BIRZEIT UNIVERSITY

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Monthly Recharge Estimation for the Auja-Tamseeh Catchment of the Western Basin Aquifers-System, Palestine.

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Supervision Committee:
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This Thesis was defended successfully on (26th of June 2004) and was approved by all members of the Supervision Committee.

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ABSTRACT

This study aims at developing a monthly recharge estimation model for the ground water system at Auja-Tamseeh surface catchment of the Western Basin Aquifer-Systems in Palestine. The study was based on the hydrological observations developed by thorough analysis of rainfall quantities and their effect on groundwater level rise inside the aquifer.

The first hydrologic observation was related to **lag-time effect** for any rainfall event. Any rainfall event doesn't recharge the groundwater basin directly. A small amount of the rainfall event in that month is observed to reach the aquifer and cause a rise in the groundwater level of that aquifer. The effect of this rainfall event was noticed to increase gradually till a maximum influence is obtained inside the aquifer three to four months after the rainfall event. Then the influence of this rainfall event decreases gradually till it vanishes three months after the peak. Hydrographs of monthly groundwater levels revealed that groundwater level peak usually took place in April except for the very wet year 1991\92 were heavy rain in February and March drifted the peak to June-July. The study assumed a three month lag-time period with a groundwater level peak at April.

The second hydrological observation was concerned with the **accumulation effect** of a rainfall event. It was noticed that the rainfall influence on the ground surface didn't produce an instant change in the groundwater level. The change in the groundwater level was noticed to increase gradually till it reached its maximum effect (peak) at April which is three months away from the maximum long term average monthly rainfall values. The groundwater level decreased gradually till it vanished three months after the peak. The influence of any rainfall event was observed to last for seven months following a log-normal distribution.

These observations and assumptions led to the development of mathematical recharge equations for the monthly estimation of recharge over the Auja-Tamseeh catchment. These equations took into consideration the spatial and temporal variations of rainfall amounts impeding on the land surface and the replenishment through the outcropping formations of the pervious geological formations of the catchment.

The developed mathematical equations were used to calculate areal recharge volumes over the Auja-Tamseeh catchment. The percentage of recharge from rainfall volumes was equal to 21 % which was close to findings of other studies like SUSMAQ study of Wadi-Natuf were this percentage was equal to 25.7 %.

Key words: Auja-Tamseeh, Surface catchment, Rainfall, Recharge, Annual recharge, Monthly recharge, Lag-time, Accumulation effect, Mathematical equations, Log-normal distribution, Peak, Groundwater level, Arid areas, Semi arid, GIS.

To my family
Khader, Nataly, Maroupi, Anwar, and Karmen
&
To my sister's family
Mona, Bader
Nida'a, Nimara, and Melvena

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Table of Contents

List of Figures

List of Tables

List of Symbols

ARIJ	Applied Research Institute of Jerusalem
EAB	Eastern Aquifer Basin
GIS	Geological Information System
GMS	Groundwater Modeling Systems
LA	Lower Aquifer
LBK	Lower Beit Kahil formation
Mcm	Million cubic meters
PGE	Palestinian Grid East
PGN	Palestinian Grid North
PWA	Palestinian Water Authority
SUSMAQ	Sustainable Management of the West Bank and Gaza Aquifers, Palestine.
UA	Upper Aquifer
UBK	Upper Beit Kahil formation
WAB	Western Aquifer Basin
Y	Yatta formation

CHAPTER ONE
INTRODUCTION

1.1 Background

Water in Palestine is a scarce and valuable commodity. Groundwater and surface water constitute the major water resources in the area. The biggest surface basin in Palestine is the Jordan River Basin. The groundwater basins are vastly distributed within the region and depend on the amounts of rainfall, which are distributed heterogeneously spatially and temporally for their recharge (Guttman, 1998).

The growing demand for water in the region has increased groundwater abstractions, which in turn led to over utilization of the available groundwater basins. Such over exploitation of water is causing a crisis and is affecting the quality and quantity of accessible water.

The water scarcity problems had prompted water engineers, hydrologists and hydrogeologists to explore possible solutions to the water crisis. Comprehensive studies of the available water resources and the development of management techniques to preserve these resources from deterioration both in quantity and quality are urgently needed.

Groundwater in Palestine is pumped from the Mountain Aquifer Basin, which consists of three sub-basins. These are the Western Aquifer Basin (WAB), which is also known as the "Yarkon- Tanninim" basin or the Timsah-Bir Sabi basin; the Northeastern basin known as the "Nablus-Gilboa" basin; and the Eastern basin. The WAB, which covers an area of 9155 km^2, is the biggest of the Mountain Aquifer sub-basins and has a safe yield of about 380-450 million cubic meters (Mcm)\ year (SUSMAQ, 2001). The political situation in Palestine is imposing limitations on the availability and accessibility of meteorological and hydrological data; therefore the study area will focus on the Auja Tamseeh catchment as a representative catchment in the WAB. The Auja-Tamseeh is a surface catchment with replenishing zones inside the West Bank thus rainfall recharge study of the Western groundwater Aquifer Basin is possible despite political constrains of data availability.

1.2 Recharge study

Groundwater recharge is defined as the downward flow of water reaching the water table, and forming a temporary or permanent addition to the ground water basins. The recharging water reaches the ground basins either directly, or indirectly. The direct recharge is the amount of water in excess of soil moisture deficits and evapotranspiration by direct percolation through the unsaturated zone. While the indirect recharge results from the percolation to the water table following run off and localization in joints (Simmers, 1997).

According to Rushton and Ward (1979), recharge is affected by many factors. The most important are listed below:

- Climatologically, the amount of precipitation falling on the land surface, the actual evapotranspiration quantities, in addition to run off quantities are decisive elements in the estimation of recharge. The areas where precipitation is almost equal to evapotranspiration have limited amounts of water to replenish the ground water basins during the recharge process. These areas require realistic and accurate approaches for the estimation of recharge quantities, especially when surface water is scarce and rare.
- Soil nature and hydraulic properties control the flow mechanisms. The nature of soil controls cracking, drying out or swelling properties of the soil, and thus affects its capability of infiltration.
- The unsaturated zone between the soil and the aquifer control the flow mechanism through the unsaturated zone. Differences in the hydraulic conductivities of this zone retards water movement.
- Type of aquifer according to its ability to accept water, and the variations of the aquifer conditions with time.

The aquifers in Palestine especially in the area of study are made of weathered bare hard rock and limestone that is jointed, cracked, and highly karstified. These rock conditions make localized or indirect recharge a significant if not the most important source of natural recharge in arid and semi-arid areas (Lerner, et al, 1990). Preferable routes for the movement of water appear in such conditions causing areas of high permeability and increasing the recharge quantities from precipitation.

1.2.1 Recharge estimation approaches

There are several approaches for recharge estimation. The most common approaches used to quantify recharge from various sources according to Lerner et al, (1990) are:

- Direct measurements
- Water balance methods
- Darcian approaches
- Methods using tracers as chlorine and hydrogen isotopes.
- Empirical methods

The areas classified as arid or semi-arid according to UNESCO (1979) classification depend on the aridity indices in addition to soil and vegetation data. The aridity index relates the mean annual precipitation to the potential evapotranspiration of the study area. The aridity index for the arid zones ranges between 0.03 to 0.20, while for the semi-arid zones it ranges between 0.20 and 0.50.

The recharge estimation approaches for the arid and semi-arid areas are not the indirect and physical approaches such as the water balance and Darcian flux measurements, for these are the least successful in the quantification of recharge in the dry regions. The tracers of chlorine (Cl and ^{35}Cl) and hydrogen (^{3}H) isotopes proved to be the simplest, least expensive, and most universal for such regions (Allison et al, 1994). Tracers are applied and monitored in order to determine rate of water movement and infer the recharge rate. If tracer observations are combined with simple water balance models, they not only enable one to infer recharge rates but yield valuable information about flow processes in the vadose zone (Hendrickx and Walker, 1990).

Recharge estimation is a prerequisite for the determination of the sustainable yield of the various Palestinian Aquifer Basins. In Palestine, which is considered as a semi-arid area, recharge takes place by two different mechanisms:

1. Direct or diffuse recharge resulting from wide spread infiltration of rainwater at the point of impact especially on karst, joints, and cavities. Direct recharge is the amount of water in excess of soil moisture deficits and evapotranspiration. It is the vertical movement of precipitation through the unsaturated zone (Lerner, et al, 1990 and Simmers, 1997).
2. Localized recharge where some horizontal flow occurs into local depressions that are not connected to any draining watercourse. The indirect recharge which results from percolation to the water table following runoff and localization in joints that take place in low lying areas or through the beds of surface watercourses (Lerner, et al, 1990).

The above estimation approaches are not easy to quantify. Some approaches require tremendous data concerning the geology and hydrogeology of the study area in addition to the meteorological data to determine the amounts of direct and indirect recharge quantities. Other studies are local where data is extracted from experiments applied to a specific study area. Use of multiple tracers for recharge estimation is the norm used by many authors like Cook, et al (1994); Phillips (1994,), Tyler and Walker, (1994), and others. All these authors used CL, ^{3}H, and ^{36}Cl for the recharge estimation of the same study area.

Recharge estimation is an important element in water resources assessment studies especially for arid and semi-arid regions. Recharge in the semi-arid regions like Palestine, is generally low and variable in magnitude over space and time. The dependence of recharge on precipitation as a major element for replenishment is an extremely heterogeneous realm where flow is transient and almost always spatially variable. The variation phenomena of rainfall quantities in Palestine over the years and months of the same hydrologic year produce varying recharge values for each month of the same year. This variation effect requires monthly estimation approaches for the quantification of monthly recharge values. Also the transient flow of the recharging water requires the study of recharge on semi annual basis or even on monthly basis rather than on annual averaging of rainfall data as developed in the analytical recharge models of Guttman and Zukerman (1995) or Zukerman (1999) cited in SUSMAQ (2002). In addition, information regarding groundwater levels and abstractions are measured on a monthly basis; therefore, availability of monthly recharge values is critical for building a more accurate recharge estimation model. Such new monthly estimation model will be based on more data points and it will take into account rainfall values. The present study is an attempt to develop recharge estimation models for Auja Tamseeh catchment on monthly basis depending on annual recharge models and empirical equations developed by Guttman and Zukerman (1995).

Studies dealing with recharge of groundwater basins are few due to limitations of data, but there are some unpublished studies. There were some pioneer studies at specific locations of Palestine which dealt with tracer concentrations as the experimental study of Lange et al (2003) for runoff generation using tracer techniques. The present study uses the empirical method to determine monthly recharge using rainfall data provided by rainfall-gauging network present in the area of study. The data of this study is mainly obtained from PWA data bases and the SUSMAQ Project of Newcastle University and PAW.

1.3 Study objectives:

The main objective of this study is to estimate monthly values of recharge which will help in providing a more accurate management plan of the available water resources. The study dealt with the following objectives:

1. Selection of the most appropriate approach of recharge estimation for the area of study by considering the limitations of data availability.
2. Monthly estimation of recharge and its distribution spatially over the study area.

3. Development of monthly recharge models for the study area.

1.4 Previous Studies

The growing demand for water was threatening the groundwater sustainability and quality in the arid and semi-arid regions. The limited recharge quantities in such regions inspired national world organizations as the UNESCO in addition to different hydrological institutions to fund research studies on recharge of groundwater in order to have better insight of natural replenishing quantities for the groundwater basins.

Various recharge estimation approaches were developed by different authors depending on the area specifications and data availability. The earliest water balance method was developed by Thornthwaite (1948) which was a simple bookkeeping of inflow and outflow water quantities required to saturate the soil. Some authors installed direct measurement techniques (e.g. lysimeters) to a study area and built their conclusions on the results of these experiments as the recharge measurements given by Kitching & Bridge (1974). Other authors followed the empirical techniques to find simple relationships between precipitation and recharge. The simplest form considers recharge as a portion of rainfall. Watson, et al. (1976) conducted a comprehensive study on 63 groundwater basins in Nevada using the empirical rainfall recharge expressions and came to a concluding remark that this method is not reliable for recharge estimation. A later study by Avon and Durbin (1994) for the same area came with better conclusions regarding the use of this approach for recharge estimation.

Following the empirical estimation approach, Mandel & Shiftan (1981) developed a formula for recharge in the Mediterranean climates as follows:

$$R = 0.90*(P - 360) \qquad 450 < P < 650 \text{ mm/ year} \qquad \text{(eq. 1.1)}$$

R: annual average recharge rate (mm / year)

P: annual precipitation (mm / year)

More complicated formulas for recharge precipitation empirical relationships were developed by Sinha & Sharma (1988). The formula developed was known by the Cheeturvedi formula and runs as follows:

$$R = 50.8*(P/25.4 - 15)^{0.4} \qquad P > 380 \text{ mm/ year} \qquad \text{(eq. 1.2)}$$

Turc (1954) developed an empirical formula that considered mean annual temperature as a new variable in the recharge estimation.

$$R = P\,(1- (0.9 + P^2 / L^2)^{-0.5}) \qquad \text{(eq. 1.3.a)}$$

$$L = 300 + 25*T + 0.05*T^2 \qquad \text{(eq. 1.3.b)}$$

T: mean annual temperature (^oC)

Use of tracers to estimate recharge was also practiced by some authors as Allison & Hughes (1978), Lloyd et al.(1981), Sharma et al.(1985) and many others. Tracers both isotopic and chemical were either environmental and already present in nature or applied by the researcher.

The studies that were mentioned above dealt with recharge in arid or semi-arid areas but not in Palestine. Few studies that dealt with recharge estimation of groundwater basins in Palestine have appeared in the literature. The study for recharge in the WAB was done by the Israeli Hydrological Service by Goldschmidt and Jacob (1958) who derived a relationship between recharge and runoff based on the long-term average rainfall over the catchment's area for ten years. The empirical equation developed was based on the annual rainfall quantities during the period 1943\44 to 1953\54.

Two studies concerning the WAB; the first by Bachmat (1995) and the second by Guttman and Zukerman (1995). In these studies Goldschmidt and Jacob's equation was modified and calibrated using numerical flow models of the area for few tens of years. Then regression models for the calibrated annual recharge rates and annual rainfall were developed and divided into three segments according to rainfall quantities to produce linear relationships between annual recharge and annual rainfall. Guttman (1998) modeled the Eastern Aquifer Basin utilizing Goldschmidt's 1958 empirical estimates of recharge.

The above equations were all based on annual averages of rainfall quantities in an area considered to be arid to semi-arid. These areas have transient flow patterns caused by the sporadic rainfall and short duration run-off events in the ephemeral drainage systems. Such areas require transient flow models for estimating recharge based on smaller time intervals. Hence, generating an accurate recharge model, required smaller time intervals that match with the abstraction and water level data that are on monthly basis.

Other studies of recharge in various parts of Palestine and the groundwater of West Bank were done by Daibes (1995). The study reviewed some of the recharge estimation approaches and referred to the tasks associated with the development of a hydrogeological conceptual model for recharge in the Northern West Bank\ Paslestine. Ba'ba (1996) studied the Eastern Basin both hydrologically and hydrogeologically then examined annual recharge of the basin. Ghanem (1999) conducted a comprehensive study of Al Fara Drainage basin considering the hydrology, hydrogeology and hydrochemistry of this basin. He also computed the annual recharge of the basin using the historical metrological data of Al Fara catchment over thirty years, in addition to the hydrological data of the area.

Sustainable Management of the West Bank and Gaza Aquifers (SUSMAQ, 2001) had made a study about West Bank Aquifers-Conceptual Recharge Estimation and established comprehensive annual and monthly recharge equations for the WAB.

Simmers (1997) published a comprehensive study of recharge in arid and semi-arid areas. According to Simmers' study, these areas are of greatest need for reliable recharge estimations in order to perform an efficient ground water recharge management in these regions.

SUSMAQ (2004) made a study for monthly recharge of Wadi Natuf catchment as a representative catchment for the WAB in Palestine. The study dealt with monthly recharge distribution based on annual recharge rates and the observations regarding the rainfall event and its effect on recharge. This thesis used SUSMAQ's approach in calculating monthly recharge of Auja-Tamseeh catchment. Unlike SUSMAQ, the study used a log-normal distribution instead of normal distribution with different predetermined values for the same parameters affecting the accumulation of monthly rainfall values. This study used a different method and software in applying the monthly recharge model to the study area than the one used by SUSMAQ. The study used the available Arcview GIS computer software instead of the GMS software (GMS is modeling software available at PWA and SUSMAQ only) for the model application.

These are some of the studies that attempted to study recharge quantitatively but on annual basis. Only the WAB had a monthly recharge model developed by SUSMAQ.

1.5 Geography of the study area

Auja-Tamseeh catchment is one of the surface catchments that extend from 130 to 183 Palestinian Grid East (PGE), and 133 to 182 Palestinian Grid North (PGN) km according to the Palestinian grid coordinates (Figure 1). The topographic map (Figure 2) with original 25 m contour map and shown for 100m contour lines intervals gives an insight for the overall shape of the area by displaying the different elevation ranges through colored zones. The study area extends over Qaliqilya, Salfit Districts in addition to parts of Ramallah and Nablus Districts. The area ranges in elevation from 0m high in the western parts which are at the sea level to 975m in the eastern part were Ramallah and Nablus mountainous ridges prevail.

1.6 Thesis components

The study is composed of six chapters and two Annexes: A and B. Chapter one is an introductory chapter that contains a general background and an introduction to recharge study. It contains previous studies regarding recharge estimation in the WAB in addition to study objectives and the geographical description for the area of study. Chapter two describes Auja-Tamseeh catchment by considering the geography, climate, geology, hydrogeology, and hydrology of the study area. Chapter three presents the study's methodology and approach developed in carrying out the monthly recharge study. Recharge estimation and analysis of monthly rainfall, well abstractions and groundwater levels, spring discharge, and monthly recharge values are all found in chapter four. Chapter five deals with calculations and results obtained and list the mathematical equations developed with the application of these equations on the study area. The study ends with concluding remarks on the study, in addition to recommendations for future studies on recharge estimation.

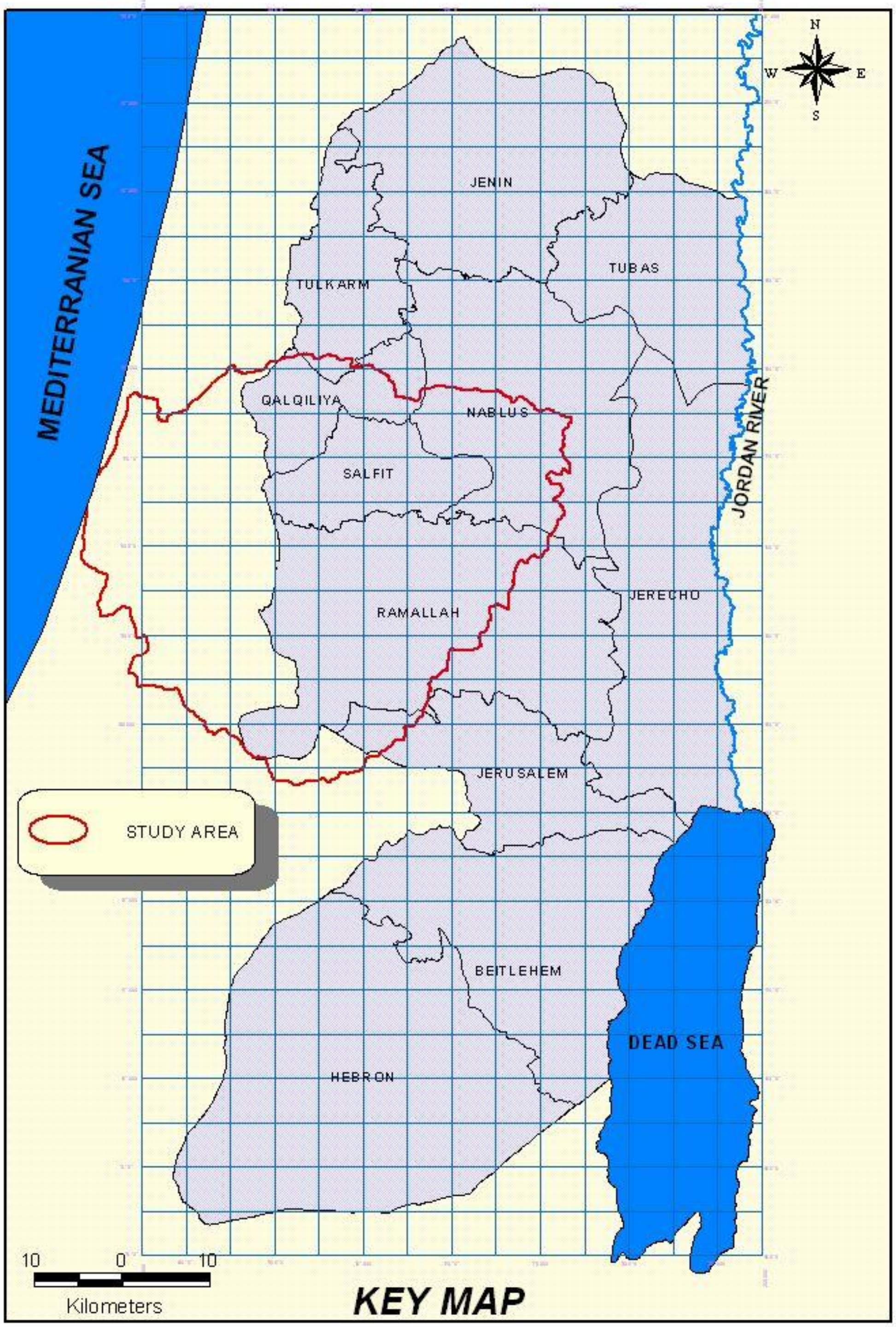


Figure 1: Key Map for the area of study that extends over the Palestinian districts (PWA)

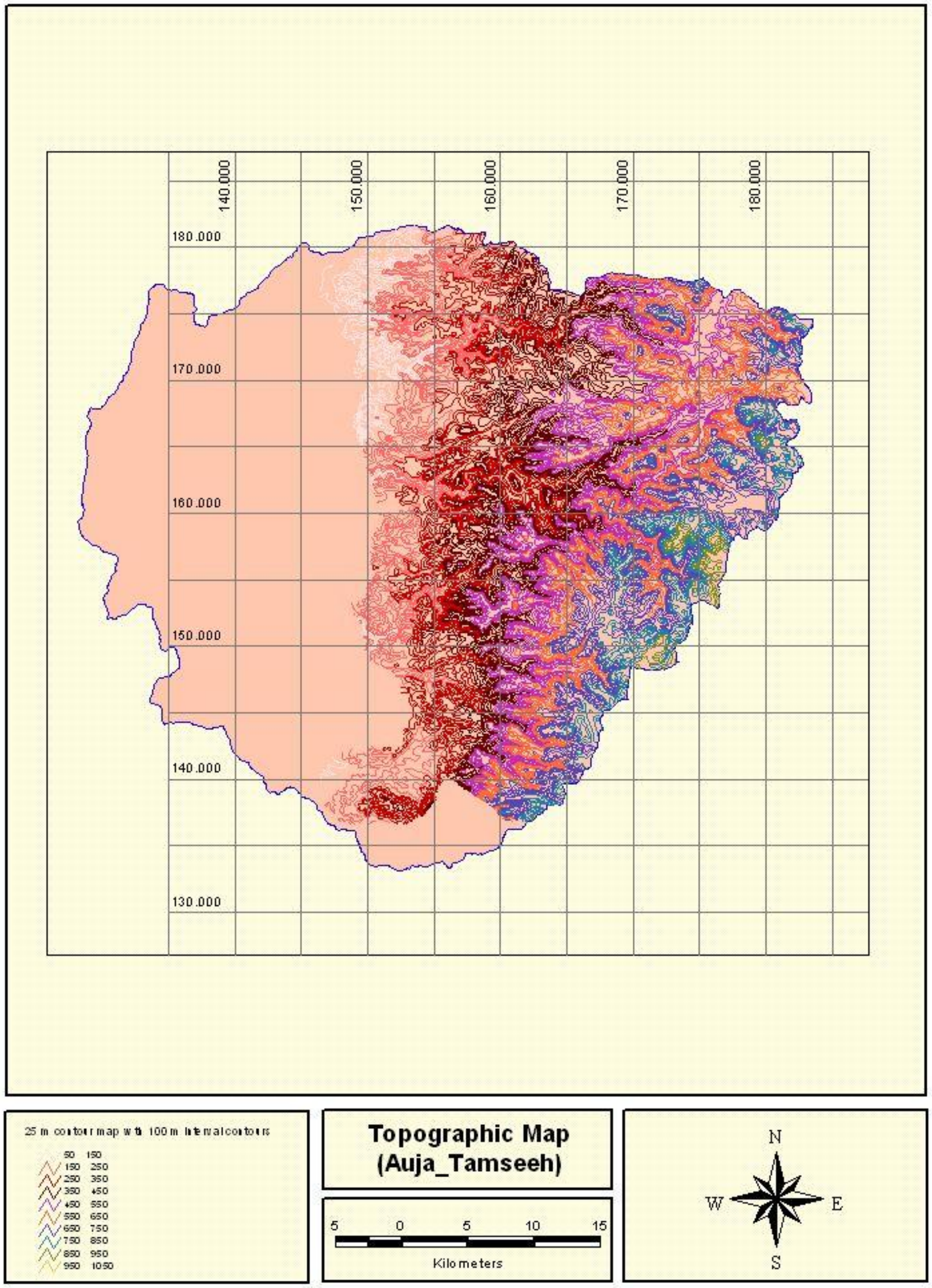


Figure 2:Topographic Map of Auja-Tamseeh catchment (PWA shape files)

CHAPTER TWO
AL AUJA-TAMSEEH GENERAL DESCRIPTION

2.1 Study area

The Western Aquifer Basin is located east of the Mediterranean Sea, west of Hebron-Ramallah- Jenin anticlinorium, north of Beer Shava, and south of Carmel slopes and Tanninim (Timsah) River. The basin extends 235 km from Mount Carmel in the north to Sinai desert in the south and 70 to 30 km from the Mediterranean coast in the west to the West Bank heights in the east (SUSMAQ, 2002).

The WAB extends over an area of 9155 km^2 with 1795 km^2 of the basin’s area lying inside the West Bank (Abed and Wishahi, 1999). The WAB includes the Palestinian countries of Qalqilia and Tulkarm and extends to areas inside the Green Line. The Palestinian gauging network provides daily data for rainfall quantities; therefore the study area is conducted on a surface catchment that lays mainly within the Palestinian boundaries- the western part inside the Green Line- known by Auja-Tamseeh surface catchment. This catchment is a strawberry like catchment that covers an area of 1810 km^2 extending from 130 to 183 PGE, and 133 to 182 PGN km according to the Palestinian grid coordinates. It stretches over the Palestinian districts of Salfit, Qalqilya, south of Tulkarm, Ramallah, and parts of Nablus (Figure 1).

2.2 Description of the study area

Recharge estimations are considerably affected by the climatic properties of the area; rainfall, runoff, and evaporation quantities. The descriptive properties of Al Auja-Tamseeh catchment that define its geology, hydrology, and hydrogeology are considered as prerequisites before embarking on the recharge study.

2.2.1 Climate of the Auja- Tamseeh

The Mediterranean climate affects the climate of the area that lies to the east of the sea. The wet winter and dry summer is typical Mediterranean weather in this region. The wet season stretches from October to May and has usually less than 50 wet days (Rofe and Raffety, 1963). The rain bearing winds force the moist air upwards, causing precipitation on the ridges. The amounts of rainfall are affected by elevation where precipitation on the western ridges ranges between 500-600 mm\year while on the eastern ridges the precipitation averages range between 450-100 mm\year (Abed and Wishahi, 1999. The decrease of rainfall quantities is the observed trend when moving eastward away from the sea, and large changes are observed within short distances. Average annual rainfall maps prepared by PWA (2001) and ARIJ (1997) demonstrate that rainfall quantities decrease moving southward towards the Negav desert and eastward away from the sea (PWA, 2001).

Summer is dry and extends from June to September. Khamassin weather may occur during spring season causing dry hot wind full of desert dust to blow in the area. Maps prepared by ARIJ (1997) illustrate mean monthly temperature variations along the study area. Ramallah, for example, has a monthly mean temperature ranging from 22-24 ^{o}C during August (the hottest month of summer), while Qalqilya in the north of the study area has a mean monthly temperature of 28-30 ^{o}C during the same month. In winter which extends from December to February the monthly mean temperature in the coldest month of winter (January) ranges from 8 – 10 ^{o}C in Ramallah to 10-12 ^{o}C in Qalqilya. The temperature is noticed to rise when moving westward towards the Mediterranean and southward towards the desert.

The relative humidity in the area varies between 50-70% with a maximum value in January and minimum in June. The mean annual relative humidity is 61% in Nablus (ARIJ, 1997).

Evaporation is particularly high in the summer months, due to the rise in temperatures, intensive sunshine and the low humidity. The potential evapotranspiration map prepared by CH2MHILL (PWA, 2002) presents the contour lines of average potential evapotranpiration of the West Bank and thus gives an insight of the potential evapotranpiration in the study area (Figure 3). The average potential evapotranspiration ranges from 1850-2300 mm per year with an increasing trend towards the east and south.

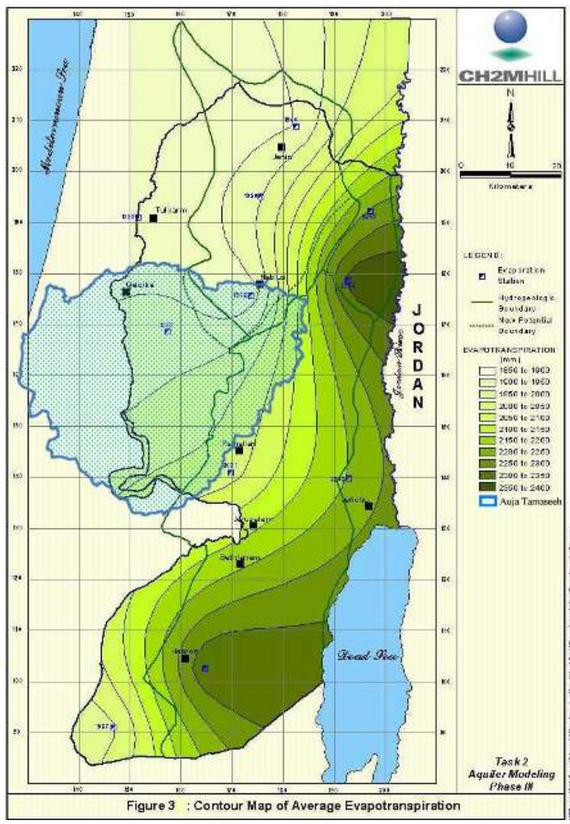


Figure 3: Contour Map of Average Evapotranspiration in the West Bank

CH2MHILL (PWA, 2002)

2.2.2 Geology of the area

The geological study of the area was taken from the geology of the WAB, which was compiled and arranged as a database for the development of the conceptual model of the WAB by SUSMAQ (2001), and Geology of Palestine (Abed and Wishahi, 1999). The study relied on Rofe and Raffety (1965) findings, in addition to the Israeli studies for the WAB geology.

The oldest geological formations present in The Auja-Tamseeh catchment are of Jurassic period. The Maleh Formation which belongs to this age is present at the anticline of Ramallah fault. Following the Maleh formation is the Ramali formation which is of Lower Cretaceous period and outcrops in the western part of Ramallah at Ein Qinya valley and south of Ein Arik. The Ramali formation is also known by the Kobar formation in Rofe and Raffety (1963) and is equal to Nabi Sa'id formation. It is also known by the Kurnub formation in Jordan. It is made of colored sandstones and is there fore a good aquifer. Limestone occurs at the upper part of the formation and increases going towards the north.

The Ramallah Group (also known as the West Bank Group) which is of Lower Cenomanian-Upper Cretaceous period overlies the Ramali formation. The Ramallah Group that outcrops at Wadi Fara' and Salfit is made of Lower Beit Kahil formation which is made of dolomatic limestone with few marl or shale. The lower part of the formation is very karistic were holes are present both in the outcrops and the subsurface. The thickness of this formation ranges from 120-180 m. It consists of very light colored and well-bedded limestone of fine crystals. The upper part of Lower Beit Kahil (LBK) is made of dolomite that is massively bedded with hard fine crystals of dark gray color.

The Upper Beit Kahil (UBK) formation that outcrops in the central and northern parts of the West Bank is made of alternating layers of limestone with marl. The distinctive difference between the Lower and Upper Beit Kahil formations is the increase of marl in the Upper Beit Kahil while marl is low in the Lower Beit Kahil.

The Yatta formation that outcrops at Nablus, Salfit, and Wadi Fara' is made of light marly stones with few lime stones. The formation is considered to be an aquiclude, but in the northern parts of the West Bank wells have revealed that the lower part of Yatta formation is made of dolomatic limestone and changes into an aquifer (Abed and Wishahi, 1999).

The Lower and Upper Beit Kahil formations that are separated by the Yatta formation form the lower Cenomanian aquifer system. The Upper Cenomanian-Turonian aquifer known by the upper aquifer system is made up of the Hebron, lower and upper Bethlehem, and Jerusalem formations that outcrop at Jerusalem, Nablus, and Hebron mountains. Hebron formation is composed of strong dolomatic limestone that is considered to be a good aquifer due to presence of joints in these rocks. Bethlehem formation that outcrops at Nablus, Ein Qinya, and Qabalan is made of chalky limestone to chalk and is considered to be an aquiclude. Jerusalem formation which is made of smooth and strong limestone is of Turonian-Upper Cretaceous period, is used in Palestine as the building stone. This formation is considered an aquifer in Jerusalem and the neighboring areas.

These are the geological formations of the lower and upper aquifer systems present in the area of study were the Palestinian names are used. Table 1 summarizes the stratigraphy of the West Bank as suggested by the PWA (2002).

Table 1: Stratigraphy of the West Bank (PWA, 2002)

Period		Age	Typical Lithology	West Bank Terminology	Hydro-strtigraphy	typical Thickness (m)
Quaternary		Holocene	Nari(surface crust) and Alluvium Gravels and fan deposits	Alluvium	Local Aquifer	0-100
		Pleistocene	Thinly laminated marl with gypsum bandsand poorly sorted gravel and pebbles	Lisan	Aquitard	10-200
Tertiary	Neogene	Miocene Pliocene	Conglomerates, marl, chalk clay and limestone	Beida	Local Aquifer	20-200
	Paleogene	Eocene(Lower-middle)	Reefal Limestone,bedded limestone chalk	Jenin	Aquifer	90-670
Creteceous	Upper	Maastrich-tian Danian	Marl Chalk ,Chalk marl	Khan Al-Ahmar	Aquitard	40-150
		Campanian	Main Chert ,Phosphate	Wadi Ai Qilt	(local Aquifer)	10-120
		Coniancian-Santonian	Chalk and Chert	Abu Dis	Aquiclude	0-450
		Turonian	White Limestone,Dolomite thin bedded limestone	Jerusalem	Upper Aquifer	40-190
		Cenomanian	Chalky limestone, Dolomite	Bethlehem		50-210
			Karstic Dolomite	Hebron		65-160
			Reefal Limstone Dolomite karst	Yatta	Aquitard	50-125
	Lower	Albian	Dolomite Limestone interbedded with Marl	Upper Beit Kahil	Lower Aquifer	10-125
			Dolomite Karstic Limestone	Lower Beit Kahil		40-160
			Marl marly nodular Limestone	Qatana	Aquitard	42
			Marly Limestone	Ein Qinya	Aquitard (local Aquifer)	55
		Aptian	Shale	Tammun	Aquiclude	300+
			Shale and Limestone	Ein Al-Assad		20+
			Marly Limestone, sandy	Nabi Sai'd	Aquifer	20+
		Neocomian	Sandstone	Ramali		70+
			Volcanics	Tayasir		35
Jurassic		Oxfordian	Marl interbedded with chalky limestone	Maleh	Aquitard	100-200
			Dolomitic limestone jointed and karstic		Aquifer	50-100

2.2.3 Hydrogeology of the area

The WAB is bounded from the east by ground water divide caused by the anticlinical ridges of the Al Fara, Ramallah, Hebron, and Bani Naim anticlines. The Western boundary is determined by the truncation phenomena caused by difference in the conductivity of the forming layers of the WAB and the Coastal Aquifer. The rocks close to the sea change into chalk and shale which are impervious to water. The northern part of the WAB is bounded by the Tamsih (different from Tamseeh which is the name of the surface catchment) stream and the Menashe Syncline axis. While the southern boundary is formed by the ground water divide formed by the Yeru'am-Dimona anticline axis.

The Auja-Tamseeh surface catchment is not a separate hydrogeological unit that has defined boundaries. The Lower and Upper Beit Kahil outcrops, in addition to the Yatta formations are inside the catchment and are considered major replenishment areas for the groundwater WAB, for most of the recharge quantities replenish the WAB while a small part replenishes the EAB. Yatta formation although considered an aquiclude, is found to have an aquiferous nature in the study area for it was found to be made of weathered dolomite and limestone that allows the passage of water. In this study the Yatta formation outcrops were assumed to have 85% of the Lower and Upper Beit Kahil formations permeability.

In section 2.2.2, the main geological formations were listed with their range of thicknesses. The major stratigraphic units found from bottom to top are:

- The Ramali formation which is also known by the Kobar Group is the base of the basin and is considered to be an aquitard.
- Ramallah Group or known as the West Bank or Judean Group is the basin's aquifer. It is composed of three lithologic units; the bottom unit which is highly conductive and is made of Lower and Upper Beit Kahil, the middle unit which is an aquiclude in parts and semi conductive in others and is made of Lower and

Upper Yatta, and the top layer which is characterized by developed karst and is made of Hebron, Bethlehem, and Jerusalem formations.

The aquifers in the area of study are the Lower and Upper Beit Kahil formations which have well developed primary and secondary porosities, allowing it to form major acceptance areas.

There are 81 wells in the Auja-Tamseeh catchment (Figure 4), which tap the upper or lower aquifer. These wells are divided into two categories according to use: domestic or agricultural. Most of the wells are agricultural (69 wells) and located in Qalqilya and Salfit Districts. Only 8 domestic wells are available for use in Ramallah, Nablus, Salfit and Qalqilya districts. The remaining 4 wells are abandoned wells used as observation wells. The observation wells are listed in Table 3. All the wells information; wells name, locality, and use are listed in Annex B9. The data related to groundwater level of wells consist of nine wells; four wells are abandoned wells at Ramallah (Shabtin 1 and Shabtin 2), two at Salfit, in addition to four agricultural wells at Qalqilya and Salfit.

The springs of the study area that discharges more than 0.1 l\s are also displayed spatially over the catchment. The springs discharge is displayed graphically through monthly discharge of bigger springs and annually for the smaller ones. The area has around 94 springs in Ramallah, Nablus, and Salfit districts. The hydrographs are present in Annex A (Annex A7, A8, A9, and A10).

2.2.4 Hydrology of the study area:

Precipitation falling on the West Bank Mountains comprises the main component of recharge to the WAB. Ras Al Ain (Yarkon) and Al Timsah (Tanninim) springs are the historical outlets of the basin in addition to the springs of Western Ramallah. The discharge of these springs is related to the amount of recharge that is affected by the groundwater levels in the basin considerably.

The PWA has constructed a rainfall gauging station network distributed at various locations of the West Bank to monitor precipitation and provide daily historical records for rainfall quantities and intensities. Depending on contour maps of long-term yearly average values of rainfall, Ramallah has an average rainfall of 600 mm per year, were as Jerusalem has an average of 550-500 mm per year, while in Jericho that is 20 km to the east, the average rainfall drops to 100-50mm per year (PWA, 2002).

The rain gauges present in the study area (Figure 4) are twenty six stations distributed at different schools and monitored by a school employee. The rainfall stations with the necessary information concerning location specified by X, Y, and Z coordinates, the name, and place of installation are listed in Table 2.

Table 2 Rainfall gauging stations ID, Name, and Location present in the study area.

ID	Name	X- km	Y-km	Z (masl)	Locality	Governate
0000003	Bir Zeit	169	153	780	Bir Zeit	Ramallah
0000004	Al Salam School	146.9	177.3	58	Qalqilya	Qalqilia
0241170	Burin	173.7	177	675	Burin	Nablus
0241200	Jinsafut School	162.5	176.3	430	Jinsafut	Qalqilia
0241250	'Azzun School	155.5	175.9	260	Azzun	Qalqilia
0241270	'Awarta	177	174	508	'Awarta	Nablus
0241300	Deir Istya	163.4	170.8	432	Deir Istiya	Salfit
0241400	Biddya Secondary School	157.5	169	315	Biddya	Salfit
0241415	Yasuf	172	168	600	Yasuf	Salfit
0241450	Salfit	167	165.5	520	Salfit	Salfit
0241500	Deir Ghassanah	159.5	161.5	460	Bani Zaid	Ramallah
0241550	Sinjil	175	160.2	775	Sinjil	Ramallah
0241599	Rantis Primary School	152	159.1	260	Rantis	Ramallah
0241630	'Atara	169	157	500	'Atara	Ramallah
0241650	Al Mazra'ah Ash Sharqiya School	176	156.8	835	Al Mazra'a ash Sharqiya	Ramallah
0241900	Al Mazra'a Al Qibliya School	164.2	151	600	Al Mazra'a al Qibliya	Ramallah
0242151	Saffa Union School	154.8	146	325	Saffa	Ramallah
0242400	Beituniya Secondary Boys School	166	143.7	810	Beituniya	Ramallah
0242935	Al Malek Ghazi Secondary School	163.7	138		Al Qubeiba	Jerusalem
0000014	Kafr Zibad Secondary Boys School	157	181.05		Kafr Zibad	Tulkarm
0000011	Qibya Primary Boys School	151.05	153.85		Qibya	Ramallah

Table 3 Observation wells name, location, and use for groundwater level monitoring

Code	Name	X- Km	Y-Km	locality	Governorate	Use
14-17/005	SALEEM 'UDAH & PARTNERS	148.80	173.90	HABLA	QALQILIA	Agricultural
14-17/036	MUSTAFA NAZZAL	147.36	177.68	QALQILYA	QALQILIA	Agricultural
14-17/037	'ABED AL RAHEEM HASAN	149.65	176.90	QALQILYA	QALQILIA	Agricultural
15-15/001	SHEBTEEN NO. 1	155.00	152.00	SHABTIN	RAMALLAH	Abandoned
15-15/002	SHEBTEEN NO. 2	154.96	153.26	SHABTIN	RAMALLAH	Abandoned
15-16/003	MUHAMMAD ABU HIJLAH	152.07	169.61	'AZZUN AL 'ATM	QALQILIA	Agricultural
15-16/005	DHEEB REDA 'UDAH	154.96	168.25	MAS-HA	SALFIT	Agricultural
15-16/005	DHEEB REDA 'UDAH	154.96	168.25	MAS-HA	SALFIT	Agricultural
5-17/008	MUHAMMAD TAHA SALAMAH	151.16	170.10	'AZZUN AL 'ATM	QALQILIA	Agricultural

The wells that are listed in Table 3 are the observation wells used by the PWA for monitoring groundwater level in the area of study. These wells provide groundwater level data on monthly or bi-monthly basis. The wells are either agricultural wells or abandoned wells.

2.2.5 Soil cover

The soil covering major parts of Ramallah and Nablus districts is the Terra Rossa, Brown Rendzinas and Pale Rendzinas soil that outcrop with rocks. This type of soil covers the central mountains and the small plateau of the mountains. Its parent materials are dolomite and hard limestone and it has reddish brown color. The major vegetation growing in this soil is grapes and olives with field crops of wheat and barely. Grumusols are found in areas with smooth sloping topography used for wheat cultivation. The parent material for this soil is the fine textural alluvial sediments. Brown lithosoils and Loessial arid brown soil covers the Eastern slops and is composed of marl, chalk, and limestone. Alluvial and brown soils are also soil types covering the study area (ARIJ, 1996).

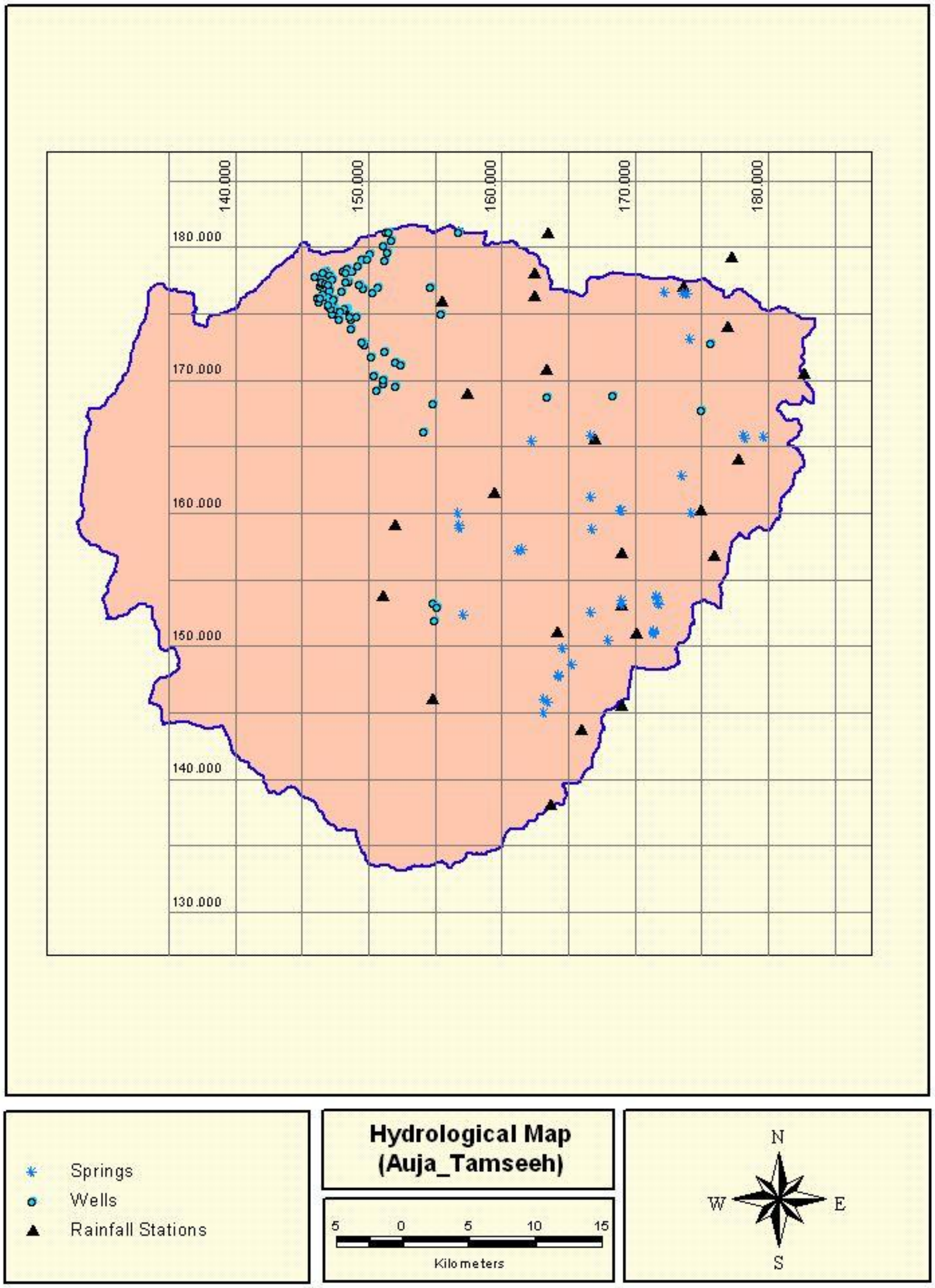


Figure 4: Distribution of wells, springs, and rainfall stations over the study area.

CHAPTER THREE
METHODOLOGY AND APPROACH

3.1. Data collection

Data used in the study was of two folds: rainfall data, well abstractions, and spring discharges for twelve consecutive years extending from 1985 to 1997. The graphical data in the form of maps and themes were used in the computer software Arcveiw GIS. Most of the data was in the form of digital Excel files and some were as GIS shape files.

Rainfall data was not suitable for the recharge study because hydrographs of the available rainfall stations had lots of missing data during the area closures and curfews of 1988 to 1990. Statistical methods were used to check the accuracy and estimate rainfall for some of the stations. Inaccuracy of measurements also leads to unbiased data. This all leads to errors in the available data and requires data screening to control the quality of the used data.

3.2. Data Preparation

The major steps of data preparation phase were as follows:

1. Preparation of the location map for the area of study in the form of shape files that can be used in the computer software Arcveiw GIS and was taken from the PWA maps (Figure 1).
2. Preparation of the geological map to determine the outcrops of the geological formations and its ages inside the study area, also taken from PWA maps (Figure 10).
3. Preparation of the Hydrogeological map to define the boundaries of the groundwater basins available in the study area and the outcrops within the

WAB. The map was digitized from PWA image and converted to a shape file (Figure 11). The hydrogeological map is part of the geological map that presents the areas of replenishment for the groundwater basins.

4. Rainfall stations were projected on the study area by converting Excel files into dbf files where each station has a specific code number called (ID) and located by the X and Y coordinates. The wells and springs were located using the same procedure (Figure 4).
5. Rainfall data were arranged into Excel sheets as daily, monthly, and yearly records. Hydrographs for the stations were drawn, and number of rainy days was counted for each month. The wet days and months were determined in addition to wet and dry years.
6. Construction of hydrographs relating water level and well abstractions to rainfall on monthly and yearly basis. The hydrographs with primary and secondary y-axis, one for the rainfall quantities and the other for the groundwater level were used for the determination of the **lag- time.** The lag time is the delay time required for a rainfall event to cause a change in groundwater level. It was measured as the time between the peak of average monthly rainfall and peak of monthly groundwater level.
7. The rainfall data were prepared into Excel sheets containing monthly and annual rainfall for all the stations for the period 1985\1986-1996\1997. These files were converted to dbf files and used later for construction of isohyetal rainfall lines (Figure 14).
8. **Calibrated annual recharge** for the time period of the study was taken from the Zukerman (1999) cited in SUSMAQ (2001) annual recharge models prepared in the Israeli literature for transient models of the WAB. Zukerman's recharge model was used because it contains calibrated annual recharge for the period 1951\52 to 1998\99. The data was spatially distributed over the outcropping area in the WAB considering the differences in the transmissivity of each geological formation. The calibrated values of recharge are the net water quantities that actually reached the ground water regardless of the paths that water followed to

reach the last destination. The calibrated values considered various losses caused by evaporation and evapotranspiration in addition to losses due to water run off and many others lost through the process of water travel into the ground basins.

The Calibrated recharge of the study area was taken from the recharge model of the WAB. The Upper and Lower Beit Kahil outcrops were considered 100% permeable while Yatta outcrops were considered to have 85% the permeability of Beit Kahil. Weathering and cracking of Yatta outcrops inside the study area made this aquiclude formation change into an aquifer with medium permeability.

The Geographic Information System (GIS) was used as the appropriate tool for illustrating the data and presenting it spatially over the study area. The Arcview 3.2 GIS was used with its extensions to distribute the rainfall and recharge quantities both monthly and annually over the area. In order to assign geological, hydrogeological, rainfall data, and recharge data for each cell, a grid of 1x1 km was prepared for the study area (Figure 12). The point rainfall quantity was changed into areal rainfall over a specified area using the hydrological methods like the Thiessen method. The recharge value was given from the model as cells with specified recharge value for each hydrologic year. These areal recharge values were changed to point values for use during application of recharge model to the study area.

Calculations of monthly recharge values were all done using the Excel software. Data was prepared on excel sheets then manipulated and displayed graphically in the form of hydrographs using the flexibility and statistical tools available in the Excel software.

The monthly recharge model made of the set of equations that will be presented later in this chapter depended on the principles of the lag time and the accumulation effect. During application of the model GIS software was used to help in calculating the areal rainfall and recharge values.

3.3 Methodology and approach

The methodology of recharge study depends on the approach of recharge estimation used. The steps followed to build the monthly recharge model and to apply the model to the selected study area were as follows:

1. The different recharge estimation approaches were illustrated and thoroughly analyzed to determine data requirements and availability of the data in the study area. Section 3.5 listed the approaches with justifications for applying the method of estimation used in this study. The empirical approach was the only approach that could be applied to the study area for rainfall data and ground water level data were the only data available.

2. Preparation of the rainfall data taken from PWA for analysis. The data had lots of missing records therefore screened and quality controlled data was taken from Yasin (2004).

3. Demonstration of the study principles that were based on hydrological observations. The monthly rainfall and mean average monthly hydrographs for all rainfall gauging stations were drawn to find trend of monthly rainfall and time of occurrence of peak rainfall. The monthly groundwater level of the monitored wells was also studied. Monthly groundwater level hydrographs were drawn to determine trend of groundwater level in addition to time of occurrence of the peak groundwater level (section 3.4.1 and 3.4.2). The lag-time and the accumulation principles were built on the results of these hydrological observations as shown in section 3.4.

4. The empirical equation derived by Goldschmidt and Jacob for annual recharge estimation was the building block of the model. Modifications of the equation were illustrated until the final equation was developed (eq. 3.4).

5. Recharge estimation model was built on Susmaq's (2004) study of Wadi Natuf catchment which derived monthly recharge estimation model of the WAB. This study used the same approach but on a different study area and with new assumptions regarding the type of distribution of the predetermined coefficients of the P_{ci} value as in sections 3.6 and 3.8.

6. Building of the monthly recharge model by defining the cumulative rainfall for each month. The cumulative monthly rainfall is the amount of rain that falls in that month in addition to certain percentages from the previous months following eq 3.6 which was based on Figure14. The cumulative rainfall explains the recharge that occurs during the zero rainfall months as June, July.

7. The monthly recharge model equations are derived and listed for all months of the hydrologic year at section 4.2 then arranged in a matrix form.

8. To apply the model equations to the study area during the time period specified, and to distribute the rainfall spatially on the study area requires dividing the study area into cells. Each cell is assigned a monthly rainfall value, annual rainfall value and name of geological formation. The geological formation gives an idea about the cells transmissivity. Some cells like the Upper and Lower Beit Kahil were considered good aquifers and allowed water to move downward. Yatta formation cells were considered medium aquifers because Yatta rocks were fractured and cracked in the vicinity of the study area thus changing it from an acquiclude into a medium aquifer (Abed & Wishahi, 1999). The transmissivity of Yatta formation was assumed equal to 85% of Upper or Lower Beit Kahil transmissivity.

9. Changing the point rainfall values taken from the stations into zones by using the hydrologic methods for areal rainfall calculation. The Thiessen polygon method was applied in this study as detailed in section 3.7.

10. The calibrated recharge model developed by Zukerman for the WAB was used and applied to the study area for monthly recharge calculations.

11. The model application into the study area was through calculation of total rainfall volumes falling on the study area in each month and the amount of monthly recharge

calculated from the model equations developed. The results of the model application were either displayed graphically or tabulated as in chapter five.

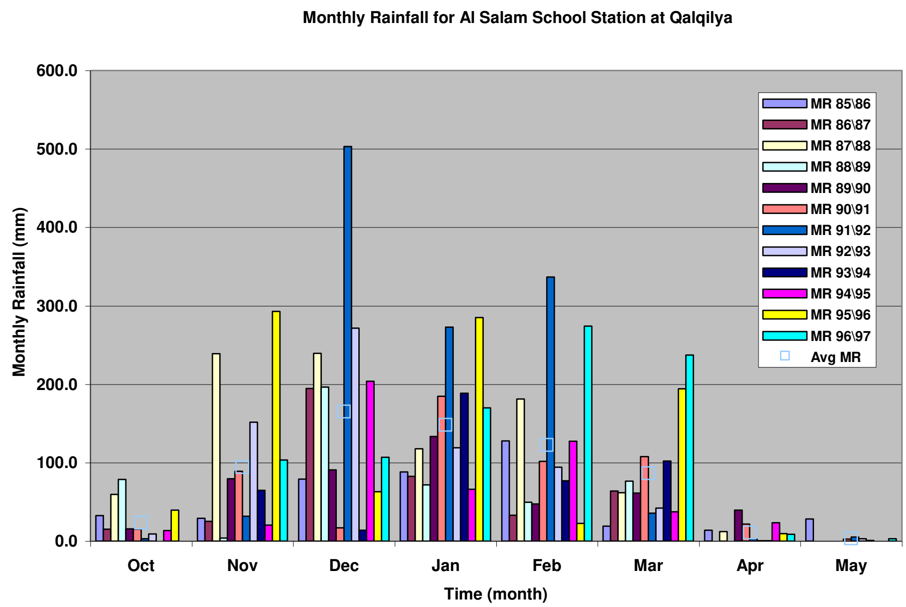
These are the major steps followed during the study course of the thesis.

3.4 Lag-time and accumulation effect

The procedure used in the lag time determination depends on hydrological observation of monthly rainfall and well level distribution over the hydrological year. This was used to determine the trend of rainfall distribution and monthly peak values, in addition to the monthly trend of the groundwater level to determine the peak value as well as its time of occurrence. A comparison between the two trends leads to the time delay effect. This delay factor is specified by: the length of the delay period in months, month of peak monthly rainfall, and month of monthly groundwater level peak.

3.4.1 Monthly rainfall analysis

Monthly rainfall data for all stations inscribed in the study area are analyzed and hydrographs are constructed for some stations as the station of Al Salam School in Qalqilya (ID 0000004) and station of Dier Istya at Salfit governate (ID 0241300) (Figure 5). Hydrographs for more rain gauge stations are found in Annex A (Annex A1, A2, and A3).



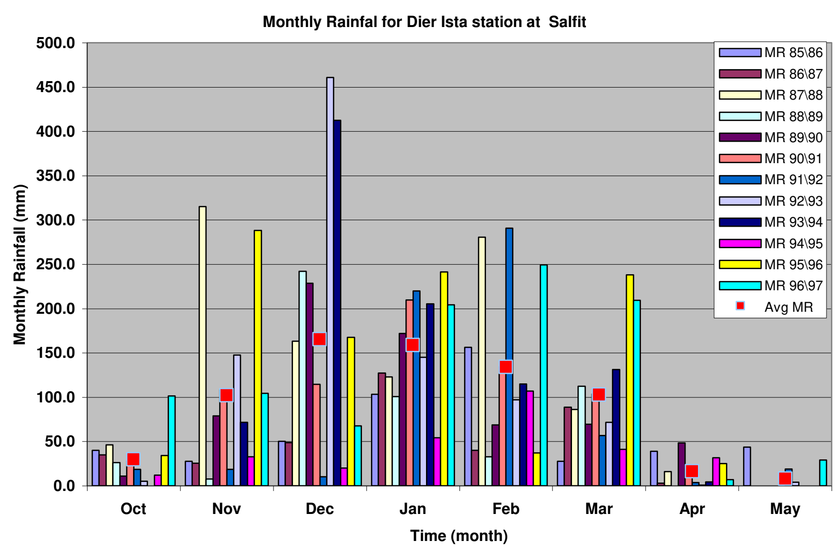


Figure 5: Hydrographs of monthly rainfall (MR) for two stations; Al Salam School station at Qaliqilya, and Deir Istya station at Salfit.

Although monthly rainfall values don't have a specific trend for the peak but hydrographs for all stations reveal that rainfall peak ranges from December to February. The long term average monthly values gave a peak at December. Only few stations had the peak in January as the station of Deir Ghassanah at Beni Zaid, and Atara station in Ramallah (Annex A and Annex B).

3.4.2 Monthly groundwater level analysis

The nine wells available in the area of study and listed in (Table 3) were used for the analysis in this thesis. These wells are the observation wells used by the PWA for monitoring monthly groundwater levels. These monthly values were graphically plotted versus time for the study period extending from 1985 to 1997 (Figures 10 and 11).

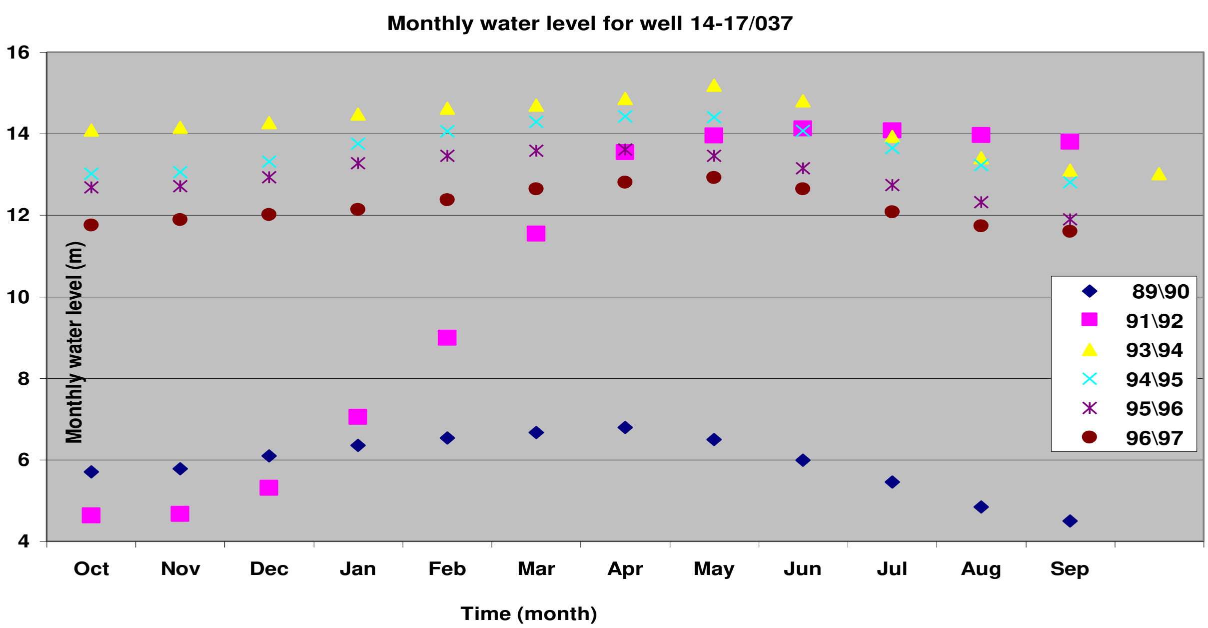


Figure 6: Groundwater Level Hydrograph for Well 14-17\037 for a number of years between 1985-1997.

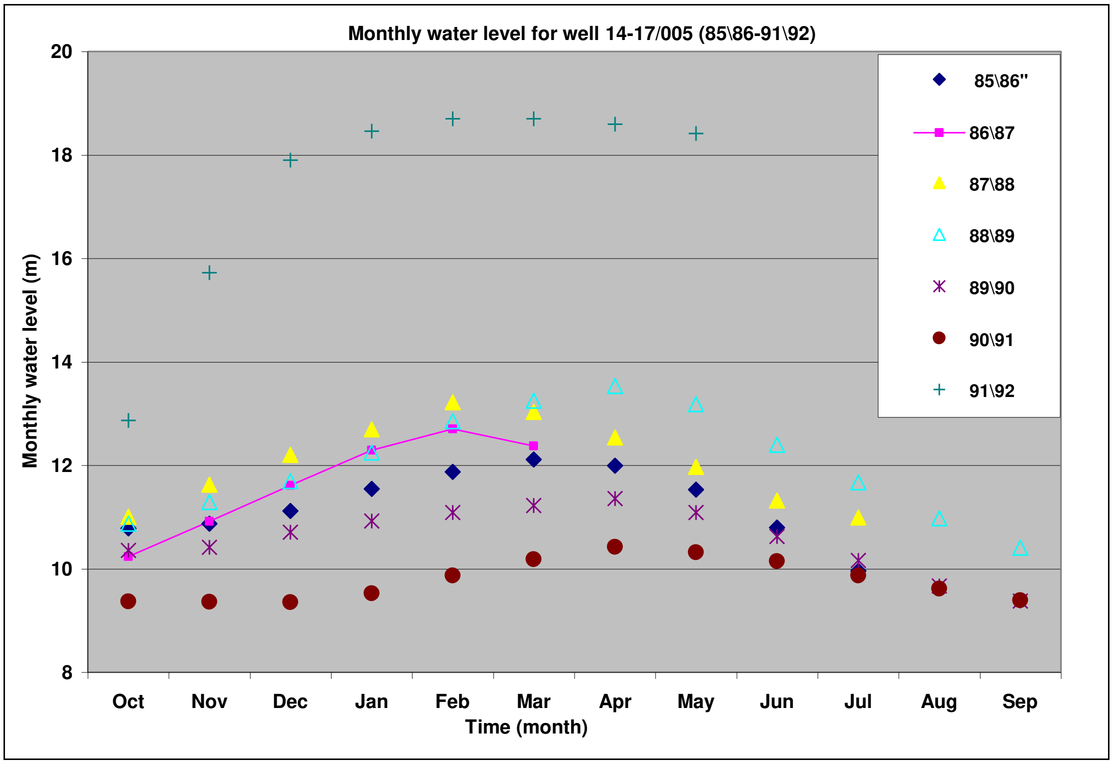


Figure 7: Groundwater level Hydrograph for well 14-17\005

The two hydrographs in Figures 6 and 7 followed a similar trend. Groundwater level was noticed to rise till a peak is obtained between March and May. A gradual decrease in water level is noticed after May till it vanishes after three months. The peak month for the different wells is given in Table 4.

Table 4: Name of peak month for groundwater level of the monitoring wells

	Month of Water Level Peak											
ID	**85\86**	**86\87**	**87\88**	**88\89**	**89\90**	**90\91**	**91\92**	**92\93**	**93\94**	**94\95**	**95\96**	**96\97**	**Avg**
14-17-005	Mar	April	April	April	April	April	June	April	May	April	April	May	May
14-17-036	Mar	April	April	May	May		June	April	April	April	April	May	April
14-17-037	Mar	April	April	April	April		June	May	May	April	May	May	April
15-15-001	April	Feb	April	April	April		Mar	Mar	April	Mar	April		April
15-15-002	Mar	May	May	April	April	May	July	April	May	July	June		June
15-16-003	Mar	April		April	April	April	June	May	April	May	April	May	April
15-16-005	April	April	April	April	April	June	July	May	Mar	April	May	May	May
15-17-008	Mar	April	April	April	April	April	July	April	Mar	April	April	May	May
16-16-002	Mar	April	April	April	April	April	July	April	Mar	May	April	May	April

Considering the data in Table 4, the percentage of occurrence of peak at April was around 65% when considering the wet year data which is an unusual event. The probability rose to 70% when year 1991\92 was excluded. The very wet year 1991\92 where rainfall values were much higher than the average annual rain falling on the same area caused groundwater level to rise dramatically. The extended rainfall for the months of February and March caused a shift in the groundwater level peak to Jun\July.

Merging hydrographs of monthly rainfall with monthly groundwater level for different wells and rainfall stations gives an insight on the period of delay (lag-time). The rainfall event causes a response in water level of the aquifer which is detected by increase in groundwater level of the monitored wells. The long term average monthly rainfall values of each station were considered because of the absence of a specified trend for monthly rainfall values except for the long term average values studied on monthly or annual basis. This is a result of the variable rainfall quantities precipitating over space and time for the semi arid nature of the study area. Monthly water level versus average monthly rainfall gives a sample of lag- time of peaks (Figure 8).

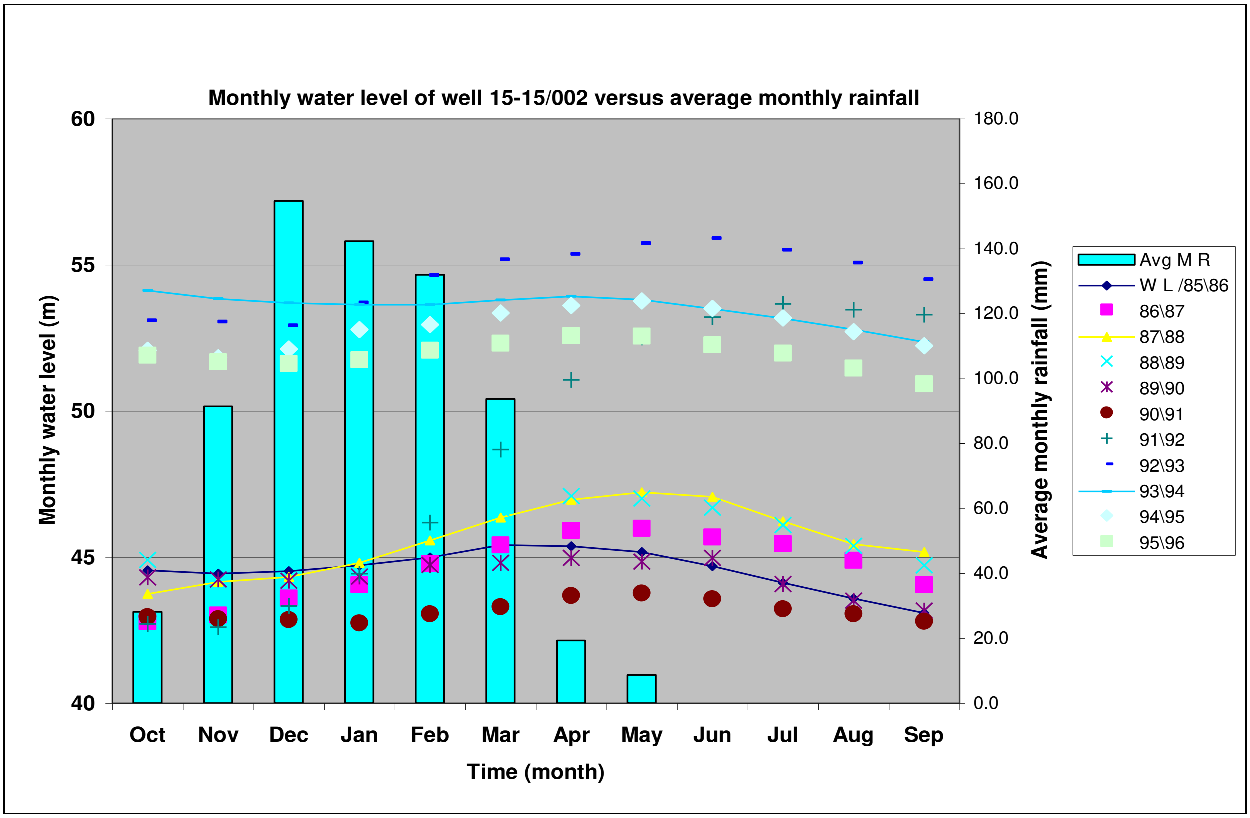


Figure 8: Monthly average rainfall versus monthly groundwater level

Conclusions can be drawn depending on the analysis presented in section 3.3 and supported by observations illustrated through Figures 6, 7, and 8. The lag-time was found equal to **three to four months.** The average rainfall peak occurred in **December** and groundwater level peak occurred between **April and May.** This supports the **delay time** effect which is one of the major principles in the study's theoretical approach. It was also noticed that the groundwater level hydrographs indicated a change in groundwater level during the dry months of the hydrologic year which extend from May to September. Also the groundwater level peak doesn't coincide with the rainfall peak. On the contrary, groundwater level peak occurred in April/ May that has low monthly average rainfall value compared to December and January. Therefore, the rainfall event doesn't cause an immediate change in the groundwater but the effect built up till it reached its maximum value after the delay time was over. This explains the rise in groundwater level during the dry months and occurrence of peak for the two variables (rainfall and groundwater level) at different months. This is referred to as the **accumulation effect** that leads to assigning new rainfall accumulated values for each month of the hydrologic year designated by P_{ci} monthly values.

3.5 Recharge estimation approach

Recharge estimation is a very complicated task that requires a vast amount of data not only historical, but data related to the climate, geology, soil and topography of the area of study. There are several approaches for the recharge estimation and they are grouped into the following:

1. Direct measurement of the water that actually left the surface and entered into the deep grounds where it will be stored. The net water that actually made its way down after deducting evaporation and other surface processes. The major problem lies in taking the measurements at depth for an undisturbed area. The measurement requires construction of lysimeters, which are very expensive, and are point measurements dealing with a local area. Recharge from precipitation and canal losses are only measured directly and frequently.

2. Water balance method estimates recharge as the residual of all other fluxes. This method uses rainfall data, runoff and groundwater level data to estimate recharge. The major disadvantage of this method is the residual that is a small difference between large numbers. Error can be high in all the other fluxes accumulating in the recharge estimation (Simmers, 1997), in addition to the difficulty of estimating the other fluxes. Actual evapotranspiration can't be estimated accurately and is often the largest outward flux. The specific yield of the area is an important physical property in the water balance calculations that is hard to define or measure.

This approach was not considered because the study area has very few evaporation stations present in Nablus, Tulkarem, Salfit, and Jenin which are not inside the study area except Salfit and parts of Nablus. The station that might resemble the area of study is the Salfit station. Another drawback of this approach is the lack of run-off data not only for this area but for all of the West Bank.

3. Darcian approach assumes that flow is controlled by Darcy's flow equation:

$$Q = K * i * A \qquad \text{Equation 3.1}$$

Q: is the ground water flow through a cross section

K: is the hydraulic conductivity

i : is the hydraulic gradient

A: is the cross sectional area

Therefore this approach requires the knowledge of the hydraulic head, pressures, moisture contents and hydraulic conductivity. Darcian law has a fundamental difficulty when applied to water movement in the unsaturated zone for it requires knowledge of soil water retention and unsaturated hydraulic conductivity curves which are difficult to determine (Simmers, 1997). Using numerical modeling, the flow will not be steady but transient and storage changes will be included in addition to spatial variability of the physical properties of the area of study. This method requires huge data requirements and the computation load is high.

4. Tracer techniques are used in arid and semi-arid areas. There are three types of tracers to be used: the environmental tracers as chloride, the artificial tracers as Tritium and bomb tracers. There are two kinds of tracer methods; the **signature** methods were parcels of water are labeled, and **throughout** methods that involve a mass balance for the tracer. It is the most accurate method to be used in the arid or semi-arid areas as is the case in our area of study. This approach is an experimental method that deals with a specified region of study. There are no

tracer experiments performed in the West Bank or the area of study till now regarding recharge estimation.

5. Empirical methods in which recharge is correlated with other variables like precipitation, elevation, and canal flow. This method is used when there is lack of data and water table is deep so no perching of water occurs.

   In this study rainfall data is the only available data. Run-off data are scarce and unpublished so far for small areas of the West Bank as the Natuf Catchment study prepared by SUSMAQ (2004) and Runoff generation from successive simulated rainfalls experimental study at the village of Deir Ibzei 10 kilometers to the west of Ramallah carried by J. Lange et al (2003). Therefore, the empirical method is the only available method for the estimation of recharge, and it will be implemented in this study.

3.6 Annual recharge from rainfall

Goldschmidt and Jacob (1958) derived a relationship between recharge and runoff based on the long-term average rainfall over the catchment's area. The empirical equation developed was based on the annual rainfall quantities during the period 1943\44 to 1953\54.This equation was first developed for Jordan and Litani catchments then it was applied to the Yarqon- Nahal Hatteninim catchments in the WAB. The equation relates the long term average total run-off from a catchment (R_{red}) to the long term average precipitation over it (P_{red}).

$$R_{red} = 0.9 * (P_{red} - 360) \text{ in mm/ year} \text{ ---------------(Eq.3.2)}$$

Storm water run-off was observed by two gauging sites placed in the area to determine the amounts of storm run-off to be deducted from total run-off quantities. This storm run-off was found to be 4.5% of the precipitation exceeding 360 mm / year. Hence the modified equation looks as follows:

$$R_{red} = 0.86 * (P_{red} - 360) \text{ in mm/year---------------(Eq.3.3)}$$

The data used by Goldschmidt and Jacob (1958) in that period were reliable for natural spring flow was approximated to equal the base flow data recorded during this period of study. Also the annual recharge of the basin was approximated to equal the spring flow when there was very little well abstractions during the period 1943\44 to 1953\54.

In other words the $\mathbf{R_{red}}$ in equation 3.2 **was approximated to equal the annual recharge R**. This recharge value R was later on divided into three segments to develop linear relationship between rainfall and recharge by Guttman and Zukerman (1995).

The final equations developed read as follows:

$$R = 0.8 * (P- 360) \qquad P>650 \text{ mm/year}$$

$$R= 0.534 * (P-216) \qquad 650> P > 300 \text{ mm/year} \qquad \text{(Eq. 3.4)}$$

$$R= 0.15 * (P) \qquad P< 300 \text{ mm/year}$$

R= Recharge from rainfall in mm/year

P= Annual rainfall in mm/year

Recharge has been calculated in previous studies as a percentage of the **long term average annual rainfall** over the area. Rofe and Raffety (1965) in their study of water resources in the Nablus District during the year 1962-1963 carried out a water balance study in order to calculate recharge to ground water. The runoff quantities were found to vary from 0.2%-5.0% of total annual rainfall depending on rainfall intensity. This value was first deducted from rainfall then evaporation was quantified and also deducted from rainfall. The remainder was the amount of rainfall that replenished the ground water aquifers.

This method was used by other studies like SUSMAQ (2004) which reveal that these values neglected the affect of geology, hydrogeology, and spatial distribution of rainfall on recharge quantities over the outcrops.

This study had divided the Auja-Tamseeh catchment into a grid of 1km by 1km cells (Figure 12). The grid was built on the Autocad software because the grid order in the GIS builds an image of the grid that can't be converted to a shape file and thus can't be dealt with as a theme. The Autocad grid was then entered to the GIS software. Each cell of the grid was assigned a monthly rainfall quantity, annual rainfall quantity, and a geological formation depending on the geology of the area.

3.7 Rainfall calculation

Rainfall quantity assigned to each cell was one of the major problems that had to be overcome. Rainfall over an area had to be estimated from point measurements. The areal rainfall had to be derived from rain gauge measurements by one of the following methods:

- The arithmetic mean is the simplest method for calculating the average rainfall over the area. It is applicable for uniformly spaced rain gauges of a plain area with little variations of rainfall amounts. The average is equal to the sum of the rainfall quantities divided by the number of gauges. This method is not applicable for the area of study since rain gauges are not uniformly distributed and the area has diversity in surface characteristics.
- The Thiessen polygon was devised by the American engineer Thiessen in 1911. It assigns to each rain gauge a weighted factor as a percentage of the total area of study, after dividing the area into polygons by lines that are equidistant between pairs of adjacent stations (Shaw, 1983). This method is good for mountainous areas of good rain gauge network. It can be used in computer processing since the Thiessen factors are fixed for a stable network. The method is not applicable for missing data (missing data were calculated) or local intense storms, which is not the case in our area. This method was used in the study after plotting the rain gauges on the area's map and constructing the polygons using the Autocad. Then the Thiessen polygons were converted into a shape file and entered into the GIS themes (Figure 13).

- Isohyetal method is the most accurate of the methods. The isohyets are drawn between the rain gauge stations over a contour base map taking into account exposure and orientation of both gauges and the catchment (Shaw, 1983). Using the GIS software rainfall contours were generated for annual and monthly rainfall. The Isohyetal rainfall contour lines were drawn for each hydrological year using the extensions of the GIS (Figure 14). The software didn't have the ability to change the isohyetal lines into polygons. These lines can't be used to assign values for the grid cells, unless isohyets were digitized for each hydrologic year and month. This process is exhausting for 84 maps have to be digitized to carry on the recharge study. This method was not used for rainfall calculations in this study.

Rainfall was calculated using the Thiessen method through out the study for Thiessen coefficients (Table 6 section 4.1.2) were fixed for the existing and stable rainfall gauging network. This method made computation of areal rainfall possible using the Microsoft Excel software for every year and every month of the hydrologic year of study. The thiessen coefficients are computed by dividing the area of the polygon constructed around each rainfall station to the whole area of study.

3.8 Monthly recharge estimation

The annual recharge models developed for the WAB were calibrated for the period 1951\52 to 1998\99 using the annual recharge transient flow models for almost 50 years as reported by Zukerman and Guttman (1995). The Equation 3.4 gave recharge values close to the measured values of the calibrated flow models and thus was considered to be reference for monthly recharge analytical equations derived in the study.

The analysis depends on the concluding remarks developed in section 3.3 for the delay-time and accumulation effects of a rainfall event. SUSMAQ (2004) assumed normal distribution of the predetermined coefficients P_{ci} considered in the accumulation effect while this study used the log-normal distribution for it reflects the actual distribution as demonstrated in the same section mentioned above.

The equation used for the monthly recharge as presented by SUSMAQ (2004) study for the Wadi Natuf catchment was:

$$R_i = (P_{ci} / P_a) * R_a \qquad \text{Equation 3.5}$$

R_i is the monthly recharge for the month i in the year i in (mm)

P_a is the annual rainfall for the year that includes month i (mm)

R_a is the **annual calibrated recharge** for the year that includes the month i (mm)

P_{ci} is the accumulated rainfall from previous months into month i (mm)

The value P_{ci} is calculated as follows:

1. The study assumes a **log- normal distribution** for P_{ci}. The rainfall of month i is assumed to be the sum of contributions of the previous months. Predetermined coefficients were assumed and assigned depending on the lag-time and accumulation effects found during the hydrogeological observations of groundwater level in wells (figure 9).
2. The analysis is based on seven month period of the wet season which extends from October to May of the next year.
3. $P_{ci}= 0.15P_{i-3}+0.12P_{i-2}+0.08P_{i-1}+0.05P_{i-0}+0.35P_{i-4}+0.2P_{i-5}+0.05P_{i-6}$ Eq 3.6

   P_{i-3} is the rainfall event three months before the month i

The coefficients in eq 3.5 are the predetermined coefficients assumed for the study relaying on the hydrological observations and the discussion.

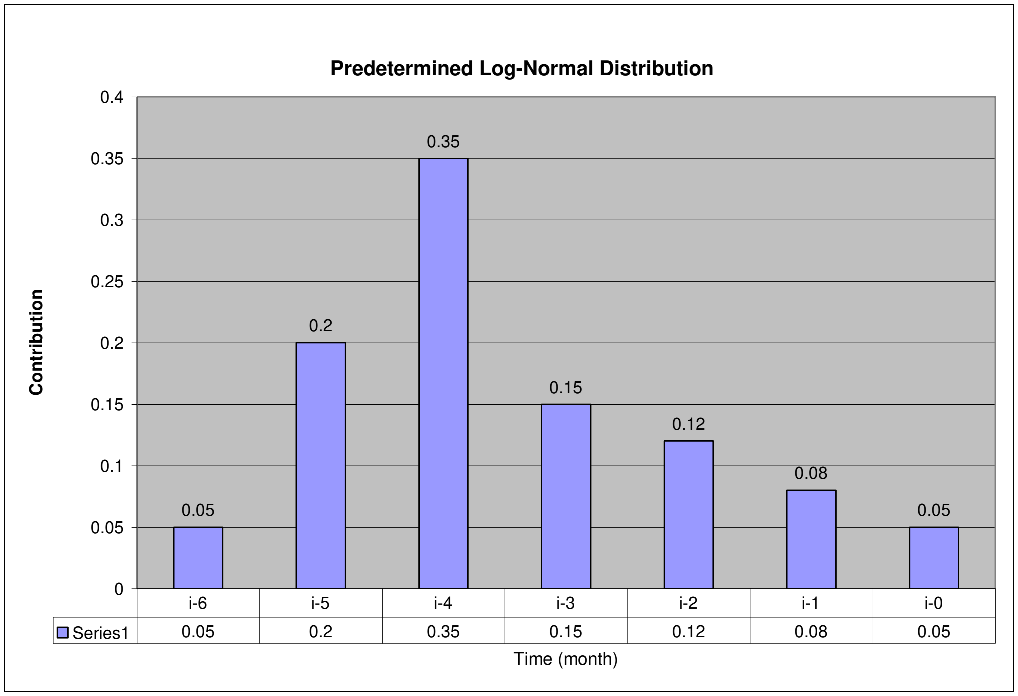


Figure 9: Predetermined coefficients of P_{ci} values

3.8 Obstacles faced during the study course

The study was conducted using the GIS Arcview software which was the available software. There were many limitations and obstacles during use of this software:

1. The software produced imagery cells when given the order convert to grid. It was impossible to divide the study area into small cells to perform the spatial analysis of rainfall and recharge quantities by using the GIS software. The produced cells couldn't be tracked in order to assign the necessary parameters for each cell. To overcome this problem, the AutoCad was used to divide the area into fixed cells in location and size and then the produced grid was exported to the GIS and converted to shape file theme, in order to display the data spatially.
2. The software is not flexible to coop with changing parameters and therefore it was not easy to use for modeling purposes as the case of other softwares like GMS or modified GIS versions as Arc Info, but these softwares are very expensive and not accessible to public use.
3. The rainfall isohyets were not possible to convert into polygons (zones) of equal rainfall quantities without digitizing these lines. This was a major problem to be

overcome because all rainfall data (monthly and annual) were point data given by the meteorological stations available in the network. Digitizing every contour line for every month in the hydrologic year for all the study period which extended from 1985 to 1997 was an exhausting task. The method used in the study was the Thiessen Polygon's approach which is not very accurate for hilly mountainous areas (Shaw, 1983), but it was the most acceptable method for assigning spatial rainfall values. Also the polygons were constructed by the AutoCad then exported to GIS to be converted into shape file.

4. The study required tremendous data in addition to the meteorological data provided by the PWA. The data included geographic maps for the area of study in addition to geological and hydrogeological maps that are only available in institutions. These data sets are not present at research centers for example to be accessible for researchers, therefore imposing more obstacles during the study. The data for the whole area of study required Israeli network data for the area lies partly inside the Israeli territories and due to political restrains this data was not provided.

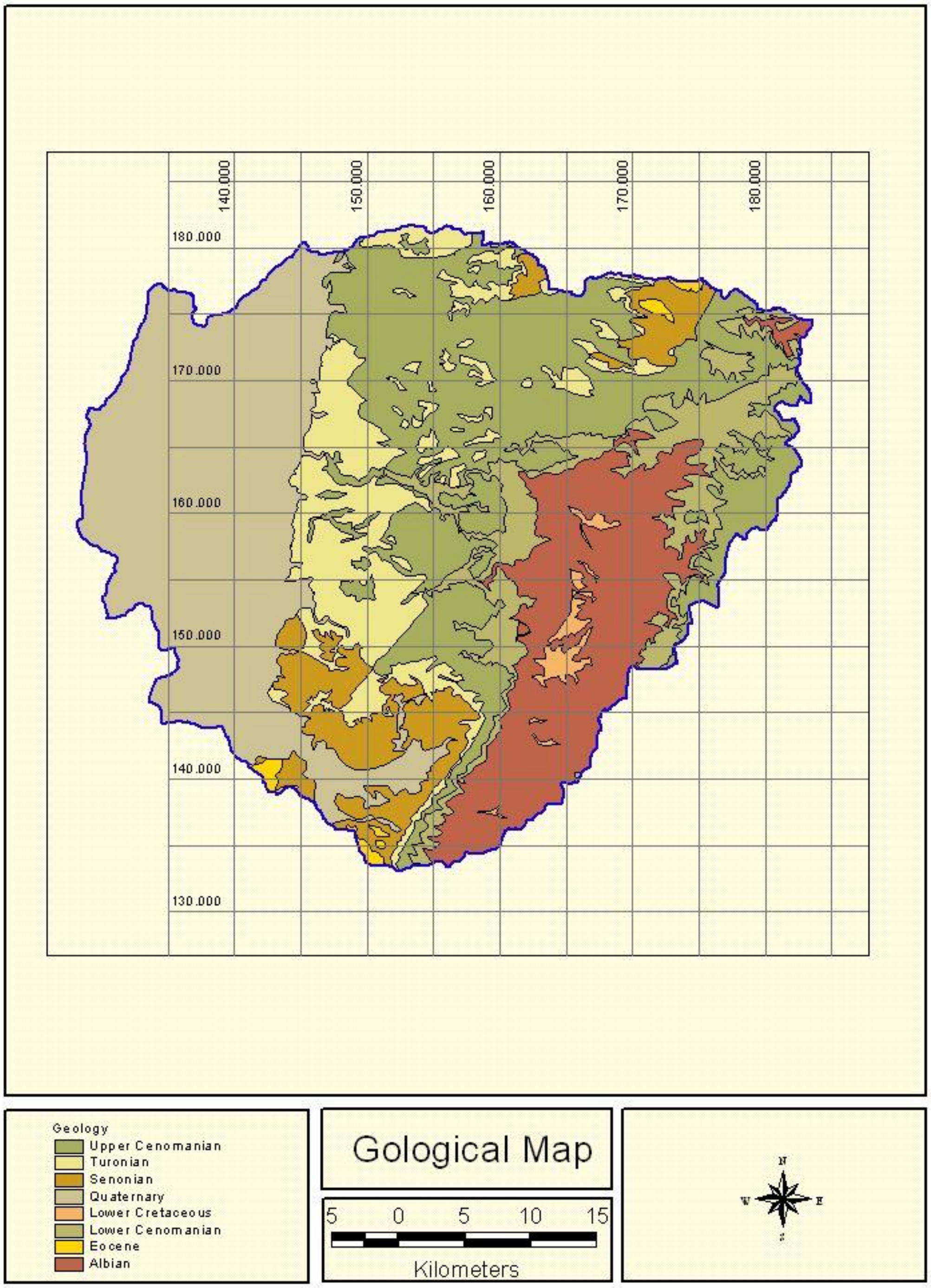


Figure 10: Geological map of the Auja-Tamseeh Catchment (PWA shape files).

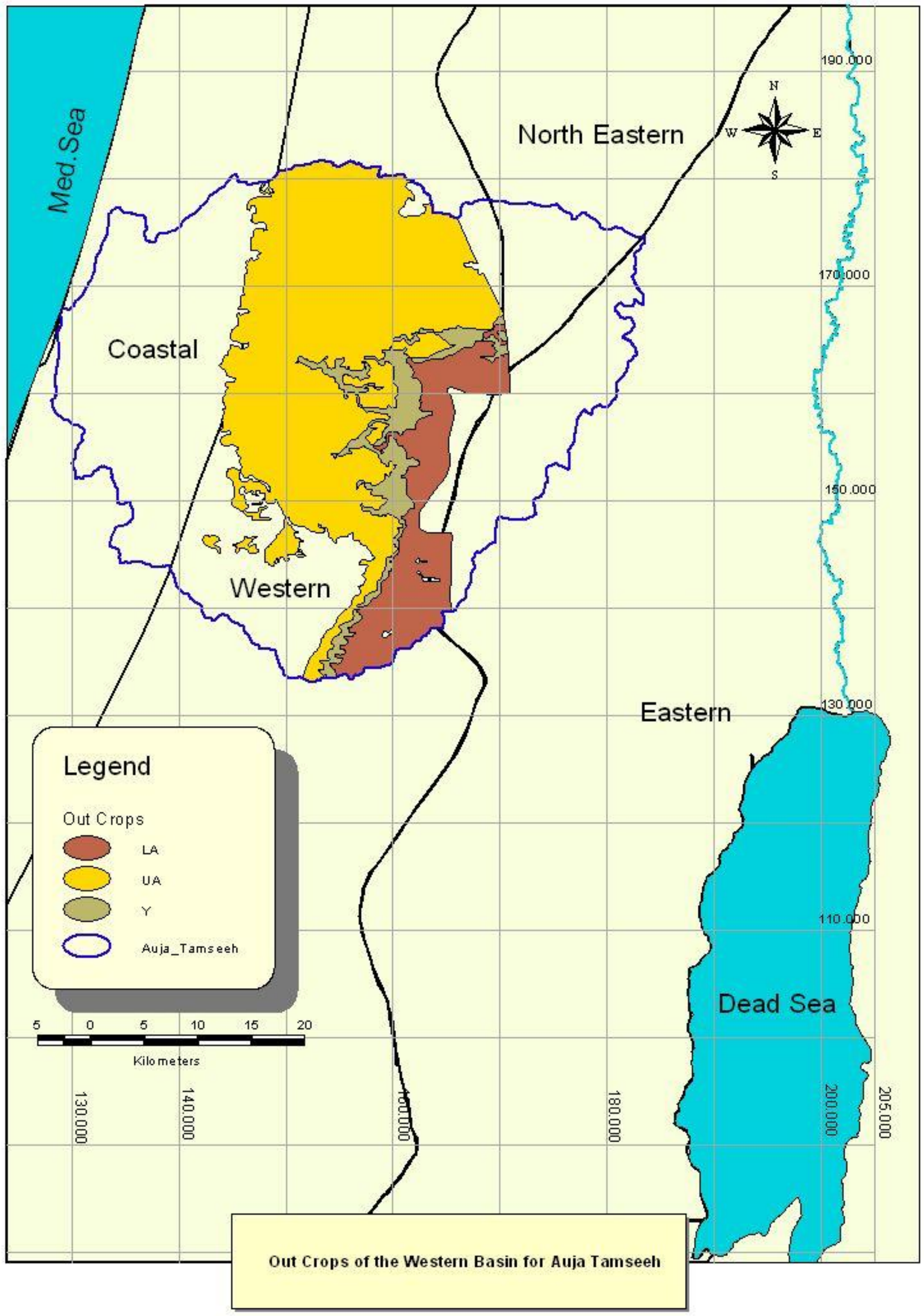


Figure11: Hydrogeological map for the Upper Aquifer (UA), Lower Aquifer (LA), and Yatta (Y) outcrops digitized from SUSMAQ outcrop map.

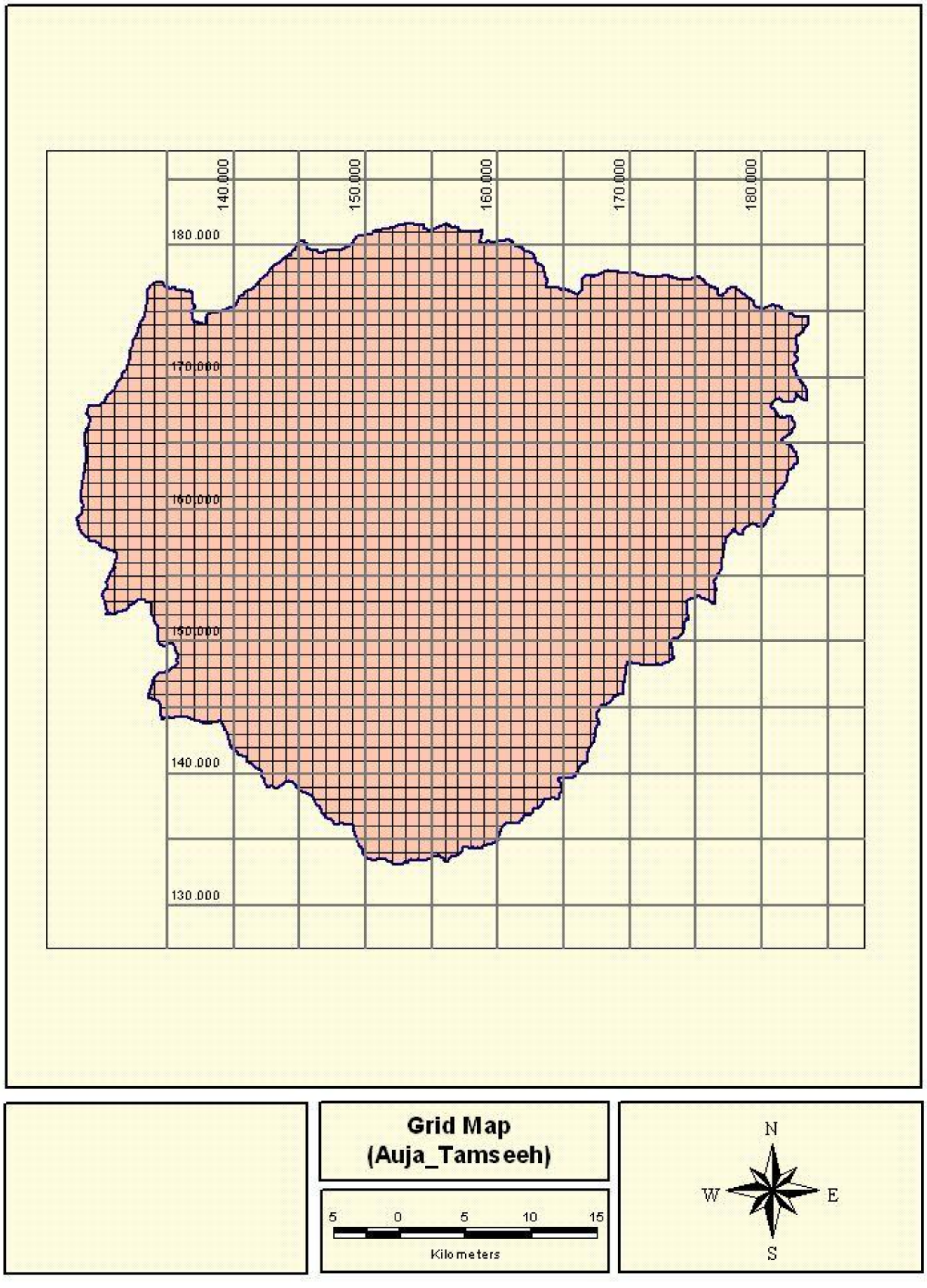


Figure 12: 1kmx 1km Grid for the study area

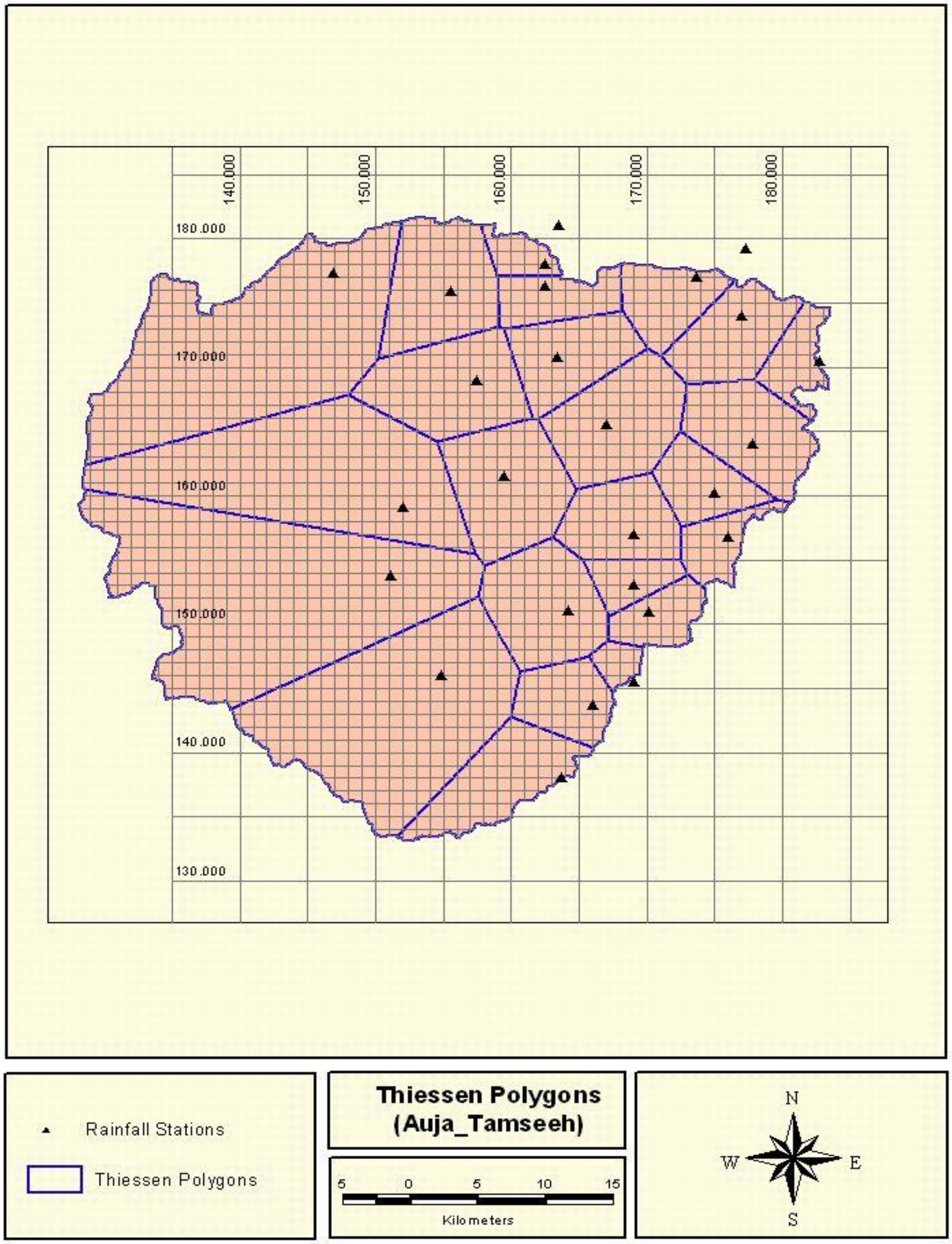


Figure 13: Thiessen Polygons for the estimation of areal rainfall in the study area.

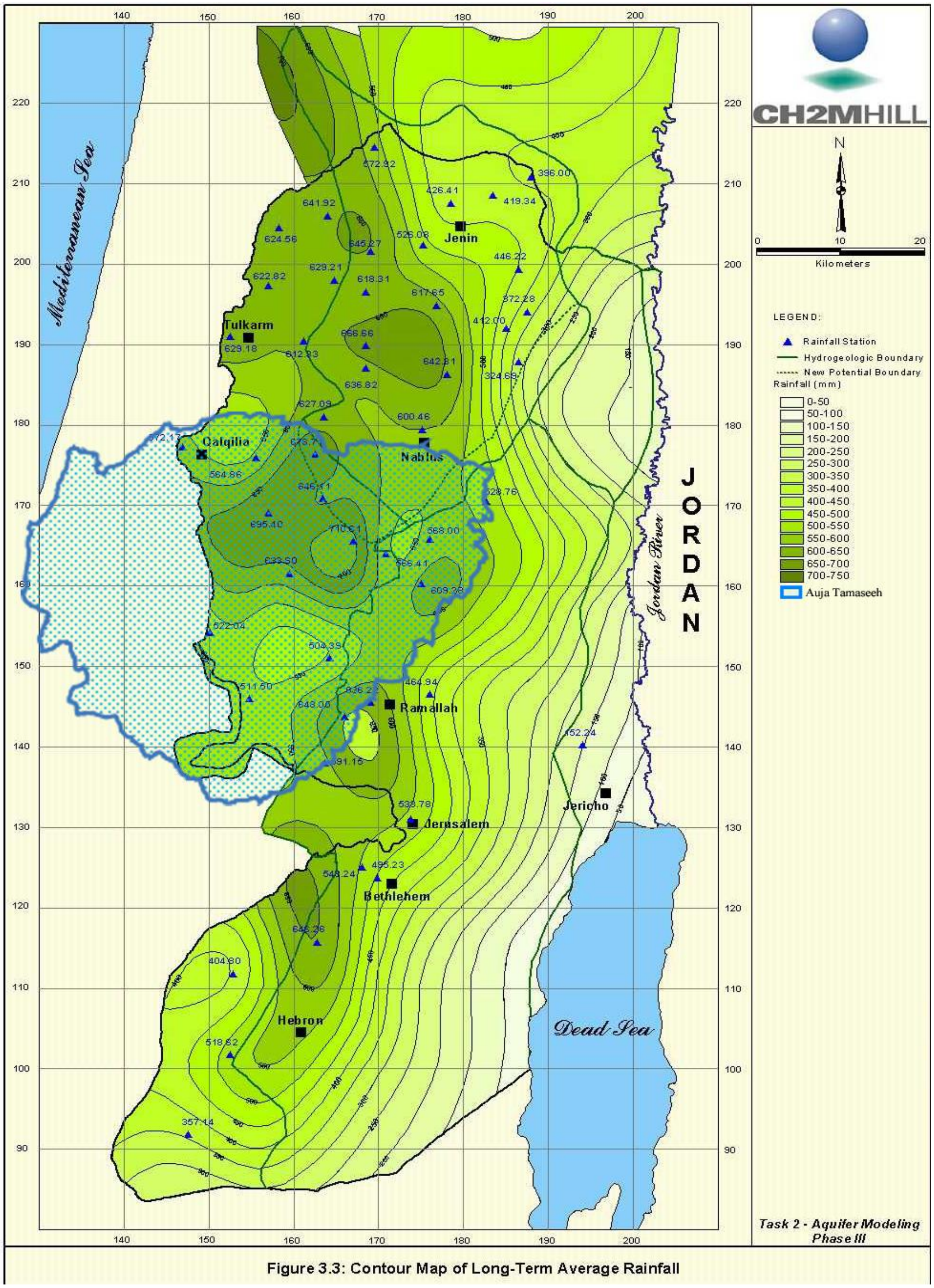


Figure 14: Long term average annual rainfall contour lines (CH2MHILL, PWA 2002).

CHAPTER FOUR
RECHARGE ESTIMATION

The Rainfall gauging network available in the Auja-Tamseeh catchment is made of twenty one stations inside the study area with historical records extending from the early fifties. Three outside stations were included in the analysis because of their influence on the areal rainfall calculations when constructing the rainfall isohyet contour lines or the Thiessen polygons. The western part of the study area is under Israeli control therefore no access to daily rainfall records was successful in this region which affects the results of the study. However, the geological maps revealed that vital areas for the replenishment of the WAB are within the Palestinian borders and are covered by a relatively well distributed gauging network. The present stations were used to cover the whole area for recharge estimation because the western part contribution to recharge is small as the existing calibrated recharge models have proved.

The study period considered twelve years extending from 1985 to 1997 for the monthly estimation of recharge required the preparation of database files for each month of the year. The study period included; dry years with rainfall quantities below the long term average annual rainfall, wet years where rainfall was almost twice the average values, and average years. The study is an attempt to analytically quantify monthly recharge for a selected area and period as a representative catchment in the WAB to be applied in the construction of the conceptual model of WAB.

4.1 Rainfall Analysis

The raw rainfall records taken from the PWA were daily records present in the excel files. A thorough analysis of the compiled daily records revealed that many stations had missing data for complete years, or the monthly values are registered for a specific day of the year. This is caused by the untrained personal responsible for data gathering.

The rainfall data required; daily, monthly, and annual analysis to eliminate any suspected records and reduce percentage of incorrect data. Data screening is not an essential part of the study but it is a prerequisite for the study calculations. The data quality control analysis needs exhaustive work and therefore screened data was taken from Yasin (2004) then used in the study calculations. The estimated missing data used was the monthly and not the daily records for decreasing error percentage.

4.1.1 Daily rainfall analysis

Time series study of daily records of the different stations was performed to produce hyetographs for these stations. The constructed hyetograph for Bir Zeit rain gauge station is available at Figure 15. These hyetographs are cumulative daily rainfall data, were November had more rainfall quantity than December and January. Also the total rainfall data didn’t exceed 250 mm \ month. Any unusual daily rainfall record could be detected easily for it appears as a sudden jump in the hyetograph.

A thorough analysis of the available rainfall stations in the study area gives general information concerning the location, number of available records, missing years and average, maximum annual rainfall values (Table 5).

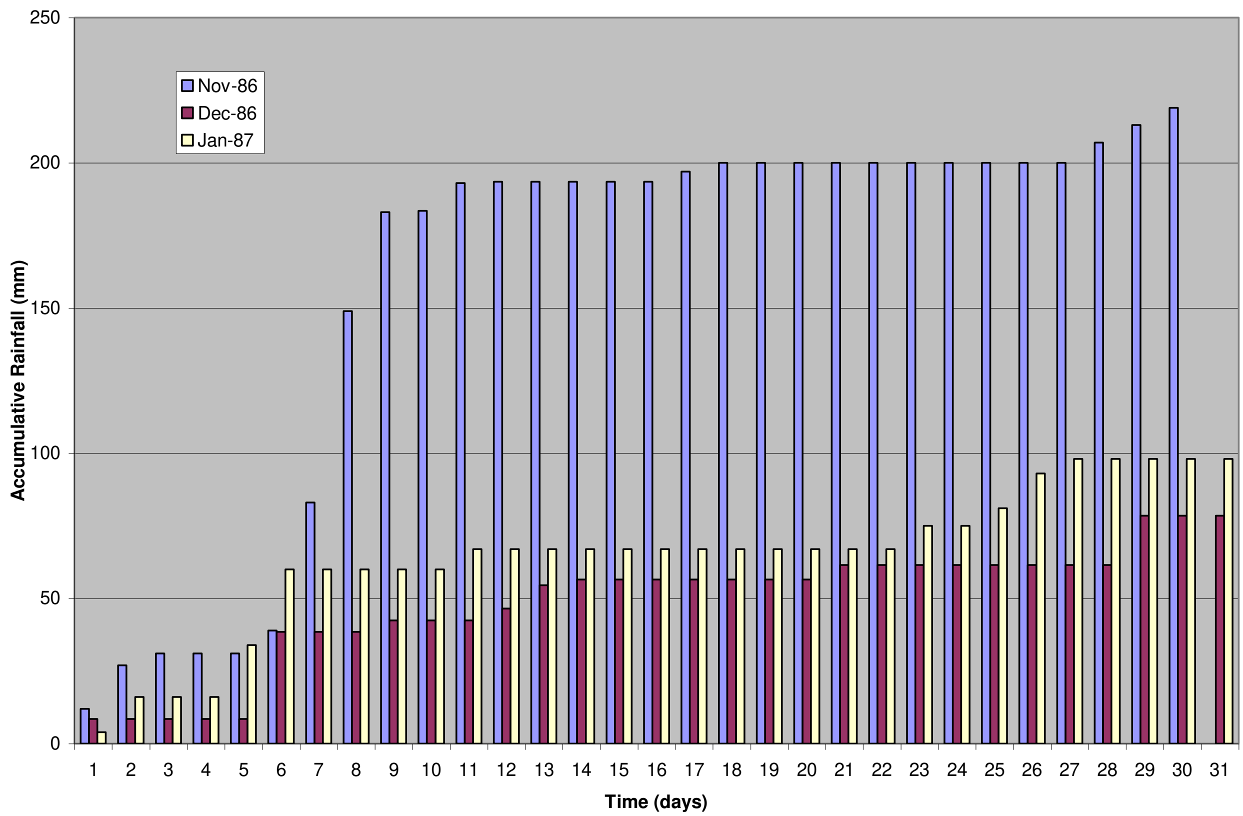


Figure 15: Bir Zeit rain gauge station daily hyetograph for the year 1986\87

The historical daily records of rainfall data were analyzed to get a general idea about the available data before being screened and quality controlled. The station's ID and location specified by the X and Y coordinates are listed in addition to information regarding the number of records available and the number of missing years. The rainfall maximum and average values are also found in Table 5.

Table 5 General information of the rain gauges available in the study area.

Station ID	X km	Y km	# of available records	Annual Average	Max Annual	Missing years
0000003	169	153	200	557.73	691	7
0000004	146.9	177.3	525	687.19	694.7	1
0241170	173.7	177	441	597.86	679.2	1
0241200	162.5	176.3	639	733.4	1963.3	0
0241250	155.5	175.9	557	730.1	1036.4	0
241270	177	174	590	599.54	679.2	0
0241300	163.4	170.8	600	679.48	802.9	0

0241400	157.5	169	570	642.68	1654.9	0
0241450	167	165.5	570	693.61	1679.5	0
0241500	159.5	161.5	288	594.18	788.6	5
0241550	175	160.2	237	524.47	586.3	2
0241630	169	157	434	670.59	773	2
0241650	176	156.8	432	604.91	853.9	2
0241900	164.2	151	345	575.16	950	6
0242151	154.8	146	326	611.03	671.7	8
0242400	166	143.7	362	679.4	839.7	2
0242935	163.7	138	417	482.44	815.7	5
0000011	151.05	153.85	164	477.68	745	3

4.1.2 Monthly Rainfall Data

The monthly values of rainfall are the accumulative daily values for all months of the hydrological year that starts in October of the current year and ends in May of the following year. The monthly records were compiled in excel sheets containing all stations monthly rainfall for each year separately. The data was then used to draw monthly contour lines for rainfall using the Arcview GIS extensions. These contour lines indicated the monthly spatial rainfall distribution over the catchment for the seven wet months of the year (Oct, Nov, Dec, Jan, Feb, Mar, April, and May).

The Thiessen method used in the study, divided the study region according to available rainfall gauges into polygons were rainfall of each station is equal to the rainfall of the whole polygon. These polygons are stationary for a fixed gauging network and the monthly rainfall can be distributed spatially over the whole area. The percentage or weight of each station in calculating areal monthly rainfall is fixed and is given by the Thiessen coefficients. The thiessen coefficients of the stations in the study area are listed in Table 6. The areal monthly rainfall for the long term average were calculated as volumes of water falling on the study area by multiplying the average monthly rainfall value of each station by the polygon area surrounding the station. The values of each station are added to obtain the total areal quantity which is the total volume precipitating on the whole area of study. The summation of the areas in column 3 (Table 6) is equal to 1810.19 km^2 which is equal to the total area of the study region. The summation of column 4 in the same table (Table 6) is equal to 1.00 which refers to the whole area of study.

Table 6: Thiessen coefficients for areal calculations

Station ID	X km	Y km	Area km^2	Thiessen coefficien
0000003	169.00	153.00	19.85	0.0110
0000004	146.90	177.30	235.18	0.1299
0000008	170.17	150.90	26.61	0.0147
0000011	151.07	153.78	275.38	0.1521
0241140	162.50	178.00	14.51	0.0080
0241170	173.70	177.00	36.29	0.0200
0241200	162.50	176.30	31.35	0.0173
0241250	155.50	175.90	71.17	0.0393
0241300	163.40	170.80	50.49	0.0279
0241350	182.70	170.50	25.12	0.0139
0241400	157.50	169.00	76.22	0.0421
0241470	177.80	164.00	60.42	0.0334
0241500	159.50	161.50	76.21	0.0421
0241599	152.00	159.10	196.21	0.1084
0241630	169.00	157.00	48.27	0.0267
0241650	176.00	156.80	24.51	0.0135
0241900	164.20	151.00	69.53	0.0384
0242151	154.80	146.00	207.80	0.1148
0242230	169.00	145.50	9.92	0.0055
0242400	166.00	143.70	36.94	0.0204
0242935	163.70	138.00	60.70	0.0335
0241450	167.00	165.50	73.67	0.0407
0241550	175.00	160.20	34.44	0.0190
0241270	177.00	174.00	49.40	0.0273

4.2. Recharge Estimation

Recharge estimation as discussed in section 3.5 is based on the annual recharge model of the long term annual average rainfall quantities and the equations 3.5 and 3.6 found in the same section.

The cumulative monthly contributions of rainfall for the months from October to May are given by the following equations:

$P_{ci}= 0.15P_{i-3}+ 0.12P_{i-2}+ 0.08P_{i-1}+0.05P_{i-0}+0.35P_{i-4}+0.2P_{i-5}+0.05P_{i-6}$ Eq 3.6

To calculate the cumulative rainfall for October using the coefficients and determining the i^{th} month as being October, then i-3 will be July, i-2 will be August and so forth. Filling the coefficients and the proper months for October will give Eq 4.1. Simplifying the equation produces Eq 4.1.a.

$P_{Oct}= .35*P_{Jun}+ 0.2*P_{May} +0.15*P_{July} +0.12*P_{Aug} +.08*P_{Sep} +.05(P_{Oct}+ P_{April})$ Eq 4.1

But there is no rainfall in the months Jun, July, Aug, and Sep therefore Eq 4.1 will be simplified as follows:

$P_{Oct} = 0.2*P_{May} + .05*(P_{Oct} + P_{April})$ Eq 4.1.a

Proceeding in the same manner and applying equation 3.6 for the entire months of the year will produce the following set of equations that could be arranged in matrix form. These equations are:

$P_{Nov} = .08*P_{Oct} + .05*P_{Nov} + .05\ P_{May}$ Eq 4.1.b

$P_{Dec} = .12*P_{Oct} + .08*P_{Nov} +.05*P_{Dec}$ Eq 4.1.c

$P_{Jan} = .15*P_{Oct} +.12*P_{Nov} +.08*P_{Dec} +.05*P_{Jan}$ Eq 4.1.d

$P_{Feb} = .35*P_{Oct} +.15*P_{Nov}\ .12*P_{Dec} + .08*P_{Jan} + .05*P_{Feb}$ Eq 4.1.e

$P_{Mar} = .35*P_{Nov} + .2*P_{Oct} + .15*P_{Dec} + .12*P_{Jan} + .08*P_{Feb} + .05*P_{Mar}$ Eq 4.1.f

$P_{April}=.35*P_{Dec}+.2P_{Nov}+.15*P_{Ja}+.12*P_{Feb}+.08*P_{Mar} + .05*(P_{April} + P_{Oct})$ Eq 4.1.g

$P_{May}= .35*P_{Jan} + .2*P_{Dec} + .15*P_{Feb} + .12*P_{Mar} + .08*P_{April} + .05*(P_{May} + P_{Nov})$ Eq 4.1.h

$P_{Jun} = .35*P_{Feb} + .2*P_{Dec} + .15*P_{Mar} + .12*P_{April} + .08*P_{May} + .05*P_{Dec}$ Eq 4.1.i

$P_{July} = .35*P_{MAR} + .2*P_{Feb} + .15*P_{April} + .12*P_{May} + .05*P_{Jan}$ Eq 4.1.j

$P_{Aug} = .35*P_{April} + .2*P_{Mar} + .15*P_{May} + .05*P_{Feb}$ Eq 4.1.k

$P_{Sep} = .35*P_{May} + .2*P_{April} + .05*P_{Mar}$ Eq 4.1.m

These equations give the contributions of monthly rainfall events into the specific month. If these P_{month} are used in previous equations (Eq. 3.5) to calculate recharge for each month, then recharge of month October for example will be equal to

$R_{Oct} = P_{Oct} *(R_a/P_a)$

Substituting the value of P_{Oct} into Eq 4.1.a produces the following equation

$R_{Oct} = .2*P_{May} + .05*(P_{April} + P_{Oct}) * R_a/ P_a$

Each recharge value is then related to the rainfall limits and coefficients specified in the Tahal equations as detailed in section 3.5. Therefore monthly recharge can also be expressed with the same limits of annual recharge and same group categories.

The above equations can be arranged in a matrix form were the recharge for each month is given by the contribution of rainfall events into the month of consideration multiplied by the calibrated annual recharge divided by the annual precipitation of the year.

The value of the x_1, x_2, x_3, x_4, x_5, x_6 are given by the predetermined coefficients as follows:

$x_1 = 0.05$, $x_2 = 0.2$, $x_3 = 0.05$, $x_4 = 0.08$, $x_5 = 0.12$, $x_6 = 0.15$, $x_7 = 0.35$

$R_a = .86*(P_a-360)$ $P_a > 650$ mm\year

$R_a = .534*(P_a-216)$ $300 < P_a < 650$ mm\year

$R_a = .15*P_a$ $P_a < 300$

$$
\begin{bmatrix} R^{j-1}_{Oct} \\ R^{j-1}_{Nov} \\ R^{j-1}_{Dec} \\ R^{j}_{Jan} \\ R^{j}_{Feb} \\ R^{j}_{Mar} \\ R^{j}_{April} \\ R^{j}_{May} \\ R^{j}_{June} \\ R^{j}_{July} \\ R^{j}_{Aug} \\ R^{j}_{Sep} \end{bmatrix}
=
\begin{bmatrix}
x1 & x2 & x3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & x1 & x4 & x3 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & x5 & x4 & x3 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & x6 & x5 & x4 & x3 & 0 & 0 & 0 & 0 \\
0 & 0 & x5 & x6 & x5 & x4 & x3 & 0 & 0 & 0 \\
0 & 0 & x4 & x5 & x6 & x5 & x4 & x3 & 0 & 0 \\
0 & 0 & x3 & x4 & x5 & x6 & x5 & x4 & x3 & 0 \\
0 & 0 & 0 & x3 & x4 & x5 & x6 & x5 & x4 & x3 \\
0 & 0 & 0 & 0 & x3 & x4 & x5 & x6 & x5 & x4 \\
0 & 0 & 0 & 0 & 0 & x3 & x4 & x5 & x6 & x5 \\
0 & 0 & 0 & 0 & 0 & 0 & x3 & x4 & x5 & x6 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & x3 & x4 & x5
\end{bmatrix}
\times
\begin{bmatrix} P^{j-1}_{April} \\ P^{j-1}_{May} \\ P^{j-1}_{Oct} \\ P^{j-1}_{Nov} \\ P^{j-1}_{Dec} \\ P^{j}_{Jan} \\ P^{j}_{Feb} \\ P^{j}_{Mar} \\ P^{j}_{April} \\ P^{j}_{May} \end{bmatrix}
$$

The expression j-1 refers to the previous year while j refers to the current year. For example the recharge of month Jan is equal to:

$R^{j}_{Jan} = (.15*P_{Oct} + .12*P_{Nov} + .08*P_{Dec} + .05*P_{Jan}) * .86*(Pa-360)/Pa \quad Pa>650$

Pa is the rainfall in year j-1

$R^{j}_{Jan} = (.15*P_{Oct} + .12*P_{Nov} + .08*P_{Dec} + .05*P_{Jan}) * .534*(Pa-216)\backslash Pa \quad 300<Pa<650$

Pa is the rainfall in year j-1

$R^{j}_{Jan} = (.15*P_{Oct} + .12*P_{Nov} + .08*P_{Dec} + .05*P_{Jan}) * .15*(Pa)\backslash Pa \quad Pa<300$

Pa is the rainfall in year j-1

The recharge for the rest of the months is computed in the same manner but taking into consideration in which year the annual rainfall takes place: year j-1, or j.

The implementation of these equations into the monthly rainfall data compiled in the excel files prepared in the previous section (section 3.2.2) produced new data sets of monthly recharge for each month.

Calibration of the recharge model uses actual groundwater level data and compares it to calculated groundwater level estimated by recharge models developed. The difference between measured and calculated values reflects the accuracy of the recharge model developed.

Abstracted water quantities are not directly related to groundwater level rise caused by recharge. On the contrary, some wells are even over pumped till it reached the red line boundary. In the case of irrigation wells the abstraction is usually constant regardless the rainy season: wet or dry but domestic wells abstraction is variable and is high during hot dry years.

The graphical plot of groundwater level versus well abstraction quantities (Figure 16) has no specified trend. The only clear observation is the increase in abstracted values during summer from June to September, while in winter the abstraction will reach its minimum value.

Calibration of the recharge model is based on transient flow models that began with the steady sate levels as initial values to run the transient model. Tahal (1999) updated the WAB (Yarkon- Tanninim Basin) for the previous thinking of a one layer model was executed and the aquifer system proved that natural recharge occurs mainly in the lower Aquifer outcrops, while abstraction was from the Upper Aquifer. The wet hydrologic year 1991\92 was one of the years that brought the thinking of model updating of the old model.

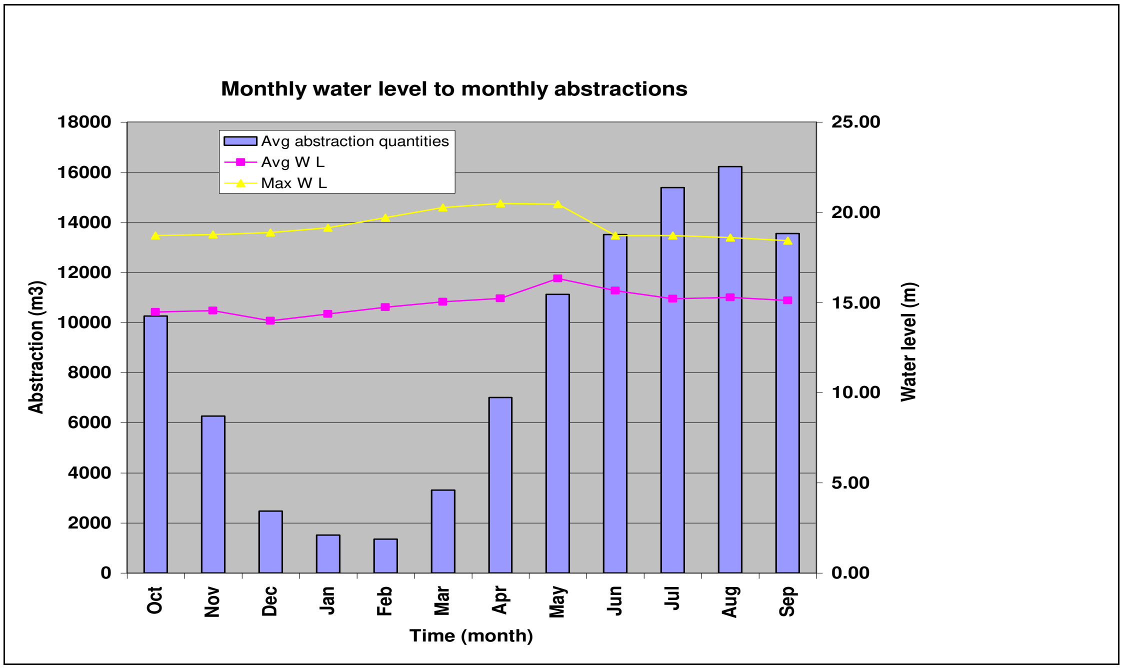
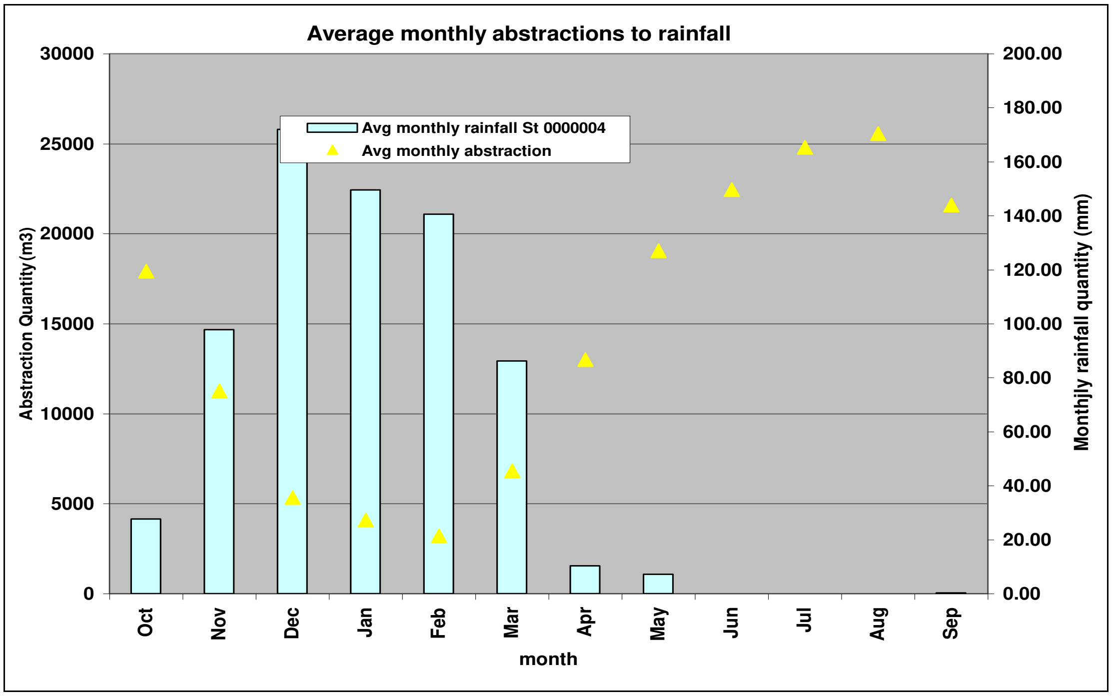


Figure 16: The monthly groundwater levels versus their monthly abstractions

The well abstraction hydrographs (Figure 17) can't be used to draw conclusions regarding the relationship of monthly rainfall precipitating on the area and monthly abstracted values. The monthly abstraction hydrographs are function of consumption whether it is domestic or agricultural and not monthly rainfall values. The abstraction usually is high and increases during dry years due to early summer and high temperatures.



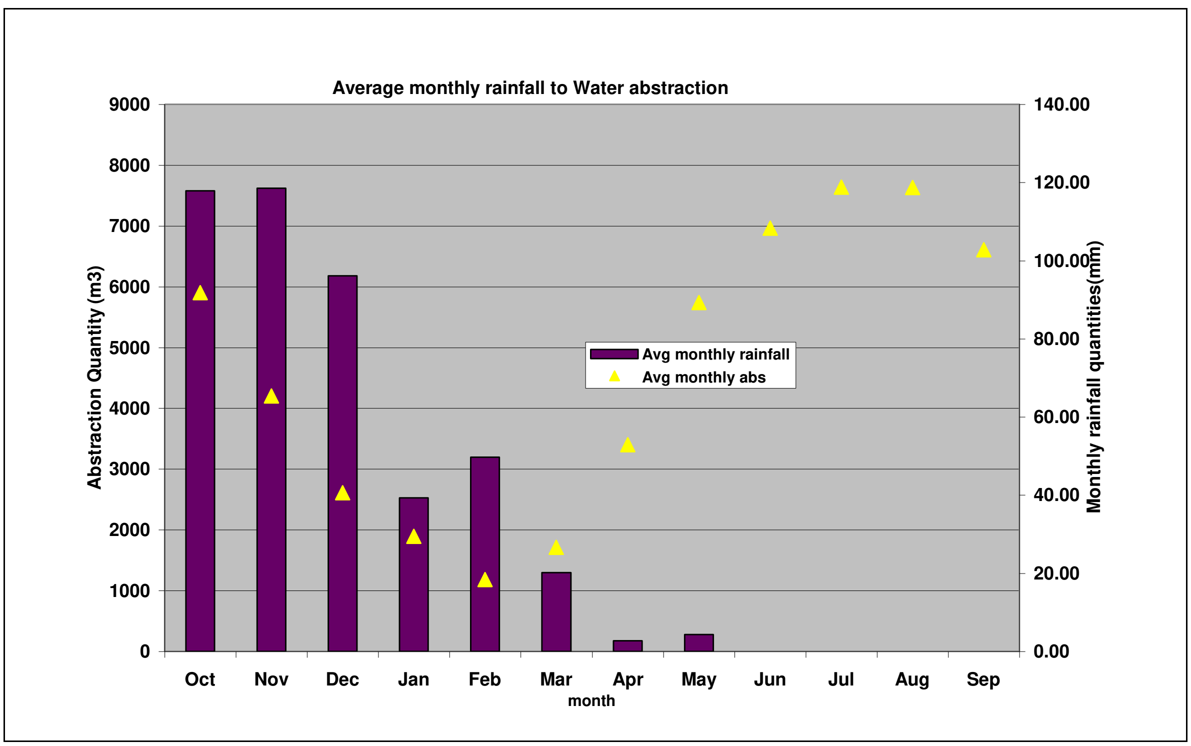


Figure 17: Monthly rainfall to monthly water abstractions for a Well and a Rainfall Gauging Station.

CHAPTER FIVE
CALCULATIONS AND RESULTS

The Groundwater Modeling Systems (GMS) software has the tendency of constructing grids of variable spacing over the study area, thus refining the cells at outcrops to distribute recharge more accurately along the outcropping formations. However, GIS Arcview is not modeling software that deals with variable conditions, and calibrated recharge was treated in the same manner as rainfall. The 1km x 1km grid was constant through out the recharge estimation. Each cell of the grid was assigned a recharge value in addition to rainfall values.

The calibrated annual recharge model used in calculating monthly recharge accounted for evaporation and runoff losses, thus giving net monthly amounts of water reaching the ground water basins. The produced monthly equations, although free of factors that considered spatial geologic and rainfall variations in addition to evaporation and runoff losses, accounted implicitly for these variables by the calibrated annual recharge.

Movement of water between the aquifers can't be determined unless chemical analysis of the water samples taken from the aquifers is performed. This study will not deal with chemical analysis of water sampling.

5.1 Recharge calculations

5.1.1 Areal Rainfall calculation

The produced equations are used to calculate total recharge quantities for the whole catchment in million cubic meters (Mcm) for each month of the hydrological year starting with October of the current year and ending with September of the following year. These values can be calculated for every year in the time period of the study. The average monthly rainfall values in mm\month for each station are tabulated in Table 7.

The areal rainfall is then calculated using the Thiessen coefficients to give volumetric values of rainfall quantities precipitating on the study area.

Table 7: Average monthly rainfall over the whole area (mm\ month)

Station ID	Oct mm	Nov mm	Dec mm	Jan mm	Feb mm	Mar mm	Apr mm	May mm
0000003	15.23	87.12	136.03	124.29	118.10	83.60	13.50	5.73
0000004	23.44	94.25	164.98	148.24	122.70	86.61	11.01	3.56
0000011	14.83	86.79	137.64	135.90	89.52	15.31	2.16	0.00
0241140	20.57	96.49	159.63	154.00	133.93	98.18	14.68	8.94
0241170	20.80	85.86	130.83	129.13	114.78	89.34	14.55	7.43
0241200	29.81	102.14	165.46	158.73	134.07	102.95	16.53	7.96
0000008	21.75	103.70	162.86	173.91	143.56	109.27	18.03	6.73
0241250	21.50	99.96	151.17	149.47	130.58	91.85	15.88	7.46
0241270	18.20	88.10	127.73	125.88	130.50	90.15	19.87	6.38
0241300	28.18	91.39	154.62	142.32	131.99	93.65	19.33	8.73
0241350	15.45	80.39	123.64	123.04	111.58	78.21	14.37	6.33
0241400	15.79	91.17	145.41	136.68	127.68	89.08	14.18	4.51
0241470	30.78	87.13	132.00	139.22	125.88	86.42	16.98	5.54
0241500	16.69	104.17	148.55	150.37	135.30	87.17	14.84	6.10
0241599	16.31	91.26	143.04	137.27	137.90	92.13	11.84	5.77
0241630	14.20	94.29	143.19	144.13	136.55	98.48	12.84	4.83
0241650	18.33	82.76	128.26	134.17	118.44	85.18	15.7	5.37
0241900	16.70	90.66	125.59	128.94	119.36	81.51	13.25	4.86
0242151	25.68	92.78	134.83	124.62	117.73	84.79	14.61	5.85
0242230	17.30	91.29	143.10	144.08	130.10	91.78	17.78	5.69
0242400	20.96	91.74	145.53	137.20	125.64	96.09	17.93	5.67
0242935	22.75	88.17	134.00	133.51	129.88	87.89	14.31	5.26
0241450	19.49	93.43	156.31	132.75	144.40	95.15	14.33	6.48
0241550	20.79	73.65	119.78	104.47	103.27	80.45	11.00	2.77

The long term average monthly rainfall values are displayed graphically for all rainfall gauge stations available in the study area (Figure 18). The average monthly values have a peak at December or January. The minimum rainfall values are in the months April and May.

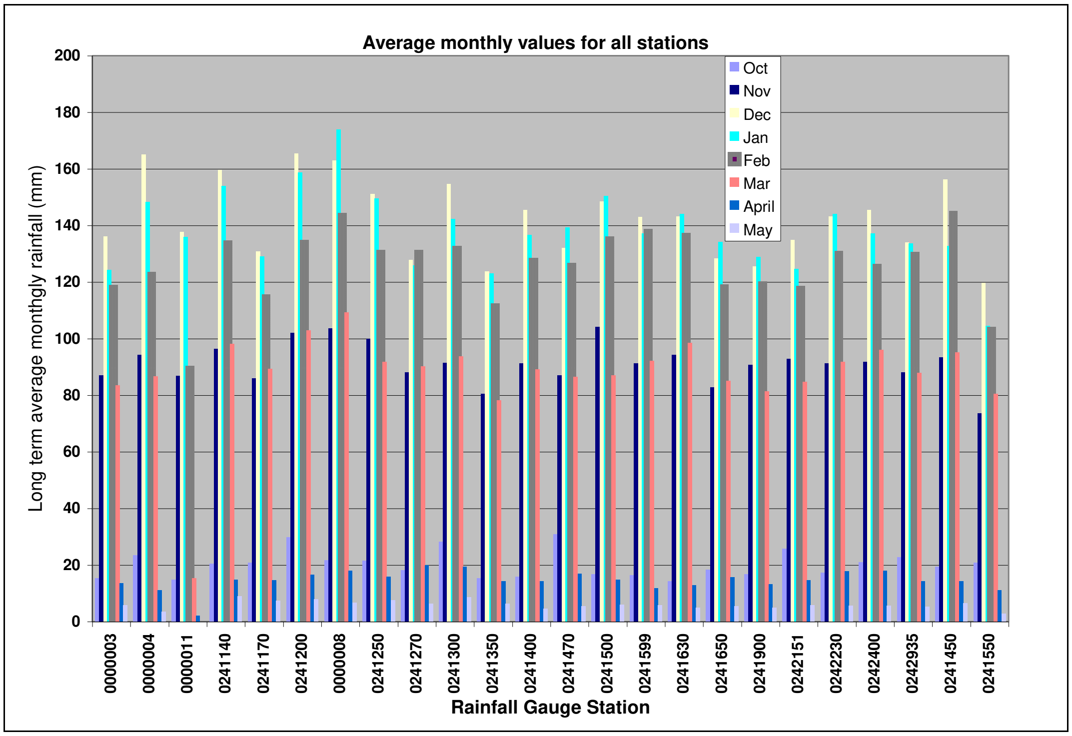


Figure 18: Long term average monthly rainfall values for all stations of the study area (1985-97)

Calculation of the total volumes of rainfall quantities falling over the study area requires multiplying monthly rainfall values times the thiessen coefficient of each station. Using the data of Annex B10, Figure 19 displays the percentage of each month of the total rainfall quantities falling over the study area.

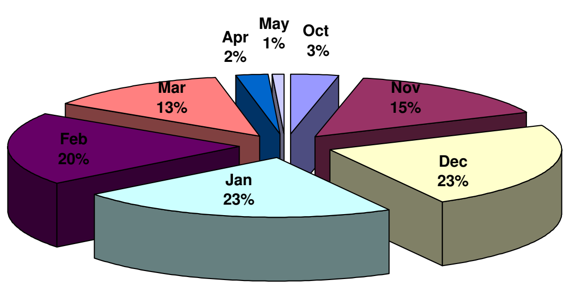


Figure 19: Percentage of each month of total volumes over the study area

The total rainfall values are then distributed spatially over the different geologic formations (Figure 20). The Lower Cenomanian formation has the maximum rainfall volume while the Qaternary formation has the lowest rainfall volume.

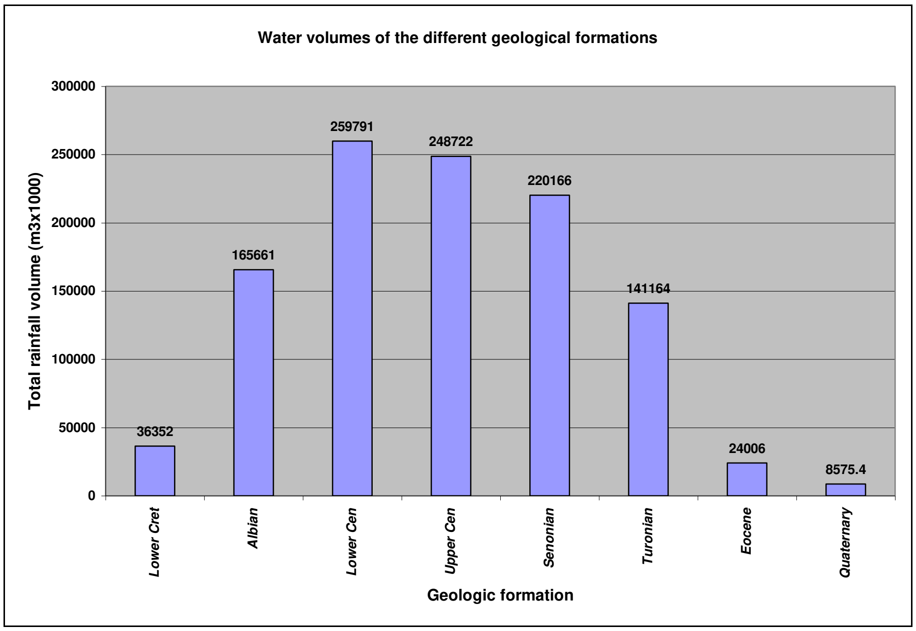


Figure 20: Water volumes that fall on the different geologic formations(Mcm)

5.1.2 Areal recharge calculation

The procedure used for areal rainfall calculation is applied to areal recharge calculation. The total monthly recharging values for the outcropping formations are present in Figure 21. The Upper Aquifer has the maximum recharge quantity, while Yatta formation has the lowest recharging quantity. Recharge took place through the outcrops only which explains excluding some rainfall stations from areal recharge calculations. The amount of monthly recharge was connected to the rainfall stations inside the outcrop area in the same manner as rainfall.

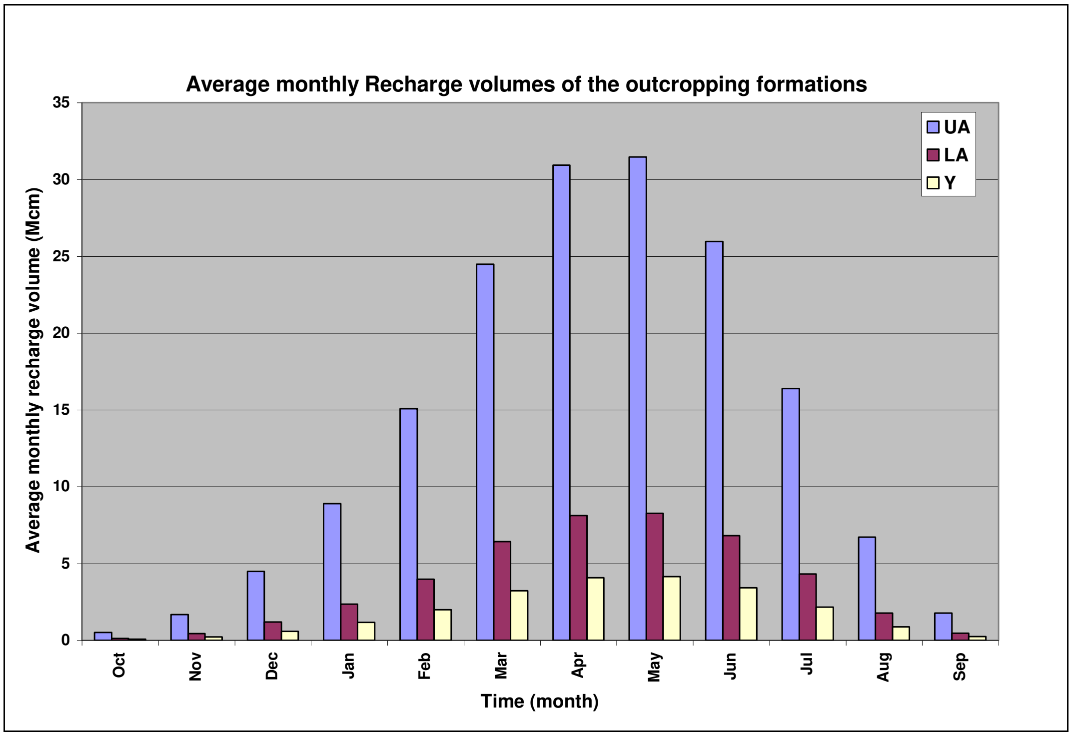


Figure 21: Average monthly recharge volumes of the outcropping formations; Lower Aquifer (LA), Upper Aquifer (UA), and Yatta formations (Y).

5.2 Model application

The average annual areal rainfall falling on the study area is computed by adding up the long term average monthly rainfall volumes of each month in the hydrologic year. The average total rainfall falling on the study area was equal to **1104.4 Mcm** of water.. The last row of Annex B10 (Table 11) is the average annual recharging value calculated to replenish the groundwater basin. This value as deducted from Annex B11 which was equal to **234.8 Mcm.** Therefore the percentage of recharge from rainfall is

Areal recharge / Areal rainfall *100%= 234.8 /1104.4 *100%= 21.3 %

The recharge- rainfall coefficient found was consistent with the findings of different studies in Palestine. Studies carried by the different authors produced different rainfall recharge percentages as listed in (Table 8) and cited by SUSMAQ (2004) study.

Table 8: Recharge-rainfall coefficient for different studies SUSMAQ (2004)

Author	% of recharge from rainfall
Scarpa(1994)	20
ANTEA(1998)	20
Blake and Goldschmidt (1947)	22-25
CDM (1997)	20-30
Arad and Michaeli (1967)	6-48
Goldschmidt (1955)	34
Rofe and Raffety (1963, 1965)	20-55
Guttman and Zukerman (1995)	25-60
Ghanem (1999)	26

The monthly rainfall volumes falling on the study area when plotted against the monthly recharge volumes produces Figure 22 below.

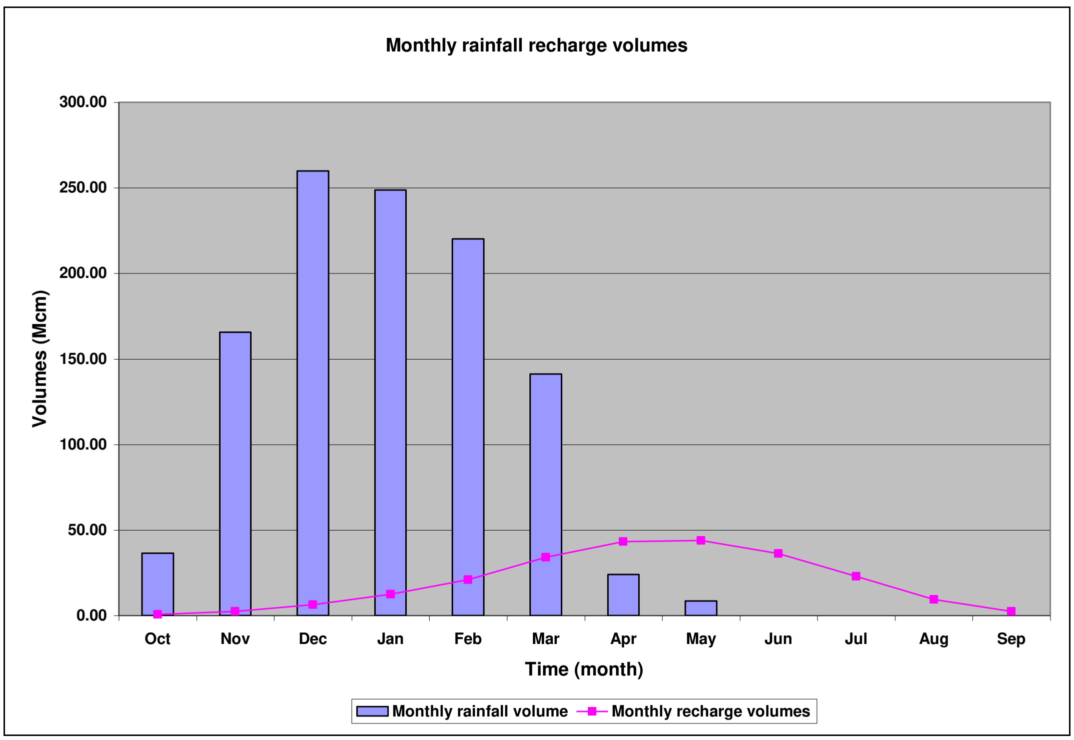


Figure 22: Monthly rainfall recharge volumes for Auja-Tamseeh (1985-97)

The recharging quantities are distributed along a log-normal distribution with a recharging peak at April- May which lags three months from the rainfall peak that took place in December January. These findings are consistent with the assumptions made concerning the delay effect of rainfall event to cause a change in groundwater level expressed by the lag-time period of peaks. Also the accumulation effect displayed by the contribution of all rainfall events into month i which was expressed by the P_{ci} for each month.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Recharge estimation study relying on empirical methods is a recent study in Palestine. Few studies were conducted to estimate recharge at different topographic and geological locations depending on the infiltration rates of these formations. Some studies were held for calculating runoff or infiltration and ended up with recharging percentages of rainfall quantities due to interference of runoff, infiltration, and recharge studies. This study used the empirical methods to estimate recharge of Al Auja-Tamseeh catchment on monthly basis. The conclusions of the study are summarized as follows:

1. Monthly rainfall data when displayed graphically doesn’t follow a consistent trend for all hydrologic years. Winter might begin early in Oct and increases till it reach its peak at Dec, while other years winter is late and the first rainfall event occurs in Dec. This variability phenomenon can be reduced if long term average monthly rainfall values are considered. The long term average monthly rainfall values are noticed to follow a specific trend which increases from Oct till a peak is noticed at Dec.
2. Monthly groundwater level values followed a specific trend when plotted against time. The groundwater level is noticed to rise gradually till it reaches a peak between April and May. The groundwater level then decreases gradually till it stops three months from the peak.
3. A comparison between long term average monthly rainfall values and monthly groundwater levels led to lag-time calculation. The lag-time was found equal to three months in this study. The groundwater level peak usually appeared in April which is three months away from the long term average monthly rainfall peak that took place in Dec.
4. The rise of groundwater level during the dry months from May to July confirmed the accumulation observation of any rainfall event impeding on the ground surface. The rainfall event requires a specific time to reach the groundwater basins depending on the geological formations of the study area. Some areas are

impervious and prevent falling water from reaching the groundwater basins, while others infiltrate water quickly. This infiltration variation is accounted for by spatial distribution of rainfall quantities over the study area.

5. Groundwater level was noticed to follow a log-normal distribution and not a normal distribution. There wasn't any axis of symmetry for the constructed groundwater level hydrographs.
6. The percentage of rainfall that recharged the study area was found equal to 21% of rainfall value. This percentage is a function of the geological nature of the study area that determines the degree of transpassivity of the formations. Although rainfall is spatially distributed along the total study area, recharge takes place only through the outcrops of the area as found by the calibrated transient flow models available in Guttman and Zukerman (1995) or Zukerman (1999).
7. The accuracy of the developed monthly equations for recharge estimation could be checked. Sensitivity of the predetermined coefficients on the study results could be determined if the study was conducted using different values of this variable.
8. The empirical approach for recharge estimation depended on actual recharge values given by the calibrated transient flow models.
9. The thorough analysis of rainfall and groundwater level data revealed the **direct relation** between precipitating quantities and rising groundwater level. This direct relation was very obvious in the wet year of 1991\92 when the groundwater level rose dramatically beyond the usual trend. The amount of abstracted water in 1991\92 decreased due to prolonged winter that decreased the evaporation rates. The abstracted quantities were also affected especially for agricultural purposes. Abstraction hydrographs conveyed no correlation between abstraction and rainfall quantities. There was an inverse relation between groundwater level and abstraction for increased abstraction quantities caused decrease in groundwater level.

6.2 Recommendations

To obtain better results in future studies, the following recommendations are vital:

1. Accessibility of the available data in the different institutions to all studies being conducted. The interrelation of recharge topic with runoff and evaporation studies require a comprehensive study of the area to compute these values for each study area, and thus be able to produce a sound management plan for the available water resources.
2. Use of modern versions of the software Arcview GIS to overcome the drawbacks of the available GIS 3.2 version.
3. Use of other recharge estimation approaches to provide means of comparison between these approaches and the approach followed in the study. The applicability of the developed model can't be determined unless the study is carried on other catchments and the results obtained are compared to calibrated model values.
4. Groundwater level in the wells should be measured on smaller time intervals as monthly and not on bi-monthly basis or every three months as the existing situation in the PWA.
5. Construction of evapotranspiration stations distributed properly to cover the climatic changes within short distances. These stations give evaporation data on monthly basis and thus provide data for recharge quantification on monthly basis using other estimation approaches.
6. Development of conceptual models for the surface and groundwater basins available in Palestine in order to be calibrated and used in recharge estimation studies as the case in this study were calibrated recharge was taken from Zukerman (1999) due to absence of calibrated Palestinian data.

This thesis is a humble attempt for developing an analytical mathematical approach for monthly estimation of recharging quantities in semi-arid to arid regions. Such studies are important for developing conceptual models for the available groundwater basin to quantify available water resources and carry sound management techniques to preserve these water resources from deterioration both in quality and quantity.

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