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MONTHLY RECHARGE ESTIMATION FOR THE AUJA–TAMSEEH CATCHMENT OF THE WESTERN BASIN AQUIFERS – SYSTEM, PALESTINE.

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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 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. 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. 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 spatial and temporal variations of rainfall amounts impeding on the land surface and the replenishment through the outcropping formations was used as a base for a developed mathematical model. The model 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, recharge, Lag-time, Arid areas.**

INTRODUCTION

The Western Aquifer Basin WAB (Figure 1), which covers an area of 9155 km^2 (Abed and Washahi, 1999), is the biggest of the Mountain Aquifer sub-basins in the West Bank and has a safe yield of about 380-450 million cubic meters (Mcm)\ year (SUSMAQ, 2001).

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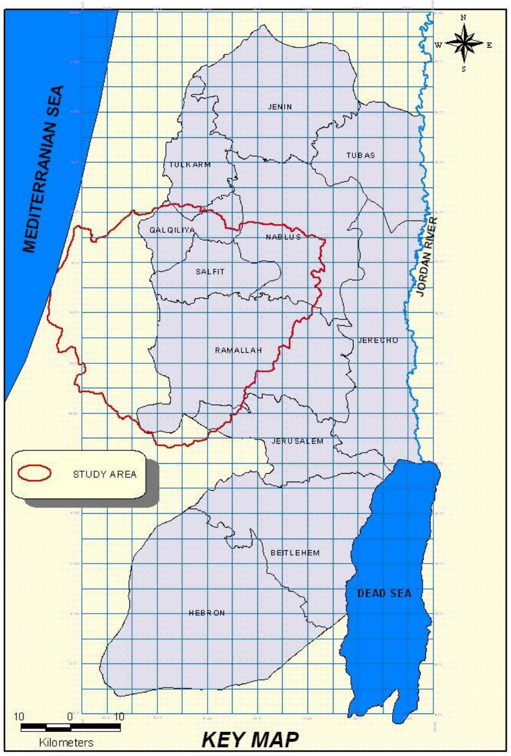

Figure 1: location map of the study area.

Water in Palestine is a scarce and valuable commodity. Groundwater and surface water constitute the major water resources in the area. Groundwater in Palestine is pumped from the Mountain Aquifer Basin, which consists of three sub-basins, Western Aquifer Basin (WAB); the Northeastern 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 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 (Ghanem, 1999). 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). Recharge in the semi-arid regions like Palestine, is generally low and variable in magnitude over space and time. 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). 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 (2004). SUSMAQ (2004) made a study for monthly recharge of Wadi Natuf catchment as a representative catchment for the WAB in Palestine.

The oldest geological formations present in The Auja-Tamseeh catchment are of Jurassic period (Figure 2). 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 (Rofe and Raffety, 1965). 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. 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 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 northern part of the WAB is bounded by the Tamsih 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. There are 81 wells in the Auja-Tamseeh catchment, which tap the upper or lower aquifer. The area has around 94 springs in Ramallah, Nablus, and Salfit districts.

METHODOLOGY

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. 2. Preparation of the rainfall data taken from PWA (2001)for analysis.

3. Demonstration of the study principles that were based on hydrological observations. 4. The empirical equation derived by Goldschmidt and Jacob for annual recharge estimation was the building block of the model.

5. Recharge estimation model was built on Susmaq's (2004) study of Wadi Natuf catchment which derived monthly recharge estimation model of the WAB.

6. Building of the monthly recharge model by defining the cumulative rainfall for each month.

7. The study area is dividing 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.

8. The Thiessen polygon method was applied in this study.

9. The calibrated recharge model developed by Guttman and Zukerman (1995) for the WAB was used and applied to the study area for monthly recharge calculations. The procedure used in the lag time determination depends on hydrological observation of monthly rainfall and well level distribution over the hydrological year.

RESULTS AND DISCUSSIONS

Lag - time

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. 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. This study had divided the Auja-Tamseeh catchment into a grid of 1km by 1km cells. 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.

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) and Guttman (1998). The equation used for the monthly recharge study for the Wadi Natuf catchment (SUSMAQ, 2004) was:

$$R_i = (P_{ci} / P_a) * R_a \quad \text{Equation 1}$$

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)

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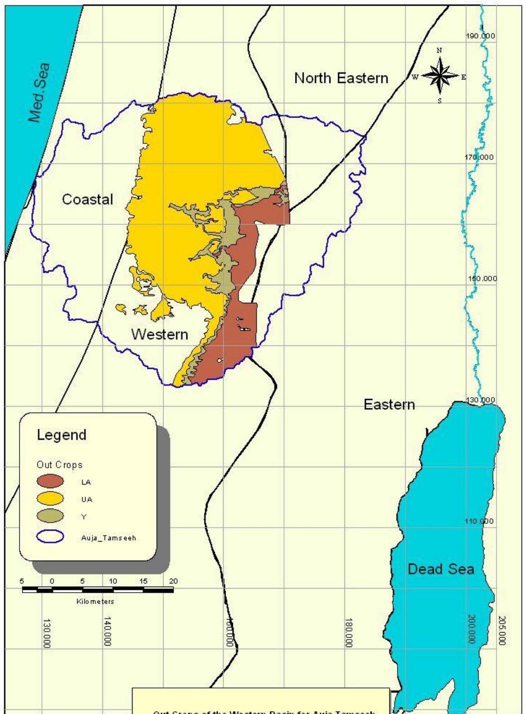

Figure 2: Hydrogeological map for the Upper Aquifer (UA), Lower Aquifer (LA), and Yatta (Y) outcrops digitized from SUSMAQ outcrop map.

Rainfall 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. 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.

Rainfall Analysis

The raw rainfall records taken from the PWA were daily records present in the excel files. 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. Time series study of daily records of the different stations was performed to produce hyetographs for these stations. 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. 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 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.

Rainfall Recharge Estimation

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

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

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 3. Simplifying the equation produces Eq 3.

$$P_{Oct}= .35*P_{Jun}+ 0.2*P_{May} +0.15*P_{July} +0.12*P_{Aug} +.08*P_{Sep} +.05(P_{Oct}+ P_{April}) \qquad \text{Eq 3}$$

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. 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

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hydrologic year 1991\92 was one of the years that brought the thinking of model updating of the old model.

Areal Rainfall calculation

The long term average monthly rainfall values are displayed graphically for all rainfall gauge stations available in the study area (Figure 3). The average monthly values have a peak at December or January. The minimum rainfall values are in the months April and May.

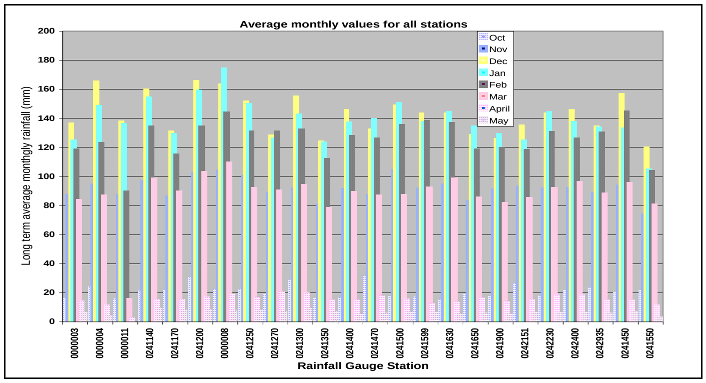

Figure 3: Long term average monthly rainfall values for all stations of the study area (1985-97)

The total rainfall values are distributed spatially over the different geologic formations (Figure 4). The Lower Cenomanian formation has the maximum rainfall volume while the Qaternary formation has the lowest rainfall volume.

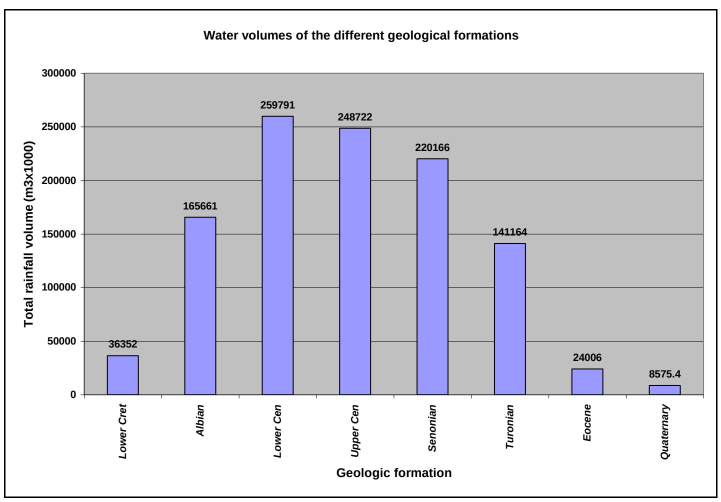

Figure 4. Water volumes that fall on the different geologic formations(Mcm)

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 5. 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.

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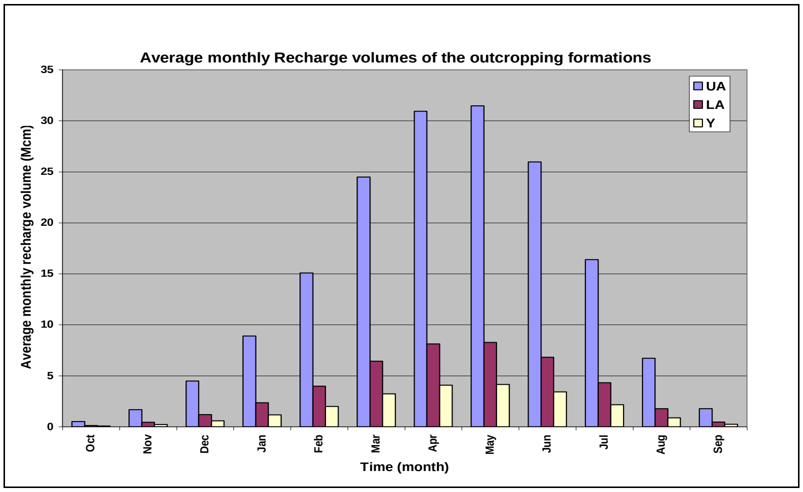

Figure 5: Average monthly recharge volumes of the outcropping formations; Lower Aquifer (LA), Upper Aquifer (UA), and Yatta formations (Y).

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 and the average of the areal recharge is equal **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 1 and cited by SUSMAQ (2004) study.

Table 1: Recharge-rainfall coefficient for different studies SUSMAQ (2004)

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

The monthly rainfall volumes falling on the study area when plotted against the monthly recharge volumes produces Figure 6.

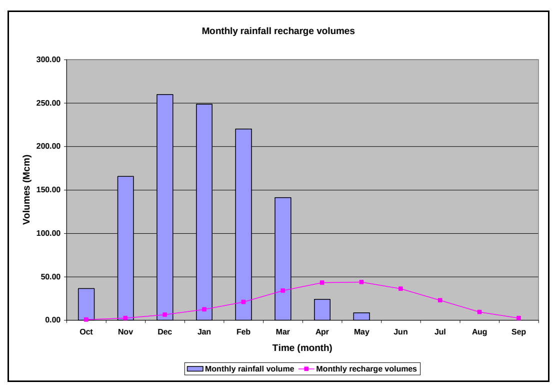

Figure 6: Monthly rainfall recharge volumes for Auja-Tamseeh (1985-97)

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

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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.

CONCLUSIONS

Monthly rainfall data when displayed graphically doesn't follow a consistent trend for all hydrologic years. Winter might begin early in October and increases till it reach its peak at December, 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. 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. 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. 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 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 transsmisivity of the formations. The thorough analysis of rainfall and groundwater level data revealed the **direct relation** between precipitating quantities and rising groundwater level.

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