An-Najah National University

Faculty of Graduate Studies

Modeling of Groundwater Budget for the Shallow Unconfined Aquifer in the Faria Catchment

By

Majd Farhan Al-Suwadeh

Supervisor

Dr. Sameer Shadeed

Co-Supervisor

Dr. Abdelhaleem Khader

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This thesis was defended successfully on 5 /12 /2016 and approved by:

Defense committee Members	**Signature**
– **Dr. Sameer Shadeed/Supervisor**	…..……………..
– **Dr. Abdelhaleem Khader/Co-Supervisor**	…………………
– **Dr. Marwan Ghanem /External Examiner**	…………………
– **Dr. Hafez Shaheen /Internal Examiner**	…………………

Dedication

I humbly dedicate this thesis to my family, namely my parents Farhan & Arwa, who taught me to keep my head up and my eyes focused on the road that leads me to my goal, my beloved husband Salameh for encouraging me to spread my wings and fly, and to his invaluable support. My brother and sisters, thanks for supplying me of permanent enthusiasm and filling my life with smiles.Also, I am specially dedicate this work tothe angelic face; my dear little son Yousef, who brought me all the good once his arrival to the world.

Thank you all for your unconditional love, guidance and motivation.

Thank you for all that you did and all that you are doing.

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الإقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان

Modeling of Groundwater Budget for the Shallow Unconfined Aquifer in the Faria Catchment

أقر بأن ما شملت عليه **الرسالة** هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وأن هذه الرسالة ككل أو أي جزء منها لم يقدم من قبل لنيل أي درجة أو لقب علمي أو بحثي لدى أي مؤسسة علمية أو بحثية.

Declaration

The work provided in this thesis, unless otherwise referenced, is the researcher's own work, and has not been submitted elsewhere for any other degrees or qualifications.

Student's Name:	**اسم الطالب:**
Signature:	**التوقيع:**
Date:	**التاريخ:**

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Abstract

This research aims to find the groundwater budget in theshallow unconfined aquifer system of the Faria catchment which is one of the most important water catchments in Palestine because of its agriculture importance.It is located in the northeastern part of the West Bank and extends over the eastern and the north eastern groundwater aquifers with a total area of 320 km^2.

The Lumped Parameter Model was employed to quantify the water budget in the study area which is divided into three sub-catchments; Al-Faria, Al-Badan and the Lower. The principle of water mass balance was applied on each sub-catchment to get the water storage.

All input and output parameters to the model domain were analyzed and processed using Excel and GIS softwares. Recharge components to the aquifer consist of rainfall, irrigation return flow, water distribution networks leakage and East-Nablus wastewater leakage. Conversely, water discharge from the aquifer comprise ofwater pumped out from agricultural wells in addition to springs discharge.

The model resulted in a positive groundwater budget, which means a surplus of groundwater in the shallow unconfined aquifer under the three sub-

catchments.Proper water management options were suggestedto utilize the available excess groundwater to enhance and strengthen the agricultural sector in the catchment.

Tapping new agricultural wells in suitable locations in the catchment is the main proposed management option. The pumped surplus water is proposed to be used in irrigation activities of new cultivation areas and successful economic crops thatcommensurate with the conditions of thesub-catchments.

It is necessary to treat East-Nablus wastewaterto stop infiltration into the groundwater, which will be collected and transmitted by piping system and utilized safely in irrigation activities.In addition to suggest the necessity to treat East-Nablus wastewaterbefore infiltrated into the groundwater, which will be collected and transmitted by piping systems to be utilized safely in irrigation activities.

The development of the suggested management options seems an important requirement for the development of the water resources in the catchment and improving its socio-economic conditions.

Chapter One

Introduction

1.1 General Background

Approximately one third of the world's land area can be classified as arid to semi-arid regions (Rogers, 1981). In the arid and semi-arid regions of the world, water resources are limited, and under severe and increasing pressure due to expanding populations and increasing per water demands for domestic and agricultural use (Wheateret al., 2007). All of which resulted from urbanization, that led to shortage in fresh water and more dependence on groundwater sources.

Groundwater is the subsurface water that occurs beneath the water table in the soils and geologic formations that are fully saturated(Freeze and Cherry, 1979).As withdrawal from groundwater aquifer increase continuously, serious depletion in groundwater table resulted. Hence, there is a need to quantify and study groundwater budget in the aquifer system which leads to a better resources management.

Groundwater budget gives an indication about water availability in the aquifersand is obtained by defining all the input and output parameters to the aquifer system to get water storage. This can be reached using groundwater modeling which is considered an essentialtool to evaluate the groundwater flow and quantify its potential (Tesfaye, 2009).

Faria catchment, located in the northeastern part of the West Bank is considered oneof the most important catchments in the region due to the intense agricultural activities (Abboushi, 2013). Its aquifer system is contained within the two main aquifers; the eastern and the north eastern aquifers.

The upper groundwater aquifer system of the Faria catchment is usually utilized through springs and agricultural wells which are used also for domestic use. During wet years, when the springs dischargeis high, abstraction from wells reduces while pumping increases in dry years (Shadeed et al., 2011).

Increasing the number of the drilled agricultural wells in the shallow unconfined aquifer and increasingtheir abstraction, had led to drying up the existing springs. All of which caused from population's growing and consequently risingtheir water needs.

Hence, it is of importance to simulate the aquifer system and find the aquifer water budget, which gives an impression about the aquifer water budget, which gives an impression about the aquifer storage status whether it has water deficit or surplus.

Groundwater models are conceptual descriptions or approximations that describe physical systems using mathematical equations. The applicability or usefulness of a model depends on how closely the mathematical equations approximate the physical system being modeled (kumar, 2002).

Modeling process requires large amount of specific physical data which makes it a difficult process and the modelmore vulnerable to uncertainty, especially in complex hydro-geological regions like the Faria aquifer system. One of the most common modeling types which have the advantages in requiring fewer input parameters and that is not interested in their spatial distribution is the Lumped Parameter Model (LPM) which is preferred in data lack catchments.

The LPM is a single-cell model used to build the hydrological model of the aquifer system in and is converted eventually to numerical model.

This research employs the LPM in finding the water budget in the unconfined shallow aquifer system of the Faria catchment using water balance equations. Quantifyingthe available water storage in the aquifer, many management options are proposed and arerelated to the agricultural sector based on the obtained results of the water budget of the aquifer.

1.2 Research Objectives

The main goal of this research is to determine the water budget of the unconfined aquifer system in the Faria catchment by developing a quantity LPM.

The following objectives are achieved:

1. Determine water balance and the groundwater budget of Al-Faria aquifer system.
2. Provide information for water resources manager to understand the behavior of the aquifer, and thus support decision making processes regarding the future development of groundwater aquifer in theFaria catchment.
3. Propose some water management options based on obtained results.

1.3 Research Questions

1. What is the water budget of the unconfined shallow aquifer of the Faria catchment?

2. What is the main water input and output components to the unconfined aquifer system of the Faria?
3. What is the aquifer available water storage that can be pumped and utilized in the aquifer?
4. What are the aquifer management options that can be proposed according to the resulted water budget?

1.4 Importance of the Study

To the best of our knowledge, the Faria catchment does not have a groundwater budget model for its shallow unconfined aquifer. This research will provide a good basis for simulating many different future scenarios for the aquifer system.

Groundwater is the main water source in the Faria catchment.For this reason, understanding the issues related to its behavior is needful.The groundwater in the catchment is highly utilized for irrigation purposes since it is considered as a very important agricultural region. It is described as the food basket of North Palestinebecause of its intensive agricultural activities.

Hence, it is of importance to simulate the aquifer system and to find if there is available water storage that can be utilized in the study area, mainly in agricultural activities which in turnpromote the socio-economic conditions in the Faria catchment.

1.5 Methodology

The overall methodology of this research study is comprised of three major steps as shown in Figure (1.1).

Relevant data of the study area has been collected from previous studies, literature review, and data bank of Palestinian Water Authority (PWA), Palestinian Metrological Department (PMD), database of Water and Environmental Studies Institute (WESI) and Palestinian Central Bureau of Statistics (PCBS). Data include: Data include: water supply, water demand, population, geological formations, cross sections, topography, soil and land use, climatic data, pumping rates and springs discharge. Most of the obtained data have been formulated in GIS-format (Shape files).

The second step starts by analyzing the collecteddata in the first step using ArcGIS and MS Excel. Thereafter, LPM is used in assessing groundwater budget. The study area is divided into three sub-catchments; Faria, Badanand the lower sub-catchment. For each sub-catchment, the potential available groundwater is obtained by setting up the LPM and applying it to different elements of water budget equation.

The third step is to optimally manage the available groundwater in the study area. Hence, different management options have been proposed. This helps the decision makers to adopt the obtained results to sustainable water resource management in order to promote and support the study area and the socio-economic situations.

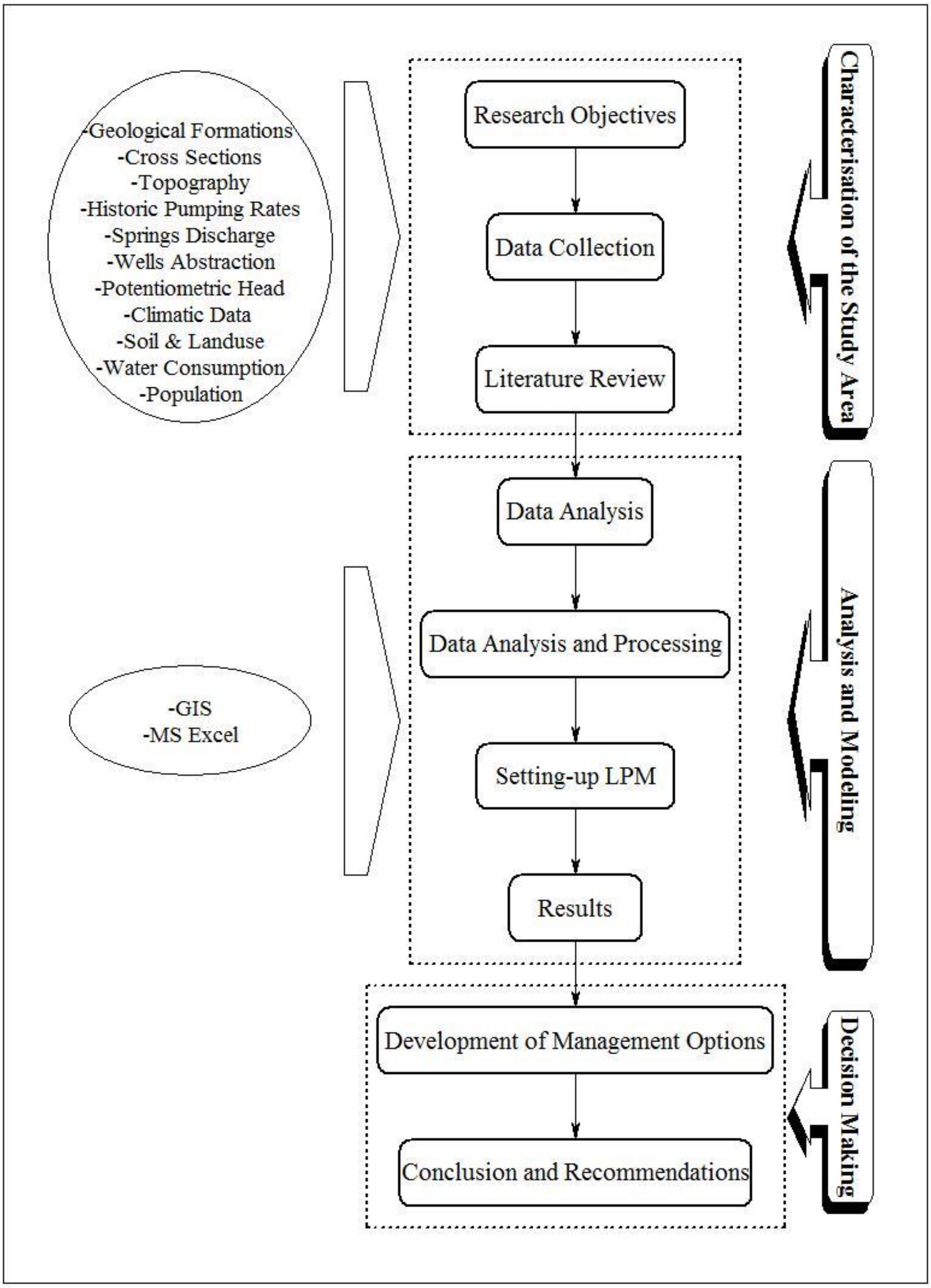

Figure (1. 1): Methodology Flowchart

Chapter Two

Study Area Description

2.1 Location

Faria catchment is one of the major arteries draining into the Jordan River. It is located in the northeastern portion of the West Bank, Palestine and extends over Nablus, Tubas and Jericho governorates.

The catchment extends 30 km from Nablus in the West to the Jordan River in the East. The catchment is completely contained within two of the main West Bank Aquifers which are the Eastern and the Upper North Eastern Aquifers as shown in Figure (2.1).

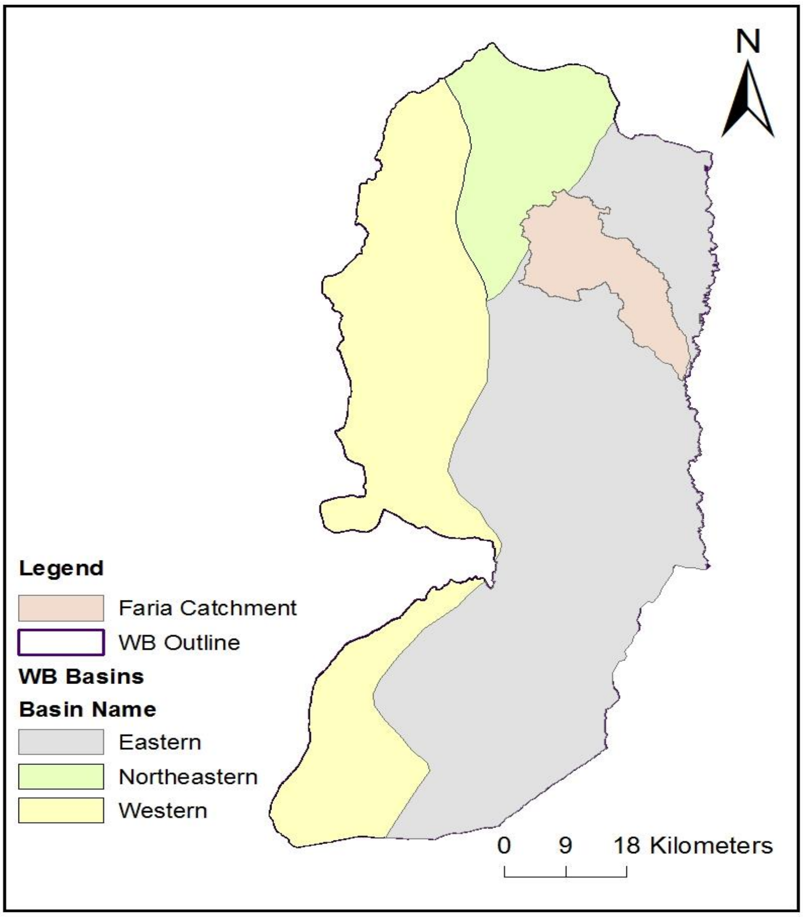

Figure (2. 1): Location ofFariaCatchment and the Main Groundwater Basins in theWest Bank

The watershed is tee-shaped with an area of 320 km^2, which accounts for about 6% of the total area of the West Bank (EQA, 2004). It is divided into three sub-catchments which are: Al-Faria (56 km^2), Al-Badan (83km^2) and the Lower (181km^2) as shown in Figure (2.2). Al-Faria and Al-Badan sub-catchments contain most of the water springs and catch most of the rain water falling within the catchment (Salahat, 2008).

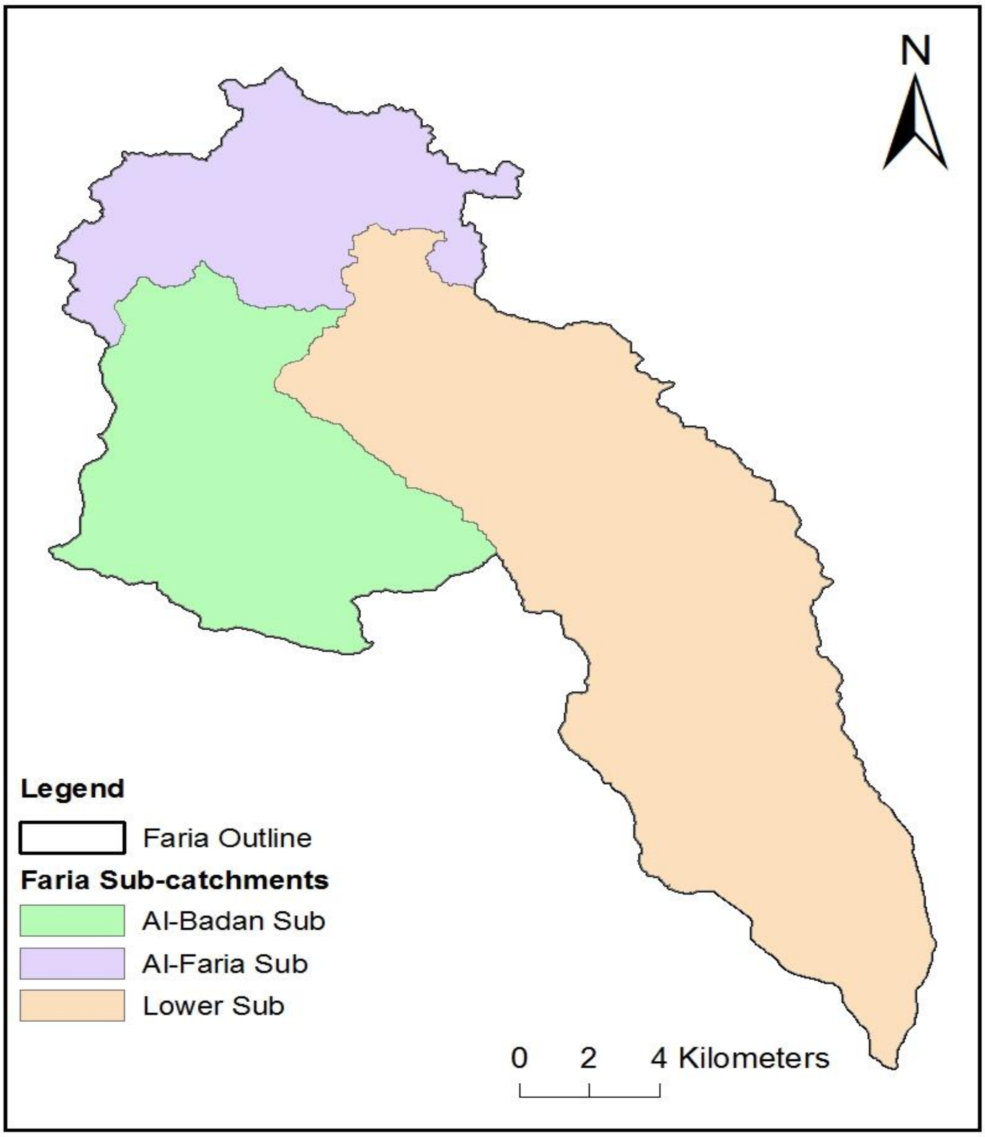

Figure (2. 2): Outline of Faria Sub-catchments

2.2 Geology

2.2.1 Regional Setting

Palestine is located in the northwestern part of the Arabian shield. Duringits geologic history, this shield separated from the great Afro-Arabianshield along the Red Sea line. A branch of this breakage extended along the line of Aqaba, WadiAraba, the Dead Sea, and the Jordan Valley, and continued northwards to Lebanon, Syria, and Turkey. The West Bank occupies an area west of this branch known as the Jordan Rift Valley (Ghanem. 1999).

The Arabian shield consists of a complex of crystalline plutonic andmetamorphic rocks. The western and northern parts of the shield receivedlarge amounts of erosion products. These sediments known as the shelfdeposits lay with unconformity over the basement rocks. Within the shielddeposits, two sedimentary mantles dominate, one is Terrestrial and theother is Marine. An inter-fingering of nitrite and lateral deposits characterizes the Terrestrial mantle. The Marine mantle dominates in theWest Bank and consists in particular of carbonate deposits from the Mesozoic-Cenozoic age (Ghanem, 1999 and EQA, 2004).

Aquifer geologycan be easily considered according the general lithology and structure headings.

Lithology is concerned with rock types, their formation and characteristics. Important hydraulic characteristics are permeability and porosity. The structure of an aquifer refers to the deformations in the strata caused by folding, faulting, uplift and other tectonic events (Saleh, 2009).

2.2.2 Stratigraphy and Lithology of the West Bank

The majority of the exposed rocks in the West Bank are Marine sedimentsparticularly made of carbonate such as limestone, dolomite, chalk and chert.

These rocks extend by age from lower Cretaceous to Quaternary. Jurassic rocks have limited exposures in the West Bank (Rofe and Raffety, 1965). The geological column of the West Bank is shown in Table (2.1) that illustrates its stratigraphy and lithology (EQA, 2004).

Table (2. 1): Geological Column for the West Bank(EQA, 2004)

Period		Age	Typical Lithology	Palestinian Terminology			Israeli Terminology	Jordanian Terminology	Typical Thickness (m)
				Group	Formation	Symbol			
Quaternary		Holocene	Alluvium, gravels, fan deposits, and surface crust (Nari).		Alluvium	All	Alluvium	Alluvium	0-100
		Pleistocene	Thinly laminated marl with gypsum bands, and poorly sorted gravel and pebbles.		Lisan	Lis	Lisan/ Kurkar Group	Lisan	Unknown
Tertiary		Pliocene-Miocene	Conglomerate, marl, chalk, clay, and limestone.		Beida	Bei	Saqiya Group	Dana	± 200
		Eocene	Numulitic limestone, reef limestone, bedded limestone, limestone with chalk, chalk with limestone (undifferentiated).		Jenin	Jen	Avedat Group	Rijam & Shallala	300-600
		Paleocene	Marl, clay, and chalk.	Gerzim	Khan Al Ahmar	KhA	Taqiya		150
Cretaceous	Lower Upper	Maastrichtian	Chalk, marl, metamorphic rocks.				Ghareb	Muwaqar	55
		Campanian	Phosphate, and chert		Al Qilt	Qil	Mishash	Amman & Hisa	50-75
		Coniacian-Campanian	White chalk, Chalky limestone, chert, and phosphate		Abu Dis	ADi	Minuha	Ghudran	50-175
		Turonian	Karstified limestone, and dolomite.	Ramallah	Jerusalem	Jer	Bina	Wadi Sir	40-120

2.2.3 Stratigraphy and Lithology of Faria Catchment

The Faria catchment is characterized as being composed of complicated and diverse geological structures dominated by small faults. The geologicalstructure of the study area is composed from limestone, dolomite and marl (Shadeed, 2005).

Rocky outcrops in the Faria catchment range in age from Cretaceous toQuaternary. Partly due to cross faulting Jurassic limestone's and Kurnub sandstones (Ramali Formation), the oldest rocks in the area, are exposed in the core of Faria anticline (EQA, 2004).The geologic formations which exist in Al-Faria catchment are presented in Table (2.2).

Table (2.2): The Layers Existed Above the Saturated Zone in Faria Catchment (EQA, 2004)

Geologic Formation	Depths Ranges	Lithology
Jenin Formation	Up to 200 m	Reef limestone, bedded limestone,limestone with chalk
Jerusalem Formation	(50-120) m	Thinly bedded limestone and Dolomite
Hebron Formation	(105-260) m	Harddolomistic limestone and chert rocks
Bethlehem Formation	(40-110) m	Limestone, dolomite with chalk, and marl massively bedded with a well-developed karst
Upper BeitKahil Formation	(10-50) m	Dolomite and dolomistic limestone
Yatta Formation (Aquitard)	Upper Yatta: (5-15) m Middle Yatta: (40-50) m	Marly limestone interbedded with dolomistic limestone or dolomite. This formation has outcrops at small localities in the middle and upper part of the catchment

The above formations are illustrated in the two cross sections shown in Figures (2.3 and 2.4) that are crossing the Fariacatchment (Saleh, 2009).

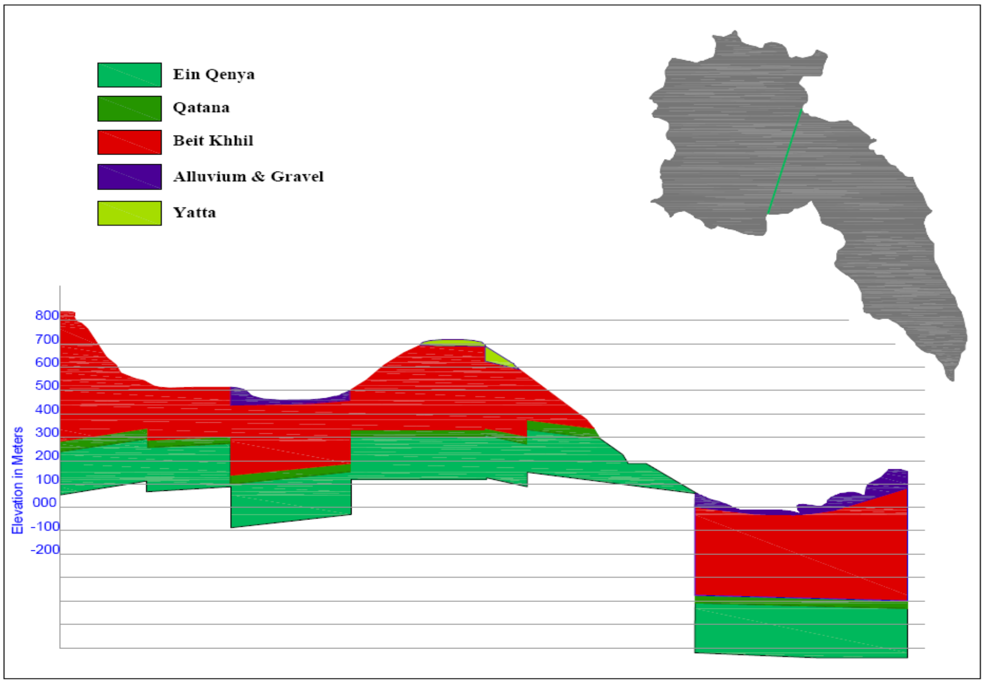

Figure (2. 3): Cross Section 1 in Al- Faria Catchment

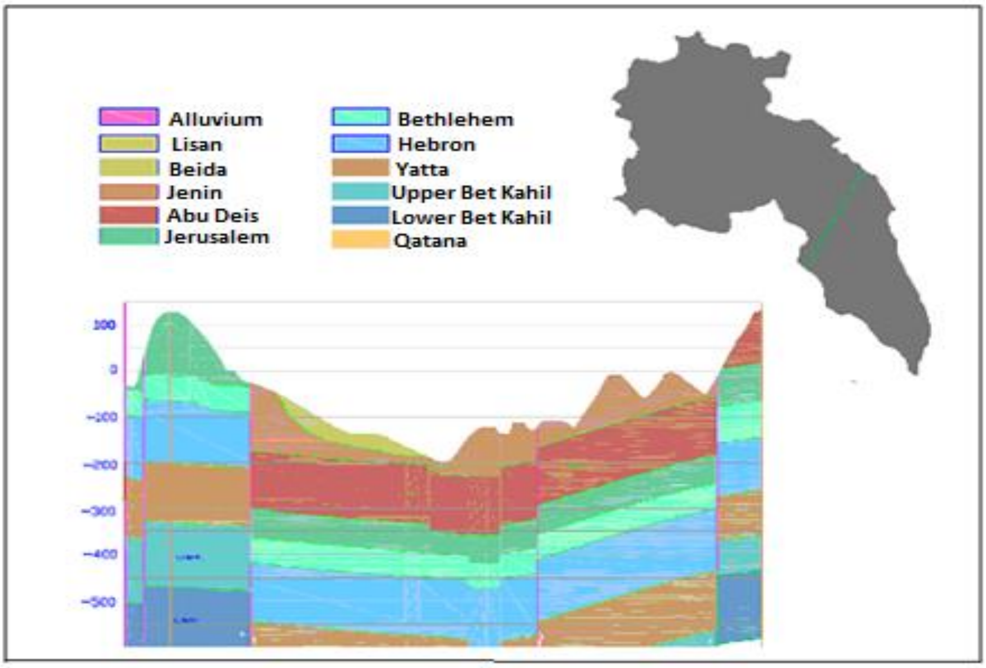

Figure (2. 4): Cross Section 2 in Al- Faria Catchment

Figure (2.5) illustrates the geological map of Al-Faria catchment that shows the predominant geologic formations.

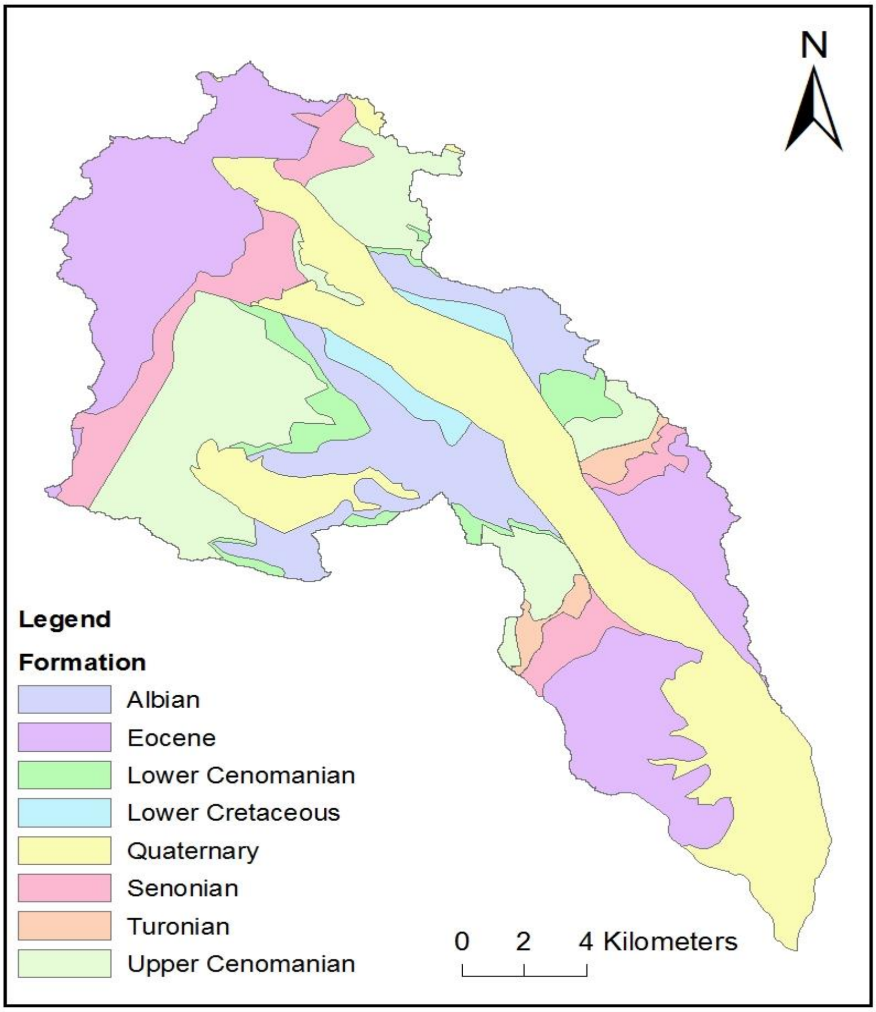

Figure (2. 5): The Geologic Map of Al-Faria Catchment

2.3 Topography

The topography in Al-Faria catchment is unique since the elevation descends from about 920m above mean sea level in Nablus Mountains to about 385m below mean sea level in the proximity of the Jordan River as shown in Figure (2.6). There is an extreme change through the area in Al-Faria terrains, where the elevation changes by 1.3 km in less than 35 km (Shadeed, 2008).

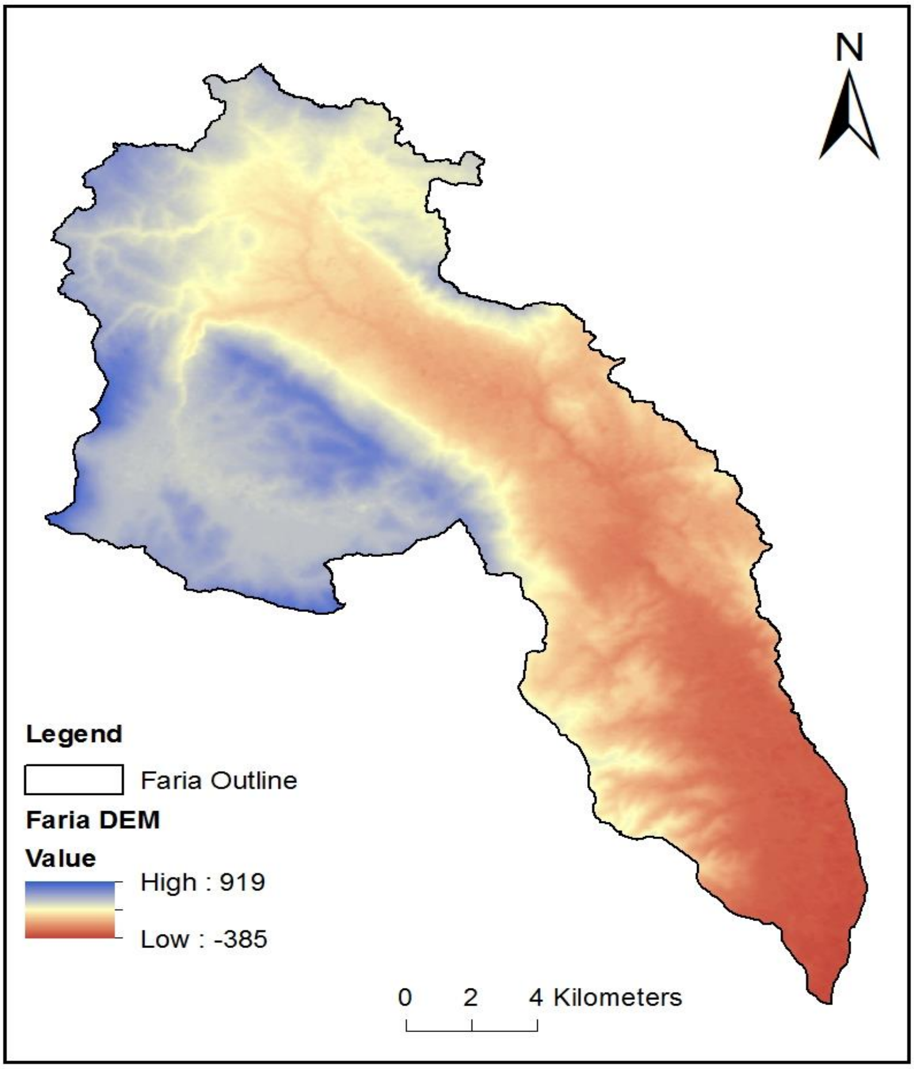

Figure (2. 6): A Digital Elevation Model of Faria Catchment

2.4 Rainfall

The climate in Al-Faria catchment is classified as arid to semiarid region from the eastern to the western part. Its climate is dry and hot in summer, wet and mild in winter.

Rainfall occurs in the period from October to May with maximum rainfall in January. The average annual precipitation varies from 450 to 650 mm in the mountainous parts in Nablus and declined to less than 200mmin the lower part.

Rainfall data in the catchment are recorded by six distributed rainfall stations. These stations are: Nablus, Talluza, BeitDajan, Tamoun, Tubas and Al-Faria stations (Shadeed, 2005) as shown in Figure (2.7). Before the year 1994, all these stations were controlled by the Israeli Authorities until the advent of the Palestinian Authority, where all the stations except Al-Faria station turned to be under the control of the PWA.

Al-Faria rainfall station is located in Al-Jiftlik in the lower part of the catchment and still under the control of the Israeli Authority; therefore its rainfall data is available for few years. Nablus station is regular weather station that has a monthly and yearly available recorded precipitation data for more than 55 years. The other four rainfall stations are simple rain gauges that measure daily precipitation. They located in the schools of Tubas, Tamoun, Talluza and BeitDajan. These stations have available monthly and yearly rainfall data for about 30 to 40 years.

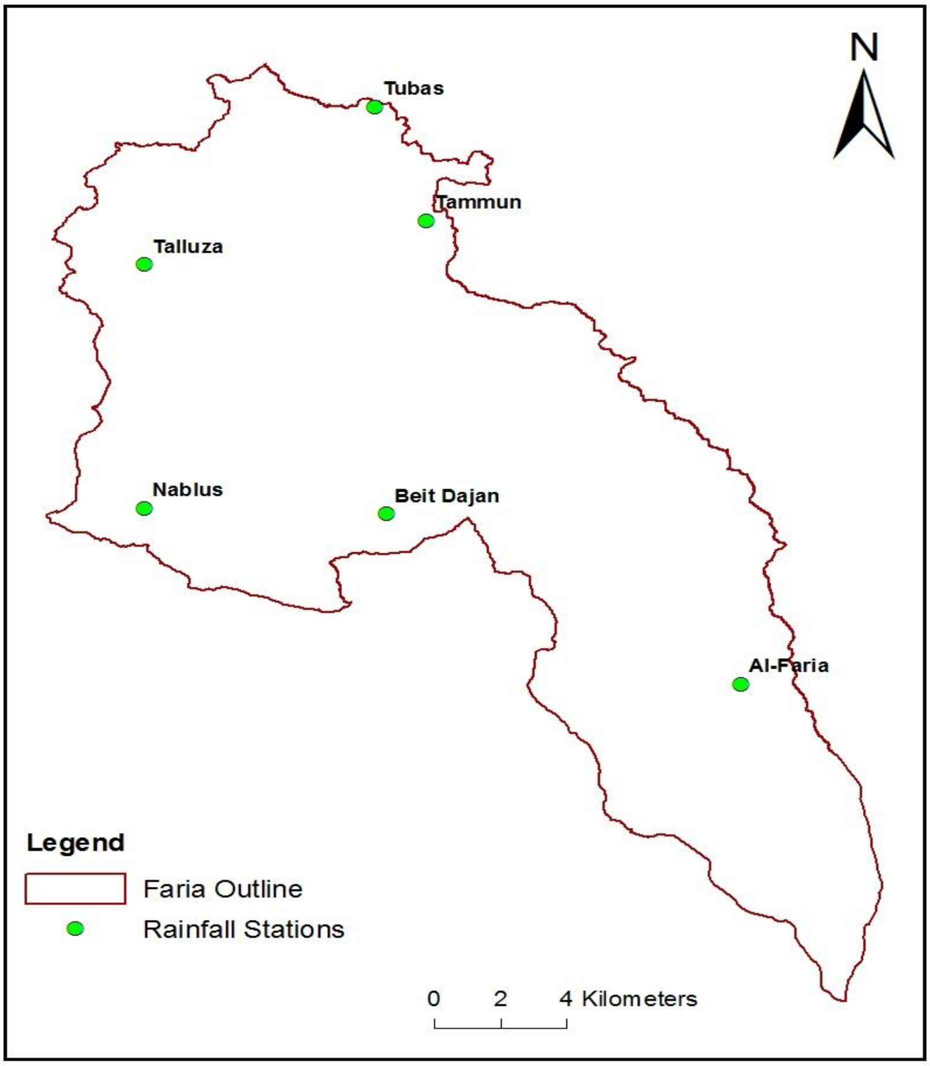

Figure (2. 7): Rainfall Stations in Faria Catchment

2.5 Water Resources

Water resources in Al-Faria catchment are sorted into groundwater resources and surface water resources. There are eighty twoworking wells in the Faria catchment.Seventy three are agricultural wells which are included in this research and pumping water from the shallow unconfined aquifer, whereas four are domestic and five are utilized by the Israeli occupation and pumping water from the deep confined aquifer.. The total annual utilization of the

Palestinian wells ranges from 9.9 MCM to 18.8 MCM (Based on the available data from PWA for the period 2000 to 2014).

Also, within Al-Faria catchment, there exist thirteen fresh water springs with an annual discharge varies from 1.3 MCM to 12.3 MCM (Based on the available data from PWA for the period 2000 to 2014).

The large divergencein the discharge minimum and maximum values of wells and springs in the last recently 15 years returns back to farmer's actions of digging illegal and randomly new agricultural wells in the catchment in the year 2008. Heavy pumping from the new wells led to declining in springs discharge and drought of the most important spring in the area which is Al-Faria spring.

Figures(2.8) and (2.9)show the distribution of wellsand springs respectively in the catchment.

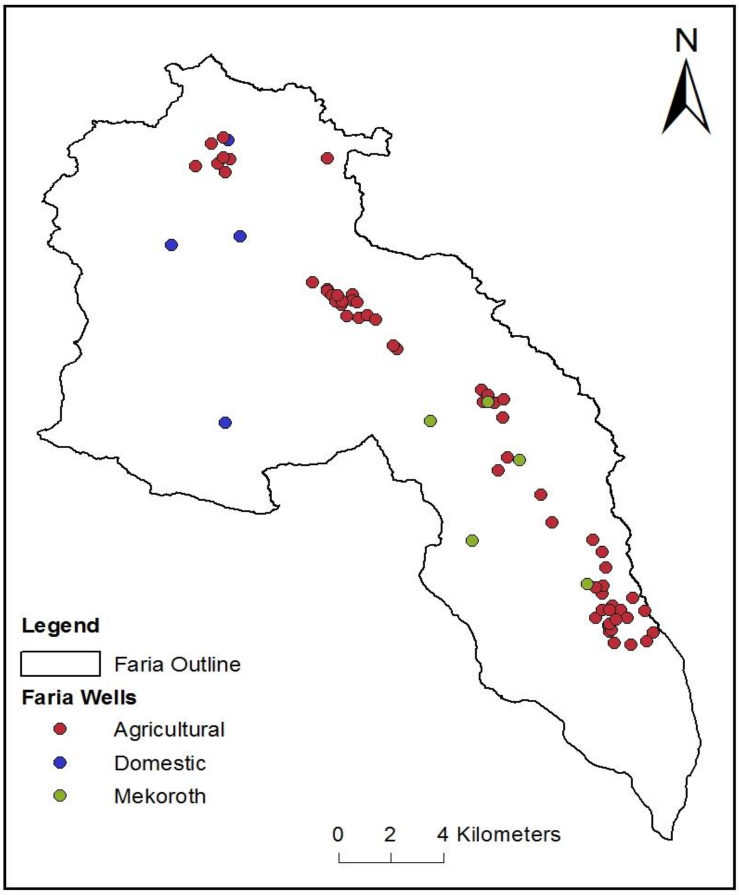

Figure (2. 8): Distribution of Wells in the Faria Catchment

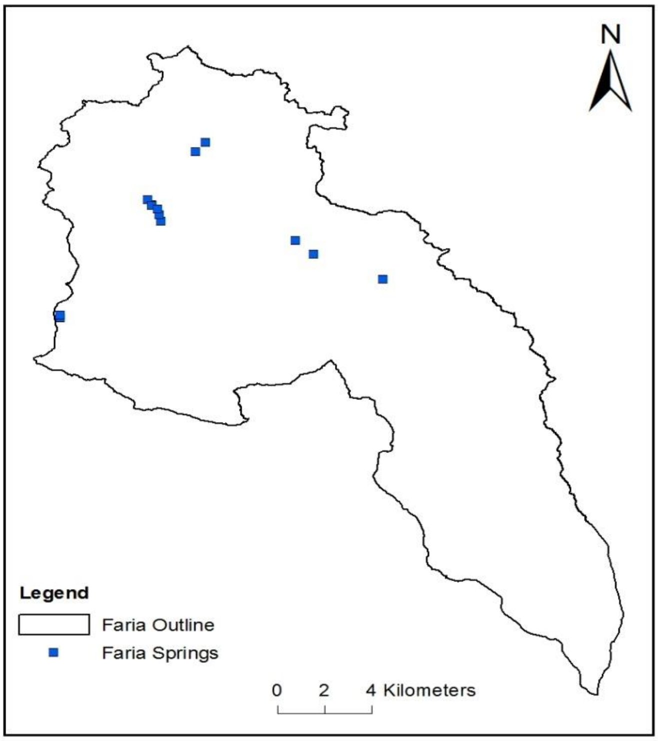

Figure (2. 9): Distribution of Springs in the Faria Catchment

2.6 Water Demand and Water Supply

The quantity of water delivered and used at the household level is an important indicator that measures the adequacy of domestic water supply and influences hygiene and public health (PWA, 2010).

World Health Organization (WHO) stated that the average water supply should be 150L/c/d, but unfortunately value is not reachable in most of the West Bank Governorates.

Table (2.3)summarizes the supply and demand quantities for (150L/c/d) in the West Bank Governorates.

Table (2. 3): Supply and Demand Quantities (for 150L/c/d) (PWA, 2010)

Governorate	Population (1000)	Needed Quantities (MCM)	Available Quantities (MCM)	Deficit (MCM)	Actual Consumption (MCM)	Actual Deficit (MCM)
Jenin	274	15.002	5.987	9.015	4.347	10.655
Tubas	55	2.998	1.7	1.298	1.190	1.808
Tulkarem	166	9.077	4.606	4.471	2.759	6.318
Nablus	340	18.621	11.234	7.387	7.920	10.701
Qalqilya	97	5.335	4.009	1.326	3.087	2.248
Salfit	63	3.457	2.567	0.890	2.015	1.442
Jericho	45	2.487	3.55	-1.0635[14]	2.684	-0.196
Ramallah	301	16.496	16.195	0.301	11.855	4.641
Jerusalem	145	7.925	4.635	3.290	2.790	5.134
Bethlehem	189	10.341	10.686	-0.345	7.010	3.331
Hebron	600	32.870	19.81	13.060	14.620	18.250
Totals	2276	124.610	84.979	39.631	60.277	64.333

Faria catchment is located within the three Governorates: Nablus, Tubas and Jericho.The numbers above show a gap between the actual consumption and the needed quantities in Nablus and Tubas Governorates by almost 10.7

MCM and 1.8 MCM respectively; unlike Jericho situation which has over excess quantities of water supply.

Chapter Three

Literature Review

3.1 Groundwater

3.1.1 General Definition

Groundwater is the water that occurs in the tiny spaces (called pores or voids) between the underground soil particles or in the fractured rocks. The substantial quantities of groundwater are found in aquifers, these aquifers are the source of water for wells and springs (Kasenow, 2001).Safe groundwater abstraction and proper groundwater management is important for the sustainability of this resource (Fetter, 2001).

3.1.2 Groundwater in Palestine

Groundwater is the main source of water for Palestinians and provides more than 90% of all water supplies (PWA, 2011).In the West Bank, most of groundwater occurs in fissures, joints, and karstic features of the carbonate Ajlun Group of Late Cretaceous period (Froukh, 2002).

There are two main groundwater aquifer basins in Palestine, which are located either partially or totally in the West Bank and Gaza Strip. These are the mountain aquiferbasin in the West Bank and the coastal aquifer basin in Gaza Strip.

The most important West Bank's aquifers are found in the CenomanianTuronian formation of the Upper Cretaceous period and in the BeitKahil formations of the Lower Cretaceous period. These formations consist mainly of limestone, dolomite, marl and chalk (Sturm et al., 1996).

The mountain aquifer extends along the mountain water divideon the mountain ridge, on a north-south line east of the cities of Nablus, Ramallah, Jerusalem and Hebron(Ataallah, 2010).

Based on water movement and infiltration on both sides of the water divide, three sub-aquifers were formed in the West Bank: the Western Aquifer, the North-Eastern Aquifer and the Eastern Aquifer as shown in Figure (3.1).

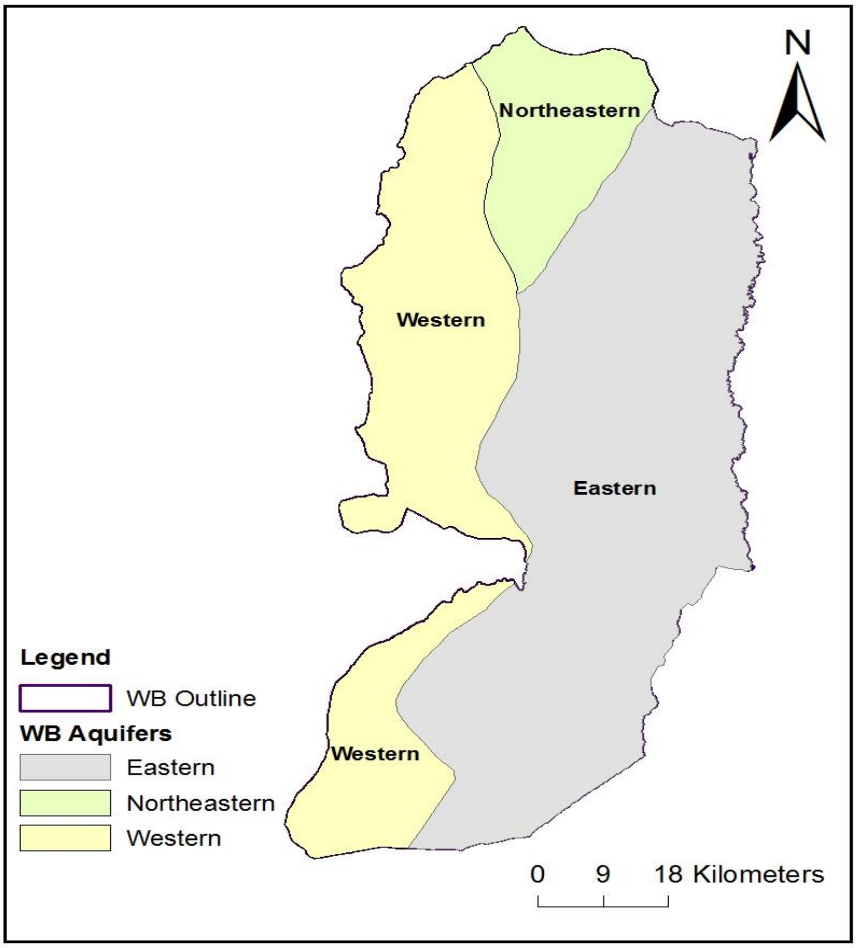

Figure (3. 1): Main Groundwater Mountain Aquifers in the West Bank

Below is a brief description of the three mountain aquifers:

1) Western Aquifer

It is a shared aquifer between the West Bank and IsraeliOccupation, with a surface area of 11,398 km^2 where the area located within the borders of the West Bank that forms the main recharge area for this Basin, estimated at about 1,596 km^2 and its average thickness is about 600-900 m (Aliewi, 2007). It is supplied and recharged from the West BankMountains and extends beyond the western boundaries of the West Bank (Kharmah, 2007).

2) North-Eastern Aquifer

   It has a surface area of 1,067 km^2 (Aliewi, 2007). It consists of Nablus-Jenin basin that drainsinto the Eocene aquifer and drains intothe Eocene and Neogene aquifers (Ataallah, 2010).

3) Eastern Aquifer

   The surface area of this basin is about 3,079 km^2 (Aliewi, 2007). It is located entirely within the West Bank and the springs emerging out of it represent around 90% of spring discharge in this area (Kharmah, 2007).

3.1.3 Groundwater Utilization and Management in Palestine

The large variations in rainfall and limited surface resources have led to widespread shortage of the fresh water resources in the region, resulting in a heavy reliance on groundwater as the major source for various uses (Murad, 2005).

However, Israeli occupationexploits the Palestinian groundwater aquifers in an unfairly mannerand shrinks Palestinians utilization to a limited amount of use. Table (3.1) shows Palestinians utilization gap in 2011 compared with Oslo Agreement.

Table (3. 1): Water Allocation According to Oslo Agreement and Utilization (PWA, 2011)

Use	Oslo Agreement (MCM)				Utilization 2011 (MCM)			
	WAB	NEAB	EAB	Total	WAB	NEAB	EAB	Total
Israel	340	103	40	483	411	103	150*	664
Palestine	22	42	54	118	25	20	42	87**
Additional Quantity for Palestinian Development	–	–	78	78	–	–	0	0
Total	362	145	172		436	123	192	

*This includes 100 MCM from Dead Sea springs, which Israel prevents Palestinians from developing

** This doesn't include the water quantity from unauthorized wells.

It is obvious from the previous Table that 17 years after the Oslo Agreement came into force; the Palestinians in the West Bank are forced to utilizeonly less than 14% of available shared groundwater resources, while the Israelis areutilizing more than 86% (PWA, 2011).

Since Israel occupied the West Bank in 1967, it has denied thePalestinian inhabitants access to the water resources of Jordan River. Accordingly, the Mountain Aquifer is their only remaining source of water. Even so, Israel limits the amount of water annually availableto the Palestiniansfrom the Mountain Aquifer to no more than 20%, while it has continued to consistently over extract water for its own usage far in excess of the aquifer's yearly sustainable yield.

Moreover, much of Israel's over-extraction is from the Western Aquifer, which provides both the largest quantity and the best quality of all the groundwater resources in Palestine(Amnesty International, 2009).

It is substantially concluded that we do not own water resourceswhich is one of our biggest crises, and so management is not possible. . It is ofimportance to preserve the limited accessible groundwater quantities and to develop many different management options to assure water availability and water budget, which result in developing public awareness and participation to conservation strategy.

Hence, the aquifer system needs to be well understood in order to construct accurate representations of the hydro-geological system, and to be easily simplified by making reasonable assumptions and simplifications. All of which lead to the need of a groundwater flow model.

3.2 Groundwater Budget

Groundwater budgets or groundwater inventories are developed by quantifying all inflows to a system, all outflows from a system, and the storage change of the system over a specified period of time. Literature on the development of groundwater budgets dates back to at least the 1930s with the work of Meinzer (1932) (Hutchison et al., 2008).

The major inputs of groundwater are from rainfall, irrigation return flow in addition to water and wastewater seepage to the aquifer. The major outputs from a groundwater system are groundwater pumping and springs discharge. Changes in groundwater storage can be attributed to the difference between inflows and outflows of water over a defined time interval.

The storage change can be expressed as:

Recharge (Input) – Discharge (Output) = Change in Storage

A positive change in storage is often termed a surplus, while a decrease in storage is termed a deficit.

Water budgets are generally described as either distributed parameter or lumped parameter budgets. Distributed parameter budgets provide details of the spatial distribution of the individualwater budget components including inflows, outflows, and storage changes, whereas the lumpedparameter budgets aggregate all of them together for an entire aquifer(IDWR, 2008).

3.3 Groundwater Modeling

First of all, a model is a tool that represents an approximation of a real world situation. Models are the best available alternative for analyzing complex resource problems (Anderson et al., 1991).

A groundwater model is a mathematical model that demonstrates the relationship between aquifer responses due to external stresses.

The first step in developing a groundwater model, and perhaps the most important, involves the design of a conceptual model. It can be defined as a hydro-geologist’s mental representation of the groundwater flow system (Chmakov et al., 2009).

The development of predictive groundwater models now provides adequate tools to evaluate management actions. Highly sophisticated mathematical models can be used in planning the development of groundwater and the conjunctive use of groundwater and surface water (Kharmah, 2007).

3.3.1 Mathematical Models

Mathematical Models are those which used mathematical equations in describing the elements of the groundwater flow.

There are three types of mathematical models and these are (Kresic, 2006):

- Empirical Models: are derived from experimental data that are fitted to some mathematical function.
- Probabilistic Models: are based on laws of probability and statistics.
- Deterministic Models: assume that the stage or futures reactions of the system (aquifer) studied are predetermined by physical laws governing groundwater flow.

The mathematical model contains the same information as the conceptual one but expressed as a set of equations which are amenable to analytical and numerical solutions (Bear et al., 1992).

Groundwater mathematical models consist of a partial differential equation together with appropriate boundary and initial conditions that express conservation of mass and that describe continuous variables (for example, hydraulic head) over the region of interest. In addition, they entail various phenomenological laws describing the rate processes active in the aquifer. An example is Darcy's law for flow through porous media (Mercer et al., 1980).

3.3.1.1 Deterministic Groundwater Models

There are two large groups of deterministic models depending on the type of mathematical equations involved (Kersic, 2006):

- Analytical models: solve one equation of groundwater flow at a time and the result can be applied to one point or "line of points" in the analyzed flow aquifer.
- Numerical models: describe the entire flow field of interest at the same time, providing solutions for as many data points as specified by the user.

Figure (3.2) illustratesthe procedure for developing a deterministic mathematical model.

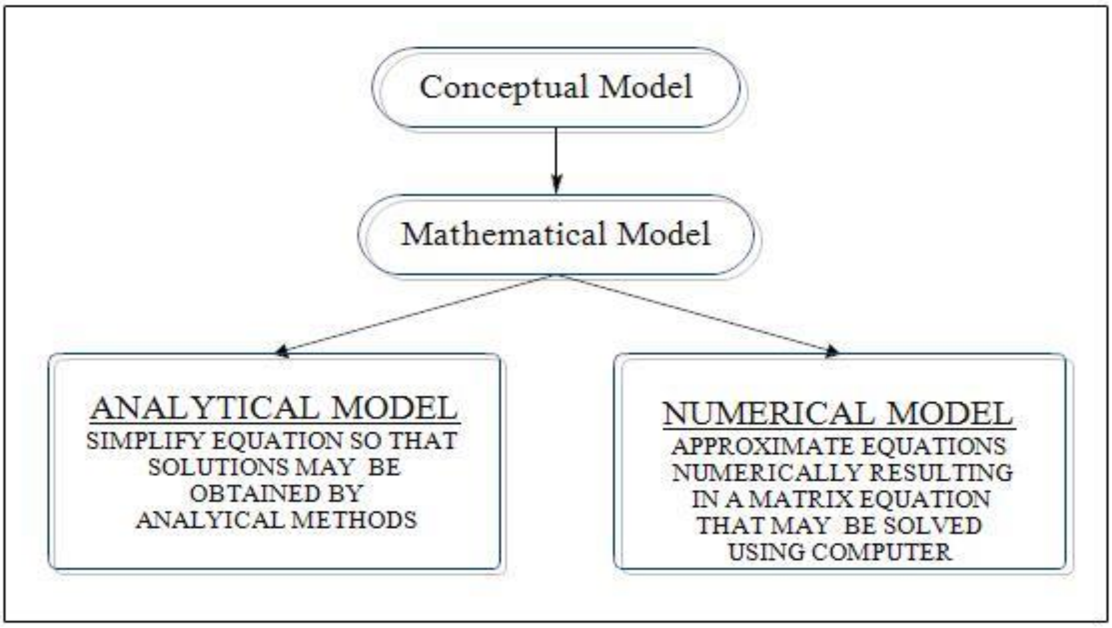

Figure (3. 2): Logic Diagram for Developing a Mathematical Model (Modified after Kharmah, 2007)

Deterministic groundwater models generally require the solution of partial differential equations. Exact solutions can often be obtained analytically, but analytical models require that the parameters and boundaries be highly idealized. Some deterministic models treat the properties of porous media as lumped parameters (essentially, as a black box), which precludes the representation of heterogeneous hydraulic properties in the model (Konikow, 1996); whereas the other distributed models are taking into account all physical hydraulic properties of the system while modeling.

3.3.2 Lumped Parameter Models versus Distributed Groundwater Models

It is of intelligence to select the proper modeling way in simulating a specific system, so that it is simple to a degree by which can be capable to mathematical equations application.

Two contrasts modeling ways may be used in groundwater modeling; these are thelumped parameter model (LPM) and the distributed model.

In the ***distributedmodels***, to completely model a system, a very detailed knowledge of the physical properties and the processes governing groundwater movement are required. These models are normally chosen to increase the accuracy of predictions and to achieve a higher degree of spatial resolution. In addition to that, input data must be developed for each cell.Consequently, these models are not used to any great extent by regulatory agencies or other groups (Cary et al., 1985; Refsgaard et al., 1999).

A spatially distributed model accounts for variations in water budget characteristics. Various methods are available, such as division of thewatershed into grid cells or use of Hydrologically Similar Units (HSU).For example, a grid cell model usesdata for each grid cell inside the basinto compute flow from cell to cell. By this method, the spatial variation in hydrologic characteristics can be handledindividually (i.e.

assuminghomogeneity for each cell), and therefore may be a more appropriate treatment(CCL, 2001).

In contrast, the ***Lumped parameter models***neglectthe spatial distribution in the input variables and the parameters in the model domain (Oude Essink, 2000). They treat a sub-watershed as a single system and use the basin-wide averaged data as input parameters. This method assumes that the hydrologic characteristics of the sub-watersheds are homogeneous(CCL, 2001).

In this model, only simple equations are solvedmust be solved and they are described as parsimonious model since they simplify the representation of the physical structureand of the processes involved (Haj Hamad, 2007).

LPM models offer the opportunity to simulate a given system with fewer data requirements for parameterization and calibration than their distributed counterparts (Haj Hamad, 2007); especially useful when there is a lack in geological data. This type of groundwater modeling is considered as a single cell models such as those developed by Gelhar and Wilson (1974), Mercado (1976), Mook (2001), Kazumba et al. (2008) and Radfar et al. (2011).

In this study, and due to lack of physical information and complexity in the study area to use the distributed model approach, it was decided to utilize the LPM since the distributed model use with lack of specificdetails might give worst results compared to that when using the LPM, where many assumptions will be assumed that do not match the reality.

3.3.2.1 LPM Applications

In groundwater, LPM gives an obvious conception about the system (aquifer) budget and its storage.

3.3.2.2 Previous studies

Radfar et al. (2011) developed a balance LPM for modeling intramountain groundwater basin to the aquifer system of Shahrekord Plain, Iran, where intense agricultural activity has required large amounts of groundwater for irrigation in the dry summer months. Consequently,piezometric levels have declined nearly continuously during the last decades because of overdrafting. The model has been applied for the period 1990-2004 and some of the water balance components have been estimated by calibrating the model using an optimization routine.

Haj Hamad (2007) has used the LPM in order to find management options for Nitrate groundwater contamination in Gaza Costal Aquifer (GCA).A single-cell model was developed and the area was divided into two tanks regarding the geology of the study area and groundwater movement. This model was employed to study different management options and to determine their efficiency in decreasing the nitrate contamination in the study area for a specified time horizon. At first, a quantity LPM was developed, followed by a quality LPM, this is because the nitrate mass in the aquifer depends on the available water quantity which can only be computed through the use of a quantity model.

Kazumba et al. (2008) developed a LPM known as tank model for regional groundwaterflows to estimate thegroundwater flow system of the Osaka plain aquifer of Japan. The aquifer was divided into tanks within which the average values of the groundwater levels were assumed to be representative in the tanks. For each tank the mass-balance equations expressing the conservation of water were written.

Chapter Four

Model Development, Results &Discussion

4.1 Introduction

The main objective of the model development is to find out the overall aquifer systemwater budget.

Model development consists of converting the conceptual model of the aquifer system to a numerical one. Thiswas done using a Single-Cell Lumped Parameter Model. LPM performs the mathematical computation and simulation and generates the results in terms of groundwater budget by using the approach of water balance which implies that the difference between gains and losses equals the change in the storage for the study area (model domain).

Al-Faria catchment is divided into three sub-catchments which are Al- Faria, Al-Badan and the lower sub-catchment. TheLPM has been applied to each sub-catchment individually in order to get the overall water quantity stored in the aquifer system.

4.2 Model Development

LPM development approach is presented in Figure (4.1). The main input parameter for the model is the natural recharge to the aquifer system. Whereas water pumped for irrigation and springs discharge are classified as the model output parameters.

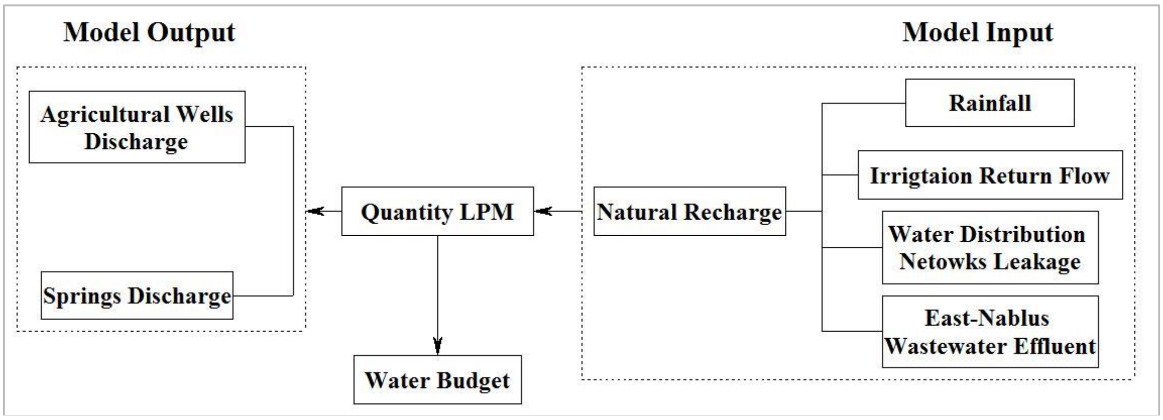

Figure (4. 1): The Overall Schematic Flowchart of the Conceptual Lumped Parameter Model

4.2.1 Input Parameters (Q_{IN})

4.2.1.1 Natural Recharge (R)

The total recharge in the study area mainly comes from rainfall, irrigation return flow, leakage to groundwater from water distribution network losses and wastewater leakage. Equation [1] was used to compute the overall recharge to the model domain for each sub-catchment as follows:

$$R_{t=} R_r + R_{irr} + R_{wnl} + R_{ww} \quad [1]$$

Where:

R_t= Total Recharge (m^3)

R_r= Recharge from rainfall (m^3)

R_{irr}= Recharge from irrigation return flow (m^3)

R_{wnl}= Recharge from water networks leakage (m^3)

R_{ww}= Recharge fromwastewatereffluent (m^3)

Each component of the overall recharge which is depicted in equation [1] will be explained in the following sub-sections.

Recharge from Rainfall (R_r)

In order to find recharge from rainfall, the locations of rainfall stationsfor each sub-catchment were mapped using GIS.As such a GIS point shapefile of rainfall stations was used. Interpolation method called the Inverse Distance Weighting (IDW) was applied on these points to get the annualaverage rainfall on each sub-catchment. Accordingly, the annual average rechargewas computed using the empirical formulas ofGuttman and Zukerman (1995),as in the following.

Recharge equation	Rainfall (mm/year)
$R = 0.8(P-360)$	$P > 650$ mm (1)
$R = 0.534(P-216)$	$650 > P > 300$ mm (2)
$R = 0.15(P)$	$P < 300$ mm (3)

Where:

R: Annual recharge from rainfall (mm)

P: Annual rainfall (mm)

Model builder in GIS was used to build the followed workflow by stringing together the sequences of geoprocessing tools and feeding the output of one tool into another tool as input to get the final result.

Analysis and results for each sub-catchment are summarized as follows:

Al-Badan sub-catchment:

The values of annualrainfall that is falling on the catchment ranging from 379mm to 642mm, so the second previous empirical equation was applied to get the annual recharge.

The model builder tool in GIS was used to illustrate the analysis that was conducted to get the final result of the net rainfall recharge that occurs into Al-Badansub-catchment as shown in Figure (4.2).

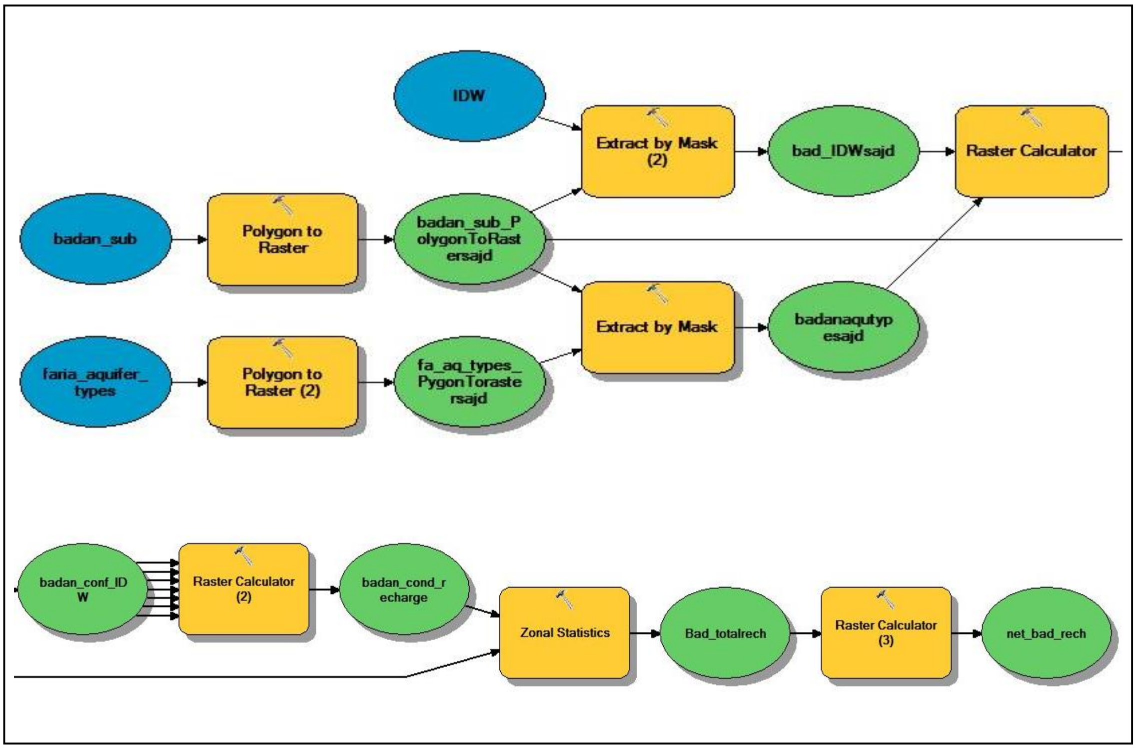

Figure (4. 2): Description of GIS Geoprocessing Sequences to Get Al-Badan Sub-catchment Rainfall Recharge

The resulted total recharge from rainfall on Al-Badan sub-catchment is 7 MCM.

Following the same steps, the quantity of rainfall recharge to the aquifer from the three sub-catchments is summarized in the following Table (4.1).

Table (4. 1): Annual Recharge from Rainfall for Al-Faria Sub-catchments Recharge from Rainfall for Al-Faria Sub-catchments

Sub-catchment	Annual Average Rainfall(mm)	Annual Recharge(MCM)
Al-Badan	379-642	7
Al-Faria	322-630	5.7
The Lower	198-507	7.4

4.2.1.2 Recharge from Irrigation Return Flow (R_{irr})

Al-Faria catchment is an agricultural area; it is cultivated by irrigated permanent and seasonal crops where each crop type needs a different water requirement from the other. As well as the water needs in summer planting season is greater than in the winter season.

In general, not all the quantity of irrigation water is used by the plant. Actually, there is a percent of water run under the plant roots recharge the aquifer.

Al-Faria catchment was divided into two zones; the upper zone and the lower zone. Table (4.2) summarized the total quantity of water demand for the irrigated areas of vegetables, trees and field crops in both cultivated upper and lower zones.

Table (4. 2): CurrentIrrigation Water Requirements in Al-Faria Catchment (EQA, 2004)

Zone	Irrigated Area (dunums)			Irrigation Demands (m^3/dunums)			Total Irrigation Demands (m^3)			Total
	Ve	Tr	Fi	V	Tr	Fi	Veg.	Tre	Fie	
Upper Zone	7,450	2,065	712	500	1,100	200	3,770,000	2,292,150	142,400	6,204,550
Lower Zone	13,447	1,605	1,330	500	1,200	300	6,723,500	1,926,000	399,000	9,048,500
Total							10,493,500	4,218,150	541,400	15,253,050

As can be seen from the table above, the upper zone combines both Al-Badan and Al-Faria sub-catchments and the lower zone represents the lower sub-catchment.

The quantities of irrigation water and irrigation return flow recharge were calculated for each sub-catchment as follows:

Al- Badan sub-catchment:

The total area of irrigated plants in Al-Badan sub-catchment was found to be quarter of the irrigated area in the upper zone that is mentioned in the water demand table, so the quantity of water demand required for irrigation (Qir)equals:

$$Qir = 0.25 * 6{,}204{,}550$$

$$= 1.55\ MCM$$

Generally, the fraction of return flow (f_{re}) from irrigation is within the range 15-30% (Mercado, 1976). This fraction for the three sub-catchments was decided depending on the average slope (DEM) of the irrigated area in each sub-catchment as shown in Table (4.3).

Table (4.3): Return Flow Fraction in Al-Faria sub-catchments

Sub-catchment	Average Irrigated Area Slope (%)	Return Flow Fraction (%)
Al-Badan	11.8	20
Al-Faria	16.8	23
The Lower	22	25

So, return flow quantity that is obtained from irrigation to become recharge (R_{irr}) in Al-Badan sub-catchment equals:

$$Rirr = fre * Qir$$

$$= 0.2 * 1{,}551{,}138$$

$$= 465{,}341\ m^3$$

Table (4.4) summarizes the recharge quantities from irrigation return flow for the three sub-catchments

Table (4. 4): Recharge Quantities from Irrigation Return Flow for Al-Faria Sub-catchments

Sub-catchment	Annual Irrigation Quantity (Q_{ir}) MCM	Return Flow Fraction (f_{re}) %	Annual Irrigation Recharge Quantity (R_{irr}) m^3
Al-Badan	1.55	20	310,228
Al-Faria	4.65	23	1,070,285
The Lower	9.05	25	2,262,125

4.2.1.3 Recharge from Water Distribution Network Leakage (R_{wnl})

The study area includes large group of communities dispersed inside as shown in Figure (4.4). Table (4.4) mentions these communities with their population in the three sub-catchments with reference to PCBS, year 2014. The mentioned communities receive water for their domestic use throughthe constructed water distribution networks. Due poor infrastructure, not all inhabitance are connected to such-networksof water and they depend on water tanks to meet their daily water needs.

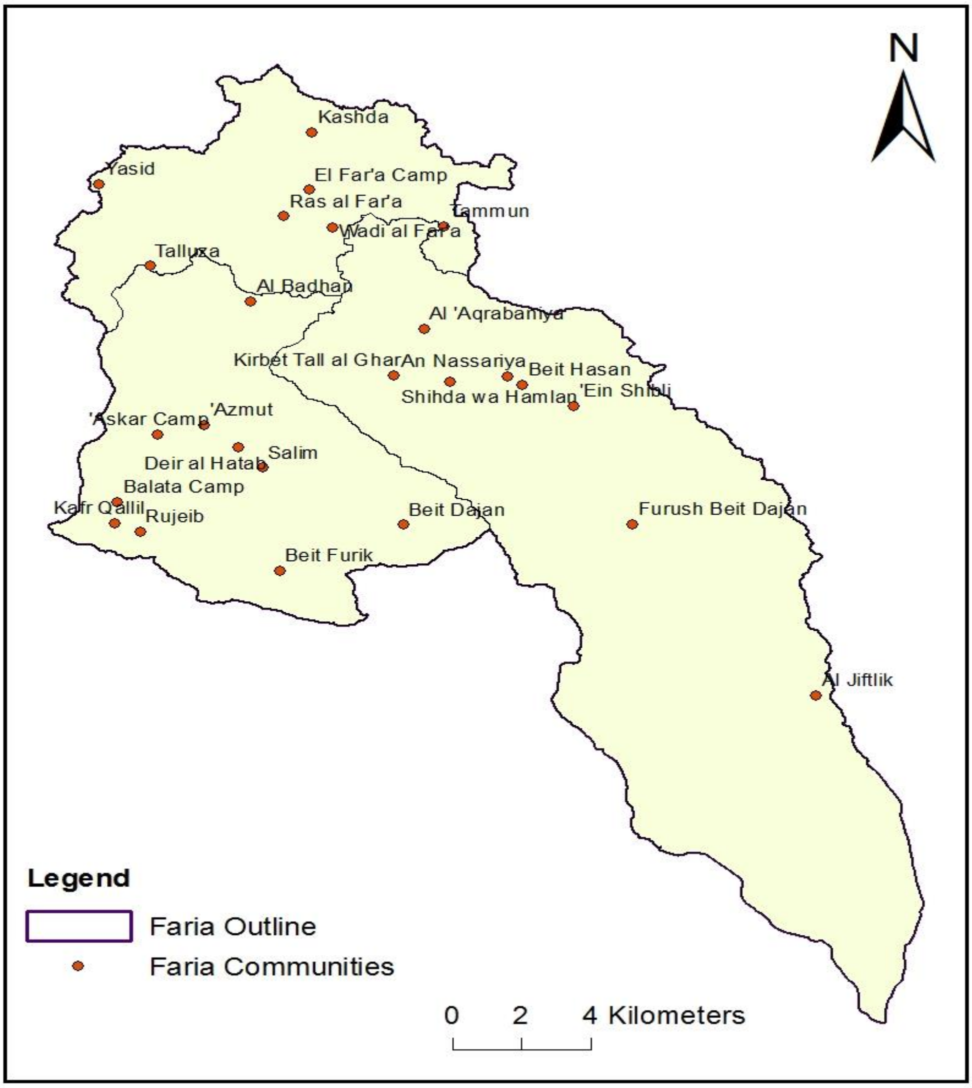

Figure (4. 3): Distribution of the Palestinian Communities in Al-Faria Catchment

Table (4. 3): Faria Catchment Communities with their Population (PCBS, 2014)

Sub-catchment	Community	Population (Capita)
Al-Badan	Talluza	**2,758**
	Al-Badan	**2,886**
	Azmut	**3,078**
	Askar Camp	**13,481**
	Deir Al-Hatab	**2,570**
	Salim	**5,879**
	BeitDajan	**4048**
	Balata Camp	**17,708**
	East Nablus	**93,155**
Al-Faria	Ras Al-Faria	**880**
	Wadi Al-Faria	**3,402**
	Tubas	**20,129**
	Tammoun	**13451**
	Faria Camp	**7,117**
The Lower	Nassariya	**1,841**
	Aqrabaniya	**1,163**
	EinShibleh	**389**
	FrushBeitDajan	**893**
	Al-Jiftlek	**4,455**

The water distribution network in the study area suffers from water leakage (losses) as a result of the lack of appropriate maintenance. The quantity of water leaked will mostly turn to recharge the aquifer. The amount of recharge equals multiplication of the total water leakage by the leakage fraction that is expected to be recharge as in the following equation:

$$Qleak = Qpd * fl$$

Whereas:

Q_{leak}: Quantity of leakage from water distribution network (m^3)

Q_{pd}: Quantity of water pumped for domestic use (m^3)

f_l: Fraction of leakage from water network(Percent of losses)

The recharge volume from the leaked water was calculated as in the following equation:

$$Rwnl = Qleak * \rho$$

Whereas:

R_{wnl}: Quantity of recharge due to leakage from water network (m^3)

ρ: Fraction of leakage (losses) from water network which turned to recharge

Recharge quantities were calculated from all communities in the study area, with reference to the data taken from Palestinian locality profiles that was implemented by ARIJ organization in the years 2012 to 2014[(1)] . Each community has its profile includes its population and specified area, average water consumption and network data includes: percent of population connected to the network and percent of losses.

The quantities of water distribution networks leakage recharge were calculated for each sub-catchment as follows:

Al-Badan sub-catchment:

Recharge volume in this sub-catchment equals the summation of recharge from the nine communities contained therein.

For example, Talluza has the population of 2,758 capita and its area is about 259 dunums(ARIJ, 2014).

The water consumption per capita equals 87L/c.d and losses equal 30%. About 95% of the population is connected to the water distribution network.

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[1]- http://proxy.arij.org/vprofile/

So that, the recharge volume was calculated using the previous formulas as the following:

$$Qleak = Qpd * fl$$

$$= 2758 * 87 * 0.95 * 0.3 * 365/1000$$

$$= 24{,}960\ m3/yr$$

 was assumed to be equals 20%in the range of (20-30%) which has been reached based on several studies carried out between the PWA with several companies taking into account several influencing factorssuch as: soil types, topography land use. is ranging in value based on rainfall intensity.

$$Rwnl = Qleak * \rho$$

$$= 24960 * 0.2$$

$$= 4{,}992\ m^3$$

The total sum of the annual recharge from the rest eight communities is summarized in Table (4.5).

Table (4. 4): Total Annual Recharge from Al-Badan Sub-catchment

Community	Q_{leak} (m^3)	R_{wdn} (m^3)
Talluza	24,960	4,992
Al- Badan	16,654	3,331
Azmut	23,310	4,662
Askar Camp	110,713	22,143
Deir Al-Hatab	46,433	9,287
Salim	86,906	17,381
BeitDajan	11,347	2,269
Balata Camp	145,427	29,085
Eastern Nablus	1,098,251	219,650
Total Recharge		312,800

On the same manner, the total annual recharge is summarized in Tables (4.6) and Table (4.7) for Al-Faria and the Lower sub-catchments respectively:

Table (4. 5): Total Annual Recharge from Al-Faria Sub-catchment

Community	Q_{leak} (m^3)	R_{wdn} (m^3)
Ras Al-Faria	7,709	1,542
Wadi Al-Faria	22,351	4,470
Tubas	168,616	33,723
Tammoun	59,652	11,930
Faria Camp	65,462	13,092
Total Recharge		64,758

Table (4. 6): Total Annual Recharge in the Lower Sub-catchment

Community	Q_{leak} (m^3)	R_{wdn} (m^3)
Nassariya	32,254	6,451
Aqrabaniya	7,259	1,452
EinShibleh	1,881	376
FrushBeitDajan	7,392	1,478
Al-Jiftlik	18,147	3,629
Total Recharge		13,387

4.2.1.4 Recharge from East-Nablus Wastewater Effluent (R_{ww})

The wastewater recharge was carried out on East-Nabluswhich is totally contains in Al-Badansub-catchment with a population of 93,155 inhabitants as it is the most significant source of wastewater that can turn to recharge to the aquifer in Al-Badan sub-catchment.

The average water consumption there is about 85 L/c.d and return flow as sewerage is about 90% since it is an urban area which is larger than the percent in ruler countries (Abu Ghoush, 2016). So the annual quantity of wastewater discharged from East-Nablus (Q_{ww}) was calculated by the following equation:

$$Qww = P * qw * \partial$$

Where:

Q_{ww}:The annual quantity of wastewater discharged from East-Nablus

P: Population

q_w: Average daily water consumption (L/c.d)

∂: Return flow percent as wastewater

$$Qww = 93{,}155 * 85 * 0.9 * 365/1000$$

$$= 2{,}601{,}120 \text{ m}^3$$

The total discharged quantity of wastewater moves through Al-Badan valley and it is subjected to a transmission loss whilemoving down stream.

Transmission losses are one of the main features that distinguish ephemeral channels from perennial channels. Transmission losses are abstractions of water volume along the flow path in the channel bed (Shadeed, 2008).

Transmission loss value depends on runoff generation mechanism whether it is Infiltration Excess Overland Flow (IEOF) or Saturation Excess Overland Flow (SEOF)(Shadeed, 2008).

The areas of a catchment where the SEOF is expected to be in valley bottom areas, near stream saturated areas, particularly headwaters hollows where there is convergence of flow and a gradual decline in slope towards the stream (Beven, 2001; Shadeed, 2008), or where groundwater discharge areas occur (Dunne et al., 1975).

The value of transmission loss is about 38% assuming the case of SEOF runoff mechanism (Shadeed, 2008), which is the same that was taken in this research for wastewater flow in Al-Badan valley.

As the water table in Al-Badan valley is not far from the surface, so 10% could be deducted from the transmission loss value as evapotranspiration (ET) and the remaining percent will be turned in to the aquifer which is about 28%.

Thus, the annual recharge quantity from wastewater is calculated as in the following equation:

$Rww = Qww * \sigma$

Where:

R_{WW}:The annual recharge quantity from East-Nablus wastewater

σ: The fraction of wastewater that is turned to recharge

So,

$Rww = 2{,}601{,}120 * 0.28$

$= 2{,}601{,}120 * 0.28$

$= 728{,}313.6\ m^3$

4.2.2 Output Parameters (Q_{OUT})

4.2.2.1 Wells Discharge (W_D)

The study examined the total water budget through the unconfined shallow aquifer, so wells abstraction was calculated only from the existing wells that tapping this aquifer.

All agricultural wells are pumping water from the unconfined aquifer, in contrast all domestic and Mekarotwells are pumpingwater from the deep confined aquifer, and have been excluded from this study.

The study area includes seventy three agricultural wells. Forty five wells are actually running and distributed in Al-Faria and the Lower sub-catchments. In addition to new twenty eight agricultural wells that have been drilled and operated since the year 2008. However, these new drilled wellslacked the presence monitoring systemto record their discharge since its inception until the year 2014. Therefore, discharge quantities during the non-monitored years have been assumed on an average value according to discharge readings in year 2014.It is noteworthy that drilling of those new wells has led to drought of most of the springs in the study area among which the Faria spring which was discharging the large amount of water (about 6 MCM/year). The new drilled wells are especially localized in Al-Faria sub-catchment.

The totalannual utilization from the agricultural wells ranges from 4.3 MCM to 15 MCM with an average of 9.03 MCM (Based on the available data from PWA for the period 2000 to 2014).

4.2.2.2 Springs Discharge (S_D)

Springs are the only natural drainage outlets for ground water in Faria catchment. Most of the springs are located in the upper and middle parts of the catchment (Shadeed, 2008).

Springs discharge data shows a high variability during the last fifteen years. This can be attributed to either deepening the existing wells or digging new wells which decline the water table in the vicinity of springs, and thus most of springs are frequently getting dried. The peak discharge was in the first part of the period with a maximum value of 12.3MCM in the year 2006, and then the discharge quantity started declining in the second part of the period to its minimum value of 1.3MCM in the year 2012 to give an average water discharge of 6.7MCM (Based on the available data from PWA for the period 2000 to 2014).

4.3 Model Results

The main result from setting up the LPM model is the groundwater budget in Al-Faria catchment. This has been achieved by developing the mathematical model that has been expressed through the general mass equation of water balance as in the following:

$$\Delta \boldsymbol{S} = \boldsymbol{QIN} - \boldsymbol{QOUT}$$

$$\Delta \boldsymbol{S} = (\boldsymbol{Rr} + \boldsymbol{Rirr} + \boldsymbol{Rwdn} + \boldsymbol{Rww}) - (\boldsymbol{WD} + \boldsymbol{SD})$$

Where:

ΔS: The groundwater storage in the aquifer (MCM)

R_r= Recharge from rainfall (m^3)

R_{irr}= Recharge from irrigation return flow (m^3)

R_{wnl}= Recharge from water networks leakage (m^3)

R_{ww}= Recharge from waste water effluent (m^3)

W_D= Wells discharge (m^3)

S_D= Springs discharge (m^3)

The numerical solution for the mathematical model was conducted using MS Excel.

The groundwater budget for Al-Faria three sub-catchments is shown in Table (4.8) for the period (2000-2014). All the input and output parameters where presented for each sub-catchment.

Table (4. 7): Groundwater budget (MCM) for Al-Faria Catchment (2000-2014)

Sub-catchment	Recharge (MCM)				Discharge (MCM)		Water Budget (MCM)
	Rainfall (R_r)	Irrigation Return Flow (R_{irr})	Water Distribution Network Leakage (R_{wdnl})	Wastewater (R_{WW})	Wells (W_D)	Springs (S_D)	
Al-Badan	7	0.31	0.31	0.73	0	3.1	5.25
Al-Faria	5.7	1.08	0.65	0	3.6	2	1.83
The Lower	7.4	2.3	0.13	0	5.6	1.6	2.63

From the Table, it can be concluded that the total inputs for the groundwater to the shallow unconfined aquifer in the three sub-catchments exceed the total outputs by a value of about 9.7 MCM. From all the water budget parameters, it is also concluded that the maximum contribution of water recharge is from rainfall. Al-Badan and the Lower sub-catchments have the largest amount of rainfall quantitythat most of which turn out to become recharge. On the other hand, recharge quantities from irrigation return flow and networks leakage becomenegligibleto some extentexcept for the Lower sub-catchment; this is due to its large areas of irrigated plants. Hence, it makes the quantity of wastewater effluent from East-Nablus of significant value, since it is usually mixed with rainfall in the Lowe sub-catchment and negatively affects water quality and thus the crops quality.

Regarding discharge quantities, it is obvious that wells discharge dominated springs discharge in Al-Faria and the Lowe sub-catchments,where farmers in the region went to dig new agricultural wells that led to dry most of springs and decrease water discharge of the other. However, springs are the only discharge source in Al-Badansub-catchmentwith a small discharge amount compared to rainfall recharge quantities, which makes ithas the larger surplus quantity of groundwater.

All results take us to set up different management optionsto preserve the amount of water available in the shallow aquifer in the optimum utilization ways in accordance with the region’s nature and its needs in order to serve its socio-economy.

4.4 Management Options

Al-Faria catchment is considered as one of the largest agricultural areas in the West Bank, which in turns produces many kinds of vegetables and citrus fruits to meet the needs of the region and to export abroad. Thus, it is of great importance to focus on the agricultural sector by supporting it through establishing water management options that promote it through increasing its good quality production which lead to raise its socio-economic level.

Hence, it is worth to utilizethe excess amount of water in the catchmentand particularly in Al-Badan sub-catchment which contains a surplus of about 5.42 MCM.

The following managementoptions are proposed:

4.4.1 Digging New Wells

4.4.1.1 Al-Badan Sub-catchment

As it was noticed in the water budget results, Al-Badan sub-catchment has the largest excess quantity of water in the catchment, so we can utilize this surplus amount of 5.25 MCM by digging new agricultural wells in the sub-catchment to pump groundwater and be used to irrigate the arable areas in the sub-catchment.

Al-Badan sub-catchment contains arable area of about 13,000 dunums that is suitable for cultivation as shown in Figure (4.5).

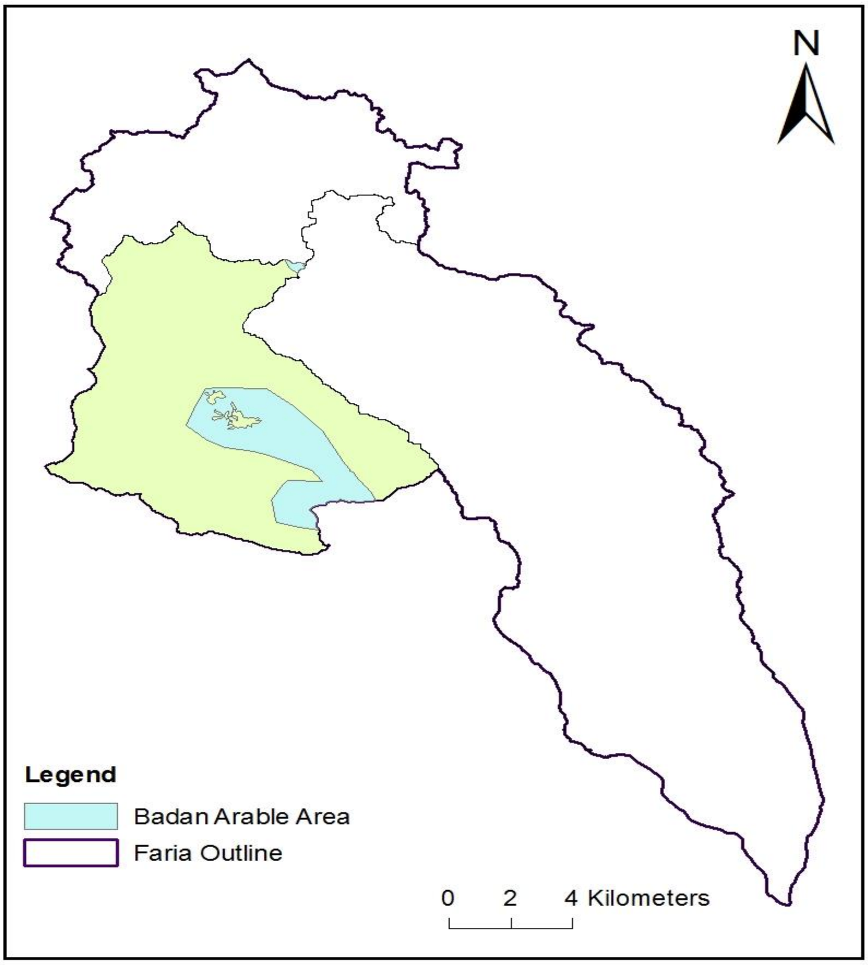

Figure (4. 4): The Arable Area in Al-Badan Sub-catchment

An area of about 5,400 dunums is suggested to be utilized from the whole available arable area, and is proposed to be planted of about 3,200 dunums of potatoes and 2,200 dunums of tomatoes.

There is no actual data about the agricultural consumption and agricultural demands for the proposed planted area, but the EQA summarized the water needs for vegetable crops in Al-Faria catchment in their report in 2004 as shown in Table (4.9).

Table (4.8): Seasonal Crop Water Consumptive Uses for Most Common Vegetable Crops (EQA, 2004)

Area		Potatoes	Tomatoes	Maize	Small Vegetables	Sweet Peppers
Upper zone	**Planting Date**	Jan 1	March 1	March 1	March 1	March 1
	Water use (mm)	360	668	559	374	546
	Planting Date	August 1	June 1	June 1	July 1	June 1
	Water use (mm)	426	579	578	452	592
Lower zone	**Planting date**	Jan 1	Jan 1	Jan 1	Jan 1	Jan 1
	Water use (mm)	388	488	391	317	375
	Planting date	Sept 1	Sept 1	Sept 1	Sept 1	Sept 1
	Water use (mm)	329	354	286	306	317

So, the total annual water needs for the intended planted area of potatoes equals 2.51 MCM, and the total yearly water needed for the supposed planted area of tomatoes equals 2.74MCM. Thus, newagricultural wells should be drilled to meet the new planted areas requirements of water.

It is suggested to dig new thirteen wells in the suitable closest areas to the proposed planted lands, in which six of them to abstract groundwater by an average of 400,000 m^3/year, four of them to extract by an average of 450,000 m^3/year and the rest three wells to pump groundwater by an average of 350,000 m^3/year.All of them are to be drilled in the unconfined shallow aquifer there. In fact, Palestinians are not allowed to drill new wells or rehabilitate existing wells without first obtaining authorization from the Israeli authorities (Amnesty International, 2009).From here comes the role of thePalestinian Authority to facilitate this step of grant licenses for new wells, in order to promote the water role in supporting the agricultural sector.

Figure (4.6) shows the proposed new thirteen wells locations in Al-Badan sub-catchment

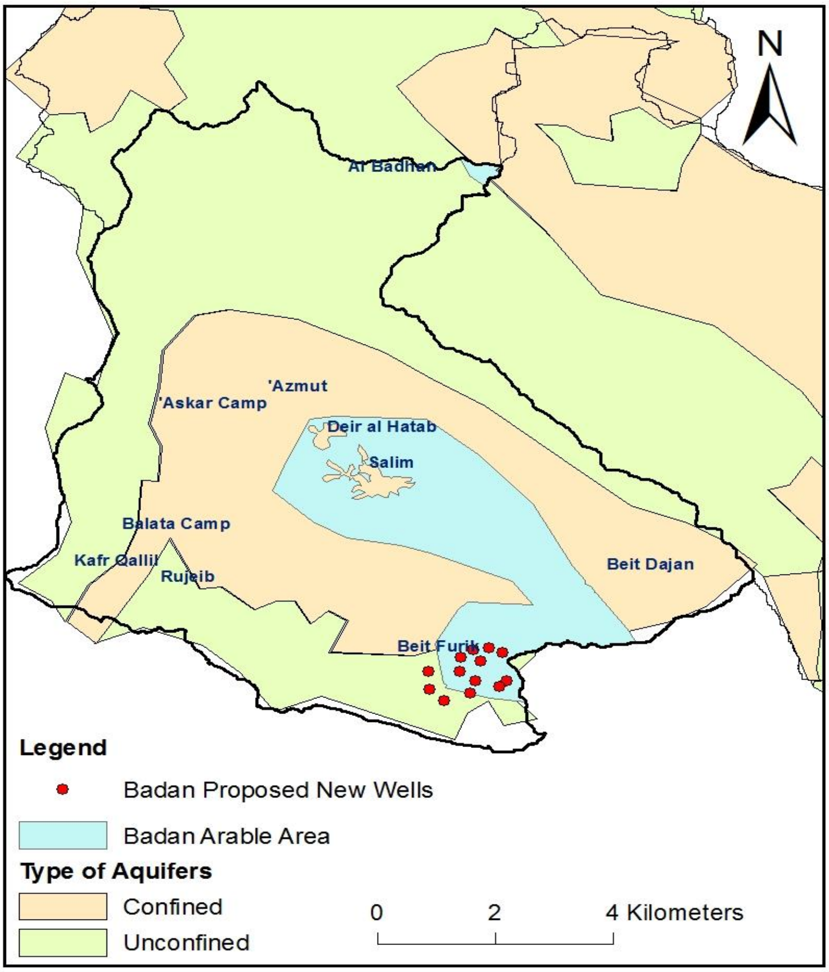

Figure (4. 5): The New Proposed Agricultural Wells Locations in Al-Badan Sub-catchment

4.4.1.2 Al-Faria Sub-catchment

Regarding Al-Faria sub-catchment, the excess amount of water was found to be 1.83 MCM, which also can be utilized in the agricultural sector to develop the region's economy.

In this sub-catchment, there is a trend toward the cultivation of medicinal herbs in the greenhouses, which also are considered as valuable and profitable cash crops, such as peppermint, thyme, basil, etc. Tons of these herbs are exported abroad at high revenue to some extent.

Peppermint in greenhouses is supposed to be planted there in the upper part of the sub-catchment where mountainous terrains are suitable for the growing of such plants.

Through the experience of the farmers thereand an oral interview with them, it was stated that each one dunum of greenhouses planted with peppermint needs around 2,000 m^3/year of irrigation water.

So, and as the water available for agriculture is about 1.83 MCM, 915dunums of peppermint can be planted there.

Figure (4.7) shows the new proposed planted area of peppermint in Al-Faria sub-catchment.

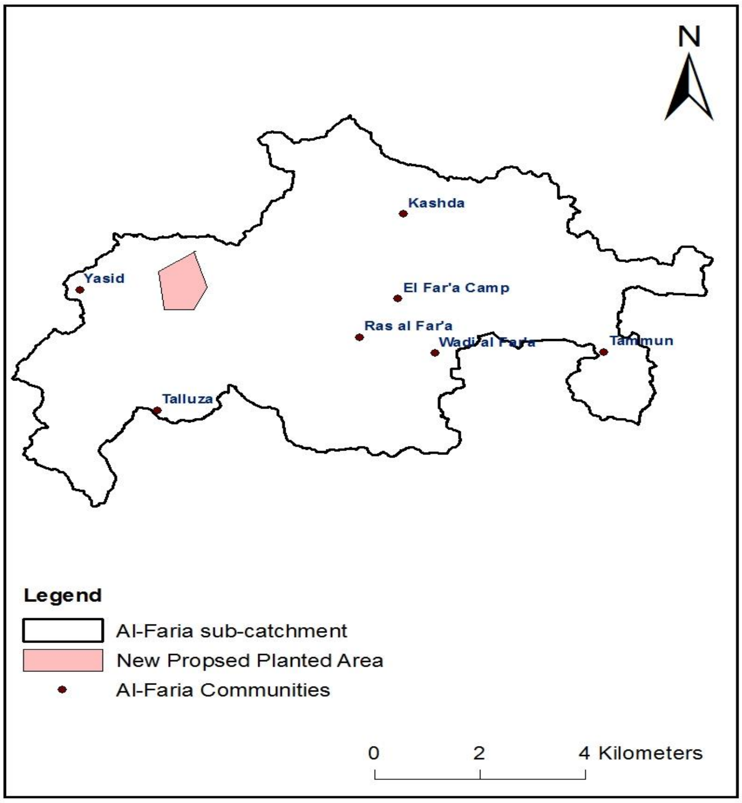

Figure (4.6): The New Proposed Planted Area of Peppermint in Al-Faria Sub-catchment

All the existing agricultural wells in Al-Faria sub-catchment are overloaded and meet the needs of certain areas. Thus, they do not accommodate irrigation of a new large area. This in turn has compiled the need to drill new wells which are proposed to be close to the suggested new planted area to reduce the pumping and distribution costs.

New six wells are proposed to be drilled. Each one is suggested to extract groundwater by an average of 305,000 m3/year.

Figure (4.8) shows the proposed sixnew wells locations in Al-Faria sub-catchment.

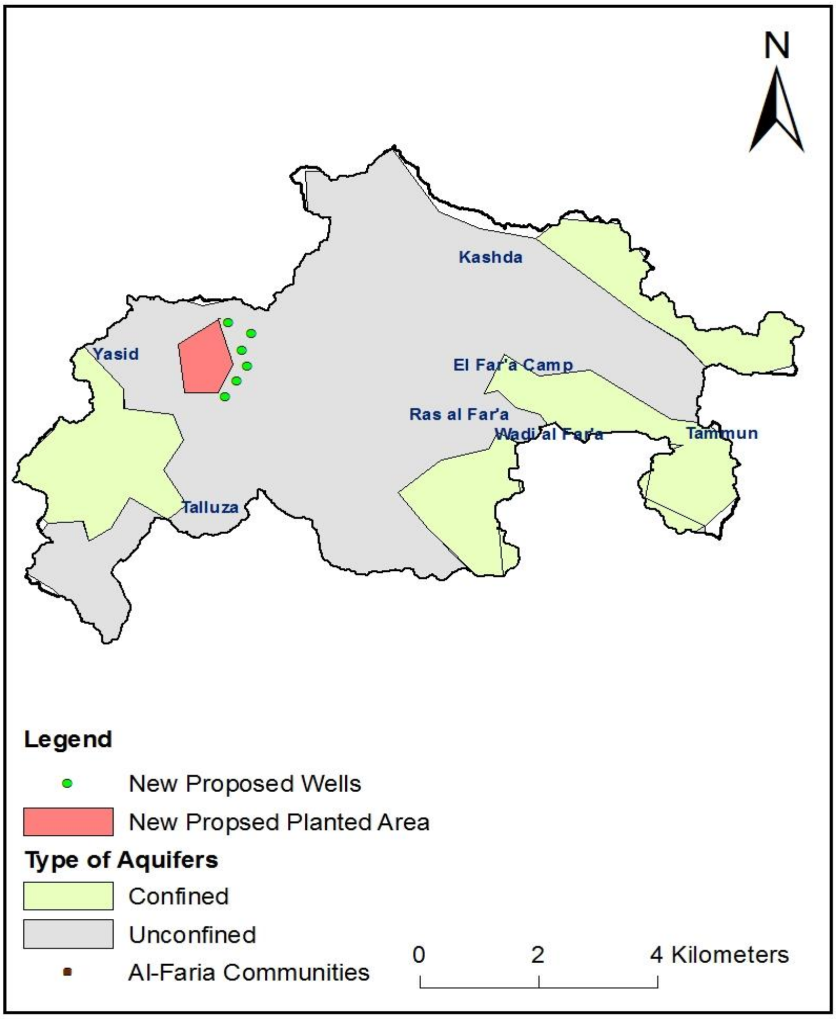

Figure (4.7): The New Proposed Agricultural Wells Locations in Al-Faria Sub-catchment

4.4.1.3 The Lower Sub-catchment

The lower part of Al-Faria catchment is considered as the Food Basket for Palestine because of its importance in the agricultural production for many different vegetables and permanent crops as its suitable climate.

Unfortunately, this region suffers from mixing the fresh rainfall and springs water with East-Nablus wastewater. Farmers in the area and due to shortage in water are using the untreated wastewater to irrigate their crops. Accordingly, this led to poor quality of the crops and consequently lackingthe ability of marketing both within the region andeven exported abroad. This in turn threatened the agricultural sector in the regionand thus the socio-economic there.

The groundwater budget results show that there is a surplus amount of groundwater of about 2.63 MCM in the shallow unconfined aquifer there. So, It is extremely important to utilize this quantity to promote the agricultural sector their and raise it up, particularly in cultivation of the permanent crops.

The yearly water requirement for these permanent crops in the lower sub-catchment was summarized by the EQA as shown in Table (4.10).

Table (4. 9): Annual Crop Water Requirements (m^3/dunum) for Permanent Crops

Area	Potential ET	Alfalfa	Citrus	Bananas	Grapes	Date Palm
Upper Zone	1,380	763	666	1,179	661	948
Central Zone*	1,460	857	763	1,343	747	1,092
Lower Zone	1,539	950	861	1,517	833	1,235

* Extrapolated as the average of Upper and Lower zones data since no climatic stations are available in this region.

So, it is proposed to plant new groves of citrus, banana and palm date by areas of 1,250 dunums, 1000 dunums and 650 dunums respectively in the available arable area in Al-Aqrabaniya and An-Nassariya.

Figure (4.9) shows the new proposed groves locations in the Lower sub-catchment.

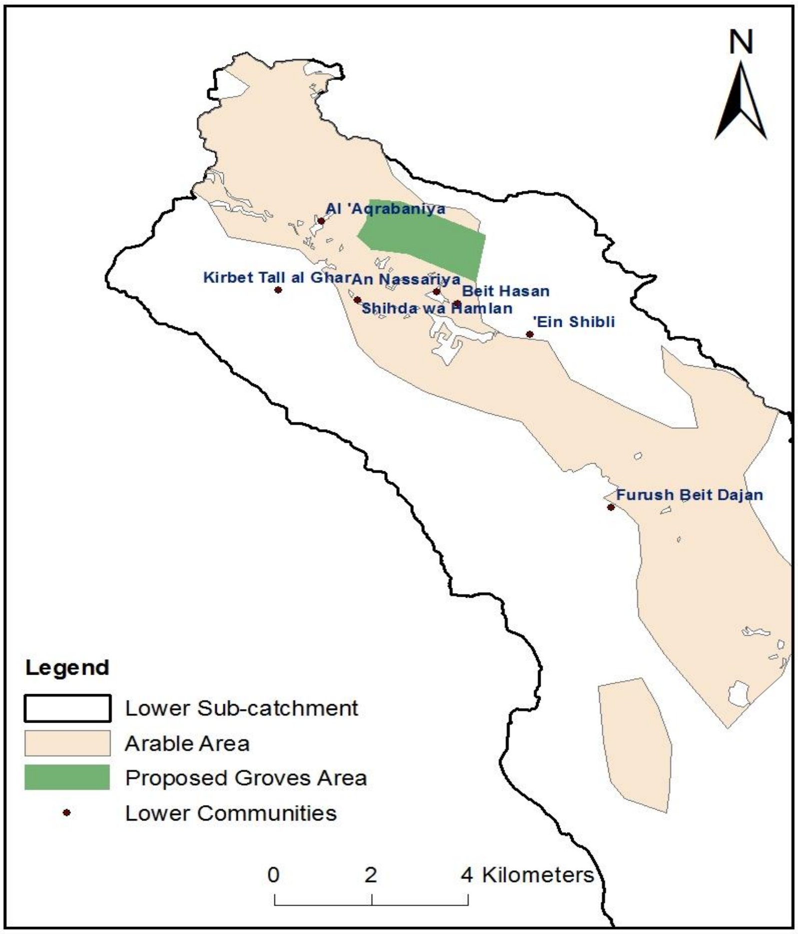

Figure (4. 8): The New Proposed Groves Locations

Accordingly, new agricultural wells are proposed to be drilled in order to meet the above crops water requirements. Nine new wells are to be drilled, in which seven of them to pump water at a rate of 320,000 m^3/ year and the others at a pumping rate of 195,000 m^3/ year.

Figure (4.10) shows the proposed nine new agricultural wells locations in the Lower sub-catchment.

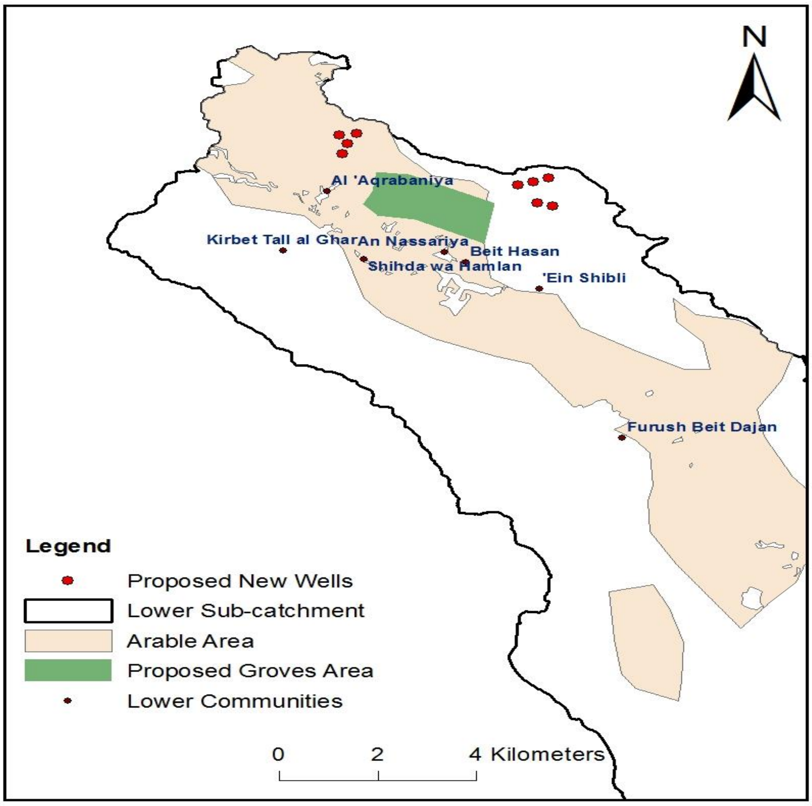

Figure (4. 9): The New Proposed Agricultural Wells Locationsin the Lower sub-catchment

It is worth noting that the suggested management option of finding new agricultural wells in the lower sub-catchment is compatible with the signed agreement of the implementation of the irrigation project in the village of An-Nassariya. The agreement was held between the Palestinian Hydrology Group for Water and Environmental Resources Development (PHG) and the Ministry of Agriculture in the year of 2014 to replace the contaminated water currently used in agriculture to another clean source of groundwater wellsfunded by the Dutch Representative Office(1).

(1)http://www.maannews.net/Content.aspx?id=676821

It is also important to mention that the lower sub-catchment is suffering frompolitical restrictions. The occupation thereconfiscates a lot of lands, and prevents water transfer to many neighboring marginalized “C” villages. These villages whichsuffering even from shortage of drinking water likekherbitA’atuf and lack of irrigation water in Sahl Al-Bqea’awhich are located to the north east of the lower sub-catchment. Thousands of dunums there can be irrigated by the surplus amounts of water in Al-Faria and the Lower sub-catchments wells, thus achievingexpansion of agricultural production in areas "C" and support the national economy(1).

4.4.2 Treating of East-Nablus Wastewater

The amount of wastewater discharged from East-Nablus must be treated so does not reach and feed the aquifer below to be collected and transported by a closed piping system to the lower sub-catchment. So, it can be used to irrigate the crops there and helps the development of the agricultural sector of the region and thus itseconomic. This is consistent withNablus Municipality’s vision to carry out the project of construction of wastewater treatment plant for the eastern part of Nablus city. This will help in solving the sewage problemand its leakage to the groundwater in Al-Badan and the lower sub-catchment besides the possibility of its utilization in irrigation (2).

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(1)https://www.alwatanvoice.com/arabic/news/2015/05/12/713036.html

(2)http://www.maannews.net/Content.aspx?id=676821

Chapter Five

Conclusions and Recommendations

5.1 Conclusions

Faria catchment is one of the most important catchments in Palestine that is divided into three sub-catchments and located above the main groundwater aquifers which are the eastern and the north eastern aquifers.

This study covers the entire catchment with an area of 320 km^2. A LPM was used to find the groundwater budget of the shallow unconfined aquifer in the three sub-catchments. Based on the results, different watermanagement options were suggested to promote the agricultural sector in the catchmentand develop its economy.

The following are the main conclusions from the research:

1. The study came up with optimistic results.
2. Applying the LPM using the water balance approach for the aquifers below the three sub-catchments shows a surplus in budget by about 9 MCM.
3. Rainfall is the dominant component for recharge in the three sub-catchments.
4. The domestic wells were excluded from this study since they pump from the deep confined aquifer, thus they are not included in the study.
5. As the model is dealing with each sub-catchment like a closed separate tank, Al-Badan sub-catchment has the largest quantity of groundwater surplus. This is because it receives a large quantity of rainfall but has a very few planted areas, thus few agricultural wells aredischarging groundwater for irrigation.

6. The used data of discharge from wells and springs for the period 2000 and 2014 have a large disparity from each other. This consequently has affected the calculated discharge average values.
7. Most springs in Al-Faria sub-catchment have dried due to the increase in the number of agricultural groundwater wells there. This decreasing in springs discharge has been compensating by increasing the wells discharge.
8. The surplus amount of water in the aquifers below the three sub-catchments was managed by suggesting drilling new wells in several unconfined locations there.
9. Drilling new wells is an expensive option.
10. The option of deepening the existing agricultural wells in the study area to increase the extracted amount of groundwater was excluded, so that the hydro-power becomes not focused with certain people.
11. It will be possible to go in the trend of deepening the existing agricultural wells if water resources regulations and determinants were adopted by the PWA on the allowed quantity of water to be extracted and water price per cubic meter to the consumer (farmers).
12. New crop areas were suggested in the available arable areas in each sub-catchment to be irrigated by the new agricultural wells.
13. In fact, the aquifers below the three sub-catchments maybe act as one aquifer and the proposed drilled wells in each sub-catchment may withdraw water from the other sub-catchments.

5.2 Recommendations

Based on the outputs of this research, the following points are recommended:

1. Greater attention should be givenregarding groundwater modeling in Palestine.
2. There must be a regulatory system to continuously monitor and record the groundwater wells discharge data.
3. Applying the physical based model is better than the LPM and gives more realistic results but remains the problem of data availability.
4. The Faria aquifer system is very complicated geologically. Hence, it is of importance to make greater efforts by experts to conduct more cross sections in several locations in the catchment to enable setting up more realistic models.
5. The Ministry of Agriculture and the PWA shouldcooperate to follow-upthe methods of irrigation in the region in order to reduce water losses ratio.
6. The quantity of wastewater discharged from East-Nablus should be treated before returning to recharge the aquifer and negatively affect its water quality.Therefore, it can be used for irrigation.

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جامعة النجاح الوطنية
كلية الدراسات العليا

نمذجة الموازنة المائية في الحوض الجوفي الضحل في منطقة الفارعة باستخدام النموذج الرياضي المجمل

إعداد
مجد فرحان عبدالله السودة

إشراف
د. سمير شديد
د. عبدالحليم خضر

قدمت هذه الأطروحة استكمالا لمتطلبات الحصول على درجة الماجستير في هندسة المياه والبيئة بكلية الدراسات العليا في جامعة النجاح الوطنية في نابلس – فلسطين

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نمذجة الموازنة المائية في الحوض الجوفي الضحل في منطقة الفارعة

إعداد

مجد فرحان عبدالله السودة

إشراف

د. سمير شديد

د. عبدالحليم خضر

الملخص

يهدف هذا البحث لايجاد الموازنة المائية للحوض الجوفي الضحل الغير محصور في منطقة الفارعة والذي يعد من أهم الاحواض المائية في فلسطين نظرا لأهميته الزراعيةفهو يوصف بسلة فلسطين الغذائية، بحيث يسد حاجته وحاجة المنطقة من المحاصيلويتم تصدير الفائض للخارج. يقع في الشمال الشرقي للضفة الغربية ضمن الحوضين الجوفيين الشرقي والشمالي الشرقي وتبلغ مساحته حوالي 320 كم^2.

تم استخدام نموذج الصندوق الأسود لتحديد الميزانية المائية للخزان الجوفي في منطقة الدراسة والتي تم تقسيمها لثلاثة أحواض فرعية وهي الفارعة، الباذان و الحوض السفلي. تم تطبيق مبدأ الاتزان العام للكتلة المائية على كل حوض بشكل منفرد لايجادالمخزون المائي فيه وبالتالي تحديد الموازنة المائية للحوض الجوفي كاملاً في منطقة الدراسة. تم تحليل كافة العناصر الداخلة للموديل والخارجة منه باستخدام كل من برنامج(Excel) وبرنامج نظم المعلومات الجغرافية (GIS).

تتكونعناصر التغذيةلطبقةالمياهالجوفية من مياهالأمطار، تدفق العائد من الري و المياه المتسربة من شبكاتتوزيع المياه بالاضافة لمياهالصرفالصحي المتدفقة من شرقمدينةنابلس.

علىالعكسمنذلك، فان عناصر تصريفالمياهمنطبقةالمياهالجوفيةتتألفمنالمياهالتييتمضخهامنالآبار الزراعيةبالإضافةإلىالمياه المتدفقة من الينابيع.

أظهر الموديل نتيجة موجبة للمخزون الجوفي، مما يعني وجود فائض في طبقة المياه الجوفية في الخزان الجوفي السطحي الغير محصور تحت الاحواض الفرعية الثلاثة، وعليه تم وضع مقترحات

ادارية مناسبة في منطقة الدراسةبما يضمن اسنغلال المياه الفائضة لتحسين وتعزيز القطاع الزراعي في المنطقة.

يعد خيار حفر آبار جديدة في مواقع مناسبة في المنطقة هو الاقتراح الرئيسي على أن يتم استخدام المياه التي يتم ضخها لري مساحات جديدة مقترحة من المحاصيل الناجحة والاقتصادية التي تتناسب مع ظروف كل حوض فرعي.

كما أنه من الضروري معالجة مياه الصرف الصحي الخارجة من شرق نابلس قبل وصولها للخزان الجوفي ورفع مستواه بالمياه الملوثة، على أن يتم تنقيتها وجمعها ونقلها بواسطة نظام انابيب مغلق، ومن ثم استخدامها في ري المزيد من المزروعات في المنطقة وخاصة في الحوض الفرعي السفلي دون أن تؤثر على نوعية المحاصيل.

ان تطوير مقترحات الادارة يعد مطلب أساسي ومهم لتطوير المصادر المائية في المنطقة وتحسين ظروفها الاقتصادية والاجتماعية والارتقاء بها.