ASSESSMENT OF RUN OFF POTENTIAL OF A SMALL WATERSHED IN SOUTHERN PAESTINE

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ABSTRACT

According to the Palestinian Ministry of Agriculture, the Governorates of the West Bank have been suffering severe drought for the past three years which affected, among other things, the agriculture sector (not enough water for the plants). In summary, water is usually in short supply and the study of surface runoff from small watershed here might help in reducing the effects of such short supply, and this is the interest of this research work.

For any hydrological studies on an ungaged watershed, a methodology has to be selected for the determination of runoff at its outlet. Many methods are used to estimate the runoff from a watershed. The curve number method is a versatile and widely used procedure for runoff estimation. This method includes several important properties of the watershed namely, soils permeability, land use and antecedent soil water conditions which are taken into consideration. In the present study, SCS method is used with GIS to estimate the runoff from Wadi Su'd watershed as a case study for agricultural watershed.

The Wadi is located in Hebron area of the West Bank, southern Palestine. The watershed having a geographical area of 1.87 square kilometer and the average annual rainfall is around 500 mm. The rainfall and land use data were used along with the experimental data of soil classification and infiltration rate for the assessment of runoff potential for the study area.

The results of the present study show that the average annual runoff depth for the study area (Wadi Su'd watershed) is 36.3 mm, and the average volume of runoff from the same watershed is 67840.2 cubic meter per year. The amount of runoff represents 7.3% of the total annual rainfall. The approach of this study could be applied in other Palestinian watersheds for planning of various conservations measures.

Keywords: Rainfall, Runoff, Watershed, SCS Curve Number, GIS.

1 INTRODUCTION

It is well known that Palestine suffers from severe water shortage problem due to natural and political reasons, and there is a necessity of searching for substantial water resources. There is consensus in most studies conducted that water harvesting is the most appropriate option for future in addition to other options. This is due to the fact that it is a considerably cheap option and there is a necessity to benefit from the water flowing into the sea during the winter season. It is also very important to state that the water harvesting projects correlate with the economic and social situation for the nations of the area.

Land degradation by soil erosion, runoff, and sedimentation, are the serious problems facing the arid and semi-arid regions in the West Bank. As a result of these problems soil tend to degraded, causing low soil fertility, in addition of the over exploitation of natural resources for agricultural production. Soil and water conservation management by different water harvesting techniques, is an effective to reduce the high intensity of runoff, and subsequently increasing soil moisture storage from rainfall, while maintaining low level of soil erosion and sedimentation.

Watershed is the area covering all the land that contributes runoff water to a common point. The problem most often encountered in hydrological studies is the need for estimating runoff from a watershed for which there is records of precipitation and no records of runoff. In Palestine, the availability of accurate information on runoff is scarcely available in most sites. However, quickening of watershed management programmed for conservation and development of natural resources management has necessitated the runoff information. Advances in computational power and the growing availability of spatial data have made it possible to accurately predict the runoff. The possibility of rapidly combining data of different types in GIS has led to significant increase in its use in hydrological applications.

An approach to solution of this problem is to compare runoff characteristics with those of watershed characteristics. Watershed characteristics which may be mostly readily compared to estimating the volume of runoff that will result from a given amount of rainfall are soil type and cover, which includes land use. Many methods are used to estimate the runoff from a watershed.
Hydrologists of the Soil Conservation Services constantly encounter the problem of estimating direct runoff where no records are available for the specific watershed. Soil Conservation Service (USDA,1985) curve number method is a well accepted tool in hydrology, which uses a land conditions factor called "the curve number". It is reliance an only one parameter and its responsiveness to four important catchment properties, i.e. soil type, land use, surface condition, and antecedent moisture condition, increased its popularity. In the present study, the runoff from Wadi Su'd watershed in Hebron area of the West Bank were estimated using SCS method with the help of GIS. It considered as a case study for small agricultural watershed.

In Palestine, the hydrological studies are limited. Some investigators have studies the hydrology of different wadis and watersheds in the West Bank and Gaza strip in order to develop additional usable water resources to help in solving future hydrological problems. Applied Research Institute of Jerusalem (ARIJ) published six articles on environmental profiles of West Bank cities. The Hebron district environmental profile shows in such area, most land is sloppy (2%-20%) and the infiltration rate is low. Consequently, low cost water harvesting could be introduced in this area. This method depends on collecting runoff water using construction such as soil dam or concrete dam.

Lange, J. et al (2000) have studies the runoff on a steep 180 m^2 Mediterranean Karts environment. To provide quantitative information, measurements are under taking on experimental hill slope plot applying artificial rainfall of predefined intensities. The results show that on a dry plot about 16 mm of rainfall was needed before terrain other bar rock generated runoff. Overall 16% of rainfall turn into runoff, while in the following day 73% of the applied rainfall arrived at the outlet of the wet plot.

The geomorphological study of Wadi Al Arroub carried out by Qannam (2000) in his master thesis shows that the topography has more effect on the drainage pattern than the structure. The relatively high relief ratio of Wadi Al Aroub drainage basin and high elongation ratio (0.78) indicate that the study area is among the sub-basins that contribute strongly to the flooding in the Dead Sea-Jordan River Basin

In the study of Mohammadin, A. et al (2003), the mount of runoff for east Bani Naim watershed in the Hebron area using soil conservation service method were calculated and estimated to be about 12% of the total annual rainfall. The study of the hydrological characteristics of different wadi's and watersheds in West Bank and Gaza Strip were carried out by different researchers. Most of them are concentrated on the study of the morphological and geological characteristics of the wadi's and the hydrochemistry of springs water available in these watersheds.

2 STUDY AREA

The study area, named Wadi Su'd, is located in the Hebron area of West Bank, southern Palestine which will known later as Wadi Su'd watershed. The watershed having a geographical area of 1.87 square kilometer, Figure (1) shows the study area and its location. Physiographically, the watershed is divided into hills, pediments. Elevation in the watershed ranges from 550 to 820 m above mean sea level. The average annual precipitation at Dura area for the last five years is approximately 500 mm. About 90% of this rainfall is received from November to April, and the major land use/land cover categories in the watershed are: pasture, agricultural area, and stony waste land (Data Obtained from Dura Municipality).

3 MATERIALS AND METHODS

3.1 Watershed Boundary, Grid Setup and Land Use

The watershed boundary was restricted and the grid to conduct the experiments in suitable sites was setup by land surveying using Navigation GPS (Magellan). The conventional land use\land cover map of the watershed was obtained by the land survey technique using (GPS), and digitized map from a rectified aerial photo for Wadi Su'd watershed.

3.2 Soil and Infiltration Tests

The Unified Soil Classification System (USCS) was adopted in this work to classify soils at different points. Sieve analysis and moisture content experiments were carried out to classify the soil samples of the project. The infiltration rate which is helped to classify the soil was measured using Double Ring Infiltrometer manufactured for this purpose.

3.3 The SCS Curve Number Method

The SCS curve number method (SCS,1972), also known as the Hydrologic Soil Cover Complex Method was developed by the Soil Conservation Service (SCS) of the U.S. Department of Agriculture for use in rural areas. It is a versatile and widely used procedure for runoff estimation. The requirements for this method are low, rainfall amount and curve number. The curve number is based on the areas hydrologic soil group, land use and hydrologic condition.

As defined by SCS soil scientists, Soils may be classified into four hydrologic groups (A, B, C and D), (USDA,1985), depend on infiltration, soil classification and other criteria. Land use and treatment classes are used in the preparation of hydrological soil-cover complex, which in turn are used in estimating direct runoff.

Antecedent Moisture Condition (AMC) is an indicator of watershed wetness and availability of soil moisture storage prior to a storm, and can have a significant effect on runoff volume. Recognizing its significance, SCS developed a guide for adjusting CN according to AMC based on the total rainfall in the 5-day period preceding a storm. Three levels of AMC are used in the CN method: AMC-I for dry, AMC-II for normal, and AMC-III for wet conditions. Table (1) gives seasonal rainfall limits for these three antecedent moisture conditions.

Table 1. Classification of Antecedent Moisture Conditions

AMC	Total 5-days Antecedent Rainfall (mm)	
	Dormant Season	Growing Season
I	<12.7	< 35.6
II	12.7 – 27.9	35.6 – 53.3
III	> 27.9	> 53.3

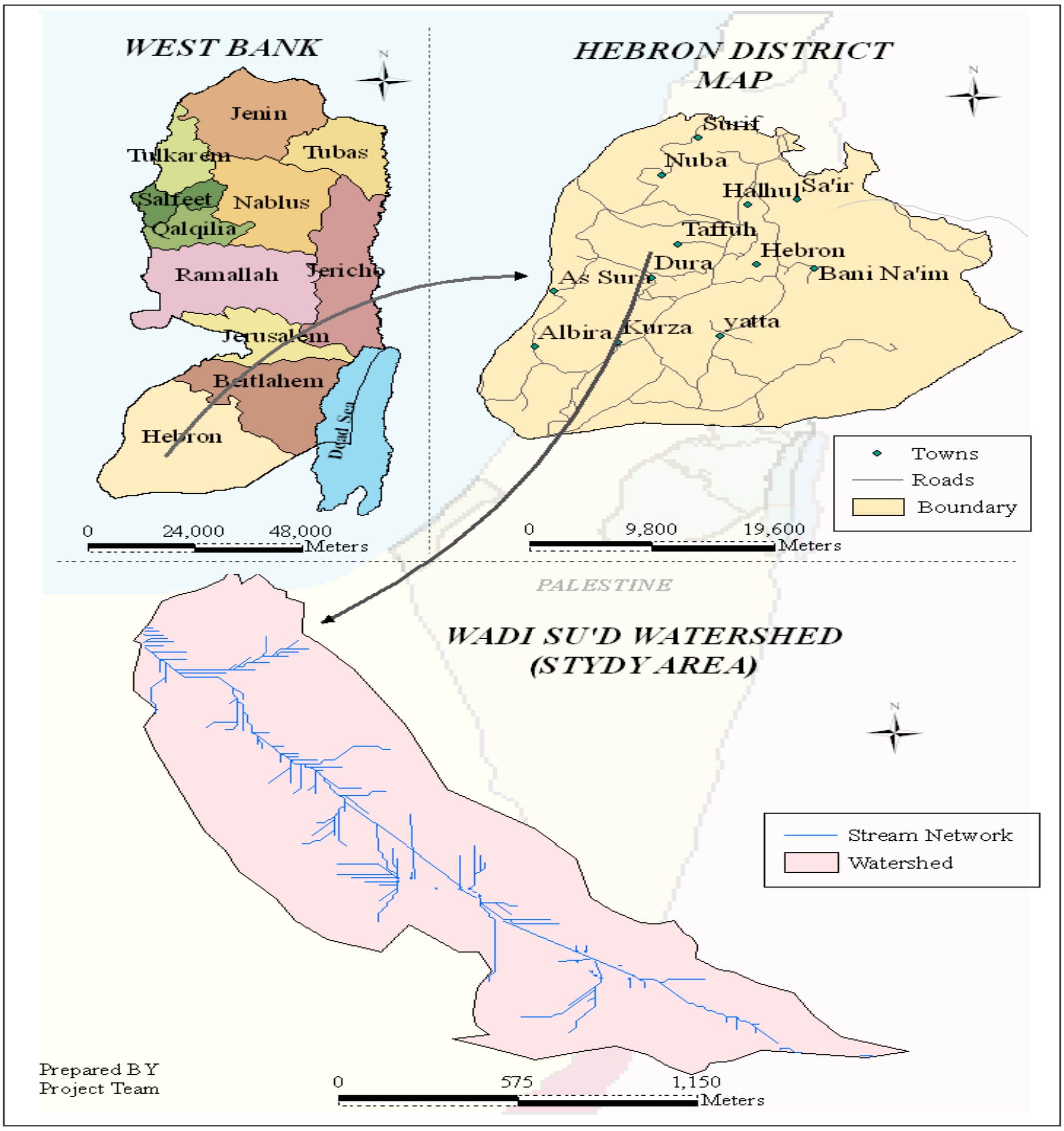

Figure 1. Location of the Study Area (Wadi Su'd Watershed)

The CN values documented for the case of AMC-II (USDA, 1985). To adjust the CN for the cases of AMC-I and AMC-III, the following equations are used (Chow, 2002):

$$CN_{(I)} = \frac{4.2 * CN_{(II)}}{10 - (0.058 * CN_{(II)})} \quad \ldots\ldots(1)$$

$$CN_{(III)} = \frac{23 * CN_{(II)}}{10 + (0.13 * CN_{(II)})} \quad \ldots\ldots(2)$$

Where, $CN_{(II)}$ is the curve number for normal condition, $CN_{(I)}$ is the curve number for dry condition, and $CN_{(III)}$ is the curve number for wet condition.

The rainfall-runoff equation used by the SCS for estimating depth of direct runoff from storm rainfall is:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad (p > 0.2S) \ldots\ldots(3)$$

Where, S is the watershed storage mm; Q is the actual direct runoff mm; and P is the total rainfall mm.

The equation has one variable P and one parameter S. S is related to curve number (CN) by

$$S = \frac{25400}{CN} - 254 \quad (4)$$

Where CN is a dimensionless parameter and its value range from 1 (minimum runoff) to 100 (maximum runoff). It is determined based on hydrologic soil group, land use, land treatment, and hydrologic conditions.

4 RESULTS AND DISCUSSION

4.1 Land Use and Land Cover

Three land use and land cover classes were categorized in the watershed as given in Table (2). The land use and land cover map for Wadi Su'd watershed is shown in Figure (2).

Table 2. Classes of Land Use/Cover of the Study Area

Land Use	Area (m^2)	Percentage of Area (%)
Agricultural	1304954.00	69.82
Pasture	531652.10	28.45
Residential	32269.60	1.73
SUM	**1868876**	**100**

4.2 Soil Classification

According to laboratory soil testing result, the soil of Wadi Su'd watershed can be classified into four types; well-graded sand, poorly-graded sand poor-clay and silt clay, distributed at the watershed as shown in Table (3) and Figure (3).

Table 3. Classification of Soil in the Study Area

Soil classification	Area (m^2)	Percentage of Area %
Silt-clay	195960.9	10.1
Poor-Clay	302170.4	16.6
Well-Sand	312363.7	16.7
Poor-Sand	1058381	56.6
SUM	**1868876**	**100**

4.3 Infiltration Rate

The measured values of infiltration rates, using a Double Ring Infiltrometer (DRI) at 23 sites covering different land use types, are interpolated in ArcGIS.9 and the infiltration rate for Wadi Su'd watershed is shown in Figure (4).

4.4 Estimation of Surface Runoff

By using the data of soil classification and infiltration rates, Wadi Su'd watershed was classified into four hydrological soil groups: Group D with infiltration rate (0-1) mm/hr, Group C (1-4) mm/hr, Group B (4-8) mm/hr and Group A (8-12) mm/hr based on grade condition of the soil (poorly or well graded). This logical condition is applied in ArcGIS.9, and the hydrologic soil group classification are given in Table (4) and displayed in Figure (5).

Table 4. Classification of Hydrological Soil Group

Hydrologic Soil Group	Area (m^2)	Percentage of Area %
Group (D)	195960.9	10.1
Group (C)	302170.4	16.6
Group (B)	312363.7	16.7
Group (A)	1058381	56.6
SUM	**1868876**	**100**

To create and detect the curve number values for each classified area; the hydrological soil group and the land use and land cover results were used. By applying expression in ArcGIS.9 and evaluating this expression, the curve number can be determined. The values of curve number for each area are presented in Table (5). The curve number map for Wadi Su'd watershed is shown in Figure (6).

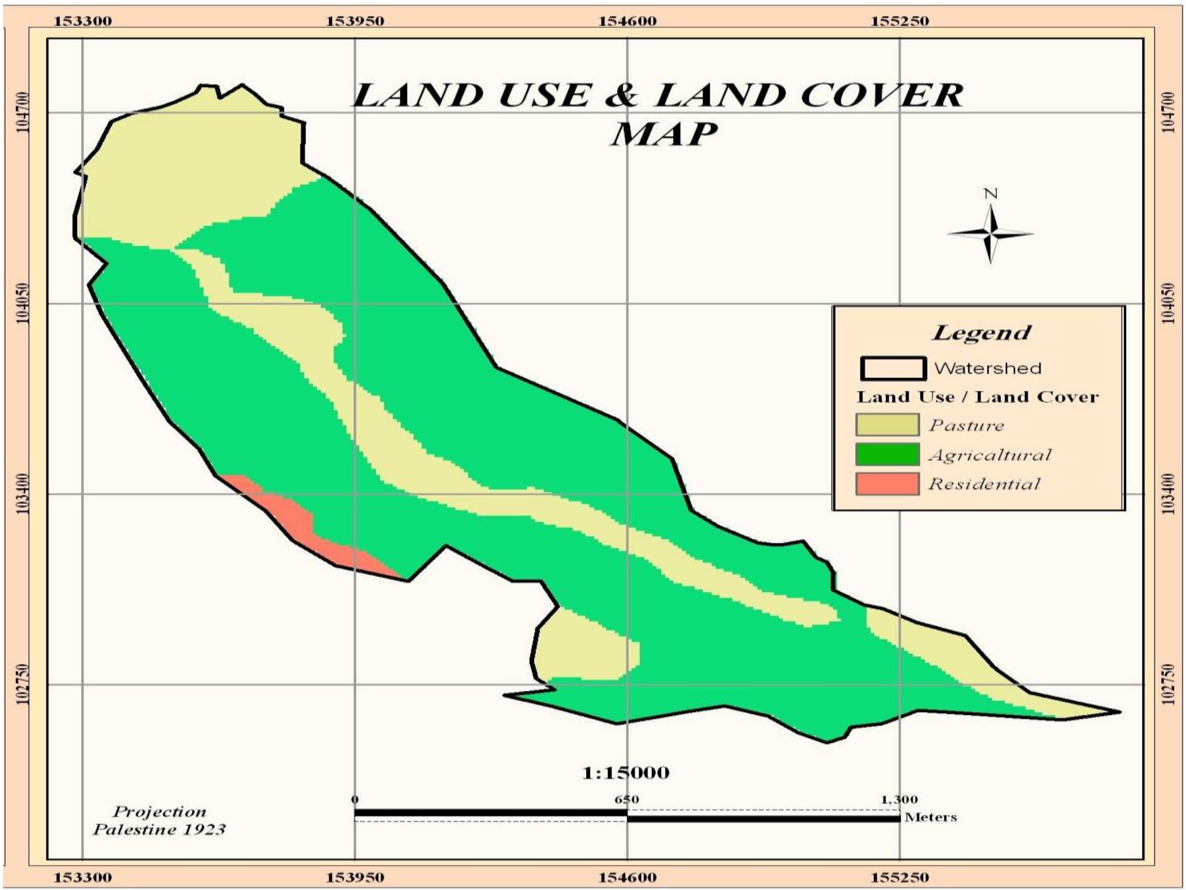

Figure 2. Land Use and Land Cover Map for Wadi Su'd Watershed

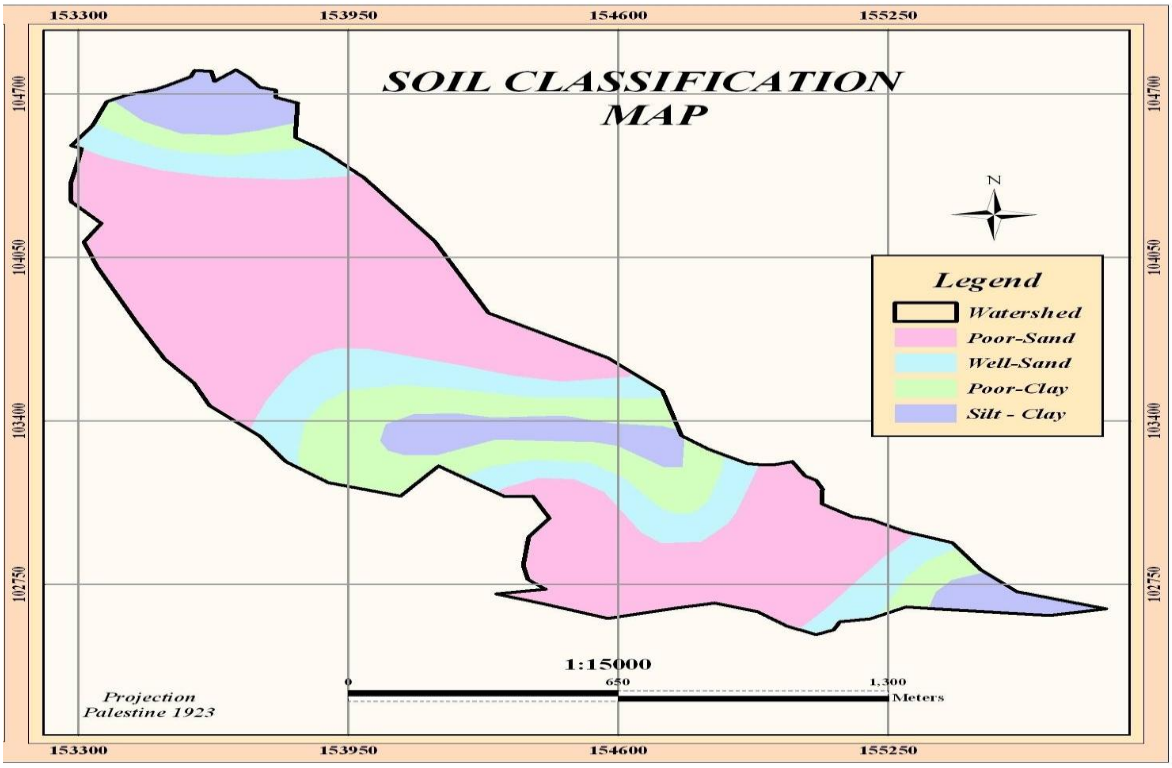

Figure 3.Soil Classification Map for Wadi Su'd Watershed

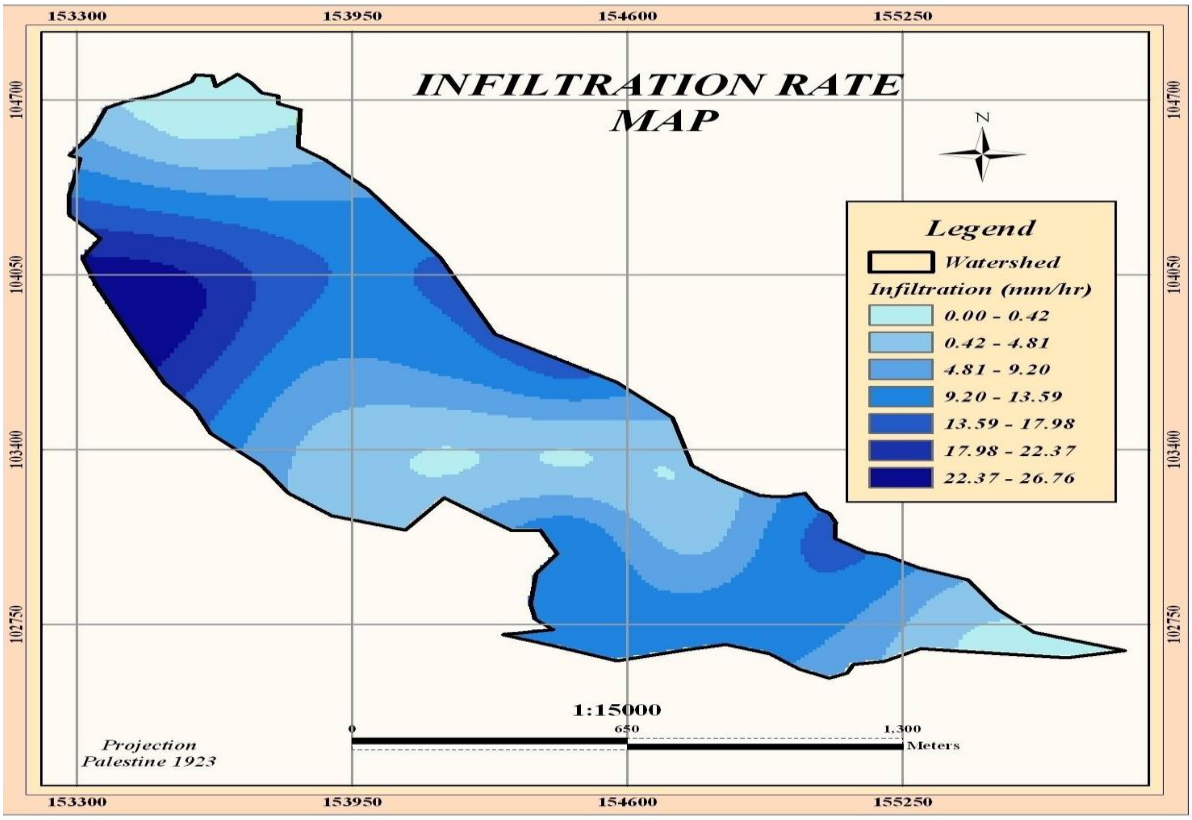

Figure 4. Infiltration Rate Map for Wadi Su'd Watershed

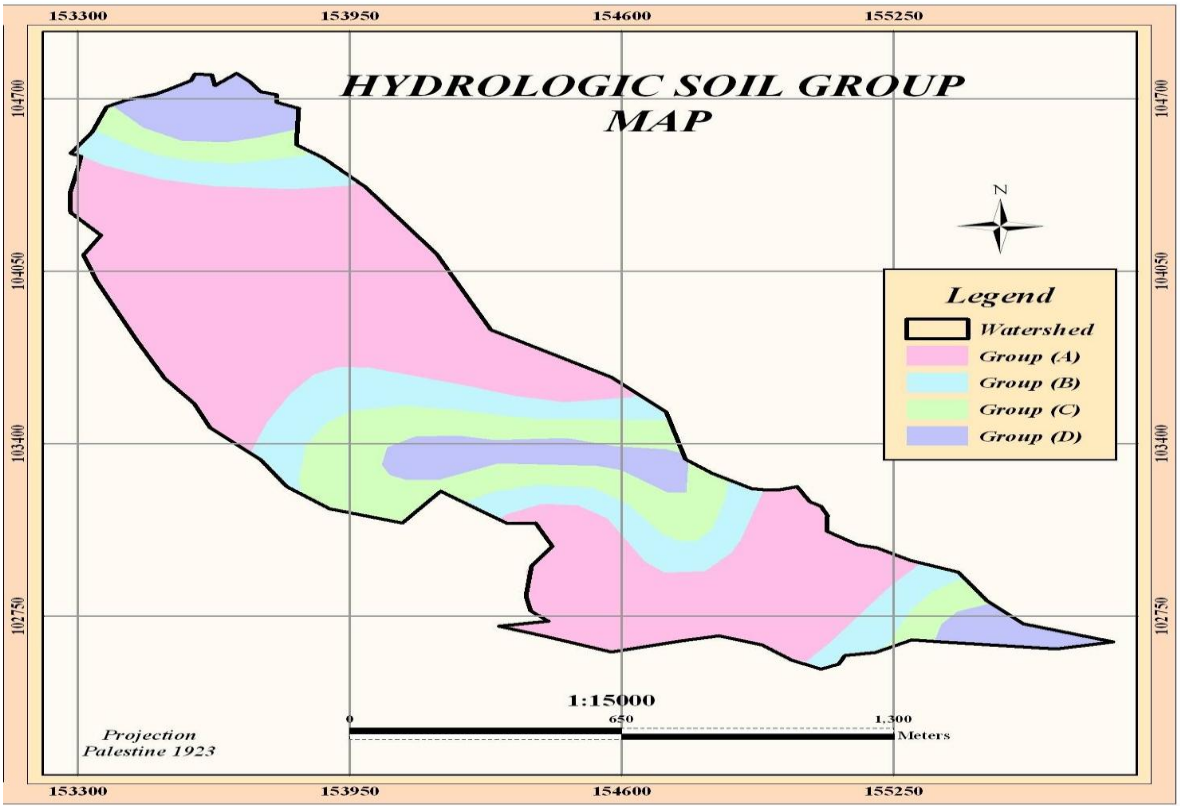

Figure 5. Hydrological Soil Group Map for Wadi Su'd Watershed

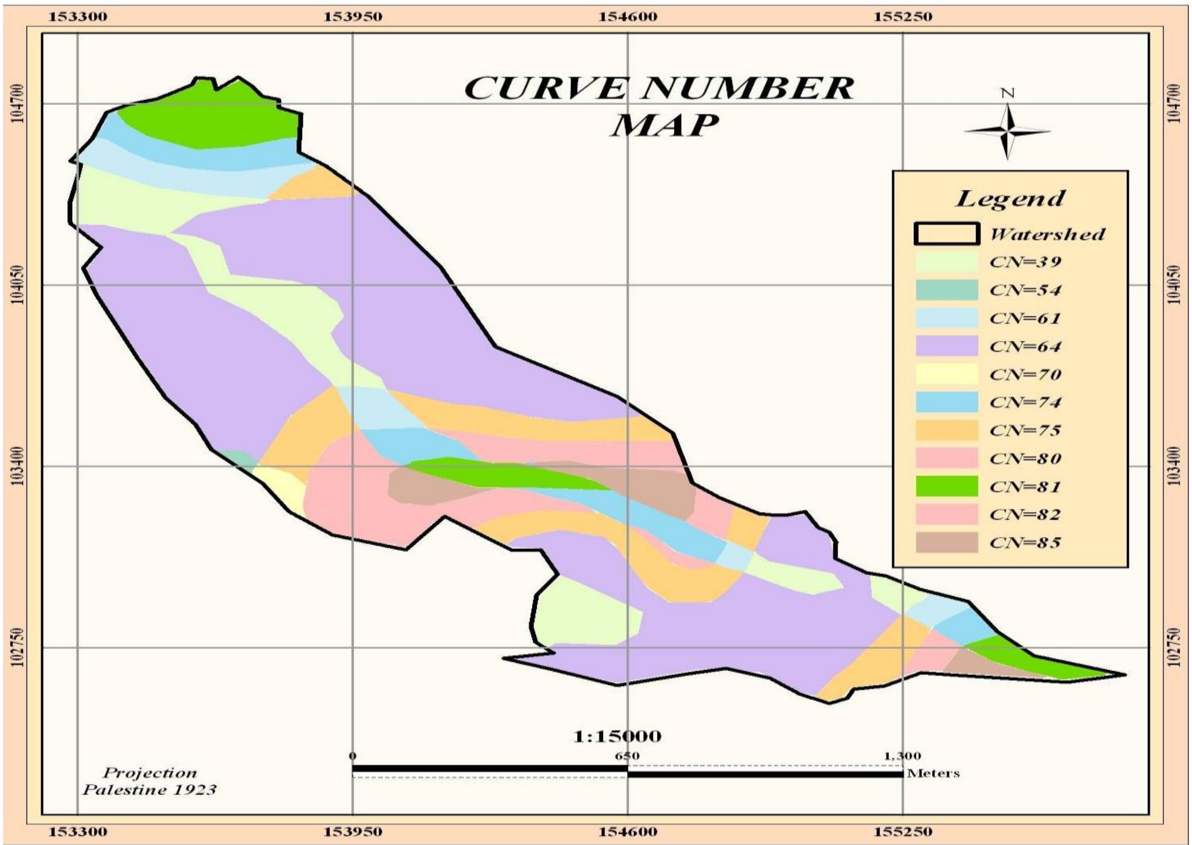

Figure 6. Curve Number Map for Wadi Su'd Watershed

Table 5. Values of Curve Number (CN)

Land Use	Hydrologic Soil Group	*(CN)*	Area(m^2)	Percentage of Area %
Agricultural	(A)	64	844260	45.1
	(B)	75	213430.1	11.4
	(C)	82	175444.88	9.4
	(D)	85	77200	4.2
Pasture	(A)	39	204092.6	10.9
	(B)	61	87300.52	4.7
	(C)	74	114856	6.14
	(D)	80	123224.1	6.6
Residential	(A)	54	4599.25	0.25
	(B)	70	11686.7	0.63
	(C)	81	12783.1	0.68

Based on the data given in Table (5), the composite curve number was found by using the following equation,(USDA,1985)

$$CN = \frac{\sum A_i * CN_i}{\sum A_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Where, CN is the composite curve number, A_i is the area for each curve number.

The composite curve number for the study area (Wadi Su'd watershed) is:

$$CN = \frac{116318101.80}{1868876.00} = 62$$

The CN is rounded 62 as the normal condition (AMCII), CN for the other two condition; the dry condition (AMCI) and the wet condition (AMCIII) were obtained using equations (1) and (2)

$$CN_{(I)} = \frac{4.2 * 62}{10 - (0.058 * 62)} = 41$$

$$CN_{(III)} = \frac{23 * 62}{10 + (0.13 * 62)} = 79$$

The values of curve number for the three antecedent moisture conditions are listed in Table (6).

Table (6): Curve Number for Three Antecedent Moisture Conditions

AMC	I	II	III
CN	41	62	79

To calculate the surface runoff depth, apply the hydrological equations (3) and (4). These equations depend on the value of rainfall (P) and watershed storage (S) which calculated from adjusted curve number. Thus, before applying equation (3) the value of (S) should be determined for each antecedent moisture condition (AMC) as shown below. There are three conditions: These results are summarized in the Table (7)

Table 7. Values Used in Hydrological Equations

AMC	CN	S	P>0.2S
I	41	365.512	73.102
II	62	155.677	31.135
III	79	67.519	13.504

The Rainfall data and the result of surface runoff depth for the last five rainfall seasons in the study area were obtained, and the result of season 2005/2006 as an example is presented in Table(8).

Table 8. Runoff Depth in the Study Area for Season (2005/2006)

Year	Months	Day	Storm Rainfall (mm)	Antec.Rainfall (mm)	AMC	(CN)	(S)	Runoff by Day (mm)
2005/2006	**10**	29	10	0	I	41	365.512	0
	11	17	31	0	I	41	365.512	0
		19	10	31	III	79	67.519	0
		22	27.5	41	III	79	67.519	2.4
		23	87.8	37.5	III	79	67.519	38.92
		27	49.7	115.3	III	79	67.519	12.63
	12	7	9	0	I	41	365.512	0
		8	6	9	I	41	365.512	0
		16	15.5	0	I	41	365.512	0
		25	28	0	I	41	365.512	0
	1	3	36.6	0	I	41	365.512	0
		4	29	36.6	III	79	67.519	2.89
		6	47	65.6	III	79	67.519	11.11
		24	45	0	I	41	365.512	0
	2	5	4	0	I	41	365.512	0
		7	20	4	I	41	365.512	0
		8	24	24	II	62	155.677	0
		9	23.6	48	III	79	67.519	1.31
		11	13	67.6	III	79	67.519	0
		12	11	80.6	III	79	67.519	0
	3	8	12.1	0	I	41	365.512	0
		9	26	12.1	I	41	365.512	0
		10	8	38.1	II	62	155.677	0
		11	4	46.1	II	62	155.677	0
	4	3	8	0	I	41	365.512	0
		4	4	8	I	41	365.512	0
SUM		**62**	**589.800**					**66.86**

As a result of the calculations, based on the SCS method, it was found that the average annual surface runoff rate (depth) for the last five years in Wadi Su'd watershed is equal to 36.3 mm multiple by the area of the watershed (A=1868876m^2) gives the total average volume of runoff as (67840.2 m^3), which represents 7.3 % of the total annual rainfall. The annual rainfall and runoff during (2000-2006) in the study area are shown in Table (9).

Table 9. The Average Annual Runoff Depth and Volume in the Study Area.

Years	Total Rainfall (mm)	Total Runoff (mm)	Runoff Percentage	Volume (m^3) Runoff × Area
2000/2001	610.4	95.86	15.7	179150.45
2001/2002	492.6	10.456	2.12	19540.96
2002/2003	645.3	27.69	4.3	51749.17
2003/2004	374.7	15.93	4.25	29771.19
2004/2005	589.8	66.86	11.34	124953.0
2005/2006	287.8	0.799	0.28	1493.23
Average	**500**	**36.3**	**7.3**	**67840.2**

The direct runoff in Wadi Su'd watershed (study area) resulting from a given precipitation and antecedent moisture condition can be estimated using an appropriate curve number shown in Figure (7).

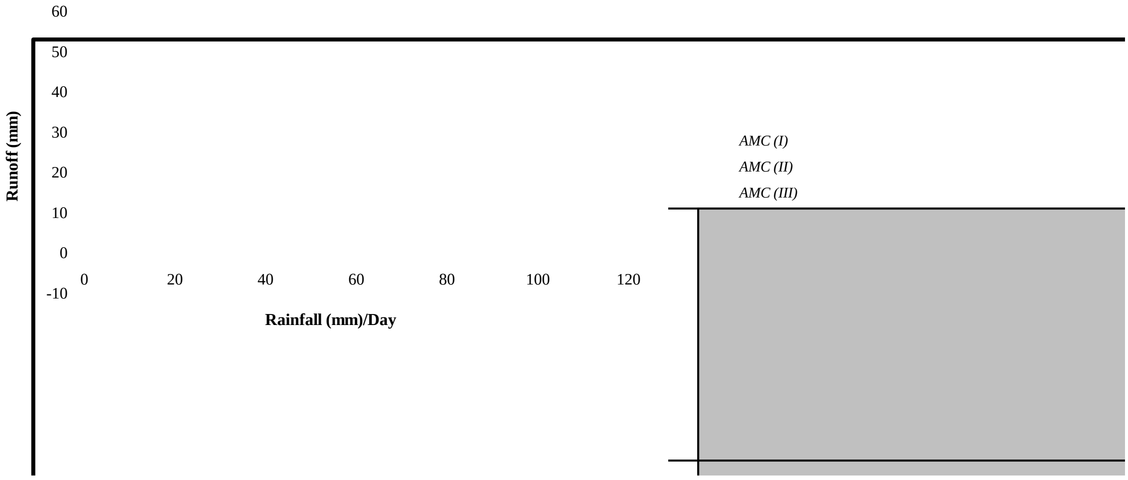

Figure 7. Estimation Direct Runoff Amounts from Storm Water

The final result in this study determine the water balance parameters of Wadi Su'd watershed in Dura area whereas the precipitation (500 mm/year) is the main input parameter in the water balance and the average monthly evaporation of the Dura whether station is around 60 mm/ month in the winter season (60 X 6 = 360 mm), estimated run off (36.3 mm), and calculated infiltration 103.7 mm (500 – 360 – 36.3 = 103.7) are the major output parameters. The results of water budget in the study area are shown in Figure (8).

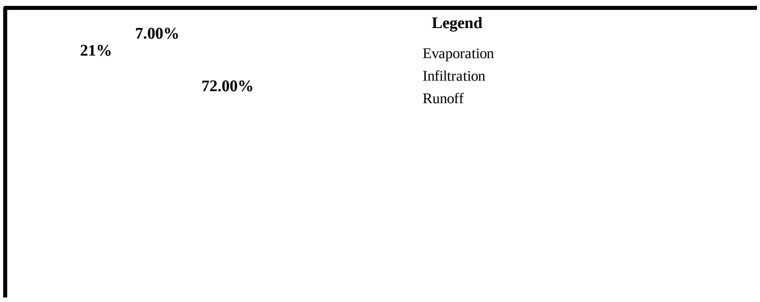

Figure 8. Water Balance of Wadi Su'd Watershed

5 CONCLUSIONS

Since there was no runoff observations available from Wadi Su'd watershed or any other watershed in the Hebron area, the results could not be compared with the measured values.

Based on the results of soil classification, infiltration rates and land use, the study area was classified into four hydrologic soil groups. The composite curve number for normal condition is 62, where for the dry and wet conditions are 41 and 79 respectively.

The calculations and results, based on the SCS method, shows that the average annual runoff depth for the last five years in Wadi Su'd watershed is equal to 36.3 mm, and if the total area of the watershed is 1868876 m^2, the total volume of water that can be collected is around 67840.2 cubic meter, which represents 7.3 % of the total annual rainfall.

The results determined the water balance parameters for Wadi Su'd watershed as, precipitation 500 mm (100%), evaporation 360 mm (72%), infiltration 103.7 mm (21%) and surface runoff 36.3 mm (7%).

In the present study, the methodology for determination of runoff for Wadi Su’d using GIS and SCS method was described. This approach could be applied in other Palestinian watersheds for planning of various conservations measures

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