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Groundwater Problems in Erbil City

The project submitted to the Water Resources Department
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In the partial fulfillment of the requirements for the degree of Bachelor of Science in Water Resources Engineering

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Dedicated to

I dedicate this research to my supervisor who helped me to complete this project and belived in me (Dr. Reem Abdul Hakim Ahmed Alrawi) and all the lecturers of Water Resources Engineering Department.This submission represents not only the culmination of my efforts, but also a testament to your unwavering commitment to excellence. Without your guidance, this achievement would not have been possible. Thank you for your patience, encouragement, and unwavering support.

Supervisor Certificate

I certify that the engineering project titled **“Groundwater Problems in Erbil City”** was done under my supervision at the Water Resources Engineering Department, College of Engineering, Salahaddin University-Erbil. In the partial fulfillment of the requirement for the Bachelor of Science in Water Resources Engineering

Supervisors

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Abstract

Ground water samples from several wells in each sub basin of the Erbil basin will be collected for this study, but the majority of them will be in the central subbasin. We'll go over the main types and sources of contamination. Numerous physical, chemical, and biological tests are carried out. The data samples that have been gathered since 2003 and through 2023 will be compared and discussed. Each well's water quality index will be determined. Each subbasin's water level will be measured, and its increase and fall will also be computed. The goal of this project is to compare contamination types and sources from 2003 till 2023 from some specified wells which used to cause major issue of the ground water quality. The total wells around districts will be specified and the result of them will be shown statically and mathematically.

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LIST OF ABBREVIATIONS

BOD	Biological Oxygen Demand
DO	Dissolved Oxygen
RO	Reverse Osmosis
Sy	Specific Yield
T.Alkalinity	Total Alkalinity
T.A	Total Alkalinity
TDS	Total Dissolved Solids
TH	Total Hardness
TS	Total Solids
TSS	Total Suspended Solids
UNICEF	United Nations International Children's Emergency Fund
WHO	World Health Organization
WQ	Water Quality
WQI	Water Quality Index

Chapter One

Introduction

Groundwater is the subsurface water that exists in fully saturated soils and geological formations below the water table [1]. The widespread usage of groundwater as a significant source of water supply is largely due to its availability. Due to its quantity, consistency in quality, and low cost of use, groundwater is the primary source of water for many large cities around the world [2]. The recommended source of drinking water for around 30% of the world's population is the ground [3]. However, groundwater makes up between 5% and 7% of Iraq's water resources, and many cities and villages rely heavily on it for agricultural and drinking water [4].

Erbil City has had extensive growth and development since 2003. It is now among the cities in the area with the quickest growth. The trend of immigration into the city is increasing as a result of increased economic activity. The availability and sustainability of the city's water supplies are under immense pressure due to population growth, increased economic activity, and changes in citizen lifestyle [5].

There are several groundwater wells that have been dug, which is a cause for concern because groundwater is a significant source of drinking water, irrigation, and agricultural operations [6]. The groundwater is at risk in Erbil because of its extremely hot summers and semi-wet winters, even though some winters have average low rainfall. For instance, in 2021, Erbil city experienced water shortages because of low rainfall in the winter of 2020 and high temperatures in the summer of 2021, which led to a drop in groundwater levels, an electricity crisis, and a drought.

1.1. General Facts and Concept about Groundwater

The use of groundwater dates back to antiquity (about 7000 B.C.) in northern Iraq. Springs were utilized for water supply, irrigation, and for animals in the mountainous areas. Wells were primarily employed to furnish water and occasionally as tactical weapons in battle. To meet the needs of water, underground facilities were also created [7].

1.2. Physical and Chemical Properties

Some of the typical characteristics of Ground Water are Weak turbidity, a consistent temperature and chemical composition, and an almost complete lack of oxygen are some of the most typical features of groundwater. With the appearance of pollutants and other contaminants, the composition of flowing groundwater might vary greatly. Additionally, the microbiology of groundwater is frequently quite pure [8]. Groundwater characteristics include temperature, turbidity, color, and mineral content. **Table 1.1** lists numerous qualities, including pH, conductivity, total hardness, alkalinity, and metals.

The qualities of groundwater's chemical, physical, and microbiological composition govern its suitability for different uses. The concentration of inorganic components is determined through chemical analysis of groundwater. Measurements of pH and specific electrical conductance are also part of the analysis. Tests to determine the presence of E. coli are typically part of a bacterial analysis [9].

Table 1.1[9] [10] illustrates the characteristics of groundwater and the description of each one of them.

Table 1.1 Groundwater characteristics and their descriptions

Groundwater characteristics	Description
pH	Is the most examined parameter in water. It stands for the alkaline or acidic of a liquid and is ranked on a range of 1-14 [11]. Water with pH > 8.5 or < 6.5 can produce staining, etching, or scaling.
Temperature	The temperature of groundwater is generally equal to the mean air temperature above the land surface.
Turbidity (mg/L)	Is an expression of level of cloudiness of water sample caused by the presence of silt, suspended matter, colloidal particles and other microorganism. The cloudier, the dirtier.
Dissolved oxygen (DO) (mg/L)	The level of DO in water is used as an indication of pollution and its potability. Low levels of DO in water are a sign of pollution.
Total Hardness (TH) (mg/L)	The two elements in charge of TH are Ca^{+2} and Mg, and have two types, temporarily and permanent. For drinking, limit of TH should be between (100-500) mg/L.
Total Alkalinity (TA) (mg/L)	Is an index of the buffering capacity of water produced anions of weak acids. An increase in TA causes a loss of color. Drinking water standard have a range of TA between (80-120) mg/L.
Nitrates NO_3^- and nitrites NO_2^-	They are considered together because conversion from one to the other occurs in the environment and the health effects of NO_3^- are generally as a result of its ready conversion to NO_2^- in the body. High concentration of NO_3^- has risk on environmental and public health. NO_3-has a range (1-50) mg/L and NO_2^- has (0.01 -2) mg/L.
Total Solids (TS) Total Dissolved Solids (TDS) and Total Suspended Solids (TSS)	TS can be classified into suspended, dissolved, and settleable solids in water. In groundwater, DS formed from Ca^{+2}, S, NO_3^-, Fe, Cl^-, P, and other ions particles move through a filter with holes of around two microns in size. Similarly, TDS is the inorganic salts and small amounts of organic matter present in water solution. In contrast, SS produced from clay and silt particles, algae, plankton, fine organic debris, and other particulate matter. Water with < 1000 mg/L is generally reasonable to drink.
Electrical Conductivity EC (µmohs/cm)	EC is the amount of total substitution dissolved in water [12]. The overall EC value is > 400 (µmohs/cm) in most of the studies.
Metals	Metals affects groundwater quality and human‟s health. Metals in groundwater include: K, Si, Na, Zn, Mn, Ni, Pb, F, Cu, Al,…etc.
Phosphate PO_4^{3-} and Sulfate SO_4^{2-}	PO_4^{3-} and SO_4^{2-} are both salts of acids and both occur in nature as minerals, but their molecular structures vary, they form from various acids and they include different minerals.

1.3. Ground Water Quality in Erbil City

When dangerous elements, frequently chemicals or microbes, enter a river, ocean, aquifer, or other body of water, the water's quality declines and it becomes toxic for people or the environment [13]. Every year, polluted water causes the deaths of more than 3.4 million people.

Solutes dissolved in the water are what cause groundwater contamination. Natural water has dissolved pollutants in it, at least in small amounts. Viral and bacterial contaminants, which can come from sewage treatment facilities, septic systems, and wild animals, are prevalent in natural water.

Since the Erbil region is one of Iraq's fastest-growing, the city must deal with problems and changes like population expansion and an increase in economic activity, which leads to an increase in incidents of groundwater pollution brought on by untreated sewage water. UNICEF emphasized that the quality of groundwater is being seriously harmed and that it is difficult and time-consuming to restore it [14]. Because it is so expensive to purify groundwater, increased human activity, which results in the release of large amounts of sewage into rivers, dams, and underground, is the main cause of groundwater contamination [15]. Three key factors, each of which is illustrated with an example, can be used to estimate the level of water contamination**Table.1.2** [14]:

Table 1.2 Features of Water contamination

Features	**Examples**
Physical	Turbidity, taste, smell, color and temperature.
Chemical	pH, chemicals, metals and minerals.
Microbiological	Helminthes, protozoa, viruses and bacteria.

There are many sources of groundwater contamination, **Table.1.3**[16] illustrates major contaminations of groundwater in Erbil city:

Table.1.3. Typical Sources of Groundwater Contamination by Land Use Category

Category	**Contaminant Source**		
Agriculture	Fertilizer storage	Irrigation Sites	Animal feedlots
Commercial	Cemeteries	Gas station	Car washes
Industrial	Chemical manufacture	Pipelines	Hazardous spills
Residential	Septic system	Sewer lines	Fuel oil
Other	Hazardous waste landfills	Municipal sewer lines	Municipal landfills

Majority of contamination of Erbil city comes from nitrates NO_3^-, for example the groundwater in Tajeel quarter contains nitrate, one of the reason is that the waste water had been going back to the same well source for various times. The other reason for the presence of nitrate goes back to cemeteries which are located in Tajeel quarter, many people, especially water experts are not aware of that, that corpse in the cemeteries decompose to ammonia, this ammonia is converted to nitrate which will cause contamination to groundwater.

1.4. Management and Strategies

Regulations are necessary to preserve and safeguard groundwater since it is a precious resource. Aquifers can get contaminated if chemicals are put to the land surface directly over the aquifer or if they accidentally leak into the aquifer. Some aquifers are naturally protected from pollution by being covered with impermeable soil or rock, but where this is not the case, aquifers can become contaminated. There are numerous methods used to protect these aquifers, the first of which is to map the areas where groundwater is most vulnerable and use this information when approving plans for potentially polluting operations. The areas of land from which water flows are also mapped for big public groundwater sources, and actions might cause pollution are carefully controlled, these areas called „Source Protection Zones‟, where industrial activities or waste sites pose a risk to groundwater they are regulated to reduce the risk of accident, and special boreholes are drilled and monitored, so that pollution can be picked up early.

If pollution occurs there are ways it can be controlled, for instance by pumping around the source of pollution and treat the contaminated water [17].

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1.5. Protection of Groundwater from Pollution

The procedure used to treat groundwater by eliminating the pollutants is known as groundwater remediation. Groundwater remediation techniques come in a wide variety, but they all aim to remediate tainted water [18].

Environmental consultants most frequently employ these three techniques for groundwater remediation: physical, chemical, and biological.

The three remediation techniques are shown in **Table1.4** [17] along with a description of each.

Table 1.4 Methods of Remediation

Remediation Methods	Description
Physical	Is the most basic type, uses air to take away clean water.
Chemical	This method takes longer time and more cost, but might be the only option for certain contaminants. Carbon absorption, ion exchange, chemical precipitation, and oxidation are all ways to achieve clean groundwater by way of chemical remediation.
Biological	Uses organic matter, microorganisms and plants to clean contaminated water. Biological methods are convenient because the contaminated water may not even need to be removed or to be treated.

1.6. Ground Water Recharge for Erbil Basin

A full body of groundwater is called an aquifer, discharge of the aquifer is the volume of groundwater flowing out of an aquifer over time and the recharge of the aquifer is the flowing in of water to fill again the aquifer.

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Aquifer has two types, confined, aquifer between two impermeable layers and the other type is unconfined which water is not confined by impermeable layers that is why water moves freely to the surface if water table rises[19].

Well holes are drilled into saturated zone, over pumping from wells causes lowering of the water table. Intergranular, Karst and Karstic aquifers are aquifers in Erbil city which wells are drilled into them.

Intergranular provide reliable supplies where there is a reasonable thickness of saturated sediment. In some places, the aquifer stands above a clay layer.

In Karst aquifer, groundwater is stored in the fractures of the rock mass in which the water in the fractures has dissolved the relatively soft rock, thereby significantly increasing the size of the fractures. Karstic aquifer is a characteristic of Karst aquifer [20]. In Erbil city [21]:

- *Intergranular aquifer*: during the years (2000 - 2004) the level of groundwater were between (180m – 220m) .The depth of the wells have been increasing due to the large number of wells and the decrease in groundwater levels. Currently, the groundwater levels are between (300m - 350m) and in some places it reached to (400m).
- *Karstic and Karst aquifers*: depths of wells until the year (2000) were (80m-100m-120m). After drought years, the depths reached (150m - 180m - 200m - 240 m), in some places it reached (300m).

The following tables are data from studies of “General Directorate of Water Recourse, KRG”,**Table1.6** and **Table1.7** data are until year 2020:

Table1.5 shows examples of groundwater level dropped down in Erbil city:

Table1.5 Drop of Groundwater Level in some Wells in Erbil City

Well Name	Aquifer type	Depth (m)	Years	Static Water Level (m)	Dropped to (m)	Drop Level (m)
Mala Omar	Intergranular	171	2000-2021	15	95.2	80.2
Qushtapa – 12	Intergranular	175	2000-2020	30.85	131	100.15
Daratu – 8	Intergranular	150	2000-2020	45.3	118	72.7
Kore - 3	Karst	130	2000-2016	8.14	67.63	59.49

Table1.6 shows statistics of permitted drilled wells in Erbil city:

Table1.7 Permitted Drilled Wells in Erbil City

Wells for Drinking Purposes	Wells for Agriculture Puposes	Wells for Industry Purposes	Total
4157	4583	164	8904

Table1.7 shows statistics of non-permitted drilled wells in Erbil city:

Table1.7 Non Permitted Drilled Wells in Erbil City

Non permitted wells (2003)	Non permitted wells (2021)
1400	4300

The more well to drill, the more groundwater is pumped. Erbil city is facing a serious water shortage problem currently and this problem is expected to be more severe in the future where the supply is predicted to be more and more over years due to low recharge resources and high discharge resources. A disaster will be waiting for Erbil city in the near future within less than ten years if protection is not put into action and contamination of groundwater is not healed.

1.7. Objectives Of This Study

- Is to clarify most of groundwater characteristics, specify contaminations which occur in Erbil city"s groundwater sources, methods to protect our groundwater resources and mentioning how to perform a good remediation to have a clean and suitable groundwater in Erbil city to use and most importantly to drink.
- The main contamination sources that cause contamination in Erbil city will be focused on and discussed with mentioning applicable protection and remediation.
- Data of Erbil city"s groundwater wells of main residual areas are collected from 2003 till 2021 and their (Bacteriological, Physical and Chemical) results will be distinguished and analyzed.
- Samples are taken from the wells with most contaminated groundwater.

The Content of the Thesis:

Three chapters make up this thesis. The introduction is included in the current chapter, which is regarded as the first chapter. We shall discuss areas and basins in Erbil city that have a high rate of water contamination in the chapters that follow, and we will choose the best strategy to protect our contaminated groundwater. The contamination and their remediation will be examined with the detection of ground water levels from Erbil's three main subbasins in the following chapter (Methodology), which will be the second chapter of the thesis. The case study will be presented in depth in chapter 3.

Chapter Two

Methodology

Examination of groundwater‟s bacteriological, physical and chemical characteristics of wells in Erbil city might take too much time, since there are 13204 wells (Permitted and Non-Permitted) and the water level of most of them have been sharply dropped down since 2003.

2.1. Biological Test

Due to the risk of obtaining diseases from microorganisms, water contamination is a severe issue. Pathogen concentrations resulting from contamination are frequently low yet the range of potential pathogens is wide. It is not practical to analyze every sample of groundwater for pathogens. Instead, pathogens are detected through the use of an indicator organism, such as Coliform Bacteria, whose detection might reveal the presence or absence of other dangerous bacteria[22].

Test Procedure[23]:

1- Make a solution by dissolving 70g of MacConkey broth in 1L of distil water for Coliform and 35g of same solution for Thermotolerent and 15g of same solution for E.Coli.

2- Bring 4 tubes and put 10ml of the solution in each tube then put a durham tube in each one of them.

3- Bring the sample of water which needs to be tested and put 10ml of it in each tube.

4- Cover them with cotton to prevent fungi in the air entering the tube and put them in autoclave with pressure of 1.5bar and temperature 121°C.

5- Put them in incubator for 24hr.

Temperature of Coliform Bacteria is 37°C as human body‟s temperature, but Thermotolerent and E.Coli‟s temperature are 44.5°C, we sterilize the place by ethanol and benzene burner. The blue flame of the benzene burner which is kept near the testing equipment kills the surrounding bacteria and virus. If the water was clean the color changes slightly, then it is *satisfactory*.

These 2 conditions must be satisfied to assure that we have Coliform Bacteria:

1- The color must change from violet to yellow
2- Producing a gas due to fermentation of microorganism with the lactose inside the medium.

We have 4 tubes and according to WHO standard:

- If one of the tubes satisfied both condition the ratio of impurity will be 2.2 in 100ml of water, then the water is *satisfactory*
- If two of the tubes satisfied both condition, the ratio of impurity will be 5.1 in 100ml of water, then we have to do the other two tests (Thermotolerent and E.Coli), (Coliform is double strained, Themotolerent and E.Coli are single strained). Durham tube is not needed for the Thermotolerent. if the result of these two tests were clean then the water is *satisfactory*. If the result of these two tests were not clean the water is *unsatisfactory*.
- If three of the tubes satisfied both condition the ratio of impurity will be 9.2 in 100ml of water then the water is *unsatisfactory.*
- If all the tubes satisfied both condition, the ratio of impurity will be 16 in 100ml of water then the water is *unsatisfactory*.

Bacteriological test of groundwater is mainly done by Coliform bacteria, the other two bacterias help with the examination of bacteriological test.

2.2. Chemical Test

2.2.1 pH

pH is measured by pH meter in laboratories. **Figure 2.1.**

2.2.2 Phosphate

Phosphate in groundwater can be tested by a color metric change. Some kits measure this by simple color wheel comparator [23]. As shown in **Figure 2.2**.

2.2.3 Nitrate

Nitrate is measured by Spectrophotometer device, **Figure 2.3.** The test procedure of nitrate is: (1) Take 10ml of sample. (2) Add 3 drops of HCL solution. (3) Take 10ml of blank. Read transmittance as %100 which is 0ppm. (4) Use wavelength of 220nm. (5) Set standard for the sample on the device as 50ppm since 50ppm or below is standard nitrate water quality in Iraq.(6)Insert a sample to cells to read transmittance and read it on the screen of the device.

Figure 2.1 pH meter

Figure 2.2 Model PO-19 test kit

Figure 2.3 Spectrophotometer

2.2.4 Dissolved Oxygen

Several tests can be used to measure the quantities of dissolved oxygen. There are several different techniques, including drop titration, electronic monitoring, and AccuVac inspections. The Winkler drop titration method and a device known as the OX-2P model 1469-00 can be used to determine the amount of DO. [23], **Figure 2.4.**

Figure 2.4 OX-2P model 1469-00 for DO determination

2.2.5 Biochemical Oxygen Demand (BOD)

The term "biochemical oxygen demand" (BOD) refers to how much oxygen is used by bacteria and other microorganisms during the aerobic (oxygen-containing) decomposition of organic matter at a particular temperature. Using a BOD analyzer, organic matter breakdown in water is evaluated as biochemical or chemical oxygen demand. [24], **Figure 2.5**

Figure 2.5 BOD Analyzer

2.2.6 Total Alkalinity (T.Alkalinity), Calcium (Ca) and Chloride (Cl)

T.Alkalinity, Ca and Cl, are all measured in the groundwater with the help of titration. We have an indicator for each one of these three which are used separately at a specific point with them that reacts with them individually. The titration device is shown in **Figure 2.6.**

2.2.7 Potassium (K) and Sodium (Na)

Both K and Na are tested by Flame Test. Flame is a procedure to detect the presence of metals such as K and Na. The color of flames also depends on temperature. The test involves introducing a sample of the element of compound to a hot blue Bunsen flame. Na is a common component or contaminant in many compounds and its spectrum tends to dominate over others, thus the color yellow overpowers the true color. K color will be lilac[25]. The flame test‟s color for Na and K are shown in **Figure 2.7**[25].

Figure 2.6
Titration Instrument

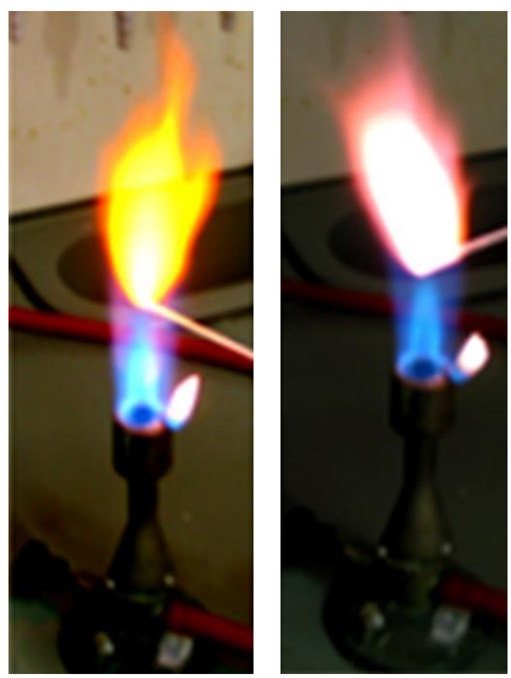


Figure 2.7
Flame Test of Na and K, respectively

2.3. Physical Test

2.3.1 Temperature

The water temperature in near-surface groundwater resources is influenced by the air temperature, and along rivers also by the temperature of infiltrating river water. In urban areas, the groundwater temperature is affected by borehole heat exchangers[26].

2.3.2 Turbidity

A Turbidimeter, an optical instrument that electronically detects the amount of light that passes through a sample of water, can be used to assess turbidity. It is depicted in **Figure 2.8.** Water used for drinking should have less than 5 NTU. The majority of Erbil City's ground water wells have turbidities that are less than 5 NTU; very seldom, however, are there any particular wells that have turbidities that are more than 5 NTU due to blasting and construction activities that fracture the aquifer's bed rock, turning it into silt and clay, which increases turbidity.

Figure 2.8 Turbidimeter

2.3.3 Color and Odor

Color can be tested by naked eye and odor can be tested by smelling the water sample. These two physical tests rarely get contaminated in Erbil city.

2.3.4 Total dissolved solids

Total dissolved solids are tested with the help of titration like total alkalinity, calcium and chloride**.**

2.4. Major Groundwater Contamination types In Erbil City

Erbil city has been affected by few contamination types, but these few types have a large presence in the area. The following table, **Table2.1** shows major contamination types in Erbil city from 2003 till 2021.

Year	**Table2.1. Major Groundwater Contamination types in Erbil City**		
	Bacteriologic/Biologic	**Chemical**	**Physical**
2003	Coliform	T. Alkalinity	X
2004	X	Nitrate & T. Alkalinity	X
2005	X	X	X
2006	Coliform	Nitrate	X
2007	Coliform & E.Coli	Nitrate	Turbidity
2008	X	Nitrate & T. Alkalinity	X
2009	X	Nitrate	X
2010	Coliform	Nitrate	X
2011	X	Nitrate	X
2012	X	Nitrate & T. Alkalinity	Turbidity
2013	X	T. Alkalinity	Turbidity
2014	E.Coli	Potassium	X
2015	X	T. Alkalinity	X
2016	X	Nitrate	X
2017	X	Nitrate	X
2018	X	Nitrate	X
2019	X	Nitrate	X
2020	Coliform	Nitrate	X
2021	X	Nitrate	X

In Erbil City, major contaminants are chemical contaminations (Nitrate and T.Alkalinity) which have been affecting Erbil city since 2003. T. Alkalinity has been treated by reverse osmosis.

2.4.1 Bacteriological (organisms) Treatment from Groundwater

Bacteriological treatment in Erbil city is mostly done by Storage and sometimes by theory of Disinfection[27].

- **Storage**

  7 days of storage can kill %90 of coli from in contaminated water which is reasonably clear.

- **Disinfection**

  Is simply the killing of potentially harmful organisms. Its objective is to obtain microbiologically clean water, which contains no pathogenic organisms and is free from biological forms that may be harmful to human health[28].

2.4.2 Nitrate Treatment from Groundwater

Numerous techniques, including ion exchange and reverse osmosis, are employed in Erbil city to remove nitrate from groundwater. Since the ion exchange approach is expensive and only partially effective at treating nitrate, it is rarely employed nowadays. Since reverse osmosis is most frequently utilized in Erbil city, we shall concentrate on it.

- **Reverse Osmosis**

  Reverse Osmosis (RO) technology is used in pump and treat applications to remove nitrate from groundwater. In RO process, contaminated groundwater is extracted and pumped through reverse osmosis cells under high pressure. RO is used for saline nitrate impacted groundwater [30][31]. RO‟s process is shown in **Figure2.9.**

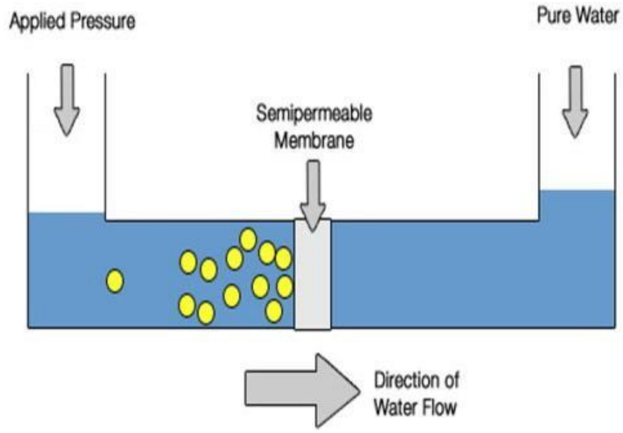


Figure 2.9 Reverse Osmosis Process

In Erbil city, during times of crisis, clear water of river is mixed with the contaminated nitrate water to reduce the nitrate level in the contaminated water. Since 2016, this method has been used alongside RO, to save more money.

2.4.3 Turbidity Treatment from Groundwater

Turbidity is also treated by storage method like bacteriologic contamination, in the past few years turbidity has not been a major contamination issue since necessary treatment has been put into action.

- **Storage**

  The storage facilities alongside killing E.Coli bacteria, they also lead to improvement in turbidity. This is accomplished during storage through sedimentation process, leading to excessive accumulation of solids for which pressure must be for removal.

2.5. Guidelines for Water Quality Parameter of Groundwater

WHO established that water must be safe after it got pumped out from ground and treated for drinking, cleaning, cooking or bathing. Water quality (WQ) standards were developed so as to ensure that WQ is of the required standards. The standards vary from a country to another. These standards help to set up rules and law that govern the use of water and prohibit water contamination activities. **Table 2.2**, provides details of the WHO WQ standards.

Table2.2 WQ Iraqi Standards according to WHO

WQ Parameters	WHO standards
Turbidity (NTU)	5
pH	6.5 – 8.5
EC (µmohs/cm)	1500
TDS (mg/l)	1000
Total Alkalinity (mg/l)	250
T.H as $CaCO_3$ (mg/l)	500
Calcium (mg/l)	75 – 200
Magnesium (mg/l)	30 – 150
Sodium (mg/l)	200 – 400
Potassium (mg/l)	12
Chloride (mg/l)	200 – 400
Nitrate (mg/l)	10 – 50
Sulfate (mg/l)	200 - 400

Chapter 3

Study Area

3.1 Geographical Information

With a population of 2,113,391, Erbil City, the capital of the Kurdistan Region of Iraq, is situated in the southern region of Iraqi Kurdistan. Its area is 15,074 km2, or 3.5% of the country's total land area. As seen in Figure 3.1, it is bordered to the west by Ninawa, to the southwest by Salah al-Din, to the south by Kirkuk, to the northwest by Duhok, and to the east by Sulaymaniyah. Over half of the population of the governorate resides in Erbil City, the governorate's principal town. [10] [37].

Figure 3.1 Location maps of the study area, shows the location of the Erbil city in Iraq, Kurdistan region and Erbil city individually.

3.2 Erbil Basin

The Erbil Basin is the province of Erbil's largest groundwater storage area. It has a depth of around 800 meters and a 3,200 km2 surface area. Due to its proximity to the surface and well-considered design, this basin is among the most significant groundwater basins in the Middle East [37] [38]. The Erbil Basin's groundwater typically flows from northeast to southwest. Within the basin, a groundwater divide directs flows in one of two directions.

either the Lesser or Greater Zab River. The Erbil Basin's groundwater contains trace quantities of soluble salts and dangerous ions that may be hazardous to human health.[39].

The Erbil Basin is divided into three sub-basins. **Table 3.1**, states the three sub-basins with description for each one of them, the last column of the table is an adopted study from the ministry of Agriculture and Water Resources by Al-Furat center. **Figure 3.2** [40]**,** shows a geological map of Erbil basin [40] [10].

Table 3.1 Sub-Basins of Erbil City

Sub-Basins of Erbil Basin	**Area**[41]	**Geographic Formation**	**Al-Furat study**
1- Northern sub-basin (Kapran)	915 km^2	Gravel, coarse and medium-grained sand, silt and clay beds	No. of wells drilled not exceed: 225 Actual No. of wells drilled: 2554
2- Central sub-basin	1400 km^2	Gravel, coarse sand, clay, and conglomerate strata.	No. of wells drilled not exceed: 738 Actual No. of wells drilled: 4257
3- Southern sub-basin (Bashtapa)	885 km^2	Coarse and mediumgrained sand, clay, with some silt or silty clay	No. of wells drilled not exceed: 500 Actual No. of wells drilled: 583

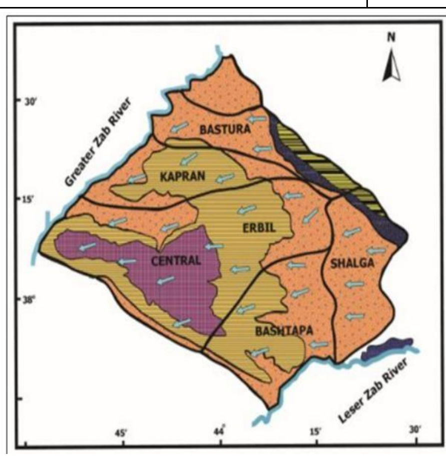


Figure 3.2 Geological map of Erbil Basin

3.3 Rainfall on Erbil Basin

The study of the rainfall in the study region is vital for the recharge of the ground water since rainfall is one of the most significant climate phenomena and it can change in a very short period of time. Seasonal variations in annual rainfall are observed. **Figure 3.3** [42] describes and depicts the weather in Erbil city, including the amount of rainfall. 590 mm of rain fall annually on average. According to **Figure 3.3,** the amount of precipitation decreases from the northeast toward the southeast of Erbil city, this denotes that the northeastern parts take more precipitation quantities than the southwestern parts of the city. For growth of crops the amount of the average rainfall must not be less than 300 (mm/year). For calculation of ground water, the precipitation data will be taken at the least average annual rainfall in the area of study, because to study and analyze the data, the critical situation is taken. Thus the average annual rainfall will be as **Table 3.2:**

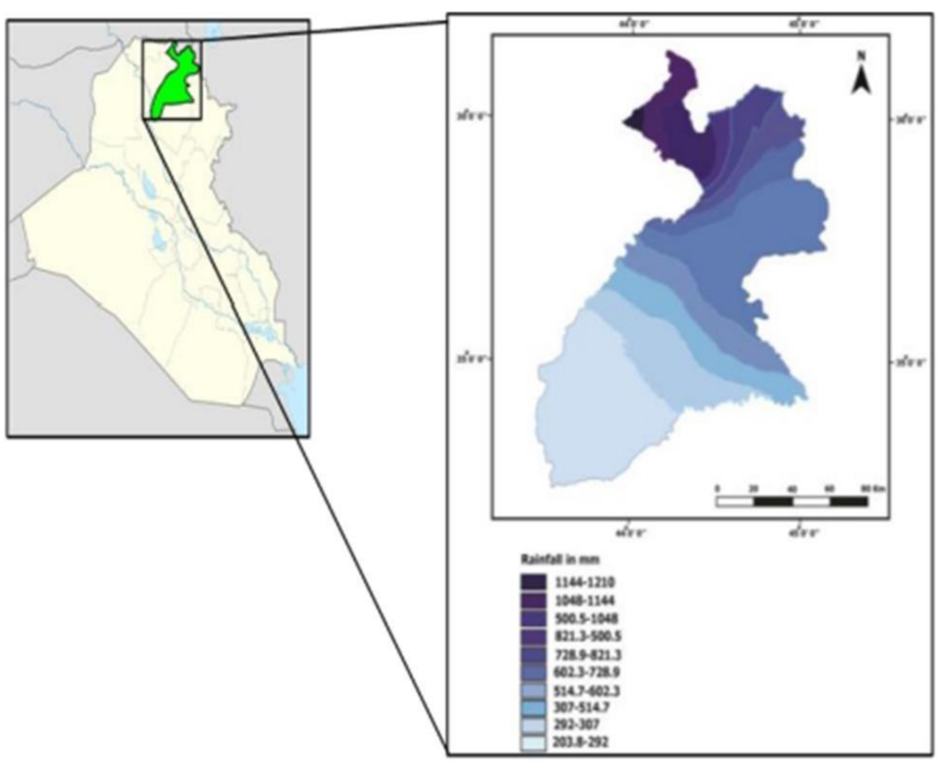


Figure 3.3 Spatial Distribution of Average Annual Rainfall in Erbil City

Table 3.2 Average Annual Rainfall during Critical Dry Periods on Erbil Bain

Sub Bains	Average Annual Rainfall (Critical) (mm/year)
Northern	420
Central	400
Southern	390

3.4 Wells From Erbil Basin

Most significant wells in each subbasin that experienced significant problems in the past, beginning in 2003, will be taken for investigation and evaluation of our data. **Figure 3.4**, which is depicted below, shows the majority of the wells in Erbil City:

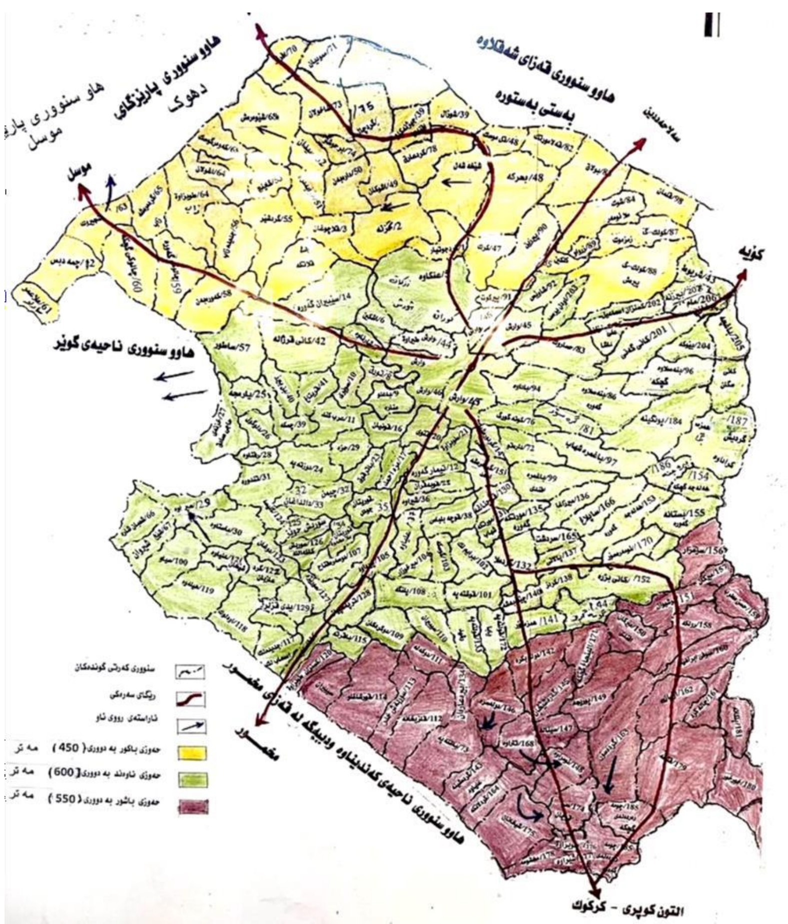


Figure 3.4 Majority of Wells In each Sub Basin of Erbil City

Chapter 4

Results and Discussion

This study will primarily concentrate on six districts from various basins in Erbil city for each physical, chemical, and biological aspect. Information was gathered from Ifraz II. Since our project is focused on these parameters and these parameters are utilized to demonstrate pollution in the last 18 years for WQI, six parameters (Turbidity, pH, TDS, T.A, T.H, and NO3-1) are taken.

4.1. Results of Water Quality Index

The WQI calculation is a useful tool for determining whether the groundwater sample is contaminated or not. The red hatched rectangles are outside the range of Iraq's WQ standard, according to the WHO, so we will be using the most recent data from Ifraz II, which is from 2022. By taking the average of eight months for each parameter, the results are as follows:

Table 4.1 Azadi District's Average Parameters Measurement of 2022

DISTRICT		AZADI								TOTAL	TOTAL / 8
2021	MONTHS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	X	X
PARAMETERS	TURBID.	0.9	1.3	2	0.4	0.6	0.6	0.8	0.7	6.6	0.8
	PH	7.7	7.9	7.5	7.3	7.4	7.5	7.5	7.7	60.7	7.6
	TDS	210	252	200	234	241	271	252	212	1660.0	207.5
	TA	210	199	180	205	185	250	195	180	1424.0	178.0
	TH	239	289	242	263	300	266	264	289	1863.0	232.9
	NO3	35	33	28	34	51	53	41	56	275.0	34.4

Table 4.2 Hawleri Nwe District's Average Parameters Measurement of 2022

DISTRICT		HAWLERI NWE								TOTAL	TOTAL / 8
2021	MONTHS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	X	X
PARAMETERS	TURBID.	1.8	0.6	1.2	5	0.6	0.9	1.1	0.7	11.2	1.4
	PH	7.4	7.7	7.3	7.6	7.4	7.7	7.7	7.6	60.4	7.6
	TDS	260	209	178	248	294	251	248	211	1688	211.0
	TA	240	195	200	200	260	200	220	223	1515	189.4
	TH	268	223	309	271	267	259	262	264	1859	232.4
	NO3	9.7	18	30	50	50	57	51	41	265.7	33.2

Table 4.3 18 Shubat District's Average Parameters Measurement of 2022

DISTRICT		18 SHUBAT								TOTAL	TOTAL / 8
2021	MONTHS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	X	X
PARAMETERS	TURBID.	0.8	0.7	0.7	0.8	0.9	0.8	0.9	0.8	5.6	0.7
	PH	7.7	7.5	7.6	7.7	7.6	7.4	7.5	7.6	60.5	7.6
	TDS	186	188	186	187	202	169	188	186	1306.0	163.3
	TA	190	185	210	190	200	202	190	192	1367.0	170.9
	TH	218	218	190	218	240	211	216	218	1511.0	188.9
	NO3	18	27	34	18	31	28	22	20	178.0	22.3

Table 4.4 Bahrka District's Average Parameters Measurement of 2022

DISTRICT		BAHRKA								TOTAL	TOTAL / 8
2021	MONTHS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	X	X
PARAMETERS	TURBID.	0.6	0.5	0.5	0.5	0.6	15.4	0.5	0.6	19.2	2.4
	PH	7.2	8.2	7.7	7.9	7	7.6	7.8	7.7	61.1	7.6
	TDS	338	238	351	314	309	274	308	334	2466.0	308.3
	TA	200	244	220	170	330	190	220	242	1816.0	227.0
	TH	356	243	413	213	375	235	310	355	2500.0	312.5
	NO3	48	18	48	43	50	18	23	41	289.0	36.1

Table 4.5 Ankawa District's Average Parameters Measurement of 2022

DISTRICT		ANKAWA								TOTAL	TOTAL / 8
2021	MONTHS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	X	X
PARAMETERS	TURBID.	1.8	0.6	1.9	0.5	1.7	0.5	0.6	1.8	9.4	1.2
	PH	7.2	7.3	7.4	8.2	7.5	7.2	7.7	7.5	60.0	7.5
	TDS	324	278	212	227	281	369	279	327	2297.0	287.1
	TA	240	238	180	220	260	350	289	290	2067.0	258.4
	TH	365	313	195	285	295	398	298	315	2464.0	308.0
	NO3	48	28	21	21	35	58	50	38	299.0	37.4

Table 4.6 Ashti District's Average Parameters Measurement of 2021

DISTRICT		ASHTI								TOTAL	TOTAL / 8
2021	MONTHS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	X	X
PARAMETERS	TURBID.	2.9	1.4	2.4	3.1	2.4	3.9	2.4	2.4	20.9	2.6
	PH	7.8	7.5	7.9	7.7	7.9	7.1	7.9	7.8	61.6	7.7
	TDS	373	212	290	320	330	361	325	372	2583.0	322.9
	TA	210	209	190	200	300	290	296	196	1891.0	236.4
	TH	400	248	273	358	361	400	382	353	2775.0	346.9
	NO3	38	40	32	62	58	60	52	59	401.0	50.1

For calculating WQI, average measurement of each parameter will be taken. Using equation (2.5) which is $= \frac{\sum Q_i W_i}{\sum W_i}$, for getting Q_i by equation (2.6) $Q_i = 100 * \frac{V_i - V_o}{S_i - V_o}$, setting V_o as 0 for all parameters except the pH (V_o=7) and for getting W_i equation (2.7) is used $W_i = \frac{K}{S_i}$, where k=1 for all parameters. As a result the status of the WQI can be defined by table (2.2). if the WQI was above 50, then %25 there is contamination in the groundwater sample. Groundwater samples of each district are shown below with their detailed calculation.

Table 4.7 WQI Calculation of Azadi's District

District : AZADI					
PARAMETERS	***Vi***	***Si***	***Qi***	***Wi***	***QiWi***
TURBIDITY	0.8	5.0	16.0	0.20000	3.2
PH	7.6	8.5	40.0	0.11765	4.70588
TDS	207.5	500.0	41.5	0.00200	0.083
TA	178.0	250.0	71.2	0.00400	0.2848
TH	232.9	500.0	46.6	0.00200	0.09316
NO3	34.4	50.0	68.8	0.02000	1.376
∑				**0.34565**	**9.74284**
				WQI =	**28.1873**
				Status : GOOD	

Table 4.8 WQI Calculation of Hawleri New's District

District : HAWLERI NEW					
PARAMETERS	***Vi***	***Si***	***Qi***	***Wi***	***QiWi***
TURBIDITY	1.4	5.0	28	0.2	5.6
PH	7.6	8.5	36.67	0.11765	4.31412
TDS	211.0	500.0	42.2	0.002	0.0844
TA	189.4	250.0	75.75	0.004	0.303
TH	232.4	500.0	46.475	0.002	0.09295
NO3	33.2	50.0	66.425	0.02	1.3285
∑				**0.34565**	**11.72**
				WQI =	**33.916**
				Status : GOOD	

Table 4.9 WQI Calculation of 18 Shubat's District

District : 18 SHUBAT					
PARAMETERS	***Vi***	***Si***	***Qi***	***Wi***	***QiWi***
TURBIDITY	0.7	5.0	14	0.2	2.8
PH	7.6	8.5	37.5	0.11765	4.41176
TDS	163.3	500.0	32.65	0.002	0.0653
TA	170.9	250.0	68.35	0.004	0.2734
TH	188.9	500.0	37.775	0.002	0.07555
NO3	22.3	50.0	44.5	0.02	0.89
∑				**0.34565**	**8.51601**
				WQI =	**24.6379**
				Status : EXCELLENT	

Table 4.10 WQI Calculation of Bahrka's District

District : BAHRKA					
PARAMETERS	***Vi***	***Si***	***Qi***	***Wi***	***Qi Wi***
TURBIDITY	2.4	5.0	48	0.2	9.6
PH	7.6	8.5	42.5	0.11765	5
TDS	308.3	500.0	61.65	0.002	0.1233
TA	227.0	250.0	90.8	0.004	0.3632
TH	312.5	500.0	62.5	0.002	0.125
NO3	36.1	50.0	72.25	0.02	1.445
∑				**0.34565**	**16.6565**
				WQI =	**48.1893**
				Status : GOOD	

Table 4.11 WQI Calculation of Ankawa's District

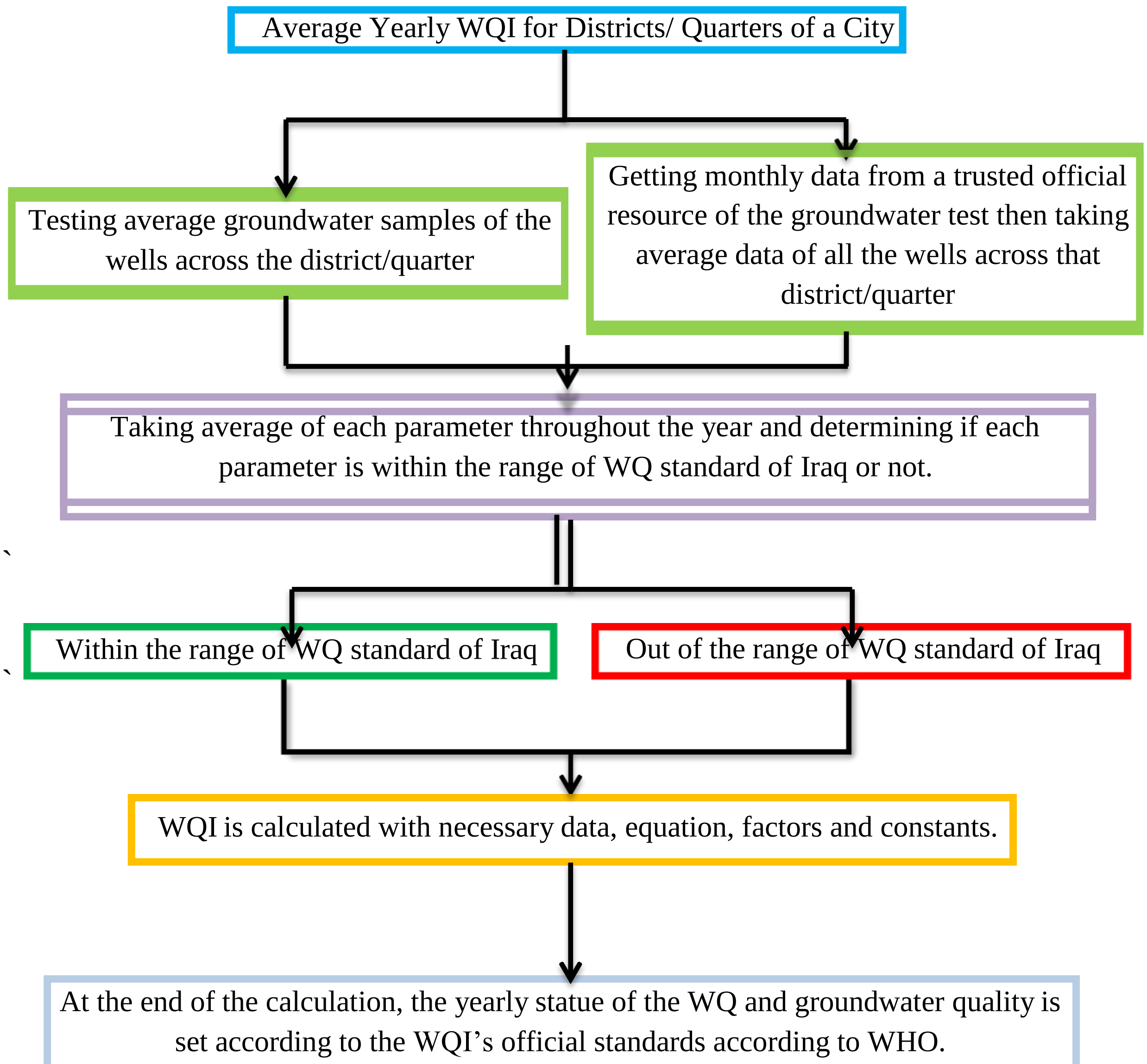
District : ANKAWA					
PARAMETERS	***Vi***	***Si***	***Qi***	***Wi***	***Qi Wi***
TURBIDITY	1.2	5.0	23.5	0.20000	4.7
PH	7.5	8.5	33.33	0.11765	3.92118
TDS	287.1	500.0	57.425	0.00200	0.11485
TA	258.4	250.0	103.35	0.00400	0.4134
TH	308.0	500.0	61.6	0.00200	0.1232
NO3	37.4	50.0	74.75	0.02000	1.495
∑				**0.34565**	**10.7676**
				WQI =	**31.1521**
				Status : GOOD	

Table 4.12 WQI Calculation of Ashti's District

District : ASHTI					
PARAMETERS	***Vi***	***Si***	***Qi***	***Wi***	***Qi Wi***
TURBIDITY	2.6	5.0	52	0.2	10.4
PH	7.7	8.5	46.67	0.11765	5.49059
TDS	322.9	500.0	64.58	0.002	0.12916
TA	236.4	250.0	94.56	0.004	0.37824
TH	346.9	500.0	69.38	0.002	0.13876
NO3	50.1	50.0	100.25	0.02	2.005
∑				**0.34565**	**18.5417**
				WQI =	**53.6436**
				Status : FAIR	

As the result, only the Ashti's district's WQI statue is (Fair) that is because of high nitrate in groundwater sample for +5 months.

If we turn the procedure of the WQI as a flow chart, the flow chart will be as follow:



The WQI determines whether the water is safe to drink and whether the groundwater source contains contamination, as was mentioned earlier in calculations and results. It should be noted that the WQI is calculated either the average WQ was within or out of the range of the WQ standard of Iraq..

From **Table 4.12**, it can be seen that Ashti's district WQI calculation for groundwater (wells) was "Fair," which is the worst among the other districts. The reason for this can be traced back to one Ashti district well whose nitrate value was outside of the standard range due to seepage of the sewerage system into groundwater, which increased the nitrate concentration.

4.2. Results of Contamination Sources in Erbil City from 2003 to 2022

Ifraz 2 results will cover the years 2003 through 2022. Then, we'll focus on the three primary parameters (Nitrate, T. Alkalinity, and Turbidity) that had the most pollution over the past 18 years. Due to various factors, there are some missing well contamination data throughout the years, and in other cases the entire year's data is absent. Some assumed data were missing. Additionally, some well-needed statistics are lacking..

There are numerous wells inside an area and in the past two decades, some groundwater wells were closed in some area due to nitrate problem which lead to lack of data. On the other hand, termination of some groundwater wells in Erbil city and its replacement by Ifraz water treatment plants is regarded as application of sustainable approach and management towards groundwater sources in the our city – Erbil city [44]. That is why, when we get our result, we will see a large difference in total affected wells between early 2000’s and late 2010’s which will be interpreted and computed below.

Table 4.13 shows the contamination sources from 2003 till 2021 in Erbil city

Table 4.13 Main Contaminations source from (Nitrate, T. Alkalinity and Turbidity) from each year (2003 – 2022) in Erbil City

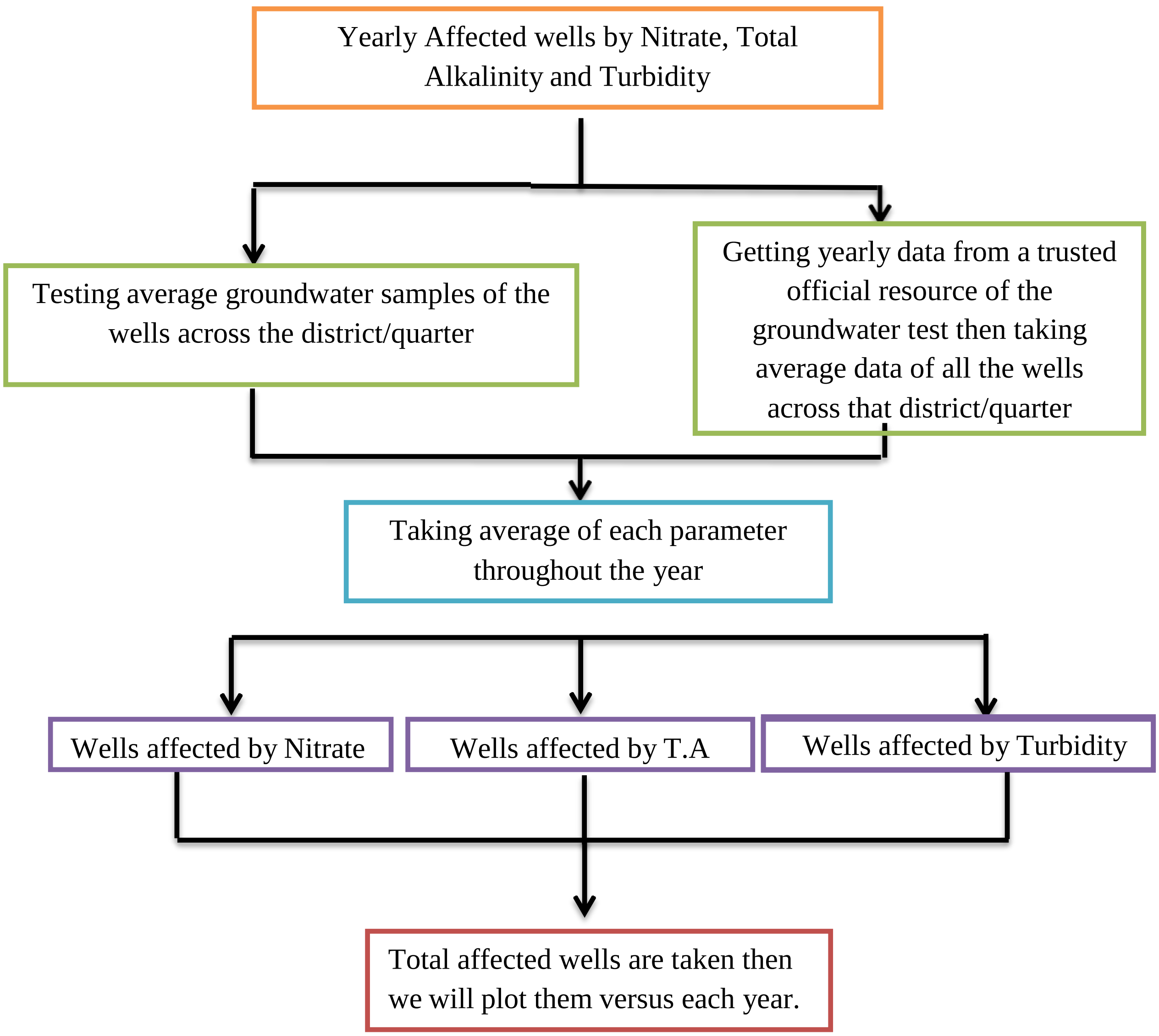
YEARS	2003	2004	2005	2006	2007
Wells affected by Nitrate	10	107	31	**391**	142
Wells affected by Total Alkalinity	**95**	**461**	23	55	71
Wells affected by Turbidity	3	30	36	27	**218**
Total affected wells	108	598	90	473	431
Main contamination source of that year	T. Alkalinity	T. Alkalinity	X	Nitrate	Turbidity

YEARS	2008	2009	2010	2011	2012
Wells affected by Nitrate	**100**	**108**	**249**	**171**	134
Wells affected by Total Alkalinity	82	73	85	91	**146**
Wells affected by Turbidity	51	23	18	5	11
Total affected wells	233	204	352	267	291
Main contamination source of that year	Nitrate	Nitrate	Nitrate	Nitrate	T. Alkalinity

YEARS	2013	2014	2015	2016
Wells affected by Nitrate	30	50	22	**37**
Wells affected by Total Alkalinity	**143**	**100**	**215**	10
Wells affected by Turbidity	169	87	37	5
Total affected wells	342	237	274	52
Main contamination source of that year	T. Alkalinity	T. Alkalinity	T. Alkalinity	Nitrate

YEARS	2017	2018	2019	2020	2022
Wells affected by Nitrate	**63**	**97**	**88**	**60**	**123**
Wells affected by Total Alkalinity	7	2	11	27	15
Wells affected by Turbidity	6	12	18	29	0
Total affected wells	76	111	117	116	138
Main contamination source of that year	Nitrate	Nitrate	Nitrate	Nitrate	Nitrate

From the previous data and previous two figures, we can see that, since 2016 till now 2021 – 2022, there is an issue with nitrate, but the affected wells are not that high compared to early 2000's and the total number of affected wells has been low compared to early 2000's.



4.3. Recharge and Renewable of Groundwater according to the Specific Yield of the Aquifer calculation

According to the **Table 2.4** ,**Table 3.1** and **Table 3.2**, the specific yield (*Sy*), total area for each sub basin and rainfall (recharge) are extracted as below **Table 4.14**:

Table 4.14. Total Data for each Sub Basin in Erbil city

Sub-Basin	Area (km^2)	Recharge (mm/year)	Discharge (m^3/min)	*Sy*
Northern	915	420	1250	0.260
Central	1400	400	1450	0.244
Southern	885	390	250	0.225

To calculate the change in head (Δh_{Rise}) by Equation (2.14) ($\Delta h_{rise} = \frac{}{Sy}$) and ($\Delta h_{Drain}$) by Equation (2.15) ($\Delta h_{drain} = \frac{V_{drain}}{A*Sy}$) the following results are obtained:

Table 4.15 Rise of Head due to Recharge (Δh_{Rise})

Sub-Basin	R (m/year)	*Sy*	Δh_{Rise} (m)
Northern	0.42	0.260	1.62
Central	0.40	0.244	1.64
Southern	0.39	0.225	1.73
		∑	4.99
		Average	**1.66**

Table 4.16 Drop in Head due to Discharge (Δh_{Drain})

Sub-Basin	Discharge * 10^6 (V_{drain}) (m^3/year)	Area (m^2) Meters x 10^6	*Sy*	Δh_{Drain} (m)
Northern	657	915	0.260	2.76
Central	762.12	1400	0.244	2.23
Southern	131.4	885	0.225	0.66
			∑	5.65
			Average	**1.9**

Table 4.17 Difference in Head change

Sub-Basin	Δh_{Rise} (m)	Δh_{Drain}(m)	Δh_{Rise} - Δh_{Drain}
Northern	1.62	2.76	**-1.14**
Central	1.64	2.23	**-0.59**
Southern	1.73	0.66	**1.07**
		$\sum$	**-0.66**
		Average	**-0.22**

The above results show that there is an overall decrease in groundwater table in Erbil basins especially in northern and central basins. Only the southern basin shows a positive result.

The results are related to the number of wells drilled in each part, the overall agricultural activity, well contaminations, population distribution and many other factors.

The overall level -0.22 meter per year, is an indicator that there will be risk of a drought for a long period of time in the future.

Chapter 5

Conclusion and Recommendation

5.1 Conclusion

1. The six districts in Erbil city (Azadi, Hawleri New, 18 Shubat, Bahrka, Ankawa, and Ashti) underwent necessary WQI calculations for their groundwater, and the results show that 18 Shubat has the cleanest groundwater quality and Ashti has the worst WQI among the six districts, but all districts' WQI data are within the range of the WHO standards.
2. According to statistics from Ifraz II, since 2016, the number of wells damaged annually by nitrate, total alkalinity, and turbidity has increased. The primary cause of the issue is nitrate, which is dealt with in Erbil either through reverse osmosis or by combining extracted water with zab water.
3. determining the water table for the Northern, Central, and Southern subbasins of Erbil city in relation to the quantity of wells drilled in each subbasin. The findings indicate that the water table level is declining in the Northern and Central subbasins while rising solely in the Southern subbasin. The decrease in level in these wells implies a scarcity of groundwater and the possibility of future drought.

5.2 Recommendation

In Erbil City, groundwater contamination such as nitrate, turbidity, total alkalinity, etc. is treated using a variety of methods including reverse osmosis and zab water mixing. To eradicate the bacteria, viruses, and other microorganisms found in tainted ground water wells in Erbil city, another option is the notion of disinfection or water storage.

Surface water is treated using the same methods as groundwater.

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