An-Najah National University

Faculty of Graduate Studies

POTENTIAL SOURCES AND MITIGATION MEASURES FOR NITRATE CONTAMINATION USING GIS AND GROUNDWATER VULNERABILITY ANALYSIS: A CASE STUDY OF YABAD EASTREN WELL (PALESTINE)

By

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This Thesis is Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Water and Environmental Engineering, Faculty of Graduate Studies, An-Najah National University, Nablus - Palestine.

2025

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Internal Examiner

Dedication

To my beloved family: my wife, Lina, whose unwavering support and love have been the cornerstone of my strength; my sons, Omar and Zain, and my daughters, Jawa and Ward, whose smiles and encouragement have been my greatest motivation throughout this journey.

To my dearest mother and father, whose sacrifices, prayers, and endless love have shaped the person I am today. To my cherished brother and sisters, who have always stood by my side with encouragement and belief in my abilities.

To my esteemed supervisor, Dr. Mohammad Almasri, whose guidance, patience, and wisdom have been invaluable in shaping this thesis.

Each of you has played an irreplaceable role in this achievement. This milestone is as much yours as it is mine.

With deepest gratitude and heartfelt appreciation.

Acknowledgements

I would like to express my sincere gratitude to my supervisor, Dr. Mohammad Almasri, for his invaluable guidance, insightful feedback, and continuous encouragement throughout my research journey. His expertise and support have been instrumental in shaping this thesis and helping me overcome challenges along the way.

My heartfelt thanks go to Dr. Subhi Smhan, Engineer Sael Weshahi, Engineer Omar Zyad, Engineer Bilal Alshayb, and Mr. Amjad Atatri and Mr.Rabe' Abu Baker from Yabad Municipality for their generous assistance, technical expertise, and valuable contributions. Their support has greatly enriched this work and helped bring it to completion.

I am deeply appreciative of An-Najah National University for providing an outstanding academic environment and the resources necessary for conducting this research. I would like to extend my gratitude to the dedicated staff of my department, whose professionalism and support have been a cornerstone of my academic progress.

I sincerely appreciate the generous funding provided by the Middle East Desalination Research Center (MEDRC), which has been essential in supporting this research on groundwater protection. Their contribution has significantly facilitated data collection, analysis, and complete this research.

To all who have contributed to this accomplishment, your efforts, encouragement, and belief in my abilities have been invaluable, and I will always remain deeply thankful.

Declaration

I, the undersigned, declare that I submitted the thesis entitled:

POTENTIAL SOURCES AND MITIGATION MEASURES FOR NITRATE CONTAMINATION USING GIS AND GROUNDWATER VULNERABILITY ANALYSIS: A CASE STUDY OF YABAD EASTREN WELL (PALESTINE)

I declare that the work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degree or qualification.

Student's Name: **Ahmad Asaf Mohammad Asaf**

Signature: Ahmad Assaf

Date: **04/02/2025**

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POTENTIAL SOURCES AND MITIGATION MEASURES FOR NITRATE CONTAMINATION USING GIS AND GROUNDWATER VULNERABILITY ANALYSIS: A CASE STUDY OF YABAD EASTREN WELL (PALESTINE)

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Abstract

The main source of fresh water for Palestinians is groundwater. Monitoring and evaluating its quantity and quality are essential. Recent research has shown that the nitrate contamination of the Eocene Aquifer's (EA) continues to trend upward. High fertilizer use, wastewater seepage are the main cause of nitrate contamination of groundwater. The problem has appeared in Yabad Eastern Well, where the nitrate concentration exceeds the allowable limit according to World Health Organization (WHO) and Palestinian guidelines. This research aims to identify the source of nitrate contamination for the well and to recommend the most relevant management options.

It is important to understand this problem by employing the proper methodology. The methodology consists of five steps, starting with studying the historical nitrate contamination of the well. Samples taken from the surrounding wells show that the nitrate concentration is below the Maximum Contamination Level (MCL), and this indicated that the problem had been limited to the well. The study area relevant to the well was determined based on many considerations in order to figure out the contamination occurrence. The research analyzed the groundwater flow direction to determine upstream and downstream areas using ArcGIS. The vulnerability of groundwater to contamination was identified to determine the potential locations of access for the contaminants to aquifer. The assessment of vulnerability was done by using the Geology, Overlying materials, Depth to groundwater (GOD) method.

By evaluating the variables affecting contamination at the well, different layers were overlaid. Each layer represents a specific variable, such as groundwater flow direction, vulnerability, and land use. This process helped identify the areas most exposed to contamination. Activities in these areas were classified based on their potential to pollute the aquifer with nitrate. The contamination pathways were also analyzed.

The results show that the old town was the most vulnerable location within the study area. This area suffers from high population and poor sewer system. Finally, this research recommends establishing a sewer network. This research suggests utilizing the isotopic method for future studies related to this case to better track the contamination sources for Yabad Eastern Well.

Keywords: Nitrate contamination, aquifer, groundwater, flow direction, GOD method, vulnerability.

Chapter One

Introduction

Groundwater is a priceless resource of drinking water that is used for domestic utilization, industrial activities, as well as agriculture. It is commonly of good quality as compared to other water resources due to filtration in soil and depth to water table (1). The groundwater is the only source of drinking water and irrigation in Yabad Town which is considered a semi-arid area. This groundwater source is recharged by infiltration due to the rainfall. It is important to keep and save this natural source from any contamination which may come from the ground surface. So, monitoring the water quality is essential by doing periodic water tests.

Water can be contaminated by microbiological, physical, and chemical pollutants, each of which is related to different sources and health-associated issues and results(2). Microbiological contamination of water sources is mainly caused by the improper disposal of animal and human wastes, giving rise to waterborne diseases (3). Coliforms in drinking water indicate possible contamination by pathogens causing waterborne diseases (4). Pathogenic microorganisms in water might cause waterborne illness such as typhoid, cholera, hepatitis, and respiratory system infections, as well as eye and skin diseases (5). The chemical contamination of water is divided into organic and inorganic. Elevated nitrate concentrations in drinking water can cause methemoglobinemia in infants and stomach cancer in adults. They originate from domestic wastewater, solid waste leachate, industrial wastewater, and agricultural runoff. Organic chemicals like chlorinated compounds are linked to cancer, toxicity, and kidney and liver diseases. Inorganic substances, such as Boron (B), Cadmium (Cd), Molybdenum (Mo), Mercury (Hg), and Barium (Ba), may cause several diseases such as, hypertension, cancer, poisoning, and babyish cyanosis. The last is linked with the toxicity of nitrate (6). High levels of water hardness might lead to kidney stone formation (2).

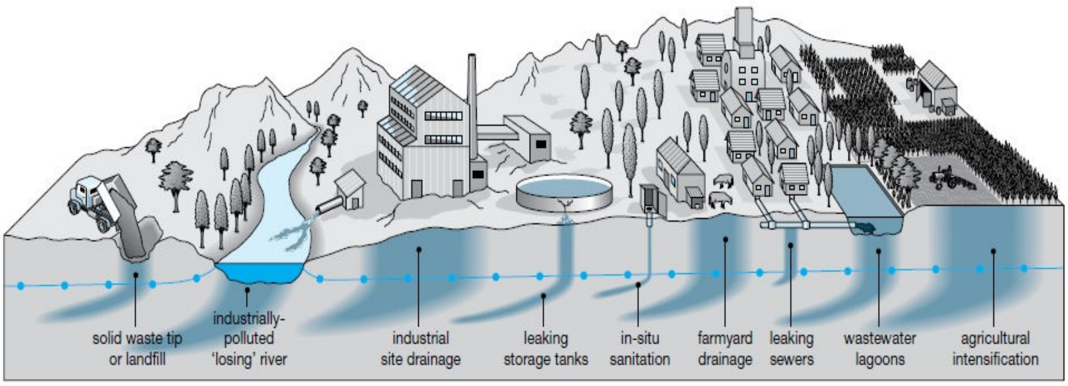
One of the most common contaminants is nitrate. Its existence in water gives indicators for contamination in groundwater due to human-induced activities or agricultural activities.

In general, this leads to major changes in the nitrogen cycle, leading to an increase in nitrate content level (MCL) of 50 mg/l NO3-N (Maximum limit of Nitrate according to World Health organization (WHO)).

Point sources, such as municipal and industrial discharge pipes where pollutants reach the water supply, are easily identifiable sources or locations of contamination. Non-point sources of contamination include acid rain, agricultural runoff, and other situations where it is difficult to pinpoint the exact source of the contamination. This has gradually led to serious non-point sources of groundwater contamination. Also, another contamination causes an increase in the nitrate content of groundwater in developing countries due to a lack of proper sanitation facilities. Figure 1 illustrates common potential sources contributing to groundwater pollution, showing various sources of contaminants infiltrating the subsurface. Key sources include solid waste landfills, industrial site drainage, leaking storage tanks, farmyard drainage, wastewater lagoons, and agricultural intensification. The most common potential cause of in-situ sanitation issues is wastewater seepage directly into the soil from sanitation systems like pit latrines or septic tanks. When poorly managed, these systems can contaminate surrounding groundwater with pathogens, nitrates, and other pollutants, posing serious risks to drinking water quality and public health.

Figure 1

Common processes and sources of groundwater pollution (7)



The Yabad Eastern Well is a vital water source for the residents of Yabad village, supplying approximately 60% of the village's residents. The water quality tests in 2022 show high concentration of Nitrate in the well (106 mg/l). This result is considered very dangerous and alarming and induces water service providers to make more investigations to identify contamination cause and sources.

1.1 The importance of study

The importance of this study is that it identifies the potential contamination sources that may increase the nitrate concentration in groundwater. It finds suitable solutions for this problem in order to protect this resource. Yabad Eastern Well is regarded by the residents of Yabad Town as a vital source of water, covering most of their water needs. Determination of the source of nitrate contamination in Yabad Eastern Well is vital to protect the water supply of 13,000 capita. This study helps determine the pollution sources, whether from agricultural, wastewater, or other activities, helping focus minimize efforts. By determination of contamination at its origin, the study helps the protection of potable water resource.

After finding that the nitrate concentration in the Yabad Eastern Well was higher than permitted by Palestinian drinking water guidelines, PWA closed the well as a precaution in order to protect the residents of Yabad from any negative effects of the contamination. Water supply problems, public anxiety, and confusion are all results of this preventive procedure, requiring for real action regarding.

The determination of nitrate contamination sources in groundwater is the purpose of research, especially when considering its effect on health and water resource sustainability. Groundwater sources consider one of the primary source of drinking water for residents in Palestine. Nitrate contamination cause serious risks to health, especially for weakness people like infants and pregnant women, as elevated nitrate levels which exceed MCL can cause to severe cases like methemoglobinemia, commonly known as "blue baby syndrome."(7)

Understanding the sources of nitrate contamination is very important for finding effective mitigation methods and protecting the drinking water. Nitrates often came from agricultural uses, including the use of fertilizers and animal waste. Additionally, poor systems of domestic wastewater and industrial effluents can influence nitrate pollution in groundwater. The Yabad village, like many other areas with high agricultural activities, is especially vulnerable to this sort of pollution. To deal with the root reasons of contamination and ensure the drinking water supply's permanent safety, it is vital to identify the exact sources of nitrates in the Yabad Eastern Well.

The importance of this research also extends to more general environmental and resource management objectives. Nitrate contamination of groundwater can reduce the aquifer's capacity to supply clean water for coming generations, increasing the need for expensive and alternative water sources. Additionally, nitrate contamination may disturb the aquatic ecosystems' natural harmony, leading to problems like pollution in surrounding surface water basins.

This study contributes to the sustainable management of groundwater resources in the Yabad area by identifying the sources of contamination and preventing the spread of pollutants to connected hydrological systems.

The study's purpose of raising awareness among stakeholders, including local government representatives, citizens, and lawmakers, is an additional essential aspect. The study can motivate action and encourage the adoption of suitable land-use practices, waste management systems, and water quality monitoring systems by highlighting the risks of nitrate contamination and the significance of protecting groundwater.

Since locals have a vital role in implementing methods that minimize pollution and protect the well, community engagement is essential to reaching these objectives.

The research is important locally, but it also gives light on the larger challenges related to managing groundwater in agricultural areas and residential areas too. It functions as a case study that can guide comparable initiatives in other regions dealing with nitrate contamination problems. The research's methods and conclusions can be used in other areas with similar hydrogeological and socioeconomic circumstances, adding to the body of knowledge on groundwater contamination and protection worldwide.

In addition to providing drinking water, the Yabad Eastern Well is a vital resource for the community it serves. Making sure it is sustainable and of high quality is important for protecting the environment and regional development in addition to public health.

By the identification of nitrate contamination sources, this study establishes the foundation for specific treatments that might maintain or enhance the water quality of the well. The dependent relationship of resource management, environmental health, and human activity is also emphasized, underlining the necessity of integrated strategies for addressing the complicated issues of groundwater contamination**.** In summary, the investigation into the source of nitrate contamination in the Yabad Eastern Well is essential because it directly affects resource management, environmental sustainability, and public health. To ensure both the wellness and health of the community, the Yabad Eastern Well, which provides the main source of drinking water for Yabad's citizens, needs to be protected against contamination. A useful effort with large effects, this research not only addresses current issues but also advances the more general objectives of environmentally friendly groundwater management.

1.2 Objectives

The objectives are to:

1. Identify the sources of the nitrate contamination of Yabad Eastern Well.
2. Propose mitigation measures to protect the well from nitrate contamination.

1.3 Research Questions

The research aims to answer the following questions:

1. Why does the nitrate level exceed the maximum contamination level (MCL) in Yabad Eastern Well?
2. Which kind of pollutant point or non-point sources have the potential to raise the nitrate level?
3. What land use activities took place inside the well capture zone that could produce this elevated nitrate concentration in the well?
4. How can we minimize the nitrate contamination and protect the well in future?

1.4 Description of study area

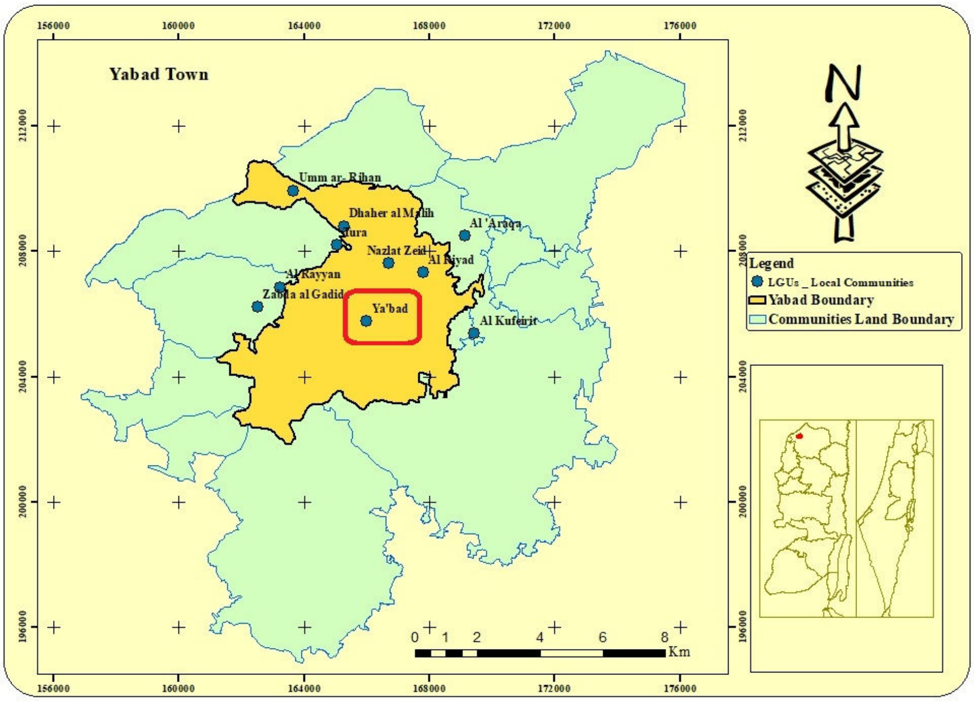
1.4.1 General Description

Yabad Town is located in the South-West of Jenin Governorate 17 km from Jenin City. Figure 1 shows the location of Yabad Town. It has an average elevation of 375 m Above Sea Level (asl). The topography of Yabad varies between plain and elevated areas. The plain areas mostly are agricultural lands, while the elevated lands are residential. Figure B 1 shows the topography of Yabad Town.

Yabad Town's landscape includes several sloping places that drain rainwater to Wadi Al Nus. However, the town's poor stormwater drainage system makes this a problem.

Figure 2

Yabad Town Location



Yabad has a population of 21794 capita as of 2023 according to the Palestinian Central Bureau of Statistics (PCBS). The climate is moderate and rainy in winter, and hot and dry in summer. The annual average maximum temperature is 25℃ and the annual average minimum temperature is 14℃. The mean annual rainfall in the town is around 450 mm (8)(PCBS).

1.4.2 Land Use

The land in Yabad Town has the following main uses: residential, agricultural, rock-minning, and coal manufacturing. The last one was ended by the government due to environmental negative consequences. Figure B 2 shows land use practices in Yabad Town.

Old town and modern town are two categories for the residential areas. The majority of the town's older buildings are located in the center; considering their poor facilities and closeness to each other, Yabad Town's sewage system is poor, as they use cesspits. Figure B3 shows the building distribution in Yabad Town.

Olive trees and tobacco plants are the most common crops in the agricultural areas. Nevertheless, in order for the tobacco plants to have a high yield, they require more water and fertilizers. Most of the high-value agricultural land is planted with tobacco plants. Figure B4 shows the agricultural areas in Yabad Town. Northeast of Yabad Town is the center of rock mining, one of the most widespread land uses. Different byproducts are produced by this activity, including aggregates, sand, crash stones for pavement, and occasionally boulders, which are raw materials required for building gravity walls.

Because the deep excavation and cutting operations affect the area's geological formation, this activity has a high negative environmental impact. Excavation can affect the natural hydrological cycle and lead to groundwater contamination (9). If suitable measures are not taken to prevent the infiltration of pollutants into the groundwater, such as chemicals from construction materials or machinery, Infiltration pollutants from construction materials and machinery include various chemicals that can harm the environment. Construction materials like paints, adhesives, and sealants release volatile organic compounds such as benzene, asbestos, lead, cement dust, polychlorinated biphenyls, and phthalates are also common pollutants in building materials. Machinery used on construction sites emits exhaust pollutants like nitrogen oxides, carbon monoxide, and particulate matter, while hydraulic fluids may leak chemicals such as petroleum-based oils and polycyclic aromatic hydrocarbons. Additionally, solvents and heavy metals like cadmium and copper from machinery can contaminate the soil, water, and air, posing environmental and health risks. it can result in contamination of groundwater. In addition, deep excavation can alter the natural flow of groundwater by changing underground water pathways and aquifer recharge patterns. This alteration can lead to changes in groundwater levels, which can affect nearby wells, springs, and wetlands (9).

1.4.3 Communities around the study area

Many communities surround Yabad Town. However, the focus of this study will be on the villages near Yabad's Eastern Well.

The communities of Tura, Al Riyad and Nazlet Zeid are near the target well and might have an impact because, as Figure 2 illustrates, their locations are close and higher in elevation than the Yabad Eastern Well location. These villages depend on cesspits for their wastewater disposal, since they lack sewer networks.

1.4.4 Geological Formations

The most important variable that directly affects any aquifer contamination is the geological formation (10). As shown in Figure B 5, the Yabad Eastern Well lies within the Senonian formation. Studying the well's geological formation, land use, and activities located within protection zone is therefore essential. A protection zone for a well is a designated area around a water well where activities are managed or restricted to prevent groundwater contamination. It typically consists of three zones: the immediate zone near the well (strictly restricted), an intermediate zone (controlled land use), and an outer zone (broader catchment area for sustainable practices). These zones safeguard water quality by regulating activities like waste disposal, chemical use, and industrial processes to ensure a clean and reliable water supply (11).

The Yabad Eastern Well is located on the outcrops of chalks and chert rocks of the Abu Dis formation, which cover parts of the western boundary of the Northeastern Basin.

Figure B 6 shows the generalized geologic map and major geologic structures of the West Bank (12). The geologic formations underlying the Abu Dis formation are a sequence of thick, existing beds of limestone, dolomitic limestone, marls, and marly limestone of the Jerusalem, Bethlehem, Hebron, Yatta and Upper Beit Kahil formations. A generalized stratigraphic section of the West Bank is shown in Figure B 7 (13). At the Yabad well location, the chalks and cherts of the Abu Dis formation are found at the ground surface, and the upper Beit Kahil Formation is found at the bottom of the well (see Table 1) (14). The Abu Dis and Yatta formations confine the Bethlehem and Hebron formations, which form the upper aquifer system in the Northeastern Basin. The Upper Beit Kahil is the lower aquifer system.

The target aquifer of the Yabad Eastern Well is composed of the Upper Cenomanian (Bethlehem and Hebron formations) the Bethlehem Formation consists of limestone, dolomite and calcite bands. It also contains dolomite alternating with calcitic limestone and Marly and chalky limestone.

The Hebron Formation is the lower unit of the Upper Aquifer System. It consists of limestone that is dolomitic and calcitic, with marly intercalations. The dolomitic limestone is brown to gray, thin bedded, densely crystalline, and well jointed.

The well also taps the lower Cenomanian (Upper Beit Kahil Formation). The regional groundwater flow in the Northeastern Basin is to north – northeast and ultimately drains to Al Nus Valley. The depth to static water level in Yabad Eastern Well was measured at 253 meters below ground surface after well construction (14).

Table 1

Summary of Lithology in Yabad Eastern Well

Period	Age	Graphic Color	Formation (West Bank) Terminology	Hydro-stratigraphy	Typical Thickness (m)	Yabad Eastern Well Thickness
Cretaceous	Seno nian		Abu Dis	Aquitard	200-450	0-52
	Turo nian		Jerusalem		40-120	52-106
	Upper Cenomania n		Bethlehem	Upper Aquifer	30-115	106-220
			Hebron		105-260	220-305
	Lower Cenomanian		Yatta	Aquitard	50-150	305-385
			Upper Beit Kaheil	Lower Aquifer	10-150	385-500
			Lower Biet Kahil		10-160	0
		Yabad Eastern Well Depth (m) =				500

According to the Yabad Eastern Well profile shown in Table 1 and Figure B 6, we note that the well is located within Abu Dis and Khan Al Ahmar geological formations which are classified as confining layers (Aquitard). In the Northern West Bank, the lithological facies of the upper Yatta formation exhibit increased dolomitization, resulting in the upper and lower aquifer systems merging into a single aquifer unit with a consistent water level across the area (Eng Sayel Weshahi, personal communication, 10 March 2024).

1.4.5 Groundwater Direction

Understanding the direction of groundwater flow helps in predicting the movement of pollutants in aquifers. Through the movement of groundwater, contaminants can spread in all directions, affecting groundwater quality (15).

The sources of contamination can be identified by following the route of groundwater flow within the aquifer. This is necessary to eliminate the source of pollution, put remediation strategies into operation and prevent further contamination.

The Northeastern Basin's regional groundwater flow eventually flows into the Al Nus Valley in a north-northeast direction.

There are three major groundwater basins within Palestine's groundwater aquifers: the Northeastern, Western, and Eastern basins. The Yabad Eastern Well is located between the northeastern basin and the western basin, as indicated by Figure B 8. It is possible to draw a hydraulic head contour map based on the wells summarized in Table 2.

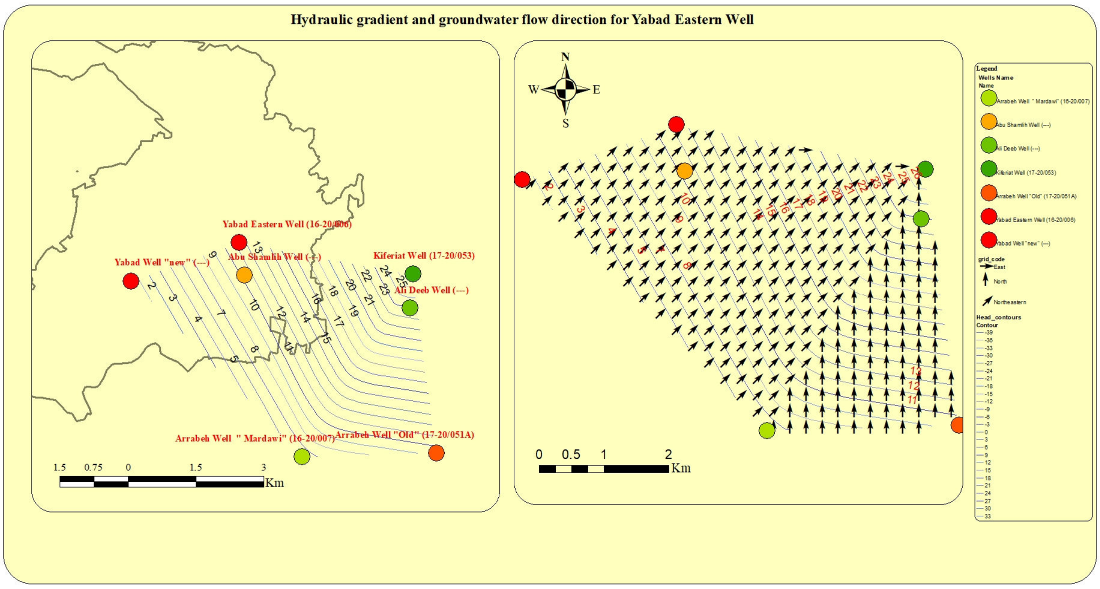
Table 2

Existing Wells around Yabad Eastern Well

Well										
1	Eastern Yabad Well	16-20/006	167003	205764.9	270	265	5	NE (Upper & Lower)	North Eastern	
2	New Yabad Well (Western)	---	164623.9	204923.3	300	265	35	NE	North Eastern	550
3	Kiferiat Well	17-20/053	170849.2	205076.8	255	295	-40	NE	North Eastern	700
4	Arrabeh Well New Arrabeh	17-20/051A	171366.6	201147.2	266	255	11	NE	North Eastern	405
5	Well (Mardawi)	16-20/007	168398.1	201068.6	285	266	19	NE	North Eastern	410

Figure 3

Hydraulic gradient and groundwater flow direction for Yabad Eastern Well



It can be concluded that the Yabad Eastern Well is part of the Northeastern Well, and the groundwater flow direction is moving from southwest to northeast as shown in Figure 3

1.4.6 History of Contamination of Yabad Eastern Well

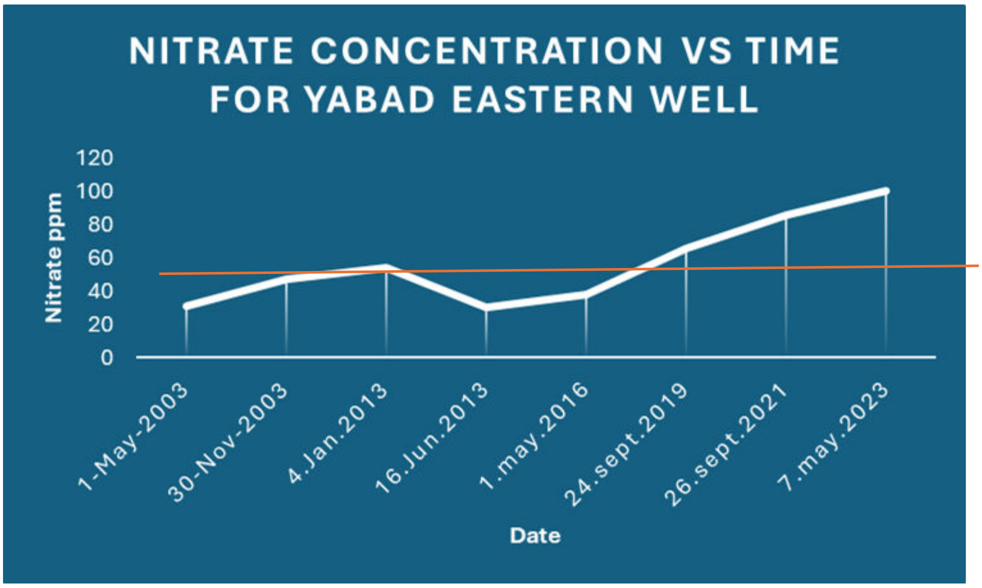
It is essential to understand the history of contamination in the aquifer and the well. This provides an indication regarding the start of the problem. By knowing when the problem started, it is possible to look into and search for the improper practices that happened based on the problem appearance data.

Based on the information shown in Figure 4, it appears that nitrate pollution for Yabad Eastern Well has become an issue for the last five years. According to Palestinian guidelines for the Ministry of Health (MoH), the highest allowable level of nitrate concentration is 70 mg/l, although the World Health Organization (WHO) limits it 50 mg/l. The issue first surfaced in 2019 when the concentration went beyond the Palestinian guidelines.

By drawing the nitrate concentration versus date, we can see that the nitrate concentration exceeds the MCL in September 2021, which indicates the start of problem.

Figure 4

Nitrate Concentration VS Time for Yabad Eastern Well



A serious environmental problem that has significant effects on water quality and human health is nitrate contamination in Palestine's Eocene aquifer. Due to a variety of human activities, the aquifer a vital groundwater resource for residential, industrial, and agricultural purposes is facing increasing nitrate levels.

The widespread use of chemical and organic fertilizers leads to significant nitrate loading, which is one of the main causes of nitrate contamination in the agricultural sector. Untreated sewage and poorly maintained wastewater systems make the issue worse by letting nitrogen compounds leak into the aquifer. Additionally, urban and industrial activities, especially in highly populated areas contribute to the contamination.

Ammonia is the most common form of fertilizer in the region; it can seep into the aquifer and change into nitrates. It is predicted that large volumes of nitrate leak into groundwater each year, reducing its quality and affecting ecosystems and human health. According to spatial analysis, areas close to urban centers and agricultural zones where nitrogen sources are concentrated have higher levels of contamination. The situation shows the vulnerability the Eocene aquifer is to pollution, highlighting the urgent need to reduce nitrate leaks and protect this essential source of drinking water. To stop additional degradation, this requires controlling runoff from agriculture, enhancing wastewater treatment, and keeping a check on groundwater quality. Consumers are extremely concerned about the safety of their drinking water because of the toxic nitrates in the Yabad Eastern Well. Many people have turned to buying bottled water out of concern for possible adverse effects on health, which has put extra pressure on already financially challenged homes. Increasing stress and a shortage of confidence in the local water supply's quality are reflected in this improvement. Furthermore, the contamination is increasing the municipality's and the Palestinian Water Authority's responsibilities, putting pressure on them to deal with the problem, keep a check on the water quality, and come up with sustainable solutions to ensure the community's access to safe drinking water.

1.5 Literature review

The widespread problem of nitrate contamination in groundwater has drawn attention from researchers, requiring a thorough investigation of its many impacts on human health as well as the environment.

The purpose of the previous studies was to acquire the necessary knowledge in this field and find solutions to ensure the continuous preservation of this resource. As a result, evaluation has to be predicated on quantity as well as quality and how the two interact.

1.5.1 Health of impact of nitrate pollution of water

A greater percentage of the world's population depends on groundwater as their main supply of water for daily requirements. The effects of groundwater pollution are becoming a major concern for livestock and the public health community. In particular, consuming contaminated water can have a negative impact on health, thus it's essential to determine whether groundwater is suitable for human consumption. All the contaminations, nitrate ($NO3$ -) pollution is the most common environmental crisis, with two different sources: natural and man-made. Groundwater nitrate pollution is mostly caused by excessive anthropogenic loading, which includes home organic and inorganic waste, pesticides and fertilizers used in agriculture, and leaks in sewage systems (16).

Ramalingam et al. gathered 40 groundwater samples, during the monsoon season and the principal ions were examined in a lab for South India region. The specific objective of this research is to evaluate the health risk to humans caused by groundwater contaminated with nitrates, which is consumed continuously by people of different ages (16).

According to the Unites States Environmental Protection Agency (USEPA), nitrate concentrations over 45 mg/L have the potential to seriously harm human health. It created a model to assess the effects of nitrate injections using two different methods: oral and thermal. The human population has been divided into six groups for this study: under six months, five to ten years, ten to fifteen years, fifteen to twenty years, twenty to sixty years, and over sixty years. The study shows that Continuous ingestion of groundwater containing high concentrations of nitrate can have detrimental consequences on humans of all ages (16).

Ward et al. study focusing on the relationship between nitrate concentration in drinking water and human health in America and Europe by reviewing more than 30 epidemiologic studies. These studies show that an increasing nitrate level in water will lead actual health problems, such as methemoglobinemia (Blue Baby Syndrome) in infants, issue with reproduction of spontaneous abortion, a higher risk of cancer, possible an increased risk of infantile gastric cancer, and higher death rates, especially in vulnerable populations (7).

The majority of negative health consequences related to nitrate in drinking water most likely result from the combination of excessive nitrate intake and endogenous nitrosation-promoting variables (7).

1.5.2 Nitrate pollution of groundwater worldwide

Many studies have been conducted about nitrate pollution of groundwater around the world. In this part will we review studies conducted in Palestine and around the world.

1. Nitrate pollution of groundwater in Palestine.

- Ahmad et al. examined sixteen West Bank wells, and additional six wells within the Eocene aquifer's boundary in Qabatiya Town were taken into consideration to study the vertical distribution of nitrate. The results indicated that nitrate concentrations in Ash-Shaarawieh, especially in Illar and Attil, are higher than the maximum contamination level. These wells, which are under irrigated areas, have the highest nitrate concentrations, mostly as a result of intensive agricultural practices(17).

- Mahmoud et al.s' study's objective was to evaluate the groundwater quality consumed in various West Bank districts for water consumption. The particular goals were to evaluate the physicochemical and microbiological characteristics (such as faecal coliforms) and potential presence of heavy metals in the groundwater. Hydro-geochemical methods, such as Piper and Gibbs diagrams, were also used to examine the geochemical structure of aquifers and potential human activity contamination. We recognize that this study has limitations because it only included seven wells sampled during the rainy season and a single sampling during the dry season. Three major aquifer basins were examined in this study: the North-Eastern Aquifer (NEA), the Western Aquifer (WA), and the Eastern Aquifer (EA). The 29 wells' groundwater samples were collected during the dry season, which usually spans from March to November. Moreover, during the wet season, samples from seven wells were also collected.(13) All the wells in this study's groundwater samples had nitrate concentrations under 30 mg/L, except for one well in Tulkarem. The nitrate concentration in the Tulkarem well, which takes water from the Upper Cenomanian aquifer, was 46 mg/L, which is close to the 50 mg/L maximum allowable limit. Because of the large amounts of nitrate in waste products and its subsurface movement, nitrate has been used as a chemical indicator of sewage contamination of groundwater. Given the negative impact on health and the highly complicated and costly treatment needed to remove it, the presence of higher nitrate concentrations in the majority of the wells included in this study is especially concerning(13).

- The study by Isaac, Qumsieh, and Owewi investigates water pollution in the West Bank, using a methodology that combines aerial photography, field surveys, and GIS mapping. Data collection included analyzing wastewater disposal practices, solid and industrial waste, and agricultural runoff. Results revealed significant contamination from untreated wastewater, poorly managed solid waste, and agricultural chemicals, exacerbated by Israeli settlements and industrial activities. According to the research's conclusions, these activities significantly damage the Jordan River and West Bank aquifer, highlighting the urgent need for environmental regulations and effective management of water resources to preserve these vital systems (18).

- Omar Zayed gathered twenty-nine groundwater samples from wells in different aquifers and basins in order to evaluate the quality of the groundwater of drinking water wells in the West Bank, Palestine. Heavy metal concentrations, microbiological traits, and physicochemical qualities were the main objects of the analysis. Most of the criteria controlling the water's appearance and health were found to be within accepted ranges for drinking water. The dominant cations were found in the order of $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+} > NH_4^{+}$, while dominant anions were $HCO_3^{-} > Cl^{-} > NO_3^{-} > SO_4^{2-}$. The groundwater was characterized as relatively hard, with an average total hardness of approximately 2.1 mmol/L, primarily attributed to calcium (60%) and magnesium.

Three major groundwater types were identified: fresh water (Ca-Mg-HCO_3), fresh water mixed with another water type (Ca-Mg-Na-HCO_3 or Ca-Mg-HCO_3-Cl), and extreme water type (Na-Ca-Mg-HCO_3-Cl or Na-Ca-HCO_3-Cl) showing high TDS, Cl^{-}, and Na^{+}. Despite generally acceptable water quality, signs of pollution were observed, including elevated levels of nitrate and ammonium in some deep wells tapping the Lower Ceneomanian confined aquifer, likely caused by uncontrolled disposal of untreated wastewater and/or agricultural activities. The study concludes that while most wells can be used for water supply after proper disinfection, concerns about elevated nitrate and ammonium levels in some wells remain. Zayed recommends further monitoring and environmental management to ensure sustainable availability of this freshwater source in the future (13).

2. Nitrate pollution of groundwater worldwide.

- In China a study conducted by Yu et al’s collected a total of 2348 samples were tested during the year 2015–2018. The nitrate content in Yantai's rural wells varies from 0.075 to 166.4 mg/L according to the study. Over 63.3% of the monitoring locations, the 11 mg/L WHO recommendation limit was exceeded. Rural Yantai's nitrate concentration is comparatively constant and unlikely to vary over time. The combination of geological elements and fertilizers may be the cause of Yantai's high nitrate concentration in rural regions. Thus, it is essential to remain alert regarding elevated nitrate levels b (10).

- Dieng et al’s conducted study involved the collection of 40 groundwater samples in the post-monsoon season in southern part of India, followed by a laboratory analysis of the main ions. The range of nitrate concentration was 24–78 mg/L, with a mean of

46.45 mg/L. The source was divided into two categories: point and dispersed sources. The research region's rural area was shown to be the widespread source of nitrate contamination. Their agricultural productivity was heavily dependent on synthetic fertilizers, and they practiced modern agriculture practices such applying nitrogen-based fertilizers. Human-caused activities such improperly maintained open wells, livestock waste disposal, uncovered septic tanks, residential waste disposal, and mining operations are some of the other sources of nitrate detected in the research area (3).

- The study by UN-IGRAC highlights nitrate contamination in the USA, particularly in agricultural areas. It found that over 10% of groundwater wells exceed the World Health Organization's safe nitrate limit of 50 mg/L. The study used groundwater monitoring data to track nitrate levels and identified fertilizers as the primary source. The research results showed the necessity of improved water management and methods for agriculture. In order to reduce nitrate pollution, the conclusion recommended improved technological and regulatory strategies (19).

- The research conducted by Kumar et al. provides a thorough evaluation of nitrate contamination in agricultural landscapes throughout Europe, highlighting the significance of biogeochemical processes and temporary hydrologic transport trends. It illustrates how basic vulnerability assessments significantly minimize the risks of nitrate leakage through the integration of detailed hydrologic simulations with theoretical models. According to the results, hydroclimatic variability puts almost 75% of farms at danger of nitrate leakage during at least one-third of the year. The study shows how future nitrate management and policy frameworks must take changing variables into account in order to enhance efforts for improving water quality.

  Based on observed weather information, Kumar the researchers employed advanced continental-scale hydrologic simulations from 1950 to 2015. Water and solvent movement in the root zone of the soil was modeled using transient formulations of travel-time distributions. The study evaluated nitrate leakage vulnerability using the dimensionless Damköhler number, which integrates biogeochemical reaction timeframes. The study focused on the geographical and temporal dynamics of

Europe's agricultural regions, highlighting the impact of environmental variables and hydroclimatic variability on the processes of nitrate transport and nitrification (20).

- The region's limited water resources and regional conflicts enhance water pollution in Israel and Palestine, which has a major adverse effect on ecosystems and public health. The West Bank, Israel's coastal regions, the Gaza Strip, alongside significant waterways like the Jordan River, the Sea of Galilee, and the Mountain Aquifer are the study's main areas of concern.

  It works to identify the causes and effects of many forms of pollution physical, chemical, and biological and recommend ways to minimize them. Through a rigorous analysis of 22 scholarly publications from 1972 to 2023, the study looks at data gathered in the field that has been analyzed in lab and GIS settings. Sedimentation, turbidity, and eutrophication are indicators of physical pollution, particularly on rivers like the Yarkon and Alexander. Groundwater in Gaza and Israel has been severely affected by chemical pollution, arising from untreated wastewater, agricultural runoff, and industrial operations. This contamination contains high levels of nitrates, phosphates, heavy metals, and salinity. Blooms of algae and contamination by bacteria are examples of biological pollution, which harms ecosystems and public health.

  The Gaza Valley and the Sea of Galilee are particularly vulnerable. According to the report, there is moderate to severe water pollution in the area, with the West Bank and Israeli rivers suffering physical pollution and the Gaza Strip suffering significant chemical contamination. To reduce pollution and protect public health, recommendations include implementing sustainable agricultural practices, enhancing water resource monitoring, developing international collaboration, and upgrading wastewater treatment facilities. Addressing the region's water issue, which is made worse by human activities and climate change, requires the following procedures. (21).

- Almasri and Kaluarachchi's research uses a GIS-based modeling approach to investigate how nitrogen loading affects groundwater quality. Within a 376-square-mile aquifer in Washington State, it evaluates nitrogen inputs from residential and agricultural sources, including fertilizers, dairy fertilizer, septic systems, and atmospheric deposition. The main source of nitrogen was found to be dairy fertilizer, which was followed by pesticides. Recharge rates and soil nitrogen transformations had a major impact on nitrate leaking. According to the research, nitrification is the most important element controlling nitrate leakage.

The efficiency of management methods including nitrification medication, reduced dairy manure loading, and improved fertilizer application rates minimizing the leakage of nitrates significantly. For example, nitrate leaching was reduced by up to 16% when manure loading was reduced by 50%, and nitrification inhibitors further reduced the amount of nitrate that was produced in soils. To decrease high-risk activities in vulnerable areas, the study also underlined the significance of regional zoning and land-use reforms. In order to manage nitrogen deposits in soils, protect drinking water supplies, and reduce environmental effects, these integrated approaches highlight the difficulty of controlling groundwater contamination and the need for long-term planning (22).

Method for detection of sources of nitrate pollution of groundwater.
Groundwater nitrate pollution considers a serious environmental problem, often occurs by sewage, industrial waste, and runoff from agriculture. Developing effective mitigation solutions requires determining the sources of nitrate pollution. For source detection, a variety of methods are used, such as statistical methods, hydrochemical modeling, and isotopic analysis. These methods identify between natural, urban, and agricultural sources of nitrate by analyzing its chemical and isotopic properties. Recent developments integrate machine learning and geographic information systems (GIS), providing better spatial understanding and accuracy of contamination patterns.

- Combine of GIS, Statistics and Machine Learning method:
  The objective of this research is to provide a complete approach for managing groundwater quality which includes both prediction and assessment of water quality.

  The approach merges machine learning, statistics, and geographic information systems (GIS). The effectiveness of this method is examined by applying it to determine and evaluate nitrate concentrations.

GIS provides the ability to consider both the processes providing, and the spatial variations related to groundwater nitrate contamination (GNC). The results of the investigation were presented using statistical descriptive analysis, which makes it possible to figure out the frequency of any abnormal event. A variety of characteristics, including land use, soil type, water shed, groundwater flow direction, well use, well depth, and others, are investigated to identify the elements that affect GNC.

- The Kriging Interpolation Method provides spatiotemporal GNC maps based on GIS. KIM can take statistical models and spatial autocorrelation into account. To forecast the probability of exceeding the globally specified NO3 limits, this study uses Random forest (RF). Because of its capacity to combine various decision tree algorithms in a cooperative way, RF was selected higher than other machine learning methods. It can produce many forecasts for the same occurrence. Moreover, it could measure the proportional value of the input-influencing variables (23).

- Physically based highly distributed groundwater models: A map that illustrates the spatial distribution of the total nitrogen from the various sources is the primary output of this work. However, there are numerous other outputs that are also important, such as the basic statistics connected to the various nitrogen sources and the corresponding percentages of occurrence. MODFLOW and MT3DMS are examples of used models in this study (24).

- Isotopic method: The effect of varied geological structure on groundwater residence times and related potential sources, mixing, and recharge mechanisms were examined using integrated isotopic methods (25) .

- Overlay and index methods: The overlay and index methods merge maps of the region's various physiographic properties (such as its geology, soils, and depth to the water table) and give each one an estimated value or score. Adoption of map overlay and index technologies has become easier as GIS technology has become more widely used (26) .

1.5.3 Vulnerability assessment for aquifer

- DRASTIC and GOD method: The application of DRASTIC method is suitable for areas with general hydrogeological setup and low data availability. It is suggested to use an even more simple method; GOD if data is limited (11). Examples of parametric systems include Haertle (1983) and DRASTIC (1987), which use a subset of parameters as indicators of vulnerability and assign their range of values and interactions to produce some sort of relative or absolute vulnerability index.

- EPIK is another noteworthy technique in this category. It was created especially for karst limestone aquifers and has been described by Doerfliger and Zwahlen (1998) (11) Compared to DRASTIC, the GLA's grading system and its adaptation, the PI method, are less subjective and more based on scientific principles.

- The modified PI technique can be used in all hydrogeological settings because it takes into consideration the GLA's limitations for karst environments (limestone, dolomite, and dolomite limestone). In regions with different lithological units, it is advised to employ a combination of the GLA or the PI methods (27).

  Management practices to address nitrate pollution in groundwater. According to previous studies, different recommendations to decrease and mitigate the nitrate issue were adopted.

- Ramalinggam et al’s suggested training farmers about the benefits of using organic fertilizers (OF). The OF has more benefits than synthetic fertilizers, such as not creating an impermeable layer on the soil's surface. they advised those involved in the water management system to examine sewage and water pipelines and educate themselves on the dangers of disposing of waste on landscapes (16)

- Hejaz et al’s recommended to give greater authority to the water institutions to monitor water sources, they must be enhanced. Wastewater treatment plants are an essential need for large societies if contamination in the aquifers is to be reduced and controlled (2)

- Judeh et al’s proposed a strategy for Palestine's sustainable groundwater quality management. Establishing groundwater monitoring programs requires cooperation between several parties, such as the Ministry of agriculture and Palestinian water authority. These actions should limit the heavy use of agriculture chemicals and cesspits in order to encourage Palestine's sustainable groundwater use (23)

- Yu et al’s suggests that regular groundwater monitoring and collaboration between communities, industry, and government agencies are crucial for promptly identifying and managing nitrate contamination. Complete solutions to protect groundwater quality from nitrate contamination can be developed by combining government efforts, environmentally friendly behaviors, and citizen participation.(10)

- The National Water Policy for Palestine (2013–2032) emphasizes comprehensive strategies to protect groundwater from pollution and ensure sustainable management of water resources. Key measures include regulating groundwater abstraction within sustainable limits, preventing contamination from fertilizers, pesticides, and untreated wastewater, and enforcing the polluter-pays principle. Strategies focus on continuous monitoring of water quality, identifying pollution sources, promoting aquifer recharge using stormwater infiltration, and developing non-conventional water resources like treated wastewater. The policy advocates for improved wastewater treatment infrastructure, efficient agricultural practices, and community involvement through public awareness campaigns. Governance measures include defining clear water rights, regulating abstraction through permits, and fostering public-private partnerships for technological and financial advancements. Progressive tariffs are recommended to ensure financial sustainability and equitable access to water and sanitation. By integrating these approaches, the policy aims to mitigate pollution, preserve groundwater, and support sustainable development under challenging climatic and geopolitical conditions (28).

- St. Foster states that supply protection areas, also known as source protection zones (11), must be safeguarded against:

1. pollutants that degrade with time, for which the strongest defense is subsurface residence time.
2. nonbiodegradable pollutants, for which flowpath-dependent dilution is required. Both are required for complete security. Degradation (breakdown) is also likely to occur for certain contaminants (and various other processes like adsorption and

precipitation for others), but the predominant attenuation process is typically contaminant dilution brought on by the advection and dispersion mechanisms connected to groundwater flow. Groundwater flow paths determine the geometry of the entire capture zone, while water balance concerns determine the area it covers. It is the area that provides the long-term yield protection. Therefore, the area of the groundwater flow system will be determined, assuming it is in a steady-state condition, as is typically the case. It should be understood, although, that the actual capture area will be greater than the protected area during long periods of drought (when groundwater recharge distance from the actual underground water extraction location is lower than typical). Additionally, the capture area will be less in regions where the aquifer is contained behind impermeable strata (11)

The innermost protection perimeter is that of the wellhead operational zone, which comprises a small area of land around the supply source itself. It is highly preferable for this area to be under ownership and control of the groundwater abstractor. In this zone no activities should be permitted that are not related to water abstraction itself, and even these activities need to be carefully assessed and controlled to avoid the possibility of pollutants reaching the source either directly or via adjacent disturbed ground (11). All parts of the zone used for well maintenance activities should have a concrete floor to prevent infiltration of oils, chemicals, and sewage used in pump maintenance. Fencing is also standard practice to prevent invasion by animals and vandalism (11)

Chapter Two

Methodology

2.1 Methodology

The following is the methodology:

1. Understanding the problem of nitrate pollution in wells. This involves assessing the nitrate data from the Yabad Eastern Well by plotting time series, which could help identify the onset of the problem and allow for comparison with activities that occurred around that time.
2. Reviewing relevant research into the West Bank's groundwater contamination. Furthermore, in-person interviews are used to gather data and conduct initial analyses. After that, all the related data and information about Yabad Eastern Well were gathered. The source of the data includes boundaries of aquifer, static water level, elevation, geological formation, and well characteristics.
3. Perform nitrate tests on the Yabad Eastern Well and nearby wells within the same aquifer. To determine the groundwater flow direction, we will use readings of static water level for five wells and use the elevation data for each well. With this data, we can calculate the hydraulic head at each well by subtracting the static water level from the elevation. By using GIS software, we can then create a digital elevation model (DEM) and generate a flow direction grid. The flow direction grid will show the direction of groundwater movement based on differences in hydraulic head between the wells. By analyzing these flow direction patterns, we can find the groundwater flow direction and determine the groundwater flow direction within the study area. GIS tools will allow for the creation of head contour lines, providing a clearer understanding of the groundwater flow direction in the study area.

   To identify upstream and downstream area, we can follow the groundwater flow direction along the flow direction grid. The upstream area is defined as the region from which the groundwater flows towards a particular well, while the downstream area is the region towards which the groundwater flows.

Following the contours and examining the flow direction allows us to map the areas upstream or downstream of the wells, helping in identifying areas that affect or contribute to groundwater movement.

4. Vulnerability analysis by using the GOD method. A popular technique for determining an aquifer's vulnerability to contamination, particularly caused by contaminants like nitrates, is the GOD method. It involves analyzing three primary elements: depth to groundwater, underlying materials, and geology. First, permeability and the ability of geological formations to transfer contaminants are taken into account by the Geology (G) factor; rocks that are more permeable are considered to be more sensitive. The form and thickness of the materials above the aquifer, including soil or clay, which may act as a natural filter to slow down or stop contamination, is determined by the Overlying Materials (O) factor. The distance between the ground surface and the aquifer is identified as the depth to groundwater (D). Shallower depths often enhance vulnerability because contaminants are more likely to reach the water table. These factors are combined to assign a vulnerability score, which can be mapped to identify high-risk areas within the aquifer. The GOD method allows for a comprehensive, spatially detailed assessment of aquifer vulnerability, providing valuable insights for land-use planning, environmental protection, and water quality management. The GOD index is a measure of the aquifer vulnerability that is computed by multiplying the influence of the three factors using Equation (1).

$$\text{GOD Index} = Ca\ Cl\ Cd \tag{1}$$

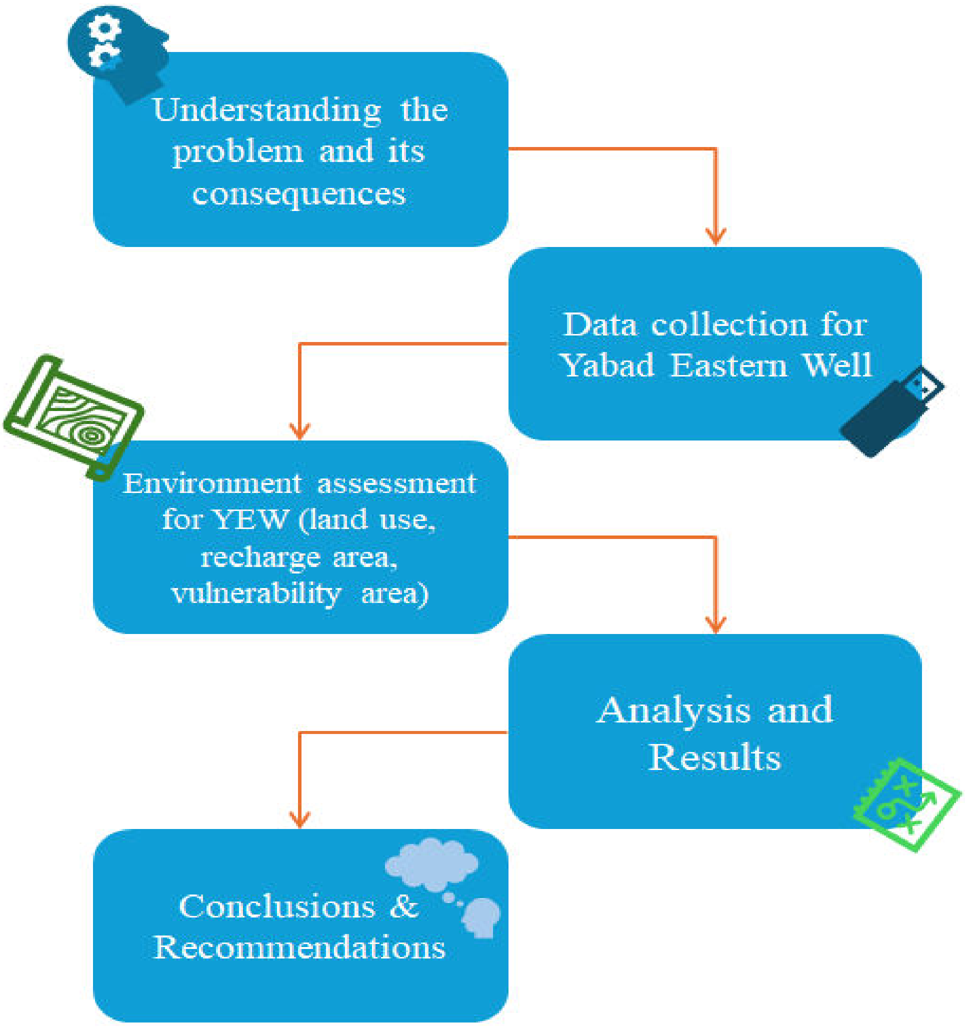
where Ca is the type of aquifer; Cl is the overlaying lithology of the zone and Cd is the depth to the aquifer.

We selected this method because there are fewer parameters which are available. However, there are many other methods that are more accurate but need more data parameters to utilize are not available.

5. Determination of the contamination source: By overlaying the three maps of flow direction, vulnerability area, and groundwater recharging area using GIS.

Figure 5

Research methodology



2.2 Data Collection

This chapter concentrates on the raw data that will be collected for analysis of Yabad Eastern Well and surrounding area. The collected data will be separated into two groups: 1st related to Yabad Eastern Well, 2nd related to aquifer and surrounding area, including other nearby wells.

2.3 Yabad Eastern Well Data

The data collected for Yabad Eastern Well is related to the historical data of nitrate at Yabad Eastern Well, and this data was gathered from the Ministry of Health, which conducted tests for Yabad Eastern Well.

The well characteristics such as depth, static water level, yielding, and elevation were gathered from a report conducted in 2002 by Ch2mHill, the summary of this report as follows:

The Yabad Eastern Well, constructed as part of the USAID Phase II Bulk Water Supply Project, is located 13 km southwest of Jenin in the West Bank. Designed to supply drinking water to Yabad Municipality, the well reaches a total depth of 500 meters below ground surface (mbgs) with a casing diameter of 13 3/8 inches and a slotted section spanning 100 meters between 250-350 mbgs. The static water level (SWL) is 253 mbgs, and the dynamic water level (DWL) is 284.4 mbgs at a pumping rate of 82 m^3/hr. The hydrogeologic setting comprises primary aquifers from the Upper Cenomanian (Bethlehem & Hebron Formations) and Lower Cenomanian (Upper Beit Kahil Formation), with regional groundwater flowing north-northeast toward the Harod Valley. The construction, spanning November 2001 to May 2002, involved detailed processes such as conductor pipe installation, nine-stage cementing with 91 m^3 of cement, manual slotting, and acidization using 24 m^3 of 22% HCl. Development efforts addressed sediment issues, although challenges like delays due to security restrictions and equipment failures persisted. Water quality testing revealed selenium (13.6 µg/L) and thallium (14.9 µg/L) exceeding benchmarks, though total dissolved solids (TDS), chloride, and iron levels were within acceptable limits. Aquifer testing showed an average transmissivity of 56.70 m^2/day. Recommendations include addressing water quality concerns, implementing sediment control, regular acidization, and long-term monitoring to ensure sustainable and safe water supply (14)

2.4 Aquifer and surrounding environment

The data related to the aquifer and the wells surrounding the Yabad Eastern Well were gathered from the Palestinian Water Authority, "PWA." This data includes the aquifer name, flow direction, geological formation, catchment area, vulnerability area, and surrounding wells elevations, static water level, and yielding flow. Other data was collected related to the study area, like land use, land classification, soil classifications, and houses from the Ministry of Local Government, "MoLG". Lastly, the data about the population was gathered from the Palestinian Central Bureau of Statistics, "PCBS."

2.5 Tests were conducted on wells located within the study area

Sampling sites were selected for laboratory analysis, where nitrate concentrations were measured at the Water and Environmental Studies Institute (WESI) laboratory at An-Najah National University. These samples were collected and analyzed as follows procedure:

Steps for Sampling Groundwater and Testing Nitrate Concentration Using a UV-Vis Spectrometer

1. Preparation:

- Materials and Equipment: Gather clean glass or plastic sampling bottles, UV-Vis spectrometer, standard nitrate solutions, 1N HCl, pipettes, a centrifuge (if needed), deionized water, and gloves.
- Sterilization: Ensure all bottles and equipment are clean and sterilized to avoid contamination.
- Reagents: Prepare reagents, including 1N HCl, to reduce Total Organic Carbon (TOC), which can interfere with nitrate measurements.

2. Sampling:

- Select Wells: Identify the seven groundwater wells for sampling based on the study objectives.
- Flush the Well: Purge the well by pumping water until fresh water from the aquifer is obtained, ensuring a representative sample.
- Collect Samples:
- Use clean bottles to collect approximately 500 mL of water from each well.
- Fill bottles completely to minimize air exposure and oxidation.
- Preserve Samples: Add 1 mL of 1N HCl to each 500 mL sample to decrease TOC levels and stabilize nitrate concentration.

3. Transportation:

- Store the samples in a cooler with ice packs at approximately 4°C to maintain integrity during transport to the laboratory.

4. Sample Preparation in the Laboratory:

- Filter Samples: Use a 0.45 µm filter to remove particulates that could scatter light during spectroscopic analysis.
- Dilution: Dilute samples with distilled water because nitrate concentrations for Yabad Eastern Well is expected to exceed the linear range of the spectrometer.

5. UV-Vis Spectrometer Setup:

- Calibrate the Instrument:
- Warm up the UV-Vis spectrometer.
- Measure a blank sample (deionized water) to zero the instrument.
- Prepare Standard Solutions: Create a calibration curve using standard nitrate solutions of known concentrations (e.g., 0, 5, 10, 20, 50 mg/L).

6. Analysis:

- Measure Absorbance:
- Transfer each sample into a clean quartz cuvette.
- Measure the absorbance at the wavelength specific to nitrate (commonly 220 nm for nitrate detection and 275 nm for organic interference correction).

7. Data Processing:

- Plot the absorbance values of the standards against their concentrations to create a calibration curve.
- Use the calibration curve to calculate nitrate concentrations in the water samples from their absorbance values.

8. Quality Control:

- Repeat Measurements: Measure each sample at least three times to ensure consistency.
- Blanks and Controls: Run blank samples and quality control standards to verify instrument accuracy and precision.

9. Interpretation and Reporting:

- Compare Results: Analyze nitrate concentrations against local or international standards (WHO guideline of 50 mg/L for drinking water).

This method ensures accurate and reliable nitrate concentration measurements while accounting for potential interferences from organic carbon and ensuring sample integrity. Table 3 summarized the results based on the tests that were carried out on 17/04/2024.

Table 3

Nitrate concentrations in wells within study area

No.	Well Name	Concentration mg/L
1	Arrabeh Well "Old"	32
2	Arrabeh Well "Al Mardawi"	21
3	Kifarit Well	26
4	Ali Deep Well	19
5	Yabad Well "New"	31
6	Abu Shamlih Well	33
7	Yabad Eastern Well	92

Chapter Three

Analysis and results

Analyzing the groundwater components and the variables that affect contamination movements is crucial for understanding the extent, sources, and risks associated with pollutants that affect this vital resource (10). This chapter focuses on the methods and techniques used to analyze groundwater contamination, providing insights into identifying pollutants sources, their movements, from where access, and the potential impacts on the well water quality.

To understand the problem, we need to make a view for the nitrate test results that are done before to know the date of nitrate problem appearing. This date obtained from the Ministry of Health; we can notice that the nitrate problem started since 2021 from the Figure 4.

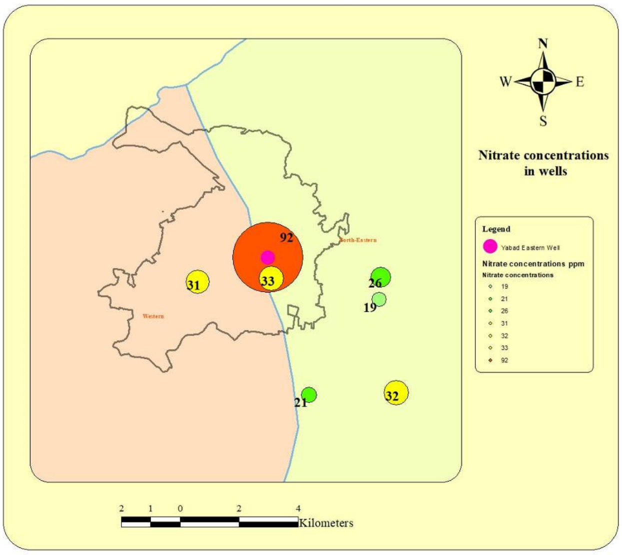
The previous step helped in determining the new activities for land use that did take place at that time within the area, which was determined in the next steps. And by taking new nitrate tests from Yabad Eastern Well and the wells existing in the surrounding area, it will help in knowing if the problem is general for the aquifer or locally in Yabad Eastern Well only. On the other hand, the new tests will also reveal if this increase in nitrate concentration is temporary or permanent.

For this research, we selected seven wells for sampling, and the results were as in Table 3.

Figure 6 displays the nitrate concentration test results for the wells in the study area. The concentrations are represented by filled circles of different sizes, with the circle size increasing proportionally to the nitrate concentration level. From Table 3 and Figure 6, we note that the increase in nitrate concentration appears only in Yabad Eastern Well, and this result gave indicators that the problem is locally for this well only. But to find if it is temporal or a permanent increase, the test was repeated in 30/04/2024 and in 09/05/2024, and the results were 92 mg/L and 89 mg/L, respectively. The nitrate results indicate that the problem is persistent.

Figure 6

Nitrate concentrations in wells within study area



For determining the area that is considered an entry or access of pollutants, we need to utilize many parameters that play major roles in this manner. Aquifer boundaries, groundwater flow direction, and vulnerability area are considered as main parameters for this analysis process.

3.1 Aquifer boundaries

Determining the aquifer boundaries is essential for studying contamination problems in Yabad Eastern Well well because it helps define the area contributing to the groundwater flow and potential sources of pollutants. By understanding the extent and limits of the aquifer, researchers can identify recharge zones, track contamination pathways, and assess the influence of surrounding land use on water quality. This information is critical for accurately modeling contamination behavior, implementing effective mitigation measures, and ensuring the long-term protection of the water supply. For determining within which aquifer the Yabad Eastern Well is within, maps obtained from the PWA were used. The aquifers are divided into three basins, the northeastern, western, and eastern as shown Figure B9 . Yabad Eastern Well is located within the northeastern aquifer as shown in Figure B10 .

But to check the accuracy of the basin boundaries map, head contours map was developed based on the between wells summarized in Table 3, If the contour lines decrease or increase in one direction without any break this means all wells are located in the same groundwater basin.

Figure B 11displays contour lines that decrease from south to north without irregular measurements, indicating that all the wells are within the same basin. However, based on the basin boundaries map obtained from the Palestinian Water Authority (PWA), the Yabad New Well is located within the western basin. Upon reviewing the source of this map, it was noted that its precision is not high. By determining the location of the Yabad Eastern Well within a specific basin and deriving contour lines from the water head, we can identify the groundwater flow direction, including the upstream and downstream areas. To evaluate potential groundwater contamination sources, it is essential to understand the components of groundwater protection, as illustrated in Figure B 12. This figure provides a clear representation of the concept of aquifer pollution vulnerability (APV) and the elements that contribute to groundwater protection. The Source Protection Area (SPA) is demarcated with concentric zones, indicating varying levels of vulnerability. Zone A, being the closest to the aquifer recharge point, represents the highest vulnerability, while Zones B and C are progressively less vulnerable due to their increased distance and potential protective barriers. The arrows showing horizontal flow directions effectively highlight the potential paths for contaminants to transport through the aquifer system, ensure the need for a detailed understanding of pollutant transport methods.

The predominant lithology of confining beds or the unsaturated zone plays a critical role in determining the aquifer’s vulnerability. Areas with thin or highly permeable lithological coverage, such as sand or gravel, are easier to contaminate due to limited natural protection, whereas thicker or less permeable layers, like clay, offer more protection. The depth to the aquifer or water table is a vital factor shown in the figure. A shallow water table, as shown in Zone A, increases the risk of contamination since pollutants require less time to travel, while deeper zones, such as Zone C, provide a greater buffer against potential contaminants.

The figure also shows the dominance of vertical flow in the unsaturated zone and horizontal flow within the saturated aquifer, which is crucial for understanding the mechanisms of pollutant migration. By combining these factors depth, lithology, and flow directions the concept of aquifer pollution vulnerability is effectively notify. However, adding further details, such as a legend to explain symbols or flow directions, would enhance clarity. Additionally, integrating land-use, such as agricultural, industrial, or residential areas, within the SPA would provide a more comprehensive perspective on pollution risks. Overall, the figure is an excellent tool for understanding groundwater protection but could benefit from slight modifications to improve practical applicability and clarity.

3.2 Groundwater flow direction

Understanding groundwater flow direction is very important for this research. This parameter helps in determining the upstream and downstream area for wells. Beside it helps in detecting the area from which pollutant is coming since the groundwater flow is considered as the transporter of pollutant.

Now, we need the hydraulic level for the wells within the study area to find the contour lines, and from contour lines can derive flow direction. By using ArcGIS and data of wells within study area shown in the Table 4 groundwater flow direction was determined.

Table 4

Data of wells within study area

Well	Name	PWA/code	X	Y	Elevation asl (m)	Static Water Level (m)	Hydraulic Level (m)	Aquifer Name	Well Depth (m)
1	Eastern Yabad Well	16-20/006	167003	205764.9	270	265	5	Northeastern	550
2	New Yabad Well (Western)	---	164623.9	204923.25	300	265	35	Northeastern	410
3	Kiferiat Well	17-20/053	170849.2	205076.8	255	295	-40	Northeastern	700
4	Arrabeh Well	17-20/051A	171366.6	201147.19	266	255	11	Northeastern	405
5	New Arrabeh Well (Mardawi)	16-20/007	168398.1	201068.59	285	266	19	Northeastern	410

The following steps will be conducted on ArcGIS software to find the groundwater flow directions:

- Import well data from csv file to ArcGIS as point shapefile GIS layer. Each point represents a well within the study area and have the data as shown in
- The result of this step appears as Figure B 13.
- To develop the contour lines, the IDW-Interpolation tool was selected and use hydraulic level values to represent z-value field to generate raster-IDW image as shown in Figure B 14.
- Use contour tool from surface tool box to create the contour lines which represent water head for the area creates by the utilized wells. he water head was calculated by subtracting the static water level from the elevation of the well. This contour lines will dervitave from previous raster image as appear in Figure B 15.
- A TIN was created using the 3D Analyst tools on the contour lines generated in the previous step to produce a TIN layer. In this step, the coordinate system was redefined, and the results are presented in Figure B 16.
- The flow direction tool from hydrology tool box was used to create flow direction raster layer as shown in Figure B 17.
- The flow direction raster layer was discretized into cells using the resample tool, as illustrated in Figure B 18.
- We will convert the resample layer to point by using raster to point tool. This step will provide each cell with point of a value that represent the direction according to ArcGIS direction code as in Figure B 19. After assigning this code for all the created points. The results appear as in Figure B 20.

After determination of the map of the groundwater flow direction, the southeastern area of the well was considered as the upstream area which the northeastern area was considered as the downstream area.

Anthoer parameter that we need to determine is the spitial distribution of groundwater recharge. The groundwater recharge helps to determine the potential locations where the contaminats entered the aquifer.

3.3 Groundwater recharge area

A groundwater recharge area is the area where water is capable to seep into the ground and refill an aquifer since no confining layer is present (29). In this study, delination of the recharge area was essential Figure B 21 shows the recharge areas within study area. This map prepared by PWA.

From the recharge area map, we can note that Yabad Eastern Well will not receive water from the recharge area with area study because the groundwater flow direction is coming from southwestern to northeastern, so any contamination source within the recharge area shown in the map will not affect Yabad Eastern Well However, identifying the groundwater recharge area relies on the vulnerability of the aquifer, which will be determined later in this research.

3.4 Vulnerability assessment of aquifer

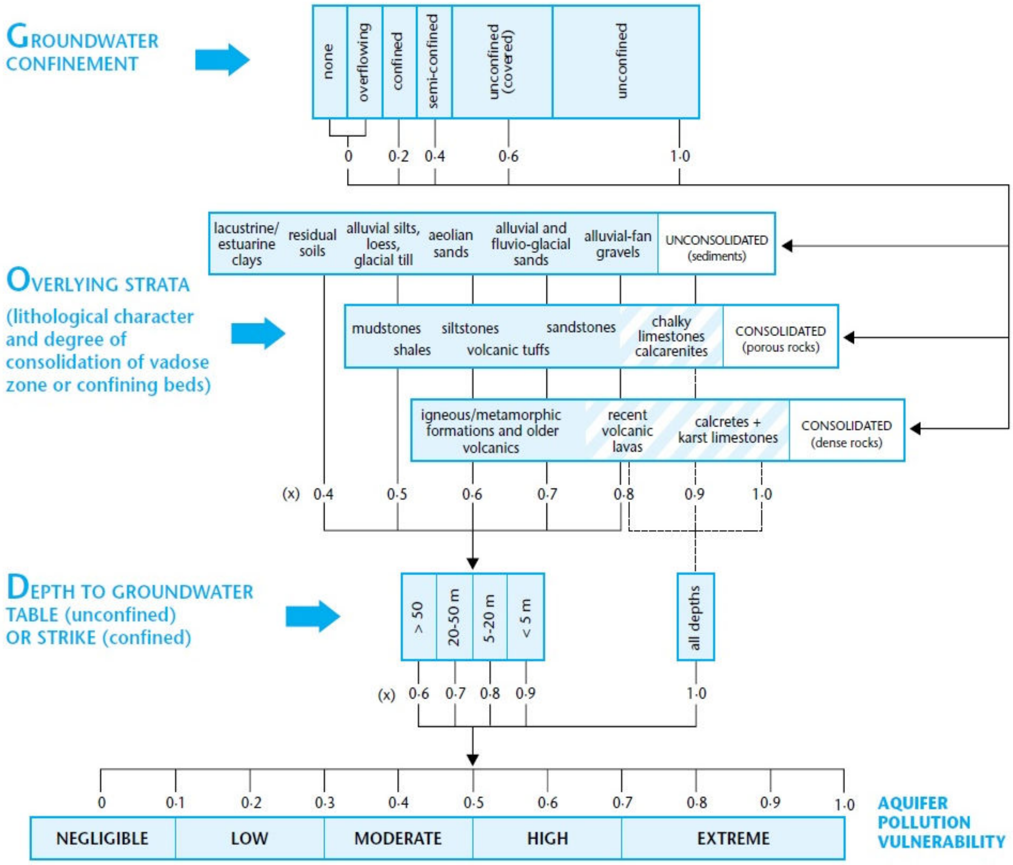
Groundwater vulnerability refers to the likelihood or potential for contaminants to reach a specific point within the groundwater system after being introduced at a location above the uppermost aquifer. The concept of groundwater vulnerability assessment recognizes that aquifers have varying characteristics across different locations, making some areas more susceptible to deterioration in both quantity and quality. Assessing groundwater vulnerability is a critical process for determining how exposed a particular region is to specific threats, whether they are natural, or human made. This assessment plays a vital role in understanding groundwater quality in an area and serves as a valuable tool for effective groundwater and environmental management (30).

Analysis of groundwater vulnerability was carried out using the GOD approach. The Geographical Investigation System methodology is used by the GOD method for the surrounding area. Groundwater vulnerability is evaluated using three parameters: depth to water table, overlaying strata, and groundwater confinement (30). The three primary factors of the GOD technique are depth to water table (D), overlaying lithology (O), and groundwater confinement (G) as shown in Figure B 22.

Figure 7 provides a detailed framework for assessing **aquifer pollution vulnerability** based on three key parameters: groundwater confinement, overlying strata, and depth to the groundwater table. Each parameter contributes to determining the vulnerability of an aquifer to pollution, with the vulnerability ranging from negligible to extreme, as depicted at the bottom of the figure.

Figure 7

GOD system for evaluation of aquifer pollution vulnerability (7)



The first parameter, groundwater confinement, categorizes aquifers based on their level of protection from overlying layers. Unconfined aquifers, which are directly exposed to surface influences, exhibit the highest vulnerability (scoring up to 1.0), while confined aquifers with thick, impermeable overlying layers have significantly lower vulnerability. This illustrates how important aquifer limitation is to reduce the entry of pollutants.

Overlying strata, the second parameter, looks at the lithological characteristics and level of consolidation of the controlling beds or vadose zone. Higher vulnerability ratings result from pollutants being able to more quickly infiltrate unconsolidated soils, such as alluvial sands and gravels. On the other hand, consolidated rocks, such as karst limestones and dense calcretes, give more protection against the infiltration of pollutants, which reduces vulnerability.

This classification highlights the protective function of the geological structures that cover aquifers.

The third measure, depth to the groundwater table, measures the depth that contaminants have to travel in order to reach the water table. Because decaying processes have less time and opportunity at shallow depths (less than 5 meters), vulnerability increases significantly. As a result, deep depths more than 50 meters offer a significant buffer, which lowers vulnerability levels. This element highlights how vertical distance affects aquifer contamination vulnerability.

The figure shows a thorough and systematic method to evaluate the vulnerability of aquifer contamination by combining these three factors. It is a useful tool for managing groundwater resources because it makes it possible to understand the behavior and identify areas that are more vulnerable. To more effectively integrate the theoretical framework in real world applications, the figure may benefit from real-world examples or scenarios for each vulnerability type. Furthermore, adding information on land use or sources of contamination could improve vulnerability assessment even more.

To assess GOD vulnerability, a number between 0 and 1 is assigned to each composing parameter, with 0 indicating the least vulnerable and 1 indicating the most vulnerable. After the parameter maps are ready, the GOD index is calculated using the parameter ranges and ratings as shown in Figure 7.

The GOD index is a tool used to assess the sensitivity of groundwater to contamination. Aquifer vulnerability that is computed by multiplying the influence of the three factors using Equation 1.

$$\text{GOD Index} = C_a \, C_l \, C_d \qquad \text{Equation 1}$$

where Ca is the type of aquifer; Cl is the overlaying lithology of the zone and Cd is the depth to the aquifer.

Although there are many more accurate vulnerability approaches that require more data parameters to utilize, we chose this method because it requires less parameters. Now, we should specify each parameter in order to determine the vulnerability value for the given scenario based on the hydrologic setting of the aquifer. The parameter values were defined with guidance from Engineer Sayel Weshahi during a personal interview. Previously, he created a matrix to assess groundwater vulnerability in the same area, which will be used as a reference and validation tool for the GOD method.

3.5 Hydrogeologic Setting

The geological map is shown in Figure 8, while the column of the West Bank is presented in Table 1 which gives a clear picture about its stratigraphy, and lithology. Below are the main hydrogeological units of the area and arranged by age from youngest to oldest:

The Shallow aquifer (Alluvium and Lisan Formation) of Plio-Pleistocene ages (Quaternary)

Geologically, the area is predominantly covered by Lisan Formation rocks, which date back to the Pleistocene age. The Lisan Formation in this region primarily consists of thinly laminated marls and gypsum beds. Structurally, the marls exhibit a simple configuration, featuring minor north-south trending folds and a slight depositional dip towards the Jordan River, the basin's center, potentially amplified by subsidence. At the margins, the lithology transitions to gravel and poorly sorted pebble beds, which are occasionally calcareous with minimal or no evaporites. In some areas, these deposits are siliceous near former or existing chert outcrops and limestone near older rocks(31).

Additionally, alluvium deposits are present along the tributaries of the Jordan River. These deposits consist mainly of unconsolidated, laminated marls, mud, and some siliceous sand. The Lisan Formation and alluvium collectively form the primary aquifer system in the region, which is extensively utilized by numerous agricultural wells. The hydrogeological properties of this aquifer vary across the area, depending on the lithological composition and sediment thickness. Recharge of the Pleistocene system primarily occurs through lateral flow from the Mountain Aquifer Systems, which are replenished in mountainous areas located 10 to 30 kilometers to the west, as well as through stormwater infiltration from flooded valleys crossing the aquifer (31).

- Khan Al Ahmar Aquiclude: The rocks of this formation are primarily composed of chalk, marl, as well as chalky and marly limestone. Generally, due to its characteristics, the Khan Al Ahmar Formation functions as an aquiclude in the area, acting as a barrier between the Pleistocene aquifer and the local Al Qilt aquifer.

- Al Qilt Aquifer: This formation primarily comprises thick chert layers interbedded with limestone, dolomite, chalk, bituminous marl, and phosphate. The chert is often highly fractured, occasionally forming chert breccia, with the layers creating undulations of a few meters. Due to its fractured nature, the Al Qilt Formation serves as a local aquifer in the area, with some wells tapping into this aquifer yielding significant discharge rates. The Al Qilt Formation is also distinguished by its rapid lateral facies changes, often occurring over very short distances.
- Abu Dies Aquiclude: Chalk rocks are the primary constituent of this formation. In certain areas, the formation also includes chalky limestone, marl, phosphate, and chert. Based on its lithological characteristics, the Abu Deis Formation functions as a strong aquiclude in the region.

3.5.1 The Upper aquifer system (Turonian-Upper Cenomanian)

Geologically, this aquifer system, according to Palestinian nomenclature, consists of the Jerusalem, Bethlehem, and Hebron formations. The rocks of the Jerusalem Formation date back to the Turonian age and are primarily composed of dark grey-brown weathered massive limestone, which locally forms cliffs. The lower part of the formation consists of finely grained lithographic limestone with pink and buff hues, while the upper part features cream-colored recrystallized dolomitic limestone, occasionally silicified. The thickness of the Jerusalem Formation ranges from 170 to 200 meters.

3.5.2 Bethlehem Formation

The Upper Cenomanian is primarily composed of cream-grey bedded chalky limestone, often fully recrystallized into cream or pink porcellaneous limestone, along with softer marly chalky limestone and marl. The thickness of the Bethlehem Formation varies between 100 and 150 meters.

3.5.3 Hebron Formation

The Upper Cenomanian Formation is composed of grey weathered dolomitic limestones and dolomite. The rock is dense, massive, and exhibits poor bedding, with a sugary texture. This texture leads to high secondary porosity and the development of karst features in several parts of the formation. The thickness of the Hebron Formation ranges between 160 and 250 meters.

3.5.4 Lower Aquifer System

The lower aquifer system consists of the Middle and Lower Yatta, Upper Beit Kahil, and Lower Beit Kahil formations, according to Palestinian terminology. The Yatta Formation is primarily composed of marl, clay, and marly limestone. The Upper Beit Kahil Formation consists of regularly interbedded chalky limestone and dolomite, becoming more massive and karstified upwards, while still maintaining thin-bedded alternations. The Lower Beit Kahil Formation is made up of dolomite and limestone interbedded with marl. Although the dolomitic limestone is well-fractured and has significant aquifer potential, the chalky layers contain clay, which restricts groundwater movement across these strata. The Lower Aquifer System is separated from the upper aquifer by the brown-grey weathered marls and chalky limestone of the Upper Yatta Formation, which acts as a confining bed in the region. Similar to other aquifer systems, groundwater generally flows eastward, with the water table located between 320 and 340 meters below the surface in this area.

Now after understanding the properties of aquifer and referring to Table 1, we can determine the value of each parameter. In this research, these values were determined based on work of Eng. Sael Weshahi.

3.5.5 G-parameter

Table 5 summarized that we assigned the lowest value for a confined aquifer which is 0.1 due to its characteristics that make it difficult for water processes to infiltrate. The vulnerability will be extremely low as a result of the prior definition, and the G-parameter will also be low. The G value for semi-confined will be 0.3 because the characteristics of aquifer in this type allow water to infiltrate more than the previous type and less than the next type. For unconfined aquifer the G value will be 0.9 because the characteristics of this type allow to water to seep and infiltrate easily to aquifer which make the aquifer very vulnerable. The map of the G-parameter is shown in Figure 8-C.

Table 5

G- parameter assumed values

Aquifer Type (G)		
Confined	0.1	Quaternary
Semi-Confined	0.3	Senonian
Unconfined	0.9	Turonian+Cenonian

3.5.6 O-parameter

The physical properties of the aquifer will be influenced by its different components. Because fine elements like clay, salt, and non-porous rocks reduce the permeability of water infiltration, their presence in the aquifer layer reduces vulnerability, which results in a small O-value. As previously explained, we observed that the value of O increased as the media's permeability decreased. Therefore, a less vulnerable aquifer is indicated by the high value for O as summarized in Table 6 and shown in Figure 8-B.

Table 6

O- parameter assumed values

Lithology of Aquifer (O)		
Fractured rocks of limestone, dolomite, igneous, gravel, chalk. ...	0.8	Turonian
Sandstone, breccia, silt, with marl, and clay	0.7	Cenomanian
Intebedded fractured rocks with semi permeable layers	0.5	Senonian
Marl, clay, chalk interbedded with porous rocks	0.4	Quaternary

3.5.7 D-parameter

The vulnerability of the aquifer is inversely related to the depth of the water table. As the depth increases, the water cover that shields the aquifer increases and creates an impermeability for water infiltration and hinders pollutant transport. Accordingly Table 7 summarized that a small value for D points to an aquifer that is not vulnerable, whereas a large value for D indicates an aquifer that is extremely sensitive. Figure 8-A shows a D-parameter map.

Table 7

D parameter value

Depth to Groundwater level "m" (D)	
0-20	0.9
20-50	0.6
>50	0.4

After the parameters of GOD method were defined, Table 5 Table 6, and Table 7, were converted to shapefile. This process starts by merge two shapefiles, 1st is the contour lines with geological formations shape files, then add new field and using contour line for water head shapefile, we will make buffer zone for each line to cover the mid distance between contours lines from both sides to create area have the same contour line value, as shown in Figure 8-D.

Next, we need to use clip tools in ArcGIS to clip the geological formations shape file referring to new created buffer zone which done before, the output will be discrete the geological formations shape file referring to buffer zone of water head. Now, we will add new other field and nominated O – parameter, this field will define by applying the values of Table 6 on the output of clipped output. The last step will be repeated by using the values of Table 7 to insert G-parameter values, as shown in Figure 8.

After insert all parameters to shape file on ArcGIS now we can apply Equation 1. on these parameters by add new field and nominated GOD index, this parameter will calculate according to equation 1 and the result will be as shown in Table A 1.

Figure 8

Discrete map into elements by using contour line to create buffer zone, G, O, D - parameters and GOD index

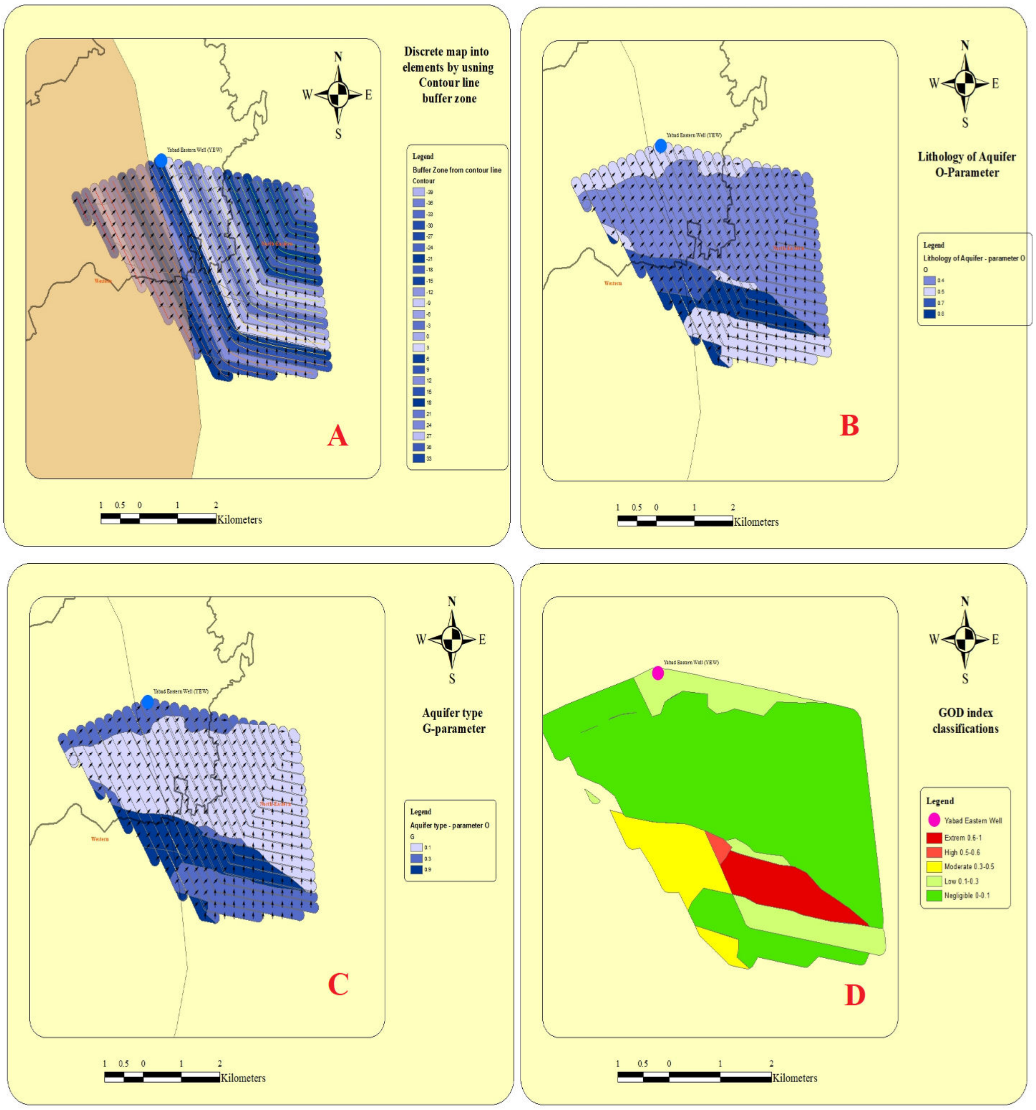


Table 8

Practical definition of classes of aquifer pollution vulnerability

Practical definition of classes of aquifer pollution vulnerability	
VULNERABILITY CLASS	CORRESPONDING DEFINITION
Extreme	vulnerable to most water pollutants with rapid impact in many pollution scenarios
High	vulnerable to many pollutants (except those strongly absorbed or readily transformed) in many pollution scenarios
Moderate	vulnerable to some pollutants but only when continuously discharged or leached
Low	only vulnerable to conservative pollutants in the long term when continuously and widely discharged or leached
Negligible	confining beds present with no significant vertical groundwater flow (leakage)

Now, after calculated GOD index for the study area as per show in Table A 1, we can represent these data in ArcGIS to know where the area is having high vulnerability could be consider as weak area to access the contamination as show in Figure 8. To understand this classification for vulnerability assessment, see the Table 8.

After determining the vulnerability classifications of the study area, we will create a map that overlaps all of the earlier factors to better understand the situation. This map will include the groundwater flow direction, land uses, and well locations with nitrate concentrations, and vulnerability area classification. This map will illustrate the potential access location where the pollutant may enter, the activities that occur there, and how the contaminant, if it is transported, could get to Yabad Eastern Well. Figure 9 and Table 9.

show the previously mentioned factors that affect nitrate concentration at Yabad Eastern Well .

The contamination of Yabad Eastern Well has been evaluated using the GOD vulnerability index classifications and associated land use and pollution sources. The analysis highlights the varying degrees of vulnerability and the contribution of different land uses and activities to groundwater contamination. This discussion integrates the figures provided, table, and data to derive meaningful insights and recommendations.

3.6 Vulnerability Classification and Spatial Distribution

The GOD vulnerability index map categorizes the study area into five levels of contamination vulnerability: Negligible, Low, Moderate, High, and Extreme. As depicted in the first figure, the extreme vulnerability zone (0.6–1.0) is concentrated in the central region of the study area. This zone coincides with agricultural activities and potential pollutant sources, such as sewage sludge disposal and in-situ sanitation. The high vulnerability zone (0.5–0.6) surrounds the extreme zone, indicating a gradual decrease in susceptibility as one moves outward.

The negligible vulnerability zone (0.0–0.1) dominates the northern and southern peripheries, characterized by natural vegetation and limited human activity. This spatial distribution suggests a strong correlation between land use intensity and groundwater vulnerability. For instance, areas with agricultural practices and urban development exhibit higher vulnerability due to increased pollutant loads and reduced soil filtration capacity.

3.7 Overlap of Land Use, Flow Direction, and Vulnerability

The Figure overlays land use patterns, groundwater flow direction, and GOD index classifications. It reveals key interactions between these factors:

1. Land Use Patterns: Agricultural lands and urban settlements are prevalent in moderate to extreme vulnerability zones. These activities introduce contaminants such as nitrates, ammonium, pesticides, and fecal organisms into the groundwater system.
2. Flow Direction: Groundwater flow direction indicates the potential movement of contaminants from pollution hotspots to vulnerable areas. The flow pathways suggest that contaminants from agricultural and urban zones may migrate toward Yabad Eastern Well, increasing the risk of contamination.

3. Contamination Sources: Dumping sites and sewage disposal areas are located within or adjacent to high and extreme vulnerability zones. These sources introduce halogenated hydrocarbons, heavy metals (e.g., lead, zinc), and microbial contaminants into the aquifer.

Table further supports the findings by listing pollution sources and their associated contaminants. Notably:

- Agricultural Activity: Identified as a primary contributor, this source introduces nitrates, ammonium, pesticides, and fecal organisms. These pollutants are prevalent in negligible vulnerability zones, but emphasizing the need for sustainable agricultural practices.
- In-situ Sanitation: Contributes nitrates, halogenated hydrocarbons, and microbial contaminants. This source is particularly concerning areas with poor infrastructure and sanitation facilities. These pollutants are prevalent in moderate and low vulnerability zones
- Sewage Sludge Disposal: Adds heavy metals and organic pollutants, further degrading groundwater quality.

Figure 9

Overlapping map for factors effect on Yabad Eastern Well

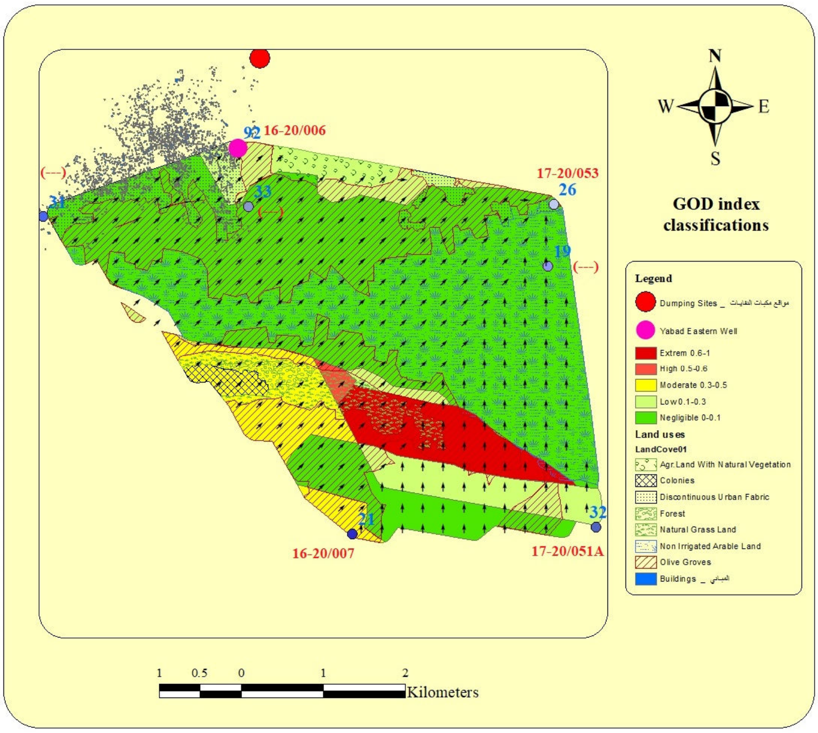


Table 9

Vulnerability index, land use, pollution source and type of contaminant

Vulnerability index	Land use	Pollution Source	Type of contaminant
Negligible	Discontinuous Urban Fabric, Non-Irrigated Arable Land, and Olive Groves	Agricultural Activity In-situ Sanitation Sewage Sludge Disposal	nitrates; ammonium; pesticides; fecal organisms nitrates; halogenated hydrocarbons; microorganisms nitrates; halogenated hydrocarbons; lead; zinc
Low	Discontinuous Urban Fabric, Agr.Land with Natural Vegetation, and Olive Groves	Agricultural Activity In-situ Sanitation Sewage Sludge Disposal	nitrates; ammonium; pesticides; fecal organisms nitrates; halogenated hydrocarbons; microorganisms nitrates; halogenated hydrocarbons; lead; zinc
Moderate	Natural Grass Land, Forest, Colonies, and Agr.Land with Natural Vegetation	Agricultural Activity In-situ Sanitation Sewage Sludge Disposal Solid Waste Disposal	nitrates; ammonium; pesticides; fecal organisms nitrates; halogenated hydrocarbons; microorganisms nitrates; halogenated hydrocarbons; lead; zinc ammonium; salinity; halogenated hydrocarbons; heavy metals
High	Natural Grass Land, and Non-Irrigated Arable Land	Agricultural Activity	nitrates; ammonium; pesticides; fecal organisms
Extreme	Natural Grass Land, Olive Groves, and Non Irrigated Arable Land	Agricultural Activity	nitrates; ammonium; pesticides; fecal organisms

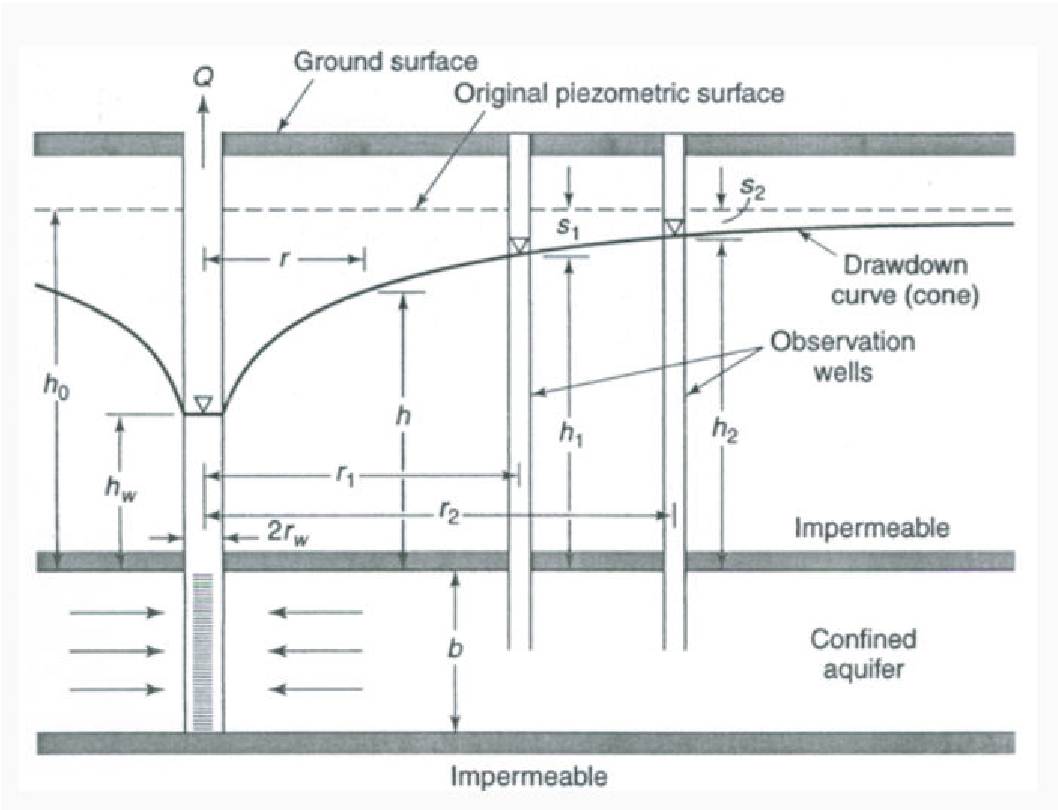
3.8 The influence area of the Yabad Eastern Well

Determining groundwater supply protection areas, also known as wellhead protection zones, is necessary to give extra protection against pollution for water sources (groundwater wells) that are used for the public water supply. It is also necessary to consider sources created for other potentially critical applications, particularly bottled natural mineral waters that are not disinfected in any way.

When water is pumped from a confined aquifer, the pumpage creates a drawdown in the piezometric surface that induces hydraulic gradient toward the well. Drawdown at a given point is the distance by which the water level is lowered. A drawdown curve shows the variation of drawdown with distance from the well Figure show a drawdown curve.

Figure 10

A drawdown curve for a typical confined aquifer



Now, to find the wellhead protection area we need to calculate the drawdown curve by using equation derived from Darcy's law related to drawdown with pumping. This was Equation 1. derivative under key assumptions:

- The potentiometric surface of the aquifer is horizontal prior to start of pumping.
- The aquifer is homogeneous and isotropic.
- All flow is radial toward the well.
- Groundwater flow is horizontal.
- The pumping well fully penetrates the aquifer.
- Steady state implies that the drawdown is a function of location only.

These assumptions are not representative of the actual situation due to previous key assumptions. However, it is necessary to apply the equation to determine the influence line of piezometric water level for Yabad Eastern Well.

$$h_o = h_w + \frac{Q}{2\pi Kb} \ln \frac{r_o}{r_w} \tag{32}$$

where:

Q: pumping rate

K: hydraulic conductivity

b: aquifer thickness

h_0: drawdown at the edge of the aquifer

h_w: drawdown at the well

r_o: radius of influence at which the drawdown is negligible

r_w: radius of influence at well wall

Kb = T, where T is Transmissivity

Table 10

Data related to Yabad Eastern Well " testing data"(33)

Transmissivity	Specific capacity	Discharge rate "Q"	Static water level	Dynamic water level	Well elevation	Total depth	Well radius "rw"	Confined aquifer thickness "b"
56.7 m^2/day	1.96 m^3/hr/m	80 m^3/hr	253.6 m	284.4 m	271.3 m	500m	22 inches	110 m

By substitute data in Table 10 in previous equation: ro=84.88 m which consider the radius of protection wellhead and influence line.

3.9 Discussion

The contamination of Yabad Eastern Well has been evaluated using the GOD vulnerability index classifications and associated land use and pollution sources. The analysis highlights the varying degrees of vulnerability and the contribution of different land uses and activities to groundwater contamination. This discussion integrates the provided figures, table, and data to derive meaningful insights and recommendations.

After finishing the analysis part of this research. The problem starts rising in 2019 when the nitrate concentration exceed the maximum allowable concentration according to historical records, so samples were toke from wells are located at the same study area in all directions except the north, the results of these samples show that the nitrate concentration are below maximum allowable concentration for these wells around, we noted that from looking to the results of the surrounding wells for the same aquifer, that’s the problem is not general in whole aquifer.

One of the significant contributors to Yabad Eastern Well contamination is the presence of in-situ sewer systems in older residential areas. These systems are typically characterized by poor maintenance, leakage, and inadequate infrastructure, leading to the infiltration of untreated wastewater into the subsurface. The proximity of such systems to moderate and low vulnerability zones exacerbates the contamination risk. The contaminants introduced include nitrates pollutant, which can directly impact the quality of groundwater.

From previous result, the problem location is within the area occupied between the surrounding wells, these lead us to study this area deeply by determine the aquifer which is the northeastern aquifer according to Palestinian water authority (PWA) map. By find the groundwater flow direction we determine the upstream and downstream area. in the northeastern aquifer the GW flow direction moving from southwestern to northeastern, according to this point, we conclude the contaminant is located at southwestern area of Yabad Eastern Well. Also, the results indicate that areas suffering from sewer problems are located within moderate to high vulnerability zones. This is particularly concerning because the groundwater flow direction suggests that contaminants from these zones are likely to migrate toward Yabad Eastern Well. The lack of centralized sewer systems and proper wastewater treatment facilities further amplifies the risk.

After identifying the potential contaminated area, we analysis the vulnerability for it depending on geological formation and depth of water table. Now, we will search for the actions that took place in the intersection zone because of the previous parameters and overlap method. This step will be done by site visits to investigate the activities and make personal communications with people. After we finish analysis and get results, we can conclude the problem cause and make specific recommendations

As a result of this step, we identified an area approximately 500 meters west and 700 meters south of Yabad Eastern Well that is classified as a moderately vulnerable zone, potentially allowing contaminants to seep into the aquifer. During a site visit to this area, we discovered it is an old town experiencing significant sewer issues.

Chapter Four

Conclusions and recommendations

4.1 Conclusions

The contamination of Yabad Eastern Well is closely linked to land use activities, inadequate sanitation infrastructure, and improper waste management practices. The identification of moderate and low vulnerability zones highlights the urgent need for targeted interventions. Upgrading sewer systems, implementing sustainable agricultural practices, and enhancing monitoring efforts are critical to mitigating contamination risks. By adopting these measures, the quality of groundwater in Yabad Eastern Well can be safeguarded, ensuring its sustainability for future generations.

The conclusions provided focus on the presence of high nitrate concentrations at Yabad Eastern Well and their potential sources, specifically poor sewage system related contamination. The conclusions also discuss the moderate vulnerability of the study area within the Yabad Eastern Well area. While agricultural activities are not identified as a threat, sewerage problems remain a significant environmental and public health issue. Below are the conclusions.

1. Measure of high nitrate concentrations at Yabad Eastern Well due to poor sewage system:

One of the primary conclusions from the study is the detection of elevated nitrate concentrations in the Yabad Eastern Well. This issue appears to be related directly to the presence of a nearby sewer system. Nitrate contamination of groundwater is a major environmental concern, as it shows significant risks to both human health and the ecosystem.

High levels of nitrates can result from various sources, with the most common being the runoff from fertilizers in agricultural areas and wastewater from sewage systems. In the case of Yabad Eastern Well, it has been found that the sewer system, particularly in the southwestern part of the area, plays a pivotal role in contributing to the contamination. This contamination is harmful, as nitrates can lead to serious health risks. Addressing this source of pollution is a vital to protecting the groundwater source for Yabad

2. Poor sewage system in the southwestern Yabad Eastern Well area “Al Hamarshi neighborhood”:

The research identifies a specific location referred to as "Al Hamarshi neighborhood"— as the potential source of the sewerage related issues. This area, located approximately 700 meters to the southwest of Yabad Eastern Well, is marked by a persistent sewer problem that affects the surrounding environment. The proximity of the sewer sources to the water sources, combined with poor sewage systems and moderate vulnerable areas, increases the risk of contamination. Sewer systems that are not properly managed or maintained can leak contaminants into nearby groundwater systems. The problem in Al Hamarshi neighborhood reflects serious urban management challenges, where rapid urbanization has take place the development of adequate sewage treatment and disposal infrastructure. This situation calls for immediate intervention to either upgrade the sewer system or provide alternative means of wastewater disposal to prevent further contamination.

3. Lack of protection around the wellhead area within a 100-meter radius:

Currently, there is no protection around the wellhead location, which is essential for pumping clean groundwater within a 100-meter radius. Contamination from neighboring sources, such as nearby cesspits and sanitary sewers, is a serious issue. Additional impact on groundwater quality is caused by the well's operation and guard room, which empty into a cesspit far 60 meters distant from bell mouth of Yabad Eastern Well. There is a serious risk to public health due to the close location of these potential contaminants to the water pumping site.

4. Agricultural activities not impacting Yabad Eastern Well due to location in low Vulnerable Areas:

Unlike the sewer-related contamination, agricultural activities do not appear to have a significant impact on Yabad Eastern Well water quality. This is due to the location of agricultural activities in areas considered to be low vulnerable. This is a positive aspect, as agricultural activities are often a major source of groundwater contamination, particularly from fertilizers, pesticides, and herbicides. However, the absence of agricultural impacts does not remove other risks, particularly those related to urbanization and inadequate wastewater management. While agricultural activities may not be a concern at present, the situation could change if land use patterns around Yabad Eastern Well change or if the current protective measures around Yabad Eastern Well are weakened.

4.2 Recommendations

The following points should be taken into consideration as recommendations:

- The municipality of Yabad should establish a sewer system for Atatrah neighborhood to properly drain the sewage flowing from houses within this area.
- The cesspit for the guard and operation room for the Yabad Eastern Well should be removed and a proper sanitary system is to be constructed instead.
- The area within a radius of 100 m from Yabad Eastern Well should be considered a wellhead protection zone where all on-ground activities must be restricted and controlled.
- A specific filter should be installed at Yabad Eastern Well to remove nitrate. However, using this method needs more attention because this process will affect other physical and chemical properties for drinking water.
- To decrease the concentration of nitrate, the yielding water should be pump to main reservoir and diluted with other water resource clean from nitrate to minimize the nitrate concentration which distributed to consumers.
- The disposal of sewage must be supervised and restricted to areas of low vulnerability in order to minimize the potential contamination of the aquifer.

4.3 Recommendations and Management Practices

To address the contamination risks posed by in-situ sewer systems and other sources, the following measures are recommended:

i. Upgrade sewer infrastructure:

- Replace the existing cesspits with centralized sewer networks to prevent sewage leakage and infiltration.
- Implement regular maintenance and monitoring of existing sewer systems to identify and fix leaks promptly.

ii. **Introducing wastewater treatment facilities**:

- In places where centralized sewer systems are unavailable or located in places far from existing sewer systems, construction or providing decentralized wastewater treatment facilities like mobile treatment plants with small capacity.
- Promote the use of natural treatment methods, such as constructed wetlands, in low-density areas.

iii. Improve land use management:

- Restrict high-risk activities, such as intensive agriculture and waste dumping, in extreme and high vulnerability zones.
- Designate buffer zones around vulnerable areas to minimize contamination risks.

iv. Adopt sustainable agricultural practices:

- Encourage the use of organic fertilizers and integrated pest management to reduce chemical runoff.
- Promote crop rotation and soil conservation techniques. These techniques have the potential to improve water quality by taking up and immobilizing nitrate that would otherwise be lost to leaching.

v. Enhance public awareness:

- Conduct community outreach programs to educate residents on the impact of improper waste disposal and sewer maintenance on groundwater quality.
- Engage local stakeholders in decision-making processes to ensure that sustainable management practices are adopted.

vi. Establish a comprehensive monitoring system:

- Regularly monitor groundwater quality to track nitrate levels and identify emerging threats.
- Use advanced modeling tools to predict the movement of contaminants and assess the effectiveness of mitigation measures. Examine the areas of susceptibility and use the isotopic approach to determine the exact location for potential contamination. It is advised to use isotopic methods to assess the risk and suggest land use restrictions for these areas because this study highlights that many of the locations are considered vulnerable and could potentially become contaminated in the future if they have activities that could contaminate the aquifer.

List of Abbreviations

Abbreviation	Maenting
ASL	Above Sea Level
DE	Digital Elevation Model
DWA	Dynamic Water Level
EA	Eastern Aquifer
GIS	Geographic Information System
GNC	Groundwater Nitrate Contamination
GOD	Geology, overlying materials, Depth groundwater
MCL	Maximum Contaminant Level
MoH	Ministry of Health
MOLG	Ministry of Local Government
NEA	North-Eastern Aquifer
OF	Organic Fertilizer
PCBS	Palestinian Central Bureau
PWA	Palestinian Water Authority
RF	Random Forest
SWL	Static Water Level
TOC	Total Organic Carbon
USAID	United States Agency for International Development
USEPA	Unites States Environmental Protection Agency
WA	Western Aquifer
WESI	Water and Environmental Studies Institute
WHO	World Health Organization

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Appendices

Appendix A

Tables

Table A 1

GOD Index

GOD Index						
Name	Contour	Area	G	O	D	God_Index
Quaternary	33	16216.646195	0.1	0.4	0.4	0.016
Quaternary	33	46485.354371	0.1	0.4	0.4	0.016
Quaternary	30	211197.	0.1	0.4	0.4	0.016
Quaternary	33	36307.168616	0.1	0.4	0.4	0.016
Quaternary	33	36307.168616	0.1	0.4	0.4	0.016
Quaternary	27	277312.	0.1	0.4	0.6	0.024
Quaternary	24	408228.	0.1	0.4	0.6	0.024
Quaternary	21	449124.	0.1	0.4	0.6	0.024
Quaternary	18	479591.	0.1	0.4	0.6	0.024
Quaternary	15	498385.	0.1	0.4	0.6	0.024
Quaternary	12	480677.7392	0.1	0.4	0.6	0.024
Quaternary	12	24815.273676	0.1	0.4	0.6	0.024
Quaternary	9	443371.30284	0.1	0.4	0.9	0.036
Quaternary	6	454215.	0.1	0.4	0.9	0.036
Quaternary	3	559173.	0.1	0.4	0.9	0.036

Quaternary	-3	788600.	0.1	0.4	0.9	0.036
Quaternary	-6	820908.26852	0.1	0.4	0.9	0.036
Quaternary	-9	776250.	0.1	0.4	0.9	0.036
Quaternary	-12	699004.	0.1	0.4	0.9	0.036
Quaternary	-15	617463.	0.1	0.4	0.9	0.036
Quaternary	-18	553420.	0.1	0.4	0.9	0.036
Quaternary	-21	509698.	0.1	0.4	0.9	0.036
Quaternary	-24	445613.50679	0.1	0.4	0.9	0.036
Quaternary	-27	373422.	0.1	0.4	0.9	0.036
Quaternary	-30	304519.	0.1	0.4	0.9	0.036
Quaternary	-33	227466.	0.1	0.4	0.9	0.036
Quaternary	-36	145546.8123	0.1	0.4	0.9	0.036
Quaternary	-39	60269.59203	0.1	0.4	0.9	0.036
Quaternary	0	706612.	0.1	0.4	0.9	0.036
Quaternary	9	24815.273676	0.1	0.4	0.9	0.036
Quaternary	9	68733.174593	0.1	0.4	0.9	0.036
Quaternary	6	68733.174593	0.1	0.4	0.9	0.036
Quaternary	6	93277.283095	0.1	0.4	0.9	0.036
Quaternary	3	93277.283095	0.1	0.4	0.9	0.036
Name	Contour	Area	G	O		God_Index
Quaternary	3	108248.81789	0.1	0.4	0.9	0.036

Quaternary	0	108248.81789	0.1	0.4	0.9	0.036
Quaternary	-3	123083.	0.1	0.4	0.9	0.036
Quaternary	-6	123083.	0.1	0.4	0.9	0.036
Quaternary	-3	122885.	0.1	0.4	0.9	0.036
Quaternary	0	122885.	0.1	0.4	0.9	0.036
Quaternary	-6	117554.35757	0.1	0.4	0.9	0.036
Quaternary	-9	117554.35757	0.1	0.4	0.9	0.036
Quaternary	-9	108802.	0.1	0.4	0.9	0.036
Quaternary	-12	108802.	0.1	0.4	0.9	0.036
Quaternary	-12	95482.147457	0.1	0.4	0.9	0.036
Quaternary	-15	95482.147457	0.1	0.4	0.9	0.036
Quaternary	-15	82758.393969	0.1	0.4	0.9	0.036
Quaternary	-18	82758.393969	0.1	0.4	0.9	0.036
Quaternary	-18	77067.513173	0.1	0.4	0.9	0.036
Quaternary	-21	77067.513173	0.1	0.4	0.9	0.036
Quaternary	-21	70324.16838	0.1	0.4	0.9	0.036
Quaternary	-24	70324.16838	0.1	0.4	0.9	0.036
Quaternary	-24	58076.066239	0.1	0.4	0.9	0.036
Quaternary	-27	58076.066239	0.1	0.4	0.9	0.036
Quaternary	-27	46369.615355	0.1	0.4	0.9	0.036
Quaternary	-30	46369.615355	0.1	0.4	0.9	0.036

Quaternary	-30	33080.610716	0.1	0.4	0.9	0.036
Quaternary	-33	33080.610716	0.1	0.4	0.9	0.036
Quaternary	-33	20174.070445	0.1	0.4	0.9	0.036
Quaternary	-36	20174.070445	0.1	0.4	0.9	0.036
Quaternary	-36	7643.127482	0.1	0.4	0.9	0.036
Quaternary	-39	7643.127482	0.1	0.4	0.9	0.036
Senonian	33	88430.2655	0.3	0.5	0.4	0.06
Senonian	30	90101.800465	0.3	0.5	0.4	0.06
Senonian	30	75162.076094	0.3	0.5	0.4	0.06
Senonian	27	115078.	0.3	0.5	0.6	0.09
Senonian	24	120991.	0.3	0.5	0.6	0.09
Senonian	21	116918.	0.3	0.5	0.6	0.09
Senonian	18	113664.	0.3	0.5	0.6	0.09
Senonian	15	121523.	0.3	0.5	0.6	0.09
Senonian	12	156164.	0.3	0.5	0.6	0.09
Senonian	27	87950.61741	0.3	0.5	0.6	0.09
Senonian	21	438.014431	0.3	0.5	0.6	0.09
Senonian	21	96217.988548	0.3	0.5	0.6	0.09
Senonian	18	223685.	0.3	0.5	0.6	0.09
Name	Contour	Area	G	O	D	God_Index
Senonian	15	479829.	0.3	0.5	0.6	0.09

Senonian	12	635903.	0.3	0.5	0.6	0.09
Senonian	21	13648.841569	0.3	0.5	0.6	0.09
Senonian	21	13648.841569	0.3	0.5	0.6	0.09
Senonian	18	17386.456832	0.3	0.5	0.6	0.09
Senonian	15	17386.456832	0.3	0.5	0.6	0.09
Senonian	15	52660.153536	0.3	0.5	0.6	0.09
Senonian	12	52660.153536	0.3	0.5	0.6	0.09
Senonian	12	59837.389582	0.3	0.5	0.6	0.09
Senonian	9	169058.	0.3	0.5	0.9	0.135
Senonian	6	127795.	0.3	0.5	0.9	0.135
Senonian	3	84289.516668	0.3	0.5	0.9	0.135
Senonian	-3	61910.513102	0.3	0.5	0.9	0.135
Senonian	-6	112827.	0.3	0.5	0.9	0.135
Senonian	-9	93202.489936	0.3	0.5	0.9	0.135
Senonian	-12	92387.988638	0.3	0.5	0.9	0.135
Senonian	-15	92792.158686	0.3	0.5	0.9	0.135
Senonian	-18	74464.275923	0.3	0.5	0.9	0.135
Senonian	-21	43120.131734	0.3	0.5	0.9	0.135
Senonian	-24	25954.49346	0.3	0.5	0.9	0.135
Senonian	-27	15698.732294	0.3	0.5	0.9	0.135
Senonian	-30	10282.446335	0.3	0.5	0.9	0.135

Senonian	-33	887.081773	0.3	0.5	0.9	0.135
Senonian	0	61766.655495	0.3	0.5	0.9	0.135
Senonian	9	1.032305	0.3	0.5	0.9	0.135
Senonian	6	1.032305	0.3	0.5	0.9	0.135
Senonian	6	11935.965822	0.3	0.5	0.9	0.135
Senonian	3	11935.965822	0.3	0.5	0.9	0.135
Senonian	3	8194.675138	0.3	0.5	0.9	0.135
Senonian	0	8194.675138	0.3	0.5	0.9	0.135
Senonian	-3	12875.063789	0.3	0.5	0.9	0.135
Senonian	-6	12875.063789	0.3	0.5	0.9	0.135
Senonian	-3	6754.971232	0.3	0.5	0.9	0.135
Senonian	0	6754.971232	0.3	0.5	0.9	0.135
Senonian	-6	15667.615732	0.3	0.5	0.9	0.135
Senonian	-9	15667.615732	0.3	0.5	0.9	0.135
Senonian	-9	12332.718107	0.3	0.5	0.9	0.135
Senonian	-12	12332.718107	0.3	0.5	0.9	0.135
Senonian	-12	13052.853686	0.3	0.5	0.9	0.135
Senonian	-15	13052.853686	0.3	0.5	0.9	0.135
Senonian	-15	12803.512644	0.3	0.5	0.9	0.135
Senonian	-18	12803.512644	0.3	0.5	0.9	0.135
Senonian	-18	6711.30127	0.3	0.5	0.9	0.135

Senonian	-21	6711.30127	0.3	0.5	0.9	0.135
Senonian	-21	674.262152	0.3	0.5	0.9	0.135
Senonian	-24	674.262152	0.3	0.5	0.9	0.135
Name	Contour	Area	G	O	D	God_Index
Senonian	-24	0.185293	0.3	0.5	0.9	0.135
Senonian	-27	0.185293	0.3	0.5	0.9	0.135
Senonian	9	627152.	0.3	0.5	0.9	0.135
Senonian	6	427816.	0.3	0.5	0.9	0.135
Senonian	9	59837.389582	0.3	0.5	0.9	0.135
Senonian	9	52819.824505	0.3	0.5	0.9	0.135
Senonian	6	52819.824505	0.3	0.5	0.9	0.135
Senonian	6	23232.947954	0.3	0.5	0.9	0.135
Senonian	3	47143.231743	0.3	0.5	0.9	0.135
Senonian	-3	29121.277605	0.3	0.5	0.9	0.135
Senonian	-6	21136.364043	0.3	0.5	0.9	0.135
Senonian	0	25100.33021	0.3	0.5	0.9	0.135
Senonian	6	9621.107035	0.3	0.5	0.9	0.135
Senonian	3	9621.107035	0.3	0.5	0.9	0.135
Senonian	3	7910.829701	0.3	0.5	0.9	0.135
Senonian	0	7910.829701	0.3	0.5	0.9	0.135
Senonian	-3	7804.331489	0.3	0.5	0.9	0.135

Senonian	-6	7804.331489	0.3	0.5	0.9	0.135
Senonian	-3	5080.216673	0.3	0.5	0.9	0.135
Senonian	0	5080.216673	0.3	0.5	0.9	0.135
Turonian	30	26572.804194	0.9	0.8	0.4	0.288
Cenomanian	27	153682.15474	0.9	0.7	0.6	0.378
Cenomanian	24	221245.	0.9	0.7	0.6	0.378
Cenomanian	21	217871.	0.9	0.7	0.6	0.378
Cenomanian	18	223883.	0.9	0.7	0.6	0.378
Cenomanian	15	226975.	0.9	0.7	0.6	0.378
Cenomanian	12	146786.	0.9	0.7	0.6	0.378
Cenomanian	15	12779.663463	0.9	0.7	0.6	0.378
Cenomanian	12	12779.663463	0.9	0.7	0.6	0.378
Cenomanian	12	21166.377252	0.9	0.7	0.6	0.378
Turonian	27	600.920554	0.9	0.8	0.6	0.432
Turonian	24	99872.64867	0.9	0.8	0.6	0.432
Turonian	21	4539.034443	0.9	0.8	0.6	0.432
Turonian	21	153964.	0.9	0.8	0.6	0.432
Turonian	18	230021.	0.9	0.8	0.6	0.432
Turonian	15	72522.820735	0.9	0.8	0.6	0.432
Turonian	12	76553.244509	0.9	0.8	0.6	0.432
Turonian	21	30858.040688	0.9	0.8	0.6	0.432

Turonian	21	30858.040688	0.9	0.8	0.6	0.432
Turonian	18	10083.58099	0.9	0.8	0.6	0.432
Turonian	15	10083.58099	0.9	0.8	0.6	0.432
Turonian	15	11362.172601	0.9	0.8	0.6	0.432
Turonian	12	11362.172601	0.9	0.8	0.6	0.432
Turonian	12	19405.618406	0.9	0.8	0.6	0.432
Name	Contour	Area	G	O	D	God_Index
Cenomanian	9	78297.446204	0.9	0.7	0.9	0.567
Cenomanian	6	15305.496636	0.9	0.7	0.9	0.567
Cenomanian	9	21166.377252	0.9	0.7	0.9	0.567
Cenomanian	9	10297.372268	0.9	0.7	0.9	0.567
Cenomanian	6	10297.372268	0.9	0.7	0.9	0.567
Turonian	9	115261.	0.9	0.8	0.9	0.648
Turonian	6	256152.77906	0.9	0.8	0.9	0.648
Turonian	3	504377.	0.9	0.8	0.9	0.648
Turonian	-3	156356.	0.9	0.8	0.9	0.648
Turonian	-6	11.458103	0.9	0.8	0.9	0.648
Turonian	0	319247.	0.9	0.8	0.9	0.648
Turonian	9	19405.618406	0.9	0.8	0.9	0.648
Turonian	9	28331.496855	0.9	0.8	0.9	0.648
Turonian	6	28331.496855	0.9	0.8	0.9	0.648

Turonian	6	67028.557603	0.9	0.8	0.9	0.648
Turonian	3	67028.557603	0.9	0.8	0.9	0.648
Turonian	3	46707.460269	0.9	0.8	0.9	0.648
Turonian	0	46707.460269	0.9	0.8	0.9	0.648
Turonian	-3	2508.178112	0.9	0.8	0.9	0.648
Turonian	-6	2508.178112	0.9	0.8	0.9	0.648
Turonian	-3	24416.452061	0.9	0.8	0.9	0.648
Turonian	0	24416.452061	0.9	0.8	0.9	0.648
Average	0.188353					
Max God_Index	0.648					
Min God_Index	0.016					

Appendix B

Figures

Figure B 1

Topography of yabad town

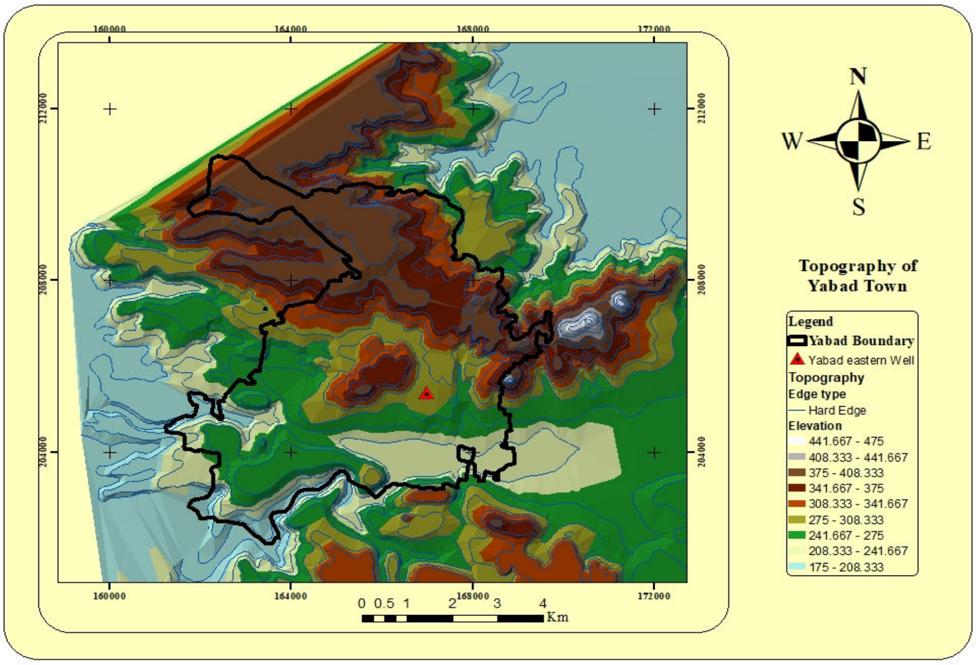


Figure B 2

Land use and practices in Yabad town

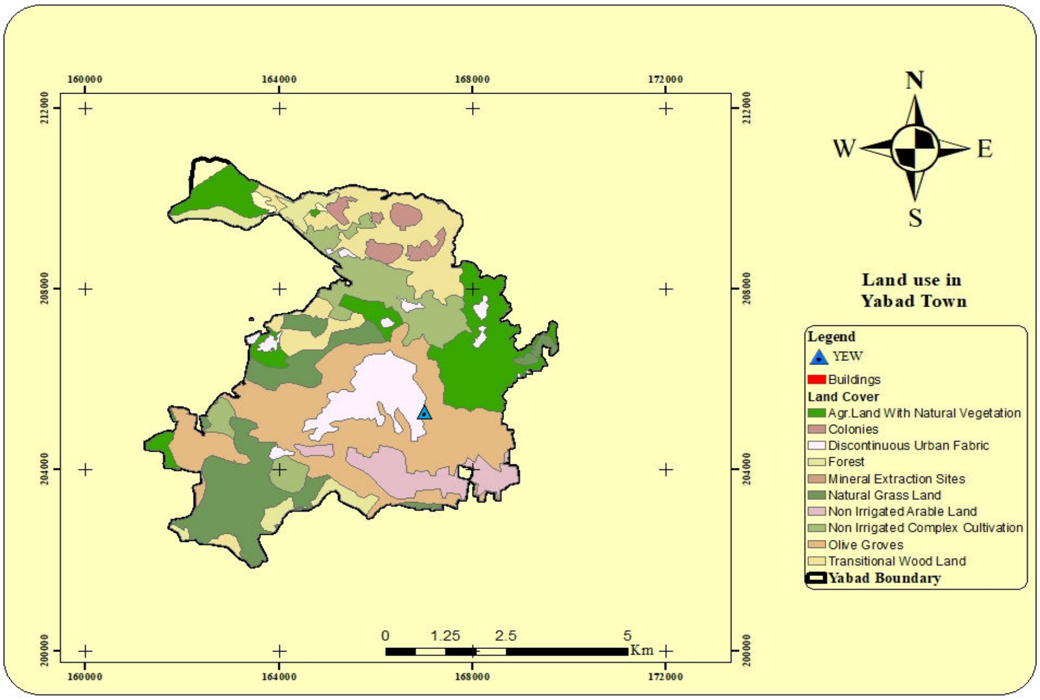


Figure B 3

Land use and buildings in Yabad town

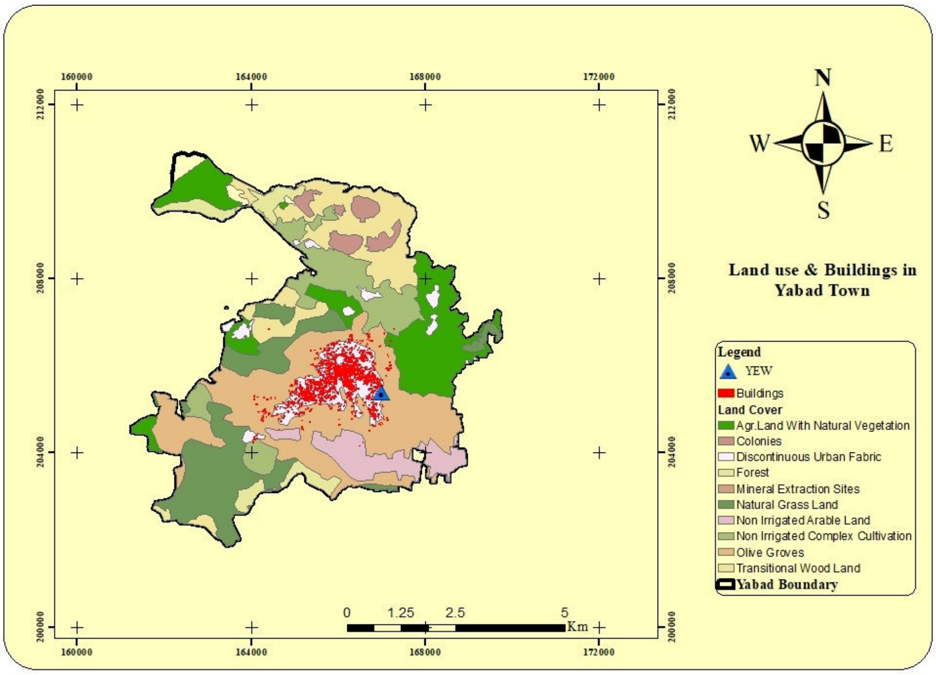


Figure B 4

Agriculture land value for Yabad town

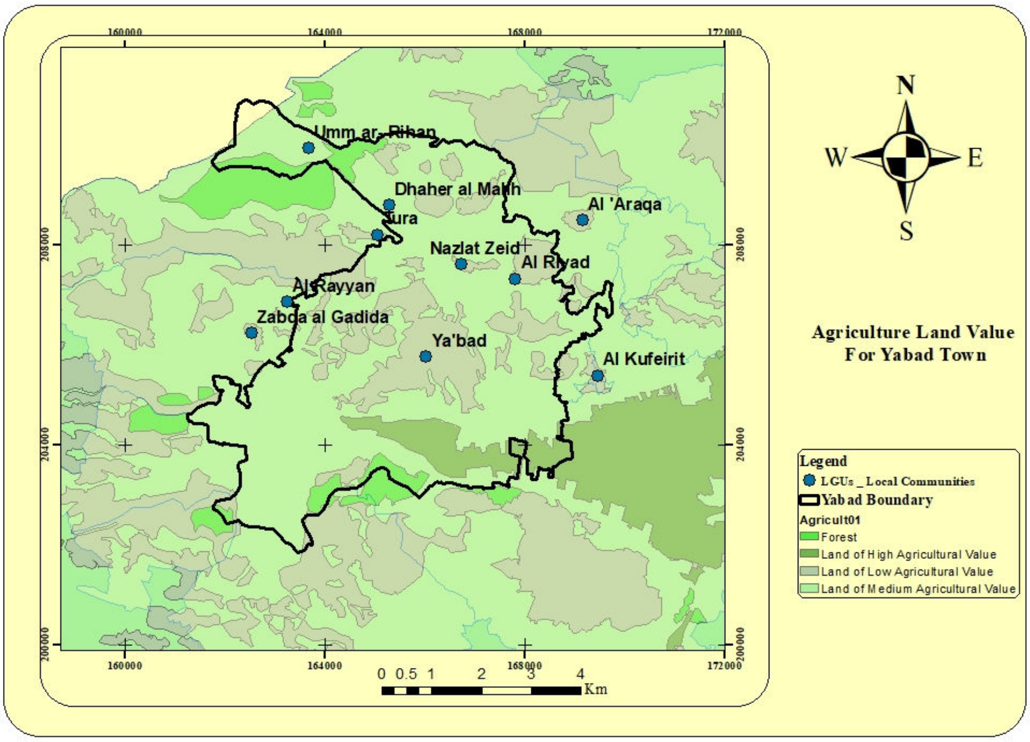


Figure B 5

Geological formation classification according to age for the aquifer.

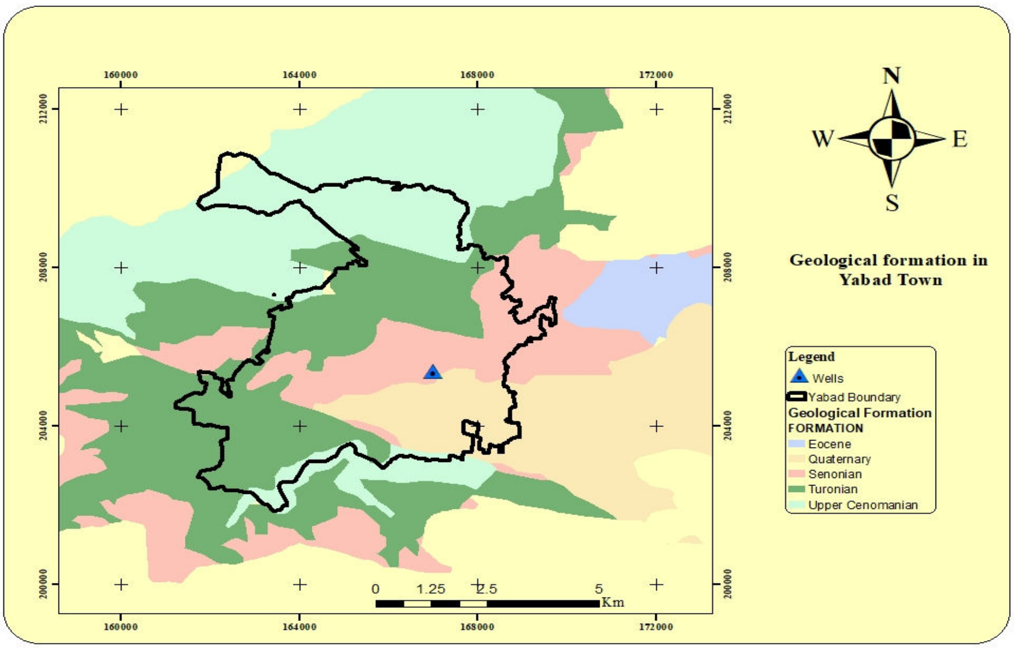


Figure B 6

Surface geological formations of Yabad town

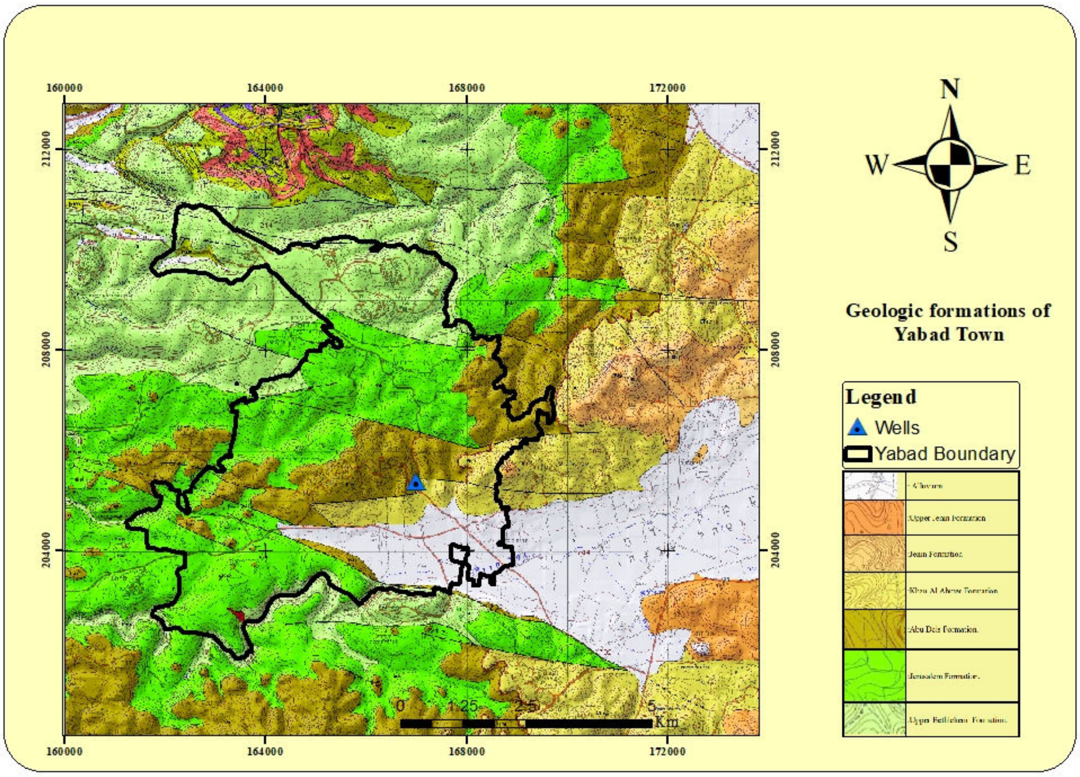
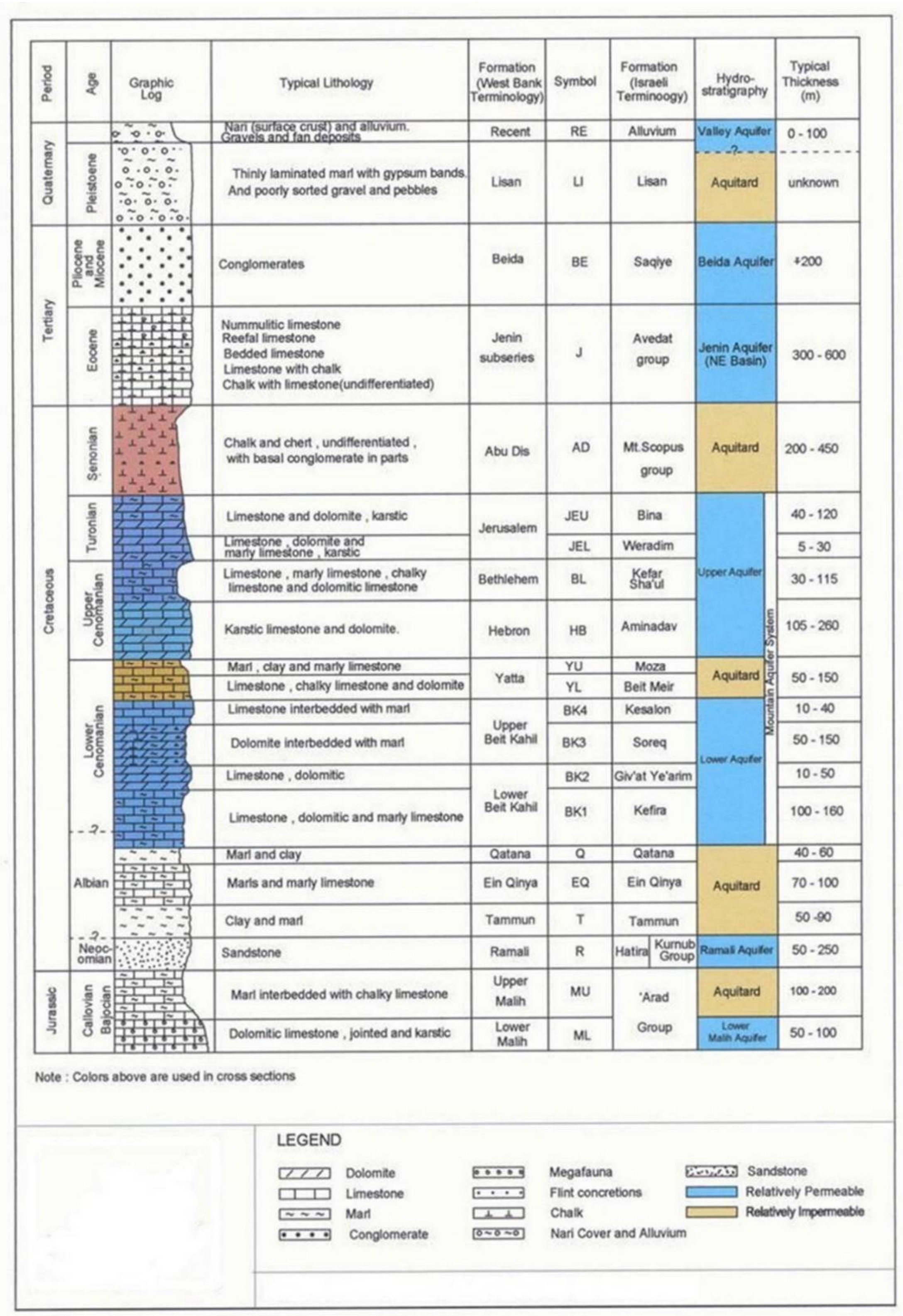


Figure B 7

Generalized stratigraphic of the west bank



Period	Age	Typical Lithology	Formation (West Bank Terminology)	Symbol	Formation (Israeli Terminoogy)	Hydro-stratigraphy	Typical Thickness (m)
Quaternary		Nari (surface crust) and alluvium. Gravels and fan deposits	Recent	RE	Alluvium	Valley Aquifer	0 - 100
Quaternary	Pleistoene	Thinly laminated marl with gypsum bands. And poorly sorted gravel and pebbles	Lisan	LI	Lisan	Aquitard	unknown
Tertiary	Pliocene and Miocene	Conglomerates	Beida	BE	Saqiye	Beida Aquifer	+200
Tertiary	Eocene	Nummulitic limestone Reefal limestone Bedded limestone Limestone with chalk Chalk with limestone(undifferentiated)	Jenin subseries	J	Avedat group	Jenin Aquifer (NE Basin)	300 - 600
Cretaceous	Senonian	Chalk and chert , undifferentiated , with basal conglomerate in parts	Abu Dis	AD	Mt.Scopus group	Aquitard	200 - 450
Cretaceous	Turonian	Limestone and dolomite , karstic	Jerusalem	JEU	Bina	Upper Aquifer (Mountain Aquifer System)	40 - 120
Cretaceous	Turonian	Limestone , dolomite and marly limestone , karstic	Jerusalem	JEL	Weradim	Upper Aquifer (Mountain Aquifer System)	5 - 30
Cretaceous	Upper Cenomanian	Limestone , marly limestone , chalky limestone and dolomitic limestone	Bethlehem	BL	Kefar Sha'ul	Upper Aquifer (Mountain Aquifer System)	30 - 115
Cretaceous	Upper Cenomanian	Karstic limestone and dolomite.	Hebron	HB	Aminadav	Upper Aquifer (Mountain Aquifer System)	105 - 260
Cretaceous	Lower Cenomanian	Marl , clay and marly limestone	Yatta	YU	Moza	Aquitard	50 - 150
Cretaceous	Lower Cenomanian	Limestone , chalky limestone and dolomite	Yatta	YL	Beit Meir	Aquitard	
Cretaceous	Lower Cenomanian	Limestone interbedded with marl	Upper Beit Kahil	BK4	Kesalon	Lower Aquifer (Mountain Aquifer System)	10 - 40
Cretaceous	Lower Cenomanian	Dolomite interbedded with marl	Upper Beit Kahil	BK3	Soreq	Lower Aquifer (Mountain Aquifer System)	50 - 150
Cretaceous	Lower Cenomanian	Limestone , dolomitic	Lower Beit Kahil	BK2	Giv'at Ye'arim	Lower Aquifer (Mountain Aquifer System)	10 - 50
Cretaceous	Lower Cenomanian ?-	Limestone , dolomitic and marly limestone	Lower Beit Kahil	BK1	Kefira	Lower Aquifer (Mountain Aquifer System)	100 - 160
Cretaceous	Albian	Marl and clay	Qatana	Q	Qatana	Aquitard	40 - 60
Cretaceous	Albian	Marls and marly limestone	Ein Qinya	EQ	Ein Qinya	Aquitard	70 - 100
Cretaceous	Albian ?-	Clay and marl	Tammun	T	Tammun	Aquitard	50 -90
Cretaceous	Neocomian	Sandstone	Ramali	R	Hatira (Kurnub Group)	Ramali Aquifer	50 - 250
Jurassic	Callovian Bajocian	Marl interbedded with chalky limestone	Upper Malih	MU	'Arad Group	Aquitard	100 - 200
Jurassic	Callovian Bajocian	Dolomitic limestone , jointed and karstic	Lower Malih	ML	'Arad Group	Lower Malih Aquifer	50 - 100

Note : Colors above are used in cross sections

LEGEND

Dolomite, Limestone, Marl, Conglomerate, Megafauna, Flint concretions, Chalk, Nari Cover and Alluvium, Sandstone, Relatively Permeable, Relatively Impermeable

Figure B 8

Main groundwater Basins in West Bank (12)

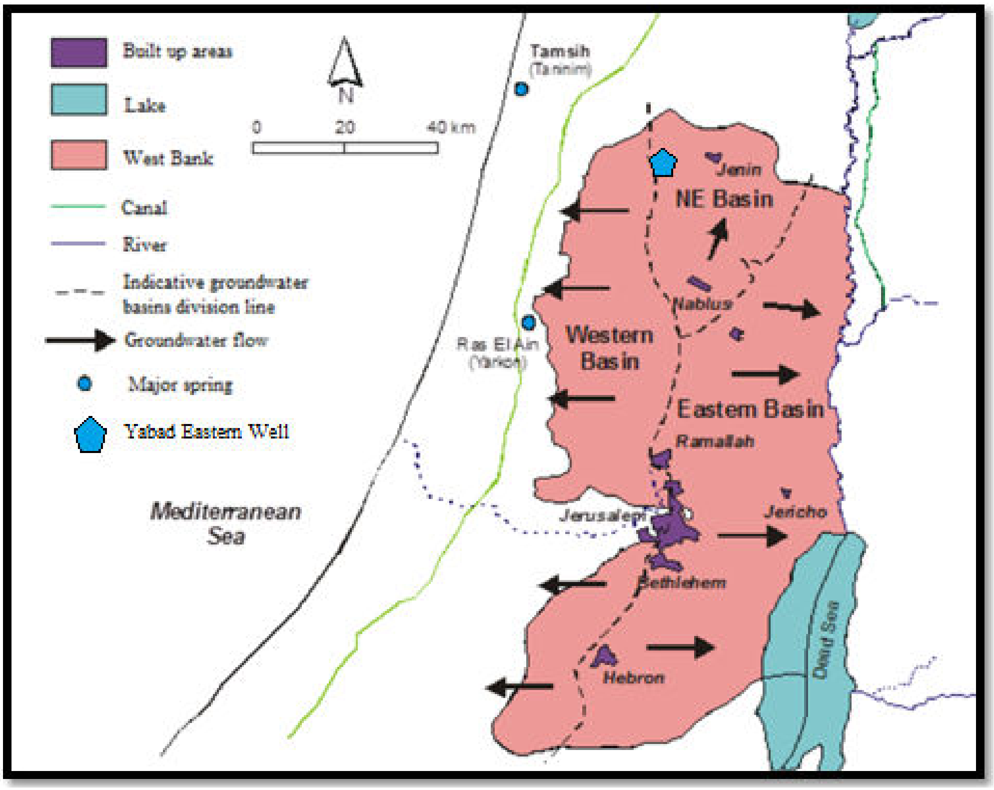


Figure B 9

Groundwater basin boundaries

Figure B 10

Yabad Eastern Well location with reference to groundwater boundaries

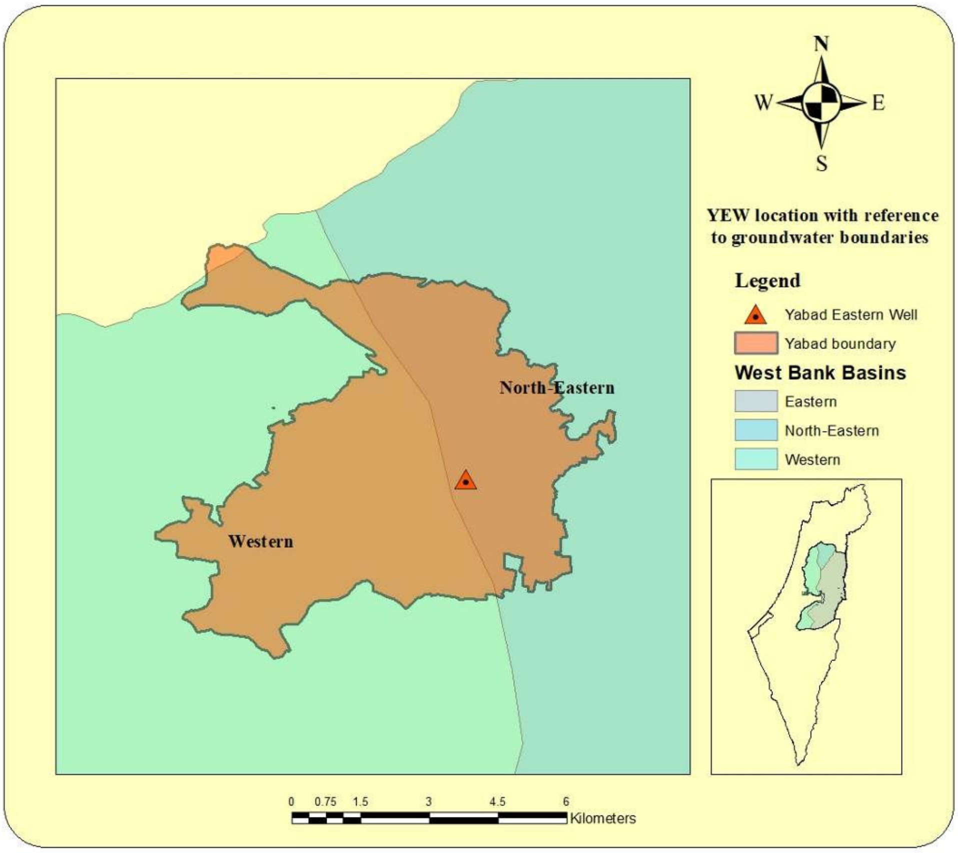


Figure B 11

Hydraulic head level and contours map

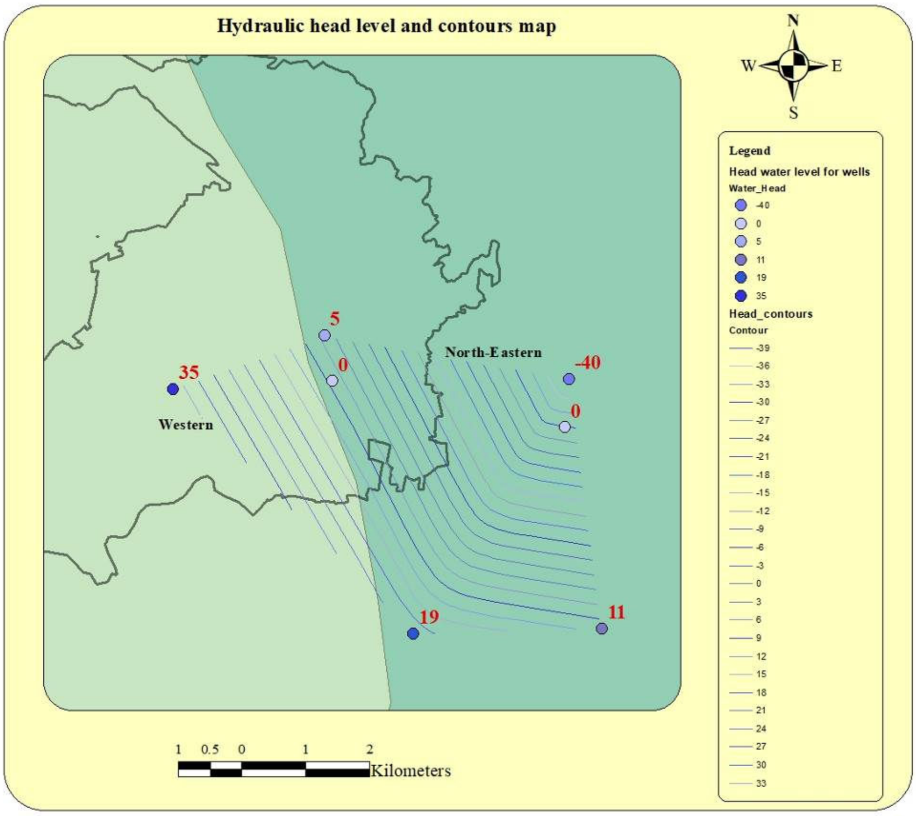


Figure B 12

Component of groundwater protection (7)

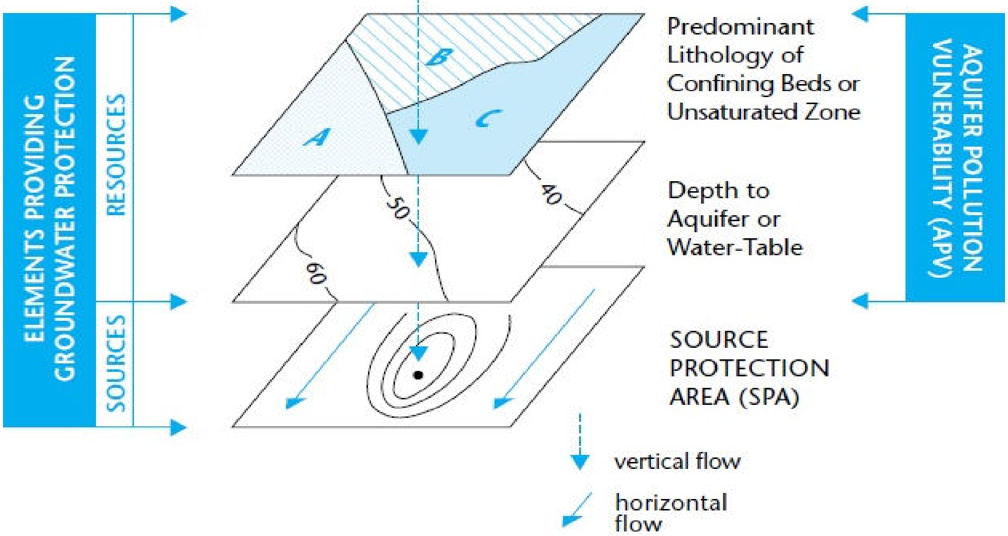


Figure B 13

Import wells data to ArcGIS

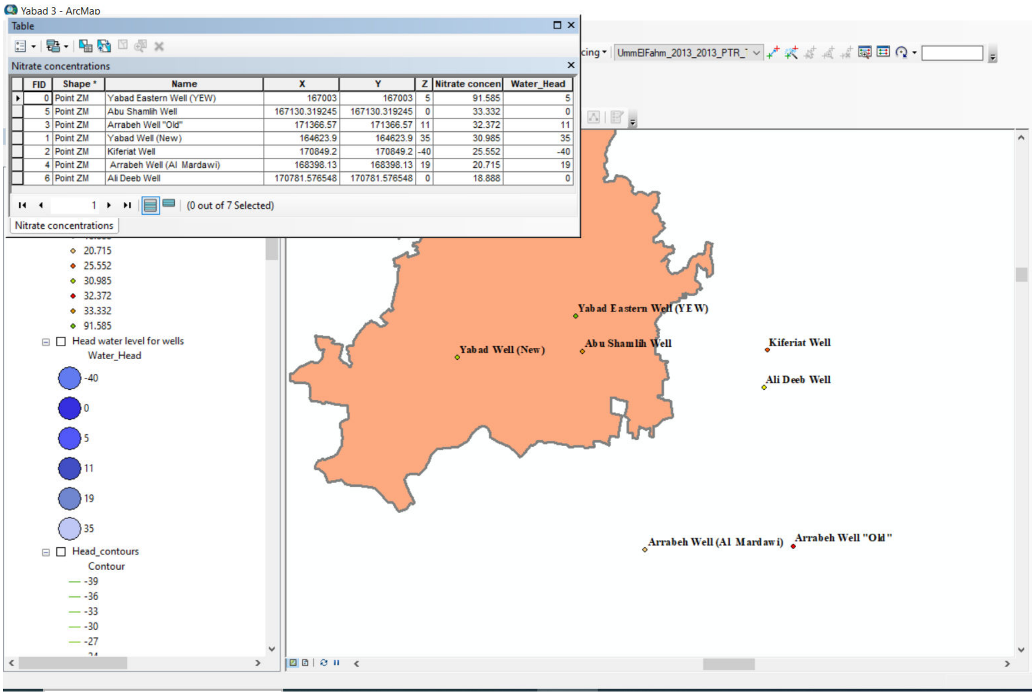


Figure B 14

Create raster image by using interpolation in ArcGIS

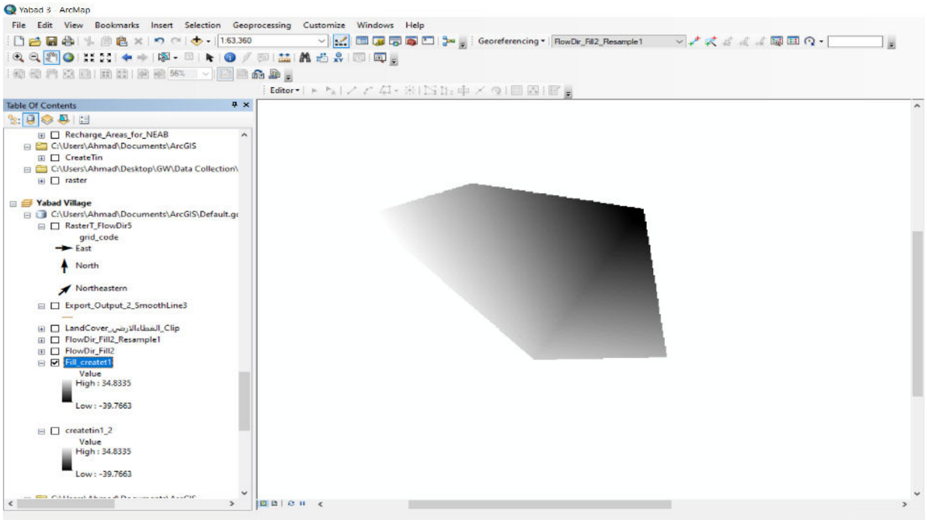


Figure B 15

Contour line for head water

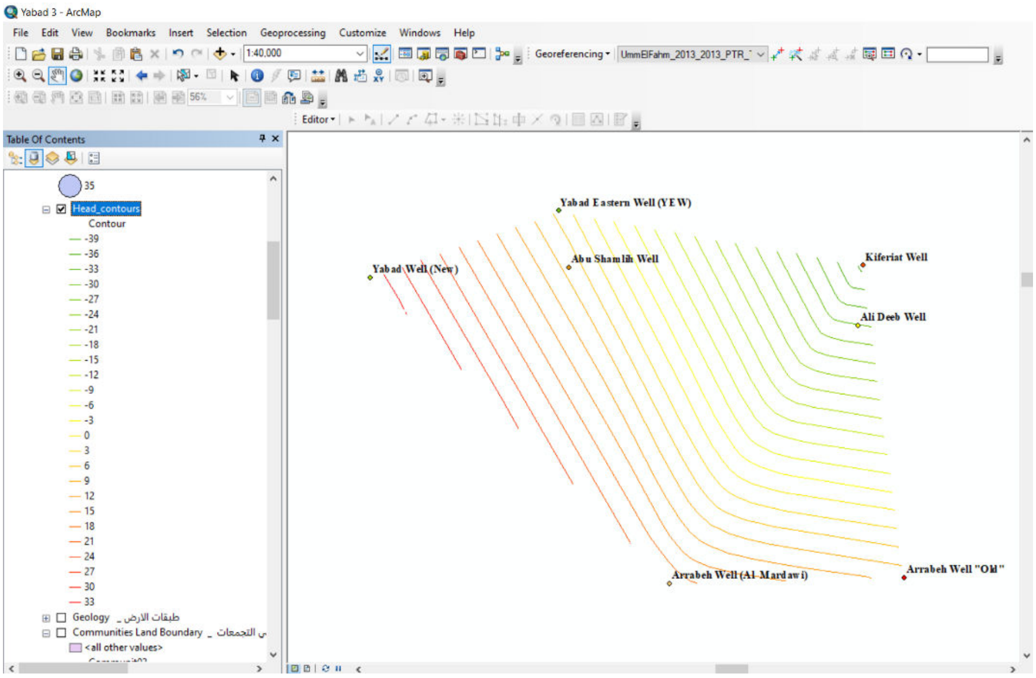


Figure B 16

Tin layer of study area

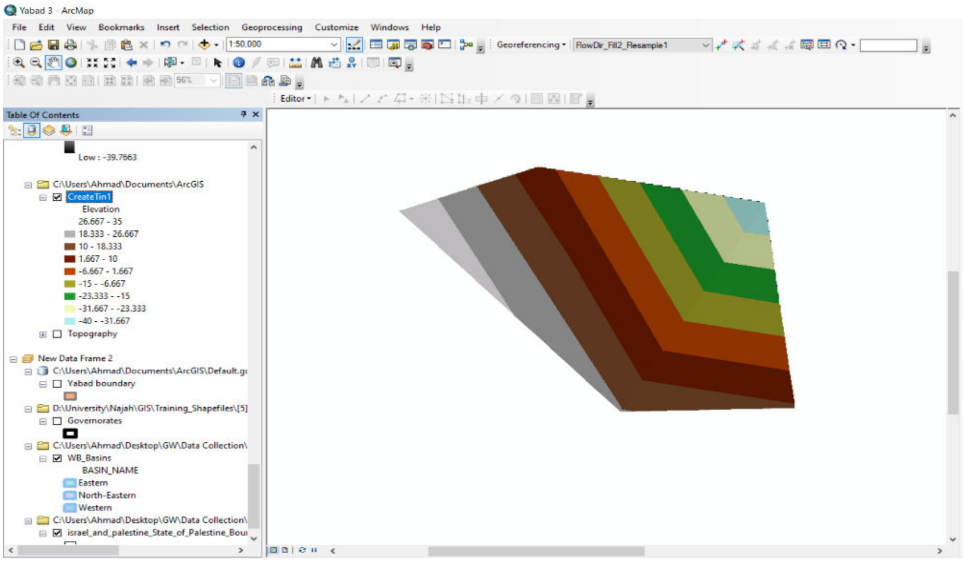


Figure B 17

Flow direction raster layer

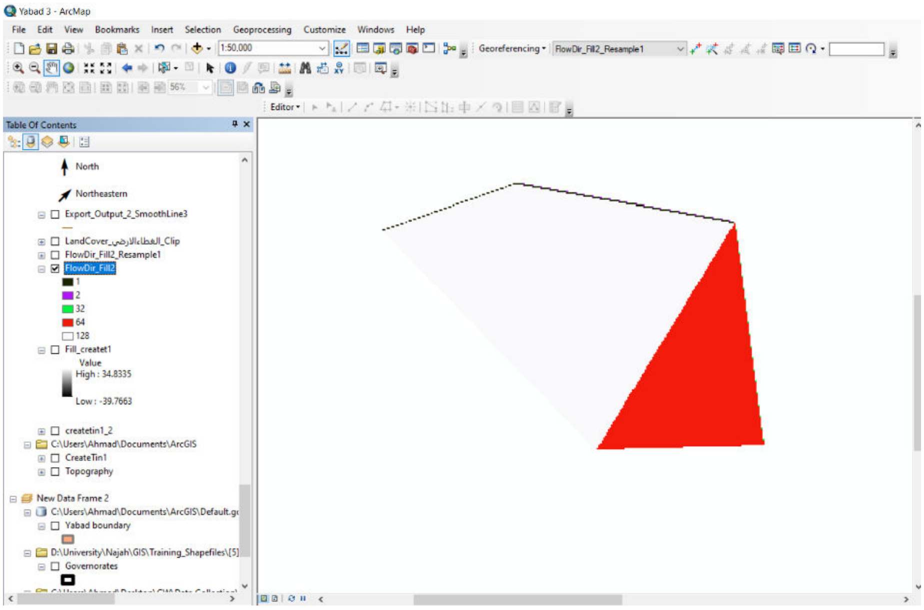


Figure B 18

Resample flow direction layer

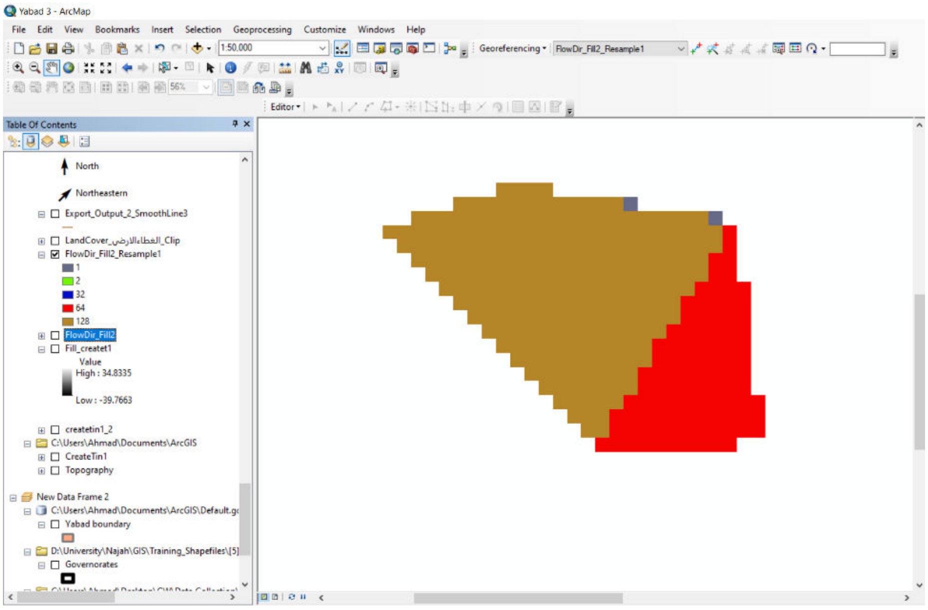


Figure B 19

ArcGIS direction codes

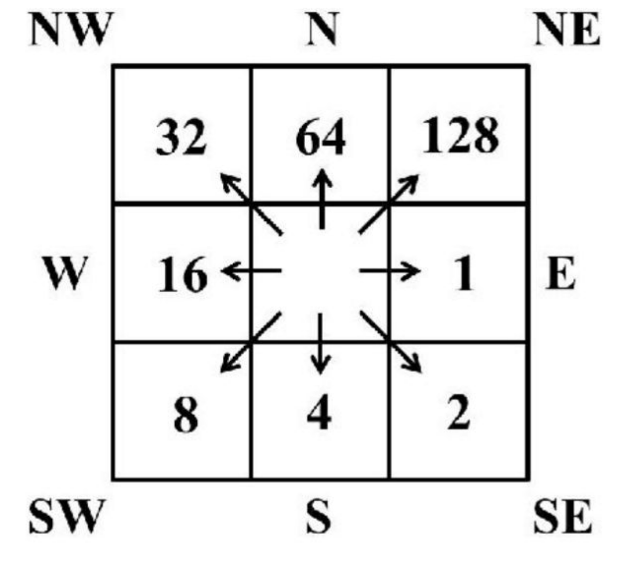


Figure B 20

Groundwater flow direction

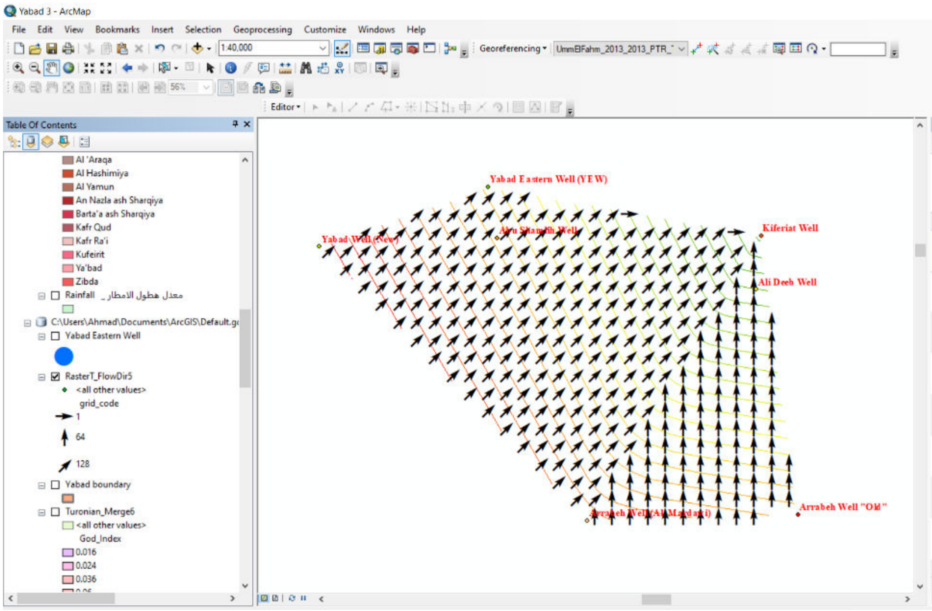


Figure B 21

Recharge areas

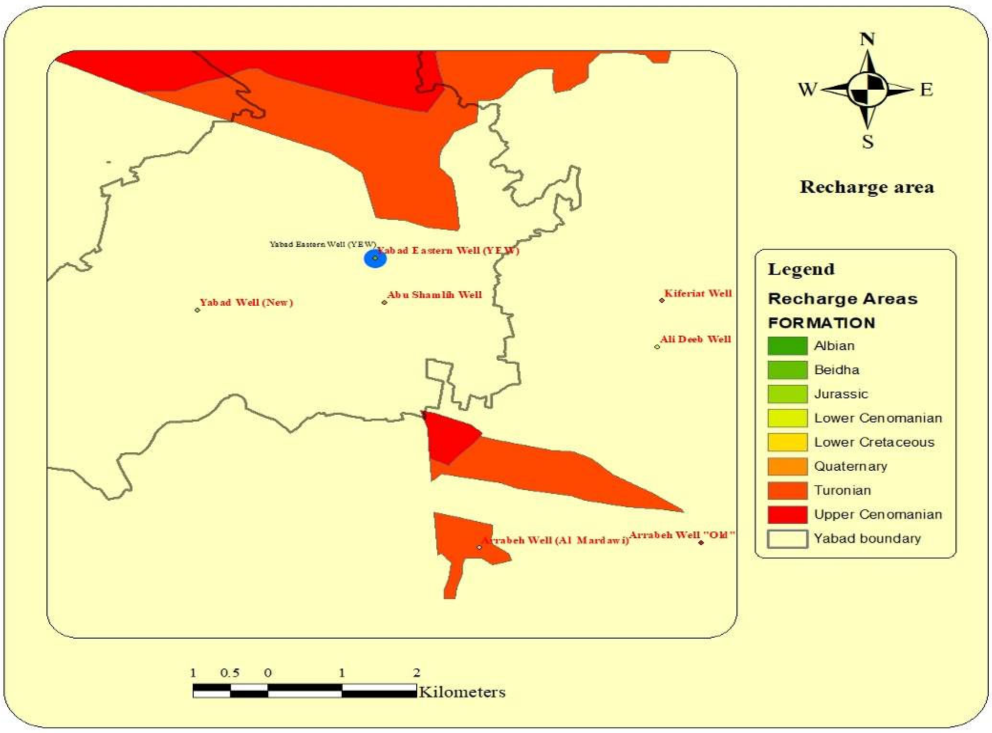
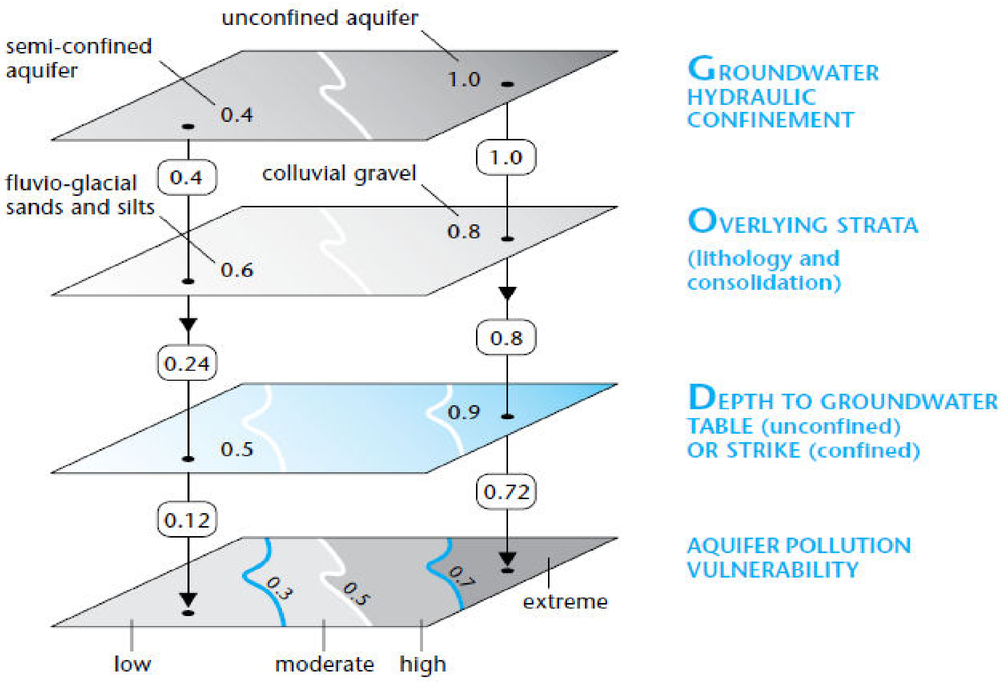


Figure B 22

Generation of aquifer pollution vulnerability map using GOD system (7)



جـامعـــة النجاح الوطنية

كليـــة الدراســـات العليـــا

المصادر المحتملة وتدابير التخفيف لتلوث النترات باستخدام نظم المعلومات الجغرافية وتحليل حساسية المياه الجوفية :دراسة حالة بئر يعبد الشرقية (فلسطين)

إعداد

أحمد عساف محمد عساف

إشراف

د. محمد المصري

قدمت هذه الرسالة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة المياه والبيئة، من كلية الدراسات العليا، في جامعة النجاح الوطنية، نابلس– فلسطين.

2025

المصادر المحتملة وتدابير التخفيف لتلوث النترات باستخدام نظم المعلومات الجغرافية وتحليل حساسية المياه الجوفية: دراسة حالة بئر يعبد الشرقية (فلسطين)

إعداد

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الملخص

يُعدّ المصدر الرئيسي لمياه الشرب العذبة للفلسطينيين في الضفة الغربية وقطاع غزة هو المياه الجوفية. لذلك، فإن مراقبة جودتها وكميتها تعتبر أمرًا ضروريًا. أظهرت الأبحاث الحديثة أن تلوث نترات المياه الجوفية في طبقة المياه الجوفية يشهد ارتفاعًا مستمرًا. وتُعتبر الاستخدام المكثف للأسمدة، تسرب مياه الصرف الصحي من الحفر الامتصاصية، وغياب أنظمة الصرف الصحي المُصممة بشكل صحيح من الأسباب الرئيسية لهذا التلوث. يمكن أن يؤدي ارتفاع مستويات النترات في مياه الشرب إلى مشاكل صحية مثل سرطان المعدة لدى البالغين ومرض "ميتهيموغلوبينيميا" عند الرضع.

في السنوات الخمس الأخيرة، برزت هذه المشكلة في بئر يعبد الشرقي، حيث تجاوز تركيز النترات الحد المسموح به وفقًا لمنظمة الصحة العالمية. ويُعتبر ارتفاع تركيز النترات أحد مشاكل تلوث المياه الجوفية في طبقة المياه الجوفية يهدف هذا البحث إلى تحديد مصدر تلوث النترات في بئر يعبد الشرقي.

لتحقيق هذا الهدف، تم تطبيق منهجية مناسبة لفهم المشكلة. بدأت المنهجية بدراسة البيانات التاريخية لجودة المياه في بئر يعبد الشرقي، والتي أظهرت ظهور مشكلة التلوث في عام 2019. أظهرت العينات المأخوذة من الآبار المحيطة ببئر يعبد الشرقي أن تركيز النترات كان أقل من الحد الأقصى للتلوث، مما أعطى مؤشرًا على أن المشكلة محصورة في بئر يعبد الشرقي فقط. وبالتالي، تم تحديد حدود منطقة البحث، حيث اقتصرت على حدود الآبار المجاورة.

بالإضافة إلى ذلك، تم دراسة ستة آبار تقع في المنطقة المحيطة بالبئر لتحديد ما إذا كان التلوث يحدث في الطبقة الجوفية أو فقط في البئر المستهدفة. بعد ذلك، تم دراسة اتجاه تدفق المياه الجوفية لتحديد المناطق الواقعة في الاتجاهين العلوي والسفلي باستخدام ارتفاعات منسوب المياه في الآبار عبر برنامج.ArcGIS

تم تحديد قابلية المياه الجوفية للتلوث لتحديد المواقع التي تسمح بدخول الملوثات إلى طبقة المياه الجوفية. تم تقييم القابلية باستخدام طريقة .GOD وبعد تحديد المتغيرات التي تؤثر على تلوث بئر يعبد الشرقي، تم دمج الطبقات المختلفة؛ حيث تمثل كل طبقة متغيرًا محددًا، مثل اتجاه تدفق المياه الجوفية، القابلية للتلوث، واستخدامات الأراضي.

تضمنت هذه الخطوة تحديد الموقع الأكثر عرضة للتلوث، وتصنيف الأنشطة التي تجري فيه والتي يمكن أن تُسبب تلوث طبقة المياه الجوفية بالنترات، وكذلك تحديد المسار الذي يسلكه التلوث للوصول إلى البئر.

أظهرت النتائج أن البلدة القديمة كانت الموقع الأكثر عرضة للتلوث في منطقة الدراسة، وهي قريبة جدًا من موقع البئر. تعاني هذه المنطقة من كثافة سكانية عالية ونظام صرف صحي ضعيف. كما وُجد أن الحفرة الامتصاصية الخاصة بحارس غرفة التشغيل للبئر تشكل سببًا آخر للتلوث.

يوصي البحث بإنشاء شبكة صرف صحي لتغطية البلدة القديمة في قرية يعبد، وإنشاء منطقة حماية حول رأس البئر بقطر 100 متر لتقليل خطر التلوث.

الكلمات المفتاحية: تلوث النترات, احواض جوفية, مياه جوفية, اتجاه تدفق المياه, طريقة الطبقات , نظم المعلومات الجغرافية, حساسية الاحواض الجوفية.