Estimation of Spatial Groundwater Recharge and Surface Runoff in the Gaza Coastal Aquifer Using GIS-Based WetSpass Model

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Abstract
Assessment of the spatial distribution of water recharge and surface runoff is essential for water resource management and planning. This research evaluates spatial distributions of groundwater recharge, surface water flow, and evapo-transpiration for the Gaza coastal aquifer, Palestine in 2020 using the WetSpass model integrated with GIS. The ArcGIS tool is implemented to create grid maps of the WetSpass model data, such as temperature, rainfall, wind velocity, potential evapo-transpiration, soil map, land use, topography, gradient, and water depth. The model generates computerized maps of yearly groundwater recharge, surface water flow, and evapo-transpiration. The WetSpass model's calibration procedures were implemented by manually altering or changing the model parameters already included in the WetSpass model within a predetermined range of values. The simulated results revealed that the average yearly groundwater recharge was 42 mm/year, surface runoff was 38 mm/year and actual evapotranspiration was 268 mm/year. The research findings would help local stakeholders and decision-makers manage groundwater resources in a sustainable and effective manner.

Keywords: Water balance, GIS, Spatial Analysis, WetSpass

1. Introduction

The Gaza Strip (Palestine) is located on the southern end of the Mediterranean Sea, between latitudes 31° 16 and 31° 45 north and longitudes 34° 2 and 34° 25 east. Its coastal zone is 42 km long and ranges in width between 6 and 12 km, encompassing an area of 365 km^2 [1]. Figure 1 illustrates a location map of the Gaza Strip. Elongated ridges and depressions characterize the topography. It extends NE–SW direction [2]. Ridges are composed of sandstone locally named as Kurkar [3]. The Kurkar deposits include silt, clay, and conglomerates [4]. The coastal aquifers are separated into four sub-aquifers close to the coastline. As depicted in Figure 2, the top sub-aquifer "A" is unconfined, while sub-aquifers "B1, B2, and C" are semi confined. Gaza coastal aquifer's average thickness is about 120 meters at the coastline. The thickness along the northern Gaza border is about 5 to 10 meters and in the south is around 60 meters [5]. Rainfall naturally recharges the Gaza coastal aquifer, and irrigation return flow provides additional recharge. The water level is around 60 meters below the ground in the east, whereas in the west, it is just a few meters deep along the coast [6].

The soil is mainly composed of sands, clay, and loess. The sand is founded in the form of dunes covering the coastline from the north to the southern border of the Gaza Sector. Due to the dunes' shape, the thickness ranges from two to about 50 meters. Clay is found in the north-eastern of Gaza. Wadis are surrounded by loess soil of thickness ranging from 25 to 30 meters [7]. Temperature is affected by geographical conditions, altitude, marine exposure, etc. Over the year, the monthly mean temperature typically varies in the Gaza Strip as the highest temperature is recorded in August (summer) while the lowest temperature is recorded in January (winter) [9]. For the year 2020, the temperature average varied from 15.7 degrees Celsius in January and 27.9 degrees Celsius in August. The wind velocity peaks at noon and gradually decreases throughout the night. Almost all the winds originate in the southwest during the winter, and the strong northwest wind blows in summer [10]. The average monthly minimum wind velocity is 3.2 m/s in October and the average monthly maximum wind velocity is 5.6 m/s in February.

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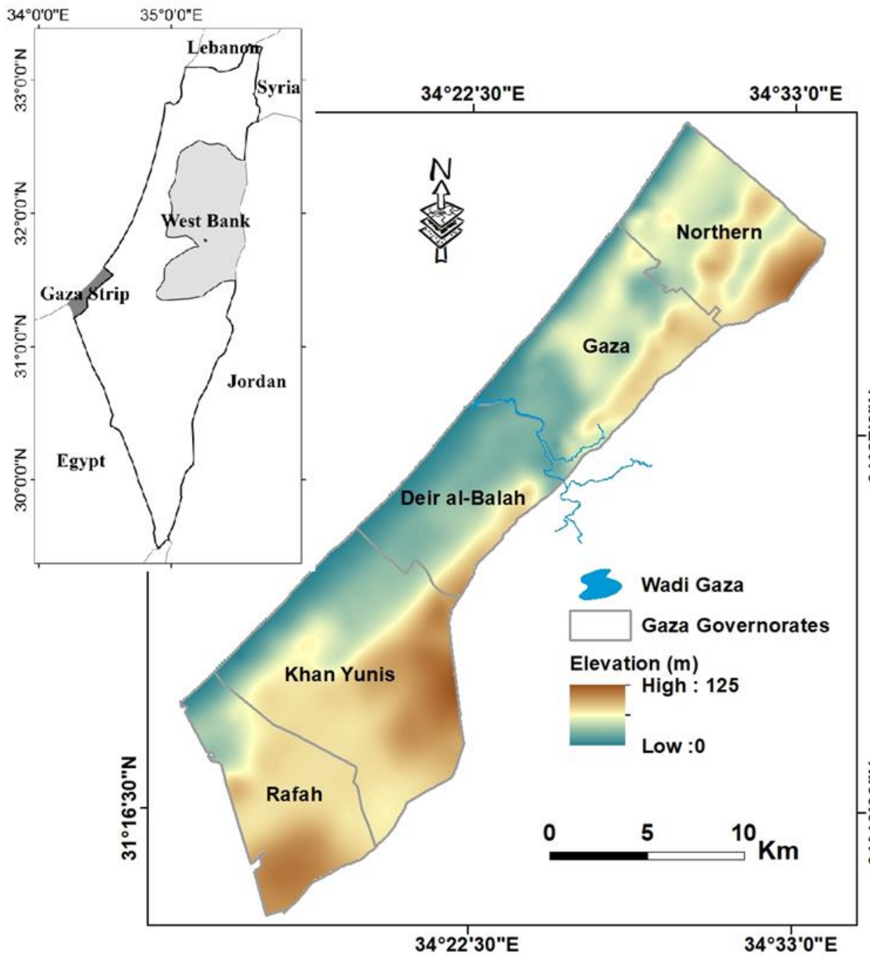

Figure 1: Map of the Gaza Strip's location and topography (Data source: PWA)

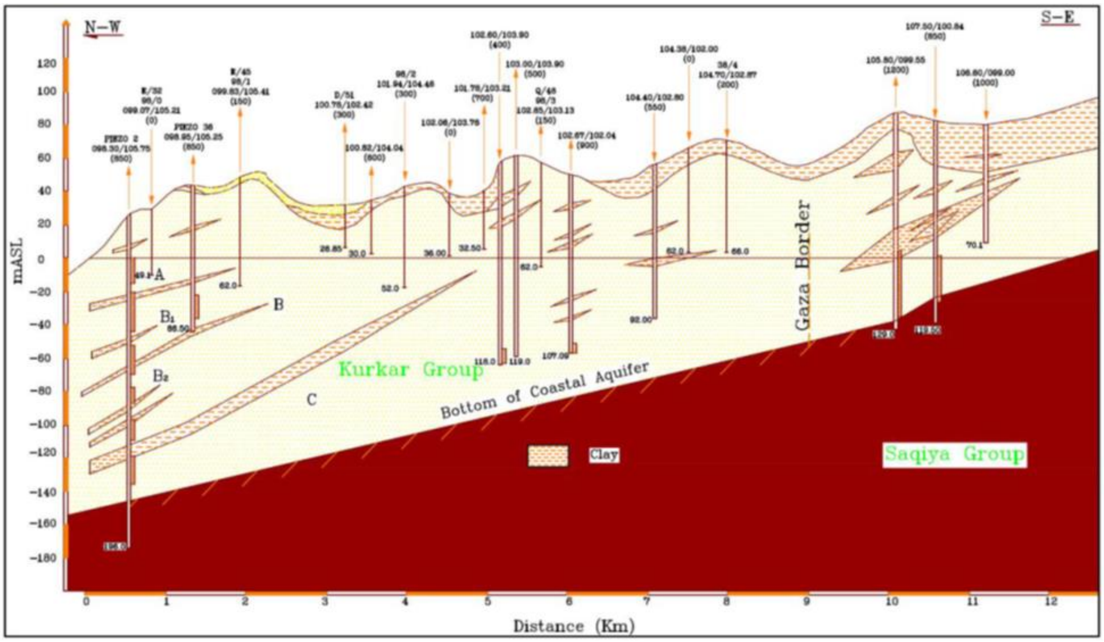

Figure 2: Hydrogeological cross section of the Gaza coastal aquifer [8]

The average monthly minimum humidity is 65.9 % for November and the average monthly maximum humidity is 85.6 % for July. The average monthly minimum sunshine hours is 4.4 for December and the average monthly maximum sunshine hours is 11.1 for July. The ArcGIS World Geocoding Service website was used to collect climatological information such as humidity, temperature, wind velocity, solar radiation, and sunshine hours, as illustrated in Table 1. Rainfall is considered the primary water source in the Gaza Sector; the most rainfall is observed in the winter, especially between October and March, with a significant annual variation. The rainfall increases from the south to the north [11]. The Palestinian Water Authority (PWA) and Ministry of Agriculture (MoA) gather daily data from 12 measuring rain gauge stations. Figure 3 shows the areal rainfall intensity distribution for the year 2020. The values vary from 579 millimeters annually in the northern area to 225 millimeters annually in the southern area, with an annual average is 348 millimeters.

2. Materials and Methods

2.1 Hydrological Modeling using WetSpass Model

Estimating groundwater recharge and surface runoff is essential for managing both surface and groundwater resources. Calculating groundwater recharge is difficult and complex because it depends on a variety of elements, including terrain, soil texture, land use and cover, groundwater depth, meteorological conditions, and other hydrologic variables. The WetSpass model was created as a physically-based approach to calculate the actual average evapotranspiration, groundwater recharge, and surface runoff [12] and [13]. A WetSpass Model is used in the current study to calculate the geographical distribution of water balance components. The model considers each raster cell's spatial distribution of topography, soil texture, slope, and climatic parameters. The WetSpass approach describes an area or basin as a regular grid cell arrangement. The water balance considerations of each locality are achieved by the vegetated, open-water, bare soil, while impervious fractions per grid pixel are calculated by the following equations [14].

$$ET_m = a_b E_b + a_v ET_v + a_o E_o + a_i E_i \quad \text{Equation 1}$$

$$S_m = a_b S_b + a_v S_v + a_o S_o + a_i S_i \quad \text{Equation 2}$$

$$R_m = a_b R_b + a_v R_v + a_o R_o + a_i R_i \quad \text{Equation 3}$$

Where ET_m is the total evapotranspiration (mm), S_m the surface runoff (mm), R_m is groundwater recharge (mm), each having (b) bare soil, (v) vegetated, (o) open water and (i) impermeable region component. The terms a_b, a_v, a_o and a_i are the fraction region of bare soil, vegetated, open water and impervious region, respectively [15]. A detailed description of the WetSpass Model can be found in the manual available on the website of the Vrije University of Brussels, Belgium (VUB).

Table 1: Average monthly weather information for the Gaza Strip in year 2020

Month	Temperature C^0	Humidity %	Wind speed m/s	Sunshine Hrs/d	Solar Radiation W/m^2
January	15.7	70.0	5.5	4.5	45.7
February	15.5	73.6	5.6	5.2	65.4
March	16.5	78.3	4.8	6.8	89.2
April	17.9	81.4	4.2	7.9	119.0
May	21.2	77.5	4.4	10.2	142.1
June	23.0	84.9	4.6	10.8	151.3
July	26.3	85.6	4.1	11.1	146.2
August	27.9	82.8	4.4	10.6	132.4
September	27.5	80.1	3.9	9.4	113.7
October	26.0	71.9	3.2	8.6	88.7
November	22.1	65.9	3.7	5.9	52.6
December	19.6	67.3	4.0	4.4	46.3
Average	21.6	76.6	4.4	8.0	104.3

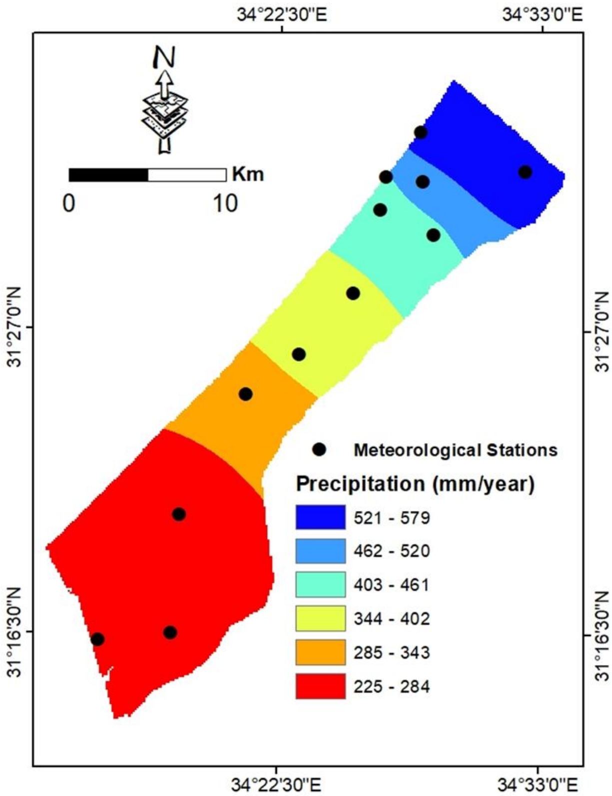

Figure 3: The Gaza Strip's spatial distribution average annual rainfall in the year 2020 (Data source: MoA and PWA)

Table 2: Input data and sources for WetSpass Model of the Gaza Coastal Aquifer

Input Parameter	Sources	Resolution
Topography and slope	PWA and own processing	50 x 50 m
Temperature	ArcGIS Word Geocoding Service and own processing	50 x 50 m
Wind speed	ArcGIS Word Geocoding Service and own processing	50 x 50 m
Precipitation	MoA and own processing	50 x 50 m
Land use	MoA and own processing	50 x 50 m
Soil type	MoA and own processing	50 x 50 m
Groundwater Depth	PWA and own processing	50 x 50 m
Table land use parameters	WetSpass Model	
Table runoff coefficient	WetSpass Model	
Table soil parameter	WetSpass Model	

2.2 WetSpass Model Data Input

The model requires two different kinds of input data: GIS grid maps and parameter tables. GIS grid maps comprise climatological data (rainfall, potential evapotranspiration, average temperature, and wind speed), groundwater depth, slope, topography, soil type, and land use. The input data were set up as a raster map using the ESRI ASCII grid format with a cell size of 50 m × 50 m. The input parameters for the WetSpass Model are shown in Table 2.

3. Results and Discussion

The simulation results are organized by digital images of the spatial distribution of yearly mean values of groundwater recharge, surface runoff, and actual evapotranspiration for the year 2020. These maps are raster-shaped, and each pixel displays the size of the corresponding water balance component, represented as layer thickness in millimeters.

3.1 Groundwater Recharge

Groundwater recharge is important for evaluating groundwater resources, although it is difficult to estimate [16]. The WetSpass model determines the annual average areal recharge distributed as an area variable based on the terrain, slope, soil, land use, climate, etc. this is mainly to consider how the groundwater system is impacted by the geographical variability of the land surface [17]. The simulated annual mean of groundwater recharge of varied from 0 millimeters per year (minimum value) to 192 millimeters per year (maximum value), with a mean of 42 millimeters per year and a standard deviation of 40 millimeters per year as illustrated in Figure 4. Precipitation and runoff have an impact on the variability of groundwater recharge. It indicates that there is significant groundwater recharge in the northern governorate. It appears that there is little groundwater recharge in the Rafah governorate. Higher groundwater recharge values were simulated for areas with lower topography and porous soil, like the coastal regions in the north. Infiltration into the groundwater is further influenced by plant cover, slope, soil type, the existence or lack of clay lenses, and water table depth.

3.2 Surface Water Runoff

The WetSpass model uses the runoff coefficient technique to calculate surface runoff. The coefficient depends on the vegetation cover type, slope gradient, and soil composition [18]. Surface runoff in the Gaza coastal aquifer varies geographically with topography and other catchment characteristics. The simulated annual surface runoff varied from 0 millimeters per year (minimum value) to 240 millimeters per year (maximum value) with a mean of 38 millimeters per year and a standard deviation of 48 millimeters per year as illustrated in Figure 5. Surface runoff is relatively low in most of the Gaza Strip locations. All values are below 92 millimeters per year, except for urban areas like the city of Gaza and the camps of refugees, which have the highest runoff values.

3.3 Actual Evapotranspiration

The model estimates the overall real evapotranspiration as the result of the transpiration of the vegetative cover, the evaporation of water, and the evaporation from bare soil between plants [19].

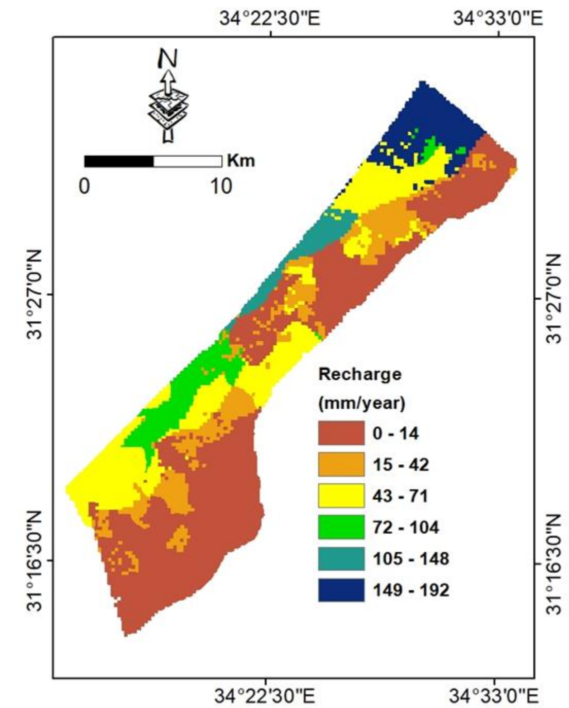

Figure 4: Simulated groundwater recharge with WetSpass model

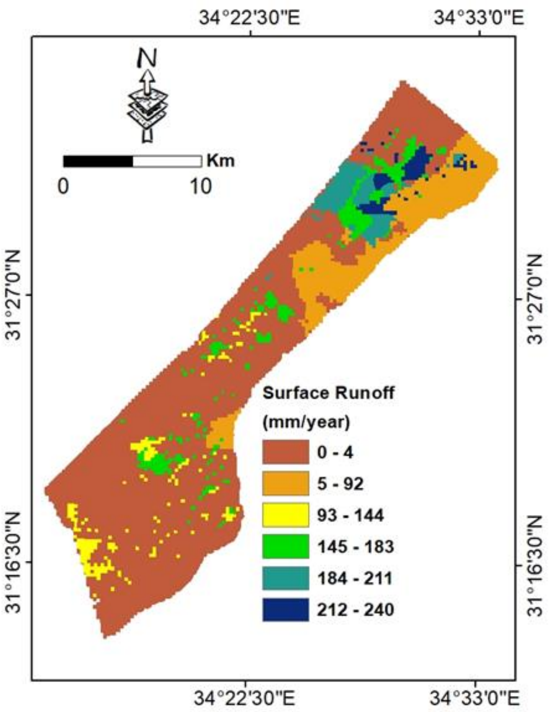

Figure 5: Simulated surface runoff with WetSpass model

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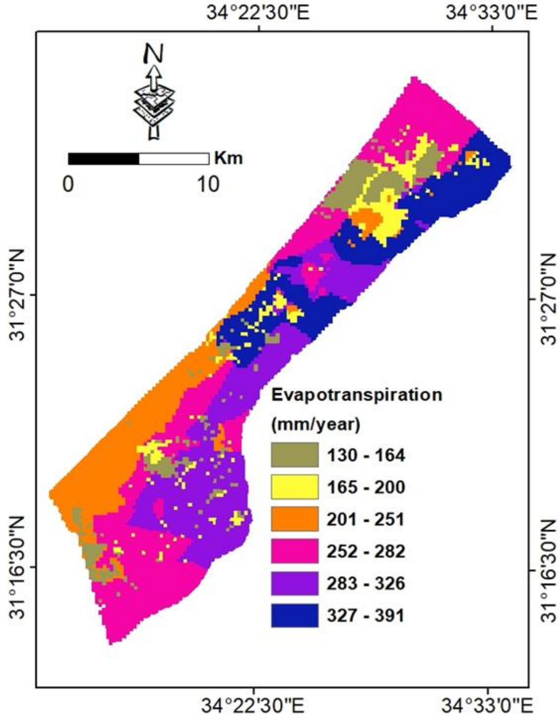

Figure 6: Simulated actual evapotranspiration with WetSpass model

Table 3: Comparison of the Gaza coastal aquifer's water balance component

Water Balance Component	Annual values (mm/year)								
	Year 2020			Year 2013			Year 1972 - 2002		
	Min.	Max.	Mean	Min.	Max.	Mean	Min.	Max.	Mean
Precipitation (p)	225	579	348	193	353	268	211	417	318
Groundwater recharge (R)	0	192	42	0	148	33	0	266	125
Surface runoff (S)	0	240	38	0	184	29	0	216	35
Evapotranspiration (ET)	130	391	268	100	300	206	60	222	158
Difference	P – ET – S – R = 0								

The simulated annual evapotranspiration of Gaza's coastal aquifer ranges from 130 millimeters per year (minimum value) to 391 millimeters per year (maximum value) as the minimum with an average value of 268 millimeters per year and a standard deviation of 46 millimeters per year. The simulated annual transpiration extended from 0 millimeters per year (minimum value) to 172 millimeters per year (maximum value) with an average value of 64 millimeters per year. The annual interception varied from 0 millimeters per year (minimum value) to 22 millimeters per year (maximum value) with an average value of 8 millimeters per year. The soil evaporation yearly average varied from 0 millimeters per year (minimum value) to 249 millimeters per year (maximum value) with an average value of 196 millimeters per year as illustrated in Figure 7. The average of evapotranspiration is about 77 % of the annual average of rainfall. A variation in evapotranspiration that correlates with rainfall and vegetation cover can be noticed in the results. The city of Gaza and camps of refugees are primarily built-up areas with limited vegetation cover.

3.4 Comparison of Water Balance for the Gaza Coastal Aquifer with Earlier Studies

Water balance mainly describes the net impact of water inflow and outflow. The most crucial input component is precipitation. Surface runoff, evapotranspiration, and groundwater discharge are water balances' three most significant outflow elements

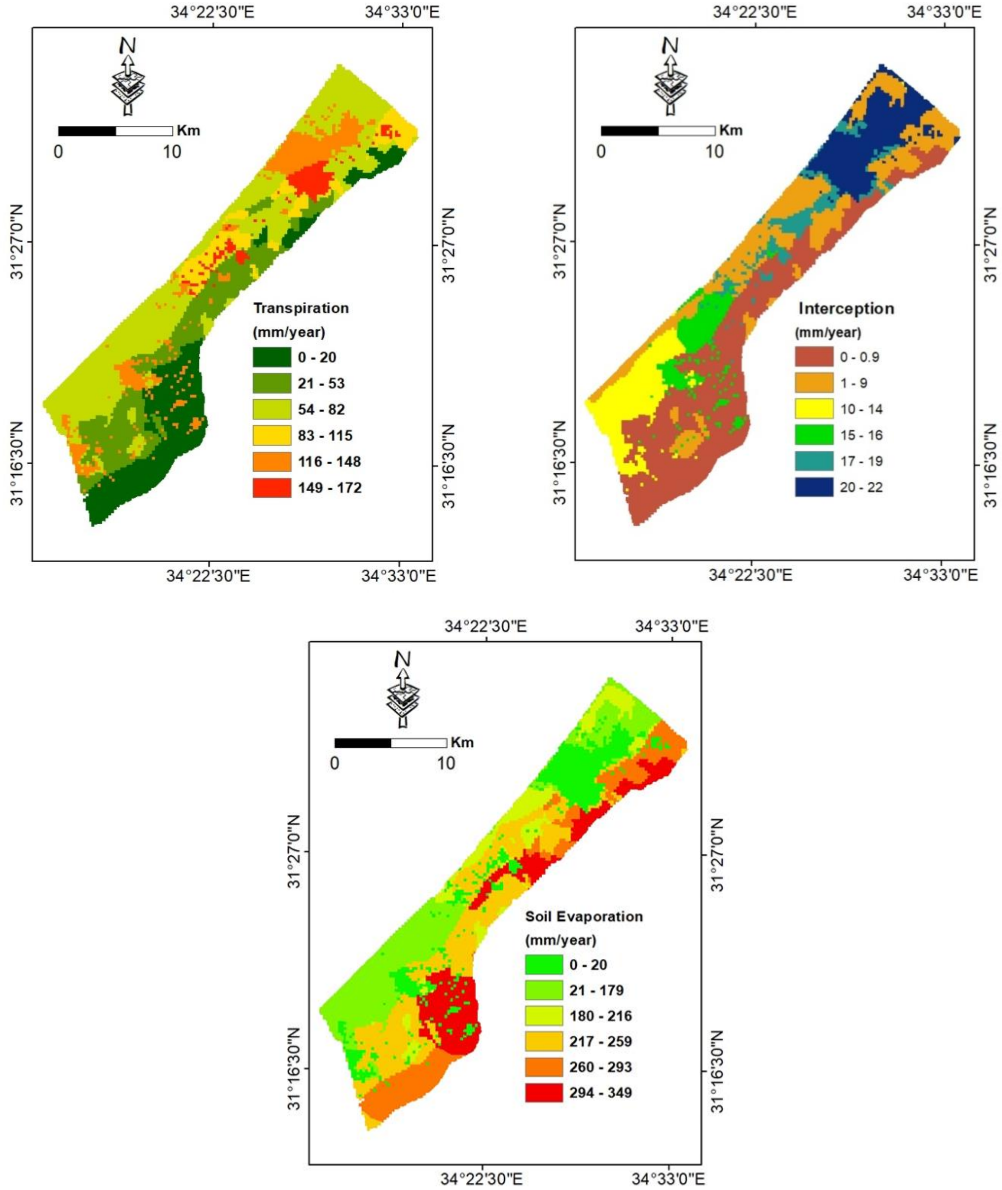

Figure 7: Simulated transpiration, interception and soil evaporation with WetSpass model

The research results compared with some research are available about earlier efforts made to estimate the water balance of the Gaza coastal aquifer such as Gharbia and Aish, [9] and [20] as illustrated in Table 3. The results from current research are in a good agreement with those of previous studies and indicates the validity of the simulated groundwater recharge, surface water runoff and evapotranspiration.

4. Conclusion

The WetSpass model was utilized to simulate areal distributions of groundwater recharge, surface runoff, and evapotranspiration for the Gaza coastal Aquifer. Using GIS tools, specific input data were created as digital maps. The WetSpass model parameter attribute tables were modified to reflect the local environment. According to model results, the annual groundwater recharge is just 12 % of the annual rainfall, varying between 0 to 192 millimeters per year with an average of 42 millimeters per year. On sandy and sandy loam of bare land and agriculture, the greatest groundwater recharge occurs. Annual surface runoff varies between 0 to 240 millimeters per year with an average of 38 millimeters per year, which makes up 11 % of annual rainfall. Built-up areas produce the highest surface runoff. Actual evapotranspiration varies from 130 to 391 millimeters per year with an average of 268 millimeters per year constituting 77 % of the annual rainfall. Mainly precipitation, potential evapotranspiration, and soil type have a major impact on actual evapotranspiration. Comparing the results of the WetSpass model and previous studies shows good agreement and indicates the validity of the simulated groundwater balance. The estimated distributed recharge can be used in regional steady-state groundwater models, reducing the uncertainty in simulated groundwater heads and pollutant transport of the Gaza coastal aquifer. This research might be utilized to build an integrated groundwater model to assess potential locations for artificial recharge by water runoff harvesting to improve groundwater storage.

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