Evaluation and assessment of water budget in the eastern aquifer basin of the West Bank, Palestine

Fadi Dweik*

Applied Research Institute,
Jerusalem, Palestine
Email: fdweik@arij.org
*Corresponding author

Mahmoud Rahil

Palestine Technical University,
Kadoorie, Palestine
Email: mrahail@yahoo.com

Mhd. Suhyb Salama

University of Twente/ITC,
The Netherlands
Email: s.salama@utwente.nl

Abstract: The study is mainly intended to assess and evaluate the water budget in the eastern basin at 1 km resolution, through a comprehensive model of the eastern aquifer by estimating the evapotranspiration (evaporation and transpiration), surface runoff and groundwater recharge in the targeted aquifer for the period (1950–2000). A spatial modelling approach and geographical information systems (ArcGIS) specialist was used to evaluate and estimate the water budget for the 50 years period (1950–2000). Hydro-meteorological data for the 50 years period were used to drive precipitation, reference evapotranspiration, evapotranspiration, runoff spatial grids, and ground water recharge along with an summed minor losses were integrated by GIS spatial interpolation. The results of this study show that the average annual ground water recharge for the 50 years period in the study area is almost 200 millions of cubic metres (MCM) per year. A variation was found in the recharge values from the eastern slopes till the central highlands in the West Bank, this variation is due to the variation in temperature and precipitation in the targeted area.

Keywords: water budget; eastern aquifer; West Bank; Palestine.

Reference to this paper should be made as follows: Dweik, F., Rahil, M. and Salama, M.S. (2017) 'Evaluation and assessment of water budget in the eastern aquifer basin of the West Bank, Palestine', *Int. J. Global Environmental Issues*, Vol. 16, Nos. 1/2/3, pp.17–28.

Biographical notes: Fadi Dweik is a Research Associate at the Water and Environment Research Department at ARIJ. His main responsibilities at ARIJ include conducting scientific researches and writing project proposals, scientific papers and project reporting, proposals on GIS and remote sensing.

He has finished his undergraduate studies in Civil Engineering from the Palestinian Polytechnic University (PPU). He also obtained his post graduate studies in Environmental Management from Mediterranean Agronomic Institute of Chania (MAICH) Greece. He has a solid experience in water management, urban planning, strategic planning issues on the environmental management in addition to the knowledge and work experience in Palestinian civil society sector.

Mahmoud Rahil is an Associate Professor in the Department of Environmental Science and Technology, Faculty of Science and Agricultural Technology at the Palestine Technical University, Kadoorie, Palestine. He received his PhD in Wastewater Reuse and Management from Department of Hydraulics, Soil Science and Agriculture Engineering at Aristotle University of Thessaloniki, Greece (2002–2006) and MSc in Land and Water Resources Management from the Mediterranean Agronomic Institute of Bari, Italy (1998–2000) and BSc in Plant Production and Protection from Faculty of Agriculture at An-Najah National University, Palestine (1994–1998).

Mhd. Suhyb Salama is an Associate Professor in Remote Sensing of Water Quality and Water Resources Management at the Department of Water Resources in the Faculty of Geo-information Science and Earth Observation (ITC) of the University of Twente, The Netherlands. He received his PhD in Civil Engineering (2003) and MSc with Great Distinction (Magna Cum Laude) in Hydraulic Engineering (1999) from the Katholieke Universiteit Leuven, Belgium and BSc in Civil Engineering (1993) from Damascus University in Syria. He was a consultant in geo-information and remote sensing applications at the Spatial Division Leuven (SADL) in Belgium before he joined ITC in July 2007. Currently, his research and teaching focus on remote sensing and numerical modelling of water quality and interactions with the ecosystem, and ecosystems responses to climate and water cycle variations.

1 Introduction

The eastern aquifer basin (EAB) is a groundwater natural resource that constitutes the eastern portion of the mountain aquifer. The area of this basin is estimated at 3,079 km^2. A large part of the eastern basin is located within the eastern borders of the West Bank. The majority of this aquifer area is located within the areas featured by low amount of rainfall in general. The resource is heavily exploited and abstraction is directly controlled and apportioned between Israel and the West Bank by Israel.

Groundwater is the main source of water in the West Bank. The annual recharge of groundwater aquifers in the West Bank is estimated at 721 millions of cubic metres per year (MCM/y) (PWA, 2012). This aquifer is divided into three sub-basins (the western aquifer, the eastern aquifer, and the northeastern aquifer). Around 80% of aquifer recharge occurs inside the West Bank.

The aquifer systems rely on natural recharge from rainfall to a great deal of extent. In the last years, there have been noticed a low variation of rainfall amount, bad distribution of rainfall, high intensity, and high water evaporation. As a result, a drastic drop in the water table elevation was noticed in many wells across the West Bank with drop by 10%–20% (Froukh, 2003).

The eastern basin is divided into three main sub-aquifers, namely the mountainous heights, northeastern tip and Jordan Valley. The annual sustainable yield of this basin is estimated at 125 to 197 MCM/y. However, the Israelis exploit the aquifer at a rate of 50 MCM/y from wells in addition to 100 MCM/y from Dead Sea springs that are controlled by Israel; while the Palestinians utilised about 53 MCM/y by wells and springs (PWA, 2012).

The average total annual recharge to the eastern basin has decreased significantly from approximately 211 MCM during the period 1976–1992 to approximately 174 MCM during the period 1993–2009 by using the cell model, while the numerical model shows a decrease from 173 MCM during the period 1976–1992 to 138 MCM during the period 1993–2009 (Israel Hydrological Service, 2012).

Surface runoff is a very important and critical parameter in this research. The quantity of water flowing into the Lower Jordan River and discharging into the Dead Sea was estimated to be not more than 30 MCM/y. While the long-term average annual flow of flood water through wadi's in the West Bank is estimated at about 165 MCM/y (PWA, 2011).

The main objective of this study is to assess and evaluate the spatial distribution and flow rates of various water budget components in the eastern aquifer at high spatiotemporal resolution. We adapted a water balance model of the eastern basin by estimating the actual evapotranspiration (evaporation and transpiration), surface runoff, and groundwater recharge for the interval years (1950–2000).

2 Materials and methods

2.1 Study area description

Historic Palestine, and generally the EAB is the focal area for this research study. The EAB is a groundwater natural resource that constitutes the eastern portion of the mountain aquifer, where water flows eastward toward the Jordan Valley. This aquifer contributes by nearly 90% of total annual spring discharge in the West Bank. Unlike the western aquifer, the EAB is almost completely situated within the borders of the West Bank. In spite of this geographical location, Israel currently abstracts approximately over two-thirds of the water supply from the aquifer. Moreover, Israeli settlers in the West Bank exploit this aquifer by installing deep wells in the high hills of settlements to pump its water for their benefits. By 2004, Israel had managed to install over 32 deep wells exploiting the Eastern Aquifer (PHG, 2010). Large part of the eastern aquifer is located within the eastern borders of the West Bank. The area of this basin is estimated at 3,079 km^2. The majority of this aquifer area is located within the areas featured by scarcity of rainfall in general. The resource is heavily exploited and abstraction is directly controlled and apportioned between Israel and the West Bank by Israel.

2.2 Datasets

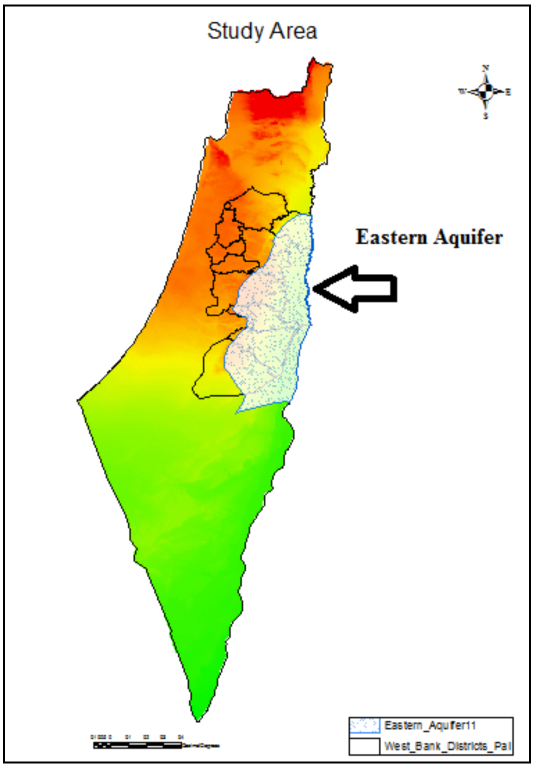
Data on interpolated climate surfaces for global land areas at a spatial resolution of 30 arc (often referred to as 1-km spatial resolution) was used in this research study. Variables included are monthly total precipitation, and monthly mean, minimum and maximum temperature, and 19 derived bioclimatic variables were downloaded from WorldClim site (Hijmans et al., 2005).

Thin-plate smoothing spline algorithm was implemented in the ANUSPLIN package for interpolation, using latitude, longitude, and elevation as independent variables. The hydro-meteorological data for the 50-years period (1950–2000) were used to derive ETo, ET, runoff, and ground water recharge spatial grids, along with assumed minor losses were integrated by GIS spatial interpolation (see Figure 2).

2.3 Model approach

For this study we applied a spatial modelling approach to evaluate and estimate water budget for the 50-years period (1950-2000). The model took into consideration various parameters ranging from physical fixed data that does not change with time for the same area to dynamic data which change with time. Fixed data used in this study model includes elevation, geographic boundaries, groundwater boundaries, watershed basin boundaries and the West Bank aquifer boundaries (recharge areas). Dynamic data used in this model includes values of weather meteorological parameters such as temperature, relative humidity, wind speed, solar radiation, evapotranspiration and runoff.

Figure 1 Study area (see online version for colours)



We estimate the reference evapotranspiration (ETo) from the 50-years monthly average temperature, relative humidity, wind speed and solar radiation using the modified FAO Penman-Monteith equation presented in the following equation:

$$ETsz = \frac{0.408\Delta(R_n - G) + \gamma \dfrac{C_n}{T+273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + C_d u_2)} \tag{1}$$

where

$ETsz$	standardised reference crop evapotranspiration for short (ET_{os}) or tall (ET_{rs}) surfaces (mm d^{-1} for daily time steps or mm h^{-1} for hourly time steps)
R_n	calculated net radiation at the crop surface (MJ m^{-2} d^{-1} for daily time steps or MJ m^{-2} h^{-1} for hourly time steps)
G	soil heat flux density at the soil surface (MJ m^{-2} d^{-1} for daily time steps or MJ m^{-2} h^{-1} for hourly time steps)
T	mean daily or hourly air temperature at 1.5 to 2.5 m height (°C)
u_2	mean daily or hourly wind speed at 2 m height (m s^{-1})
e_s	saturation vapour pressure at 1.5 to 2.5 m height (kPa), calculated for daily time steps as the average of saturation vapour pressure at maximum and minimum air temperature
e_a	mean actual vapour pressure at 1.5 to 2.5 m height (kPa)
Δ	slope of the saturation vapour pressure-temperature curve (kPa °C^{-1})
γ	psychrometric constant (kPa °C^{-1})
C_n	numerator constant that changes with reference type and calculation time step (K mm s^3 Mg^{-1} d^{-1} or K mm s^3 Mg^{-1} h^{-1})
C_d	denominator constant that changes with reference type and calculation time step (s m^{-1}).

Units for the 0.408 coefficient are m^2 mm MJ^{-1}.

The surface runoff was calculated by using the US Soil Conservation Service (SCS-CN). The standard SCS-CN method is based on the following relationship between rainfall, *P* (mm), and runoff, *Q* (mm) (SCS, 1986; Schulze et al., 1992):

$$Q = \begin{cases} \dfrac{(P - Ia)^2}{P - Ia + S}, & P > Ia \\ 0, & P \le Ia \end{cases} \tag{2}$$

where *S* (mm) is potential maximum retention after runoff begins. *Ia* is all loss before runoff begins. It includes water retained in surface depressions, water intercepted by vegetation, evaporation, and infiltration. *Ia* is highly variable but generally is correlated with soil and land cover parameters. To remove the necessity for an independent estimation of *Ia*, a linear relationship between *Ia* and *S* was suggested by SCS (1985) as: Ia = λS, where λ is an initial abstraction ratio. The values of λ vary in the range of 0 to 0.3 and have been documented in a number of studies encompassing various geographic locations in the USA and other countries (Shrestha, 2003). Through studies of many small agricultural catchments, *Ia* was found to be approximated by empirical equations such as $Ia = 0.2S$. By removing *Ia* as an independent parameter, a combination of *S* and *P* to produce a unique runoff amount can be approximated (Hawkins et al., 2002). Substituting $Ia = 0.2S$ gives the following equation:

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \tag{3}$$

The variable S, which varies with antecedent soil moisture and other variables, can be estimated as follows:

$$S = \frac{25,400}{CN} - 254 \tag{4}$$

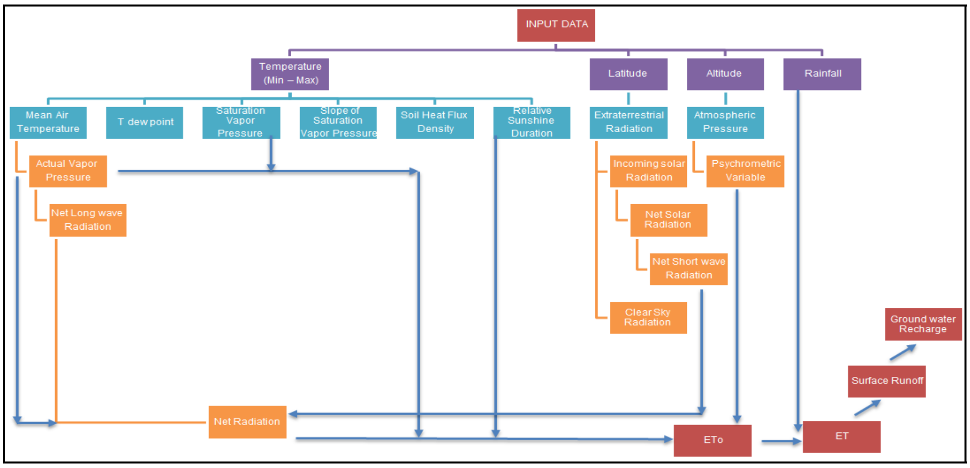
where CN is a dimensionless catchment parameter ranging from 0 to 100. A CN of 100 represents a limiting condition of a perfectly impermeable catchment with zero retention, in which all rainfall becomes runoff. A CN of zero conceptually represents the other extreme, with the catchment abstracting all rainfall and with no runoff regardless of the rainfall amount.

The spatial recharge coverage was derived by subtracting the spatial grids of precipitation, ET, and surface runoff as shown in the following simple mass balance equation:

$$P - ET - Q = Re \tag{5}$$

where P is precipitation, ET is evapotranspiration, Q is runoff and Re is groundwater recharge.

Figure 2 Methodology diagram (see online version for colours)



3 Results and discussion

3.1 Climatic parameters

Spatially-distributed input data such as temperature, humidity, sunshine hours, and precipitation across the study area were produced as a main element for computing the reference evapotranspiration. However, reaching this stage needed several parameters and indicators to be calculated individually. Twelve maps were generated for each parameter representing the monthly average data for 50 years (from January until December) and these parameters are:

- relative sunshine duration (n/N)
- atmospheric pressure (P)
- psychrometric variable (γ)
- saturation vapour pressure (e_s)
- actual vapour pressure (e_a)
- slope of the saturation vapor pressure-temperature curve (Δ)
- relative humidity (RH)
- extraterrestrial radiation (R_a)
- solar radiation (R_s)
- net solar or net short-wave radiation (R_{ns})
- net long-wave radiation (R_{nl})
- clear sky solar radiation (R_{so})
- soil heat flux density (G)
- net radiation (R_n).

Figures 3 and 4 represent the average annual precipitation and the required parameters for computing reference evapotranspiration.

Figure 3 Average annual precipitation for the 50 years (1950–2000) (see online version for colours)

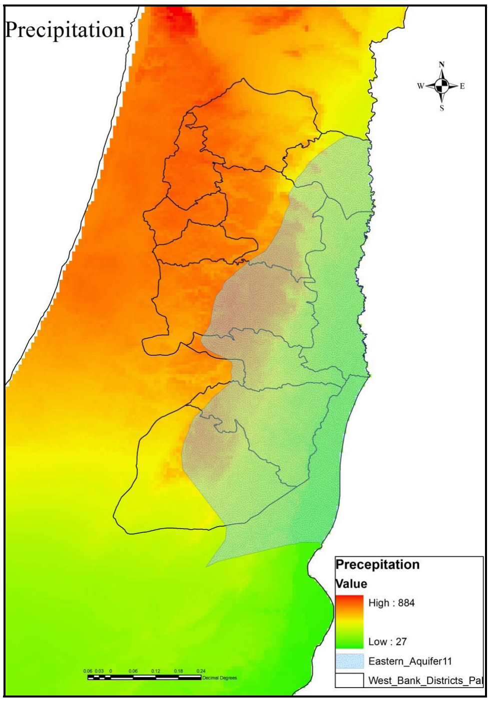


Figure 4 Main parameters for computing reference ET (June) (see online version for colours)

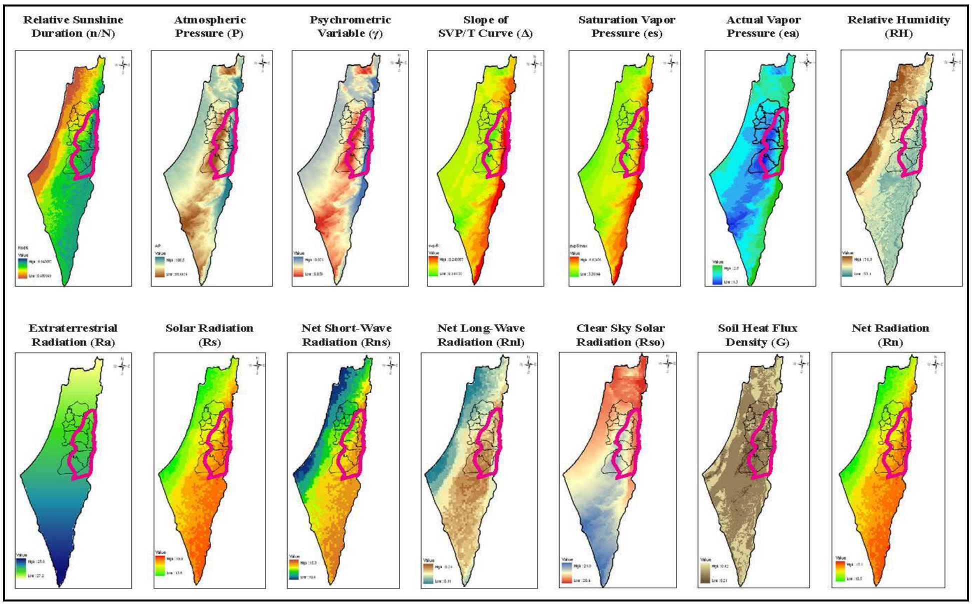
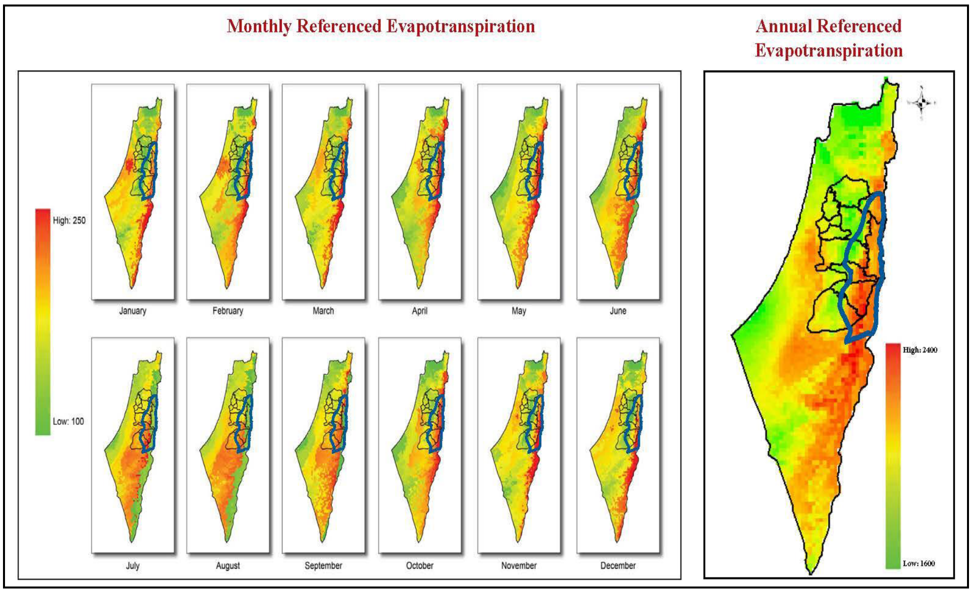


Figure 5 Monthly and annual average referenced evapotranspiration for the 50 years (see online version for colours)



3.2 Reference evapotranspiration

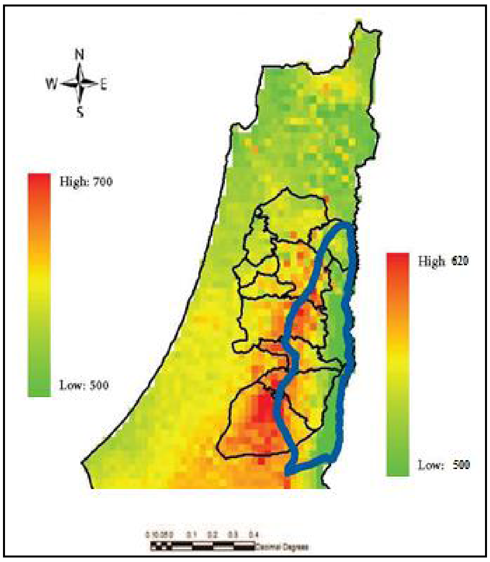
The FAO Penman-Monteith method was applied for computing the monthly average reference evapotranspiration and the average annual one [equation (1)]. As seen in

Figure 5, the reference evapotranspiration (ETo) of historic Palestine increases from west to east and from north to south, and its value vary from 1,600 mm/year to 2,400 mm/year which are comparable to prior studies such as (Sabbah, 2004) who found ETo values vary from 1,144 mm/year to 1,980 mm/year. In other studies, the Israeli meteorological services found that the ETo values range from 1,308 mm/year to 1,891 mm/year, while, the national report on the implementation of the UN Convention to combat desertification in year 2000 found an ETo values vary from 1,200 mm/year to 2,800 mm/year.

3.3 Evapotranspiration

Evapotranspiration is considered as a significant water loss from drainage basins. Types of vegetation and land use significantly affect the amount of evapotranspiration, and therefore the amount of water leaving a drainage basin. Because water transpired through leaves comes from the roots, plants with deep reaching roots can more constantly transpire water. In areas that are not irrigated, actual evapotranspiration is usually no greater than precipitation, with some buffer in time depending on the soil's ability to hold water. It will usually be less because some water will be lost due to percolation or surface runoff. The amount of evapotranspiration was varying from 500 to 700 mm/year for the historic Palestine and from 500–620 mm/year for the eastern aquifer area, as shown in Figure 6.

Figure 6 Average annual evapotranspiration for the 50 years (see online version for colours)



3.4 Surface Runoff

The results showed that the average annual surface runoff in the historic Palestine vary from 0 mm/year to 660 mm/year. However, the EAB variations were from 50 mm/year until 250 mm/year (Figure 7). The values increase from south to north and from east to west.

3.5 Groundwater recharge

The average annual ground water recharge for the period 1950–2000 was calculated by using the simplest relation [equation (5)]. The results showed that the average annual ground water recharge for the 50 years period in the study area is almost close to 200 MCM per year (Figure 8). A variation in the values from the eastern slopes till the central highlands in the West Bank and this variation is due to the variation in temperature and precipitation in the targeted areas.

Figure 7 Average annual surface runoff for the 50 years (see online version for colours)

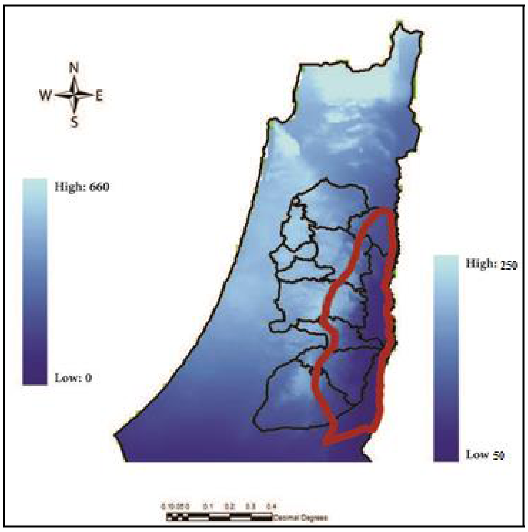
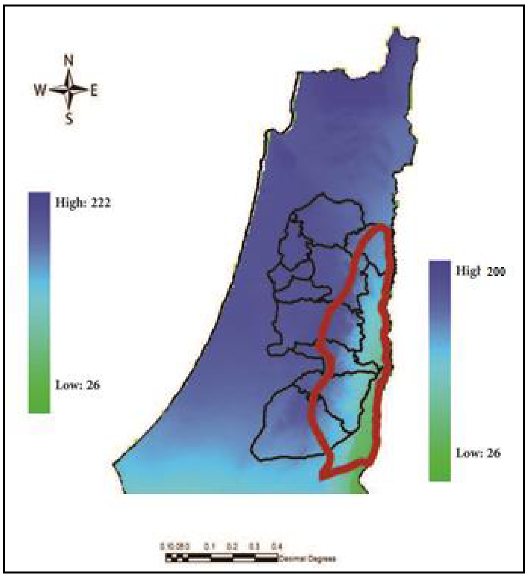


Figure 8 Average annual groundwater recharge for the 50 years (see online version for colours)



4 Conclusions

Ground water recharge estimation for the eastern aquifer is important in order to have a good understanding of the water budget in this particular basin. This helps to achieve a balance between total pumping and recharge; and a good understanding of the main factors that can affect the aquifer capacity.

Estimation of groundwater recharge at the EAB has been generated using a water balance model. Results of this study indicated that, the average ground water recharge during the study period of 50 years was equals to 200 MCM/y, however, these results are very close to the results which were from cell and numerical models conducted for the same aquifer, which show a recharge values of 211 MCM/y during the period 1976 to 1992, and a values of 174 MCM during the period 1993 to 2009.

A geographical information system environment is an effective and important tool for estimating the spatial variability of recharge. In addition, GIS facilitates the analysis of the interrelated relationships between the different explanatory parameters related to the calculation of the ground water recharge.

The water balance model adaptation for the interpolated climate surfaces at 1 km^2 spatial resolution was suitable for the chosen study area, and this was obvious from the results obtained especially for the reference and the actual evapotranspiration, surface runoff, and recharge. However, it should be mentioned that further research should be carried out to increase the confidence of the resulted values.

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