UtahStateUniversity

Geographic Information System in Water Resources

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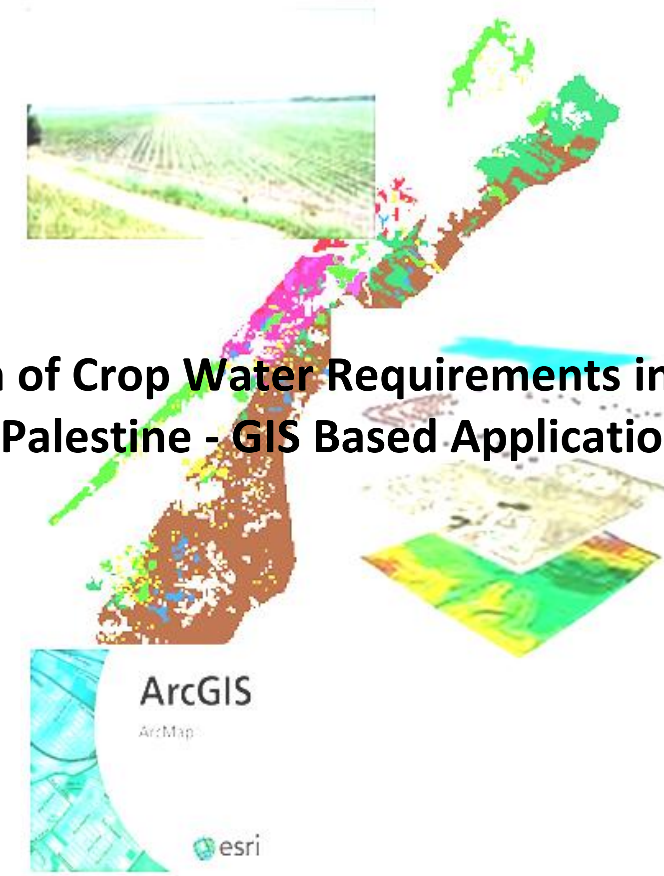

Estimation of Crop Water Requirements in Gaza Strip, Palestine - GIS Based Application

To:

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INTRODUCTION

The Groundwater aquifer in Gaza Strip (semi-arid region) is considered to be the sole source of water exploitation that is extensively deteriorated and may take long time to restore its fresh water conditions. Municipal groundwater wells are currently being used for drinking and domestic purposes while private wells are being used for irrigation not to mention the increasing number of household water wells. The GS is one of the most densely populated areas in the world population of 1.6 million inhabitants **[1]** More than 90% of the population is connected to the municipal drinking water network while the other 10%, mainly rural or distant areas is dependent on the private wells. There are an estimated 4000 wells within the GS. Almost all of these are privately owned and used for agricultural purposes **[2]**.

It is well known that in arid and semi-arid regions agriculture for crop production is the primary user of water. Increasing water demand, the growing scarcity and misuse of the available water resources in these regions are becoming major threats not only to sustainable agricultural development but to other sectors of the economy as well in the Middle East in general and in Gaza Strip, Palestine in particular. It is vital for socio-economic growth and sustainability of the environment. Gaza Strip is in critical situation that requires immediate and concerted efforts to improve the water situation in the term of quality and quantity. Demand greatly exceeds water supply. In addition water quality is very poor and the aquifer is being over pumped. Very limited water supplied for domestic use is potable. About 70% of the total pumped water is used for agricultural purposes **[3]**.

BACKGROUND

Study Area

The Gaza Strip (GS) is located at the south-eastern coast of the Mediterranean Sea as show in **Figure (1)** below, on the edge of the Sinai Desert between longitudes 34° 2” and 34° 25” east, and latitudes 31° 16” and 31° 45” north. It has an area of about 365 km^2 and its longest width is about 45 m **[4]**.

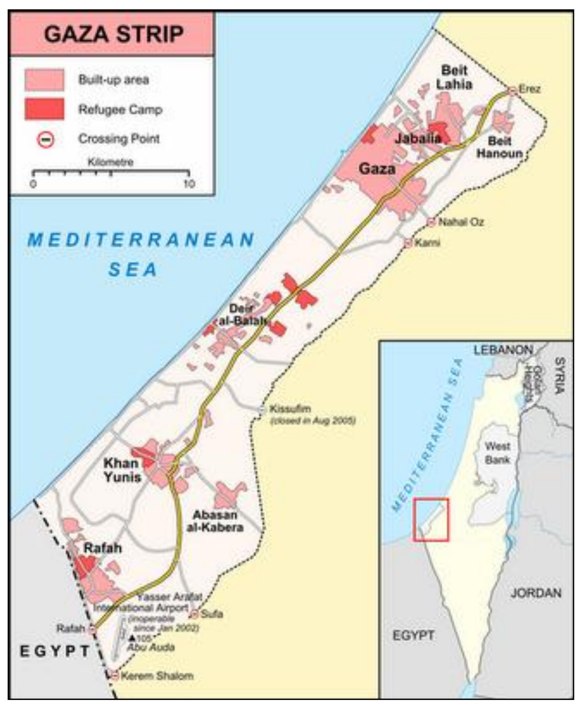


Figure 1 . National Geographic location of GS (Courtesy of Wikipedia)

Climate

GS climate is typical Eastern Mediterranean with hot dry summers and mild winters. Temperature gradually changes throughout the year, reaches it’s maximum in August (summer) and its minimum in January (winter), the average monthly maximum temperature range from about 17.6 C° for January to 29.4 °C for August while the average monthly minimum temperature for January is about 9.6 °C and 22.7 for August **[5].**

The GS is located in the transitional zone between the arid desert climate of the Sinai Peninsula in Egypt and the temperate and semi-humid Mediterranean climate along the coast. This fact could explain the sharp decrease in rainfall quantities of more than 200 mm/year between Beit-Lahia in the north and Rafah in the South of GS **[6]**.

The average long term annual rainfall is 350mm occurs between October and March. The long-term average annual open surface evaporation is 1300mm with its maximum in summer season (June – August).

Gaza Coastal Aquifer

The entire GS lies within the Coastal groundwater basin over the Coastal Aquifer. The Coastal Basin covers an area of 2,000 square kilometers as shown in **Figure (2)**, and is located in the Coastal Plain physiographic province. The Coastal Aquifer is comprised of water-bearing sand, sandstone, gravel, and conglomerate that typically overlie relatively impervious clay, marl, limestone, and chalk **[7].**

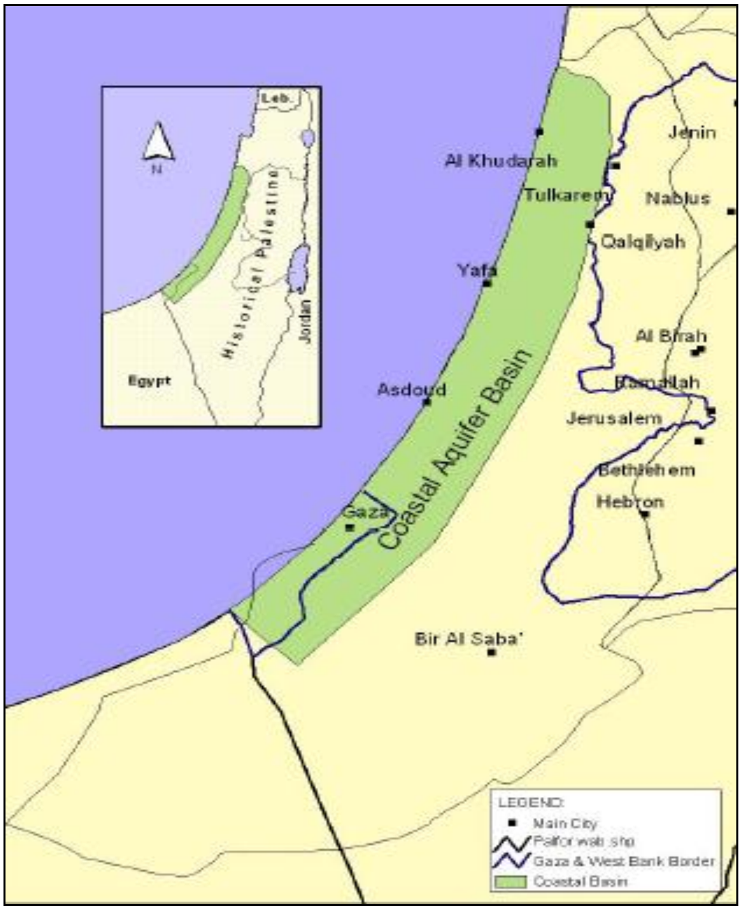


Figure 2 . Location of Gaza Coastal Aquifer in Palestine [8].

STATEMENT OF OBJECTIVES

In Gaza Strip, which characterized by semi-arid region, irrigation practices are only based on the farmer's knowledge and experience, they decide when and how to irrigate their crops based on the appearance and texture of the soil as well as on the climatic conditions. Taking the fact that FAO Guidelines for computing crop water requirements are dealt in many countries, it is barely used in Gaza Strip for most common cultivated crops (citrus, almonds, date palms, grapes) due to socio-economical issues.

Accordingly, the main objective of this term project is to use ArcMap; ArcGIS 10 based approach to estimate the crop water requirement (CWR) for Gaza Strip by utilizing the available information of land use, rainfall, FAO guidelines, and other meteorological data in a way to compare the current water consumption by the agricultural sector. Another objective is to produce maps showing the spatial distribution of the monthly/yearly crop water requirement for the use of water resources planners or any related further work.

METHOD AND MATERIALS

Data employed

The data were obtained from several sources such as: Palestinian Water Authority (PWA), Coastal Municipalities Water Utility (CMWU) data bank's departments. The data can be summarized as following:

- The major file needed to assess the extent of any data in space and time was the GazaStrip.shp file (National Grids-Palestinian Grid 1923) which was obtained from (CMWU) data bank, which details the boundaries of Gaza Strip where the spatial extension ends. The grid cell will be 130 meter, since it is the average farm size in Gaza Strip.
- **Shape files:** Gaza Strip and its governorates, agriculture land use (crop cover) (sources: Palestinian Ministry of Planning and International Cooperation, PWA and CMWU).
- **Meteorological data:** 20 years rainfall records for 12 meteorological stations covering Gaza Strip (source: CMWU and Palestinian Meteorological Department) and other climatic figures.
- Crop information such as growing season, crop height, and crop coefficient (source: FAO papers 24, 33, and 56).

Dataset Processing

Rainfall data

Data available from 12 meteorological stations distributed along Gaza Strip were obtained. The records in PWA and CMWU were based on monthly rainfall depth collected measurements from rain gauges that start in July of particular year and ends in June of next year.

Table (1) lists details about these stations and **Figure (3)** shows how spatially they are distributed in Gaza Strip, where year 2009 was addressed for purpose of study. The table was added, and then it was exported to be a layer within the assigned geodatabase. The stations were located along with their average yearly rainfall.

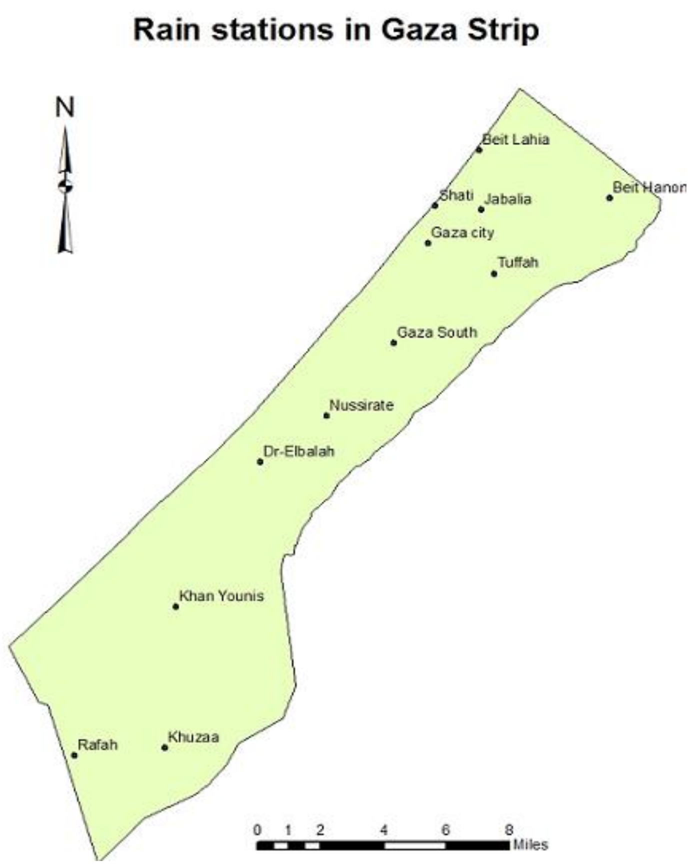


Figure 3. Location of Rainfall stations in Gaza Strip.

Table 1. Rainfall dataset in 2009 study year (mm/year)

Station Name	mm/year	X	Y
Beit Hanoun	428	106420	105740
Beit Lahia	455	99750	108280
Jabalia	432	99850	105100
Shati	371	97500	105320
Gaza City	359	97140	103300
Tuffah	362	100500	101700
Gaza South	357	95380	98000
Nusseirat	351	91950	94080
Deir Al Balah	321	88550	91600
Khan Younis	317	84240	83880
Khuzaa	313	83700	76350
Rafah	238	79060	75940

Figure (4) below shows the annual rainfall distribution in Gaza Strip. It is worth mentioning that the rainfall amount decreases to almost half as we move 40 km to the south. This is so because Gaza Strip is located in a transitional zone between a semi humid climate north of Gaza Strip and arid climate of Sinai desert of Egypt in the south.

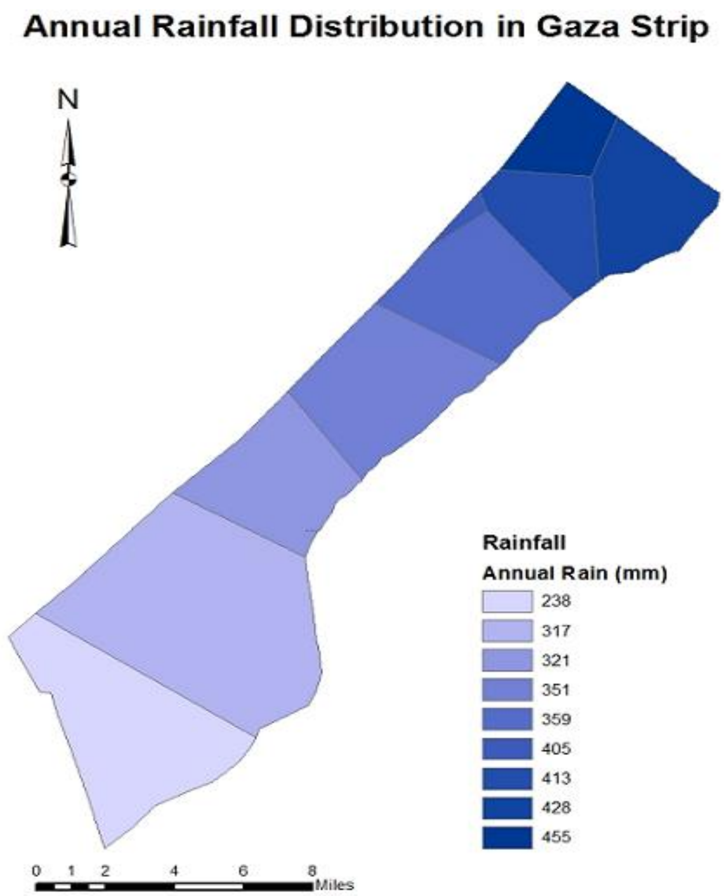


Figure 4. Annual rainfall distribution for Gaza Strip (mm/year).

Crop water requirement (CWR)

Crop information such as growing season, crop height, and crop coefficient were obtained from FAO **[9]**. Basically, the crop water requirement computation is based on the USDA soil conservation service method **[10]**:

$$\textbf{Crop Water Requirement (CWR)} = ET_o \times K_c - P_{eff}$$

Where,

- ET_o is the reference evapotranspiration was calculated by excel spreadsheet using Penman Monteith FAO equation in mm. ***FAO paper 56***
- K_c is the crop coefficient values (K_c) for each crop categories were obtained from ***FAO papers 56 and 33*** and then added to the attribute table of crop cover theme.
- P_{eff} is the effective rainfall and it can be calculated using the following equation:

$$P_{eff} = f * (1.25\ P^{0.843} - 2.93) * 10^{(0.0000955 * ET_o)}$$

Where,

- f = correction factor depends on soil moisture depletion before each irrigation. For the purpose of this study f value is taken as 1.0 in this term project for easy reference.
- *P = the gross monthly rainfall in mm.*

Climate Data

The reference evapotranspiration was calculated by excel spreadsheet using the **Penman Monteith** FAO equation. New fields for monthly Evapotranspiration for each station were then added by editing the attribute table of the Agricultural land use. **Table (2)** shows the calculation values of reference evapotranspiration as per **Annex 2** and based to **Annex 1** equations.

Table 2. Values of Monthly reference evapotranspiration

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Reference Evapotranspiration ETo (mm)	**1.99**	**2.3**	**3.28**	**4.3**	**4.15**	**4.84**	**5.2**	**5.05**	**4.49**	**3.2**	**2.06**	**2.1**

Crop Data

The crop patterns were classified into five main categories. The classification was based on growing season, crop coefficients, and crop cover and height of FAO guidelines where **Table (3)** below shows these categories.

Table 3. Crop categories.

Crop Category	Crop Type
Citrus	Orange - lemon - grapefruit
Fruit trees	Apples - pears - peaches - apricots - almonds
Vegetables1	Cucumber -squash - cabbage
Vegetables2	Tomato - sweet peppers - egg plants - potato
Field crops	Wheat - barley

Crop coefficient values (K_c) for each crop categories were obtained from ***FAO papers 56 and 33*** and then added to the attribute table of crop cover theme. **Table (4)** below shows the value of crop coefficient and the growing season for each crop categories. Moreover, **Figure (5)** below shows the distribution of these crops in Gaza Strip as per **Annex 3** values.

Table 4. Crop Coefficient values (K_c) for different crop categories.

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Citrus	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.65	0.65	0.65	0.65	0.65
Fruit trees	0.9	0.9	0.9	0.65	0.65	0.65	0.65	0.4	0.4	0.4	0.4	0.9
Vegetables1	1.15	1.15	0.95						0.6	1	1	0.75
Vegetables2	0.8			0.6	0.6	1.15	1.15	0.8	0.6	1.15	1.15	0.8
Field crops	1.15	0.4								0.3	0.3	1.15

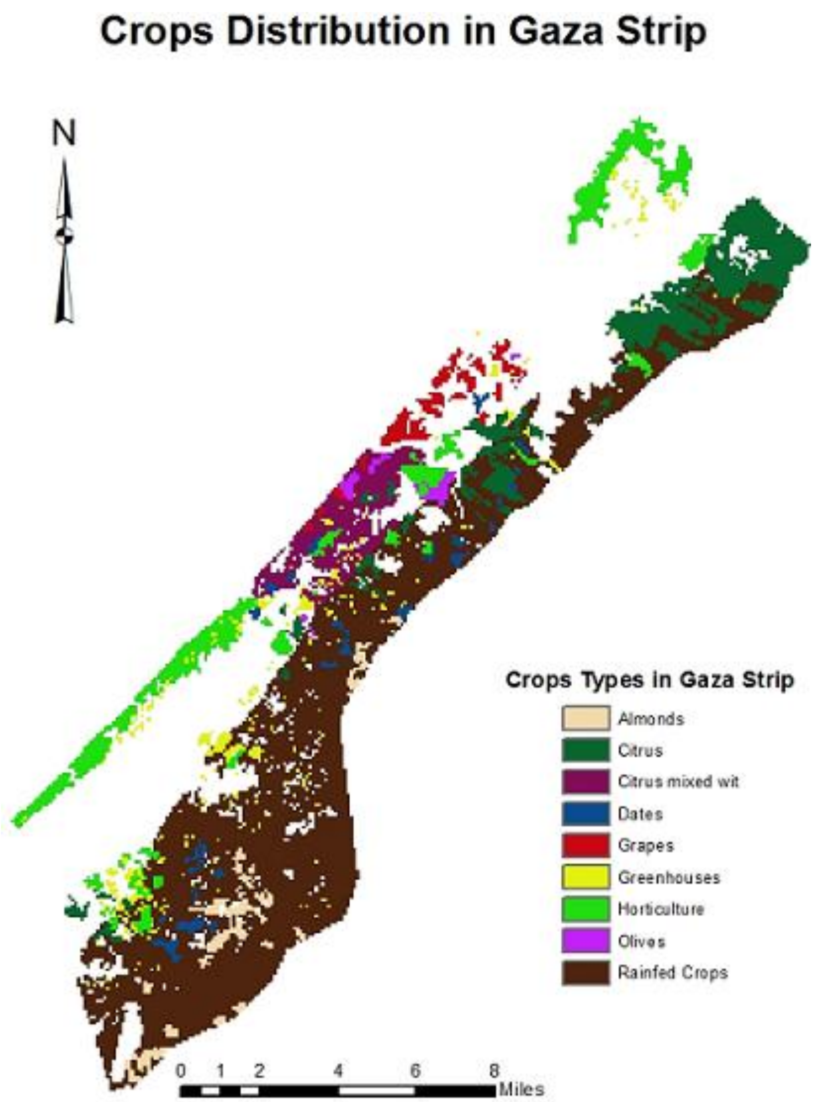


Figure 5. Crop cover distribution grid for Gaza Strip.

At this stage, each grid cell contains values for rainfall, reference evapotranspiration, and crop coefficient, which are related to crop type and growing season.

Brief Methodology of Work

Basic GIS techniques were used throughout this term project and it can be summarized as follows:

- Using ArcCatalog create personal geodatabase.
- Adding data/tables and then exporting them to be layers within the assigned geodatabase file.
- Unifying the coordinate systems to (**National Grids-Palestinian Grid 1923**) using ArcToolbox Data management tools/projection and transformations/define projection.
- Joining the attribute file of Agricultural land-use with **ET_o** and **ET_o*K_c** data that were assigned for each crop.
- Feature classes were prepared as layers and then as rasters for easy calculation.
- The crop water requirement was then computed for each month and the final Total crop water requirement CWR was computed for each month and then the Total CWR was the summation of all monthly CWRs.
  TOTAL CWR = [CWRJan] + [CWRFeb] + [CWRMar] + [CWRApr] + [CWRMa] + [CWRJun] + [CWRJul] + [CWRAug] + [CWRSep] + [CWROct] + [CWRNov] + [CWRDec]
- Modelbuilder was utilized to build a model for this term project in order to expedite the calculation process. Main tools used were conversion tool (feature class to raster) and Map Algebra tool (raster calculation) as shown in **Figure (6)**. Total of 49 procedures were built in the model.

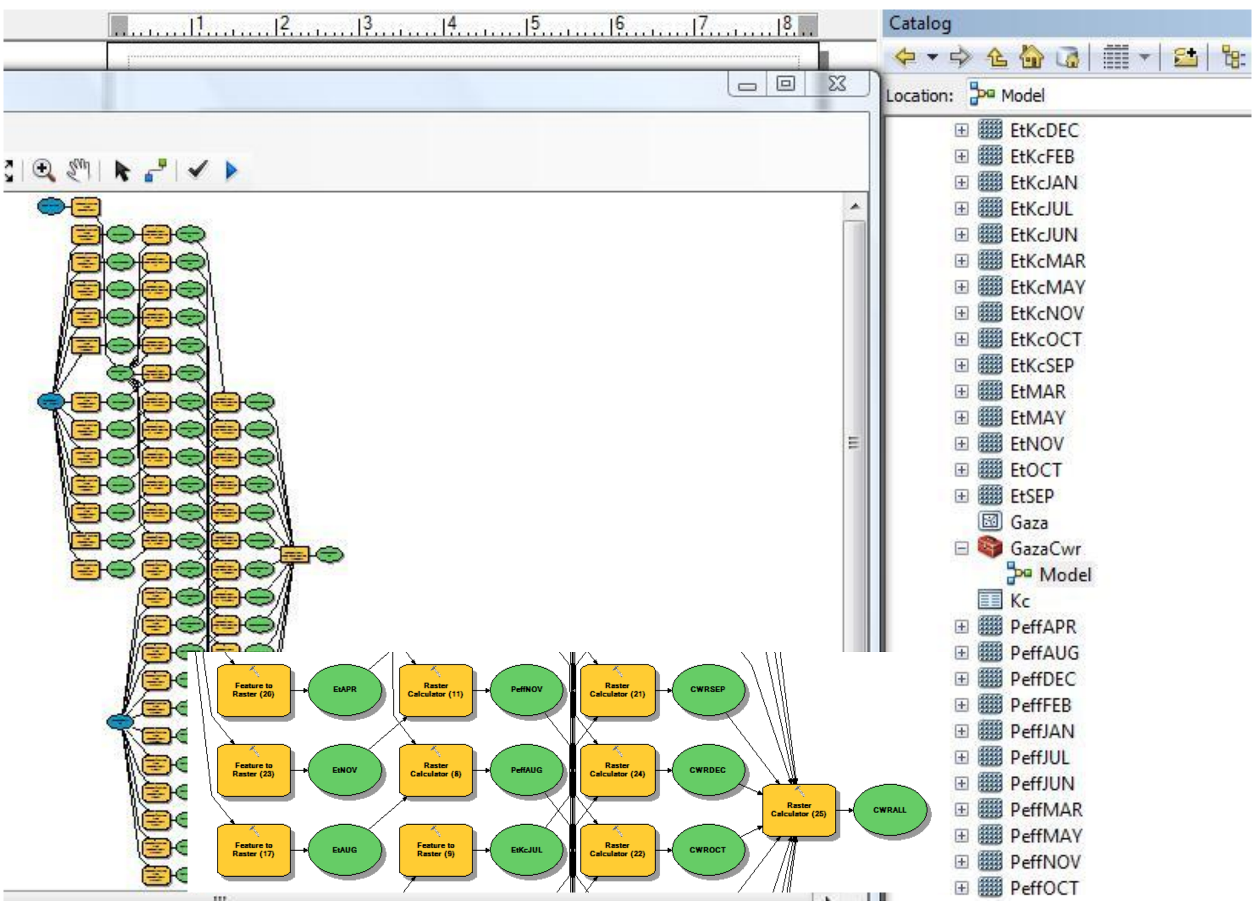


Figure 6. Crop Water Requirement Model Layout.

RESULTS AND DISCUSSIONS

The annual total crop water requirement for Gaza Strip is calculated as **64.7 million cubic meters (MCM)**. Two studies that have investigated the required water consumption for agricultural sector in Gaza Strip:

- 85 MCM **[11]**.
- 83 MCM **[12]**.

We can address the fact that the annual crop water requirement for Gaza Strip varies from 0 to 10000 m^3/gridcell (the grid cell is 130m x 130m since the average farming area is 130*130 m^2). **Figure (7)** below shows the spatial representation of annual crop water requirement in Gaza Strip (mm).

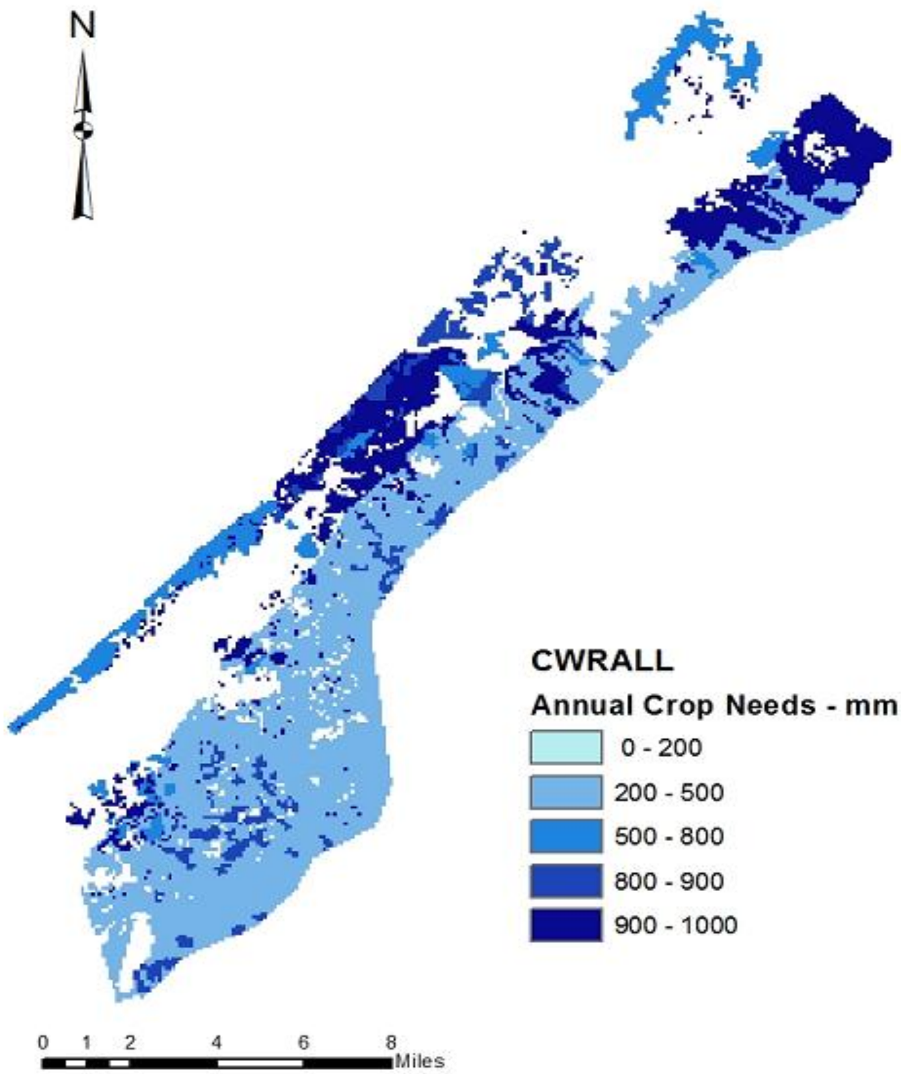


Figure 7. Annual crop water requirement distribution in Gaza Strip (mm).

Lowest crop requirements values occurs in the area cultivated with rainfed crops. High values occur in the areas cultivated with citrus trees, which is characterized by high annual crop evapotranspiration as shown in **Figure (8)**. Even the traditionally rainfed crops, such as wheat and barley, are given supplementary irrigation with surface or groundwater, depending on its availability.

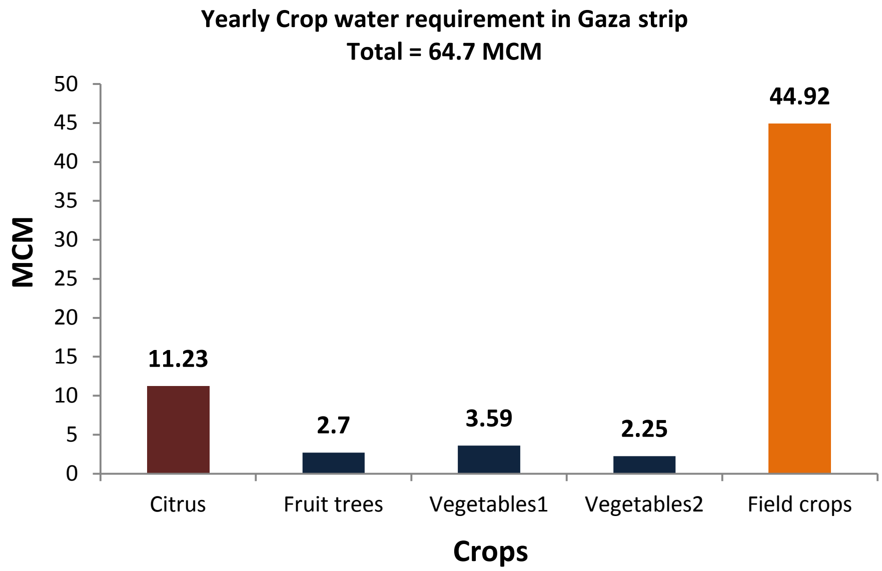


Figure 8. Chart illustrates the distribution of annual Crop Water Requirement per crop.

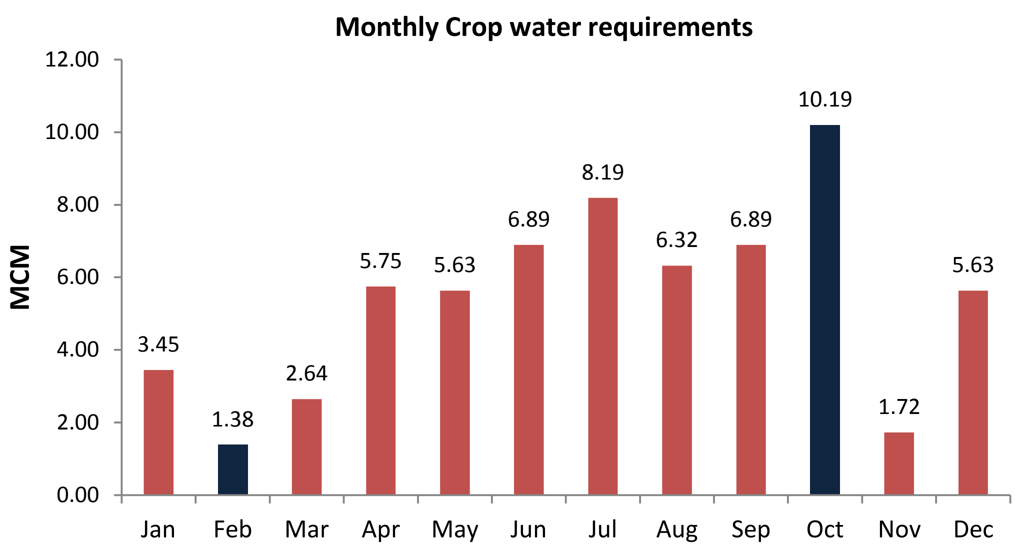


Figure 9. Chart illustrates the distribution of Monthly Crop Water Requirements

Figure (9) above and **Figure (10)** below both shows the monthly variation in crop water requirement for the whole area of Gaza Strip. Although high values generally occur during summer months the highest crop water requirement was found in October. This is so because in October all the land will be cultivated and the monthly rainfall is low.

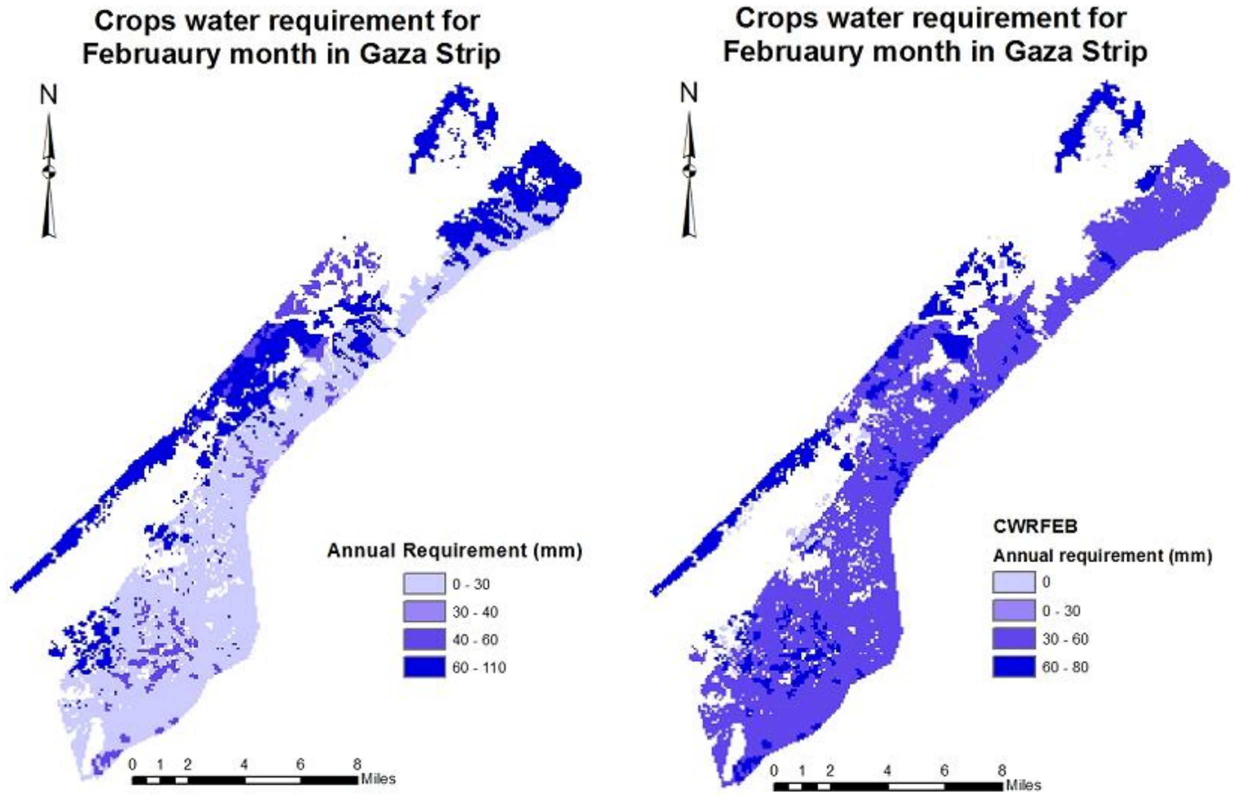


Figure 10. spatial distribution of Crops water requirements in months of October and February

In other words October is the month where all the crops contribute to the weighted crop coefficient. The same could be said about February but the steep variation in the monthly rainfall causes the drop in the monthly crop water requirement.

CONCLUSION

It was concluded that GIS has been a useful mechanism in utilizing its tool for tackling the agricultural water consumption in Gaza Strip to come up with spatial representation of crops and monthly/yearly crop water requirements for further analysis and investigation. The comparison of the figure we had calculated **64.7 (MCM)** vs. the two studies of 83 and 85 (MCM), we can conclude that the total losses due to delivery system, partially traditional irrigation techniques, and over application by the farmers is about 22-24 %.

A publication by the World Health Organization - Eastern Mediterranean Regional Office in 2005**, titled as: Economizing in water use for crop production in the Near East Region [13]**, has stated that the irrigation efficiency was around 35 percent in the Middle East countries. Yet the resulted efficiency of 22-24% seems to be reasonable and acceptable within the current circumstances in Gaza Strip of farmers' practices, over-consumption of water, and lack of alternative water supplies.

To my opinion, the traditional irrigation techniques that have been used so far on the long term proved to be optimized in Gaza Strip despite the fact that the water scarcity problem in that region was due to enormous increase in the population and the urban expansion attributed with that increase during the last 10 years.

Further, uncertainties in the above work could involve general errors due to schematization and simplification process, data accuracy, and computational methods. In addition, several variables might have impacted the results:

- K_c - Generalizing crop coefficient for the crop category rather than applying it to each crop type
- f - has been taken as 1 in real situation this factor varies from 0.7 to 1.14.
- Other factors related to metrological data methods of measurements, recording, and ... etc.

FUTURE WORK

The work that has been done (GIS based approach) along with the obtained results can be a management tool for the planners and decision makers in drafting plans for improving farmers' practices in agricultural sector (use of low water consuming crop species, adapted fertilization to available water, disease and pest control, optimal planting and seeding, selected varieties able to accomplish their cycle within the climate growing period, irrigation schedules, … etc) and to minim the water loss (evaporation reduction by mulching or rapid crop cover, windshields, minimum tillage, weeding …etc).

Not to mention that this study should include more agricultural technical aspects such as: water mass balance equation, soil type and sorption properties, infiltration rate, residence time, fertilizers used and its impact, and various associated hydrogeological properties.

This work could be part of a regional water resources management project. So, estimates for other demand sectors; domestic, industrial, and other users could be done. This also could be linked with water resources availability in the region and water rights for different demand sectors. The same type of study could be applied at the micro-scale studies and analyses for each crop type to give the exact crop water requirements in Gaza Strip.

REFERENCES

[1] PCBS, 2011. Results for the Census of Population and Inhabitants. Palestinian Central Bureau of Statistics, Ramallah.

[2] PWA, 2000b. Summary of the Palestinian Hydrologic Data, Volume 2: Gaza. Technical and financial support from US Agency for International, Development (USAID) and US Geology Survey, Palestinian Water Authority: Gaza.

[3] CMWU, 2011 databank. Coastal Municipalities Water Utility – Data bank department Gaza, 2011.

[4] MOPIC, 1998. Master Plan for Sewage and Stormwater Drainage in the Gaza governorate- Final Master Plan report. Main Report, Palestinian National Authority, Ministry of Planning and International Cooperation.

[5] Qahman K. A., 2003. Identification and modeling of seawater intrusion of the Gaza Strip aquifer, Palestine.

[6] Shahen Sami, 2007. Thesis in Nitrate pollution and groundwater modeling of Wastewater Plant in Rafah area, Gaza Strip, Palestine.

[7] EXACT, 1998. Overview of Middle East Water Resources, prepared by the Jordanian Ministry of Water and Irrigation, the Palestinian Water Authority, and the Israeli Hydrological Service for the Executive Action Team, Middle East Water Data Banks Project.

[8] MEDA, 2007. Euro - Mediterranean Partnership project. Database on Transbounbdary Aquifers Version 2.1.1. Data Collection Questionnaire. http://www.inweb.gr/html_reports/Coastal%20Aquifer.html.

[9] Food and Agriculture Organization Guidelines for computing crop water requirements: papers 24, 33, 56

- Richard G. A., Luis S. P., Dirk R., Martin S.: FAO - Food and Agriculture Organization of the United Nations - Irrigation and drainage paper 56. Crop evapotranspiration - Guidelines for computing crop water requirements - Rome, 1998.
- Doorenbos J., Kassam A.H., and Bentvelson C.L.M: FAO - Food and Agriculture Organization of the United Nations - Irrigation and drainage paper 33. Yield response to water. Rome, 1979.

[10] Obreza, T. A., and D. J. Pitts. 2002. Effective rainfall in poorly-drained microirrigated citrus orchards. Soil Sci. Soc. Amer. J. 66:212-221.

[11] PWA, 2000. Palestinian Water Authority. Water Sector Strategic Planning Study, Final Report. Specialist studies, Part B: Focal areas. , Volume III.

[12], Palestine Economic Policy Research Institute (MAS), 2009. Jerusalem and Ramallah. Future Water Needs study in Palestine. www.mas.ps

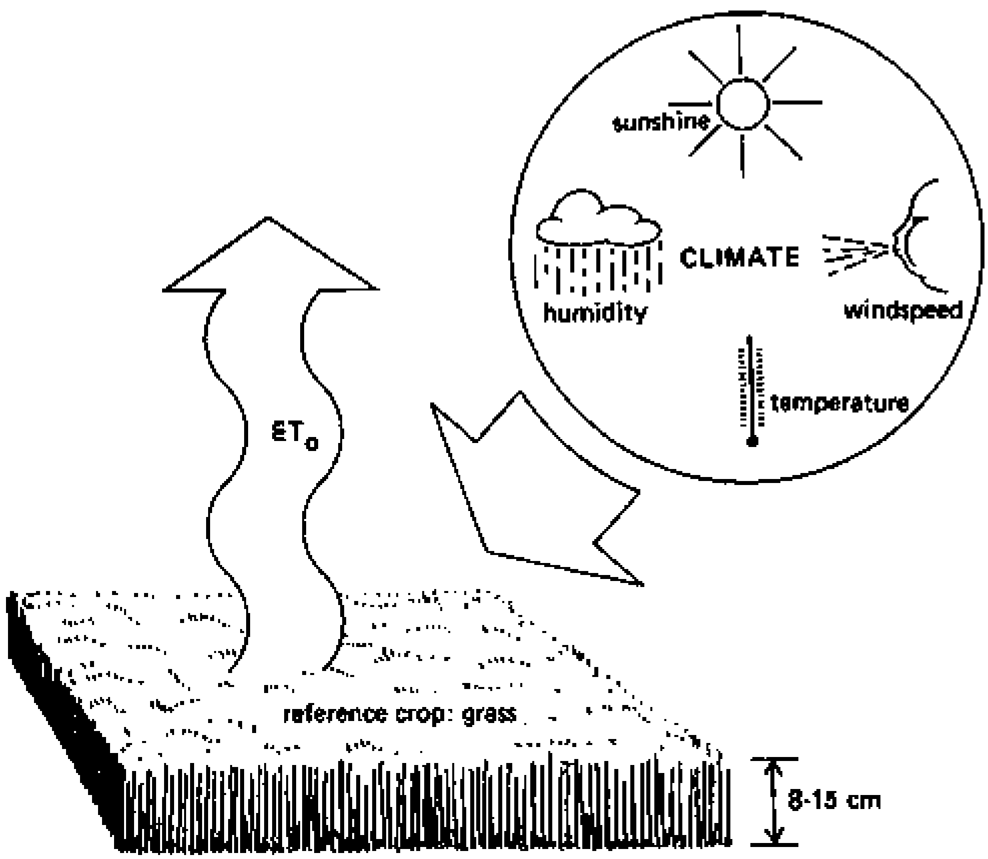
[13] World Health Organization – Near East Region, Eastern Mediterranean Regional Office in 2005, Economizing in water use for crop production in the Near East Region. www.emro.who.int

ANNEXES

Annex 1 - Equations and Calculations

Reference Evapotranspiration (ET_o)

Reference evapotranspiration (ET_0) was calculated using **Penman Monteith FAO equation presented in FAO paper 56**. This paper defines the reference evapotranspiration as the evapotranspiration from the hypothetical grass reference surface and provides a standard to which evapotranspiration in different periods of the year or in other region can be compared and to which the evapotranspiration from other crops can be related. Penman Monteith equation cab be written as:



$$ET_0 = \frac{0.408 * \Delta * (R_n - G) + \gamma * \left(\frac{900}{T - 273}\right) * U_2 * (e_s - e_a)}{\Delta + \gamma * (1 + 0.34 U_2)} \quad \text{---(1)}$$

Where:

R_n = net radiation at the crop surface ($M\,J\,m^{-2}\,day^{-1}$);

G = soil heat flux density ($M\,J\,m^{-2}\,day^{-1}$)

T = mean daily air temperature at 2m height (^{o}C)

U_2 = wind speed at 2m height ($m\ s^{-1}$)
e_s = saturation vapor pressure (kPa)
e_a = actual vapor pressure (kPa)
Δ = slope of vapor pressure curve ($kPa\ ^oC^{-1}$)
γ = psychometric constant ($kPa\ ^oC^{-1}$)

These parameters are calculated using meteorological data such as altitude, latitude, mean relative humidity, sunshine hours, absolute minimum and maximum temperature, mean minimum and maximum temperature, mean monthly temperature, and wind speed.

The followings are the equations used to calculate these parameters based on FAO paper 56.

(R_n): The net radiation at the crop surface is given by the equation:

$$R_n = R_{ns} - R_{nl} \quad \text{---- (2)}$$

Where:
R_{ns} *= the net solar or short wave radiation given by:*

$$R_{ns} = 0.77 * R_s \quad \text{---- (3)}$$

Where :
R_s *= the total solar or short wave radiation given by:*

$$R_s = \left(0.25 + 0.5 * \left(\frac{n}{N}\right)\right) * R_a \quad \text{---- (4)}$$

Where:

- *n/N* = relative sunshine hours determined by n which is the measured sunshine hours and N which is the mean daylight hours given for different latitudes.
- R_a = extra terrestrial radiation which is based on the latitude.

Referring back to equation (2):
R_{nl} = the net long wave radiation given by

$$R_{nl} = \sigma * \left(\frac{T_{max} - T_{min}}{2}\right)\left(0.34 - 0.14\sqrt{e_a}\right)\left(1.35\frac{R_s}{R_{so}} - 0.35\right) \quad \text{----(5)}$$

Where:
T_{max} *= absolute monthly maximum temperature in Kelvin*
T_{min} *= absolute monthly minimum temperature in Kelvin*

R_{so} = clear sky solar radiation given by:

$$R_{so} = \left(0.75 + 2 * 10^{-5} * Z\right) * R_a \quad \text{----(6)}$$

Where;
Z = the latitude

(G): Soil heat flux in (M J m^{-2} day^{-1}) given by the equation:

$$G_{month} = 0.07 * (T_{month(i+1)} - T_{month(i-1)}) \quad \text{----(7)}$$

Where;

$T_{month(i+1)}$ = mean monthly air temperature for the month after

$T_{month(i-1)}$ = mean monthly air temperature for the month before

(*P*): Atmospheric pressure in (kPa) given by the equation:

$$P = 101.3 * \left(\frac{293 - 0.0065Z}{293}\right)^{5.26} \quad \text{----(8)}$$

(γ): Psychometric constant in (kPa / ^{0}C) given by the equation:

$$\gamma = 0.665 * 10^{-3} * P \quad \text{----(9)}$$

(e^0): Saturation vapor pressure in (kPa) given by the equation:

$$e^0(T) = 0.6108 \exp\left(\frac{17.27T}{T + 237.3}\right) \quad \text{---(10)}$$

Where:

T = the mean monthly temperature in ^{0}C

(e_s): Mean saturation vapor pressure in (kPa) given by the equation:

$$es = \frac{e^0_{(T\max)} + e^0_{(T\min)}}{2} \quad \text{---(11)}$$

Where;

$e^0_{(T\max)}$ *:= saturation vapor pressure at maximum temperature*

$e^0_{(T\min)}$ *:= saturation vapor pressure at minimum temperature*

(e_a): Actual vapor pressure in (kPa) given by the equation:

$$e_a = \frac{RH_{mean}}{100} * \frac{e^0_{(T\max)} + e^0_{(T\min)}}{2} \quad \text{---(12)}$$

Where;

RH_{mean} = mean monthly relative humidity

(Δ): Slope of saturation vapor pressure curve in (kPa / ^{0}C) given by the equation:

$$\Delta = 4098 \frac{e^0_{(T)}}{(T + 237.3)^2} \quad \text{---(13)}$$

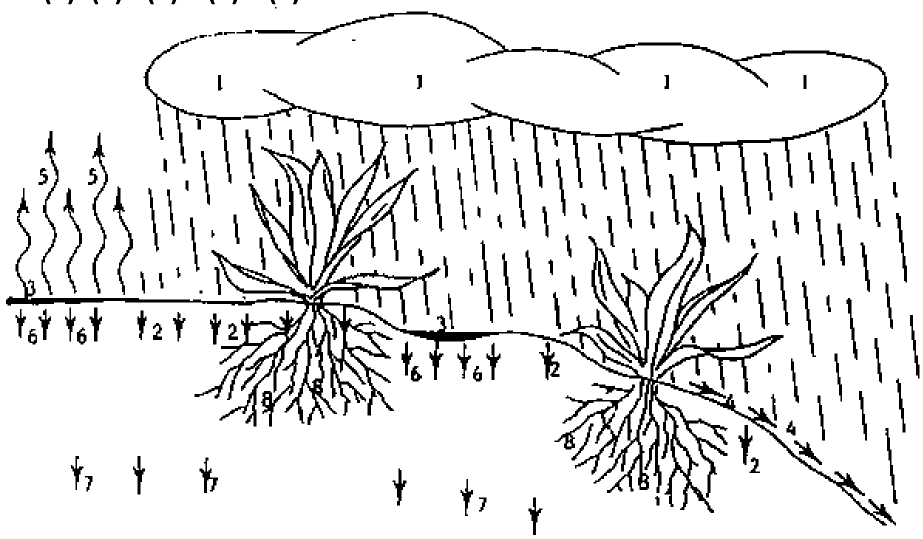
(U_2): Wind speed corrected at 2 m above the ground surface in (m/s) given by the equation:

$$U_2 = U_Z * \left(\frac{4.87}{\ln(67.8Z - 5.42)}\right) \quad \text{---(14)}$$

Where;
U_Z = the wind speed at given elevation

Effective Rainfall (Peff)

The effective rainfall is calculated using USDA-SCS (US Department of Agriculture – Soil Conservation Service) procedure. This procedure is used for general estimates of monthly effective precipitation for planning and most systems design. The USDA-SCS procedure is described by the following equation:
Effective rainfall (8)=(1) - (4) = (5) = (7)



$$Peff = f * (1.25P^{0.834} - 2.93) * 10^{(0.000955ET_0)}$$

---(15)

Where;

- f = correction factor depends on average net application depth or soil moisture depletion before each irrigation. For the purpose of this study f value is taken as 1.0, which the value corresponds to the net depth of water depletion of 75mm assumed as the average value for the study area.
- P = the gross monthly rainfall in mm
- ET_0 = the monthly reference evapotranspiration

Annex 2 - Calculation of reference evapotranspiration from meteorological data

Parameters and variables	Symbols	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
mean relative humidity (%)	**RHmean**	66	69	64	67	73	77	76	75	65	66	72	62
actual daily sunshine hours	**n**	4.75	5.54	6.9	9.49	7.81	9.93	10.7	10	9.8	9.2	6.8	4.5
mean day light hours	**N**	10.2	10.95	11.8	12.75	13.55	14	13.85	13.15	12.2	11.25	10.4	10
relative sunshine duration	**n/N**	0.47	0.51	0.58	0.74	0.58	0.71	0.77	0.76	0.80	0.82	0.65	0.45
absolute minimum temperature (C^o)	**Tmin**	5	8.6	8	10.5	15.2	19.2	21.5	23.5	21.2	17	14.8	9.6
absolute maximum temperature (C^o)	**Tmax**	23.5	26.7	28.5	40.4	36.8	29.8	32.8	33.2	32	39	27.5	31.4
mean minimum temperature (C^o)	**T'min**	10.29	11.42	11.9	15.8	18.57	21.56	23.2	25	22.7	20.4	17.4	12.7
mean maximum temperature (C^o)	**T'max**	18	18.38	19.6	24.74	24.78	27.12	29.8	31.9	30	27.6	24.2	20.8
mean monthly temperature (C^o)	**Tmean**	14.14	14.9	15.6	20.27	21.67	24.3	26.7	28.3	27	24	20.8	16.6
soil heat flux (M J m^{-2} day^{-1})	**Gmonth**	0.12	0.10	0.38	0.42	0.28	0.35	0.28	0.02	0.30	0.43	0.52	0.47
saturation vapor pressure (KPa)	e^o	1.61	1.69	1.77	2.38	2.59	3.04	3.50	3.85	3.57	2.98	2.46	1.89
saturation vapor pressure at max temperature (kPa)	$e^{o\,(Tmax)}$	2.06	2.11	2.28	3.12	3.13	3.59	4.19	4.73	4.24	3.69	3.02	2.46
saturation vapor pressure at min temperature (KPa)	$e^{o(Tmin)}$	1.25	1.35	1.39	1.80	2.14	2.57	2.84	3.17	2.76	2.40	1.99	1.47
mean saturation vapor pressure (KPa)	e_s	1.66	1.73	1.84	2.46	2.63	3.08	3.52	3.95	3.50	3.04	2.50	1.96
actual vapor pressure (KPa)	e_a	1.09	1.19	1.18	1.65	1.92	2.37	2.67	2.96	2.28	2.01	1.80	1.22
vapor pressure deficit (KPa)	e_s-e_a	0.56	0.54	0.66	0.81	0.71	0.71	0.84	0.99	1.23	1.04	0.70	0.75
slope of saturation vapor pressure curve (KPa/C^o)	**Δ**	0.10	0.11	0.11	0.15	0.16	0.18	0.21	0.22	0.21	0.18	0.15	0.12
measured wind speed (km/hr)	γ	12.12	12.1	17.1	14.33	12	10.66	7	5	7.7	6.4	7	12
measured wind speed (m/s)	**Uz**	3.37	3.36	4.75	3.98	3.33	2.96	1.94	1.39	2.14	1.78	1.94	3.33
wind speed corrected for 2m altitude (m/s)	U_2	2.27	2.27	3.21	2.69	2.25	2.00	1.31	0.94	1.45	1.20	1.31	2.25
extraterrestrial radiation (M J m^{-2} day^{-1})	R_a	20.5	25.3	31.05	36.65	40	41.3	40.65	37.95	33.1	27.1	21.65	19.15
solar radiation	R_s	9.90	12.73	16.84	22.80	21.53	24.97	25.86	23.92	21.57	17.86	12.49	9.10
clear sky solar radiation	R_{so}	15.38	18.99	23.30	27.50	30.02	30.99	30.50	28.48	24.84	20.34	16.25	14.37
	R_s/R_{so}	0.64	0.67	0.72	0.83	0.72	0.81	0.85	0.84	0.87	0.88	0.77	0.63
net solar/short wave radiation	R_{ns}	7.62	9.80	12.97	17.56	16.58	19.23	19.92	18.42	16.61	13.75	9.62	7.00
net long wave radiation (M J m^{-2} day^{-1})	R_{nl}	3.38	3.66	4.19	4.88	3.57	3.54	3.53	3.15	4.20	4.81	3.86	3.44
net radiation (M J m^{-2} day^{-1})	R_n	4.24	6.14	8.77	12.68	13.01	15.69	16.39	15.26	12.41	8.94	5.76	3.56
Reference Evapotranspiration (mm/day)	ET_0	**1.99**	**2.30**	**3.28**	**4.30**	**4.15**	**4.84**	**5.20**	**5.05**	**4.49**	**3.20**	**2.06**	**2.10**

Annex 3 – ET_o and Crop coefficient (K_c) generalized values

K_c – Crop Coefficients												
Crop Category	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Citrus	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.65	0.65	0.65	0.65	0.65
Fruit trees	0.9	0.9	0.9	0.65	0.65	0.65	0.65	0.4	0.4	0.4	0.4	0.9
Vegetables1	1.15	1.15	0.95	0	0	0	0	0	0.6	1	1	0.75
Vegetables2	0.8	0	0	0.6	0.6	1.15	1.15	0.8	0.6	1.15	1.15	0.8
Field crops	1.15	0.4	0	0	0	0	0	0	0	0.3	0.3	1.15

Generalizing the crop coefficients to the current crops types in Gaza Strip												
Crop Types	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Citrus	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.65	0.65	0.65	0.65	0.65
Citrus mixed wit	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.65	0.65	0.65	0.65	0.65
Almonds	0.9	0.9	0.9	0.65	0.65	0.65	0.65	0.4	0.4	0.4	0.4	0.9
Olives	0.9	0.9	0.9	0.65	0.65	0.65	0.65	0.4	0.4	0.4	0.4	0.9
Grapes	0.9	0.9	0.9	0.65	0.65	0.65	0.65	0.4	0.4	0.4	0.4	0.9
Dates	0.9	0.9	0.9	0.65	0.65	0.65	0.65	0.4	0.4	0.4	0.4	0.9
Horticulture	1.15	1.15	0.95	0	0	0	0	0	0.6	1	1	0.75
Greenhouses	0.8	0	0	0.6	0.6	1.15	1.15	0.8	0.6	1.15	1.15	0.8
Rainfed Crops	1.15	0.4	0	0	0	0	0	0	0	0.3	0.3	1.15

ET_o*K_c*30 days												
Crops	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Citrus	41.79	48.3	68.88	90.3	87.15	101.6	109.2	98.48	87.56	62.4	40.17	40.95
Citrus mixed wit	41.79	48.3	68.88	90.3	87.15	101.6	109.2	98.48	87.56	62.4	40.17	40.95
Almonds	53.73	62.1	88.56	83.85	80.925	94.38	101.4	60.6	53.88	38.4	24.72	56.7
Olives	53.73	62.1	88.56	83.85	80.925	94.38	101.4	60.6	53.88	38.4	24.72	56.7
Grapes	53.73	62.1	88.56	83.85	80.925	94.38	101.4	60.6	53.88	38.4	24.72	56.7
Dates	53.73	62.1	88.56	83.85	80.925	94.38	101.4	60.6	53.88	38.4	24.72	56.7
Horticulture	68.66	79.35	93.48	0	0	0	0	0	80.82	96	61.8	47.25
Greenhouses	47.76	0	0	77.4	74.7	167	179.4	121.2	80.82	110.4	71.07	50.4
Rainfed Crops	68.66	27.6	0	0	0	0	0	0	0	28.8	18.54	72.45

Annex 4 – Irrigation in Gaza Strip in pictures