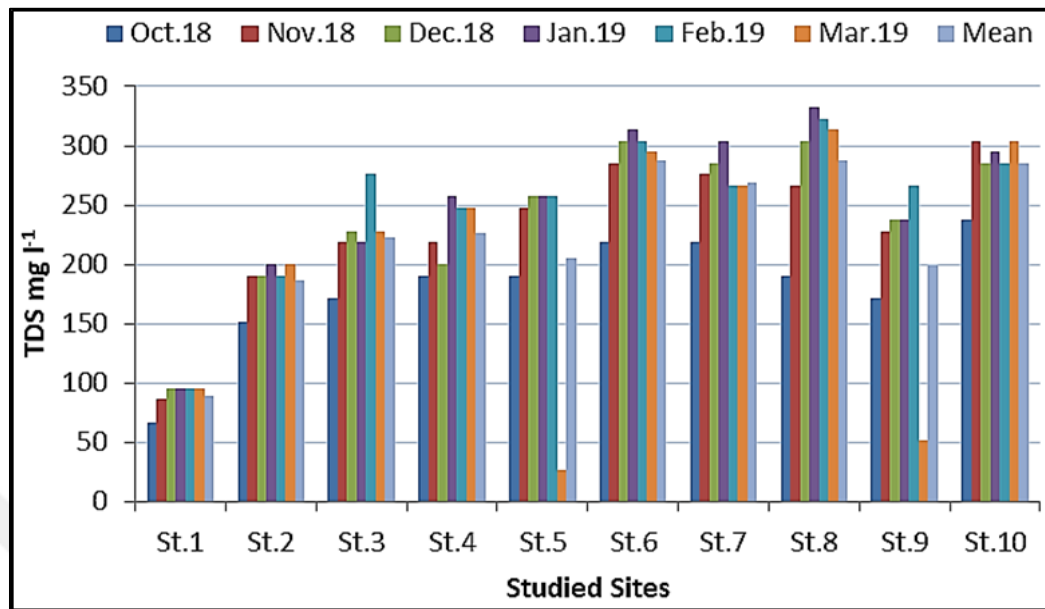


Figure 4.5. Total dissolved solids (TDS) ( $\text{mg l}^{-1}$ ) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.6. Turbidity

Turbidity is determined by quantifying the degree of light passing through a water column that is spread by inorganic particles and organic suspended (including algae) (Leggett *et. al.* 2001). Turbidity levels showed that there are obviously significant differences ( $P < 0.01$ ) between the springs being studied, whereas there is no significant difference between the sampling date during the period of the study. The minimum level of 0.50 NTU was measured in site 1 during January 2019, while the maximum value of 13.3 NTU was recorded in site 7 during November 2018. According to the above mentioned guidelines the acceptable levels of turbidity in drinking water should be lower than 5 NTU, thus among our selected springs, except sites 4 and 9, all spring sites were within allowable levels. The same results were observed by Aziz (2011) and Abdulwahid (2012).

Table 4.6. Turbidity levels (NTU) recorded for 10 spring stations within Erbil province, during the studied period.

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	0.76	1.14	1.71	2.66	4.2	0.82	0.32	2.85	2.38	1.33	1.8
	Nov.	1.43	1.52	3.61	6.3	3.80	7.1	13.3	6.7	9.4	7.3	6.0
	Dec.	2.09	9.5	2.38	10.1	2.85	3.99	2.66	3.33	8.6	1.90	4.7
2019	Jan.	0.48	0.95	4.75	4.75	1.90	6.18	4.75	3.80	5.70	4.5	3.8
	Feb.	4.28	3.33	4.1	5.70	4.75	6.65	5.23	4.75	1.90	8.5	4.9
	Mar.	2.38	3.80	6.65	5.23	3.80	4.75	2.38	3.33	4.28	5.2	4.2
Mean	1.90	3.37	3.87	5.8	3.55	4.86	4.77	4.13	5.38	4.8	4.2	

LSD (0.01) for studied sites=5.44

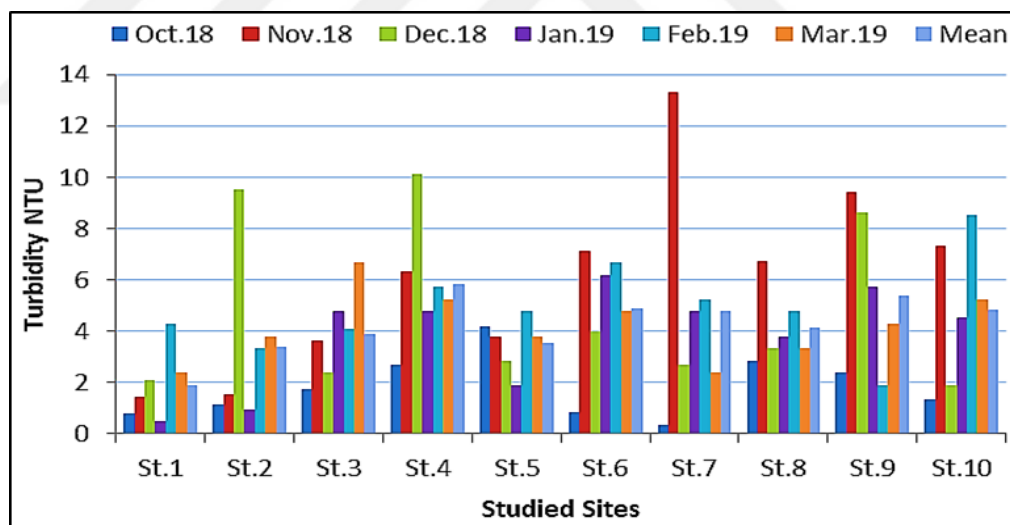


Figure 4.6. Turbidity levels (NTU) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.7. Total alkalinity

Water alkalinity is its potential to neutralize acid, the amount of a strong acid necessary to neutralize alkalinity is called total alkalinity (Batram and Ballance, 1996). Generally total alkalinity is represented by bicarbonate ions and the alkalinity. The results of the studied area revealed a significant differences ( $P < 0.01$ ) between locations and date

of sampling. An overall mean of alkalinity  $222 \text{ mg CaCO}_3 \text{ l}^{-1}$  was recorded for all spring stations. Site 1 showed low levels of alkalinity, with minimum value of  $87 \text{ mgCaCO}_3 \text{ l}^{-1}$  during the studied period. The highest value of alkalinity ( $352.4 \text{ mgCaCO}_3 \text{ l}^{-1}$ ) was recorded in site 6 during October 2018. The total alkalinity in the region consisting mainly of bicarbonate, agreed with (Rasheed, 1994; Aziz, 1997; and Ganjo, 1997, Aziz, 2011 and Abdulwahid, 2012). On the basis of seasonal variation, the alkalinity decreased from October 2018 to January 2019, then increased till March 2019.

Table 4.7. Total alkalinity ( $\text{mg CaCO}_3 \text{ l}^{-1}$ ) recorded for 10 spring stations within Erbil province, during the studied period.

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	121.8	311.0	311.5	293.6	272.3	352.4	330.6	217.5	161.4	213.2	258.5
	Nov.	108.8	203.6	208.8	205.3	221.9	246.2	250.6	252.3	174.0	213.2	208.5
	Dec.	91.4	200.1	217.5	121.8	226.2	304.5	261.0	269.7	234.9	217.5	214.5
2019	Jan.	87.0	165.3	213.2	221.9	217.5	282.8	230.6	243.6	217.5	226.2	210.5
	Feb.	95.7	321.9	261.0	261.0	226.2	269.7	208.8	191.4	178.4	213.2	222.7
	Mar.	100.1	213.2	252.3	213.2	221.9	295.8	236.6	217.5	200.1	221.9	217.2
<b>Mean</b>	100.8	235.8	244.0	219.5	231.0	291.9	253.0	232.0	194.4	217.5	222.0	

LSD (0.01) for date of sampling=77.2

LSD (0.01) for studied sites=50.10

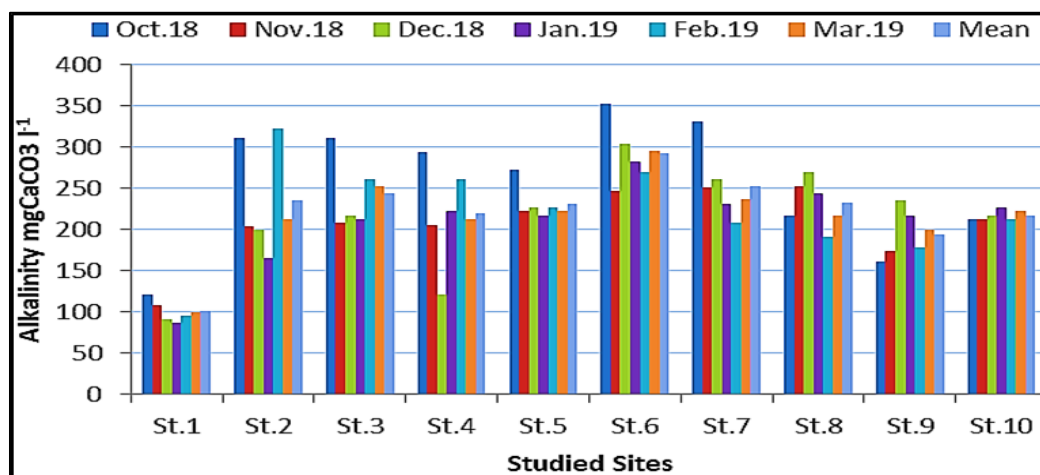


Figure 4.7. Total alkalinity (mg CaCO<sub>3</sub> l<sup>-1</sup>) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.8. Total acidity

Water acidity is its quantitative ability to respond to an assigned pH with a solid base (APHA, 2012). Total acidity values for all locations revealed obvious variations with significant differences ( $P < 0.01$ ), ranged from 0.37 mgCaCO<sub>3</sub> l<sup>-1</sup> to 8.28 mgCaCO<sub>3</sub> l<sup>-1</sup>. The highest value of acidity was observed in site 6 during December 2018, while the most reduced value was recorded in site 2 during a similar period. An overall mean (3.24 mgCaCO<sub>3</sub> l<sup>-1</sup>) of acidity was calculated for all studied springs.

Table 4.8. Total acidity (mg CaCO<sub>3</sub> l<sup>-1</sup>) recorded for 10 spring stations within Erbil province, during the studied period.

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	2.34	5.80	5.01	3.73	4.71	2.90	1.92	1.66	2.18	2.52	3.27
	Nov.	1.21	2.26	1.89	3.02	2.63	6.59	5.88	4.15	4.52	4.67	3.68
	Dec.	1.50	0.37	1.70	2.11	1.13	8.28	4.52	4.89	4.15	3.76	3.24
2019	Jan.	2.07	3.02	2.45	4.33	3.58	6.22	3.76	3.47	3.47	2.45	3.48
	Feb.	2.63	3.24	3.62	3.58	3.20	5.28	2.26	2.26	1.81	1.73	2.96
	Mar.	2.26	2.75	3.02	3.08	3.31	4.71	2.41	2.18	1.95	2.26	2.79
Mean	2.00	2.90	2.95	3.309	3.09	5.67	3.46	3.10	3.01	2.89	3.24	

LSD (0.01) for date of sampling=24.35

LSD (0.01) for studied sites=15.8

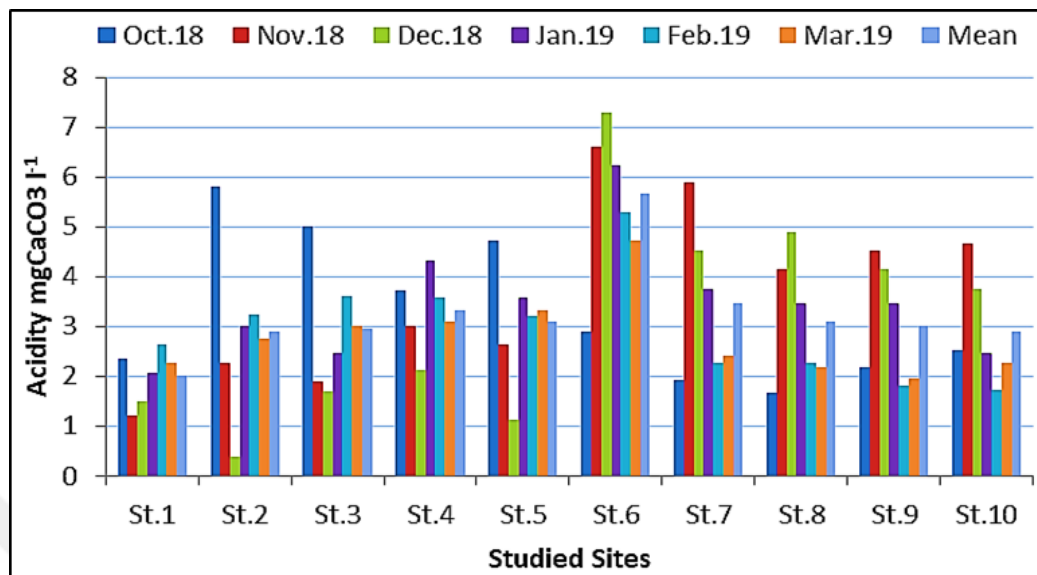


Figure 4.8. Total acidity (mg CaCO<sub>3</sub> l<sup>-1</sup>) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.9. Total hardness

Total hardness results indicated a significant difference ( $P < 0.01$ ) between studied stations, whereas there is no significant differences between date of sampling during the period of this investigation. Site 5 characterized by high levels of hardness which was 301 mgCaCO<sub>3</sub> l<sup>-1</sup> during December 2018, while the lowest level of 57 was detected in site 1 during October and November 2018. The overall mean of 150 mgCaCO<sub>3</sub> l<sup>-1</sup> was calculated for all spring sites during the studied period.

In fresh water, the principle hardness – causing ions are calcium and magnesium, originated from the sedimentary rocks, the most common being limestone and chalk (WHO, 2011). According to Sawyer and MacCarty (1978), sites 1, 2, 4, 8 and 10 were classified under moderately hard water, because their annual mean levels of hardness were between 75 and 150 mg CaCO<sub>3</sub> l<sup>-1</sup>, while sites 3, 5, 6, 7, and 9. The results of this study were in accordance with the observations of Ibrahim (1981) on Sulaimani springs; Bilbas (2004), Aziz (1997) and Aziz (2011) on Erbil springs.

Table 4.9. Total hardness (mg CaCO<sub>3</sub> l<sup>-1</sup>) recorded for 10 spring stations within Erbil province, during the studied period.

Date		Sites										Mean
		1	2	3	4	5	6	7	8	9	10	
2018	Oct.	57	141	153	104	124	136	109	84	133	122	116
	Nov.	80	118	124	130	133	158	170	136	141	136	130
	Dec.	90	158	181	136	301	147	141	149	163	153	162
2019	Jan.	96	136	203	186	141	186	164	158	183	158	161
	Feb.	119	164	170	175	147	192	153	179	154	164	161
	Mar.	113	153	198	167	190	209	171	175	170	141	169
Mean		93	145	171	150	173	171	151	147	157	146	150

LSD (0.01) for studied sites=19.13

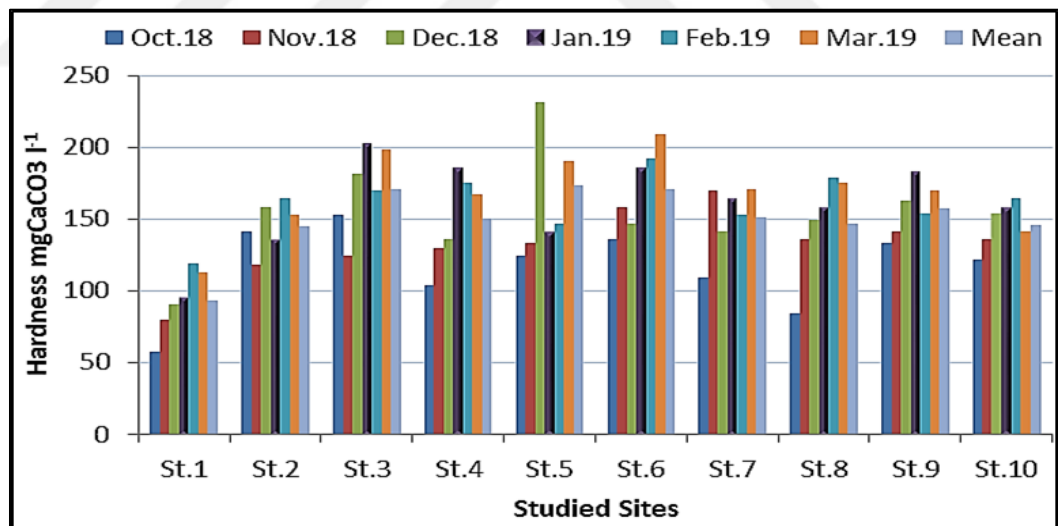


Figure 4.9. Total hardness (mg CaCO<sub>3</sub> l<sup>-1</sup>) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.10. Chloride-Cl<sup>-</sup>

The results of chloride showed seasonal variations with differences ( $P < 0.01$ ) between date of sampling and studied sites with an overall mean of (20.9 mg l<sup>-1</sup>). The

maximum levels of  $117.9 \text{ mg l}^{-1}$  was recorded in site 6 during October 2018, while the minimum levels of  $3.9 \text{ mg l}^{-1}$  was observed in site 1 during December 2018.

Chloride is widely distributed in nature, usually from salts of sodium (NaCl), potassium (KCl) and calcium ( $\text{CaCl}_2$ ), and the presence of chloride in natural waters can be attributed to salt deposits dissolved (WHO, 2011). The concentrations of chloride in this investigation were ranged from  $3.9$  to  $117.9 \text{ mg l}^{-1}$  at sites 1 and 6 during December and October 2018 respectively. On the basis of seasonal variation the levels of chloride decreased constantly from October 2018 to March 2019.

According to USEPA (2018) the maximum allowable permission of chloride in drinking water must be lower than  $250 \text{ mg l}^{-1}$ , so the quality of studied springs was known as fresh water since they have low chloride concentrations.

Table 4.10. Chloride levels ( $\text{mg l}^{-1}$ ) recorded for 10 spring stations within Erbil province, during the studied period.

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	7.3	11.8	21.8	10.2	12.1	117.9	42.7	12.1	37.2	39.9	31.3
	Nov.	5.1	9.3	15.3	11.1	7.8	88.9	28.8	19.5	38.0	33.4	25.7
	Dec.	3.9	7.4	9.7	10.2	5.8	77.8	14.9	13.5	24.8	14.6	18.3
2019	Jan.	5.8	8.7	11.6	7.4	7.0	79.9	13.4	11.4	22.9	14.8	18.3
	Feb.	4.6	11.9	16.0	8.8	9.6	55.7	11.6	10.3	14.0	16.3	15.9
	Mar.	5.8	11.6	13.2	7.6	8.0	57.0	10.8	11.4	17.1	15.0	15.8
Mean		5.4	10.1	14.6	9.2	8.4	79.5	20.4	13.0	25.7	22.3	20.9

LSD (0.01) for date of sampling=7.13

LSD (0.01) for studied sites=4.63

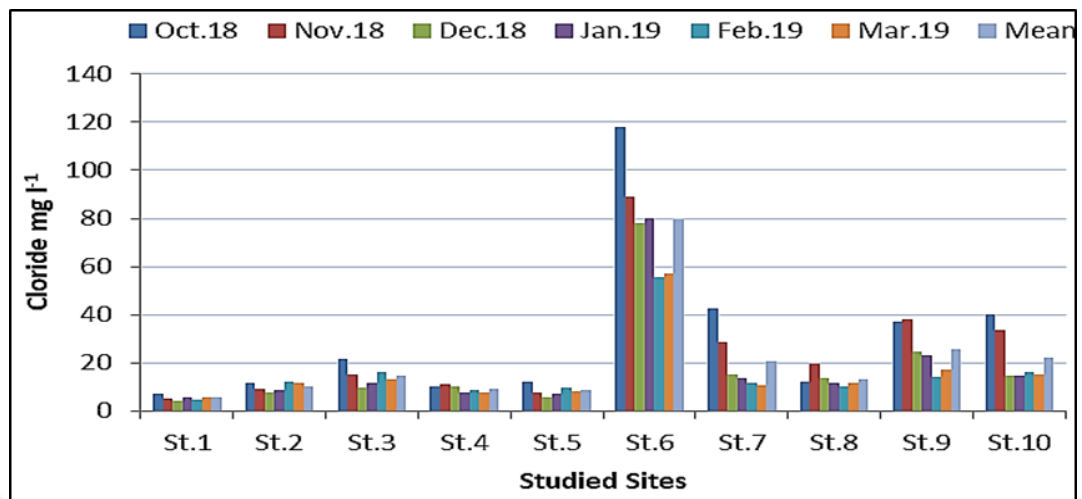


Figure 4.10. Chloride levels ( $\text{mg l}^{-1}$ ) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.11. Sulfate- $\text{SO}_4^{-2}$

Sulfate concentration results for all spring stations revealed a quite fluctuations with a significant difference between date of sampling and studied sites throughout the period of the study, sites 6 and 9 showed high levels of sulfate concentrations, which never fall below  $150 \text{ mg l}^{-1}$  during the whole studied period, while sites 1 and 5 recorded low levels of sulfate concentrations, which never exceeded  $100 \text{ mg l}^{-1}$  during the studied period. The maximum level of sulfate was recorded  $497 \text{ mg l}^{-1}$  in site 6 in November 2018, whereas the minimum level of sulfate was  $36 \text{ mg l}^{-1}$  recorded in site 1 in October 2018.

In many rocks, sulfate occur naturally in water in as minerals, including barite ( $\text{BaSO}_4$ ), epsomite ( $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$ ), and gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ) (WHO, 2011). Sulfate levels range from a few to many thousand  $\text{mg l}^{-1}$  in natural waters (APHA, 2012). In general, inland waters of Iraqi Kurdistan usually contain considerable amounts of sulfate (Rasheed, 1994; Ganjo, 1997; Al-Naqishbandi, 2002; Bilbas, 2004; Aziz, 2011 and Abdulwahid, 2012) in Erbil province, Maulood and Hinton, (1978a) in Sulaimani province, and Al-Nakishbandi (2002) in Duhok province.

The permission levels of sulfate by guideline of WHO (1996) was not more than 500 mg l<sup>-1</sup>, while according to USEPA (2018) the allowable concentration must be lower than 250 mg l<sup>-1</sup>, accordingly all sites were suitable for drinking purpose.

Table 4.11. Sulfate concentration (mg l<sup>-1</sup>) recorded for 10 spring stations within Erbil province, during the studied period.

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	36	108	77	68	90	271	104	81	154	81	107
	Nov.	77	63	124	140	63	497	190	90	176	190	161
	Dec.	81	81	140	145	59	407	118	190	298	172	169
2019	Jan.	68	45	136	57	50	384	145	118	262	181	144
	Feb.	77	63	127	81	68	283	127	95	240	190	135
	Mar.	72	90	185	108	81	362	163	113	203	145	152
<b>Mean</b>	69	75	131	100	69	367	141	115	222	160	145	

LSD (0.01) for date of sampling=28.69  
 LSD (0.01) for studied sites=18.62

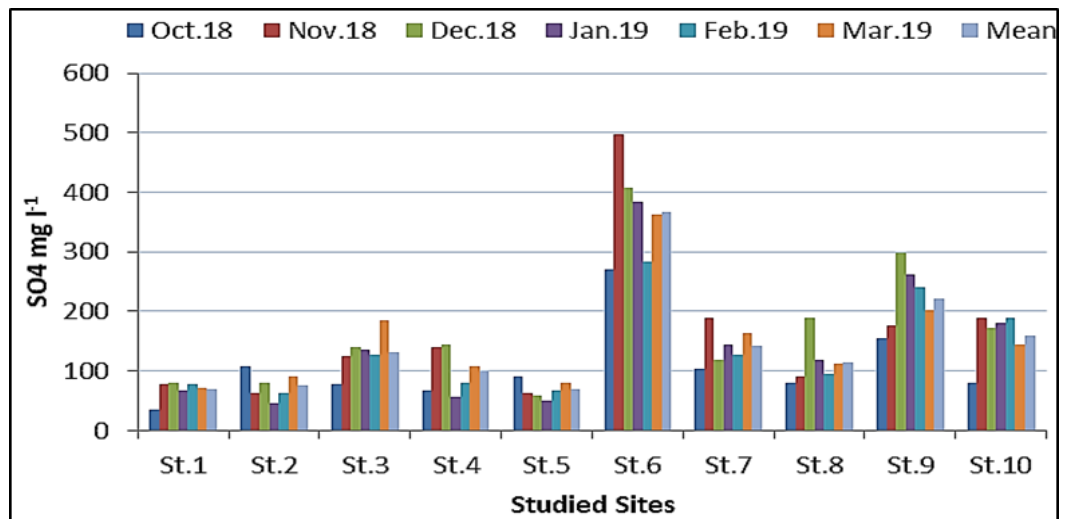


Figure 4.11. Sulfate concentration levels (mg l<sup>-1</sup>) recorded for 10 spring stations within Erbil Province during the studied period.

#### 4.1.12. Nitrate-NO<sub>3</sub>

Nitrate concentration data indicated significant differences ( $P < 0.01$ ) between studied factors during the studied period of this investigation. The lowest and highest recorded values were 0.27 and 1.2 mg-at N-NO<sub>3</sub> l<sup>-1</sup> in sites 2 and 10 during October 2018 and March 2019 respectively.

In water, nitrate is usually more stable than nitrite or ammonium; it's the final step in the oxidation of ammonia and other nitrogen compounds (Bartram and Ballance, 1996). The seasonal variation in nitrate concentrations were obvious between studied springs and during the period of the study by an overall mean calculated was 0.64mg-at.N-NO<sub>3</sub>l<sup>-1</sup> for all spring sites in the studied area.

High nitrate levels in drinking water may pose a risk to children because the low acidity of their stomachs promotes the conversion of nitrate to nitrite through microbial activity, and then nitrite absorbed by blood to produce methamoglobin (Bartam and Ballance, 1996). For this reason USEPA (2018) suggested the acceptable levels of nitrate in potable water should be lower than 10 mg l<sup>-1</sup>, accordingly all studied springs were contained low nitrate concentrations and thus, they are suitable for drinking purposes.

Table 4.12. Nitrate concentration (mg N-NO<sub>3</sub> l<sup>-1</sup>) recorded for 10 spring stations within Erbil province,during the studied period.

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	0.58	0.27	0.29	0.49	0.44	0.58	0.31	0.31	0.31	0.97	0.45
	Nov.	0.97	0.49	0.84	0.35	0.27	0.66	0.35	0.40	0.80	0.71	0.58
	Dec.	0.71	0.75	0.97	0.75	0.58	0.40	0.53	0.58	0.97	0.80	0.70
2019	Jan.	0.80	0.80	0.80	0.49	0.35	0.97	0.71	0.62	0.71	1.1	0.74
	Feb.	0.35	0.53	0.62	0.44	0.66	0.71	0.44	0.75	0.35	0.93	0.58
	Mar.	0.44	0.84	0.53	0.62	0.80	0.84	1.0	0.84	0.53	1.2	0.77
<b>Mean</b>	0.64	0.61	0.67	0.52	0.52	0.69	0.56	0.58	0.61	1.0	0.64	

LSD (0.01) for date of sampling=0.30

LSD (0.01) for studied sites=0.19

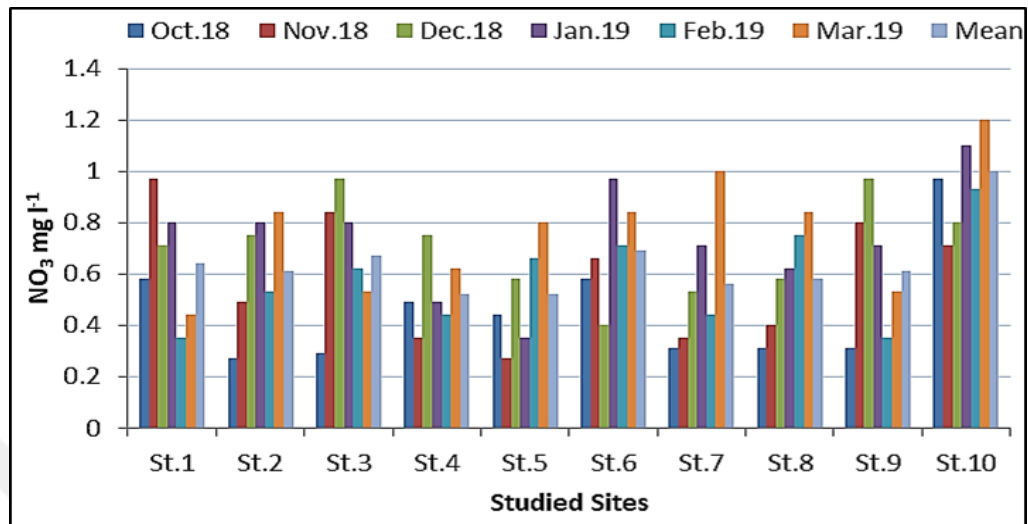


Figure 4.12. Nitrate concentration (mg N-NO<sub>3</sub> l<sup>-1</sup>) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.13. Reactive phosphorus-PO<sub>4</sub><sup>-3</sup>

Reactive phosphorus showed an overall mean of 0.83 mg-P-PO<sub>4</sub> l<sup>-1</sup>, the non-detectable levels 0.00mg-P-PO<sub>4</sub> l<sup>-1</sup> were observed in some cases during the studied period especially during December 2018 in sites 1, 6, 7, and 9, while the maximum value of 3.56 mg-P-PO<sub>4</sub> l<sup>-1</sup> was recorded during February 2019 in site 9. The results revealed a seasonal variation with significant differences ( $P < 0.01$ ) between spring sites and sampling date throughout this study. Moreover, sites 4, 6, and 10 showed high levels of reactive phosphorus concentrations, whereas sites 2, 7 and 8 characterized by low levels during the period of this study.

Phosphorus is one of the most important phytoplankton growth limitation factors in many drainage basins owing to the geochemical scarcity of phosphorus (Goldman and Horne, 1983). Phosphorus concentrations during the period of this investigation ranged from non-detectable levels to 3.56mg-P-PO<sub>4</sub>l<sup>-1</sup>, low to moderate concentrations of phosphorus was evident in the studied springs, this situation have been referred to by many authors like Al-Shahwani (1980) and Ibrahim (1981) in Sulaimani province,

Rasheed (1994), Aziz (1997), Ganjo (1997), Al – Naqishbandi (2002), Aziz and Ganjo (2003) and Bilbas (2004) in Erbil province, and Al–Nakshbandi (2002) in Duhok province. On the other hand, the phosphorus concentration was decreased in high altitude springs, especially sites 1, 2, and 3.

Table 4.13. Concentration of reactive phosphorus ( $\text{mg l}^{-1}$ ) in 10 spring sites within Erbil province, during the studied period.

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	1.80	0.14	0.89	0.36	0.75	0.14	0.14	0.36	0.34	0.21	0.51
	Nov.	1.49	0.57	1.49	1.32	1.10	0.50	0.50	1.00	0.64	2.84	1.14
	Dec.	0.00	0.41	0.71	2.06	0.39	0.00	0.00	0.07	0.00	0.68	0.43
2019	Jan.	0.46	0.25	0.95	0.53	0.60	0.54	0.21	0.14	0.24	0.77	0.47
	Feb.	0.53	1.24	0.71	1.42	1.42	2.77	2.65	0.00	3.56	2.13	1.64
	Mar.	0.43	0.97	0.47	0.97	0.97	2.25	0.38	0.13	0.58	0.74	0.79
Mean	0.79	0.60	0.87	1.11	0.87	1.03	0.65	0.28	0.89	1.23	0.83	

LSD (0.01) for date of sampling=0.78

LSD (0.01) for studied sites=0.51

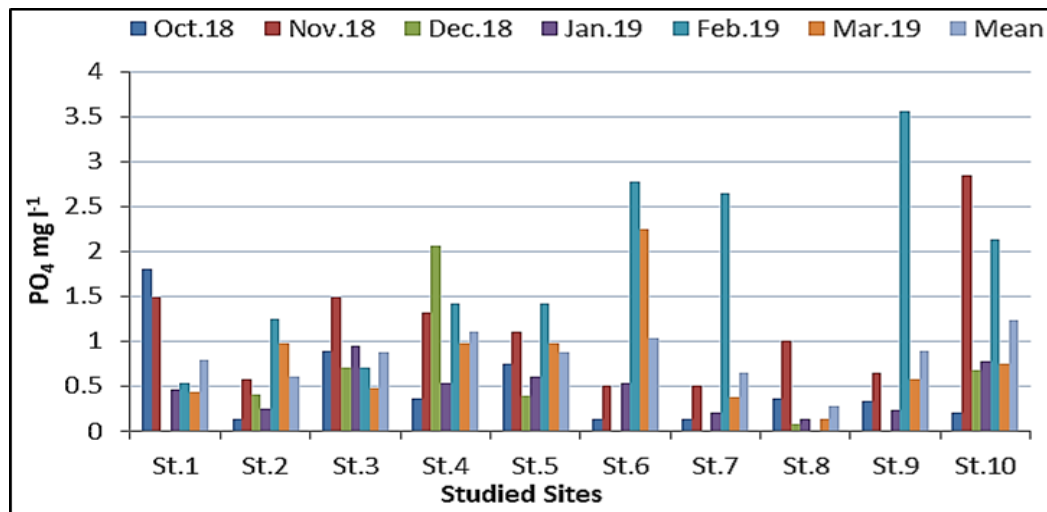


Figure 4.13. Reactive phosphorus concentration ( $\text{mg l}^{-1}$ ) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.14. Reactive silicate-SiO<sup>2</sup>

The reactive silicate concentrations for all spring stations were high and never fall below 0.25 mg-Si-SiO<sub>2</sub> l<sup>-1</sup>, with overall of 1.62mg-Si-SiO<sub>2</sub> l<sup>-1</sup>, while the highest and lowest levels of 3.38 and 0.25 mg-Si-SiO<sub>2</sub> l<sup>-1</sup> were recorded in sites 6 and 1 during February 2019 and November 2018. On the other hand, high levels of silicate were detected in site 6 during the whole studied period. The results were significant difference (P<0.01) as affected by the studied factors.

Silicate forms the rigid algal cell wall in diatoms which dominated in most aquatic systems (Goldman and Horne, 1983). The presence of silica in natural waters is due to degradation of silica – containing rocks, and geothermal water often contains abundance of silicate (APHA, 2012). The reactive silicate results revealed high levels and ranged from 0.25 to 3.56mg-Si-SiO<sub>2</sub>l<sup>-1</sup>.

Table 4.14. Reactive silicate-silicon level (mg l<sup>-1</sup>) in 10 spring sites within Erbil province, during the studied period.

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	1.47	1.51	1.41	1.49	1.36	1.44	1.39	1.29	1.33	1.41	1.41
	Nov.	0.25	0.36	0.26	0.38	0.41	0.78	0.50	0.26	0.38	0.28	0.39
	Dec.	1.86	1.07	0.70	1.47	1.74	2.17	1.78	1.16	1.40	1.65	1.50
2019	Jan.	1.88	2.52	1.44	1.84	2.13	3.05	2.10	1.46	1.50	1.90	1.98
	Feb.	1.93	2.28	1.98	2.02	1.93	3.38	2.35	1.58	1.78	2.09	2.13
	Mar.	1.99	2.16	2.10	1.90	1.80	3.93	2.48	1.97	1.81	2.73	2.29
<b>Mean</b>	1.56	1.65	1.31	1.52	1.56	2.46	1.77	1.29	1.37	1.68	1.62	

LSD (0.01) for date of sampling=0.58

LSD (0.01) for studied sites=0.38

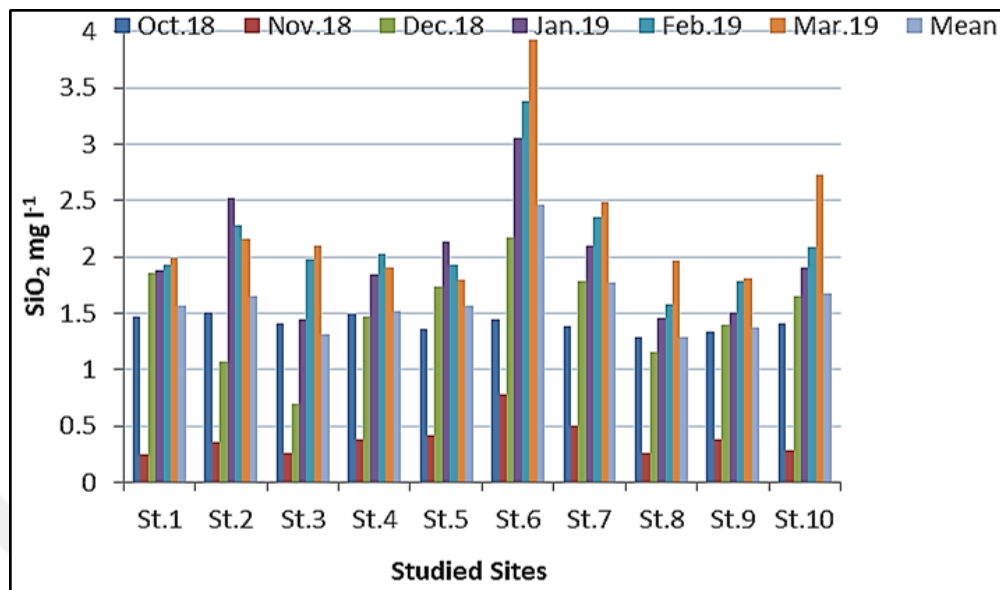


Figure 4.14. Reactive silicate-silicon concentration ( $\text{mg l}^{-1}$ ) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.15. Calcium- $\text{Ca}^{+2}$

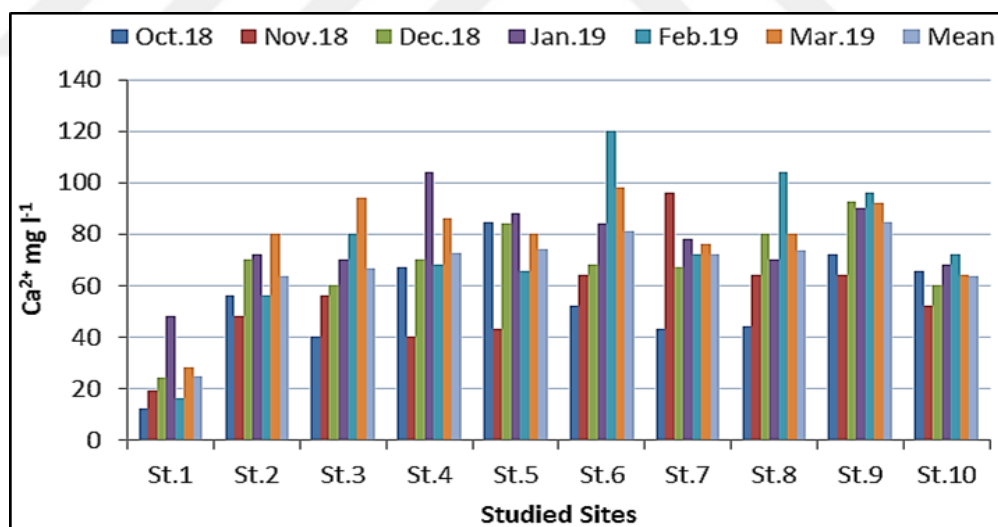
Calcium concentrations for the studied area indicated a very high fluctuation ranged from 12 to 120  $\text{mg Ca}^{+2} \text{l}^{-1}$ . An overall mean of calcium levels 67.7  $\text{mg Ca}^{+2} \text{l}^{-1}$  was calculated for all spring stations during the studied period. The minimum and maximum calcium concentrations were observed in sites 1 and 6 during October 2018 and February 2019 respectively. On the other hand, sites 6, and 9 showed high levels of calcium concentrations, while site 1 was characterized by low levels. The results indicated that there is a significant difference ( $P < 0.01$ ) between studied sites and date of sampling. This pattern of distribution reflects that the total hardness in the studied area were dominated by calcium other than magnesium, this may be due to the distribution of calcareous rocks in natural waters, the same situation was observed by Ibrahim (1981) in Sulaimaniyah, Rasheed (1994) and Aziz (1997) in Arbil, and Al – Nakshbandi (2002) in Duhok.

Table 4.15. Calcium level (mg l<sup>-1</sup>) in 10 spring sites within Erbil province, during the studied

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	12.0	56.0	40.0	67.2	84.8	52.0	43.2	44.4	72.0	65.6	53.7
	Nov.	19.2	48.0	56.0	40.0	43.2	64.0	96.0	64.0	64.0	52.0	54.6
	Dec.	24.0	70.0	60.0	70.0	84.0	68.0	67.2	80.0	92.8	60.0	67.6
2019	Jan.	48.0	72.0	70.0	104.0	88.0	84.0	78.0	70.0	90.0	68.0	77.2
	Feb.	16.0	56.0	80.0	68.0	65.6	120.0	72.0	104.0	96.0	72.0	75.0
	Mar.	28.0	80.0	94.0	86.0	80.0	98.0	76.0	80.0	92.0	64.0	77.8
Mean	24.5	63.7	66.7	72.5	74.3	81.0	72.1	73.7	84.5	63.6	67.7	

LSD (0.01) for date of sampling=10.79

LSD (0.01) for studied sites=7.00

Figure 4.15. Calcium concentration (mg l<sup>-1</sup>) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.16. Magnesium-Mg<sup>+2</sup>

An overall mean of magnesium concentrations of 19.9 mg Mg<sup>+2</sup> l<sup>-1</sup> was calculated, the results showed significant (P<0.01) seasonal variations between sites and date of sampling. The highest level of magnesium concentrations 43 mg Mg<sup>+2</sup> l<sup>-1</sup> was recorded in

site 2 during February 2019, whereas the lowest value 7.0 mg Mg<sup>+2</sup>l<sup>-1</sup> was measured in site 3 during March 2019. In general the results revealed that magnesium concentrations were lower than calcium in the studied area and during the period of this study. This may be due to the distribution of calcareous rocks in natural waters, the same situation was observed by Ibrahim (1981) in Sulaimaniyah, Rasheed (1994) and Aziz (1997) in Arbil, and Al – Nakshbandi (2002) in Duhok.

Table 4.16. Magnesium level (mg l<sup>-1</sup>) in 10 spring sites within Erbil province, during the studied period.

Date		Sites										Mean
		1	2	3	4	5	6	7	8	9	10	
2018	Oct.	16.8	26.4	40.8	3.8	1.9	26.4	20.3	8.9	13.4	12.5	17.1
	Nov.	12.5	21.1	19.2	31.2	29.3	28.8	14.4	19.2	21.6	26.4	22.4
	Dec.	17.0	18.4	17.6	13.0	19.4	24.0	19.7	14.4	13.4	24.8	18.2
2019	Jan.	12.0	14.4	22.0	16.8	7.2	26.2	19.0	17.8	10.8	25.0	17.1
	Feb.	40.8	43.0	24.0	33.6	23.0	9.6	21.6	23.0	7.7	26.4	24.6
	Mar.	23.0	25.2	7.0	12.2	13.2	37.6	25.0	24.6	14.4	21.6	20.4
Mean		20.3	23.6	21.8	18.4	15.7	25.4	20.0	18.0	13.6	22.8	19.9

LSD (0.01) for date of sampling=9.05

LSD (0.01) for studied sites=5.87

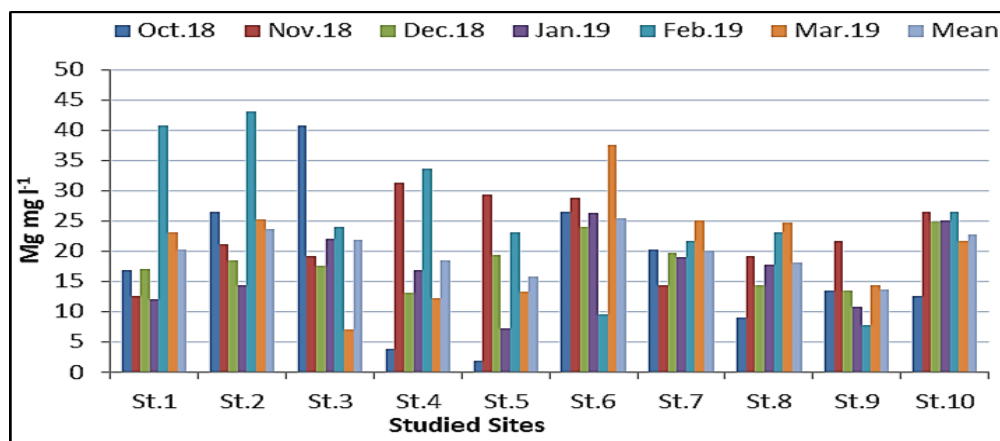


Figure 4.16. Magnesium concentration (mg l<sup>-1</sup>) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.17. Dissolved oxygen-DO

Dissolved oxygen concentration results showed significant differences ( $P < 0.01$ ) between spring stations and date of sampling during the studied period with an overall mean of  $4.97 \text{ mg l}^{-1}$ . On the other hand, sites 1 and 8 showed high levels of dissolved oxygen concentrations with maximum level of  $10.5 \text{ mg l}^{-1}$  at site 8 during October 2018, whereas the minimum value of  $0.92 \text{ mg l}^{-1}$  was measured in site 2 during November 2018.

Oxygen reaches water by photosynthesis of marine biota and oxygen exchange across the air – water network, the amount of oxygen the water may carry depends on water temperature, salinity and pressure. (Leggett *et. al.*, 2001). However, the non-thermal cold springs contained high levels of Do to compared with thermal springs, this depend on gas solubility which increased by decreased temperature, the results of Leggett *et. al.*, (2001) of selected wetlands and springs in northwestern Namibia confirm this relationship between DO and temperature. The measurement of DO provides a good indication of water quality.

Table 4.17. Dissolved oxygen concentration ( $\text{mg l}^{-1}$ ) in 10 spring stations within Erbil province, during the studied period.

Date		Sites										Mean
		1	2	3	4	5	6	7	8	9	10	
2018	Oct.	8.28	1.66	2.76	3.68	5.34	3.86	7.73	10.5	5.70	9.8	5.93
	Nov.	6.62	0.92	1.61	5.61	2.94	3.22	3.86	9.2	7.82	5.06	4.69
	Dec.	6.44	1.93	1.56	5.52	3.68	2.39	5.52	9.7	5.98	5.52	4.82
2019	Jan.	6.90	2.76	2.39	5.06	5.98	2.02	5.89	7.36	4.60	6.62	4.96
	Feb.	7.36	1.47	2.21	7.91	4.14	1.38	5.52	5.70	5.70	7.18	4.86
	Mar.	6.90	1.66	2.85	6.44	4.14	2.30	5.34	5.52	5.52	5.15	4.58
Mean		7.08	1.73	2.23	5.70	4.37	2.53	5.64	7.99	5.89	6.56	4.97

LSD (0.01) for date of sampling=0.99

LSD (0.01) for studied sites=0.64

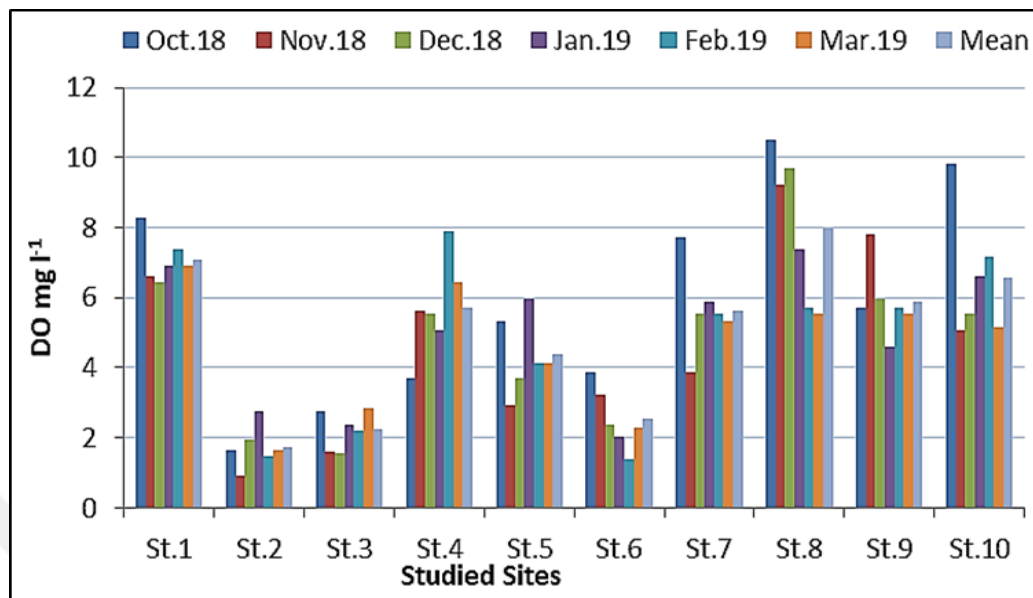


Figure 4.17. Dissolved oxygen concentration ( $\text{mg l}^{-1}$ ) recorded for 10 spring stations within Erbil Province, during the studied period.

#### 4.1.18. Biological oxygen demand-BOD<sub>5</sub>

The results of five-day Biological Oxygen Demand (BOD<sub>5</sub>) indicated significant difference ( $P < 0.01$ ) between studied sites and during the period of the study with an overall mean of  $1.58 \text{ mg l}^{-1}$  for all spring stations. The highest level recorded was  $4.14 \text{ mg l}^{-1}$  in sites 8 November 2018, while the lowest levels recorded was  $0.18 \text{ mg l}^{-1}$  in site 3 during February 2019. On the other hand, sites 6, 8, 9, and 10 showed high levels of BOD<sub>5</sub> with mean value never fell below  $2 \text{ mg l}^{-1}$  during the period of the study, whereas sites 2 and 3 were rarely exceeded  $1 \text{ mg l}^{-1}$  during whole studied period. The results revealed that all studied springs have a good water quality.

Biological Oxygen Interest for five days (BOD<sub>5</sub>) characterized as the measure of oxygen required by microscopic organisms while balancing out decomposable natural issue under high-impact conditions inside 5 days (Sawyer and McCarty, 1978).

Table 4.18. Biological oxygen demand concentration (mg l<sup>-1</sup>) in 10 spring stations within Erbil province, during the studied period.

Date		Sites										Mean
		1	2	3	4	5	6	7	8	9	10	
2018	Oct.	1.06	1.10	1.10	0.74	0.92	3.50	3.31	3.86	2.58	3.31	2.21
	Nov.	0.87	0.46	0.78	1.10	0.64	2.94	1.10	4.14	1.93	3.22	1.72
	Dec.	0.37	0.74	0.46	1.75	1.10	1.79	2.30	2.76	2.94	1.84	1.61
2019	Jan.	1.38	0.92	0.55	0.46	0.55	1.66	1.52	2.21	2.07	2.62	1.39
	Feb.	1.10	0.55	0.18	1.47	1.38	1.15	1.10	0.64	1.56	2.94	1.21
	Mar.	1.66	0.83	0.87	1.10	1.70	2.16	0.87	1.10	1.33	1.66	1.33
Mean		1.07	0.77	0.66	1.10	1.05	2.20	1.70	2.45	2.07	2.60	1.58

LSD (0.01) for date of sampling=0.73

LSD (0.01) for studied sites=0.47

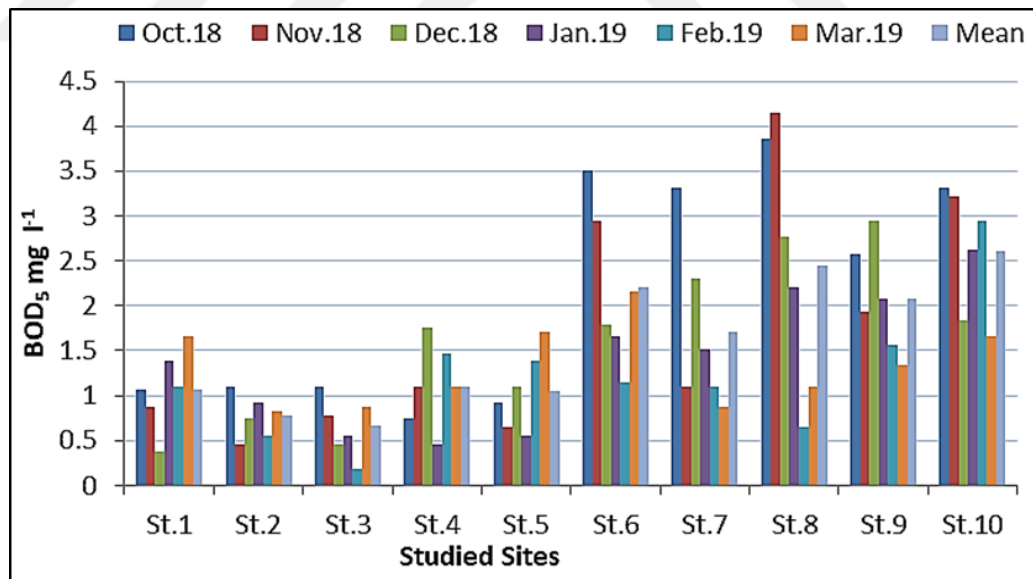


Figure 4.18. Biological oxygen demand concentration (mg l<sup>-1</sup>) recorded for 10 spring stations within Erbil Province, during the studied period.

## 4.2. Algal Study

### 4.2.1. Diatom species composition

Diatomes, *Heterokontophyta* Divisiio, is a group of organisms connected to *Bacillariophyceae* class. As seen in Table 4.19, Table 4.20, Table 4.21, Table 4.22 and Figure 4.19 at Choman District spring water research stations, 7 dias, 10 families, 45 sex-related taxa were tested during the study.

As seen in Table 4.20 Figure 4.19, in the distribution of taxa diagnosed at the Choman District spring water research stations by teams, the highest was ranked as *Naviculales* (38), *Fragilariales* (17), *Achnanthes* (12) and at least *Eunotiales* (1).

As seen in Table 4.21, the highest *Cymbella* (7; 8.05%), *Navicula* (7; 8.05%), *Nitzschia* (6%) in the distribution of the number and percentage of diatom taxons of Choman District spring water research stations by sex. 6,90), while at least 25 genera (1; 1.15%) such as *Achnanthes* and *Cyclostephanos*.

Table 4.19. Diatom taxa recorded during the working period of Choman District stations

Division: Heterokontophyta	Order: Naviculales
Class: Bacillariophyceae	Family: Naviculaceae
Order: Eupodiscales	<i>Gyrosigma</i> Hass., 1895.
Family: Cosinodisceae	<i>G. acuminatum</i> Kuetz.
<i>Cyclotella</i> (Kuetz.) de Brebisson, 1838.	<i>G. attenuatum</i> (Kuetz) Rabh.
<i>C. meneghiniana</i> Kuetz.	<i>Mastogloia</i> Thwaites ex. W. Smith, 1856.
<i>Pantocsekiella kuetzingiana</i> (Thwaites) K.T.Kiss & E.Ács	<i>M. muradii</i> Voigt.
<i>Aulacoseira</i> Thwaites, 1848	<i>M. smithii</i> Thwaites.
<i>A. ambigua</i> (Grunow) Simonsen	<i>Navicula</i> Bory, 1824.
<i>A. granulata</i> (Ehrenberg) Simonsen	<i>N. cincta</i> (Ehr.) Kuetz.
<i>Cyclostephanos</i> Round, 1987	<i>N. cryptocephala</i> Kuetz.
<i>C. dubius</i> (Hustedt) Round	<i>N. gregaria</i> Grun.
Order: Fragilariales	<i>N. lanceolata</i> (Agardh.) Ehr.
Family: Fragilariaceae	<i>N. phyllepta</i> Kuetz.
Subfamily: Diatomoideae	<i>N. radiosa</i> Kuetz.

<i>Diatoma</i> de Cand., 1805.	<i>N. radiosa</i> var. <i>tenella</i> (de Brebisson) Grun.
<i>D. elongatum</i> (Lyngb.) Heib.	<i>Craticula cuspidata</i> (Kützing) D.G.Mann
<i>D. hiemale</i> (Lyngb.) Agardh.	<i>Sellaphora pupula</i> (Kützing) Mereschkovsky
<i>D. vulgare</i> Bory.	<i>Diadesmis laevissima</i> (Cleve) D.G.Mann
<i>Meridion</i> Agardh, 1824.	<i>Nedium</i> Pfitzer, 1871.
<i>M. circular</i> Agardh.	<i>N. affine</i> (Ehr.) Cleve.
Subfamily: Fragilliodeae	<i>Pinularia</i> Ehrenberg, 1843.
<i>Fragilaria</i> Lyngb., 1819.	<i>P. appendiculata</i> (Agard.) Cleve.
<i>F. capucina</i> Demaz.	<i>P. brebissonii</i> (Kuetz.) Rabh.
<i>F. capucina</i> var. <i>vaucheriae</i> (Kützing) Lange-Bertalot	<i>P. stomatophora</i> Grun.
<i>F. construens</i> var. <i>venter</i> (Ehr.) Grun.	<i>P. viridis</i> (Nitzsch.) Ehr.
<i>F. crotenensis</i> Kitton.	<i>Stauroneis</i> Ehrenberg, 1843.
<i>F. famelica</i> (Kützing) Lange-Bertalot	<i>S. smithii</i> Grun.
<i>Fragilariforma virescens</i> (Ralfs) D.M.Williams & Round	Family: Cymbellaceae
<i>Pseudostaurosira brevistriata</i> (Grunow) D.M.Williams & Round	<i>Amphora</i> Ehrenberg, 1840.
<i>Staurosira construens</i> Ehrenberg	<i>A. ovalis</i> Kuetz.
<i>Staurosira neoproducta</i> (Lange-Bertalot) Chudae & Gololobova	<i>A. pediculus</i> Kuetz.
<i>Staurosirella pinnata</i> (Ehrenberg) D.M.Williams & Round	<i>Halamphora</i> (Cleve) Mereschkovsky, 1903
<i>Synedra</i> Ehrenberg, 1832.	<i>H. veneta</i> (Kützing) Levkov
<i>Ulnaria acus</i> (Kützing) Aboal	<i>Cymbella</i> Agardh, 1830.
<i>Ctenophora pulchella</i> (Ralfs ex Kützing) D.M.Williams & Round	<i>C. affinis</i> Kuetz.
<i>Tabularia tabulata</i> (C.Agardh) Snoeijs	<i>C. aspera</i> Ehr.
<i>Ulnaria ulna</i> (Nitzsch) Compère	<i>C. caespitosa</i> (Kuetz) Grun.
<i>Synedra balthica</i> Ehrenberg.	<i>C. cistulla</i> Hemprich.
Order: Eunotiales	<i>C. hustedtii</i> Krasske.
Family: Eunotiaceae	<i>C. parva</i> (W. Smith) Cleve.
<i>Euonotia</i> Ehrenberg, 1837.	<i>C. tumidula</i> Grun.
<i>E. flexuosa</i> Kuetz.	Family: Gomphonemaceae
Order: Achnanthales	<i>Gomphonella</i> Rabenhorst, 1853
Family: Achnanthaceae	<i>G. olivacea</i> (Hornemann) Rabenhorst
Subfamily: Achnanthioidae	<i>Gomphonema</i> Ehrenberg, 1831.
<i>Achnanthes</i> Bory, 1822.	<i>G. angustatum</i> (Kuetz) Rabh.
<i>Achnantheidium affine</i> (Grunow) Czarnecki	<i>G. constrictum</i> Ehr.
<i>Planothidium delicatulum</i> (Kützing) Round & Bukhtiyarova	Order: Epithemiales
<i>Lemnicola hungarica</i> (Grunow) Round & Basson	Family: Epithemiaceae
<i>Planothidium lanceolatum</i> (Brébisson ex Kützing) Lange-Bertalot	<i>Denticula</i> Kuetz., Bacil. 1844.
<i>Achnantheidium minutissimum</i> (Kützing) Czarnecki	<i>D. elegans</i> Kuetz.
<i>Platessa saxonica</i> (Krasske ex Hustedt) C.E.Wetzel, Lange-Bertalot & Ector	<i>Epithemia</i> de Brebisson ex. Kuetz., 1844
Subfamily: Cocconeioideae	<i>E. argus</i> Kuetz.
<i>Cocconeis</i> Ehrenberg, 1838.	<i>E. sorax</i> Kuetz.
<i>C. disculus</i> Schumann.	<i>E. adnata</i> (Kützing) Brébisson.
<i>C. pediculus</i> Ehr.	Order: Bacillariales
<i>C. placentula</i> Ehr.	Family: Nitzchiaceae

<i>Peronia</i> Brebisson et. Arnott, 1868.	<i>Hantzschia</i> Grunow, 1877.
<i>P. fabula</i> (de Brebissonet Arnott) Ross.	<i>H. amphioxys</i> (Ehr.) Grun.
<i>Rhoicosphenia</i> Grunow, 1860.	<i>Nitzschia</i> Hass., 1845.
<i>R. abbreviata</i> (C.Agardh) Lange-Bertalot	<i>N. amphibia</i> Grun.
Order: Naviculales	<i>N. commutata</i> Grun.
Family: Naviculaceae	<i>N. dubia</i> W. Sm.
<i>Caloneis</i> Cleve, 1894.	<i>N. linearis</i> W. Smith.
<i>C. permagna</i> (Bailey) Cleve.	<i>N. palea</i> (Kuetz) W.Sm.
<i>C. ventricosa</i> (Ehr.) Meister.	<i>N. paleacea</i> Grun.
<i>Diploneis</i> Ehrenberg, 1824.	Order: Surirellales
<i>D. elliptica</i> Kuetz.	Family: Surirellaceae
<i>D. ovalis</i> (Hilse) Cleve.	<i>Surirella</i> Turpin, 1828.
<i>Frustulia</i> Rabh., 1853.	<i>S. amphioxys</i> W.Smith
<i>F. vulgaris</i> Thwaites.	<i>S. ovalis</i> de Brebisson.
<i>Gyrosigma</i> Hass., 1895.	Toplam / 87 takson

Table 4.20. Distribution of diatom taxa by teams in Choman District stations

Team	Cins	Taksa
<i>Naviculales</i>	17	38
<i>Fragilariales</i>	9	17
<i>Achnanthes</i>	8	12
<i>Bacillariales</i>	3	9
<i>Eupodiscales</i>	5	6
<i>Epithemiales</i>	2	4
<i>Eunotiales</i>	1	1
<b>Average</b>	<b>45</b>	<b>87</b>

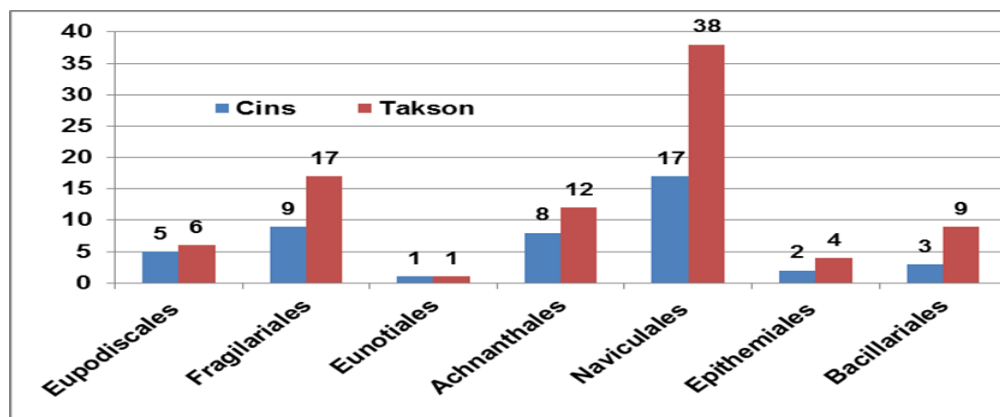


Figure 4.19. Distribution of diatom taxa by teams in Choman District stations

Table 4.21. Number of diatom taxa and% of Choman District stations by sex

<i>Cinsler</i>	Taxon number	Percent (%)	<i>Cinsler</i>	Taxon number	Percent (%)
<i>Cymbella</i>	7	8,05	<i>Cyclotella</i>	1	1,15
<i>Navicula</i>	7	8,05	<i>Denticula</i>	1	1,15
<i>Nitzschia</i>	6	6,90	<i>Euonotia</i>	1	1,15
<i>Fragilaria</i>	5	5,75	<i>Fragilariforma</i>	1	1,15
<i>Pinularia</i>	4	4,60	<i>Frustulia</i>	1	1,15
<i>Cocconeis</i>	3	3,45	<i>Hantzschia</i>	1	1,15
<i>Diatoma</i>	3	3,45	<i>Meridion</i>	1	1,15
<i>Epithemia</i>	3	3,45	<i>Nedium</i>	1	1,15
<i>Aulacoseira</i>	2	2,30	<i>Peronia</i>	1	1,15
<i>Amphora</i>	2	2,30	<i>Pantocsekiella</i>	1	1,15
<i>Caloneis</i>	2	2,30	<i>Rhoicosphenia</i>	1	1,15
<i>Diploneis</i>	2	2,30	<i>Pseudostaurosira</i>	1	1,15
<i>Gomphonema</i>	2	2,30	<i>Stauroneis</i>	1	1,15
<i>Gyrosigma</i>	2	2,30	<i>Synedra</i>	1	1,15
<i>Mastogloia</i>	2	2,30	<i>Ulnaria</i>	1	1,15
<i>Melosira</i>	2	2,30	<i>Tabularia</i>	1	1,15
<i>Surirella</i>	2	2,30	<i>Lemnicola</i>	1	1,15
<i>Staurosira</i>	2	2,30	<i>Platessa</i>	1	1,15
<i>Achnanthidium</i>	2	2,30	<i>Craticula</i>	1	1,15
<i>Planothidium</i>	2	2,30	<i>Sellaphora</i>	1	1,15
<i>Achnanthes</i>	1	1,15	<i>Diadesmis</i>	1	1,15
<i>Cyclostephanos</i>	1	1,15	<i>Halamphora</i>	1	1,15
			<i>Gomphonella</i>	1	1,15
			<b>Toplam</b>	<b>87</b>	<b>% 100</b>

As seen in Table 4.22 and Figure 4.20, the monthly change and periodicity of the diatom taxa of the Choman District spring water research stations are maximum from the lowest to March (56), February (46), January (31), December (25), October ( 24) was realized as November (14). The high number of diatom taxa in March and February can be explained by the high silica and nitrate values in water (Egge and Aksnes, 1992).

As seen in Figure 4.21, Choman District spring water research stations in the number of incidence of diatom taxa in all six-month stations; *Tabularia tabulata*, *Ulnaria*

ulna and *Pinularia brebissonii* 6 times; *Diatoma hiemale* and *Cymbella affinis* were the highest taxa 5 times, 14 taxa 4 times, 17 taxa 3 times 28 taxa 2 times and 22 taxa 1 time.

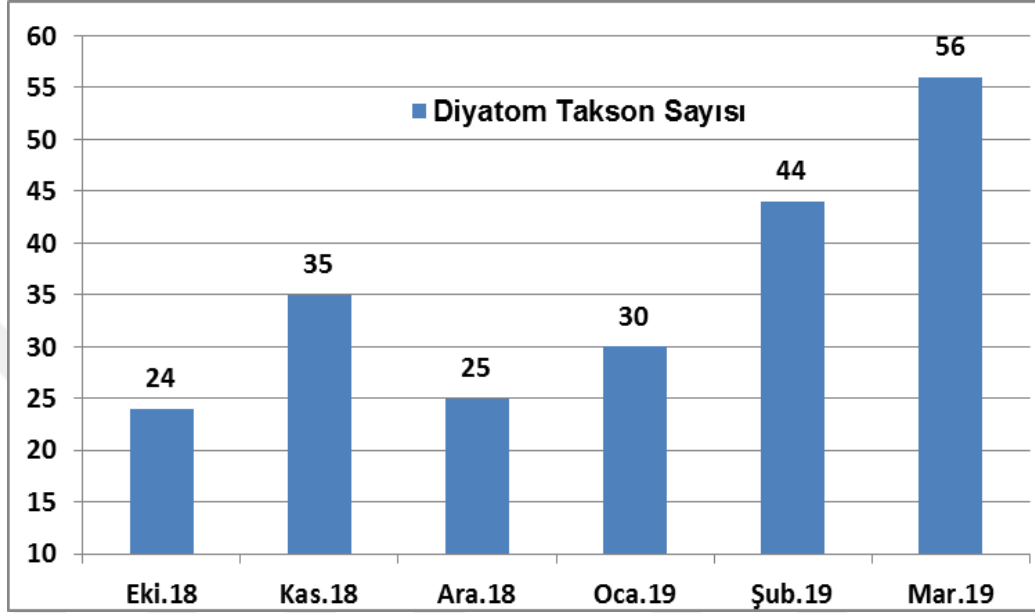


Figure 4.20. The number of times the diatom taxa of Choman District stations are seen at all stations by months.

Table 4.22. Choman District stations diatom taxa monthly change and periodicity

Diatom species	Months					
	2018				2019	
	October	November	December	January	February	March
<i>Cyclotella meneghiniana</i>						+
<i>Pantocsekiella kuetzingiana</i>	+	+				
<i>Aulacoseira ambigua</i>	+	+	+			+
<i>A. granulata</i>		+	+			
<i>Cyclostephanos dubius</i>	+	+				+
<i>Diatoma elongatum.</i>		+			+	
<i>D. hiemale</i>	+	+		+	+	+
<i>D. vulgare</i>		+			+	+
<i>Meridion circular</i>				+	+	
<i>Fragilaria capucina</i>	+	+			+	+
<i>F. capucina</i> var. <i>vaucheriae</i>			+			+
<i>F. construens</i> var. <i>venter</i>					+	+
<i>F. crotensis</i>	+	+		+		
<i>F. famelica</i>	+	+				+
<i>Fragilariforma virescens</i>	+	+	+		+	
<i>Pseudostaurosira brevistriata</i>		+				
<i>Staurosira construens</i>						+

Diatom species	Months					
	2018				2019	
	October	November	December	January	February	March
<i>Staurosira neoproducta</i>		+	+			+
<i>Staurosirella pinnata</i>		+				
<i>Ulnaria acus</i>	+	+			+	+
<i>Ctenophora pulchella</i>					+	+
<i>Tabularia tabulata</i>	+	+	+	+	+	+
<i>Ulnaria ulna</i>	+	+	+	+	+	+
<i>Synedra balthica</i>	+				+	+
<i>Euonotia flexuosa</i>						+
<i>Achnantheidium affine</i>	+	+			+	+
<i>Planothidium delicatulum</i>				+		
<i>Lemnicola hungarica</i>			+			+
<i>Planothidium lanceolatum</i>	+			+	+	+
<i>Achnantheidium minutissimum</i>				+	+	+
<i>Platessa saxonica</i>		+				+
<i>Cocconeis disculus</i>	+	+				
<i>C. pediculus</i>		+	+	+	+	
<i>C. placentula</i>	+	+			+	+
<i>Peronia fabula</i>			+	+		
<i>Rhoicosphenia abbreviata</i>			+			+
<i>Caloneis permagna</i>		+			+	+
<i>C. ventricosa</i>		+				+
<i>Diploneis elliptica</i>						+
<i>D. ovalis</i>		+				
<i>Frustulia vulgaris</i>		+			+	+
<i>Gyrosigma acuminatum</i>					+	+
<i>G. attenuatum</i>						+
<i>Mastogloia muradii</i>		+				
<i>M. smithii</i>		+	+			
<i>Navicula cincta</i>	+	+				+
<i>N. cryptocephala</i>		+	+			
<i>N. gregaria</i>	+					
<i>N. lanceolata</i>	+			+		
<i>N. phyllepta</i>		+	+			+
<i>N. radiosa</i>					+	+
<i>N. radiosa var. tenella</i>	+					+
<i>Craticula cuspidata</i>	+					
<i>Sellaphora pupula</i>		+				+
<i>Diadesmis laevisissima</i>					+	
<i>Nedium affine</i>						+
<i>Pinularia appendiculata</i>				+	+	+
<i>P. brebissonii</i>	+	+	+	+	+	+
<i>P. stomatophora</i>	+	+	+	+		
<i>P. viridis</i>			+	+	+	+
<i>Stauroneis smithii</i>			+	+	+	
<i>Amphora ovalis</i>			+	+	+	+
<i>A. pediculus</i>					+	+
<i>Halamphora veneta</i>					+	

Diatom species	Months					
	2018				2019	
	October	November	December	January	February	March
<i>Cymbella affinis</i>		+	+	+	+	+
<i>C. aspera</i>	+	+	+	+		
<i>C. caespitose</i>				+	+	+
<i>C. cistulla</i>				+		
<i>C. hustedtii</i>						+
<i>C. parva</i>				+	+	+
<i>C. tumidula</i>						+
<i>Gomphonella olivacea</i>				+	+	
<i>Gomphonema angustatum</i>			+	+	+	+
<i>G. constrictum</i>					+	+
<i>Denticula elegans</i>				+	+	+
<i>Epithemia argus</i>					+	
<i>E. sorax</i>						+
<i>E. adnata</i>					+	+
<i>Hantzschia amphioxys</i>			+			
<i>Nitzschia amphibian</i>			+	+		
<i>N. commutate</i>				+	+	
<i>N. dubia</i>					+	+
<i>N. linearis</i>						+
<i>N. palea</i>				+	+	+
<i>N. paleacea</i>					+	+
<i>Surirella amphioxys</i>			+	+	+	+
<i>S. ovalis</i>				+	+	
<b>Toplam / 87 takson</b>	<b>24</b>	<b>14</b>	<b>25</b>	<b>31</b>	<b>46</b>	<b>56</b>

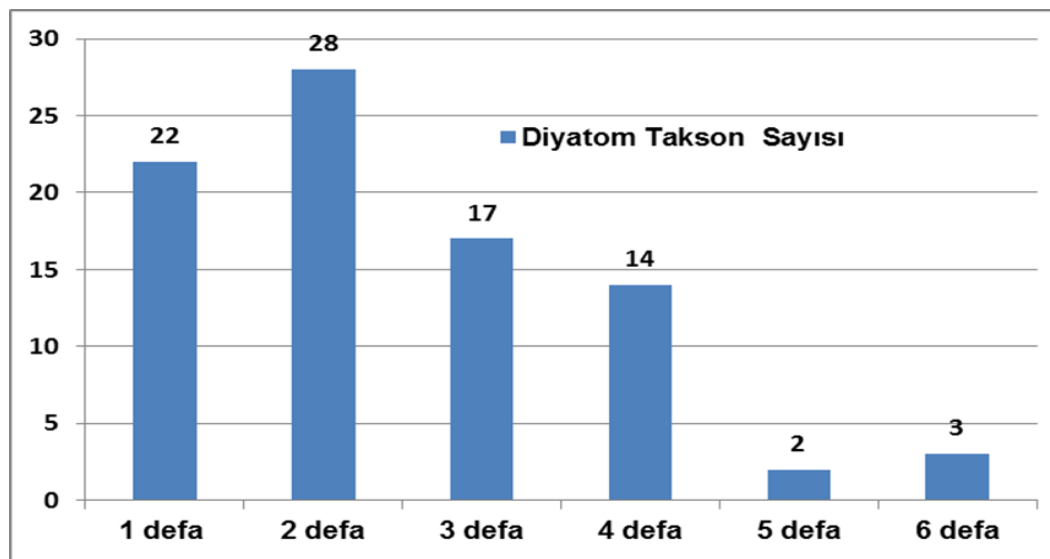


Figure 4.21. Number of diatom taxa of Choman District stations at all stations

#### 4.2.2. Diatom productivity (Total number of diatoms)

Table 4.23 and Figure 4.22, the total number of diatom cells ( $\times 10^3$  l<sup>-1</sup>) of the total stations of the Choman District spring water research stations change from the highest to the lowest stations; 2nd station (397.8), 4th station (299.7), 3rd station (293), 5th station (123.4), 1st station (98.9), 6th station (97.4), 10th station (69.2), 9th station (65.6), 7th station (57.7) and 8th station (42.8). The change according to the months; November (117.4), October (115.7), March (106.7), December (104.9), January (60.93) and February (52.83). According to months, the high number of diatom taxa can be explained by day length, air and water temperature, high silica and nitrate values in water (Egge and Aksnes, 1992).

Table 4.23. Total number of diatoms (cells  $\times 10^3$  l<sup>-1</sup>) in 10 spring sites during the studied period.

Date	Sites										Mean	
	1	2	3	4	5	6	7	8	9	10		
2018	Oct.	116.	491.	367.	398.	164.	118.	62.	46.8	72.3	191.	115.7
	Nov.	119.	474.	370.	374.	198.	113.	65.	46.5	76.4	192.	117.4
	Dec.	105.	429.	335.	347.	106.	99.5	68.	62.3	77.2	171.	104.9
2019	Jan.	67.8	294.	225.	224.	63.1	71.4	40.	27.7	41.2	110.	60.93
	Feb.	69.2	284.	156.	139.	73.3	63.4	36.	23.3	40.3	93.2	52.83
	Mar.	114.	412.	302.	314.	134.	118.	73.	49.7	85.8	168.	106.7
Mean	98.9	397.	293.	299.	123.	97.4	57.	42.8	65.6	69.2	154.5	

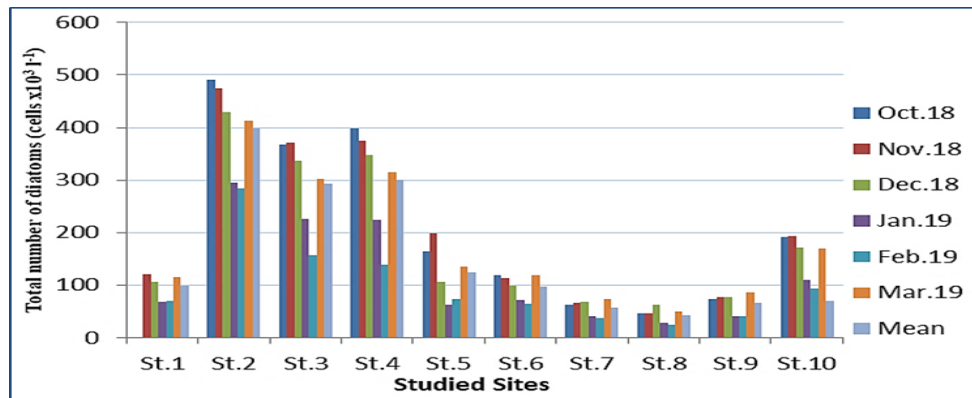


Figure 4.22. Total number of diatoms (cells  $\times 10^3$  l<sup>-1</sup>) in 10 spring sites during the studied period

### 4.2.3. Diatom species diversity

Diversity indices is an alternative method to determine an indicator organisms, as a means of assessing water quality, using community structure or its diversity in terms of the number of individuals within a sample, changes in the diversity index may be used to estimate changes in community structure (Hellawell, 1978).

Species diversity can refer to all organisms in a community, but usually restricted to that species which seems to be more common among others (Barnes et. al., 1998). In aquatic ecosystem, Diversity indexes are primarily a biological performance method through the community structure (Ismael and Dorgham, 2003).

In the present study, Shannon's diversity index was used. The value of diversity index during the period of the study were ranged from 1.09 to 2.02 (Table 22) at sites 2 and 9 during November 2018. Ali (2002) obtained levels of species diversity lower than one in main sewage channel in Erbil. Generally the diatom species diversity throughout whole studied period never fell below the value of one with an overall mean of 1.74, which means that all spring sites in Choman district characterized good to very good diatom species diversity and indicate good water quality in the area. On the other hand, sites 1 and 4 characterized by high diversity values with mean of greater than 1.9 during the studied period while site 9 have lower mean value with 1.34 among the studied spring sites.

High diversity index values for Choman District spring water research stations indicate well-balanced communities in an ecosystem, while low index values indicate stress and negative impact. Species diversity increases as you approach 5 in Shannon-Weiner (0-5) (Çiçek, 2011). Shannon-Weiner index species number richness, total number of individuals, generally followed a parallel course.

Table 4.24. Shannon diversity value of diatoms in 10 spring sites during the studied period.

Date		Sites										Mean
		1	2	3	4	5	6	7	8	9	10	
2018	Oct.	1.93	1.73	1.93	1.85	1.72	1.76	1.86	1.68	1.37	1.81	1.76
	Nov.	2.02	1.69	1.88	1.93	1.79	1.83	1.67	1.62	1.09	1.77	1.73
	Dec.	1.97	1.84	1.91	2.01	1.80	1.74	1.85	1.71	1.40	1.92	1.81
2019	Jan.	1.82	1.86	1.92	1.90	1.56	1.55	1.77	1.52	1.33	1.56	1.68
	Feb.	1.82	1.60	1.73	1.74	1.76	1.75	1.50	1.70	1.42	1.60	1.66
	Mar.	2.00	1.73	1.90	1.98	1.74	1.83	1.86	1.75	1.42	1.84	1.81
<b>Mean</b>		1.93	1.74	1.88	1.90	1.73	1.74	1.75	1.66	1.34	1.75	1.74

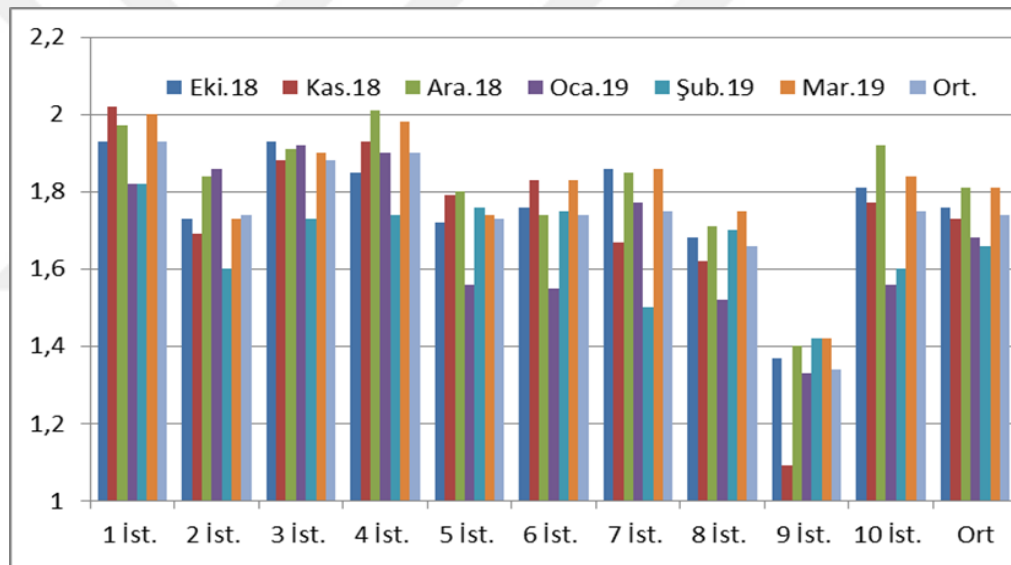


Figure 4.23. Changes of Shannon-Weiner diversity index values of the diatoms of Choman District stations.

## 5. CONCLUSION and RECOMMENDATIONS

### Conclusion and Recommendation

During the studied period in some spring sites in Choman district area, the following conclusions were noted:

1. The area characterized by moderate to cold weather with overall mean of 17°C.
2. All studied spring sites lied in the alkaline side of neutrality (pH > 7).
3. Site 1 (Kofi Ranginan spring) characterized by cold water with overall mean of 11°C, whereas site 3 (Banan spring) characterized by warm water quality with overall mean of 23.3°C.
4. Studied springs characterized by softly hard to hard water quality, site 1 (Kofi Ranginan spring) was soft, while site 5 (Perdok spring) site 6 (Mam Said spring) were moderately hard.
5. In all studied spring sites, calcium ion concentration dominated over magnesium ion concentration.
6. The three thermal springs in high altitude (sites 2, 3, and 4) were constantly in acidic condition of neutrality during whole studied period, although other springs were slightly alkaline and rarely exceeded pH 8.
7. All investigated springs classified as good quality, because of biochemical oxygen demand occasionally exceeded 2 mg l<sup>-1</sup>, and most of time the value was fluctuated around 1 mg l<sup>-1</sup>.
8. Phycologically, a total of 87 diatom species was identified and represented by 8 orders, 10 families and 30 genera.
9. Naviculaceae was placed in the first ranked order among the total identified diatoms represented by 25 species, dominated by *Navicula* with 10 species.
10. The value of diversity index during the period of the study were ranged from 1.09 to 2.02 and never fell below the value of one with an overall mean of 1.74, which means that all spring sites in Choman district characterized good to very good diatom species diversity and indicate good water quality in the area.

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## CURRICULUM VITAE

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### EDUCATION

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### RESEARCH INTERESTS

Ecology

### FOREIGN LANGUAGE

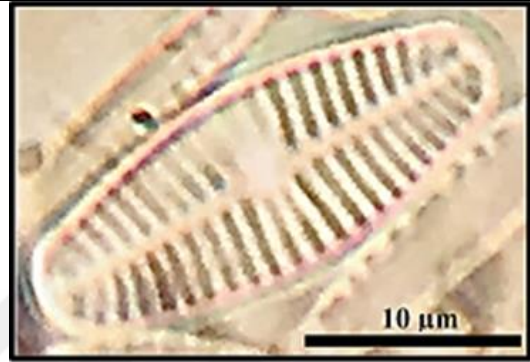
English, Turkish and Arabic

## APPENDICES

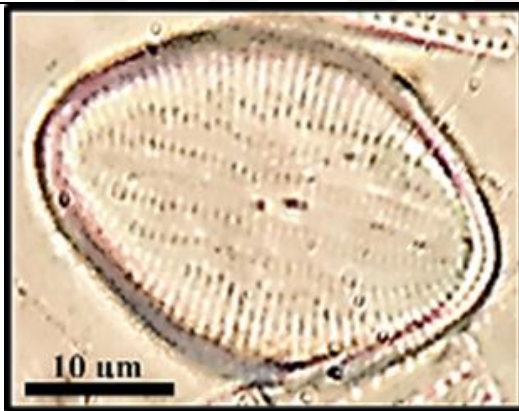
Some common types of diatoms recorded in the Choman region



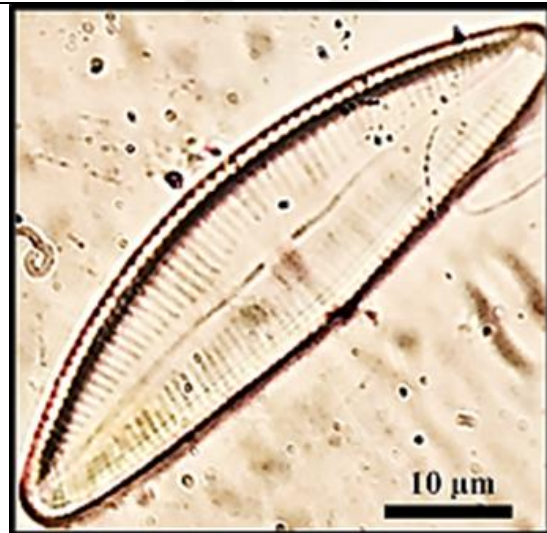
*Amphora pediculus*



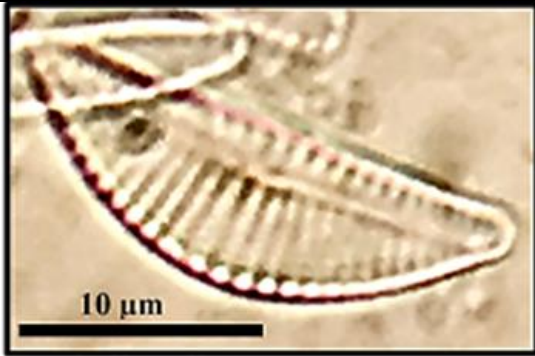
*Achmanthes lanceolata*



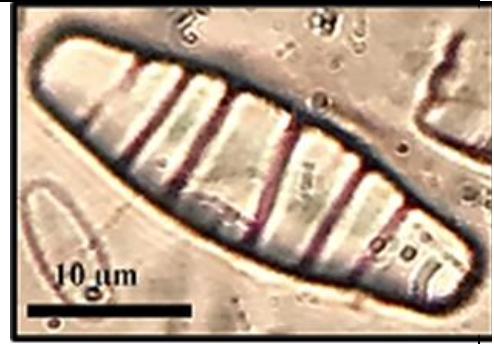
*Cocconeis placentula*



*Cymbella helvetica*



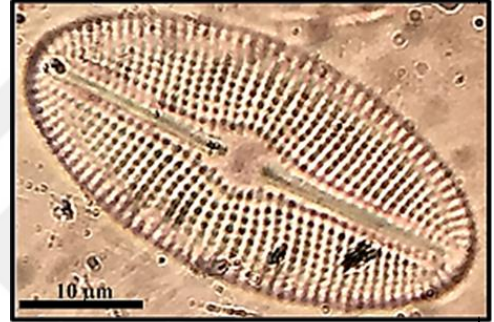
*Cymbella affinis*



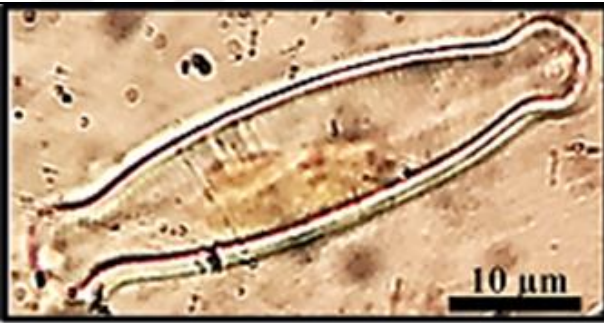
*Diatoma hiemale*



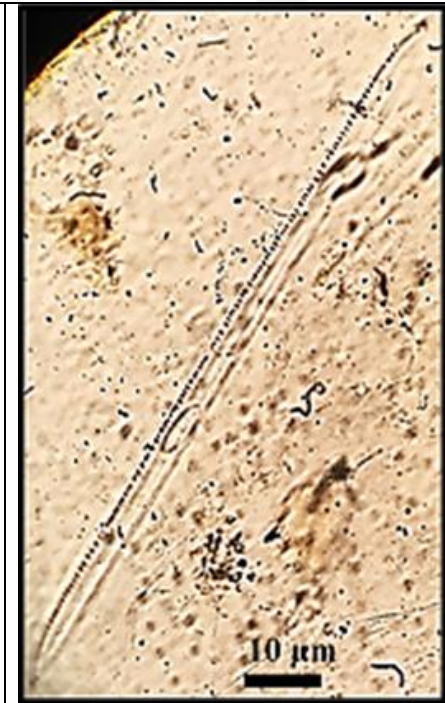
*Fragilariforma virescens*



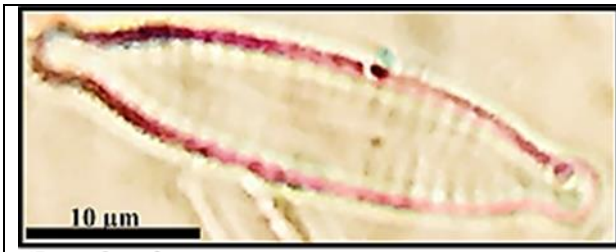
*Deploneis ovalis*



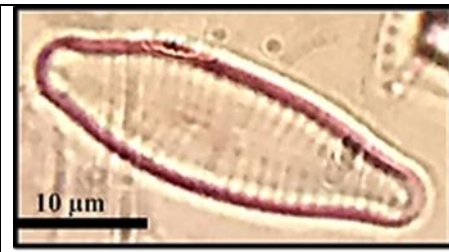
*Frustulia vulgaris*



*Nitzschia linearis*



*Fragilariforma virescens*



*Gomphonema constrictum*



*Nitzschia umbonata*



*Stauroneis smithii*



*Nitzschia subtubicola*