# Estimation of Water Balance Components in the Gaza Strip with GIS Based WetSpass Model

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**Abstract**
This study was initiated to estimate the water balance components in the Gaza Strip for the year 2013 using the WetSpass spatially distributed water balance model. Relevant input data for the model is prepared in the form of digital maps using GIS tools such as rainfall, air temperature, wind speed, potential evapotranspiration, soil, water depth, Topography, slope and land-use. The model produces digital maps of long-term average annual surface runoff, evapotranspiration and groundwater recharge. Results of the model show that 77% of the precipitation in the Gaza Strip is lost through evapotranspiration, 11% becomes surface runoff and 12% recharges the groundwater system. Analysis of the simulated results shows that WetSpass model is good enough to simulate the hydrological water balance components of the study area.
**Keywords:** Water balance, WetSpass model, GIS

## 1. Introduction

The Gaza Strip is located on the south-eastern coast of the Mediterranean Sea, between longitudes 34° 2” and 34° 25” east, and latitudes 31° 16” and 31° 45” north. Its area is about 365 km$^2$ and its length is approximately 45 km along the coast line, it consists of five governorates. The location map of the Gaza Strip is shown in Figure 1. Gaza Strip is considered as one of the most densely populated areas all over the world. The population characteristics are strongly influenced by political developments, which have played a significant role in its growth and distribution over the Gaza Strip. The total population is around 1.8 million and the natural rate of population growth in the Gaza Strip is estimated at 3.37% per year according to Palestinian Central Bureau of Statistics (PCBS, 2013). Gaza's topography is characterized by elongated ridges and depressions, dry streambeds and shifting sand dunes. The ridges and depressions generally extend NE–SW direction, parallel to the coastline (Bartov *et al.* 1981). Ridges are narrow and consist primarily of Pleistocene-Holocen sandstone (locally named as Kurkar) alternated with red brown layer locally named as Hamra. In the south, these features tend to be covered by sand dunes (Anan & Zaineldeen, 2008). The Kurkar Group has a Pliocene-Pleistocene age and consists of marine and continental deposits (Bartov *et al.* 1981; Frechen *et al.* 2004; Al-Agha & El-Nakhal, 2004; Galili *et al*. 2007; Ubeid, 2010).

The soil in the Gaza Strip is composed mainly of three types, sands, clay and loess. The sandy soil is found along the coastline extending from south to outside the northern border of the Strip, at the form of sand dunes. The thickness of sand fluctuates from two meters to about 50 meters due to the hilly shape of the dunes. Clay soil is found in the north eastern part of the Gaza Strip. Loess soil is found around Wadis, where the approximate thickness reaches about 25 m to 30 m (Melloul & Collin, 1994, Wieder & Gvirtzman, 1999).

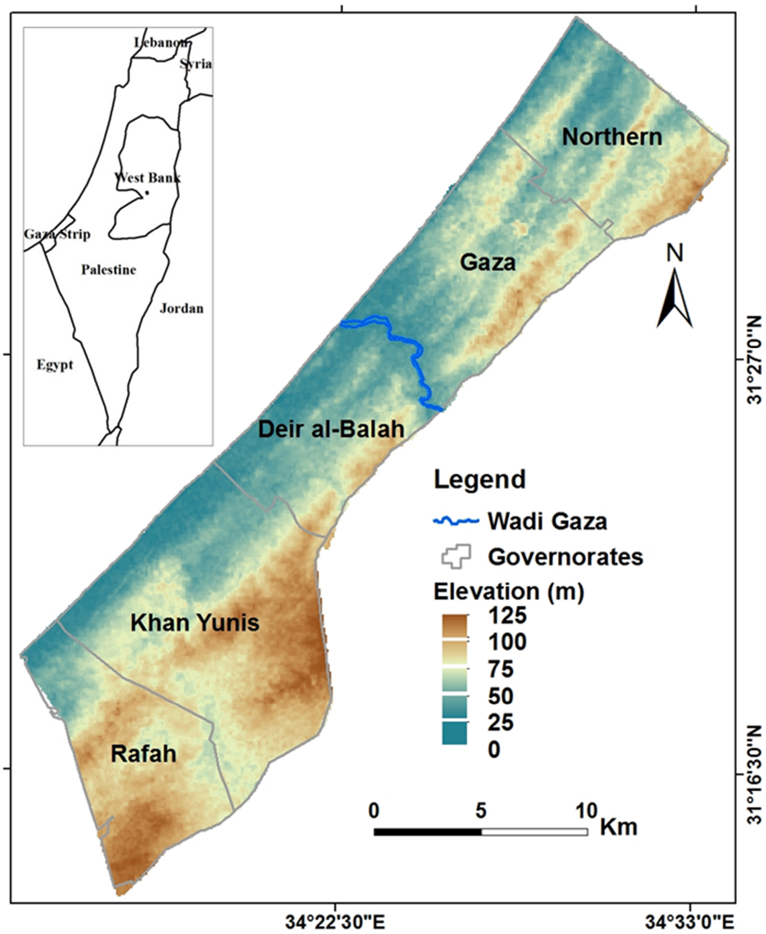


Figure 1. Location map of the Gaza Strip with elevation (data source PWA)

Temperature in the Gaza Strip gradually changes throughout the year. It reaches its maximum in August (summer) and its minimum in January (winter) (Aish *et al.* 2010). The average monthly temperature is 13.1 C° for January and the average monthly temperature is 27.2 C° for August. Wind speed reaches its maximum value at noon period and decreases during night. During the winter, most of the winds blow from the Southwest and in summer, strong winds blow regularly at certain hours come from the Northwest direction. The meteorological data such as, temperature, , humidity, wind speed and sunshine hours and solar radiation were collected from Palestinian Water Authority in the Gaza Strip shown in Table 1.

The winter in the Gaza Strip is the rainy season, which stretches from October up to March. Rainfall is the main source of recharge for groundwater. The rainfall is gradually decreases from the north to the south. There are 12 measuring stations with daily data collected from Palestinian Water Authority (PWA). The areal distribution of the rainfall in the meteorological stations for the year 2013 is shown in Figure 2. The values range from 353 mm/year in the north to 193 mm/year in the south with mean value is 268 mm/year.

Table 1. Average monthly meteorological data for the year 2013 in the Gaza Strip

| Month | Temperature $C^0$ | Humidity % | Wind speed Km/d | Sunshine Hrs/d | Solar Radiation $MJ/m^2/d$ |
|---|---|---|---|---|---|
| January | 13.1 | 64.2 | 282.6 | 4.7 | 9.8 |
| February | 13.4 | 66.4 | 277.2 | 6.1 | 13.3 |
| March | 17.8 | 68.1 | 263.4 | 7.5 | 17.8 |
| April | 19.3 | 67.1 | 251.6 | 8.2 | 20.9 |
| May | 24.1 | 72.3 | 232.8 | 9.7 | 24.4 |
| June | 25.4 | 77.5 | 238.1 | 10.4 | 24.8 |
| July | 26.5 | 74.7 | 235.2 | 10.9 | 25.6 |
| August | 27.2 | 72.2 | 240.4 | 10.5 | 24.5 |
| September | 25.6 | 68.1 | 250.3 | 9.4 | 21.3 |
| October | 21.3 | 67.3 | 257.2 | 8.3 | 16.7 |
| November | 19.6 | 65.1 | 260.1 | 5.9 | 11.6 |
| December | 13.5 | 62.6 | 262.5 | 4.3 | 8.5 |

The coastal aquifer of the Gaza strip consists of the Pleistocene age Kurkar group. The Kurkar group consists of marine and aeolian calcareous sandstone (Kurkar), reddish silty sandstone (Hamra), silts, clays, unconsolidated sands and conglomerates. The Kurkar group consists of complex sequence of coastal, near-shore and marine sediments (Anan, 2010).

The layered stratigraphy of the Kurkar Group within the Gaza Strip subdivides the coastal aquifer into four separate sub-aquifers near the coast. Further east, the marine clays pinch out and the coastal aquifer can be regarded as one hydrogeological unit. The upper sub-aquifer "A" is unconfined, whereas sub-aquifers "B1, B2, and C" become increasingly confined towards the sea as shown in Figure 3. The thickness of the entire coastal aquifer sequence at the coastline is on average about 120 m. At the eastern Gaza border, the saturated thickness is about 60 m in the north, and only 5-10 m in the south near Rafah (Melloul & Collin, 1994). The Gaza aquifer is a major component of the water resources in the area. It is naturally recharged by precipitation and additional recharge occurs by irrigation return flow. The consumption has increased substantially over the past years; the groundwater use is about 140 to 145 $Mm^3$/year, the agricultural use about 85 to 90 $Mm^3$/year, domestic and industrial consumption about 55 to 60 $Mm^3$/year (Al-Yaqubi *et al*. 2007).

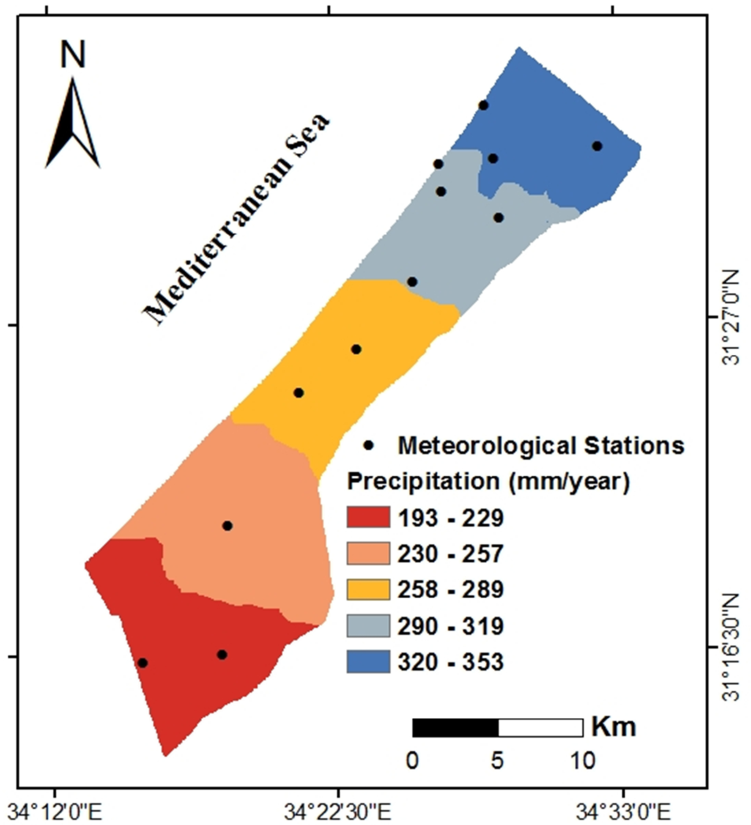


Figure 2. The spatial average annual rainfall distribution for Gaza strip (data source: PWA)

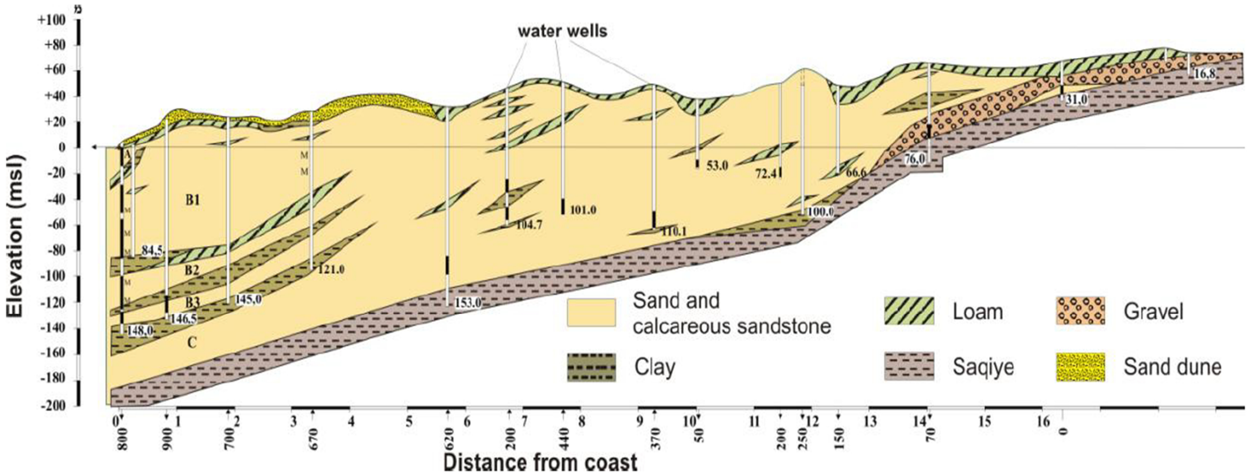


Figure 3.Typical hydrogeological cross section of the Gaza coastal aquifer (Weinberger,G., *et. al*. 2012)

The Groundwater level in the Gaza coastal aquifer declines in areas where abstraction is the greatest and in highly populated areas according to the data collected from Palestinian Water Authority (PWA). The groundwater level ranges between 18.2 m below sea level to about 11.8 m above sea level. The most water level depletion zones are located in the northern governorate in Jabalia refugee camp and in the Rafah governorate due to high groundwater production rates as shown in Figure 4. In the middle governorate, depletion water level is relatively low where the saturated aquifer thickness in this area is characterized by low saturated thickness and poor water quality, high chloride concentration, so the groundwater production rates are very low for both domestic and agriculture use.

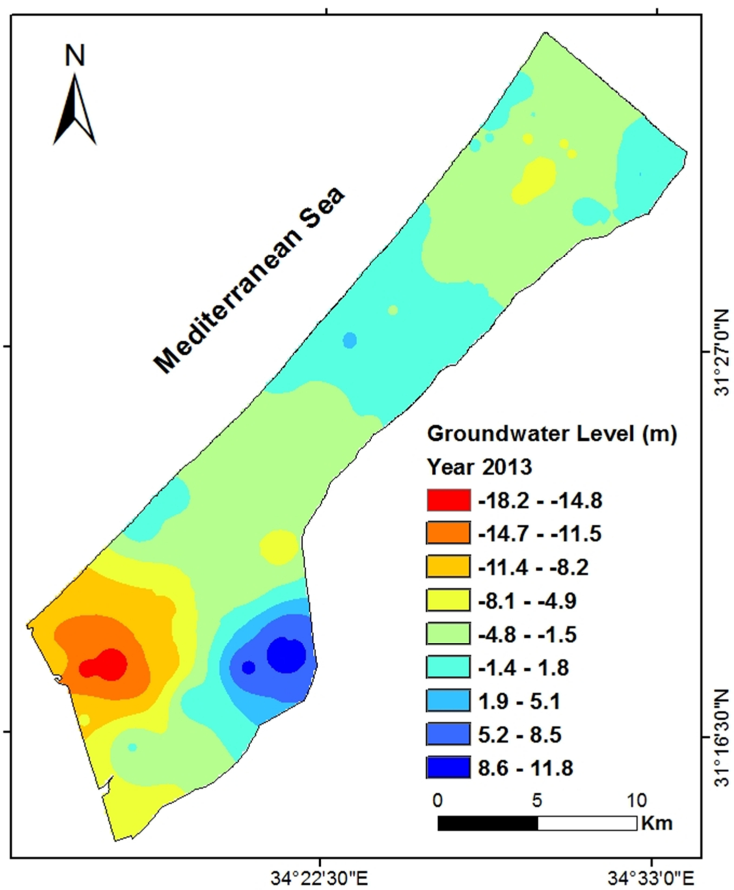


Figure 4: Groundwater level in the Gaza Strip for year 2013 (data source PWA)

## 2. Methodology

A physical based quasi-steady state time independent WetSpass model has been used to estimate the long-term average spatially varying water balance components. The model is originally developed mainly to compute the long term average spatially distributed groundwater recharge, it's also simulates runoff, evapotranspiration, interception, transpiration and soil evaporation. The model gives various hydrologic outputs on yearly and seasonal (summer and winter) basis (Batelaan & DeSmedt, 2001, 2007). All input maps for the model are prepared by use of grid GIS technology and digital data such as precipitation, land-use, temperature, wind speed, groundwater depth, soil, slop and topography.

The methodology can be schematized as follows (for details refer to the manual available at http://www.vub.ac.be/WetSpa/introduction_wetspass.htm). The model is based on the long-term average seasonal water balance equation:

P = S + ET + R, (1)

where P is precipitation [L], S is surface runoff [L], ET is evapotranspiration [L], and R is groundwater recharge [L]. Surface runoff is determined as:

S = f1 (LV, ST, SA) x Pn, (2)

where f1(.) is a runoff factor depending upon land-use and vegetation characteristics (LV), soil texture (ST) and slope angle (SA), and Pn is the net precipitation [L], i.e. precipitation minus interception, the latter being also a function of LV. Evapotranspiration ET is determined from soil evaporation and transpiration by the vegetation, as:

ET = f2 (LV, ST) x Ep, (3)

where f2(.) is an evapotranspiration factor depending upon land-use and vegetation characteristics (LV) and soil texture (ST), and Ep is the potential evaporation of open water [L] (Gebreyohannes., *et.al.* 2013). The groundwater recharge is determined as the closing term in Eq. (1). In the equations above, all variables and parameters are digital maps and the calculations and derivations are obtained by means of GIS tools.

## 3. Results and discussion

**Evapotranspiration:** Evapotranspiration is a determining factor in the water balance. WetSpass approach aims at describing the evapotranspiration process in a physically based way. The model calculates the total actual evapotranspiration as a sum of the evaporation of water, intercepted by vegetation, the transpiration of the vegetative cover and the evaporation from the bare soil between the vegetation (Abu-Saleem, A., 2010). WetSpass simulated the average annual evapotranspiration of the Gaza Strip ranged from100 to 300 mm/year as the minimum and maximum values respectively with mean value 206 mm/year and standard deviation 45 mm/year which is a sum of the transpiration, interception and soil evaporation as shown in Figure 5. The simulated average annual transpiration ranged 0 to 132 mm/year as the minimum and maximum values respectively with mean value is 49 mm/year and standard deviation is 34 mm/year. The simulated average annual interception ranged 0 to 17 mm/year as the minimum and maximum values respectively with mean value 6 mm/year and standard deviation 6 mm/year. The simulated average annual soil evaporation ranged from 0 to 268 mm/year as the minimum and maximum values respectively with mean value 151 mm/year and standard deviation 76 mm/year. The evapotranspiration average accounts for about 77% of the total rainfall. The result shows a fluctuation in evapotranspiration that correlates with vegetation cover and annual rainfall. The Gaza city and refugee camps are mostly urban areas with a minimum vegetation.

**Surface runoff:** The WetSpass model uses the runoff coefficient method for the estimation of surface runoff. The surface runoff coefficient is a function of vegetation type, soil texture and slope (Al Kuisi, M., & El-Naqa, A., 2013). The simulated average annual surface runoff of the Gaza Strip ranged 0 to 184 mm/year as the minimum and maximum values respectively with mean value 29 mm/year and standard deviation 50 mm/year as shown in Figure 6. Most of the Gaza strip areas have very little surface runoff. The values are generally less than 100 mm/year except for the urban area such as Gaza city and refugee camps which have the maximum runoff value.

**Groundwater recharge:** Recharge is the entry of water into the saturated zone of water made available at the water table surface, together with the associated flow away from the water table within the saturated zone (Freeze, R.A., & Cherry, J.A., 1979). Recharge is an important factor in evaluating groundwater resources but is difficult to quantify (Alley *et al.* 2002). The WetSpass model determines the long-term average spatially distributed recharge as a spatial variable dependent on the soil texture, land-use, slope, meteorological conditions etc, this is primarily to take into account the influence of the spatial variability of the land surface on the groundwater system (Batelaan & Woldeamlak, 2004).

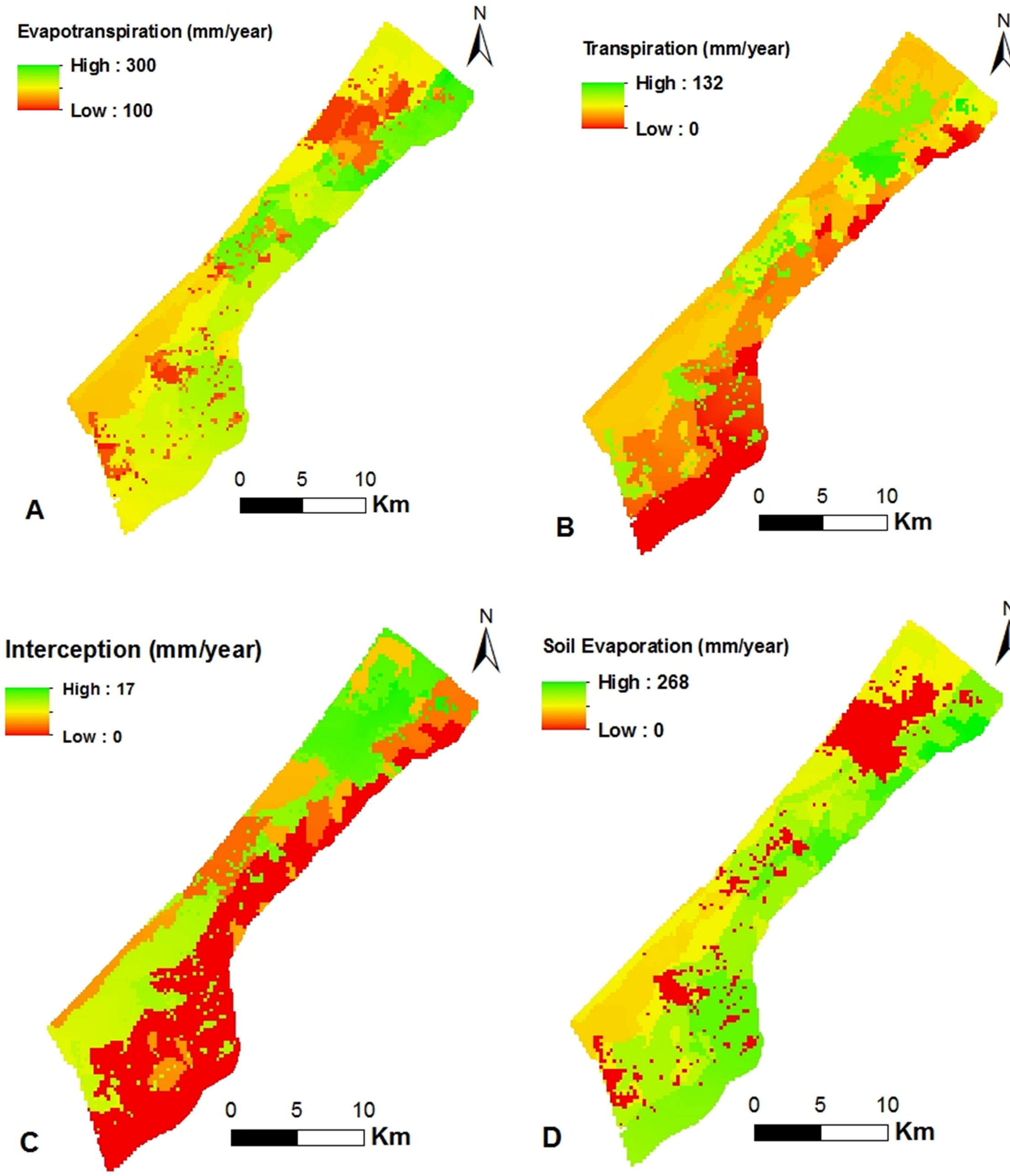


Figure 5, simulated evapotranspiration (A), transpiration (B), interception (C) and soil evaporation (D) with the WetSpass model for the Gaza Strip

 

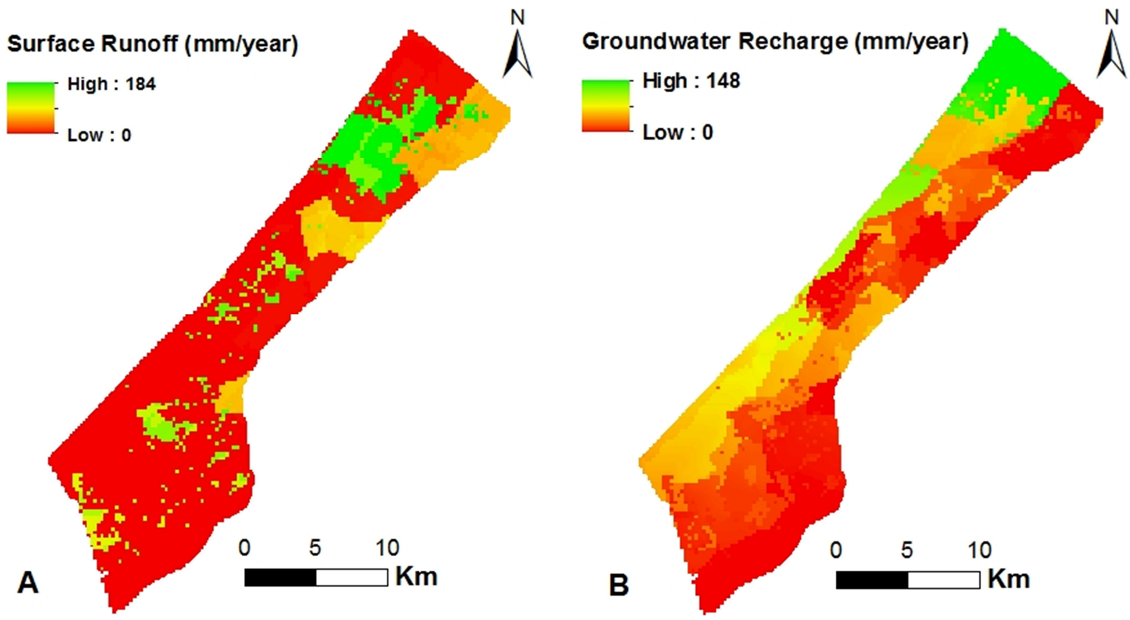


Figure 6. Simulated surface runoff (A) and groundwater recharge (B) with the WetSpass model for the Gaza Strip

The simulated average annual groundwater recharge of the Gaza Strip ranged from 0 mm/year to 148 mm/year as the minimum and maximum values respectively with mean value 33 mm/year and standard deviation 39 mm/year as shown in Figure 6. The variability of groundwater recharge is influenced by precipitation and runoff. The northern governorate appears to be a high groundwater recharge area. In Rafah governorate, it appears to be a low groundwater recharge area. Higher values are simulated for regions with low topography and permeable soils such northern coastal zones. Also the amount of infiltration into the groundwater depends on vegetation cover, slop, soil composition, the presence or absence of clay lenses and depth to water table.

**Annual water balance:** Water balance is essentially a representation of the net result of the inflow and outflow of water. Precipitation is the most significant inflow component. The most important outflow components of water balance are surface runoff, evapotranspiration and groundwater recharge. An area of the world would have water surplus if it receives more rainfall than the amount that it loses mainly through the process of evapotranspiration. Similarly, regions with water deficit would get fewer rains than the amount that they lost through evapotranspiration. Meanwhile, those which neither get surpluses nor deficits will experience some sort of water balance. The overall summary of the water balance component of the Gaza Strip is given in Table 2. Only a small fraction of the annual precipitation remains to recharge the groundwater reservoirs, the rest leaves the basin mainly through evapotranspiration and to a lesser extent by surface runoff. The small error in the water balance comes from the assumption that water bodies can evaporate unlimitedly at PET rate.

Table 2: Annual water balance of the Gaza Strip predicted with the WetSpass model

| Water balance component | Annual values (mm/year) | | | |
|---|---|---|---|---|
| | Min. | Max. | Mean | St. dev. |
| Precipitation (p) | 193 | 353 | 268 | 42 |
| Evapotranspiration (ET) | 100 | 300 | 206 | 45 |
| Surface runoff (S) | 0 | 184 | 29 | 50 |
| Groundwater recharge (R) | 0 | 148 | 33 | 39 |
| Difference | P – ET – S – R = 0 | | | |

Note: Evapotranspiration includes transpiration, interception and soil evaporation

## 4. Conclusions

The WetSpass model was applied to simulate the water balance components in the Gaza Strip. Specific input data were prepared in the form of digital maps using GIS tools. Parameter attribute tables in the WetSpass model were adjusted to the conditions prevailing in the study area. Results of the model indicate that evapotranspiration ranges from 100 to 300 mm with a mean of 206 mm which constitutes 77% of the total annual precipitation and is mainly influenced by precipitation and potential evapotranspiration and to some extent by soil type. Annual surface runoff ranges from 0 to 184 mm with a mean of 29 mm, which amounts to 11% of the total precipitation and occurs mainly during the winter season. Bare land, agriculture and urban land-uses on sandy clay soils produce the highest surface runoff in the area. Annual groundwater recharge ranges from 0 to 148 mm with a mean of 33 mm, which constitutes only 12% of the annual precipitation. Sandy and Sandy loam on bare land and agriculture produce the highest groundwater recharge in the Gaza Strip.

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