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Groundwater Assessment and Protection Zone Plan in Al- Fawwar Wells Field

Amjad Yaser Al- Darabi

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By

Amjad Yaser Al- Darabi

B.Sc. of IT-Technical Palestine Collages - Palestine

Supervisor

Dr. Jawad A. H. Shoqeir

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Prepared by: Amjad Yaser Al- Darabi
Registration no.: 20811704

Supervisor: Dr. Jawad A. H. Shoqeir

Master thesis submitted and accepted, 11 of May 2015.The names and signatures of examiners committee members are as following:

Head of committee: Dr. Jawad Shoqeir Signature: ………………

External Examiner: Dr. Marwan Ghanem Signature: ………………

Internal Examiner: Dr. Amer Kanan Signature: ………………

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Dedication

To my Father and Mother who supported me

To my lovely wife Tasneem for her encouragement, care, and unconditional support

To my little man Yaser the Life dialogue

To my brothers and sisters

To my friends who have been encourage and supporting me

Declaration

I declare that, this thesis submitted for the degree of environmental sciences master the result of my own research, except where otherwise acknowledged, and that this thesis (or any part of the same) has not be submitted for a higher degree to any other university or institution.

Signature: …………….

Date:

Acknowledgment

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Abstract

Al Fawwar wells 1 & 2 are major source of drinking water for number of communities like Al- Fawwar camp, Hadeb Al- Fawwar, Al- Higri town and the southern part of Hebron city. The increase in population led to increased water demand and also there is ability to increase the pollution levels. The aim of this study is the delineation of Wellhead Protection Areas (WHPA) for Al- Fawwar wells 1 & 2 in Hebron Governorate due to lack of studies in the West Bank that covers the protection of public drinking water wells from potential sources of pollution by considering the groundwater protection regulation developed by Palestinian Water Authority. It also investigates the potential sources of pollutants that affect the groundwater in the catchment area that extend from Dura at west to Al- Fawwar refugee camp at east, Hebron city at north and Khursa and Tarama villages in south.

The lithology of Al- Fawwar wells 1 & 2 was determined by carrying out a geo-electrical investigation by using Vertical Electrical Surrounding (VES). Three main geological formations in the study area were concluded; Hebron formation, Bethlehem formation and Jerusalem formation which consist of dolomite, marl and limestone.

The water budget of Al Fawwar wells 1 & 2 catchment was calculated, the area of the wells catchment was about 16 km^2, the volume of: precipitation was 7.93 MCM, water import was 0.438 MCM, evapotranspiration was 5.70 MCM, surface runoff 0.91 MCM, groundwater recharge was 1.84 MCM spring production was 0.354 MCM and a wells abstraction was 0.691 MCM. The evapotranspiration was about 72% of precipitation, the surface runoff was about 11.5% and the groundwater recharge was about 23%. The water loss from precipitation was calculated to be 83.5%.

The potential sources of contamination in the catchment determined to include; agricultural lands (use fertilizers and pesticides), lack of sewage network (instead of it, use cesspits to dispose wastewater); for this the groundwater quality of Al- Fawwar wells 1 & 2 was evaluated for domestic purposes. The results show that the concentration of nitrate of Al- Fawwar wells 1 & 2 was (101 and 104 mg/L) respectively, that exceed the acceptable limits of nitrate in drinking water according to

WHO and PWA standards for drinking water. The results of Fecal coliform (FC) and Total coliform (TC) tests were (zero cfu/ 100 ml) (after chlorination of water) that accepted with WHO and PWA standards for drinking water.

The boundaries of Wellhead Protection Area (WHPA) of Al- Fawwar wells were identified using two methods: Calculated Fixed Radius (CFR) and Wellhead Analytic Element Model (WhAEM2000). According to the results of using CFR method for Al- Fawwar well no. 1, the radius of 50 days zone is 51.19 m, for 2 year is 195.6 m and for 5 year is about 309.29 m. For Al- Fawwar well no. 2, the radius of 50 days zone was 38.2 m, for 2 year was 145.8 m and for 5 year was about 230.5 m. According to the results of using WhAEM2000 method for Al- Fawwar well no.1, the travel time parameter (Ť) of 50 days is 0.49, (0.1< Ť < 1), the radius (R) and the eccentricity (δ) is 16.31 m, 5.10 m respectively. For 2 year (Ť) is 7.18, (Ť > 1), the boat shaped radiuses L_u, L_s and Y_{max} are 149.25 m, 15.77 m, 49.5 m respectively. For 5 year (Ť) is 17.94, Ť > 1, the boat shaped radiuses L_u, L_s and Y_{max} are 330.53 m, 15.77 m, 49.5 m respectively. For Al- Fawwar well no. 2, the travel time parameter (Ť) of 50 days was 0.93, (0.1< Ť < 1), the radius (R) and the eccentricity (δ) was 12.89 m, 5.2 m respectively. For 2 year (Ť) was 13.55, (Ť > 1), the boat shaped radiuses Lu, Ls and Ymax were 139.7 m, 8.55 m, 26.85 m respectively. For 5 year (Ť) was 33.87, Ť > 1, the boat shaped radiuses Lu, Ls and Ymax were 320.4 m, 8.55 m, 26.85 m respectively.

There were violations in the well filed that must prevented after delineation of WHPA of Al- Fawwar wells 1 & 2 like grazing and presence of cesspit in Zone 1. Also there were violations in the boundary of Zone 2 like using of fertilizers and pesticides. By this study, it’s recommended to delineate WHPAs for public drinking water wells mainly by using the WhAEM2000 method.

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List of Abbreviations

ARIJ	Applied Research Institute- Jerusalem
Avg.	Average
AET	Actual Evapotranspiration
CM/ yr	Cubic Meter per year
EC	Electrical Conductivity
EQA	Environmental Quality Affair
ET	Evapotranspiration
FC	Fecal Coliform
JMWI	Jordanian Ministry of Water and Irrigation
Km^2	Kilometer square
m	Meter
m^3	Cubic meter
Max.	Maximum
MCM/ yr	Million Cubic Meter per year
MEnA	Ministry of Environmental Affair
mg/L	milligram per Litter
mm/ yr	millimeter per year
MoA	Ministry of Agriculture
NGOs	Nongovernmental Organizations
NO_3^-	Nitrate
NWC	National Water Council
P	Precipitation
PCBS	Palestinian Central Bureau of Statistics
PHG	Palestinian Hydrology Group
PWA	Palestinian Water Authority
Qin	Water import
Qout	Groundwater recharge
Qspring	Springs production
Qwell abstraction	Wells abstraction
SR	Surface runoff
TC	Total Coliform
TDS	Total Dissolved Solid
U.S. EPA	United State Environmental Protection Agency
WB	West Bank
WHO	World Health Organization
WHPA	Wellhead Protection Area

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1 Chapter One: Introduction

1.1 Water Situation in Palestine

Water is the most important natural resource on our planet and perhaps the scarcest commodity of the 21st Century. The groundwater is the most important component of the freshwater resources of the world, mainly in the arid and semiarid regions, where the groundwater represents the main water resource in these regions; adequate groundwater management is a prerequisite for the sustainable use of the scarce water resources (Schelkes, et al., 2004, Tarazi, 2009).

The Mediterranean Region is suffering from significant water shortage and the demand on clean water is increasing. As a result, the search for new resources along with protecting used ones becomes a very pronounced priority for the researchers and the decision makers in the region (Saleh, 2011). The large variations in rainfall and limited surface resources have led to widespread scarcity of the fresh water resources, resulting in a heavy reliance on groundwater as the major source for various uses (Murad, 2004).

In Palestine, the main resources of fresh water are the Jordan River, the groundwater underlying the West Bank (WB) and the coastal area (mainly utilized through wells and springs). But, only 10% of the ground water resources are allocated to Palestinians because of the control of the Israeli occupation that drain water resources, dispossess and exploit Palestinians of their water rights (Carmon et al. 1997, Saleh, 2011). So, this water shortages and also acute water quality problems continue to negatively affect the lives and livelihoods of millions of Palestinians in the WB (PWA, 2012). So protection of existed water resources from possible contamination is a central imperative of sustainable development of groundwater resources in Palestine (Carmon et al, 1997).

1.1.1 Groundwater Recourses Protection

Water is essential to sustain life, and one of the most important factors for development in any country including Palestine is the availability of adequate and safe water supply to be used for all purposes. So improving access to safe drinking water has tangible benefits of health and every effort should be made to achieve a safe drinking water quality (Ikhlil, 2009).

South Palestine is considered as semiarid areas which characterized by low rainfall, high temperature and high evapotranspiration. The reasons of water shortage are due to; the scarcity of natural available water resources and rapid increasing demand on these resources as a result of the rapid population growth. Add to this, the lack of proper management and the inefficient usage of these water resources in some cases (Ikhlil, 2009). In addition, the Israeli occupation and their water policies that is against the water rights of Palestinian population. Israel controls on water resources, so the Palestinian access to water is controlled by it. In addition, the available amount of water to Palestinians is limited and it does not enough their needs. Palestinian consumption of water in the West Bank (WB) is about 70 liters a day per person, which is below the 100 liters per capita that is daily recommended by the World Health Organization (WHO), whereas Israeli daily per capita consumption, about 300 liters, which is about four times as much. In some rural communities Palestinians consumption of water is less than 70 liters, in some cases it may reach 20 liters per day, the minimum amount recommended by the WHO for emergency situations response. Israel uses more than 80% of the water from the Mountain Aquifer, the only source of underground water in Occupied Palestine, also all of the available surface water from the Jordan River is prevented to use for Palestinians (Amnesty International, 2009).

Also, the quality of groundwater is vital; because human activates can change the natural composition of groundwater causing undesirable changes in its quality (Tarazi, 2009). Although that ground water is protected by layers of rocks and soil that act as filters, but it is vulnerable to contamination. Groundwater quality could be influenced by many factors including climate, topography, aquifer lithology, surface water recharge and human activities (Wu et al., 2011).

The protection of groundwater is aim to protect the remained amount of groundwater in the aquifer from pollution through prevent spreading of pollutants from any possible pollution sources. There is different types of contaminants can enter groundwater, like solid waste landfills, chemical spills, leaking underground storage tanks, food industry like olive mill wastewater and improperly managed hazardous waste sites. Groundwater pollution also may result from the agricultural activities that depend on use of fertilizers and pesticides, also the disposal of human, animal, and agricultural waste (U.S. EPA, 1987).

In Palestine, there is a shortage of high quality water which is considered a main problem; this resulted from overdraft of water and the salinity of water. The groundwater as well is in danger of being becoming contaminated as a result of spelling of liquids that result from solid wastes and the direct disposing of untreated wastewater which may enters to the aquifer (PWA, 2005).

The protection of groundwater quality is a high priority because of many reasons Geological survey of Irland, 1999, El- Fahem, 2012):

- Groundwater is an important source of water for drinking water, and for industrial, agricultural and other activities; but these human activities can increasing the risks to the groundwater quality;
- Protecting public health;
- If the pollution source of water eliminated, then the polluted groundwater cannot be treated easily because the slow movement of water in the ground so the impact of human activities lasts for a long time;
- Reducing the cost of water treatment and ensuring a long-term supply of clean water;
- The national regulations require that pollution must be prevented (as part of sustainable groundwater quality management).

So, to maintain safe groundwater resources in Palestine, this needs to prevent the pollution. Many methods are used in local and regional scales to protect the valuable groundwater recourses. One method of groundwater protection is depend on minimize of the possible groundwater contamination through protect the recharge zone by assessing potential threats to groundwater in areas near the well as a Wellhead Protection Area (WHPA) (Virginia commit, 1998, Moghier and Tarazi, 2010).

1.1.2 Water Contamination Sources

The good and safe quality of groundwater that used for drinking purposes is considered the base of good human health because water essential for life, but if this water polluted with undesirable substances it becomes dangerous on humans health. There are different possible threats to groundwater that can cause deterioration of water quality (Schmoll et al., 2006). Pollutants come from different activities on the land and it can seep into the ground to move toward a well. Also, there are different activities that have negative effects on groundwater mainly when it not managed properly. These activities include: commercial activities, industrial activities, urban activities and agricultural activities, (Subah and Margane, 2010, El-Fahem, 2012).

In Palestine, the PWA established initial classification of activities based on the most common and relevant activities in a Palestinian context as shown in **Table (1.1)**. The table lists activity categories, typical activities within each category, and the most common pollutants associated with these activities (PWA, 2005, Tarazi, 2009).

Table (1.1): Activities and pollutants (PWA, 2005, Tarazi, 2009).

Activity categories	**Activities**	**Pollutants**
Water and Wastewater	Treatment Plant Sewerage sludge landfill Septic tank effluent Treated wastewater infiltration basins	Heavy metals, high organic, nutrients (P, K, N*), Faecal bacteria, viruses, protozoa
Solid waste disposal	Municipal landfill Industrial landfill Open dumps	Sulphate, chloride, ammonia, TOC*, TDS*, Biological contaminants, fatty acids, lactates
Waste Treatment Disposal	Storage of hazardous waste Waste handling	Hazardous substance
Storage and Transport	Storage of hazardous materials Fuel storage Oil and grease discharge	Hazardous materials, Petrlouem, hydrocarbons, benzene, ethylbenzene
Agricultural productions	Cropping practices	Pesticides, herbicides, nitrate, TDS, heavy metals, High nitrogen, phosphorus loads and biological contaminants.
Electricity generation	Fly ash ponds and landfills Waste briquettes, tars	Sulphate, heavy metals, TDS, petroleum hydrocarbons, PAH
Manufacturing	Food processing Nutrients	Nutrients, nitrogen, K, P, TDS

* P: Phosphorus, K: Potassium, N: Nitrogen, TOC: Total Organic Carbon, TDS: Total Dissolved Solids.

For effective groundwater protection management, it is needed to determine the types of pollutants then locate and map their sources before the delineation of WHPA for the target well.

1.2 Wellhead Protection Area (WHPA)

Groundwater protection and pollution prevention can be effective when the planners of land use and the managers of water resources use groundwater wellhead protection schemes (Geological survey of Irland, 1999).

Wellhead protection aims to protect groundwater which is a source of public water supply from the threat of contamination from nearby residential, industrial, commercial, agricultural, waste management, or transportation activities (Virginia commit, 1998). This protection occurs by implement of restrictions on land uses and human activities within the boundary of the Wellhead area (Margane, 2003).

1.2.1 Wellhead Protection Area (WHPA) Definition

The US Environmental Protection Agency (U.S. EPA, 1987) defined a Wellhead Protection Area as “the surface or subsurface area surrounding water well or well field supplying a public water system, through which contaminants are reasonably likely to move toward and reach such well or well field”. Protection zone is the land area which determined to provide recharge to a public drinking water supply well, designated on maps to determine the allowable land use and activities. Protection zones may comprise all or a portion of a Wellhead Protection Area (WHPA) (Tarazi, 2009). Wellhead protection is a process as shown in **Figure (1.1)**.

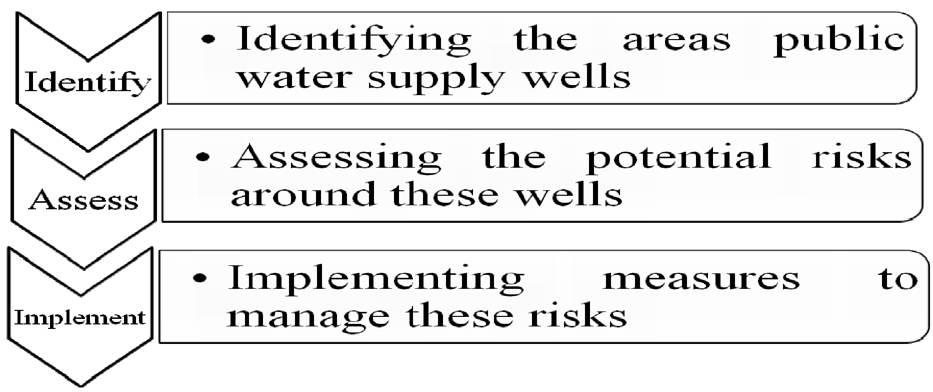


Figure (1.1): Process of Wellhead Protection Area (WHPA) (Verginea commit, 1998).

1.2.2 Delineation of WHPA

One of the most important elements in groundwater protection is the delineation of WHPA. Where the delineation of the WHPA considered as a process to determine the boundaries of geographical area that should be included within a wellhead protection program, then we can manage this area of land to minimize the potential of groundwater contamination by human activities that occur on the land surface or in the subsurface (Frind et al., 2002). Also, the delineation of groundwater protection area provides guidelines for the planning and licensing authorities to help them in carry out their functions, and determine a framework to assist the location, nature and control of activities within the boundary of protection zone so protect groundwater sources and maintain the beneficial use of groundwater (Geological survey of Irland, 1999).

The delineation of WHPA needs determining of a group of inputs that include: time of travel (TOT) which is the time required for a contaminant to travel through the saturated zone from a specific point to reach the well., flow boundaries, daily volume, groundwater flow field and aquifer transmissivity (Geological survey of Irland, 1999, Tarazi, 2009).

1.2.3 WHPA Plan

The benefit of protection area can be occurred only if there is ability to restrict polluting activities within it. This is required activation of legislation that regulates land use planning or pollution control of the country. The determinations of the zones need specific requirements, which are met by enacting relevant restrictions or introducing permitting systems (Schmoll et al., 2006).

Developing WHPA plan occurred through the following stages (Mogheir and Tarazi, 2010):

- 1st stage: defines the area to be protected and managed for wellhead protection. This is the subsurface area surrounding a well that supplies a public water system, through which contaminants are likely to move through and reach the well. The boundaries are scientifically calculated.

- 2nd stage: creates a contaminant source inventory with the purpose to identify potential sources of contamination which may impact the public water supply well.
- 3rd stage: is zoning and land use management.

1.2.3.1 Zoning System

Protection zones are particularly effective to control pollution from diffuse sources (e.g. agriculture) (Schmoll et al., 2006). In which the dimensioning of the protection zones has to be done very carefully in order to balance competing interests: as large as necessary for safeguarding the water supply, as small as possible for avoiding inadequate restrictions (Subah and Margane, 2010, El- Fahem, 2012).

According to Jordanian guideline (2006) for drinking water protection the zoning system of water wells divided into (JMWI, 2006, Subah et al., 2008):

- Zone 1 (Immediate Protection Zone): protects the extraction point and its immediate environment from any contamination and interference.
- Zone 2 (Inner Protection Zone): protection against pathogenic microbiological constituents such as bacteria, viruses, parasites and worm eggs.
- Zone 3 (Outer (Wider) Protection Zone): protection from contamination affecting water over long distances such as contamination by chemicals which are non- or hardly degradable and which can travel long distances.

The description of the dimension and the allowed activities of zone 1, zone 2 and zone 3 of water well are summarized in **Table (1.2)**.

Table (1.2): Zoning system (JMWI, 2006, Borgstedt and Subah, 2006, Subah et al., 2008).

Description	Zone 1	Zone 2	Zone 3
Area	Comprises an area of 1 dunum around each well. 25 m upstream of the well, 15 m on both sides of the well and 10 m downstream of the well.	Starts at the outer border of Zone 1 and ends at a virtual line from where the groundwater flow will take 50-days until it reaches the well. This distance should not exceed 2 km upstream and 50 to 150 m downstream of the extraction point.	Protection of the entire groundwater catchment area of the abstraction point.
Allowed activities	Activities needed for the water abstraction. All installations required for the operation of the well has to be constructed downstream of the well.	Connection to a local sewerage system or installation of a properly managed cesspit. Organic agriculture.	All development, agricultural, industrial, and social activities are allowed under the condition that they comply with the laws.

1.2.3.2 Prevented Activities Based on WHPZ

There are restrictions on the activities in each zone of the wellhead protection area, **Figure (1.2)** and **Figure (1.3)** shows the prevented activities in Zone 1 and Zone 2 respectively.

In Zone 1, it is prevented, for any person to exceed the fence that bounded the area around the well, also it is prevented to graze animals and dispose of any wastes (Subah and Margane, 2010).

Figure (1.2): Prevented activities in Zone 1 (Subah & Margane, 2010).

In Zone 2, it is prevented, to use pesticides and fertilizer, also to dispose or spill any derivatives of petrol and oils and to dispose of any wastes. In addition, the septic tank in the boundary of Zone 2 must be disposed frequently to prevent the leakage of the wastewater from it (El- Fahem, 2012).

Figure (1.3): Prevented activities in Zone 2 (El- Fahem, 2012).

1.2.4 WHPA in Palestine

According to Palestinian water law, 2014 the water zone defined as "a specified area surrounding a water resource or a water facility aimed at their protection from any external activity or impact or any kind of pollution". The Palestinian water law (Article 52) said that if the quality or quantity of water under risk of contamination or depletion, the Palestinian water authority (PWA) coordinate with other relevant parties can consider the area that contain water resource as a protected zone in accordance with a regulation issued by the Cabinet of Ministers in this regard. So, PWA in cooperation and coordination with relevant authorities is the responsible parties on water resources protection through the delineation of protection zones to prevent pollution (Palestinian water law, 2014).

The principle of WHPA delineation depends on restrictions placed on the use of land through which are able to control the areas of wellheads, working toward the goal of controlling contamination of water which may lead to place restrictions heavily on projects which produce dangerous materials in those areas and this ensures no contamination of the area surrounding the project. The identification of areas of the wellheads reduces the use of cesspits in areas that are not serviced by a public sewage network which reduces the contamination of the well in areas densely populated (PWA, 2005).

The PWA defines (within the scope of regulations for pollution protection control for groundwater) the following three zones) (PWA, 2005):

- Zone I (Inner source protection) constitutes the accident prevention zone, is located immediately adjacent to the groundwater source. It is designed to protect against the human activity which might have an immediate effect upon the source.

- Zone II (Outer Source Protection) is the attenuation zone; it is larger than Zone I. This zone is established to protect a well from contact with pathogenic microorganisms (e.g. bacteria and viruses), which can emanate from a source (e.g. septic system, latrines, sewers, animals etc.) located or held (animals) close to the well, as well as to provide emergency response time to begin active cleanup and/or implementation of contingency plans.

- Zone III (Source catchment) is defined as the remedial zone that covers the complete catchment area of groundwater source. All groundwater within it will eventually discharge to the source. It is defined, as an area needed to support an abstraction from long-term annual groundwater recharge (effective rainfall).

1.3 Literature Review

There are many countries come a long way in protecting water sources and the development of protection plans to protect water sources and implement many of the studies and the implementation of several projects for the protection of water sources, but developing countries, and Palestine one of them still week in this field because they suffer from lack of financial capabilities, scientific and technical expertise in this area and the absence of binding legislation by the decision maker to implement these measures. In this part of thesis, there were different studies that related to the subject of the thesis are summarized as following:

Teutsch & Hofmann, 1990: The aim of this study was to delineate of the protection zone II using large scale hydraulic test, then compare it with the measurements which obtained from a forced gradient tracer test that cover zone II. The results was show that transport predictions result from the hydraulic data far from reality; the migration of point-source pollution look unpredictable at local scale (zone II). The model calculations based on parameters obtained from standard pumping test interpretation and sieve analysis produce very similar results. The high prediction error for the injection-point shows the magnitude of uncertainty possibly involved in the delineation of wellhead protection areas. So, this study concluded that the zone II area estimates differ by more than 100%, depending on the type of data used. Therefore, for the calculation of protection zone areas a conservative approach with a large safety margin is recommended.

Matthess, 1990: The aim of this study was to evaluate the German system of drinking water protection areas, and compare it with other protection systems for other countries. The results was show that the well head protection zone area procedure mustn’t be applied on small or limited areas because that shows only general assessments to minimize the errors of a prognostic treatment of the behavior of chemicals in the environment. It should compare the behavior of known substances with different environmental conditions. For this purpose, the available simple techniques can be used for important parameters under natural conditions. Then, the obtained data can be used for an extended model to produce better assessments.

Foster & Skinner, 1995: The aim of this study was to review the underlying principles and describes the approach which is being adopted in Britain for groundwater protection. The results show that the protection of groundwater depends on use both of vulnerability map and source protection areas. The delineation of protection zones used to restrict different types of polluting activity; this occurred by increase awareness of risk, through make risk management and risk minimization programmes; make plans for land-use management; help regulatory agencies and water users prioritize their deployment of human and financial resources; promote public understanding of the problem of groundwater protection.

Bates & Evans, 1996: The aim of this study was to evaluates several different delineation methods that are used for Wellhead Protection programs, as determined by the Safe Drinking Water Act Amendments of 1986 in Ohio- USA , these method are 3 groundwater flow models: an analytical (GPTRAC), semi-analytical (CAPZONE) and finite difference (MODFLOW) model .The result was show that the choosing of the appropriate model to be used in Wellhead protection area from the previous models depend mainly on three critical variables which are: aquifer transmissivity, porosity, and anisotropy

Carmon et al, 1997: The aim of this study was to evaluate the effects of urban development on the quantity and quality of rainwater which infiltrates into the soil on its way to recharge the aquifer. The results was show that it is feasible to reduce the negative effects of urban development on the quantity and quality of groundwater in aquifers underlying the area, And agriculture has an adverse effect on groundwater, and conversion from agriculture to urban, a common occurrence in Israel's coastal plain provide an opportunity to improve matters for groundwater: increase recharge and reduce pollution and water-sensitive urban planning has the potential to be viable technically, economically and socially, and contribute to sustainable development.

Moinante & Ferreira, 2005: The aim of this study was to define the WHPA around - wells located in Montemor-o-Novo region by use different methods. Calculated Fixed Radius method, Wyssling method and Krijgsman and Lobo-Ferreira Method and mathematical model ASMWIN was also applied. The result was showe that analytical methods are user friendly and easy to be applied, and some of them, like Krijgsman and Lobo-Ferreira method, can give solid solutions and also more precision in the delineation of WHPA and Numerical models can also give solutions in the case of complex hydrogeologic systems but their use implies the availability of large amount of complex information and also more expertise, which makes their application more expensive.

Hammouri & El- Naqa, 2008: The aim of this study was to presents groundwater vulnerability mapping for Jerash area, north Jordan generated using EPIK and DRAS-TIC models. These models have been implemented by using GIS to delineate groundwater protection zones and to suggest a protection plan to improve groundwater quality of the major springs and wells. The result was showing the vulnerability maps allow an initial assessment of the risk of groundwater contamination in the area. The comparison of vulnerability maps obtained from both models indicates that there is a high degree of agreement of the areas with high vulnerability in DRASTIC and EPIK models in some areas. The obtained vulnerability maps were compared with microbiological contamination (fecal coliform bacteria) and with nitrate levels. There is a good correlation between the areas with high microbiological and chemical pollution evidences and the areas which have shown high vulnerability from both EPIK and DRASTIC methods.

Lee et al, 2008: The aim of this study was to give the background to the Groundwater Protection Scheme datasets and outline some of the uses to date in Irish. The result was show that the ongoing vulnerability mapping will continue to improve the national groundwater vulnerability and groundwater protection scheme datasets. Apart from groundwater protection, the underpinning layers, in particular the subsoil permeability map, have been proven to be necessary components for other derived maps, such as the recharge maps. All of these maps are essential to make appropriate decisions in a spatial planning context, which is becoming increasing important with the continuation of the Water Framework Directive process, and to model the impacts of changing environmental parameters on future resources.

Ahmed & Ali, 2009: The aim of this study was to address the integrated role of geochemical processes, agriculture and urbanization in evolution of groundwater composition, and their impact on groundwater quality to help in management and protection of groundwater resources in Sohag area which is part of the Nile Valley, Egypt using geochemical modeling techniques and geographical information systems. The results shows that groundwater properties are varied spatially and its evolution in the study area is generally controlled by the prevailed geochemical processes represented by leaching, dissolution, and precipitation of salts and minerals, ion exchange, in addition to human activities represented by agriculture and urbanization as well as climatic and poor drainage conditions. Management alternatives should be followed in the study area to avoid degradation of groundwater quality and provide sustainable development.

Al-Swiety, 2009: The aim of this study was to investigate the hydrogeological and hydrochemical characteristics of the dug wells along Wadi Abu Al-Qmrah in Dura city. The results showed that dug wells in the study area found to be discharging from Hebron formation com from Upper Cenomanian-Turonian Aquifer which mainly composed of limestone and dolomite. Evaporation rate varies from 4mm/d in January to 6.22 mm/d in July and 186.6 mm/month in the summer and 121 mm/month in the winter. The average of rainfall is 500mm, the average of surface runoff is 58.8 mm (11.75% of the precipitation) and recharge is 151 mm (30.3% of the precipitation), the annual volume of the precipitation in the study area is 1.125 MCM. The average concentration of EC is 1373 μS/cm, and TDS is 1058 mg/l which is 57.1 % from the wells > 100 mg/l; where the study concluded the increasing for TDS comes from agricultural activities and mixing with sewage in aquifer. According to pseudo cross section shows that the lithology of the wadi consists of several layers in different depth with different thickness, the aquifer thickness towards the east in the wadi. This explains why discharge of wells in the east is few.

Ikhlil, 2009: The aim of this study was to provide a database of springs and dug wells in Dura city, to identify the concentration of anions and cations, to determine the cause of the pollution that leads to increased concentration of these ions, and determine the adequate of water for domestic and agriculture use, and determine the geological region as well as the location of springs and dug wells. The study showed that only five wells were considered suitable for drinking purposes according to WHO from the forty eight springs and dug wells that tested in this study, the rest forty three springs and dug wells were unsuitable for drinking purposes, all the springs and dug wells were suitable for irrigation purposes. The results show that most of samples were contaminated with fecal and total coliform. Some of the polluted springs and dug wells which located in near houses where direct contamination from seepage takes place.

Tarazi, 2009: The aim of this study was preserving and protecting the groundwater from any pollutants caused by industrial installations through the work of delineation of Wellhead Protection Areas (WHPA) for municipal supply wells in Gaza Governorate boundaries. The results showed that all the industrial installations located in the WHPA should be carefully checked and investigated by Environment Quality Authority (EQA). Mitigation measures for pollutants caused by these industrial installations should be identified. In addition, EQA must give licenses for the establishment of any new industrial installations based on the delineation of WHPAs using the previously mentioned methods. The study compared between three different methods used to delineated WHPA: Calculated Fixed-Radius Method (CFR), Analytical Method (AM), and Wellhead Analytic Element Model (WhAEM2000), the study showed WhAEM2000 method is the best method because it uses a hydrogeological computer model of groundwater flow and it provides a more accurate delineation of the WHPA. It often produces a smaller area to manage than other methods. And CFR method is the weakest method because it does not take into account regional groundwater flow, causing a hydraulic gradient.

1.4 Objectives

The main objective of this study is to delineate Wellhead Protection Area (WHPA) for Al Fawwar wells 1 and 2.

Sub objectives are:

1. Calculate the water budget of Al Fawwar wells catchment.

2. Map and determine of all types of potential sources of pollutants that affect the groundwater in the catchment.

3. Check the status of water sources in the study area, the relevant legislations and roles to assist public authorities to meet their statutory responsibilities for the protection and conservation of groundwater resources; such as Palestinian Water Authority, Palestinian Ministry of Health and Palestinian Ministry of Agriculture and Dura Municipality.

1.5 Hypothesis

The lack of a local Palestinian law implementation for groundwater sources protection increase the contamination of groundwater sources.

1.6 Importance of the Study (Problem Statement)

Severe water shortages and acute water quality problems continue to negatively affect the lives and livelihoods of Palestinians (PWA, 2012). The present water supplies are neither adequate to provide acceptable standards of living for the Palestinian people, nor sufficient to facilitate economic development. This is a result of the limitation on supply and restrictions on development of new water resources and supply infrastructure (PWA, water demand management). A comprehensive and effective legislative framework is essential for the smooth operation of the water sector and for it to meet its goal of providing an adequate water supply (Tarazi, 2009). Groundwater protection measures have to be incorporated in integrated water management activities as an important feature for sustainable development. Many countries have developed and implemented policies for preventing the pollution of groundwater, these commonly involve regulatory control of activities which generate or use polluting materials, or control of the entry of potential pollutants into underground waters. However, protection zones are not applied in all countries (mainly the developing countries including Palestine) despite recognition of their desirability, this may be due to a number of factors, including the lack of sufficient detailed information regarding the hydro-geological or existing land uses that impede enforcement of such a concept (Schmoll et al., 2006).

This thesis studies the delineation of wellhead protection areas for Al- Fawwar wells 1 & 2 in Hebron Governorate (as a case study) because there is few studies in the West Bank that covers the protection of public drinking water wells from potential sources of pollutions by considering the groundwater protection regulation developed by Palestinian Water Authority (PWA). This study focuses on WHPA which is an important part of PWA regulations (environmental regulations) and it will help PWA and EQA to grant license for environmental sound land use.

Al Fawwar wells are a major source of water, they were until a few years ago the source to provide the communities surrounding them with fresh water, the increase in population led to increased water demand and also there is ability to increase the pollution levels; because there are many sources of pollution in the region of catchment area as wastewater, gas station, olive mills, agriculture (fertilizers, pesticides), random drilling. **Figure (1.4)** shows violations in the zero boundaries of Al- Fawwar wells, like grazing of cattle's and the dead donkey which cause pollution of groundwater. These violations are prevented to be in the boundary of the water well (Zone 1) according to Jordanian and Palestinian laws.

Figure (1.4): Violations in Al- Fawwar wells zero boundary, A: grazing cattle's, B: death donkey

1.7 Study Area

1.7.1 Location

This study applied on Al Fawwar wells. Al Fawwar wells 1 & 2 are located in Al Fawwar refugee camp; is located within the Dura village boundary at an elevation of 760 m above sea level. It is about 8 km south of Hebron city in the southern part of the West Bank. It is bounded by Al Rihiya village to the east, Hebron city to the north, Dura city and Hadab al Fawwar village to the west and Yatta city to the south, see Figure (1.5) (ARIJ, 2009).

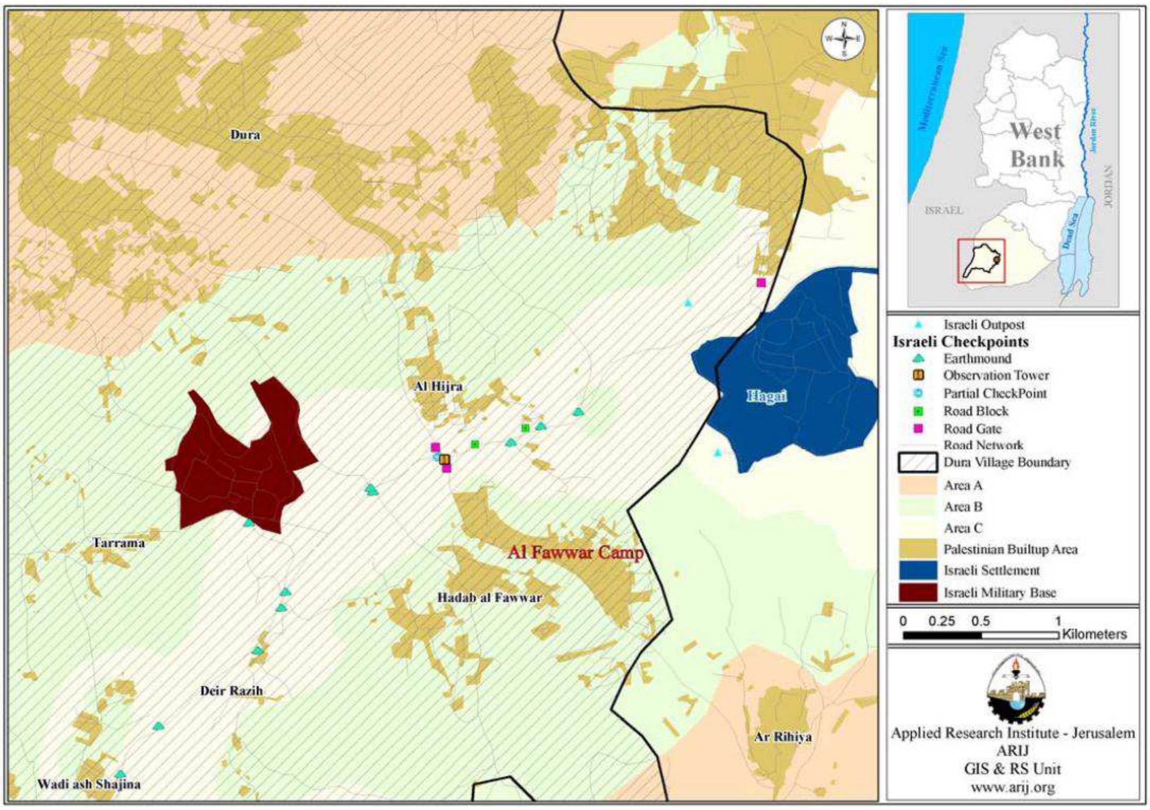


Figure (1.5): Study area, Al Fawwar refugee camp (Arij, 2009).

The study area include the catchment area that feed Al- Fawwar wells which extended from Dura at west to Al Fawwar refugee camp at east, Hebron city at north and Khursa & Tarama villages in south, with an area of approximately (16.25 Km^2), see **Figure (1.6)**.

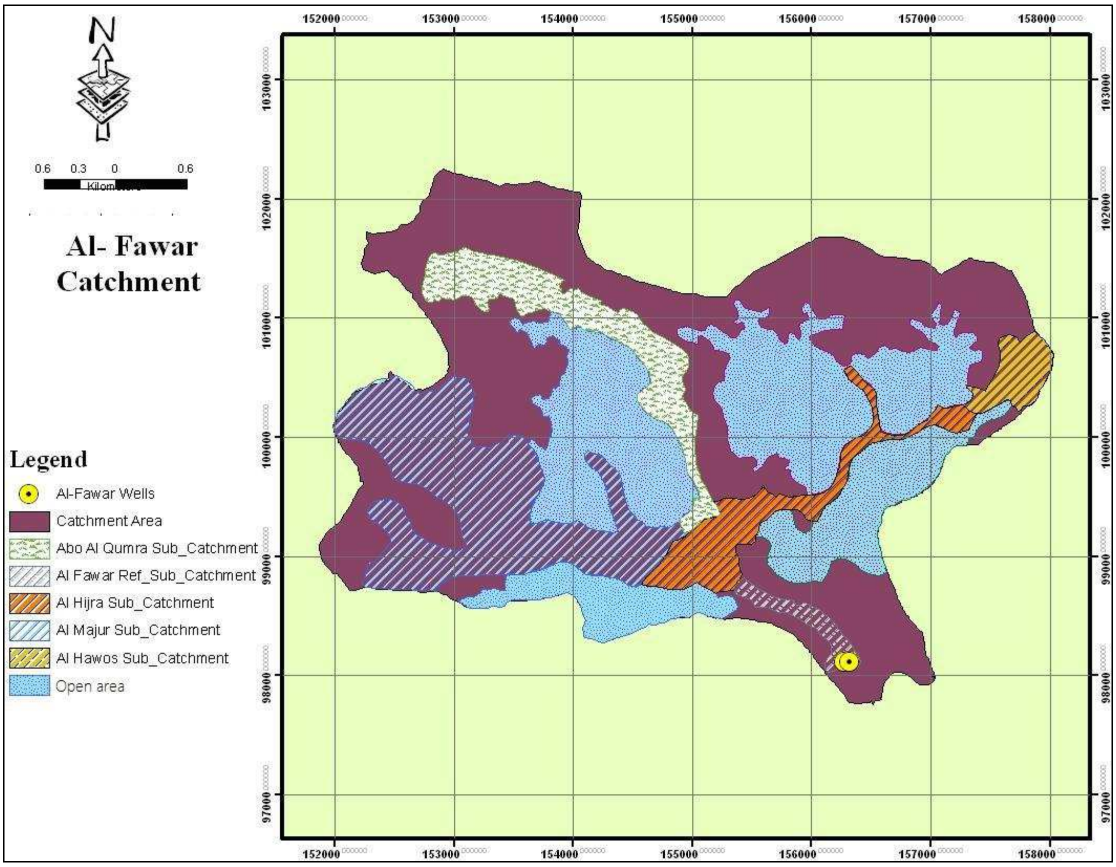


Figure (1.6): Study area- Al- Fawwar wells catchment area.

1.7.2 Population and Land Use

The number of population in the camp is about 8,223 (PCBS, 2013) with about 1,092 housing units. The population density in the camp is very high; in 1997 it was 5,567 km^2 (ARIJ, 2009). The total area of Al Fawwar Refugee Camp is approximately 870 dunums, around 500 dunums is built up area and about 300 dunums that are considered to be arable, though only 139 dunums are actual agricultural land (ARIJ, 2009).

The number of population in the catchment area is about 37,000 inhabitants and includes about 7400 housing units (PCBS, 2013). The area of agricultural land in the study area about 4500 dunums area, and 6556 dunums urban area from 16206 dunums total catchment area (ARIJ, 2009).

1.7.3 Climate and Rainfall

The climate in the study area is ranged from arid to semi arid climate, characterized by long, hot, dry summer and short, cool, rainy water (Awadallah & Owaiwi, 2005). The average annual rainfall in the study area is 489 mm according to Dura meteorological station, see Figure 1.7 that represents the average annual rainfall in the study area during the period from (2000- 2014). The average annual temperature is about 16 °C and the average annual humidity is 60.6% (Palestinian meteorological department, 2014).

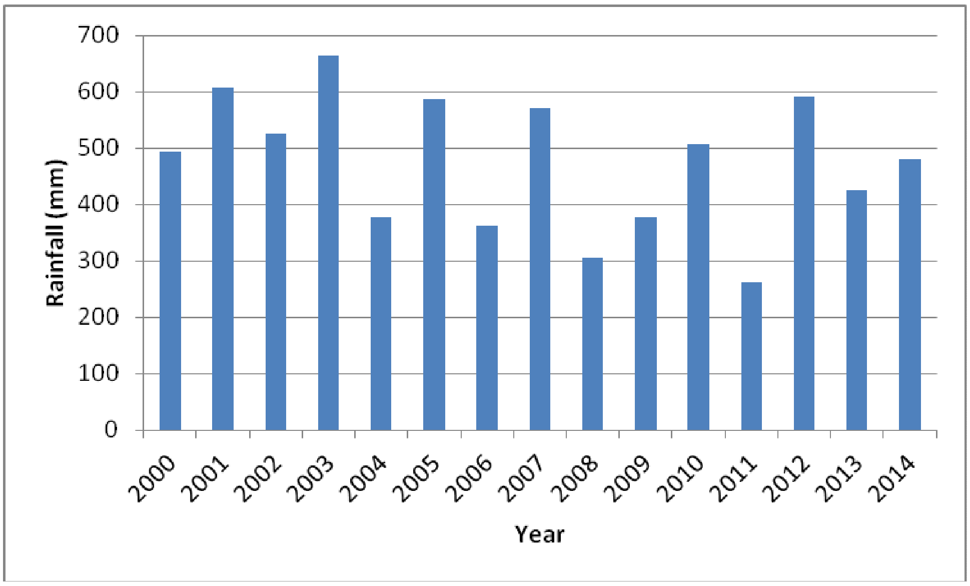


Figure (1.7): Rainfall quantity in the study area from 2000- 2014 (Palestinian metrological department, 2014).

1.7.4 Geology

Hebron is located on the crest of anticline structure extending from Berr Shava' area in the south to Jerusalem area in the north forming the Hebron mountain series. The geology of the Hebron district is composed of sedimentary carbonate rocks of Albian to Eocen age in general (Arij, 1995). In the study area there are three geological formations, Bethlehem formation, Hebron formation (Upper Cenomanian) and Yatta formation (Lower Cenomanian) (Sneh & Roth, 2012) see **Figure (1.8)** that represents the geological structure of the study area and the available water resources in it.

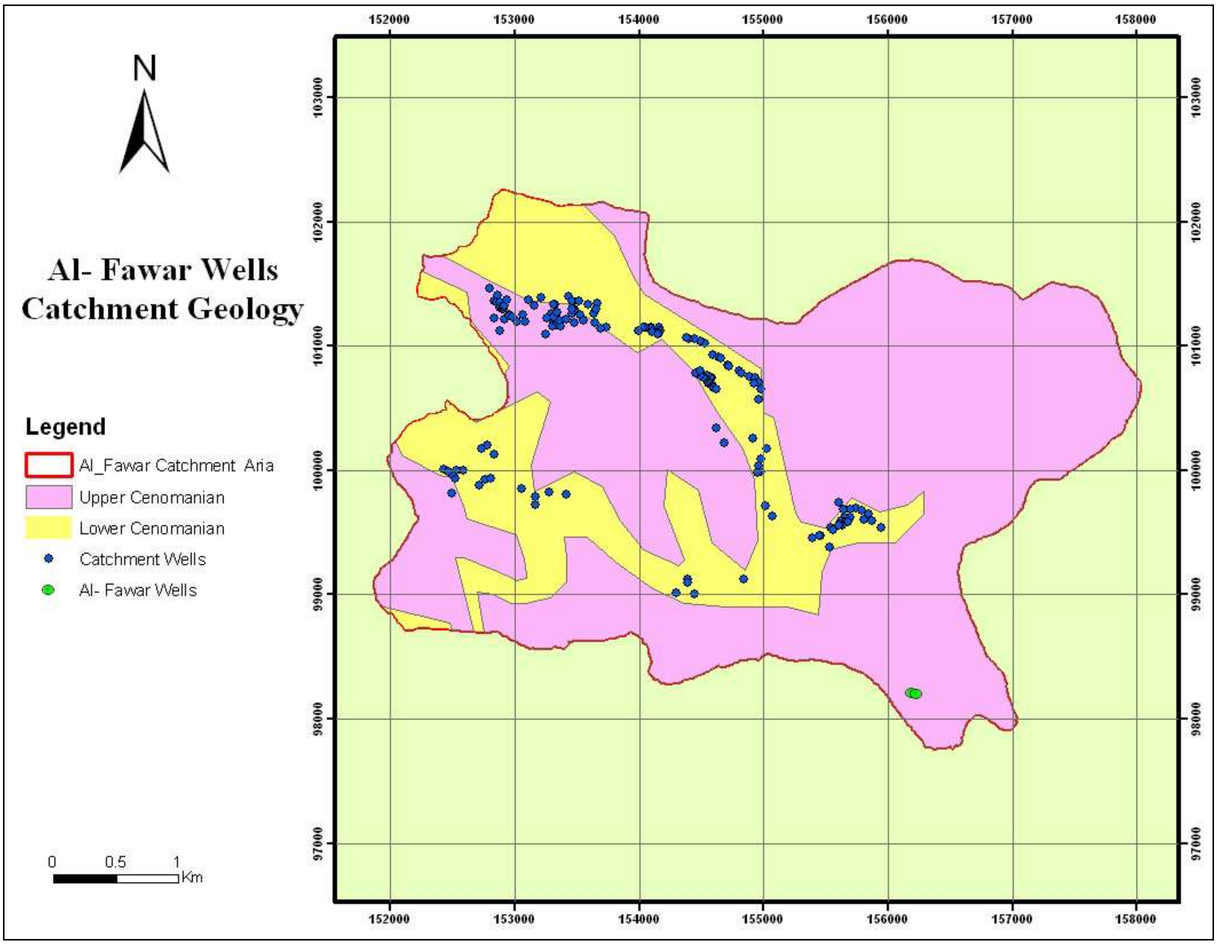


Figure (1.8): Geological structure of the study area.

The stratigraphy of the study area ranges between Lower Cenomanian and Upper Cenomanian. Yata and Hebron Formations which extend by the age from Lower Cenomanian to the end of Recent age Upper Cenomanian and Bethlehem Formation Upper Cenomanian. The characteristics of these geological formations in the area are as follows:

1. Yatta Formation (Lower Cenomanian)

Yatta Formation is divided into two parts, the lower part of Yatta (YL), Beit Meir formations in Israeli literature, and the upper part of Yatta (YU), Moza formations in Israeli literature. It overlies the Upper Beit Kahil formation and under Hebron formation. The lower part of Yatta is yellowish and brown, contains fine to medium crystalline dolomite and limestone, with marly intercalation, marly at bottom. Its thickness ranges from (40- 150 m), and the upper part of Yatta (YU) stands out due to its high content of marl or clay and marly limestone, usually highly enriched with fossilised fauna see **Figure (1.9)**. Its thickness lies between (10- 60 m) (SUSMAQ, 2001).

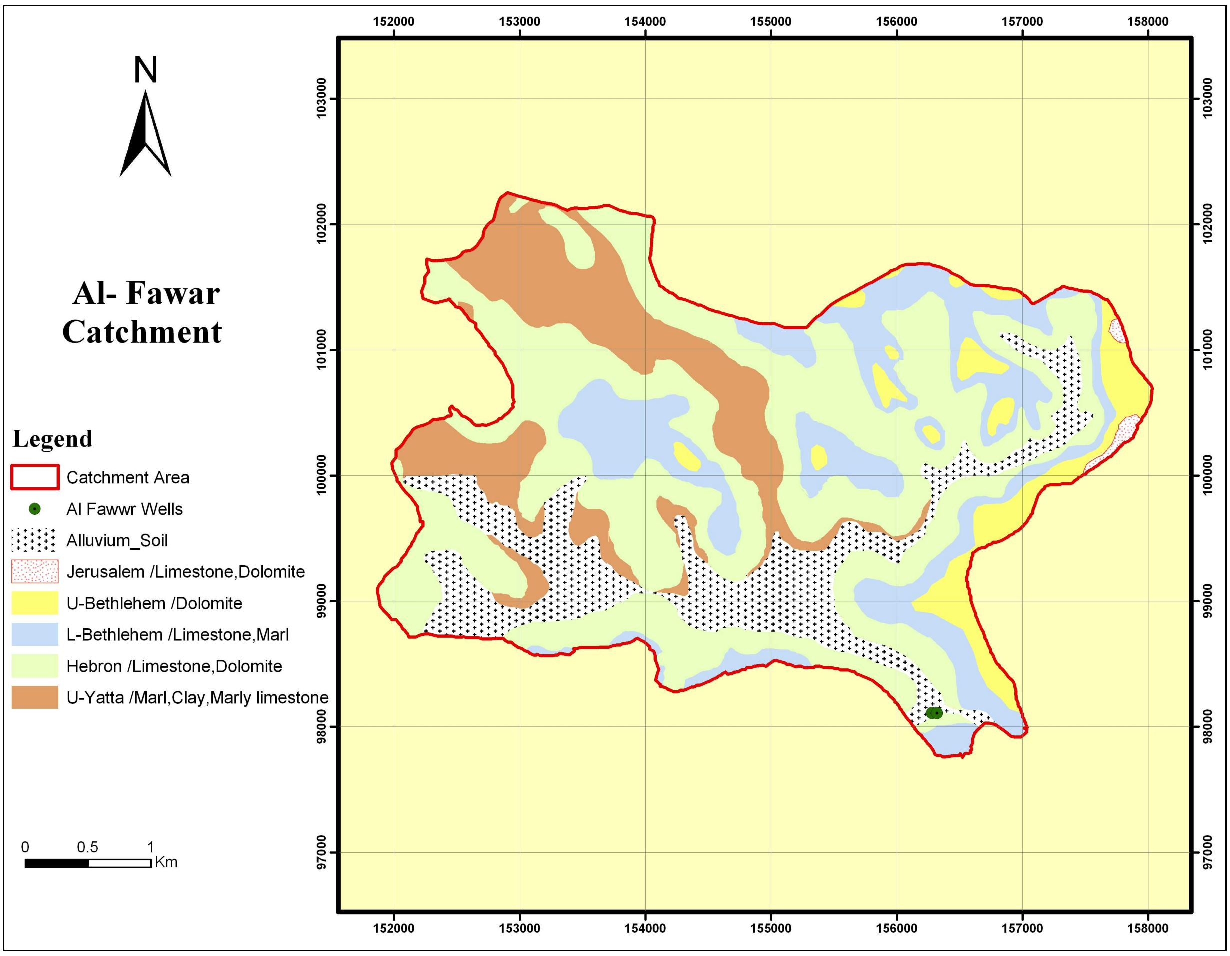


Figure (1.9): Geological formations of Al- Fawwar catchment study area.

2. Hebron Formation (Upper Cenomanian)

Hebron Formation (Aminadav in Israeli literature) is large distribution in mountains of Hebron and Jerusalem. It consists of hard and massive dolomite or limestone and it follow the upper cenomanian from upper cretaceous (**Figure 1.9)**. It is highly karstic and it's a good aquifer because of the high secondary porosity that resulted from the faults and the existence of dolomite and because of the high relatively thickness, homogeneity of limestone and dolomite composition. So, it is the most important aquifer within the West Bank, it is considered as an excellent aquifer. The thickness of this formation ranges between (105- 260 m) (SUSMAQ, 2001, Qanam, 2003).

3. Bethlehem Formation (Upper Cenomanian)

The lower part of Bethlehem consists of limestone and dolomite, chalky limestone, with marl and rich in faunal remains. The thickness is (20-50 m). The upper part of Bethlehem is built up of dolomite, massive, coarse crystalline and limestone lenses well bedded. The thickness is (25-100 m). The Israeli divide Bethlehem into two units, the lower unit is referred to as Kefar Sha'ul or as Avon on the east and in the Naqab and the upper part is called Weradim formation (SUSMAQ, 2001).

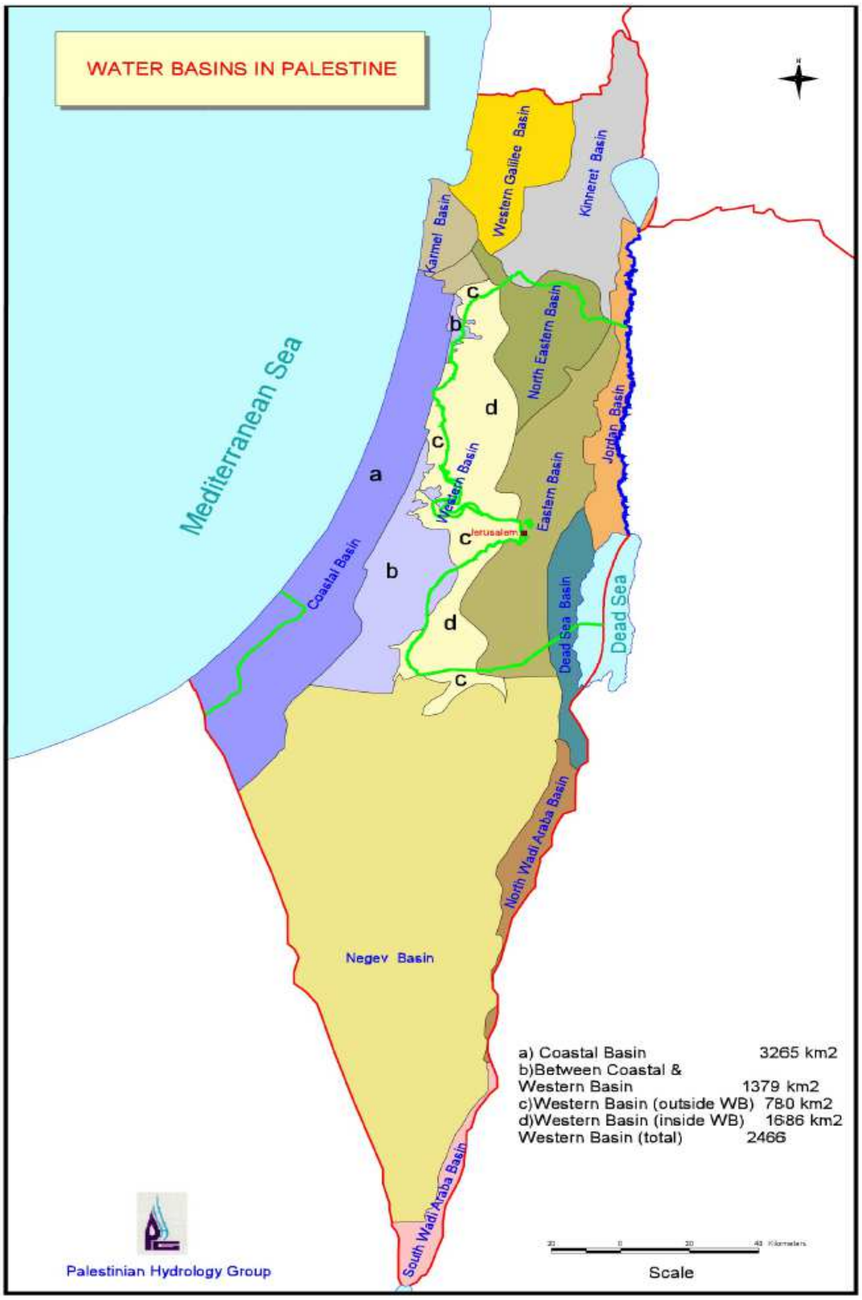
The Hebron, Bethlehem, and Jerusalem Formations are usually considered from a hydrogeological point of view, as a single system of aquifers bounded below by the Yatta Aquitard and the Cenomanian-Turonian Aquifer. This aquifer represents the upper aquifer of the Western Aquifer Basin under study. The Upper Aquifer is more important than the lower one since 95% of groundwater extraction and spring flow discharge from the western basin passes through this aquifer (Sabbah, 2005).

1.7.5 Hydrogeology

The primary source of water in Palestine comes from groundwater aquifers, geological formations below the ground that contain water which can then be extracted from wells and springs. The two main aquifers in historical Palestine are the Mountain and Coastal Aquifers. The Mountain Aquifer system composed of three major aquifer basins, classified according to flow direction into: the Western, Eastern and Northeastern aquifer basins. The three aquifer basins usage and extraction rates are presented in **Table (1.3)**. The approximate boundaries between the three basins are presented in **Figure (1.10)** (PWA, 2012, Kouttab, 2013). Al- Fawwar wells and the catchment area of the study are located within the Western basin.

Table (1.3): Aquifer basins usage and extraction rates (mcm/ yr) (WaSH MP, 2004).

Aquifer Basin	Palestinian Extraction	Israeli Extraction	Additional Settler Use	Total Extraction	Safe Yield
Western	20	340	10	372	362
Northeastern	42	103	5	145	150
Eastern	54	40	50	144	172



(Figure 1.10): Ground water basins and exposed aquifers in the West Bank / Palestine (WaSH MP, 2004).

The Western Aquifer basin is considered the most important aquifer in the West Bank and the largest of all groundwater basins in Historical Palestine (SUSMAQ, 2001, Kouttab, 2013). It covers an area of 9155 km^2, where the area located within the borders of the West Bank forms the main recharge area for this basin, estimated at about 1,596 km^2, this area provides the aquifer for more than 73% of the basin's water (SUSMAQ, 2001). The recharge area of the unconfined part of the Western aquifer inside the West Bank is 1686 km^2 (68% of the total unconfined aquifer area). The area outside the Green Line (mainly discharge or abstraction area except in the Jerusalem area) is 780 km^2 (32% of the unconfined aquifer area (WaSH MP, 2004).

The Western Aquifer falls in the middle-to-late-Cretaceous Judea Group, it is divided into two main sub-aquifers (upper and lower) separated by a lower permeability layer Yatta formation, The upper and lower sub-aquifer rocks are mainly composed of a sequence of hard, karstic and permeable limestone and dolomite with a thickness of (600- 1000 m) (Abusaada, 2011). Western Aquifer is the most fruitful, flowing toward the Mediterranean with a replenishment capacity of approximately 362 MCM/ yr, followed by the Eastern Aquifer, with a capacity of 170 MCM/ yr (though nearly 50% of this is brackish) and finally, the Northeastern Aquifer at 145 MCM/ yr, total annual recharge of about 679 MCM from the three aquifers (WaSH MP, 2004).

1.7.6 Soil

Hebron distributed to different climates in terms of temperature and the amount of rain where there is a Mediterranean climate in the north and west of Hebron, and the dry climate in the south and east; where the study area constitute the center of this region. There is a variable geological formation and sedimentary rocks, and difference topography: mountains, plains and flat valleys, in addition to variation in land use and population distribution. These factors combined have created the presence of many types of soil in Hebron in general and in study area in particular (Awadallah and Owaiwi, 2005, LRC, 2006).

Al- Fawwar catchment area includes two main soil associations: Terra Rossa and Rendzina (see **Figure 1.11**). Terra Rossa soil the parent materials from which this soil is originally initiated are mainly dolomite and hard limestone with numerous rock outcrops that could reach to about 30% to 50% of the soil content. The characteristic red to orange color of the soil is the result of iron-bearing minerals oxidizing or rusting within carbonate structures. This type of soil is characteristic of the hilltop areas and high & medium gradient areas of some mountain slopes and constitute model for central Soil Mountains in the center of the West Bank. These soil usually located in areas where a Mediterranean climate and rainfall rate ranges from (400- 700 mm) and average temperatures between (15- 20 °C). Soil depths ranging from (0.5- 5 m) are found in the study area. This soil type has a pH range of (7.5 – 8.1) (LRC, 2006).

Rendzina soil Like terra rosa soil often brown soil found in shallow areas limestone or calcareous rocks, parent materials are mostly marl and hard or soft chalk coated solid Igneous crust. Rendzina has two distinct layers: a top layer, also known as brown rendzina, and a bottom layer, known as pale rendzina. The top layer of rendzina, though rich in carbonate, is relatively fertile and ranges from neutral to slightly alkaline. This soil usually located in areas where a Mediterranean climate and rainfall ranges from (300- 600 mm) and average temperatures between (18 -20 °C). Soil depths ranging from (0.5- 5 m) or (6 m) are found in the study area. This soil type has a pH range of (7.5- 8.0) (Awadallah and Owaiwi, 2005, LRC, 2006).

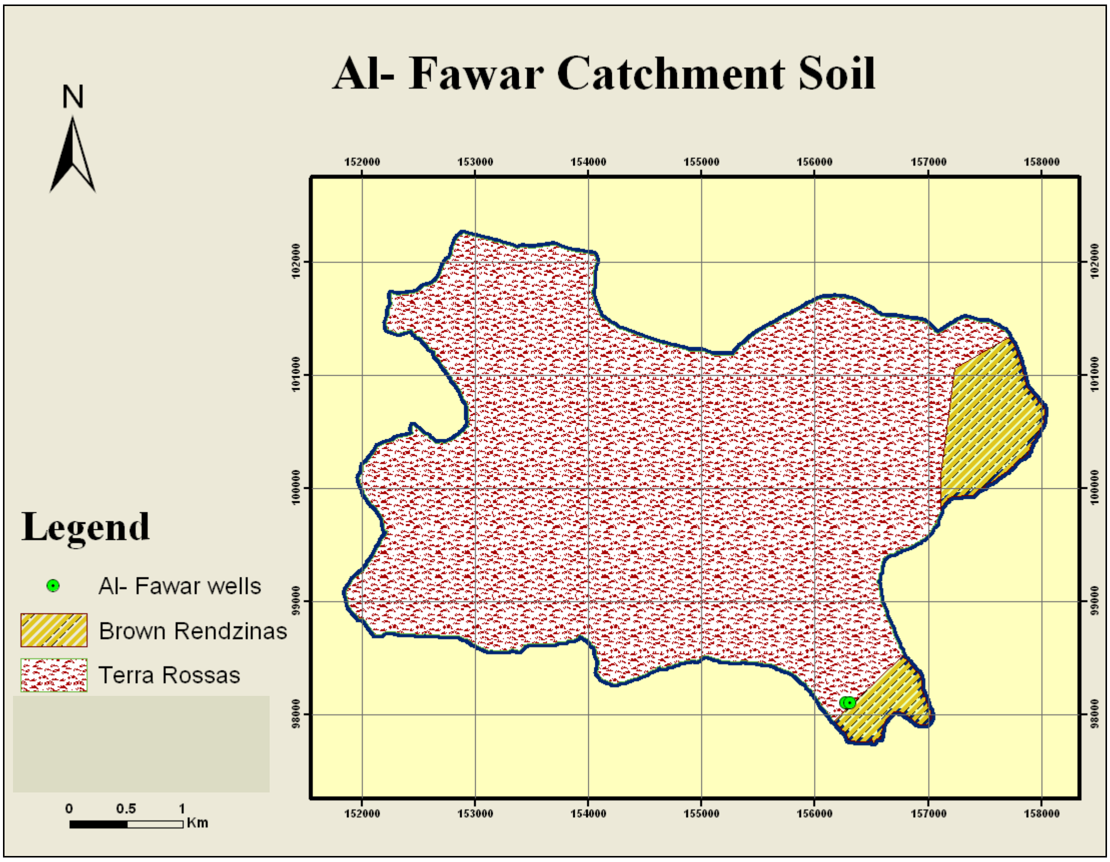


Figure (1.11): Soil types in the study area.

2 Chapter Two: Water Sector Legislations Framework in Palestine

2.1 Background

Palestine has one of the scarcest water availability (per capita supply) in the world. The scarcity of water is due to both natural and man-made constraints; mainly resulting from the Israeli occupation (ARIJ, 2011). Moreover, the shortage of good quality potable water mainly in villages that still haven't piped water system and the existing facilities suffer for most of them from leakages and interruptions in supply deteriorating the water quality (PWA, 2006). Over time water shortage in Palestine will increase and becomes a greater problem as a result of population growth, higher standards of living, expected climate change, and above all, Israeli practices and restrictions imposed on both the water resources and its sector's development (ARIJ, 2011).

Water sector aim is to provide adequate supply of water to all the population. The water sector in Palestine is currently going through a crucial period; the existing situation is set in the context of unbalanced opportunities (PWA, 2012). It also suffers from fragmented institutional and legal framework, which hinders developing the sector and managing and maintaining water resources and infrastructures (ARIJ, 2011). So, there is an essential need to reform and address legislation framework (**Figure 2.1**) to improve the water sector role and management of water resources in Palestine (Tarazi, 2009).

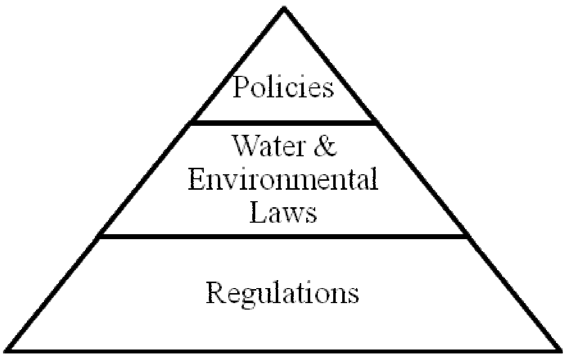


Figure (2.1): Legislative framework (Mogheir & Tarazi, 2010).

Legislation is “a tool to incorporate water policy within the national political-legal framework and should aim to protect both individual and communal water right issues”. Legislation of water sector must cover many aspects rather than water quality, it also cover the sufficient quantity of supplied water, the price of water and the access assurance (Tarazi, 2009).

2.2 Legislation Framework Elements

The main elements of legislation frame work are the following:

1. Water policies
2. Institutional roles
3. Water and Environmental laws
4. Regulatory framework

2.2.1 Palestinian Water Policies

The Palestinian develops water policy through a group of principles that organize the decisions and structure of water sector. The main water policy elements in Palestine are (Nofal & Dudeen, 2007, Palestinian water law, 2014):

- All Water Resources in Palestine shall be considered public property, and PWA manages these resources to ensure the efficiency in distribution.
- Every person has the right to obtain his needs of drinking water with suitable quality at specific prices determined according to the Tariff Regulation.
- Water used for different purposes that include domestic, agriculture and irrigation, industrial, tourism, trade and commerce.
- The quantity of water specified for different sectors and region determined by PWA and other relevant parties according to the annual water budget but the provided water for domestic uses have the absolute priority over all other uses in determining the allocation of available water resources.
- Water indeed is an economic commodity; therefore, the damage resulting from the destruction of its usefulness (pollution) should be paid by the party causing the damage (pollution).

- The development of the water resources of the Palestinian territory must be coordinated on the national level and carried out on the appropriate local level.
- Water supply must be based on a sustainable development for all available water resources.
- Public participation in water sector management should be ensured.
- Water management at all levels should integrate water quality and quantity.
- Water supply and wastewater management should be integrated at all administrative levels.
- Consistent water demand management must complement the optimal development of water supply.
- Protection and pollution control of water resources should be ensured.
- Conservation and optimum use of water resources should be promoted and enhanced.
- The Palestinian will pursue their interests in connection with obtaining the rights of water resources shared by other countries.

2.2.2 Institutional Roles

The roles and responsibilities of the different institutions must be clearly determined within the legislation framework to avoid difficulties in enforcement or overlapping of responsibilities within the water sector actors. Palestine is still suffering from the overlaps in roles and responsibilities and mainly with presence of Israel occupation that scatter the roles and responsibilities (Klawitter & Barghouti, 2006, Tarazi, 2009).

2.2.2.1 Palestinian Water Sector Parties

The water sector in Palestine is regulated by the Water Sector Regulatory Council (WSRC), the Palestinian Water Authority (PWA) in cooperation and coordination with group of relative ministries, local and international NGOS (PWA, 2006, Tarazi, 2009).

2.2.2.2 The Water Sector Regulatory Council (WSRC)

The Water Sector Regulatory Council established by a decision of the Cabinet of Ministers. The Council enjoys a legal personality and is financially and administratively independent. The objective of the Council is to monitor all matters related to the operation of water service providers including production, transportation, distribution, consumption and wastewater management, with the aim of ensuring water and waste water service quality and efficiency to consumers in Palestine at affordable price. The responsibilities of NWC are (Palestinian water law, 2014):

- "Approval of water prices, costs of supply networks and other services required for the delivery of water and waste water services, as well as review and monitoring of these costs to ensure compliance with the policy adopted by the Authority.
- The issuance of licenses to Regional Water Utilities and any operator that establishes or manages the operation of a facility for the supply, desalination, or treatment of water or the collection and treatment of waste water, and the levying of license fees, in accordance with the provisions of this law and a regulation issued by the Cabinet of Ministers.
- The Monitoring and inspection of compliance with the terms, requirements and indicators stipulated in licenses and permits.
- The development of performance incentives programs for Service Providers, in accordance with a regulation issued by the Cabinet of Ministers for this purpose.
- The approval of internal bylaws, the financial and administrative regulations and organizational structure of the Council and their submission to the Cabinet of Ministers duly issuance".

2.2.2.3 PWA

The Palestinian Water Authority (PWA) was established in 1995. It is responsible for water resources management, development and infrastructure planning in Palestine and it is considered as the main regulatory and policy making body for the water resources (PWA, 2006, Tarazi, 2009).

PWA is a public institution and enjoys a Legal personality; its budget is part of the general budget of the State of Palestine. PWA responsibilities include (Palestinian water law, 2014):

- Manage water resources in Palestine and apply principles of integrated and sustainable management of it
- Prepare general water policies, strategies and plans then ensure their implementation in coordination with other relatives.
- Survey the available water resources and ensure effective allocations of water for different sectors according to the priorities that ensure sustainable management of water demand.
- Protection of water resources through the establishment of protection zones to prevent pollution, in coordination with relevant authorities.
- License and development of water resources utilization, in cooperation and coordination with the relevant authorities.
- Improve the management of water sector by development of plans and training of the staff that work in the water sector.
- Coordinate and supervise scientific researches related to water and wastewater to find creative and innovative solutions to existing problems in Palestine.

2.2.2.4 Ministries

There are several ministries which work in the water sector with the PWA. These ministries are presents in Table (1.1).

Table (2.1): Coordination between PWA and Palestinian ministries in water sector

#	Ministry name	Roles in water sector
1	Ministry of Planning & International Cooperation	General planning, International (Donor) coordination
2	Ministry of Justice	Water law Water regulation
3	Ministry of Finance	Water pricing and tariff setting Full cost recovery
4	Ministry of Industry	Sector planning Hearing licensee
5	Ministry of Health	Water quality standards
6	Ministry of Local Government	Organization of operator level Hearing licenses
7	Ministry of Agriculture	Sector planning Hearing licenses
8	Environment Quality Authority	Environmental action planning Risk assessments and monitoring Hearing licenses

2.2.2.5 Non Governmental Organizations (NGOS)

The main role of NGOS is providing financial and technological support to water sector projects. These NGO's include Palestinian Hydrology Group (PHG), Center on Housing Rights and Eviction (COHRE) through the right to water program, Applied Research Institute of Jerusalem (ARIJ) and many other local and international NGOS (Jayyousi & Srouji, 2009).

The NGOs contributed in the infrastructure development projects and applied water research but the absence of formal coordination to avoid duplication or improvement of funds' usage caused complications in developing the water supply sector and in managing and maintaining the infrastructure. Generally the work of NGOs is in competitively form with PWA without presence of cooperative between them to avoid duplication of work and make better use of available funds to the sector (ARIJ, 2011, Klawitter & Barghouti, 2006).

2.2.3 Water and Environmental Laws

Palestinian Water Law a new water law established to develop and manage the water resources. It approved and signed by President of the State of Palestine, on 2 June 2014. The Water Law includes vision, goals, policy and strategic principles for the management of the Palestinian water sector and will function in parallel with other relevant legislation (Palestinian water law, 2014).

The objective of Water Law:

According to (Article 2) of Palestinian water law for the year 2014, the water law aims to:

- Develop and manage the water resources in Palestine,
- Increase water resources capacity,
- Improve water resources quality to preserve and protect them from pollution and depletion,
- Improve the level of water services through the implementation of integrated and sustainable water resources management principles.

Palestinian Environmental Law establishes the general legal framework for environmental protection in Palestine. It adopted by the Palestinian Legislative Council on 6 June 1999 and approved by President of the Palestinian Authority, on 28 December 1999 (UNEP, 2003).

The Objective of Environmental Law:

The protection of the environment (land, water, air, marine environment) by preventing all types of pollution; promotion of public health and welfare; preservation of biodiversity and improvement of those areas which are environmentally degraded. It also promotes public awareness and encourages sustainable resource development for the benefit of present and future generations on the basis of intergenerational equity. The law also covered the environmental planning and enforcement tools (including impact assessment, licensing, inspection and administrative procedures, and penalties), and incorporates the ‘polluter pays’ principle and sets out government/public sector duties, including the basis for inter-sectoral coordination (UNEP, 2003).

2.2.4 Regulatory Framework

PWA is the responsible of water sector regulations. These regulations should satisfy the requirements of the various stakeholders and governmental requirements at different levels (Tarazi, 2009, UNEP, 2003).

Regulation is sets of commands issued by governments, which are designed to control behavior, with accompanying ‘police forces’ and penalties that it aims to improve access to services, ensure the quality of service and promote efficiency in the production and consumption of services, in addition to protection of the customer. It deals primarily with issues related to the cost and quality of services, as they are perceived by the individual consumer. The regulation should apply equally to all water service providers regardless of whether they are private or public sector entities (Tarazi, 2009). The main element of regulation frame work presents in **Figure (1.2)**

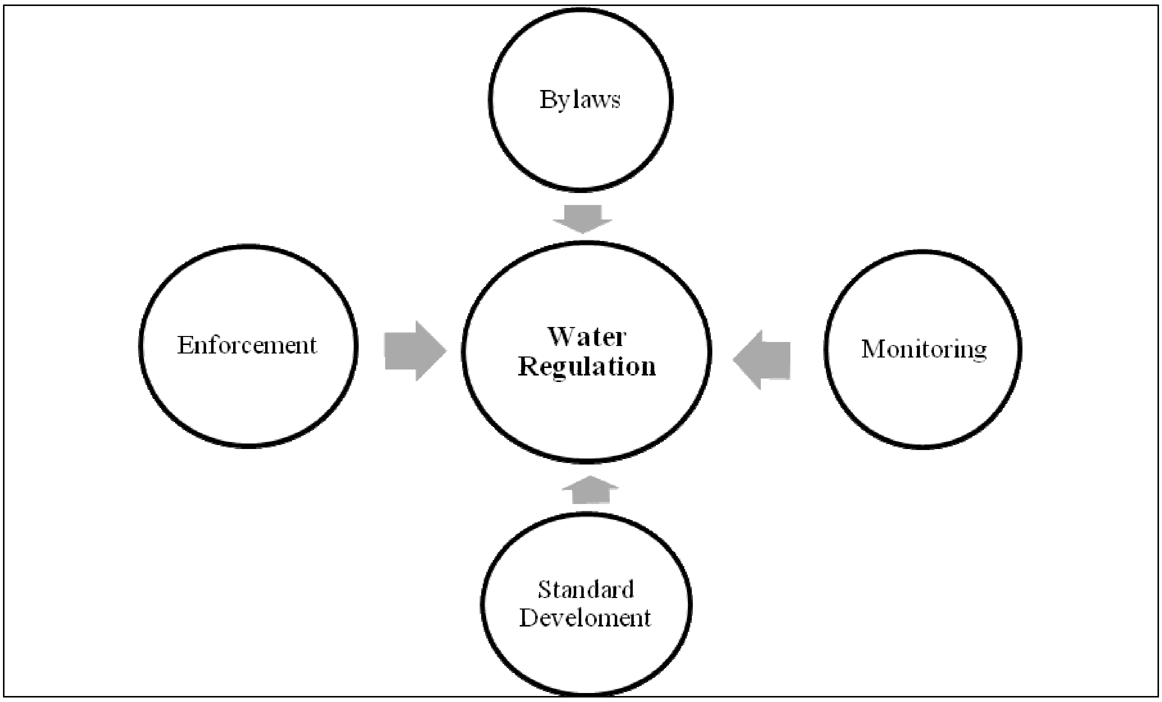


Figure (2.2): Regulation framework elements (Tarazi, 2009).

2.3 The Need for Ground Water Protection

Water is essential to sustain life and a satisfactory (adequate, safe and accessible) supply must be available to all. Improving access to safe drinking-water can result in tangible benefits to health. Every effort should be made to achieve a drinking-water quality as safe as practicable (Ikhlil, 2009).

Palestine depends on groundwater. Groundwater is all water which occurs within the 'hydrologic cycle' below the land surface. It is a pervasive resource, interacting with the land surface, streams and lakes (ANECC, 1995).

Groundwater is the main source of water in Palestine, for domestic, agriculture and industrial purposes (Carmon et al., 1997). Consequently, the need to protect groundwater resources is directly related to the value of these resources and the risk of devaluation or destruction of this resource due to human activities (ANECC, 1995).

In Palestine, there is need to develop a groundwater protection guidelines to provide a national framework for the protection of the quality of groundwater from contamination and also focus on land-based management of the groundwater resource. Water quality is an important pillar for any water management program and one of the most important environmental issues that facing Palestine is the degradation of groundwater quality so the management of groundwater must be dealt within very effective ways (Tarazi, 2009).

According to national guidelines for groundwater protection there is three major types of protection are classified into three 'legislative' groups:

1. First legislative group includes a whole range of traditional groundwater management measures available, such as vulnerability maps, aquifer classification systems and wellhead protection plans.

2. Second legislative group includes a range of land-use planning measures which can help prevent contamination occurring at inappropriate locations.

3. Third legislative group includes a variety of environmental protection measures emerging which tackle modern waste management problems in progressive ways (ANECC, 1995).

This research will apply the first legislative group of water management (the traditional measures) through make pollution sources map for Al- Fawwar wells (the target wells in the study) and plan a wellhead protection zone for it.

2.3.1 Vulnerability Maps

Vulnerability is a technique that used to determine the groundwater body's vulnerability to contamination. It considered as one of strategies that used for assisting the development of groundwater protection. The vulnerability defined as “a relative evaluation of the potential exposure of a groundwater resource (and consequently, its beneficial use) to contamination from planned and unplanned sources”. Vulnerability map is necessary to determine the need for groundwater protection and so determine the protection mechanisms according to the loss of a beneficial use of that groundwater resource. A vulnerability map will be designed in this research on Al- Fawwar well field.

2.3.2 Wellhead Protection Plans

Pollution prevention is the key to maintain the public water supply wells in Palestine from pollution. So the delineation of well head protection plans in Palestine is necessary. According to United State Environmental Protection Agency (U.S. EPA, 1987), well head protection area defined as "surface or subsurface area surrounding water well or well field supplying a public water system, through which contaminants are reasonably likely to move toward and reach such well or well field".

According to Australian groundwater protection guidelines public water supply wells can be contaminated in many ways that include:

- Incompatible land-use practices within well recharge areas, eg. septic tanks;
- Leakage of contaminants into the well or around the outside of the casing, if not properly sealed or poorly operated and maintained;
- Aquifer contamination by leakage of poor quality or contaminated groundwater from one aquifer to another via improperly constructed or corroded wells;
- Interaquifer leakage in well holes drilled for mineral or oil and gas exploration which are not properly abandoned; and
- Drill stems not properly cleaned, thus transferring bacteria or contaminants.

Before delineation of WHPAs it must identify and locate the source of pollutants that can cause contamination of groundwater. Monitoring and management of groundwater in Palestine is very necessary and this considered as essential part of PWA responsibilities. This research will determine a well head protection plan to Al-Fawwar well field.

2.4 Summary of Current Situation of Water Sector

Water is an important commodity and a vital input to domestic uses, agriculture uses and industries uses, so our economy. For this, groundwater resource monitoring and reviewing are important elements to maintain and protect these resources. Good water governance refers to a range of political, social, economic and administrative systems that must be in place to regulate the development and management of water resources and provision of water services at different levels of society.

Palestinians polices and strategies in water sector were established but the enforcement of regulations is still very weak due to the sovereignty issue over land and water mainly in the presence of occupation. There is also a scatter and unclear roles and responsibilities of different water sector parties that also affected on the sector management and future development. It is important to define roles, responsibilities and regulation of water sector to develop Palestinian water protection guidelines. This research concentrated on WHPZ which is an important topic for PWA regulation in the future.

The aim of WHPA delineation of Al- Fawwar wells is to prevent the contamination of the groundwater within the catchment area. The benefit use of Al- Fawwar wells water is related to Hebron municipality but the boundaries of the catchment that fed the wells are within Dura municipality and other community councils. Generally, PWA and West Bank water department are the responsible parties of water resources management in the West Bank. So, the protection of Al- Fawwar wells as water source is under the responsibility of: PWA, MoH, Dura municipality, Hebron municipality and community council for Tarama, Hadab Al- Fawwar and Al- Fawwar camp. For this, it is important to regulate the responsibilities between these parties to prevent any pollution in the future for Al- Fawwar well and to make plan for control and management of the wells and their catchment area. So, there is a need to regulate the: strategies, regulations and evaluation of the possible pollution sources in the catchment area before give licensing of construction to prevent the pollution in the future and put emergency plan to control pollution cases and stop pumpage from well.

3 Chapter Three: Materials and Methods

3.1 Field Survey

Field survey was carried out in the study area to determine the boundaries of the catchment area and examine the current situation of Al- Fawwar wells 1 & 2. Add to this, investigate and mapping the possible pollutant sources that affect groundwater in the catchment area using handheld Global Positioning System (GPS). Then the collected data was inserted and analyzed using (Reproject me software) and (GIS software) to draw the pollution source map and other maps.

The methodology of the research is summarized in **Figure (3.1).**

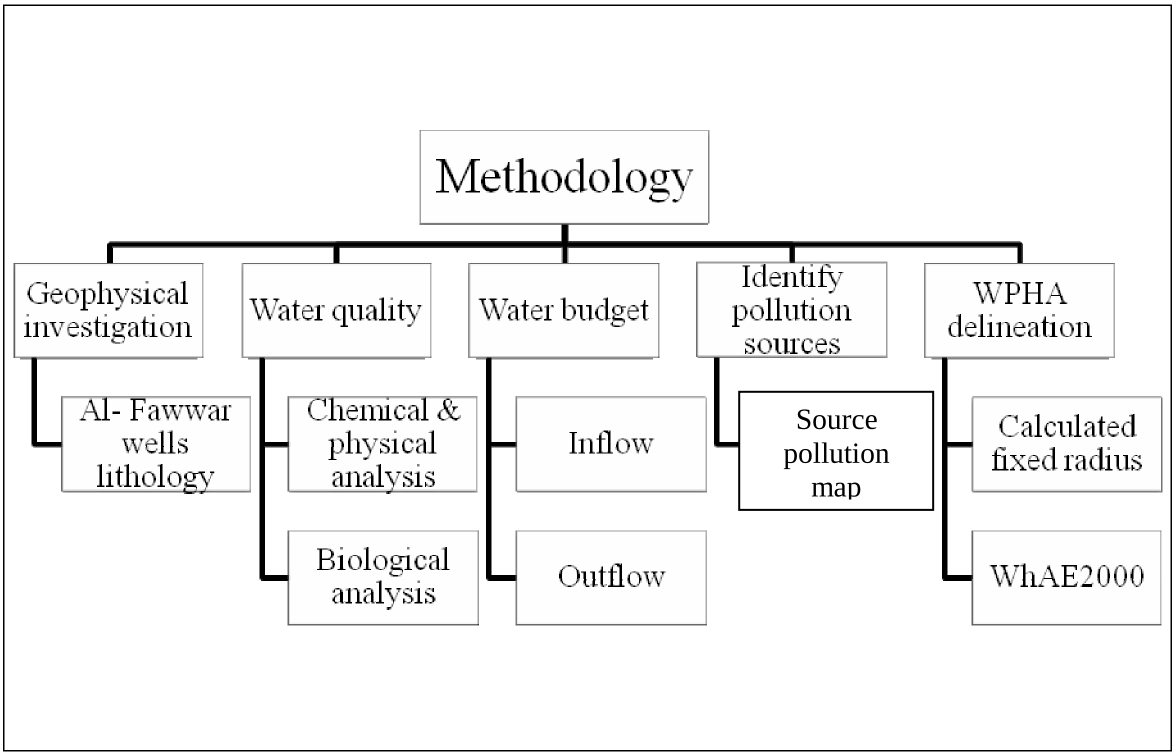


Figure (3.1): Research methodology.

3.2 Geophysical Investigation

Geophysical survey methods measuring the electrical properties of soils and rocks are using artificially generated electrical currents that are imported into the ground and measure the potential difference generated on the free surface. The current input and the voltage measurements are obtained using stainless steel electrodes. Resistance of a material is defined as the Ohmic resistance between two surfaces of the same material with a prescribed boundary. Resistance in Ohms is a physical property that can vary from material to material but can also vary in the same material from point to point (Barounis& Karadima, 2011). The geophysical methods are one of the best modern ways to determine the sources of groundwater and hideaways; it is also used for identification of ranges overlap between freshwater and saltwater or contaminated. Furthermore, it is an accurate way that can determines the vertical changes of resistance with varying depth and its ability to penetrate into the remote depths by vertical electrical sounding methods (VES) Schlumberger array (Lashkaripour, et al, 2005).

3.2.1 The Principle of Schlumberger Array Technique

When doing resistivity sounding survey electrodes are distributed along a line, centered about a midpoint that is considered the location of the sounding. Such measurement needs to inject a continuous electric current (low frequency) in the earth by using two electrodes (A and B) as input, and using other electrodes (M and N) as output as represented in (**Figure 3.2**) (Barounis& Karadima, 2011, Thaher, 2010). The resulting potential field voltage is measured at the surface by a voltmeter between a second pair of electrodes. The subsurface ground resistivity can be calculated by using the electrode spacing, geometry of the electrode positions, applied current and measured voltage (Sbeh, 2009).

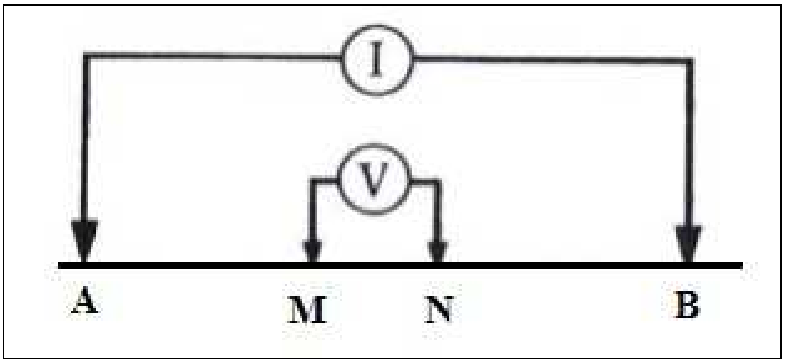


Figure (3.2): Sketch diagram of Schlumberger array (Barounis& Karadima, 2011).

From the current (I) and voltage (V) values, an apparent resistivity (*pa*) value can be calculated by the following equation:

***pa* = k V / I …………. (1)**

Where, k is the geometric factor which depends on the arrangement of the four electrodes, V is the potential or voltage and I is the electric current (Loke, 2000, Sbeh, 2009).

Resistivity meters normally give a resistance value, R = V/I, so in practice the apparent resistivity value can be calculated by the following equation:

***pa* = k R …………. (2)**

Where, K is the geometric factor and R is the resistance (Loke, 2000).

The calculated resistivity value is not the true resistivity of the subsurface, but an “apparent” value which is the resistivity of a homogeneous ground which will give the same resistance value for the same electrode arrangement. The relationship between the “apparent” resistivity and the “true” resistivity is a complex relationship. To determine the true subsurface resistivity, an inversion of the measured apparent resistivity values using a computer program must be carried out (Loke, 2000).

3.2.2 Field Experimental Design

To determine the lithology of Al- Fawwar wells, geoelectrical investigation was carried out depends on (Wenner- Schlumberger Array) method by using Vertical Electrical Surrounding (VES) points. This technique determined the depths of the subsurface rocks boundaries and identifying the electrical proprieties of the different lithology (Al- Swiety, 2009, Thaher, 2010). The geophysical investigation was conducted by staff from Water & Environmental Analysis Lab in Al- Quds University (**Figure 3.3**).

Figure (3.3): Determination of Al- Fawwar wells lithology by using Vertical Electrical Surrounding (VES).

4 VES measuring points are accomplished in Al- Fawwar wells field using PASI instrument. Schlumberger array is used in the 4 VES points. The array spacing distances are illustrated in (**Table 3.1**), the measurements were done with four electrode array consisting of two current and two potential electrodes. The VES is to expand the electrode array from a fixed center. Current reached more depth by increasing the spacing between the outer electrodes; consequently the resistivity of the

different successive horizontal rocks layers will be reached. The different lithological successive are mean different electrical response (different resistivity).

Table (3.1): Electrical sounding spacing during the investigation

Spacing number	***AB/2**	***MN/2**
1	1	0.4
2	3	0.4
3	4	2
4	5	0.4
5	5	2
6	10	2
7	10	4
8	15	2
9	15	4
10	30	4
11	40	4
12	40	20
13	50	4
14	50	20
15	100	20
16	100	40
17	150	20
18	150	40
19	200	40
20	300	40

* AB: Current electrode, MN: Potential electrode.

3.3 Samples and Water Quality Evaluation

Evaluation of the water quality for domestic uses was based on a comparison of the biological, physical, and chemical parameters of Al- Fawwar wells water with the drinking water guidelines of WHO (1995) and the Palestinian drinking water standards (PWA, 2005). The main parameters of concern were the fecal coliform bacteria and nitrate. Samples of water from Al- Fawwar wells were collected and taken in glass bottles (**Figure 3.4**), stored at 4°C in ice boxes. Collected samples were taken immediately to the Central Public Health Laboratory of MoH in Ramallah. Analysis of samples includes (Total coliform, Fecal coliform, pH, Nitrate).The measured parameters were analyzed according to standard procedures that used for the examination of water and wastewater (APHA, 1995).

Figure (3.4): Water samples collection from Al- Fawwar wells.

3.4 Water Budget Calculation

The water budget in Al- Fawwar well field was calculated according to the following equation: (Schmidt et al., 2012)

$$\mathbf{P = ET + SR + Q_{spring} + Q_{well\ abstraction} + Q_{out}} \text{ ………… (1)}$$

Where:

P: Precipitation.

ET: Evapotranspiration.

SR: Surface Runoff

Q_{spring}: Springs production

Q_{well} abstraction: Wells production

Q_{out}: Groundwater recharge – (Q springs + Wells Abstraction)

The data of precipitation (P) was obtained from Dura metrological data, where the data of springs production (Q_{spring}) and wells production (Q_{well} abstraction) was obtained from PWA database.

The surface runoff estimated according to Goldschmidt equation (Al- Sweity, 2009):

$$\mathbf{SR = 0.237 * (P - 252)} \text{ ………… (2)}$$

Where SR is the average annual runoff and P is the average annual rainfall. Both SR and P are in mm/yr.

3.5 Delineation of WHPA Boundaries

To determine the boundaries of Wellhead Protection Area (WHPA) of Al- Fawwar wells, two methodologies where tested as following

3.5.1 Calculated Fixed Radius (CFR) Method

The radius of the protection zone was calculated according to the following equation (SLE, 1999, Kraemer et al., 2007):

$$\mathbf{r} = \sqrt[2]{\frac{Qt}{\pi b n}} \quad \text{………….} \ \mathbf{(7)}$$

Where:

r is radius (distance from well) in meters.

Q is maximum approved pumping rate of the well (m^3/day).

t is saturated travel times for each well capture zone (50 days, 2 years and 5 years).

b is saturated thickness of screened interval (well casing).

n is Aquifer porosity.

π is 3.14.

3.5.2 Wellhead Analytic Element Model (WhAEM2000)

WhAEM2000 is a geo- hydrology computer model used for delineating capture zones for pumping wells; it’s public domain developed by the U.S. Environmental Protection agency (US EPA) (Kraemer et al., 2007).

The calculations of WHPA dimensions using WhAEM2000 depend on several parameters, including the magnitude and direction of the ambient flow near the well or well field, which is challenging to characterize. The magnitude of the uniform flow is denoted by Q□ (m^2/day), and can be estimated from the hydraulic gradient i and the aquifer transmissivity kH (hydraulic conductivity k times saturated aquifer thickness H) (m^2/day) (Kraemer, 2009).

The magnitude of the uniform flow rate is calculated as:

$$Q\square = kHi \text{ .... } (3)$$

The flow (Q□) is the total amount of water in the aquifer integrated over the saturated thickness, per unit width of the aquifer.

The shape and size of a simplified time-of-travel capture zone can be related to a dimensionless travel time parameter, Ť, defined as:

$$\check{T} = \frac{TOT}{T_{o}} \text{ .... } (4)$$

Where T is the time of travel [TOT] and T_o is a reference time defined as:

$$T_{o} = \frac{(nHQ)}{(2\pi Q_{o}{}^{2})} \text{ .... } (5)$$

Where *n* is the aquifer porosity, and *Q* [L^3/T] is the pumping rate of the well.

When $\check{T} \leq 0.1$, the radius (R) centered on the well, including a safety factor for a non-zero ambient flow field, is given by:

$$R = 1.1543\sqrt{\frac{QT}{\pi Hn}} \text{ ... ... } (6)$$

When $0.1 < \check{T} \leq 1$, the R is given by:

$$R = L_{S}[1.161 + \ln(0:39 + \check{T})] \text{ .... } (7)$$

Where L_s is the distance from the well to the stagnation point down gradient from the well given by:

$$\mathbf{Ls = \frac{Q}{(2\pi Q_o)}} \text{............ } \mathbf{(8}$$

And where the eccentricity δ is the measure of the deviation from center of circular to center of well given by:

$$\mathbf{\delta = L_s[0.00278 + 0.652\check{T}]} \text{ .... } \mathbf{(9)}$$

When Ť > 1, a uniform flow envelope, the so-called boat-shaped capture zone, can be defined as:

$$\mathbf{x = \frac{y}{\tan\frac{y}{Ls}}} \text{............ } \mathbf{(10)}$$

Where y is bounded by:

$$\mathbf{{}^{-}Q/2Q\square < y < {}^{+}Q/2Q\square} \text{ .... } \mathbf{(11)}$$

And clipped at the up-gradient distance L_u given by:

$$\mathbf{L_u = L_s\ [\check{T} + \ln(e + \check{T})]} \text{ .... } \mathbf{(12)}$$

And where (e = 2.718) (Kraemer et al., 2007, Mogheir & Tarazi, 2010).

The previous calculation sequence and results are shown in **Figure (3.5)**.

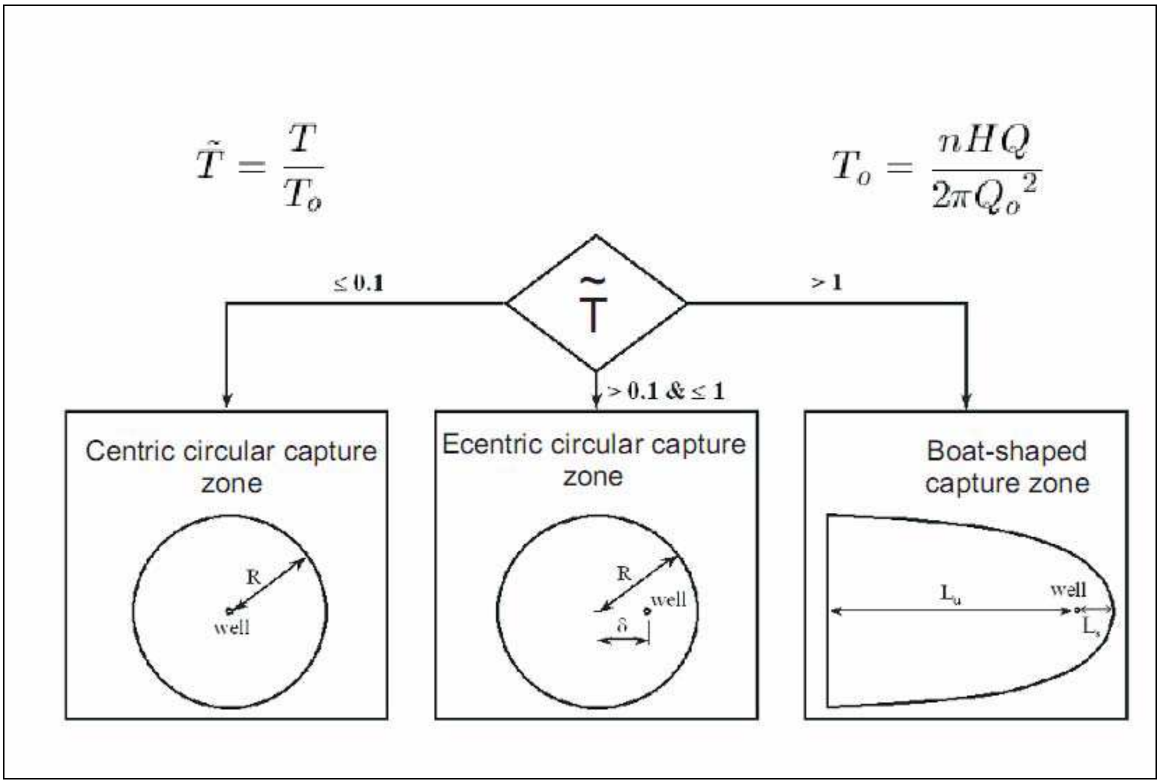


Figure (3.5): Simplified delineation techniques for a well pumping at rate Q, in an ambient flow field Q□, with aquifer saturated thickness H and porosity n, and time of travel capture zones of time T (Kraemer et al., 2007, Tarazi, 2009).

4 Chapter Four: Results and Discussion

4.1 Geophysical Investigation of Al- Fawwar Wells Field

4.1.1 Geophysical Field Survey of Al- Fawwar Wells Field

The Geophysical method (Vertical Electrical Sounding (VES)) was applied in this study to evaluate the aquifer lithology of Al- Fawwar wells. The VES method is useful to identify the litological and geological characteristics of the underground.

The geophysical investigation of the study area consists of two profiles, which are labeled from A - A□ to B - B□ **(Figure 4.1)**. Each profile composed of two Vertical Electrical Sounding (VES) points. These four VES points were plotted on Google satellite map **(Figure 4.1)**.

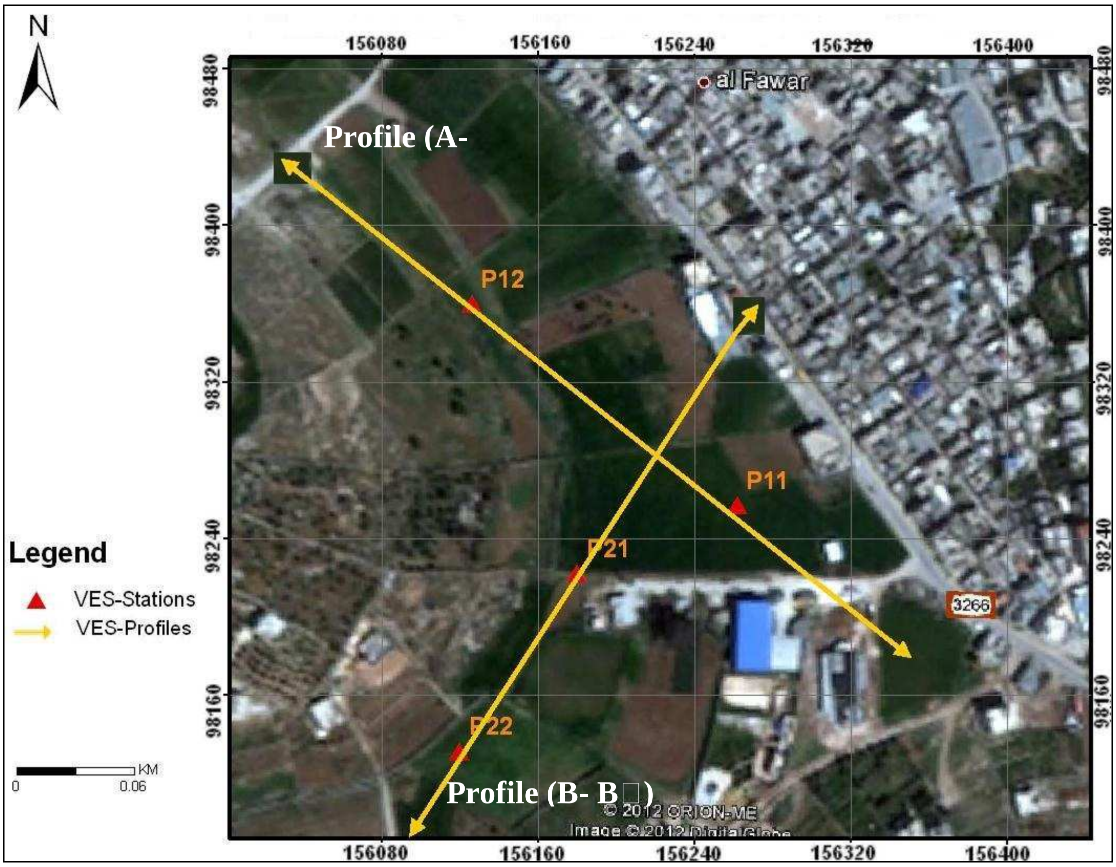


Figure (4.1): Location of Geo-electrical sounding profiles.

The locations of the four VES points of the all profiles are presented in (**Table 4.1).** The maximum depth for all VES stations is 150 m.

Table (4.1): Location of VES points in Al- Fawwar wells field.

Point no.	East	North	Elevation (m.a.s.1)
P 1-1	156262	98257	722 m
P 1-2	156126	98360	718 m
P 2-1	156180	98222	714 m
P 2-2	156120	98131	713 m

Data interpretation for lithological compositions based on the electrical resistivity values describing in (**Figure 4.2**).

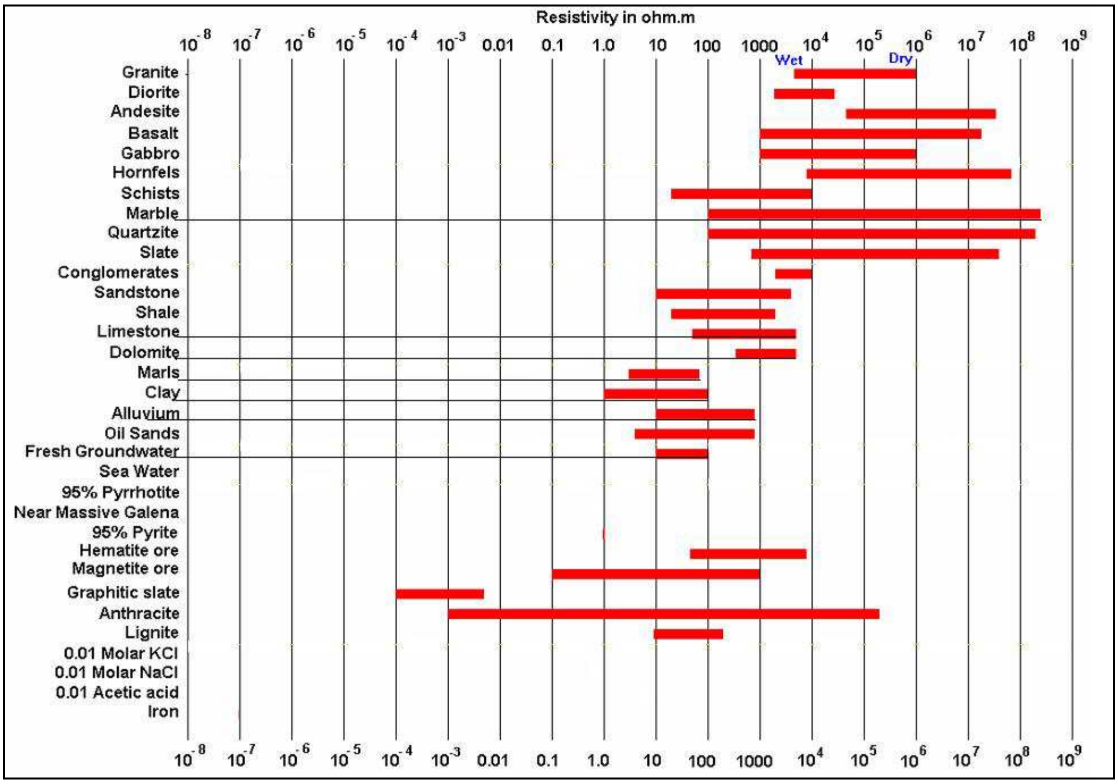


Figure (4.2): Resistivity’s of some common rocks, minerals and soils (Loke, 2000).

4.1.1.1 Vertical Electrical Sounding and Lithological Description

The geophysical investigation was constructed 2 profiles and 4 VES points that are used to explain the lithology of Al- Fawwar wells.

1. Profile 1 (A-A')

This profile is extended from south-east to north-west, and it is north Al- Fawwar wells field, 2 stations (P1-1 and P1-2) were taken in this profile with (171 m) length between each station as shown in (**Figure 4.1**). The measurement was started from the surface (the depth was zero) and the maximum depth reached up to 150 m. The minimum resistivity value was (5 Ω.m) and the maximum resistivity was (2489 Ω.m) (**Figure 4.3**).

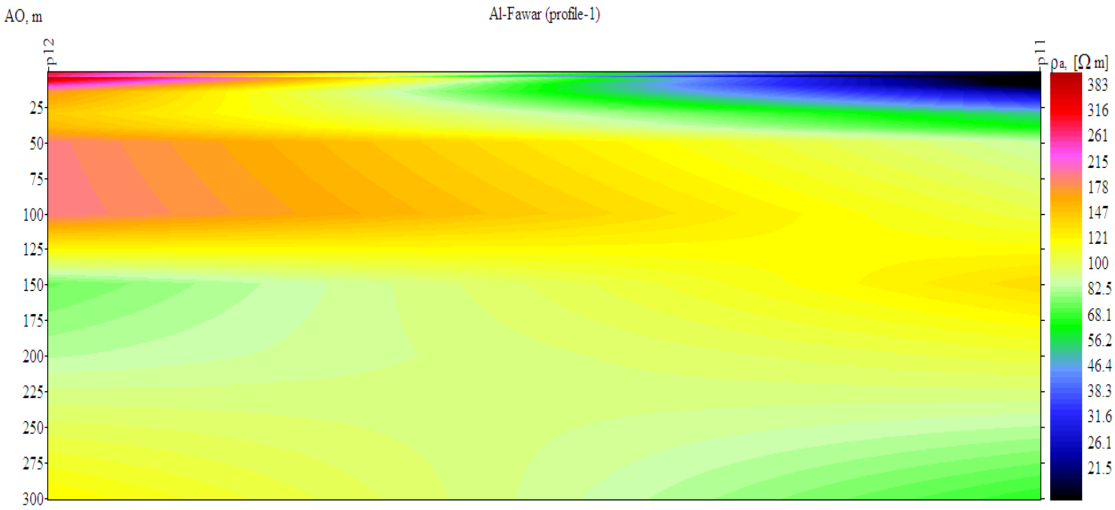


Figure (4.3): (A - A') vertical electrical sounding profile.

The lithological characteristics corresponding to the values of resistivity is illustrated in (**Figure 4.4**) and described in (**Table 4.2**). Along this profile there were 2 VES stations, P1-1 from (0- 150m) depth and P1-2from (0- 150m) depth.

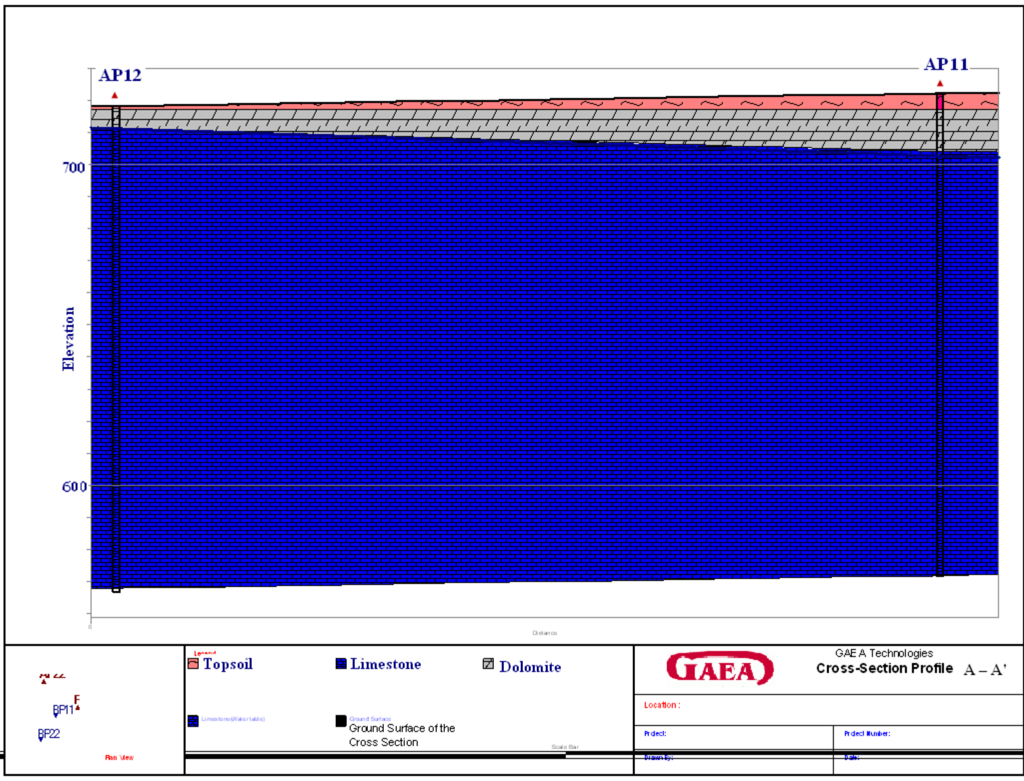


Figure (4.4): Lithology of the electrical profile (A - A□).

Along the 1st station (P1-1) there were three main layers: Top soil layer with thickness (5m), the minimum resistivity value was at this layer (5Ω.m). Dolomite layer with thickness (13m), this layer is aquifer for water. The maximum resistivity value was at this layer (2489Ω.m). And Limestone layer with thickness (132m), also it is aquifer for water. These two layers are related to Hebron formation.

Along the 2nd station (P1-2) there were 6 main layers: Top soil with thickness (1m). Dolomite inter bedded with marl layer with thickness (2m), this layer considered as aquiclude layer. Limestone layer with thickness (4m), this layer is aquifer for water. Dolomite layer with thickness (10m). And Limestone layer with thickness (52m). All these layers are related to Hebron formation.

Table (4.2): Lithological description of (A - A□) profile.

Point - ID	Depth (m)	Resistivity	Avg. Resis (Ω.m)	Lithology
P1-1	0- 5	5- 60	22	Top soil
	5- 18	419- 2489	1393	Dolomite
	18- 150	10- 123	35	Limestone
P1-2	0- 1	70- 150	113	Top soil
	1- 3	406- 1307	1023	Dolomite + marl
	3- 7	22- 94	45	Limestone
	7- 17	526- 1119	845	Dolomite
	17- 150	8- 180	69	Limestone

From **Table (4.2)** the resistivity of lime and dolomite was not homogenous; because the resistivity for each one determined according to the values present in **Figure (4.2)** as a pure component but in the field there is a combination between limestone and chalk or dolomite and marl so the resistivity changed at different depths.

2. Profile 2 (B-B')

This profile is extended from north-east to south-west, 2 stations (P2-1 and P2-2) were taken in this profile with (110 m) length between each station as shown in (**Figure 4.1**). The measurement was started from the surface (the depth was zero) and the maximum depth reached up to 150 m. The minimum resistivity value was (6 Ω.m) and the maximum resistivity was (13527 Ω.m) (**Figure 4.5**).

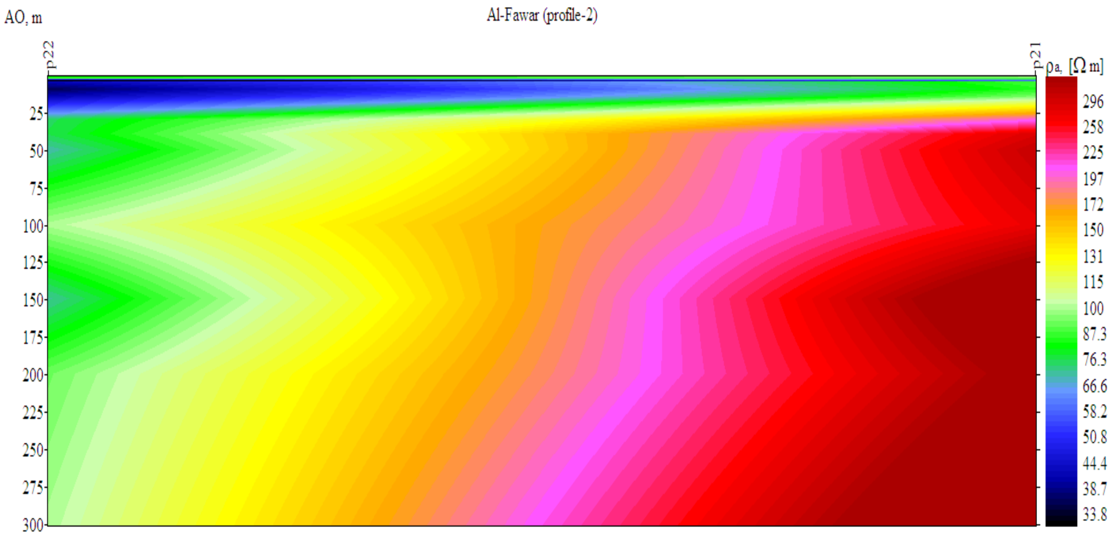


Figure (4.5): (B - B□) vertical electrical sounding profile.

The lithological characteristics corresponding to the values of resistivity is illustrated in (**Figure 4.6**) and described in (**Table 4.3**). Along this profile there were 2 VES stations, P2-1 from (0- 150m) depth and P2-2from (0- 150m) depth.

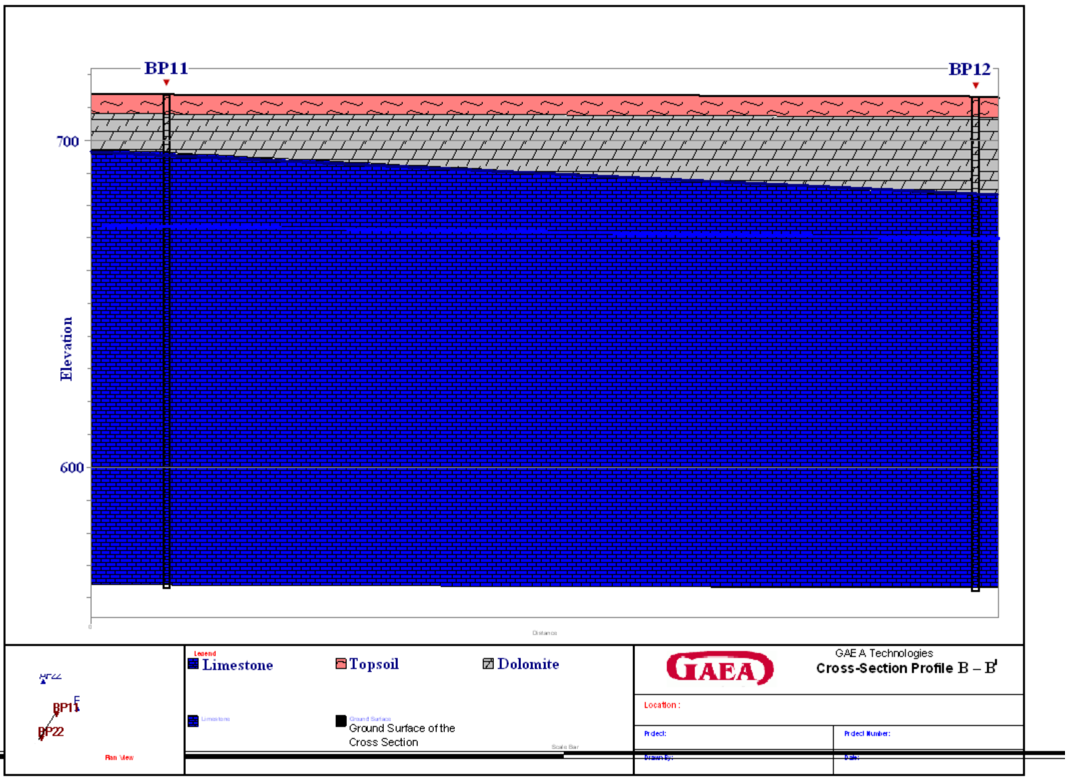


Figure (4.6): Lithology of the electrical profile (B - B).

Along the 1st station (P2-1) there were 4 main layers: Top soil layer with thickness (6m). Dolomite inter bedded with marl with thickness (12m), this layer considered as aquiclude layer. Limestone layer with thickness (27m), this layer is aquifer for water. And Dolomite layer with thickness (105m), this layer is aquifer for water, the maximum resistivity value was at this layer (13527Ω.m). All these layers are related to Hebron formation.

Along the 2nd station (P2-2) there were 4 main layers: Top soil with thickness (6m), the minimum resistivity value was at this layer (6Ω.m). Dolomite inter bedded with marl layer with thickness (24m) and Limestone layer with thickness (77m).

Table (4.3): Lithological description of (B - B□) profile.

Point - ID	**Depth**	**Resistivity**	**Avg. Resis (Ω.m)**	**Lithology**
P2-1	0- 6	20- 80	48	Top soil
	6- 18	207- 5591	2124	Dolomite + marl
	18- 45	22- 427	161	Limestone
	45- 150	839- 13527	4595	Dolomite
P2-2	0- 6	6- 170	44	Top soil
	6- 30	97- 539	285	Dolomite + marl
	30- 73	16- 38	28.7	Alluvium + water
	73- 150	105- 4261	1528	Limestone

Also, in **Table (4.3)** the resistivity of lime and dolomite was not homogenous and this explained as previous discussion for **Table (4.2)** page 58.

4.2 Water Budget of Al- Fawwar Wells Field

4.2.1 Background

Water budget is a basic tool that can be used to evaluate the occurrence and movement of water through the natural environment. Water budgets provide a foundation for evaluating its use in relationship to other important influencing conditions such as other ecological systems and features, as well as social and economic components (IWM, 2009). It assumed for water budget of any hydrological system that the input = the output and any increase or decrease of one of them lead to change in the storage (Ibrahem et al., 2012).

Water budget calculation can be useful to study and understand the dynamics of water throughout the flow system. Water budget for Al- Fawwar well field can be looked at as water inputs, outputs and changes in storage. The inputs into the study area (precipitation, anthropogenic inputs such as waste effluent) must be equal to the outputs (evapotranspiration, water supply abstractions, and surface or groundwater outflows) as well as any changes in storage within the area.

4.2.2 Water Budget of Al- Fawwar Wells 1 & 2Field

The water budget in Al- Fawwar wells 1 & 2 field calculated according to the following equation (Schmidt et al., 2012):

$$\mathbf{P = ET + SR + Q_{spring} + Q_{well\ abstraction} + Q_{out} \ldots\ldots\ldots\ldots (1)}$$

Where:

P: Precipitation.

ET: Evapotranspiration.

SR: Surface Runoff

Qspring: Springs production

Qwell abstraction: Wells production

Qout: Groundwater recharge – (Q springs + Wells Abstraction) (Schmidt et al., 2012)

In general, precipitation is the main input parameter in the water budget, whereas the actual evapotranspiration, recharge and runoff are its major output parameters (Xu & Singh, 1998, Qannam, 2009).

Therefore, this chapter provides information about each parameter in order to come up with an answer about water budget of the well field.

4.2.2.1 Precipitation

Rain is the main source of water in Palestine, which feed the aquifers, streams and valleys (PWA, 2011). It also used to irrigate large areas of agricultural lands. The annual rate of precipitation in Palestine ranges from (100- 650 mm) according to the variation in topography. It is estimated that the volume of precipitation in Palestine around 10 billion CM, particularly 2947.1 MCM in the West bank (MoA, 2013).

The annual precipitation in Al- Fawwar well field was obtained from Dura meteorological station during the period (1963- 2014) as presented in Appendix 1**.** The annual average of precipitation is 489 mm, and that Al Fawwar field has an area of 16 km^2 (16206207 m^2), the area of AL- Fawwar field was calculated by using geometry tool of GIS software. Precipitation is the major input of water balance in the study area.

The annual volume of the precipitation over the area was 7.93 MCM (7924835 m^3), it was calculated according to the following equation:

$$\mathbf{P = (P\ (mm/\ yr) * 1000/\ Area\ (m^2)\ \ldots\ldots\ldots\ldots\ (2)}$$

P (CM) = 489 mm* 1000/ 16206207 m^2
P = 7924835 CM/ million $\longrightarrow$ P = 7.93 MCM/ yr.

Changes of precipitation rate with years as presented in **Figure (4.7)** during the period of (1963- 2014) may affect the water reserves in Al- Fawwar wells, so the protection of Al- Fawwar wells from pollution is important to keep this available source of drinking water mainly with the increase of water demand because of increase of population number and change of life style. Also there is need to develop a plan to increase the benefit of precipitation amounts by decrease the rate of evapotranspiration and increase water infiltration to the groundwater.

To ensure if the changes of rainfall rate with year affect the water level, a cross section of Al- Fawwar aquifer was joined with the well drawdown as represented in **Figure (4.8)**. The depth of well no. 1 was 100 m and the depth of well no. 2 was 150 m, with distance between them 38 m. The aquifer formations were dolomite and limestone. The water table arises from the limestone formation. The water levels of Al- Fawwar aquifer obtained from PWA database (shown in Appendix 2) used to obtain the **(Figure 4.7)**, by make comparison between the annual average of rainfall and water level of aquifers, it was find that there is no any relation.

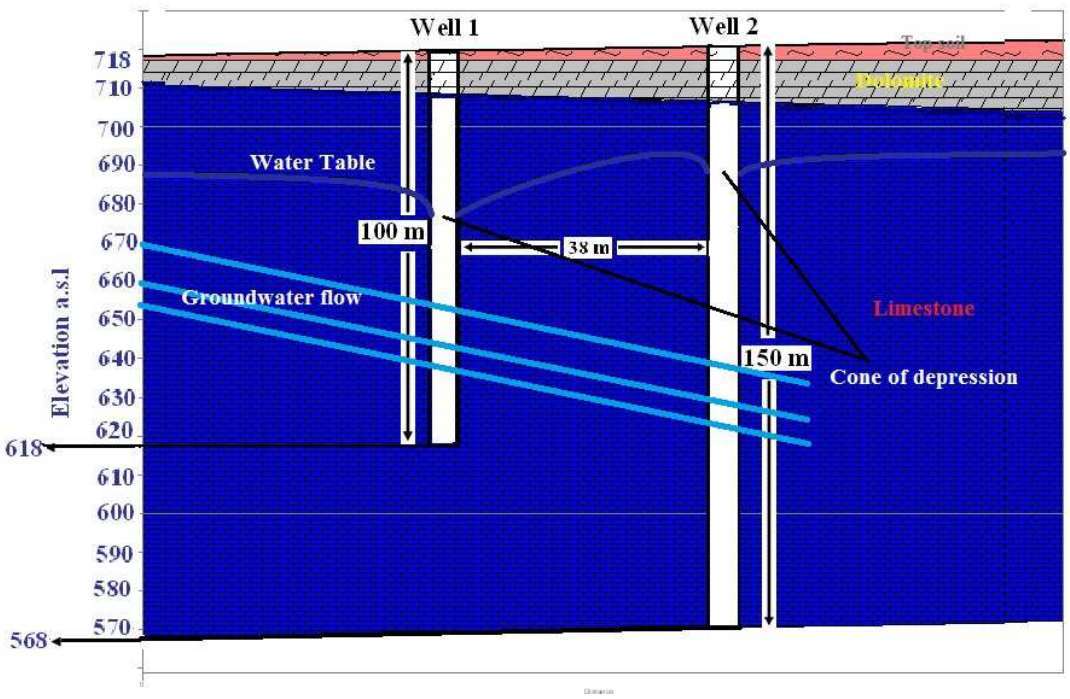


Figure (4.7): Cross section of pumped confined aquifer and well drawdown.

4.2.2.2 Runoff

Runoff measurements in the West Bank are very rare and the most of the available data are estimations (Qnnam, 2009). According to reports of Ministry of Agriculture,

10% of precipitation is runoff in Palestine, where 60- 70% of precipitation is evaporated and the remaining (25%) is recharged to groundwater (MoA, 2013).
In this study, Surface Runoff (SR) estimated according to Goldschmidt equation (Al-Swiety, 2009):

SR = 0.237 * (P- 252) …………. (3)

Where, P is precipitation.

SR = 0.237 * (498- 252) = 56.17 mm/ yr
SR (CM) = (56.17 mm/1000) * 16206207 m^2
SR = 910286 CM/ million ⟶ SR = 0.91 MCM/ yr

Goldschmidt equation estimates that the annual surface runoff in Al- Fawwar wells field was 56.17 mm (0.91 MCM) which represent 11.5% of the average annual precipitation, this results was agreed with the report of MoA that 10% of P is runoff.

4.2.2.3 Evapotranspiration (ET)

Evapotranspiration is the loss of water from a vegetated surface through the combined processes of water evaporation, soil evaporation and plant transpiration (ET definition). The actual evapotranspiration can be measured directly in the field by device known as lysimeters (Qannam, 2009), but it’s not available in the study area until the year of 2014 (MoA, 2014).

The ET was calculated in Al- Fawwar field by applying different methods that are described as following:

1. Hydrometeorological method was applied to obtain the ET as the following equation (Qnaam, 2003):

AET = P - (Q+R) …………. (4)

Where, P is precipitation.
Q is surface runoff.
R is recharge.

Before the calculations of ET the recharge (R) was calculated according to the following formula (Schimidt et al., 2013):

$$\mathbf{R = 0.534 * (P- 216) \ldots\ldots\ldots\ldots (5)}$$

R = 0.534 * (489 – 216) = 145.78 mm /yr

Then, ET = 489- (56.17 + 145.78) = 287.05 mm/ yr.

2. Empirical equation (Turc formula) was used to obtain the ET by applying the following equation:

$$\mathbf{AET (Turc) = P / [0.9 + (P/L)^2]^{0.5} \ldots\ldots\ldots\ldots (6)}$$

Where: $L = 300 + (25* t) + (0.05* t^3)$

t: is the temperature (°C). The average temperature for the last 12 years is 16.3°C.

$L = 300 + (25 * 16.3) + (0.05 * 16.3^3) \longrightarrow L = 924$

Then, $AET_{(Turc)} = 489/ [0.9+ (489/924)^2]^{0.5} \longrightarrow AET_{(Turc)} =$ 450 mm.

3. According to the Ministry of Agriculture (MoA) rainfall report, 60- 70% of precipitation was lost as evapotranspiration. According to this, the ET was calculated as:

$$\mathbf{ET = (65 * P)/ 100 \ldots\ldots\ldots\ldots (7)}$$

Then, ET = 65 * 489/ 100 = 317.85 mm/ yr

In order to calculate the water budget in the study area, the average between ET values that resulted from equations (4, 6 and 7) will be used to represent the average annual ET in this area.

Avg. ET = 287.05 + 450 + 317.85 $\longrightarrow$ Avg. ET = 351. 63 mm/ yr which is represent 70% of annual precipitation.

ET (CM) = (351.63 mm/1000) * 16206207 m^2

ET = 5698589 CM/ yr $\longrightarrow$ ET = 5.70 MCM/ yr

4.2.2.4 Springs Production (Q_{spring})

Delbah spring is located to the east of Dura town and west of Al Fawwar wells. It's far about 1.71 km from Al– Fawwar wells. The usage of Delbah spring is for drinking. The maximum annual discharge of Delbah spring according to PWA reports is 35532 CM/yr (0.354 MCM/ yr).

4.2.2.5 Wells Production ($Q_{well\ abstraction}$)

Al- Fawwar wells are located in Al –Fawwar camp, south of Hebron city between Dura and Yatta. They were drilled in 1962 under administrations of Jordan to the West Bank. The usage of Al- Fawwar wells for drinking. The annual pumpage of both wells according to PWA, 2000 reports is 545279 CM/yr. Also, there are about 163 drilling and dug wells in the catchment area of the study used for drinking and agricultural purposes. These wells were survived in this research (Appendix 3), where the total abstraction of these well is 146000 CM/ yr. So the total wells production in the catchment area is 691279 CM/ yr (0.691 MCM/ yr).

4.2.2.6 The Remaining Lateral Outflow ($Q_{\square ut}$)

The remaining lateral out flow was calculated according to the following equation:

$$Q_{\square ut} = (\text{Groundwater recharge}) - (Q_{springs} + Q_{wells\ abstraction}) \ldots\ldots\ldots\ldots (8)$$

Where, Groundwater recharge = (P) – (ET + SR)
Groundwater recharge = (489) – (351.63 + 56.17)
Groundwater recharge = 81 mm/ yr.

If we take in consideration the result of equation 5 that was used to calculate the value of recharge R = 0.534 * (489 – 216) = 145.78 mm /yr. Then we take the average of both values of groundwater recharge, Avg. of groundwater recharge = (81 + 145.78)/2 = 113.49 mm/ yr which represent 23% of precipitation, these results was agreed with the result of MoA rainfall report.

The average annual groundwarter recharge is 113.49 mm/ yr

Groundwater recharge (CM) = 113.49 *1000/ 16206207.

Groundwater recharge (CM) = 1839242 $\longrightarrow$ 1.84 MCM/ yr

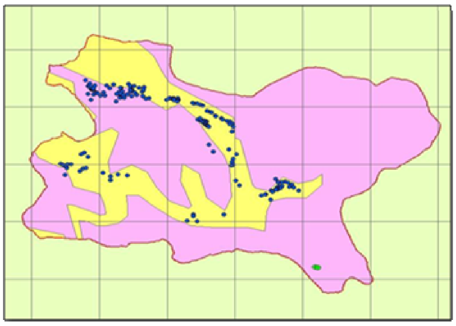
Then, $Q\square_{ut}$ = 113.49- (21.87 + 42.66)

$Q\square_{ut}$ = 48.97 mm/ yr.

Al- Fawwar wells water budget was summarized in **Figure (4.8)**

Water Budget for Al- Fawwar Wells Field

$$P = ET + SR + Q_{spring} + Q_{well\ abstraction} + Q_{out}$$



Inflow	MCM/a	mm/a
Precipitation	7.93	489

Outflow	MCM/a	mm/a
EvapoTransp.	5.70	351.63
Surface runoff	0.91	56.17
GW recharge	**1.84**	**113.49**
→ Q spring	0.35	21.87
→ Q well abstr.	0.69	42.66
→ Q out	0.79	48.97

Remaining lateral outflow

- Recharge Area size is 16 Km^2
- 2 Abstraction wells
- 162 dug and drilling wells
- 1 Spring

Figure (4.8): Water budget of AL- Fawwar wells catchment area.

4.3 Groundwater Quality Evaluation of Al- Fawwar Wells

4.3.1 Background

The groundwater quality is very important to determine suitability of the water for various water use purposes (Sabbah, 2005). Water quality is defined to be the chemical, biological and physical characteristics of water. The use of water (drinking, irrigation …etc.) is the main factor in determining the required water quality. Water is said to be good or acceptable for a special use, if its characteristics meet the standards for that use (Qannam, 2009). The water quality needs to satisfy the standards for each purposes of use in order to avoid any negative effects against the user. This means that the contents in water must fit the situations which never affect the health of the consumers over the life of consumption (Ikhlil, 2009).

4.3.2 Pollution Sources in the Catchment Area of Al- Fawwar Wells 1 & 2

In the study area there are many potential sources of contamination as represented in **(Figure 4.9)** that include;

1. The presence of agricultural lands (that depends on use of chemical fertilizers and pesticides) represent about 4503 dunum, in which 200 dunum of it had about 123 greenhouses. The quantity of used chemical fertilizers in the greenhouses ranges from (0.5 – 1 ton) annually (MoA, 2014).

2. The presence of urban area that use cesspits to dispose wastewater. The no. of houses that still use cesspit and septic tank are about 6630 houses and there is only about 770 houses (in Al- Fawwar camp) that connected to sewage network in the year of 2002 (Dura municipality).

3. The presence of two olive mills, four gas stations and other industry utilities. (There coordination's in Appendix 4 and photos of pollution sources in Appendix 5).

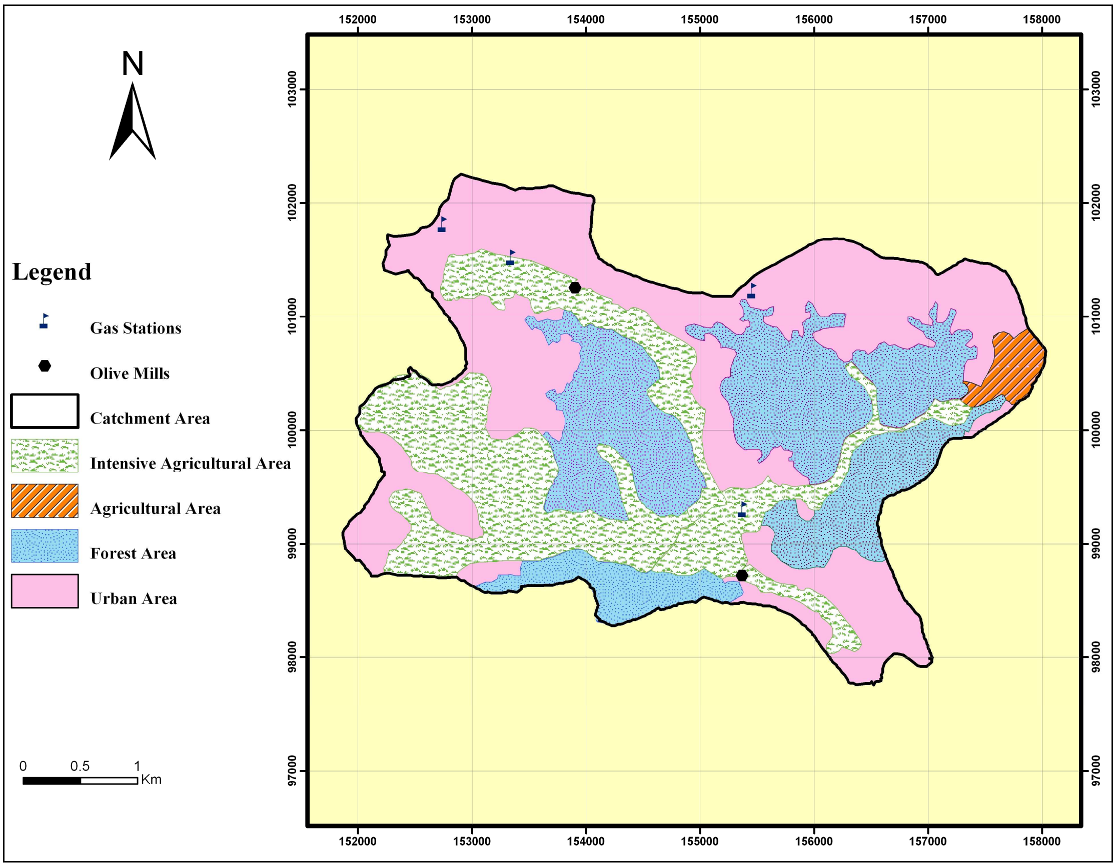


Figure (4.9): Pollution sources in the catchment area.

4.3.3 Previous Water Quality Analyses in the Catchment Area

There is previous studies in the study catchment area that gives a possible pointers of pollution; like (Ikhlil, 2009) that was sampled and tested 48 springs and dug wells in Dura for different water quality parameter. The results showed that only 5 wells are suitable for drinking purposes according to WHO standards and the rest 43 springs and dug wells are unsuitable for drinking purposes. In addition to (Al- Swiety, 2009) that was sampled dug and drilling wells in Wadi abu al- qmra, his results showed high concentration of nitrate. Also, (Al- Jabari, 2013) sampled and tested Al- Fawwar wells for total phenol parameter that result from olive mills wastewaters, her results showed that the concentration of total phenol was 2740 and 3430 µg/L in the wells that exceeded the maximum allowable concentration of phenol compounds in drinking water (0.5 µg/L) and according to WHO standards the total phenol content of water to be chlorinated should be kept below (1 µg/L). Moreover, there is a previous analysis of Al- Fawwar wells 1 & 2 taken from PWA from the year (1984- 2004), the analysis of nitrate concentration shown as figure in Appendix 6, the nitrate concentration exceeds the allowable limits of Palestinian standards and WHO guidelines for drinking water. Also there is a variation of nitrate concentration from year to another this may depend on the quantity of used fertilizer or the amount of disposed wastewater.

4.3.4 AL- Fawwar Wells Water Quality Evaluation

In this part of the study, the water quality of Al- Fawwar wells was evaluated for domestic water quality. The physical characteristics include (pH and TDS) was determined, also the chemical characteristics include (Cl^- and NO_3^-) was determined and the biological characteristics (include fecal coliform and total coliform) was determined as presented in the **Table (4.4)**. These analyses were measured in the Central Public Health Laboratory of MoH. The results compared with the World Health Organization (WHO) guidelines and Palestinian standards for drinking water.

Table (4.4): Water quality measurements of Al- Fawwar wells in comparison with the Palestinian standards and World Health Organization (WHO) guidelines for drinking water.

Parameters	**Well no.1**	**Well no.2**	**Palestinian standards (2004)**		**WHO guidelines (2004)**
			Basic	**Conditional***	
pH	7.4	7.5	6.5- 8.5	9.5	6.5- 8.5
TDS (mg/L)	559	626	1000	1500	500- 1000
Cl^- (mg/L)	75	72	250	500	250
NO_3^- (mg/L)	101	104	50	70	50
TC (c/ 100 ml)	0	0	0	3	0
FC (c/ 100 ml)	0	0	0	3	0

* Conditional Palestinian standards: are the maximum allowable limits, in the absence of other resources of better water quality.

4.3.4.1 Chemical and Physical Quality Evaluation

One of the most important parameter for chemical quality evaluation of water is nitrate. It must be controlled in drinking water because of its negative effects on the human health mainly the infants less than 2 years old. According to WHO and PWA standards for drinking water, nitrate concentration limit is 50 mg/L. The presence of nitrate in water is considered indicator of ground-water contamination by wastewater, animal manure or nitrogen fertilizer. The results show that the concentration of nitrate in Al- Fawwar wells is (101and 104 mg/L) that exceed the acceptable limits of nitrate in drinking water. So the water is not suitable for drinking. Other anaion was measured which is chloride (Cl^-). The results show that the concentration of Cl^- in Al-Fawwar wells was (75 and 72 mg/L) that are acceptable with the limits of WHO and PWA standards for drinking water.

Total dissolved solids (TDS) concentration was measured, is considered a secondary drinking water standard and it is regulated because of its esthetic effect rather than a health hazard (Qannam, 2009). The results show that the concentration of TDS in Al-Fawwar wells was (559 and 626 mg/L) that are acceptable with the limits of WHO and PWA standards for drinking water. Also the value of pH was measured, the results shows that the pH value in Al- Fawwar wells was (7.4 and 7.5) that are acceptable with the limits of WHO and PWA standards for drinking water.

4.3.4.2 Biological Quality Evaluation

To determine the suitability of water to be used for domestic purposes the biological evolution is very important. The infectious diseases caused by pathogenic bacteria, viruses, protozoa or parasites are the most common and widespread health risk associated with drinking water. According to WHO (1993), the examination for total and fecal indicator organisms is the most sensitive and specific way for assessing the hygienic quality of water (Qannam, 2009, Ikhlil, 2009), therefore this test was used in this study.

According to WHO and PWA standards for drinking water, the FC and TC count must be zero in 100 ml of water. Ministry of Health (MoH) examines the FC and TC of Al- Fawwar wells periodically. The results of these measurements from 28/1/2013 to 9/9/2014 (23 water samples) were taken from Dura department. The results of FC during the previous period were zero /100 ml that are suitable with WHO and PWA standards for drinking water. The results of TC were show that 18 sample was zero count and 5 samples were (3, 15, 60, 5, 3 colony/ 100ml) before chlorination of water. These results agreed with the result of nitrate test that repent high nitrate value in the water; the source of this pollution is expected to be from wastewater.

4.4 Delineation of WHPA for Al- Fawwar Wells

4.4.1 Background

U.S.EPA (1987) defined five criteria that may be used singly or in combination to define the area around a well in which contaminants could represent a threat to drinking water drawn from the well: distance, drawdown, time of travel, flow boundaries and assimilative capacity. Various methodologies for the delineation of wellhead protection areas have been proposed, they are varying in complexity, cost, level of data and hydro-geological analysis required. These methodologies include:

- Calculated fixed radius
- Analytical methods
- Hydro-geological mapping
- Numerical modeling (Groundwater protection scheme, 1999, Frind et al., 2002).

In this research the delineation of WHPA boundaries for AL- Fawwar well was identified by using 2 methods: Calculated Fixed Radius (CFR) and Wellhead Analytic Element Model (WhAEM2000). These methods depend on the time it takes groundwater to travel a specified horizontal distance. Three well zones were delineated, the first zone is 50 days time of travel (TOT), the second zone is 2 years TOT and the third zone is 5 years TOT. Different values of the radius of WHPA were obtained using these methods.

4.4.2 Calculations of WHPA of Al- Fawwar wells

4.4.2.1 Calculated Fixed Radius (CFR) method

Calculated Fixed Radius (CFR) method was used to delineate the protection zones dimensions for AL- Fawwar well. The delineated area was divided into Time of Travel (TOT) zones (50 day, 2 years and 5 years zones) (SLE, 1999). This method estimates the zone of contribution for a specified time of travel. This method also known as the "cylinder method", it is easy to use and it is based on simple hydro-geological principles that require limited technical expertise (Mogheir & Tarazi, 2010).

The radius was calculated according to the following equation (SLE, 1999, Kraemer et al., 2007):

$$r = \sqrt[2]{\frac{Qt}{\pi b n}} \quad \ldots\ldots\ldots\ldots (9)$$

Where:

r: radius (distance from well) in meters.

Q: maximum approved pumping rate of the well (m^3/day).

t: saturated travel times for each well capture zone (50 days, 2 years and 5 years).

b: saturated thickness of screened interval (well casing).

n: porosity.

π: 3.14.

The pumping rate (Q) of the well is equal (well flow * operating hour). So, the maximum approved pumping rate of Al- Fawwar well is equal 270 m^3/ day.

The required data about Al- Fawwar well no. 1 to delineate WHPA using the CFR method (equation 8) are shown in **Table (4.5)**.

Table (4.5): Al- Fawwar well no. 1 data (PWA database).

Parameter	**Symbol**	**Value**	**Unit**
Well flow	___	18	m^3/ hr
Operating hour	hr	15	hr/ day
Porosity	n	0.2	____
Screened interval (well casing)	b	3.048	m
Time of travel	TOT	50 / 730/ 1825	day
Maxi. approved pumping rate	Q	270	m^3/ day

From the data in the **Table (4.5)** the equation (8) was applied to obtain the following radiuses:

The Radius for TOT 50 days, $\mathbf{r_{50\ days}}$ **= (**(270* 50)/ (3.14* 0.2* 3.048))$^{0.5}$ = 51.19 m.

The Radius for TOT 2 years, $\mathbf{r_{2\ years}}$ = ((270* 730)/ (3.14* 0.2* 3.048)) $^{0.5}$ = 195.6 m.

The Radius for TOT 5 years, $\mathbf{r_{5\ years}}$ = ((270* 1825)/ (3.14* 0.2* 3.048)) $^{0.5}$ = 309.29 m.

Figure (4.10) represent the zones boundary of Al- Fawwar well at travel of time 50 days, 2 years, and 5 years.

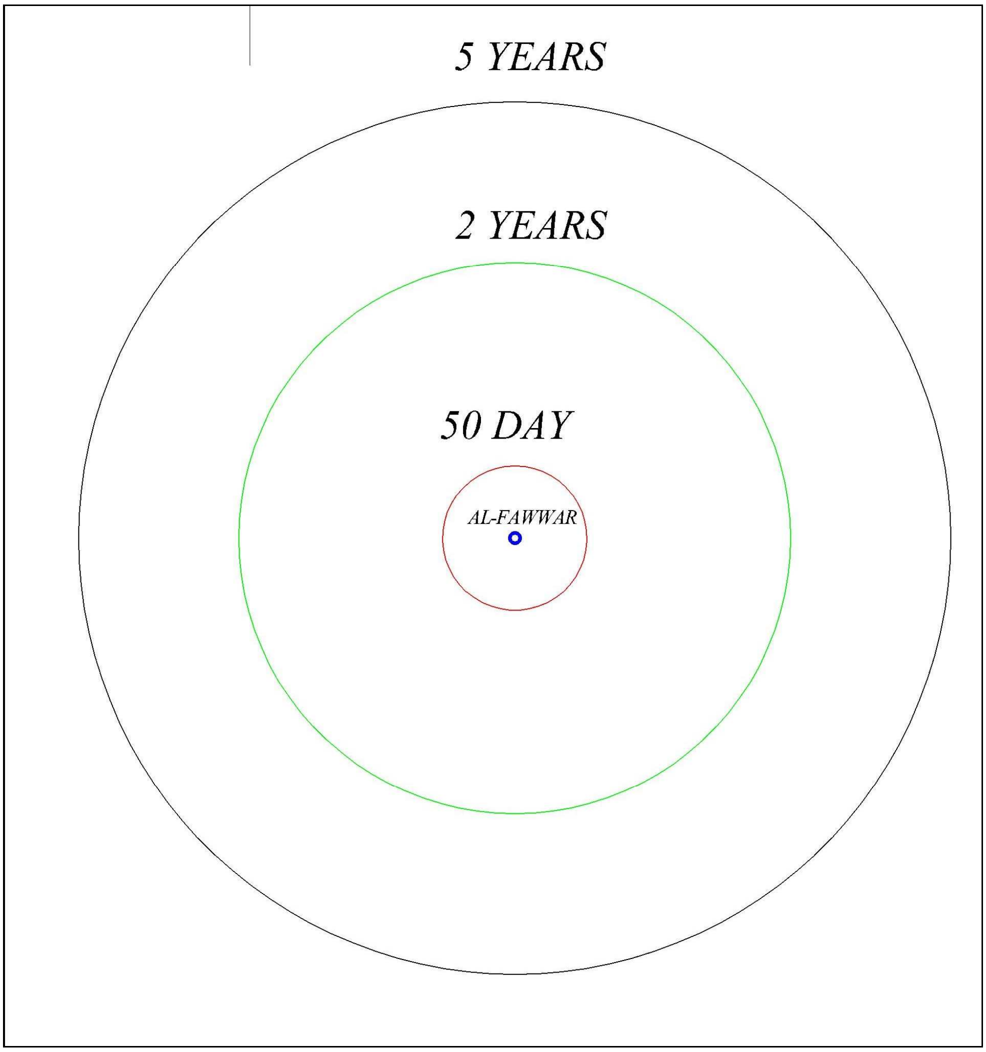


Figure (4.10): The zones boundary of Al- Fawwar well no. 1 by using CFR at travel of time 50 days, 2 years, and 5 years.

The required data about Al- Fawwar well no. 2 to delineate WHPA using the CFR method (equation 8) are shown in **Table (4.6)**.

Table (4.6): Al- Fawwar well no. 2 data (PWA database).

Parameter	**Symbol**	**Value**	**Unit**
Well flow	___	15	m^3/ hr
Operating hour	hr	10	hr/ day
Porosity	n	0.2	____
Screened interval (well casing)	b	3.048	m
Time of travel	TOT	50 / 730/ 1825	day
Maxi. approved pumping rate	Q	150	m^3/ day

From the data in the **Table (4.6)** the equation (8) was applied to obtain the following radiuses: the radius for TOT 50 days, $\mathbf{r}_{\mathbf{50\ days}}$ = 38.16 m, the radius for TOT 2 years, $\mathbf{r}_{\mathbf{2\ years}}$ = 145.8 m and the radius for TOT 5 years, $\mathbf{r}_{\mathbf{5\ years}}$ = 230.53 m.

The Calculated Fixed Radius method is a simple method that usually used where the hydro-geological information is poor or where time and resources are limited and because it also requires little technical expertise. However, it cans both over- and under-protect (Groundwater protection scheme, 1999).

4.4.2.2 Wellhead Analytic Element Model (WhAEM2000)

The U.S. Environmental Protection Agency Wellhead Analytic Element Model, WhAEM2000 is a computer tool to support stepwise, progressive modeling, and delineation of source water areas for pumping wells (Kraemer et al., 2007, Mogheir & Tarazi, 2010).

The required data about Al- Fawwar well no.1 that will be used in the calculations to delineate the boundaries of WHPA are shown in **Table (4.7)**.

Table (4.7): Al- Fawwar well no. 1 data (PWA database).

Parameter	**Symbol**	**Value**	**Unit**
Well flow	_____	18	m^3/ hr
Operating hour	hr	15	hr/ day
Porosity	n	0.2	_____
Aquifer thickness	H	88	M
Hydraulic conductivity	k	3	m/ day
Depth to water	DTW	30	M
Z coordination elevation	Z	718	M
Far from well to sea	F	66600	M
Time of Travel	TOT	50/ 730/ 1825	Day
Well flow per day	Q	270	m^3/day

The delineation of WHPA dimensions using WhAEM2000 depend on several parameters and equations as described in section (3.5.2). The calculations of these equations are detailed as following:

Well flow per day = Well flow * Operating hr

Well flow per day = 18 * 15 = 270 m^3/ day

The hydraulic gradient (i) = (Z coordination- DTW)/ Far from well to sea

i = (718 - 30)/ 66600 = 0.0103

The magnitude of the uniform flow rate ($Q\square$) = kHi

$Q\square$ = 3 * 88 * 0.0103 = 2.73 m^2/ day

The reference time $T_o = (nHQ)/ (2\pi Q\square^2)$

$T_o = (0.2 * 88 * 270)/ (2 * 3.14 * 2.73^2) = 101.74$ day

The shape and size of a simplified time-of-travel capture zone can be related to a dimensionless travel time parameter, $\check{T} = TOT/ T_o$

1. For TOT = 50 day

$\check{T} = 50/ 101.74 = 0.492$

When $0.1 < \check{T} < 1$, then

$R = L_s[1.161 + \ln(0.39 + \check{T})]$

Where $L_s = Q/ (2\pi Q\square)$

$L_s = 270/ (2 * 3.14 * 2.73) = 15.77$ m

$R_{50day} = 15.77 * (1.161 + \ln(0.39 + 0.492)) = 16.31$ m

The eccentricity $\delta = L_s[0.00278 + 0.652\check{T}]$

$\delta = 15.77 * (0.00278 + 0.652 * 0.492) = 5.10$ m

2. For TOT 2 years (730 days)

$\check{T} = 730/ 101.74 = 7.18$

When $\check{T} > 1$, then

$^{-}Q/ 2Q\square < y < {}^{+} Q/ 2Q\square \longrightarrow {}^{-}270/ (2 * 2.73) < y < {}^{+} 270/ (2 * 2.73) \longrightarrow$

$Y_{max} = 49.5$ m

$L_s = 15.77$ m

$L_u = L_s [\check{T} + \ln(e + \check{T})]$, where e = 2.718

$L_u = 15.77 * (7.18 + \ln (2.718 + 7.18)) = 149.25$ m

3. For TOT 5 years (1825 days)

$\check{T}$ = 1825/ 101.74 = 17.94

When $\check{T} > 1$, then

$^{-}Q/ 2Q\square < y < {}^{+}Q/ 2Q\square \longrightarrow$ Y_{max} = 49.5 m

L_s = 15.77 m

$L_u = L_s [\check{T} + \ln(e + \check{T})]$, where e = 2.718

L_u = 15.77 * (17.94 + ln (2.718 + 17.94)) = 330.53 m

Figure (4.11) represent the zones boundary of Al- Fawwar well no.1 at travel of time 50 days, 2 years, and 5 years.

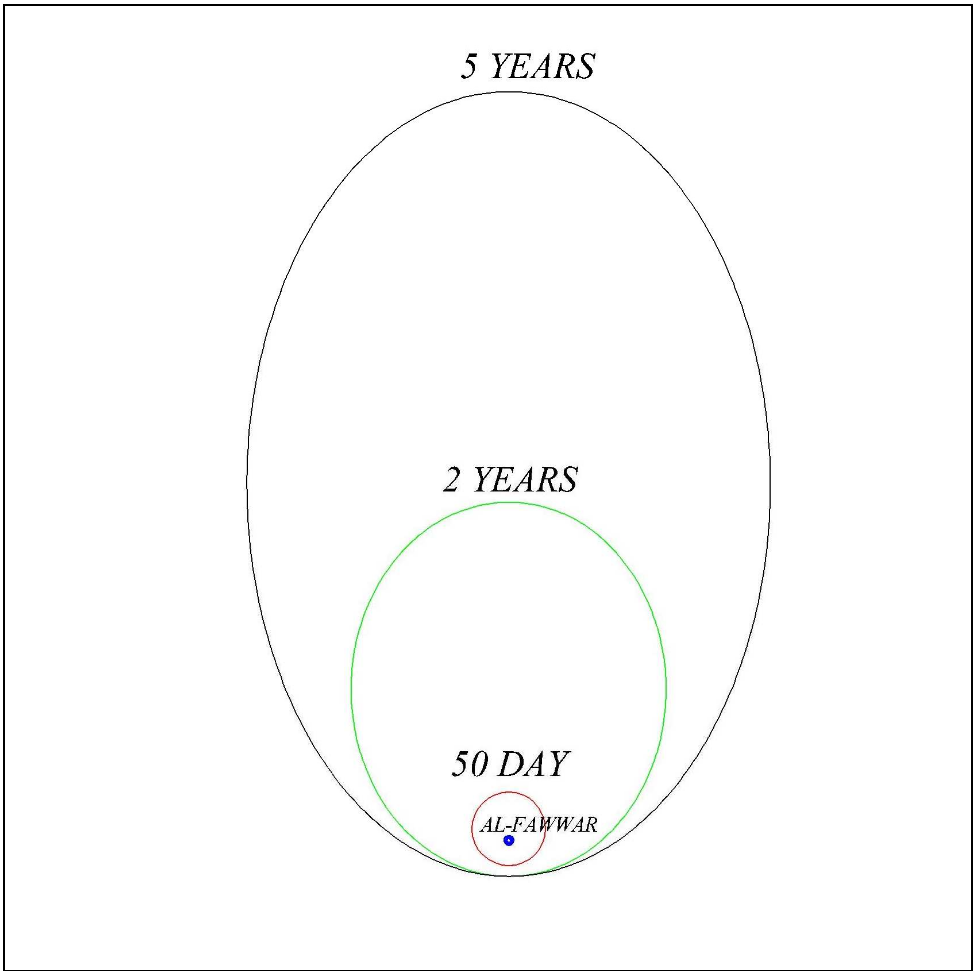


Figure (4.11): The zones boundary of Al- Fawwar well no. 1 by using WhAEM2000 at travel of time 50 days, 2 years, and 5 years.

The required data about Al- Fawwar well no. 2 that will be used in the calculations to delineate the boundaries of WHPA are shown in **Table (4.8)**.

Table (4.8): Al- Fawwar well no. 2 data (PWA database).

Parameter	**Symbol**	**Value**	**Unit**
Well flow	______	15	m^3/ hr
Operating hour	hr	10	hr/ day
Porosity	n	0.2	______
Aquifer thickness	H	88	M
Hydraulic conductivity	k	3	m/ day
Depth to water	DTW	13	M
Z coordination elevation	Z	718	M
Far from well to sea	F	66638	M
Time of Travel	TOT	50/ 730/ 1825	Day
Well flow per day	Q	150	m^3/day

The hydraulic gradient (i) = 0.0106

The magnitude of the uniform flow rate (Q□) = 2.79 m^2/ day

The reference time T_o = 53.89 day

1. For TOT = 50 day

Ť = 0.93
When 0.1 < Ť <1, then

R_{50day} = 12.3 m and δ = 5.2 m.

2. For TOT 2 years (730 days)

Ť = 13.55

When Ť > 1, then Y_{max} = 26.85 m, L_s = 8.55 m and L_u = 139.7m

3. For TOT 5 years (1825 days)

Ť = 33.87

When Ť > 1, then Y_{max} = 26.85 m, L_s = 8.55 m and L_u = 320.4m.

The WHPA radius according to different TOT that calculated by using CFR method and WhAEM2000 for AL- Fawwar wells 1 & 2 is summarized in **Table (4.9).**

Table (4.9): WHPA radius for Al- Fawwar well by using CFR & WhAEM2000

Method	CFR	WhAEM2000					
TOT	**r (m)**	**Ť**	**(0.1< Ť ≤1)**		**Ť > 1**		
			R (m)	**∂ (m)**	**L_s (m)**	**L_u (m)**	**Y_{max} (m)**
Al- Fawwar Well no. 1							
50 day	51.19	0.49	16.31	5.10	—	—	—
2 year	195.6	7.18	—	—	15.77	149.25	49.5
5 year	309.29	17.94	—	—	15.77	330.53	49.5
Al- Fawwar Well no. 2							
50 day	38.2	0.93	12.89	5.2	—	—	—
2 year	145.8	13.55	—	—	8.55	139.7	26.85
5 year	230.5	33.87	—	—	8.55	320.4	26.85

Note: WHPA direction - 55°

Note: the protection area for the 2 wells can be merged to produce on protection area that collects the 2 wells, where the center of the protection area will be on the midpoint between the 2 wells.

WhAEM2000 method provides more accurate delineation of the WHPA than CFR method. The WhAEM2000 is geo-hydrology computer model of groundwater flow, provides a more accurate delineation of the WHPA. It often produces a smaller area to manage than CFR method. The CFR method doesn't take into account regional groundwater flow, causing a hydraulic gradient. So the WHPAs identified by this method may be either too large or too small, resulting in wellhead overprotection or under protection.

According to the Jordanian and Palestinian laws in Zone 1, it is prevented for any person to exceed the fence that bounded the area around the well, it is also prevented to graze animals and dispose of any wastes. Where in the well field of AL- Fawwar there are many violations like grazing of animals as presented in **Figure (4.12)** and also there is a septic tank in the zone. The zone dimension of Al- Fawwar according to CFR r is 51.19m and according to WhAEM2000 R is16.31 m and ∂ is 5.1 m so should be prohibited in these dimension to graze animals or dispose waste. Where, in Zone 2 it is prevented to use fertilizers and pesticides. Where in the boundary of Zone 2 there are agricultural lands.

Figure (4.12): Violations of Laws in the boundary of Al- Fawwar wells field by grazing of animals in zone 1.

5 Chapter Five: Conclusion and Recommendations

5.1 Conclusion

From this research the following conclusions can be outlined:

- The lithology of Al- Fawwar wells 1 & 2 was concluded, three main layers were identified; Hebron formation, Bethlehem formation and Jerusalem formation that consist of dolomite, marl, and limestone.

- The evaluation of water quality of Al- Fawwar wells 1 & 2 was showed high concentration of nitrate in both wells that exceed the acceptable limits of nitrate in drinking water according to WHO and PWA standards for drinking water; so it make water unsuitable for drinking. It is concluded that nitrate contamination result from sewage disposal system because there is no sewer system in the catchment area and they depend on use cesspit and the use of animal manure, or nitrogen fertilizers because there is agricultural lands and greenhouses in the catchment area.

- Water budget of Al- Fawwar wells 1 & 2 field was calculated. The annual volume of: precipitation was 7.93 MCM, evapotranspiration was 5.70 MCM, surface runoff was 0.91 MCM, groundwater recharge was 1.83 MCM, spring production was 0.35 MCM, wells abstraction was 0.691 MCM and the remaining lateral outflow was 0.79 MCM. The evapotranspiration was representing about 72% of precipitation, the surface runoff was representing about 11.5% and the groundwater recharge was representing about 23%. The water loss from precipitation was calculated to be 83.5%.

- WHPA delineated to Al- Fawwar wells 1 & 2 by using two methods:
  1. The Calculated Fixed Radius (CFR)
  For Al- Fawwar well no. 1, the radius of 50 days zone was 51.19 m, for 2 year was 195.6 m and for 5 year was about 309.29 m.

  For Al- Fawwar well no. 2, the radius of 50 days zone was 38.2 m, for 2 year was 145.8 m and for 5 year was about 230.5 m.

2. Wellhead Analytic Element Model (WhAEM2000)

For Al- Fawwar well no. 1, the travel time parameter (Ť) of 50 days was 0.49, (0.1< Ť < 1), the radius (R) and the eccentricity (δ) was 16.31 m, 5.10 m respectively. For 2 year (Ť) was 7.18, (Ť > 1), the boat shaped radiuses Lu, Ls and Ymax were 149.25 m, 15.77 m, 49.5 m respectively. For 5 year (Ť) was 17.94, Ť > 1, the boat shaped radiuses Lu, Ls and Ymax were 330.53 m, 15.77 m, 49.5 m respectively.

For Al- Fawwar well no. 2, the travel time parameter (Ť) of 50 days was 0.93, (0.1< Ť < 1), the radius (R) and the eccentricity (δ) was 12.89 m, 5.2 m respectively. For 2 year (Ť) was 13.55, (Ť > 1), the boat shaped radiuses Lu, Ls and Ymax were 139.7 m, 8.55 m, 26.85 m respectively. For 5 year (Ť) was 33.87, Ť > 1, the boat shaped radiuses Lu, Ls and Ymax were 320.4 m, 8.55 m, 26.85 m respectively.

- In Zone1 for AL- Fawwar wells 1 & 2 it must prevent grazing and using cesspit. And in Zone 2 it must prevent using fertilizers and cesspit.

- WhAEM2000 method is better than CFR because it is geo-hydrology computer model of groundwater flow, provides a more accurate delineation of the WHPA. It often produces a smaller area to manage than other methods.

- CFR method is weak method because it does not take into account regional groundwater flow, causing a hydraulic gradient. WHPAs identified by these methods may be either too large or too small, resulting in wellhead overprotection or under protection.

5.2 Recommendations

According to the results of this research, it’s recommended to:

- Delineate WHPA for Al- Fawwar well and other wells using WhAEM2000 method.
- Study and apply of wellhead protection area before the construction of any new urban area.
- Create sewage network in the catchment instead of use septic and cesspit tanks.
- Recommended to build ponds to collect surface runoff water from streams during winter month to use it in agriculture instead of abstraction from wells.
- Prevent the random drilling of wells by applying the water and environmental laws.
- Long-term spatial and temporal monitoring of the water quality, especially the fecal coliform count, NO_3^- and Cl^- concentrations.
- Make rehabilitation of Al- Fawwar wells to maintain it as a source of drinking water in the catchment area.
- Build vulnerability map for Al- Fawwar wells catchment area.

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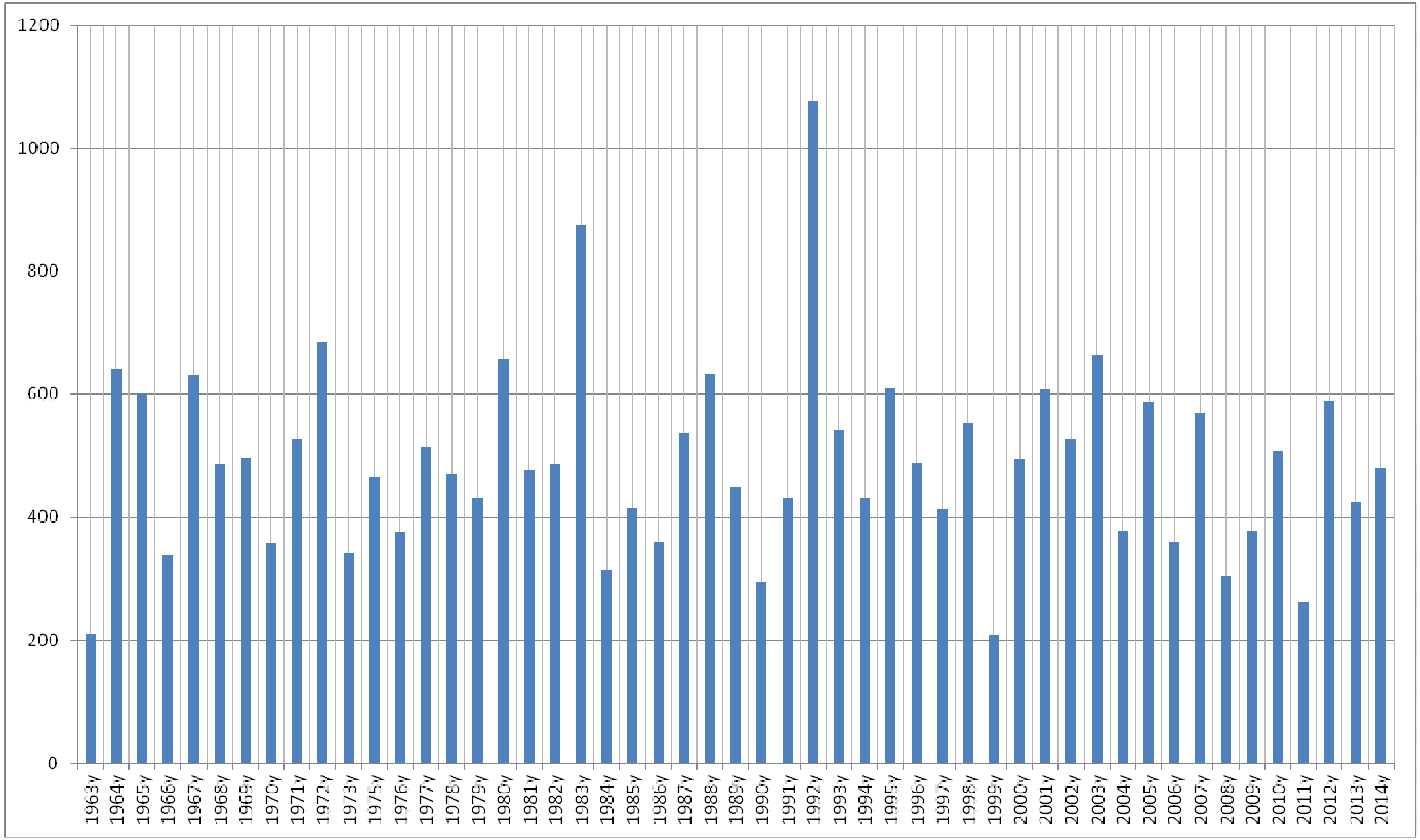
Appendix 1: Average of rainfall in study area during period from 1963- 2014 (Palestinian meteorological station, 2014).



Appendix 2: Water Level Data of Al- Fawwar Wells

Al-Fawwar well no.1 Water Level Data

Year	**Rainfall**	**WD m**	**Well Depth m**	**Aquifer Water Level m**
1968	487 mm	11	150	708
1969	496 mm	12	150	707
1970	357 mm	14	150	705
1971	527 mm	15	150	704
1972	684 mm	11	150	708
1973	341 mm	13	150	706
1974		11	150	708
1975	464 mm	12	150	707
1976	376 mm	15	150	704
1977	514 mm	13	150	706
1978	470 mm	12	150	707

Al-Fawwar well no.2 Water Level Data

Year	Rainfall	WD m	Well Depth m	Aquifer Water Level m
1968	487 mm	25	100	694
1969	496 mm	37	100	682
1970	357 mm	49	100	670
1971	527 mm	57	100	662
1972	684 mm	44	100	675
1973	341 mm	46	100	673
1974		38	100	681
1975	464 mm	49	100	670
1976	376 mm	55	100	664
1977	514 mm	50	100	669
1978	470 mm	64	100	655

Appendix 3: The Data of the Drilling and Dug Wells in Wadi abu Al-Qmra Area in Dura.

Name	ID	Type	Location	East	North	Elevation	Well depth m	Water use	Use	Productivity
البئر الشرقي - بلدية دورا	1	Open dug well	North .S.A	152800	101460	852	10	Agricultural	Yes	10 m^3
بئر محمود ربعي 1	2	Drilling well	North .S.A	152861	101400	845	20	Agricultural	Yes	2m3
بئر محمود ربعي 2	3	Drilling well	North .S.A	152838	101357	842	20	Agricultural	Yes	2m3
بئر محمود ربعي 3	4	Drilling well	North .S.A	152856	101348	843	20	Agricultural	Yes	5 m3
بئر محمود ربعي 4	5	Drilling well	North .S.A	152882	101349	845	20	Agricultural	NO	
بئر احمد طالب العواودة 1	6	Drilling well	North .S.A	152886	101302	847	19	Agricultural	Yes	2m3
بئر احمد طالب العواودة 2	7	Drilling well	North .S.A	152901	101297	846	20	Agricultural	Yes	3m3
بئر احمد طالب العواودة 3	8	Drilling well	North .S.A	152909	101295	844	19	Agricultural	Yes	2m3
بئر محمود طه العواودة 1	9	Drilling well	North .S.A	152908	101307	843	26.5	Agricultural	Yes	1m3
بئر محمود طه العواودة 2	10	Drilling well	North .S.A	152917	101322	842	28.5	Agricultural	Yes	2m3
بئر ماهر يوسف عمرو	11	Drilling well	North .S.A	152836	101219	845	27	Agricultural	Yes	2m3
بئر ابو شرار	12	Drilling well	North .S.A	152882	101115	859	27	Agricultural	Yes	2m3
بئر مريم هديب	13	Drilling well	North .S.A	152918	101211	848	23	Agricultural	Yes	3m3
بئر مصنع الغزاوي	14	Drilling well	North .S.A	152934	101370	843	25	Agricultural	Yes	1m3
بئرالدكتور يوسف عمرو	15	Drilling well	North .S.A	152955	101243	849	27	Agricultural	Yes	2m3
بئر اكرم كاظم الشريف 1	16	Drilling well	North .S.A	152954	101240	845	25	Agricultural	Yes	1.5m3
بئر اكرم كاظم الشريف 2	17	Drilling well	North .S.A	152979	101231	846	27	Agricultural	Yes	1m3
بئر اكرم كاظم الشريف 3	18	Drilling well	North .S.A	153020	101196	852	27	Agricultural	NO	
بئر موسى حسين الدرابيع 1	19	Drilling well	North .S.A	153066	101243	844	35	Agricultural	Yes	1m3
بئر موسى حسين الدرابيع 2	20	Drilling well	North .S.A	153086	101191	845	32	Agricultural	Yes	4m3
بئر خميس ربعي	21	Drilling well	North .S.A	153247	101089	843	28	Agricultural	Yes	0.5m3
بئر عايد عودة الله 1	22	Drilling well	North .S.A	153335	101160	841	25	Agricultural	Yes	6m3
بئر عايد عودة الله 2	23	Drilling well	North .S.A	153310	101201	841	30	Agricultural	N0	

بئر عايد عودة الله 3	24	Drilling well	North .S.A	153294	101256	837	35	Agricultural	Yes	6m3
بئر حسين شاهين	25	Drilling well	North .S.A	153306	101153	844	27	Agricultural	Yes	5 m3
بئر مجدي شحدة زامل	26	Drilling well	North .S.A	153369	101155	850	37	Agricultural	Yes	2m3
بئر عبد العزيز شديد1	27	Drilling well	North .S.A	153334	101196	842	30	Agricultural	Yes	2m3
بئر عبد العزيز شديد2	28	Drilling well	North .S.A	153336	101209	841	33	Agricultural	Yes	4m3
بئر عبد العزيز شديد 3	29	Drilling well	North .S.A	153337	101210	841	36	Agricultural	Yes	2m3
بئر عبد العزيز شديد 4	30	Open dug well	North .S.A	153361	101205	840	13	Agricultural	No	
بئر اكرام الشريف	31	Drilling well	North .S.A	153319	101225	839	30	Agricultural	No	
بئر محمد عزو دودين	32	Drilling well	North .S.A	153347	101266	836	30	Agricultural	No	
بئر غبد القادر دودين	33	Open dug well	North .S.A	153328	101331	827	8	Agricultural	Yes	5m3
بئر ال شاهين الدرابيع	34	Open dug well	North .S.A	153313	101332	838	7	Agricultural	Yes	6m3
بيارة عبد القادر يونس	35	Open dug well	North .S.A	153214	101382	849	8	Agricultural	Yes	6m3
بئر عيسى شاهين	36	Open dug well	North .S.A	153256	101215	835	8	Agricultural	Yes	2m3
بئر موسى شاهين 1	37	Drilling well	North .S.A	153159	101323	838	35	Agricultural	Yes	1m3
بئر كاظم الشريف	38	Spring	North .S.A	153113	101363	840	8	Agricultural	Yes	6m3
بئر موسى شاهين 2	39	Drilling well	North .S.A	153158	101324	838	35	Agricultural	Yes	1.5m3
بئر عبد العزيز عبد المجيد	40	Open dug well	North .S.A	154076	101135	812	31	Agricultural	Yes	2m3
بئر مصباح النمورة	41	Open dug well	North .S.A	154093	101150	814	8	Agricultural	Yes	5m3
بئر الوادي	42	Open dug well	North .S.A	154097	101141	823	8	Agricultural	No	
بئر عبد العزيز عبد المجيد عمرو	43	Open dug well	North .S.A	154049	101145	811	5	Agricultural	No	
بئر عادل مسلم الدروايش1	44	Open dug well	North .S.A	154033	101146	811	9	Agricultural	Yes	5m3
بئر عادل مسلم الدروايش2	45	Open dug well	North .S.A	153995	101114	811	9	Agricultural	Yes	3m3
بئر حجة القديم	46	Open dug well	North .S.A	154106	101106	813	0	Agricultural	No	--
بئر صلاح حجة	47	Open dug well	North .S.A	154158	101149	824	9	Agricultural	Yes	2m3
بئر علي حجة 1	49	Open dug well	North .S.A	154168	101119	815	6	Agricultural	Yes	1m3

بئر علي حجة 2	50	Open dug well	North .S.A	154166	101102	811	8	Agricultural	Yes	1m3
بئر علي حجة 3	51	Open dug well	North .S.A	154149	101089	810	8	Agricultural	Yes	8m3
بئر جمال محمد حسن عمرو1	52	Open dug well	North .S.A	153739	101144	826	7	Agricultural	No	
بئر جمال محمد حسن عمرو2	53	Open dug well	North .S.A	153688	101132	826	6	Agricultural	No	
حسن محمد حسين نصر	54	Open dug well	North .S.A	153647	101186	825	7	Agricultural	No	
بئر محمد راشد قطيط 1	55	Drilling well	North .S.A	153461	101254	829	25	Agricultural	No	
بئر محمد راشد قطيط 2	56	Drilling well	North .S.A	153419	101213	835	22	Agricultural	Yes	5m3
بئر خالد الشريف	57	Open dug well	Meddal.S.A	153436	101395	835	9	Agricultural	Yes	5m3
بئر محمد الشريف	58	Open dug well	Meddal.S.A	153459	101360	834	10	Agricultural	Yes	1m3
بئر النمورة1	59	Open dug well	Meddal.S.A	153515	101355	836	7	Agricultural	Yes	1m3
بئر النمورة2	60	Open dug well	Meddal.S.A	153479	101289	838	8	Agricultural	Yes	1m3
بئر 5 -------	61	Drilling well	Meddal.S.A	153477	101287	840	--	Agricultural	Yes	
بئر 6------	62	Open Well	Meddal.S.A	153464	101289	837	7	Agricultural	Yes	2m3
بئر شارع البلدية	63	Open Well	Meddal.S.A	153530	101249	839	12	Agricultural	Yes	1m3
بئر ابو شرار-قزاز	64	Open Well	Meddal.S.A	153595	101326	834	10	Agricultural	Yes	2m3
بئر الحريبات	65	Open Well	Meddal.S.A	153665	101341	830	9	Agricultural	No	
بئر عمر حسن عمرو	66	Open Well	Meddal.S.A	153634	101258	834	10	Agricultural	Yes	3m3
بئر البركة 11	67	Open Well	Meddal.S.A	153655	101291	832	8	Agricultural	Yes	4m3
بئر ابو شرار-قزاز 2 القديم	68	Open Well	Meddal.S.A	153557	101205	835	11	Agricultural	Yes	1m3
بئر نصر غرب*	69	Open Well	Meddal.S.A	153483	101182	838	12	Agricultural	Yes	2m3
بئر مركز الشرطة	70	Spring	Meddal.S.A	154527	101016	806	6	Agricultural	Yes	2m3
سبخة الواد ي1	71	Spring	Meddal.S.A	154490	101034	804	0.5	Agricultural	Yes	0.5
سبخة الوادي 2	72	Spring	Meddal.S.A	154443	101057	810	0.5	Agricultural	Yes	0.5
سبخة الوادي 3	73	Spring	Meddal.S.A	154401	101055	810	5	Agricultural	Yes	1m3
بئر عمرو	74	Open Well	Meddal.S.A	154381	101061	815	5	Agricultural	Yes	1m3

نبعة كمال عمرو 1	75	Open Well	Meddal.S.A	154593	100928	805	6	Agricultural	Yes	10m3
نبعة كمال عمرو 2	76	Open Well	Meddal.S.A	154637	100907	805	6	Agricultural	Yes	11m3
بئر محمد عبد الرحمن ابو زنيد	77	Open Well	Meddal.S.A	154657	100896	806	10	Agricultural	Yes	3m3
محمد يونس عودة الرجوب	78	Open Well	Meddal.S.A	154714	100845	814	5	Agricultural	Yes	2m3
يوسف جبر رجوب	79	Open Well	Meddal.S.A	154719	100837	815	7	Agricultural	Yes	1m3
محمد حسين عمرو1	80	Drilling well	Meddal.S.A	154584	100736	787		Agricultural	Yes	3m3
محمد حسين عمرو2	81	Drilling well	Meddal.S.A	154578	100741	791		Agricultural	Yes	4m3
بئر الدكتور يوسف عمر 2	82	Drilling well	Meddal.S.A	154553	100758	798	35	Agricultural	Yes	3m3
بئر عاهد قزاز	83	Drilling well	Meddal.S.A	154538	100730	798		Agricultural	Yes	3m3
بئر رياض قزاز	84	Drilling well	Meddal.S.A	154521	100737	805		Agricultural	Yes	3m3
بئر عمر عمرو	85	Open Well	Meddal.S.A	154497	100756	800	12	Agricultural	Yes	3m3
بئر فايز ابو سباع 1	86	Open Well	Meddal.S.A	154464	100773	802	10	Agricultural	NO	
بئر محمود قطيط	87	Open Well	Meddal.S.A	154452	100778	800	10	Agricultural	NO	
بئر فايز ابو سباع 2	88	Open Well	South.S.A	154489	100792	796	5	Agricultural	NO	
بئر وليد عمرو السيخ	89	Open Well	South.S.A	154559	100697	815	12	Agricultural	Yes	6m3
بئر وليد عمرو	90	Open Well	South.S.A	154577	100692	804	4	Agricultural	Yes	4m3
بئر وليد عمرو2	91	Open Well	South.S.A	154590	100676	799	8	Agricultural	Yes	3m3
البئر القديم الشرقي	92	Open Well	South.S.A	154599	100671	793	8	Agricultural	Yes	2m3
بئر الشرق 3	93	Open Well	South.S.A	154603	100659	798	6	Agricultural	Yes	1m3
بئر البركة الجديد	94	Open Well	South.S.A	154624	100644	794	10	Agricultural	Yes	6m3
بئر عين ديوان رجوب	95	Open Well	South.S.A	154807	100799	805	7	Agricultural	NO	
عبدالله عودة الرجوب	96	Open Well	South.S.A	154823	100774	803	4	Agricultural	Yes	5m3
بئر نبعة الرجوب	97	Open Well	South.S.A	154889	100747	812	6	Agricultural	Yes	2m3
بئر ديوان الرجوب	98	Open Well	South.S.A	154935	100736	810	5	Agricultural	Yes	2m3
بئر عودة الرجوب	99	Open Well	South.S.A	154965	100705	816	5	Agricultural	Yes	2m3

نبعة البركة / سطحي	100	Open Well	South.S.A	154929	100692	822	4	Agricultural	Yes	1m3
نبعة العين القديمة	101	Open Well	South.S.A	154979	100645	808	5	Agricultural	NO	
بئر تيسير محمد عودة الرجوب	102	Open Well	South.S.A	154962	100565	806	6	Agricultural	Yes	1m3
عين الشريف	103	Open Well	South.S.A	154687	100217	796	2	Agricultural	NO	
نزازة الشريف2	104	Open Well	South.S.A	154623	100338	804	8	Agricultural	Yes	1m3
بئر هاني الشريف	105	Drilling well	South.S.A	154920	100257	785		Agricultural	Yes	
بئر خالد ربعي	106	Open Well	South.S.A	155027	100171	786		Agricultural	Yes	
بئر الصخر /جنوب	107	Open Well	South.S.A	154983	100083	773	14	Agricultural	Yes	1m3
بئر الوداي	108	Open Well	South.S.A	154961	100036	771		Agricultural	Yes	
بئر عمرو 1	109	Drilling well	South.S.A	154981	99985	761		Agricultural	Yes	
بئر عمرو 2	110	Drilling well	South.S.A	154952	99975	763		Agricultural	Yes	
بئر العواودة المهجور	111	Open Well	South.S.A	155022	99710	805	8	Agricultural	NO	
بئر انور دودين	112	Open Well	South.S.A	155072	99623	754	30	Agricultural	Yes	4m3
عين الدلبة	113	Spring	South.S.A	154847	99116	785	3	Agricultural	Yes	50m3
بئر الفوار 1	114A	Well	South.S.A	156197	98207	718	100.5	Domestic	Yes	432m3
بئر الفوار 2	114 B	Well	South.S.A	156237	98202	720	100	Domestic	Yes	360m3
بئر طلب عمرو	115	Dug well	Al Majnonh	154447	99004	773	5	Agricultural	Yes	4m3
نبعة المجنونة 1	116	Spring	Al Majnonh	154394	99124	777		Agr -Dome	Yes	10m3
نبعه المجنونة 2	117	Dug well	Al Majnonh	154391	99090	780	6	Agricultural	Yes	4m3
عمرو 2	118	Dug well	Al Majnonh	154300	99014	773	5	Agricultural	Yes	4m3
قفيشة 1	119	Drilling well	Al Hijra	155946	99537	773	27	Agricultural	Yes	3m3
قفيشة 2	120	Drilling well	Al Hijra	155842	99647	782	28	Agricultural	Yes	3m3
ايهاب دودين 1	121	Drilling well	Al Hijra	155872	99586	775	30	Agricultural	Yes	3m3
ايهاب دودين 2	122	Drilling well	Al Hijra	155813	99602	773	31	Agricultural	Yes	3m3
ياسر مشارقة 1	123	Drilling well	Al Hijra	155749	99688	784	30	Agricultural	Yes	4m3
ياسر مشارقة 2	124	Drilling well	Al Hijra	155792	99672	784	30	Agricultural	Yes	3m3

خليل مشارقة	125	Drilling well	Al Hijra	155603	99733	790	30	Agricultural	Yes	5m3
محمد رومي	126	Dug well	Al Hijra	155699	99616	772	20	Agricultural	No	
ابو مقدم 1	127	Dug well	Al Hijra	155697	99679	773	23	Agricultural	Yes	5m3
ابو مقدم 2	128	Dug well	Al Hijra	155641	99680	781	22	Agricultural	Yes	5m3
ابو مقدم 3	129	Drilling well	Al Hijra	155649	99616	773	30	Agricultural	Yes	3m3
ابو مقدم 4	130	Drilling well	Al Hijra	155627	99592	772	30	Agricultural	Yes	3m3
خالد ابو مقدم	131	Drilling well	Al Hijra	155658	99580	769	17	Agricultural	Yes	5m3
محمد خالد دودين	132	Drilling well	Al Hijra	155678	99576	768	30	Agricultural	Yes	3m3
سلام دودين	133	Drilling well	Al Hijra	155638	99553	768	30	Agricultural	Yes	3m3
يوسف ابو مقدم 1	134	Drilling well	Al Hijra	155618	99560	770	30	Agricultural	Yes	3m3
يوسف ابو مقدم 2	135	Drilling well	Al Hijra	155604	99550	770	30	Agricultural	Yes	3m3
يوسف ابو مقدم 3	136	Dug well	Al Hijra	155546	99533	773	19	Agricultural	Yes	3m3
اياس محمد دودين	137	Dug well	Al Hijra	155564	99520	770	16	Agricultural	Yes	6m3
فراس دودين 1	138	Drilling well	Al Hijra	155457	99472	771	30	Agricultural	Yes	3m3
فراس دودين 2	139	Drilling well	Al Hijra	155449	99468	771	30	Agricultural	Yes	3m3
فراس دودين 3	140	Dug well	Al Hijra	155396	99449	771	9	Agricultural	Yes	5m3
عين الدلبة	141	Spring	Al Hijra	155533	99374	760	10	Agr -Dome	Yes	12m3
احمد عمرو	142	Dug well	Wad Sweety	152778	100201	865	7	Agr -Dome	Yes	3m3
جمال عمرو	143	Dug well	Wad Sweety	152737	100173	862	7	Agr -Dome	Yes	5m3
عبدالله ابو شرار	144	Dug well	Wad Sweety	152834	100121	852	7	Agr -Dome	Yes	5m3
امطير النمورة1	145	Dug well	Wad Sweety	152583	99991	838	12	Agr -Dome	Yes	5m3
امطير النمورة2	146	Dug well	Wad Sweety	152532	99993	839	12	Agr -Dome	Yes	5m3
امطير النمورة 3	147	Dug well	Wad Sweety	152524	99927	835	12	Agr -Dome	Yes	5m3
عبد اللطيف النمورة	148	Dug well	Wad Sweety	152499	99966	837	12	Agr -Dome	Yes	5m3
مروان النمورة	149	Dug well	Wad Sweety	152427	100008	841	13	Agr -Dome	Yes	5m3
جمال عمرو 2	150	Dug well	Wad Sweety	152472	99982	840	14	Agr -Dome	Yes	5m3

رائد ابو شرار	151	Dug well	Wad Sweety	152497	99807	836	8	Agr -Dome	Yes	5m3
محمد موسى خلاف	152	Dug well	Al Majoor	153171	99717	821	6	Agr -Dome	Yes	5m3
سعيد خلاف	153	Dug well	Al Majoor	153165	99783	827	6	Agr -Dome	Yes	5m3
طه عمرو	154	Dug well	Al Majoor	153055	99848	827	6	Agr -Dome	Yes	5m3
أمين ربعي	155	Dug well	Al Majoor	153414	99797	814	6	Agr -Dome	Yes	5m3
محمود ربعي	156	Dug well	Al Majoor	153280	99824	821	6	Agr -Dome	Yes	5m3
جمال يوسف عمرو	157	Dug well	Al Majoor	152760	99917	826	9	Agr -Dome	Yes	5m3
جمال يوسف عمرو2	158	Dug well	Al Majoor	152808	99933	826	9	Agr -Dome	Yes	5m3
نبعة عيون الفريديس	159	Spring	Al Majoor	152713	99871	824	1	Agr -Dome	Yes	3m3

Appendix 4: Coordination of Pollution Sources in the Study Area

Name	ID	Type	Location	East	North
Al janob comp- G.S	1	G.S	N.E	155460	101226
Dura comp- G.S	2	G.S	Central	153347	101520
Yamane Sharawna G.S	3	G.S	W	152745	101814
Al Fawwar G.S	4	G.S	E	155377	99302
Al janob O.M	5	O.M	Central	153917	101239
Aljamaia	6	O.M	E	155369	98718
Loley Comp	6	I.C	Central	153915	101295

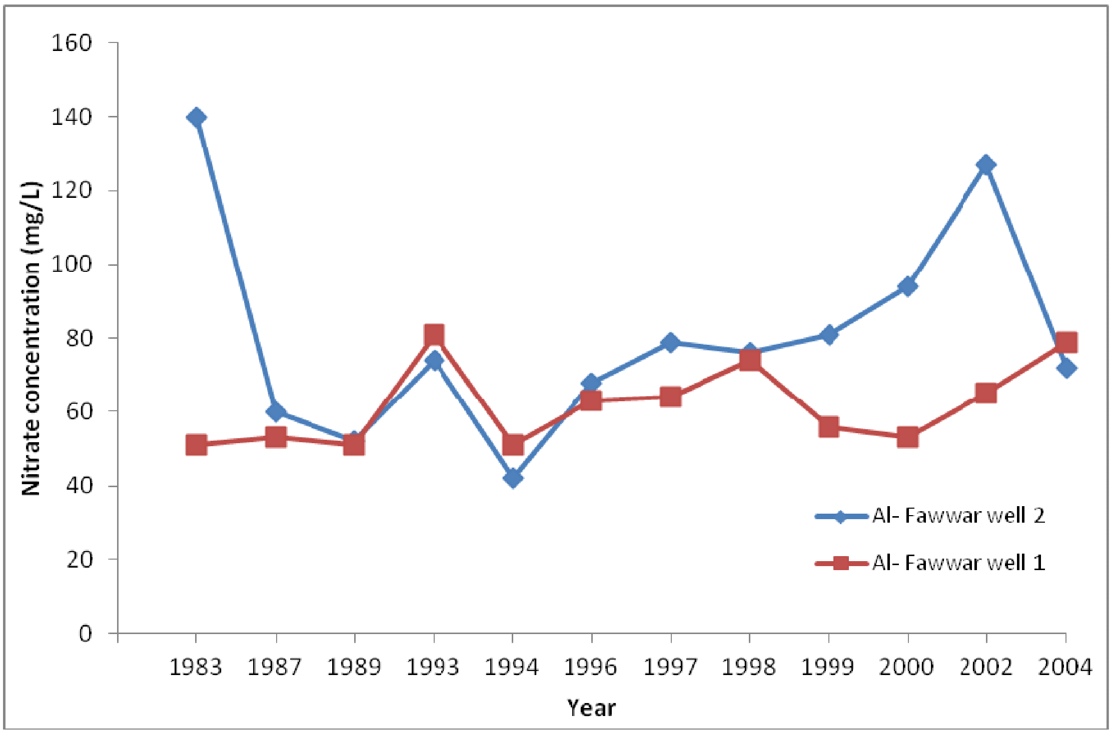
Appendix 5: Photos for Pollution Sources in the Catchment.

Disposed olive mill wastewater from olive mill in the catchment area

Agricultural land beside Al- Fawwar wells field

Wastewater and animals inside Al- Fawwar wells field

Appendix 6: Nitrate Concentration during the Period of (1983- 2004) in Al- Fawwar Wells 1 & 2.



الملخص بالعربية

تقييم مصادر المياه الجوفيه وخطة حماية حرم البئر في منطقة الفوار

الاسم "مجد ياسر الدرابيي!

تعتبر آبار الفوار (رقم 1 ورقم 2) مصدر رئيسي للمياه حيث تزود ل من (م!يم الفوار و حد) الفوار وقري" ال'$ر& وال$ز% ال$#وبي لمدي#" ال!ليل) بمياه ال,ر)+ زياد* (دد الس ان 2د1 ال/ زياد* ال4ا) (ا/ المياه و2ي3ا 2د1 ال/ زياد* معد. - التلوث5

ت'د ; :9* الدراس" ال/ تحديد حرم لحماي" آبار الفوار 8ي محا78" ال!ليل+ حيث تفتقر ال3ف" ال=ربي" لو$ود م<ل :9ه الدراسا- التي ت'د ; ال/ حماي" آبار مياه ال,ر) من مصادر التلوث المحتمل" با.(تماد (ا/ قوا#ين سل4" المياه الفلس4ي#ي" لحماي" المياه ال$و8ي"5 با<3ا8" لتحديد مصادر التلوث التي ت?<ر (ا/ المياه ال$و8ي" 8ي م#4" الحصاد للدراس"5

تم تحديد ال4بقا- الم و#" @بار الفوار من !Bل است!دام 4ري6" 8حA المقاوم" ال 'ربائي" العمودي" لل4بيع" الفيزيائي"5 تم تحديد <Bث ت وي#ا- رئيسي"C ت وين ال!ليل وت وين بي- لحم وت وين ال6دD وتت ون :9ه الت وي#ا- من الدولومايا- والح$ر ال$ير& وال4مي5

تم حسا) الميزا#ي" المائي" لم#4" الحصاد @بار الفوار+ حيث تبلE مساح" م#4" الحصاد 1F م^2 و ان ح$م ل منC الم4ر G5HI مليون متر والتب!رJال#تK L5GM مليون متر م ع) وال$ريان الس4حي M5H1 مليون متر م ع) والت=9ي" للمياه ال$و8ي" 15NO مليون متر م ع) وا#تا$ي" (ين الدلبي M5ILO مليون متر م ع) ومعدل P3 ا@بار M5FH1 مليون متر م ع)5 ي, ل التب!رJال#تK ما #سبتQ 2RG من معدل اS4مار وي, ل ال$ريان الس4حي ما #سبتQ R115L وت, ل الت=9ي" ما #سبتQ 2R5I معدل الفاقد من مياه اS4مار يعادل 5RNI5L

يو$د العديد من مصادر التلوث 8ي م#64" حصاد الدراس" حيث ت,مل 2را T زرا(ي" تعتمد (1/ است!دام اSسمد* والمبيدا- الزرا(ي" با<3 8ا" ل است!دام الحفر ا<متصاصي" #تي$" (دم و$ود ,ب ا- صر ; صحي5 الW9 تم 8حA $ود* مياه آبار الفوار+ 7'ر- ال#تائV ارتفاU #سب" ال#يترا ي- 8ي المياه (1M2 و 1MO ملXE لتر) و:9ه التراكيز تتعد1 الحد المسموY بQ لتر يز ال#يترا ي- 8ي مياه ال,ر) حس) قوا#ين م#7م" الصح" العالمي" و سل4" المياه الفلس4ي#ي"5 و7'ر- #تائV الفحA البيولو$ي ([ ] [\ ] Z) ب^ن تر يز:ما (صفرX 1MM ملم) و:9ا يت#اسب) مـ قوا#ين م#7م" الصح" العالمي" وسل4" المياه الفلس4ي#ي"5

تم است!دام 4ري6تين م!تلفتين لحسا) حدود م#ا4` حماي" حرم البئر @بار الفوار5 4ري6" حسا) ال46ر ال<اب- و4ري6" ال#م9$" التحليلي" لع#اصر حرم البئر التي تست!دم من قبل و ال" حماي" البيئ" 8ي الو.يا- المتحد* اSمري ي"5 7'ر- ال#تائV Q#2 (#دما است!دام 4ري6" حسا) ال46ر ال<اب- 8a#ن #صـ; ق4ر م#64" الحماي" اSول/ لبئر الفوار رقم 1 يساو& L151H متر و#صـ; ق4ر م#64" الحماي" ال<ا#ي" يساو& 1HL5F متر و#صـ; ق4ر م#64" الحماي" ال<ال<" يساو& IMH52H متر5 #صـ; ق4ر م#64" الحماي" اSول/ لبئر الفوار رقم 2 يساو& IN52 متر و#صـ; ق4ر م#64" الحماي" ال<ا#ي" يساو& 1OL5N متر و#صـ; ق4ر م#64" الحماي" ال<ال<" يساو& IM5L 2 متر و7'ر- #تائV است!دام 4ري6" ال#م9$" التحليلي" لع#اصر حرم البئر لبئر الفوار رقم 1 2ن b c 1F5I1 متر و ∂ c L51M متر لم#64" الحماي" اSول/ 5 و2ن 2#صا ; 2ق4ار ال, ل ال6اربي لم#64" الحماي" ال<ا#ي" de و df و g h i j ا#- 1OH52L متر و 1L5GG متر و OH5L متر (1/ التوالي5 و2ن 2#صا ; 2ق4ار ال, ل ال6اربي لم#64" الحماي" ال<ال<" de و df و g h i j ا#- IIM5LI متر و 1L5GG متر و OH5L متر (1/ التوالي5 2ما م#64" حماي" حرم بئر الفوار رقم 2 68د ا#- b c 125NH متر و ∂ c L52 متر

لم#64" الحماي" اSول/5 و2ن #2صا ; 2ق4ار ال, ل ال6اربي لم#64" الحماي" الا<#ي" de و df و g h i j ا#- 1HI5G متر و N5LL متر و 2F5NL متر (ا/ التوالي5 و2ن #2صا ; 2ق4ار ال, ل ال6اربي لم#64" الحماي" الا<ا<" de و df و g h i j ا#- I2M5O متر و N5LL متر و 2F5NL متر (ا/ التوالي5

يو$د العديد من الم!الفا- 8ي حرم بئر الفوار والتي ي$) م#ع'ا لت4بي` م#ا4` حماي" حرم البئر5 ت,مل :9ه الم!الفا- الر(ي واست!دام الحفر ا<متصاصي" للت!اA من المياه العادم" دا!ل حدود م#64" الحماي" اSول/5 با<3ا8" <ست!دام المبيدا- الزرا(ي" واSسمد* 8ي اSرا3ي الزرا(ي" التي ت6_ 8ي م#64" الحماي" الا<#ي"5 توصي :9ه الرسال" باست!دام 4ري6" ال#م9$" التحليلي" لع#اصر حرم البئر لتحديد م#ا4` الحماي" الا<Bث @بار مياه ال,ر)5