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Watershed modelling development for generating runoff estimation of Sarida Catchment/Central West Bank

Marwan Ghanem (ID) **· Muath Abu Sadah ·**
Yacoub Keilani

Abstract Watershed modelling was carried out in Sarida Catchment in the West Bank (Palestine) in order to determine the physical characteristics of the watershed. Generated storm water and runoff were estimated for watershed sub-catchments for enhancing the potentiality of rainwater harvesting development. Climatic data across eight years (seven wet seasons) were used for watershed modelling by using the software application systems of Watershed Modelling and Hydrologic Modelling. The Geographical Information System (GIS) and Microsoft Excel were used as well for the estimation of different model parameters and features. The physical and meteorological characteristics for each sub-catchment including land use, topography, soil, rainfall, and other parameters were identified. The model results provided sensitive conceptual principles for understanding the runoff mechanisms in the watershed. The average generated storm water over the seven seasons (2008/09 to 2014/15) is 23.16 and 13.44 Mm^3/year for northern and southern sub-catchments in Sarida watershed, respectively. The generated runoff of the sub-catchments over this period ranged between 2.13 and 23.18 million cubic meters per year. The results suggest a high potential for rainwater harvesting to promote agricultural development and the need to establish a climatic monitoring network in Sarida watershed, as well as in other catchments in the West Bank, for better informing watershed management practices and policies.

Keywords Surface modelling · Watershed · Sarida · Runoff

M. Ghanem (✉)
Birzeit University, P.O. Box 14, Ramallah, Palestine
e-mail: marwan.ghanem2012@gmail.com

M. Abu Sadah
Hydro-Engineering Consultancy, Ramallah, Palestine
e-mail: muath@hydro-pal.com

Y. Keilani
Ministry of Agriculture, Ramallah, Palestine
e-mail: keilani90@yahoo.com

Introduction

Watershed management is an adaptive, comprehensive, and integrated multi-resource management planning process that seeks to balance healthy ecological, economic, and cultural/social conditions within a surface catchment (Wang et al., 2016). It takes into account both ground and surface water flow, recognizing and planning for the interaction of water, plants, animals, and human land use within the physical boundaries of a watershed (Maliwal, 2020). Watershed and runoff management, combined with reclaiming water from pollution sources, plays a significant role in agricultural practice in drought-prone regions in order to protect the crops from stress during the growth period (Slayback & Renney, 1972). A watershed is not simply a hydrological unit but also

socio-political–ecological entity which plays crucial role in determining food, social, and economic security and provides life supporting services to rural communities. The size of watershed is preferred to be small in areas of intensive agricultural development (Weslati et al., 2020). Geological formations control the topographic features of the catchment as well as the soil and surface features of the watershed which act as an important function for watershed management (Izadi et al., 2020).

The West Bank is a water-scarce lower-middle-income territory with a relatively water-dependent economy and complicated geopolitical boundaries. For the West Bank, water security requires adequate well-managed water resources, including management of risks, and water service providers that provide sustainable, efficient, and equitable services (World Bank, 2018). Water governance in the West Bank deals with the steering, organization, and guidance of water resources management, water quality, and socio-political status (Judeh et al., 2017). Agriculture is of vital importance to the West Bank, but irrigated agriculture constitutes only 6% of the total cultivated areas (MoA, 2018). The application efficiency for irrigation systems in the West Bank is relatively high, which is not due to good management but mainly due to the shortage of water in most of the irrigated areas (MoA, 2018). Water resources in Palestine are scarce and under the threat of depletion and degradation by land use activities (e.g., dumping and poorly regulated industries), the lack of infrastructure to prevent deterioration (e.g., adequate wastewater treatment and solid waste management), and a lack of resource management plans (Thawabta, 2006).

The gap between water supply and demand in the West Bank is increasing as a result of socio-economic growth, continued Israeli control on the Palestinian water resources, and the impacts of climate change, and insufficient water has constrained sustainable development (PWA, 2011). Rainwater harvesting is one approach to stretch available water resources for household and agricultural purposes. By drawing upon the techniques of water poverty mapping (an easy and effective way to map the spatial distribution of water-poor agricultural areas), agricultural rainwater harvesting suitability mapping is an approach to identify potential locations where the implementation of harvesting techniques would be both viable and valuable (Thakur et al., 2017). The objective of

the study is to develop a numerical model for Sarida watershed by using the estimated storm water across eight years of available data (2008–2015), or seven wet seasons. The results from this study aim to aid decision makers in building their strategies for enhancing the water harvesting techniques in Palestine and will serve to determine the physical and climatic characteristics of Sarida watershed as a case study within the West Bank watersheds.

Study area

Sarida catchment is one of the largest western watersheds within Palestine, located in the central part of the West Bank. It starts from the western side of Ramallah mountains with an area of 571 km^2 (Fig. 1). The watershed is highly populated with more than 260,000 inhabitants living in 79 communities (PCPS, 2016). The studied catchment, which includes the city of Salfit, and villages of Kafr Al-Dik and Bruqin, is located in the middle of the northern part of West Bank, about 20 km to the south-west of the city of Nablus, between latitude of 32°, and longitude of 35° (LRC, 2008), with an altitude of 250–570 m above sea level. The climate of Sarida watershed is classified as semi-arid, and governed by Mediterranean climate including rainy winters with moderate temperature, while summers are dry and hot. The wind is northwesterly and southwesterly with 237 (km/day) speed average, and the atmospheric pressure is high (ARIJ, 2011). The seasonal stream, Sarida Wadi, is about 12 km long and is considered as a strategic replenishment resource for the Palestinian Western aquifer basin. This Wadi is negatively affected by poorly treated and untreated wastewater from Salfit and the Israeli colony of Ar'el. The study area lies within the western aquifer basin and is composed of Cenomanian–Turonian limestone which is karstic nature due to the dissolution process of the limestone system (Issar, 2000).

Methodology and material

Under conditions of highly diverse geology, relief, vegetation, and land use, the complexity and variability of spatially distributed hydrological processes remain a modelling challenge in many regions around the world. Several previous studies contributed
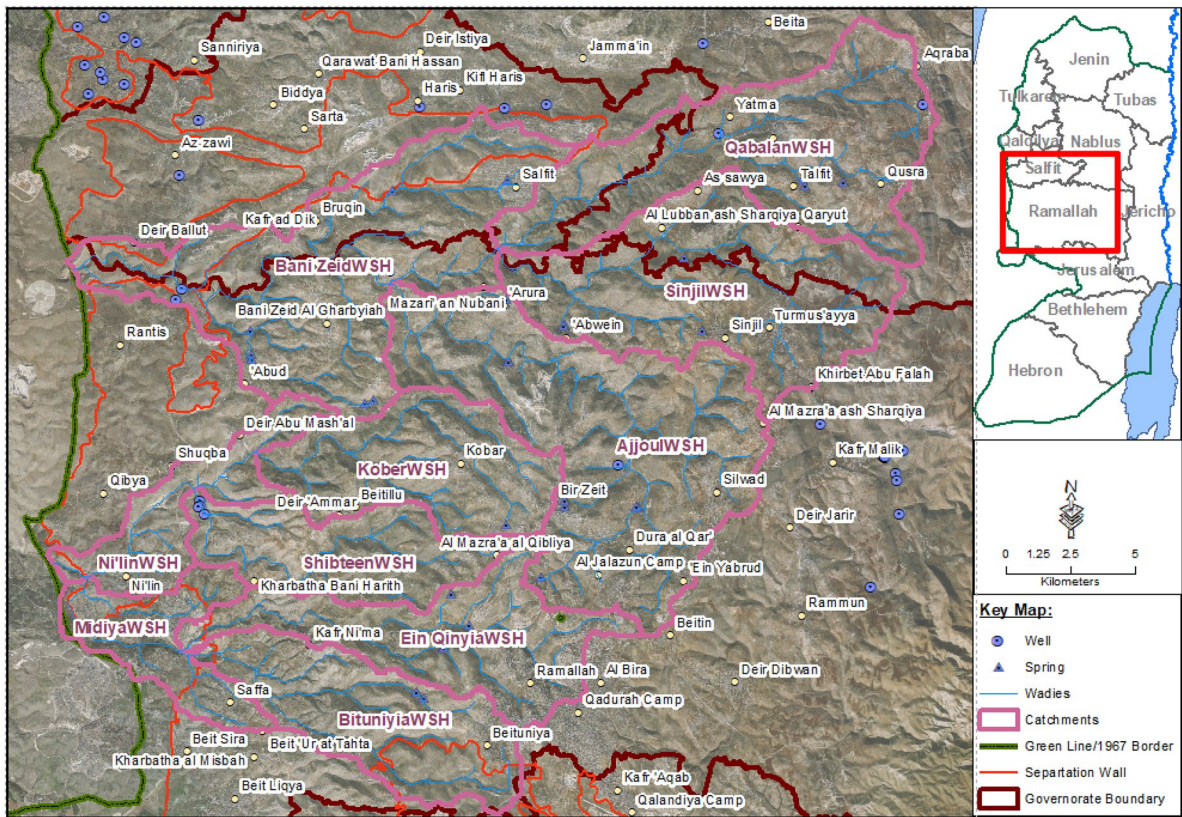
Fig. 1 Location Map of Sarida watershed as well as its sub-catchments

critical components to the development of the Sarida watershed model. A GIS-based SCS-CN approach was developed by Shadeed and Masri (2010) to calculate the composite curve number of West Bank catchments and can be considered applicable to the Sarida catchment as well. Groundwater vulnerability mapping and assessment was carried out using the GLA method in order to account for the pollution sources affecting vulnerable regions in two adjacent catchments (Sarida and Natuf) (Ghanem et al., 2017). The results showed that the study area has high effectiveness of protective cover (P-factor), which was obtained by overlying topsoil, bedrock, subsoil, and recharge layers. Additionally, Messerschmidt et al. (2020) found that the karst aquifers in the neighboring Natuf catchment showed recharge coefficients (RC) above 40% and even the less prominent slightly aquitardal local aquifers reached RC values above 30%. Given the similar hydrogeologic conditions of

the Sarida watershed, the results from Natuf can be used here.

Two software applications were used for developing the Sarida watershed model: Watershed Modelling System (WMS) and Hydrological Engineering Center—Hydrologic Modelling System (HEC-HMS). Moreover, Geographical Information System (GIS) and Microsoft Excel were also used for estimating model parameters and features for the model. The WMS is developed by the Environmental Modelling Research Laboratory (EMRL) at Brigham Young University, and it is a comprehensive graphical modelling environment for all phases of watershed hydrology and hydraulics. It includes powerful tools to automate modelling processes such as basin delineation, geometric parameter calculations, and GIS overlay computations (CN, rainfall depth, roughness coefficients). The WMS supports hydrologic modelling with HEC-1 (HEC-HMS), TR-20, TR-55,

Rational Method, NFF, MODRAT, and HSPF. The Hydrologic Modelling System (HEC-HMS) is developed by the Hydrologic Engineering Centre of the US Army Corps of Engineers in Davis, CA, and it is designed to simulate the complete hydrologic processes of dendritic watershed systems. The software includes many traditional hydrologic analysis procedures such as event infiltration, unit hydrographs, and hydrologic routing. HEC-HMS also includes procedures necessary for continuous simulation including evapotranspiration, snowmelt, and soil moisture accounting.

There are seven weather stations (rain gauges) installed by the Palestinian Meteorological Department (PMD) within the Sarida watershed. Their records were used to describe the climatic conditions of the study area.

Precipitation

Winter is the wet season in Palestine and is typically influenced by the Mediterranean front and is characterized by long rainfall duration and low rainfall intensity. The annual average rainfall during years 2008 to 2015 at the weather station located in Birzeit (inside the boundary of Sarida Watershed) is estimated to be 744.5 mm where about 92% of the annual rainfall occurs between November and March months (PMD 2016). In October and April, precipitation is usually very low, while in May and September, rainfall is rare. June, July, and August months are almost entirely without rain. Figure 2 and Table 1 describe the characteristics of precipitation in the Birzeit weather station for the 8-year period of 2008 to 2015.

Temperature

Generally, temperatures in the West Bank vary according to the geographical position, altitude, exposure to marine influences, etc. Throughout the West Bank, the hottest days of the year occur in the month of August. The average monthly temperature within Sarida watershed during summer months (June, July, August, and September) is within the range of 23.2 °C, while the mean monthly temperatures during
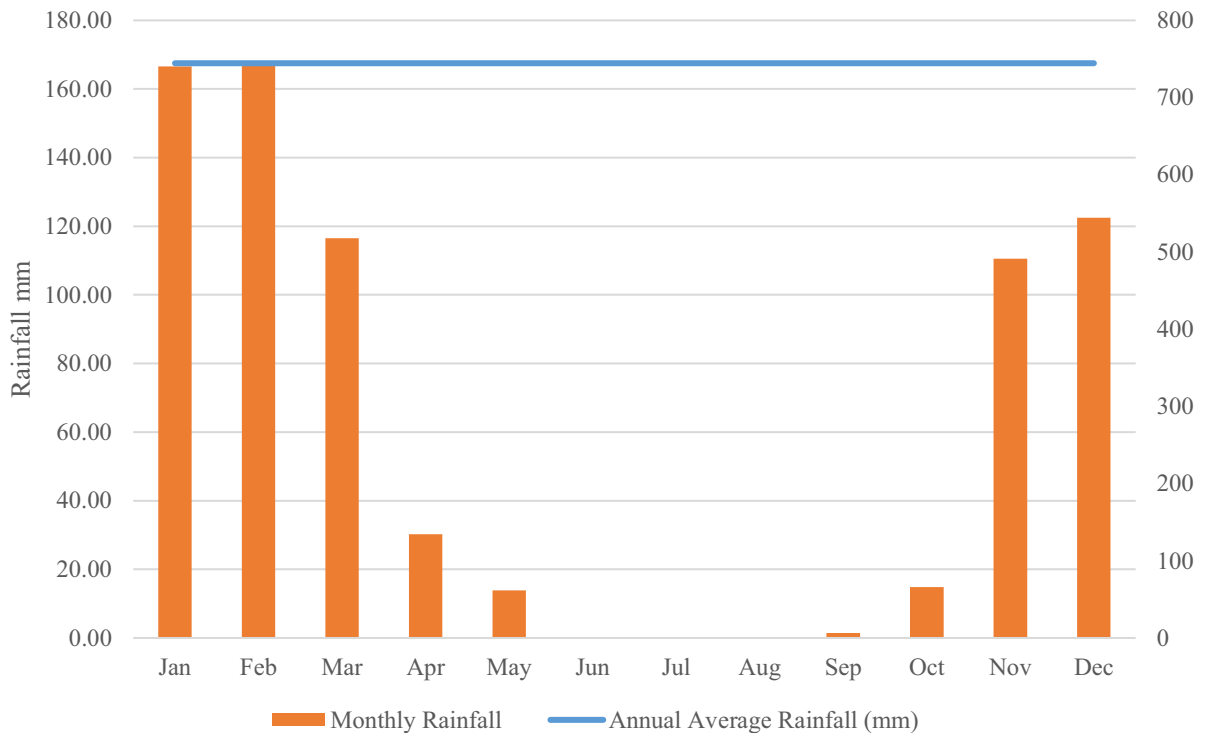

Fig. 2 Monthly and annual average of rainfall distribution at Birzeit station for the period 2008–2015

Table 1 Rainfall characteristics during years 2008–2015 at Birzeit Station; analysis is based on PMD (2016) database

No. of rainy days				Max. daily rainfall	Total monthly rainfall (mm)				Item
%	Min	Max	Avg		%	Min	Max	Avg	
17.20	2	12	5.4	142	22.38	9.4	271	166.60	Jan
20.38	3	11	6.4	203	22.58	25.8	322	168.10	Feb
14.65	2	8	4.6	160	15.65	5	238	116.50	Mar
6.69	0	6	2.1	42	4.06	0	95.9	30.20	Apr
1.91	0	2	0.6	58	1.87	0	68	13.90	May
0.00	0	0	0	0	0.00	0	1.1	0.00	Jun
0.00	0	0	0	0	0.00	0	0	0.00	Jul
0.00	0	0	0	0	0.00	0	0	0.00	Aug
0.32	0	1	0.1	9.8	0.19	0	5	1.40	Sep
4.14	0	3	1.3	45.3	1.99	0	58.1	14.80	Oct
14.97	0	11	4.7	98.3	14.84	0	88.8	110.50	Nov
19.75	2	10	6.2	94.9	16.45	51.1	167	122.50	Dec
100	na	na	31.4	na	100	na	na	744.5	Total

na not available.

winter months (December, January, February, and March) is 10.4 °C (Table 2; Fig. 3).

Digital elevation model

Sarida watershed lies on the western side of the West Bank which are characterized by high slopes in the eastern and northern sides of the watershed to gentle slopes in the north-western sides (Figs. 4 and 5). Its elevation is ranging between 200 m above sea level in the northern side to 1000 m above sea level in the eastern side.

Table 2 Temperature characteristics during years 2007–2014; analysis is based on PMD (2016) database

Mean average monthly			Item
Min	Max	Avg	
6.1	11.4	8.7	Jan
6.9	12.9	9.9	Feb
8.7	16.0	12.3	Mar
10.3	20.9	15.6	Apr
15.3	24.8	20.0	May
17.7	27.3	22.5	Jun
18.9	28.4	23.6	Jul
19.0	28.6	23.8	Aug
18.1	27.5	22.8	Sep
16.4	24.5	20.4	Oct
12.3	18.7	15.5	Nov
8.0	13.3	10.6	Dec
13.1	21.2	17.1	Avg

Land use

The land use of Sarida watershed is classified into six types: intensive urban areas, urban area, terraced orchards, scattered orchards, shrub lands, and field crops (Table 3; Fig. 6).

Soil

The dominant soil types accounting for 77% of the study area are Terra Rossas, Brown Rendzinas, and Pale Rendzinas (Table 4). Terra Rossas soil is mainly composed of shallow Terra Rossas with inclusions of Brown Rendzinas and Pale Rendzinas, in addition to numerous outcrops of limestone. The soil depth differs greatly within short distances, so that deep soils occurring in solution pockets or in hollows alternate abruptly with rock outcrops. The Brown Rendzinas and Pale Rendzinas soil is mainly composed of shallow brown Rendzinas with numerous outcrops of limestone or calcareous crust (Nari, calcrete). Shallow to moderately deep Pale Rendzinas are typical of slopes where the calcareous crust has been eroded. Grumusols, accounting for 5% of the study area, form inclusions on bottomland. Colluvial-alluvial soils occur in narrow valleys. The parent material of this soil is hard limestone and dolomite with inclusions of chalk, marls, and calcareous shales. The natural soils contained a moderate to high content of organic matter, which was destroyed as a result of cultivation and erosion. The moderately deep soils on gentle
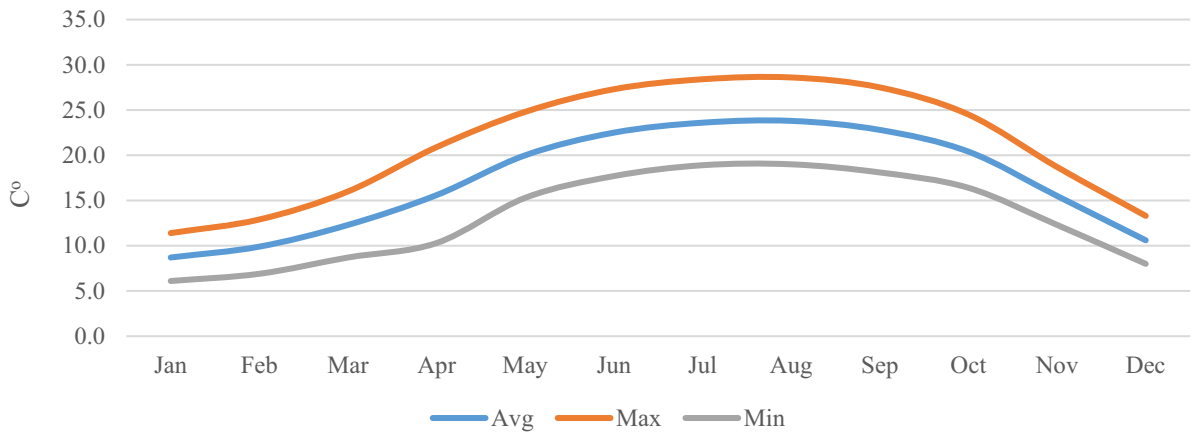
Fig. 3 Monthly average temperature distribution

mountain slopes and narrow valleys are used mainly for growing fruit, including grapes, olives, apricots, and almonds, often on terraced land; the shallow and rocky soils are left for grazing and reforestation. Valleys are cultivated for different field crops, lately with supplemental irrigation.

Watershed delineation and parameter estimations

The WMS software was used to define the boundaries of the watershed and its catchments as well as to calculate some physical parameters for each catchment using the digital elevation model (DEM), land use, and soil distributions for the basin. The land use base map was developed based on aerial photography from 2014 and the Ministry of Agriculture (MoA) soil map (MoA 2015).

Watershed delineation

The boundary of Sarida basin is defined based on a DEM with resolution 25 cm and by using the Watershed Modelling System (WMS). The estimated boundary for the basin was used as an initial boundary for the watershed in order to define the outlets of the watershed close to the western boundary of the West Bank (Fig. 7a). The WMS application used the DEM in order to define the accurate boundary of Sarida watershed. As a result, two main sub-basins were defined and named Sarida North and Sarida South sub-basins (Fig. 7b).

The two main sub-basins were also divided into sub-catchments to define the physical and meteorological characteristics for each sub-catchment including land use, topography, soil, rainfall, and other parameters. The sub-catchments for each main-sub-basin are listed in Table 5.

Calculated parameters

Based on the physical characteristics of the watershed, the WMS and GIS applications calculated different parameters for the use of surface modelling. Runoff curve number (SCS) is a simple, widely used, and efficient method for determining the approximate amount of runoff from a rainfall even in a particular area. The curve number for each catchment is estimated based on the area's hydrologic soil group, land use, and hydrologic condition. Slopes of reaches and catchments (i.e., defined by the WMS) were calculated by the WMS using the DEM of the watershed. The determination of the impervious areas (i.e., green houses, buildings, and paved roads) within each catchment is very important parameter for the surface modelling. The impervious area has high runoff coefficient since minor infiltration will be occurred during rainfall storms. Consequently, the GIS was used to estimate the areas of buildings, paved roads, greenhouses, and other sealed areas within each catchment. As a result, the percentage of impervious areas within each catchment was determined.
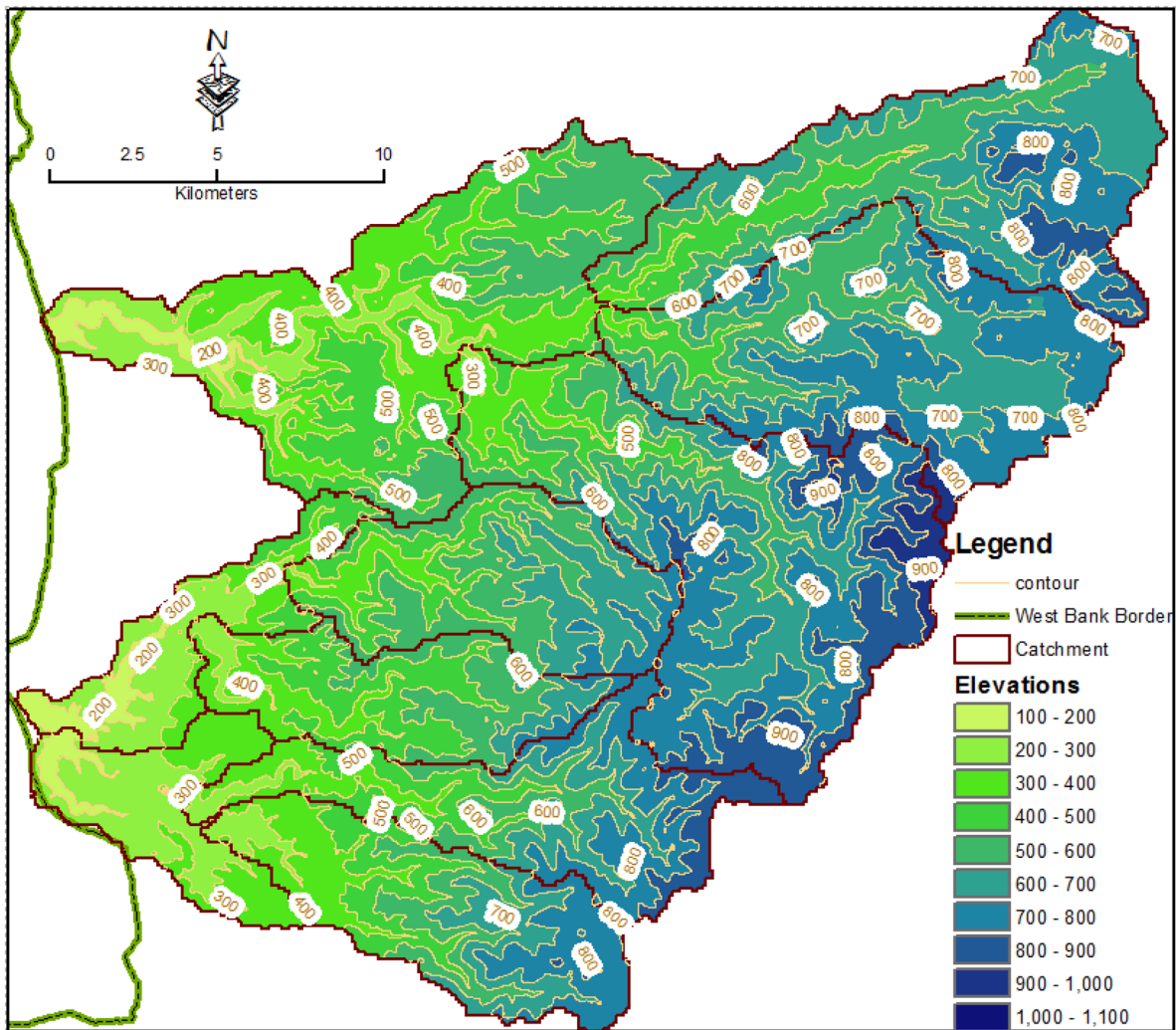
Fig. 4 Topographic map of Sarida watershed

Results and discussions

Numerical model and model setup

The HEC-HMS software was used to develop surface water model for Sarida watershed, and this application was linked with WMS. Consequently, the model components (i.e., basins, reaches, junctions) with all estimated parameters were transferred to the HMS model. All process (e.g., losses, transform, routing) and their parameters as well as meteorological data are estimated. According to the model delineation, two main sub-basins were

defined: Sarida North and Sarida South sub-basins. These two sub-basins are divided into four and six sub-catchments for northern and southern sub-basins, respectively (Fig. 8). Each sub-catchment was presented by sub-basin and reach elements, and the reach of each catchment is connected with a junction element as the outlet of each catchment. In some cases, two reaches were connected to the same junction (e.g., Qabalan and Sinjil catchments); as a result, the generated flow from the two catchments was accumulated and then flow together to the downstream watershed (e.g., Bani Zeid catchment).
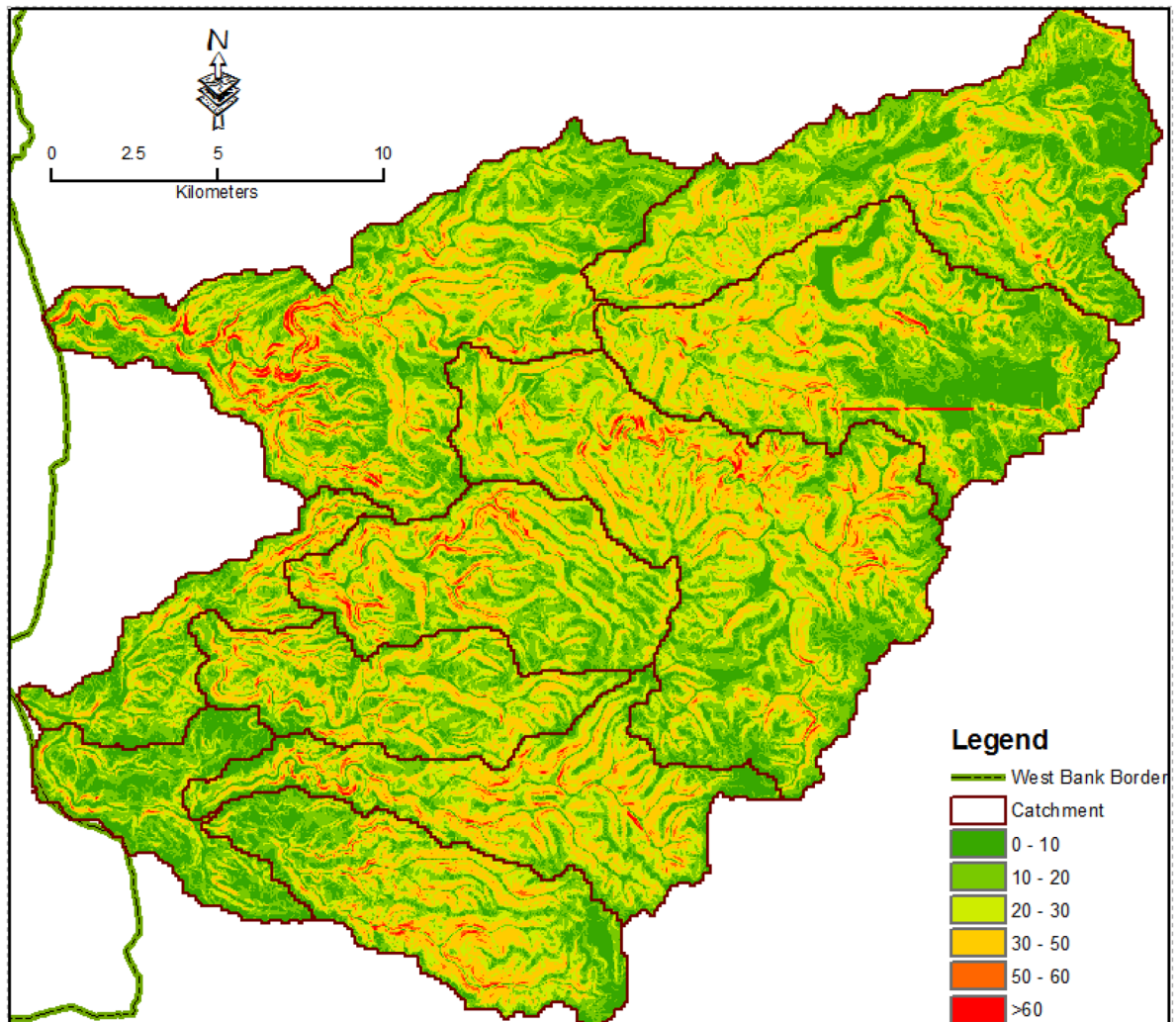
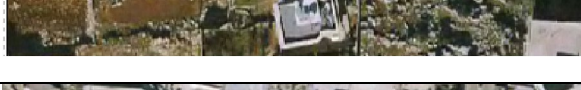**Fig. 5** Slope map of Sarida watershed (%)

Setting model processes

The physical parameters for each catchment including catchment area, slope, reach length, curve number, and lag time were estimated using the WMS application. In HMS-HEC model, selecting the appropriate processes and their parameters for each model element is a major step for setting up the model.

Catchments process

In sub-basin element, two processes are defined: the loss and transform methods. The loss method represents infiltration, surface runoff, and subsurface

processes interacting together. The actual infiltration calculations are performed by a loss method contained within the sub-basin. The sum of infiltration and precipitation left on the surface will always be equal to total incoming precipitation. In this model, the "Deficit and Constant" method was selected. The deficit constant loss method uses a single soil layer to account for continuous changes in moisture content. This method is used in combination with a meteorological model that computes evapotranspiration. Consequently, the potential evapotranspiration computed by the meteorological model is used to dry out the soil layer between precipitation events. This method is assumed that infiltration only occurs when the soil

Table 3 Land use distribution in Sarida watershed.

Landuse	Area (Km^2)	Area (%)	
Field Crops	10	1.75%	
Orchards scattered/ not-organized	161	28.20%	
Orchards terraces/ organized	17	2.98%	
Scrublands	260	45.53%	
Urban areas	101	17.69%	
Intensive urban areas	21	3.68%	
Sum=	571	100.00%	

layer is saturated. There are four parameters requested by this method: the initial deficit (mm), maximum deficit (mm), constant rate (mm/hr), and impervious area (%). Consequently, no loss calculations were carried out on the catchment area; all precipitation of the sub-basin becomes excess precipitation and subject to direct runoff. In this model, 85% of the building and paved roads are considered as an impervious areas.

The transform method is used to calculate the actual runoff within each sub-basin. A total of seven different transform methods are provided in the HEC-HMS application. The unit hydrograph method is selected for this model. This method was originally developed from the observed data collected in small, agricultural watersheds. Accordingly, the general hydrograph is scaled by the time lag to produce the unit hydrograph for use. The standard lag is defined as the length of time between the centroid of precipitation mass and the peak flow of the resulting hydrograph. Studies by the USDA Natural Resources Conservation Service (2018) found that in general the lag

time can be approximated by taking 60% of the time of concentration. In Sarida watershed, the lag time was calculated by the WMS application.

Reach process

Reach element conceptually represents a segment of stream or wadi in each catchment. There are two processes defined in the reach element: the routing and loss/gain methods. The routing method is used to calculate the flow within the stream. A total of six different routing methods are provided by HEC-HMS. Each method provides a different level of details regarding each stream including length, slope, shape, Manning's coefficient, and other parameters depending on the selected routing methodology. In Sarida model, the Muskingum-Gunge method is used. It is based on the combination of the conservation of mass and the diffusion representation of the conservation of momentum. It represents attenuation of flood waves and can be used in reaches with a small slope. This
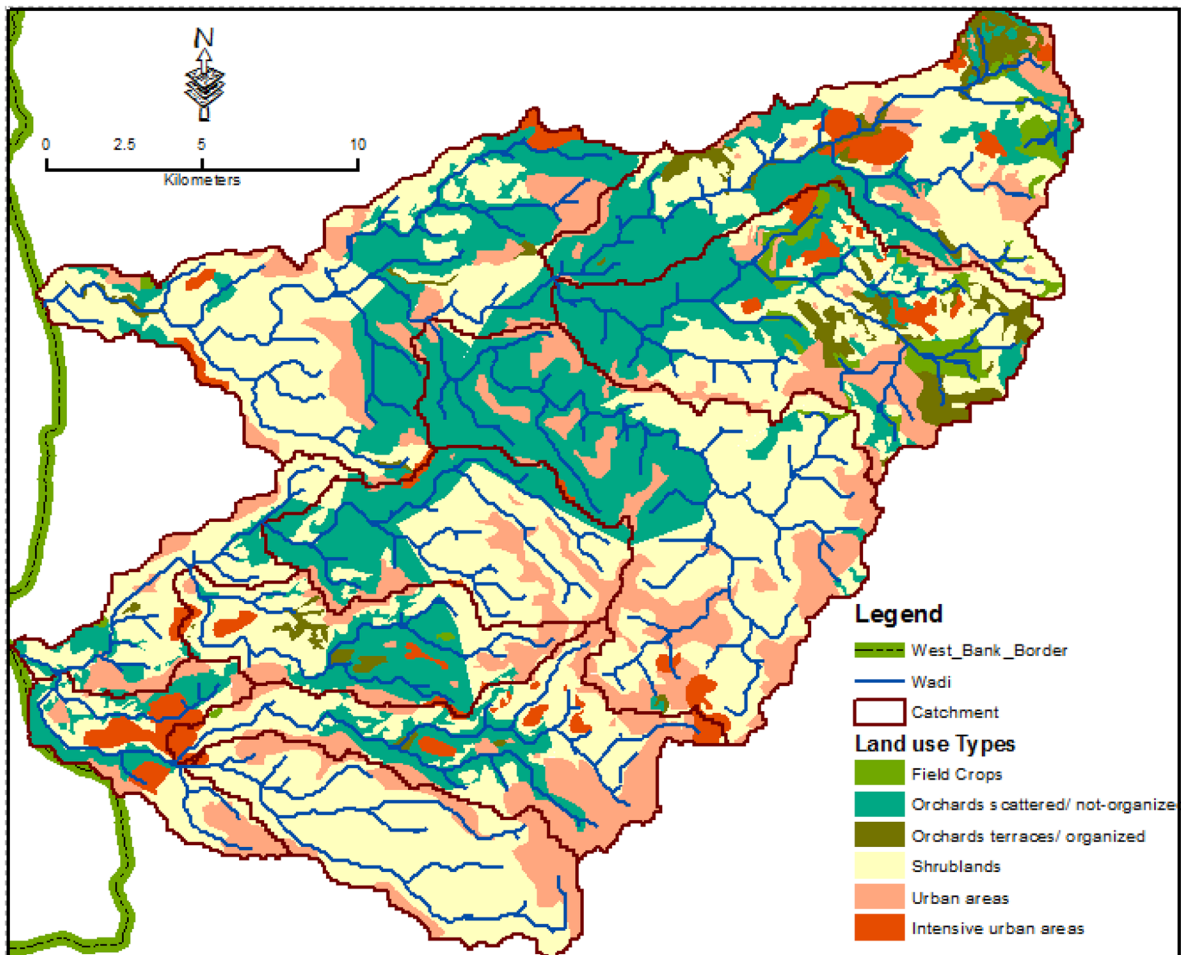
Fig. 6 Land use map for Sarida watershed

method required the parameters of length, Manning's roughness coefficient, and shape of the reach (Barnes, 1967). In Sarida watershed, the trapezoidal shape was selected. Accordingly, the average cross section width and side slope were entered.

A loss/gain method represents losses from the channel to the deep soil/groundwater. There are two different gain/loss methods that are provided by HEC-HMS: percolation and constant methods. The percolation method was considered as the most appropriate method in Sarida watershed. It uses a constant infiltration rate in combination with the inundated area in the reach to compute channel loss. The rate parameter specifies percolation in terms of a flow rate per area. The inundated area is multiplied by the rate to determine the channel loss for each time interval. Table 6 show the most important parameters used in the numerical model for all catchments. However, some parameters were slightly modified during the model run.

Modelling period and time step

The surface model of Sarida watershed was run for years 2008 to 2015 due to data availability. For each season, one model with daily time step was developed (i.e., in total seven models were developed). Consequently, the daily rainfall in millimetre and monthly potential evapotranspiration were entered.

Table 4 Soil distribution of Sarida area.

| Soil	Name	Area (km^2)	Area (%)
A	Terra Rossas, Brown and Pale Rendzinas	439	76.93%
B	Brown and Pale Rendzinas	103	18.05%
C	Pale Rendzinas	0	0.04%
H	Grumusols	28	4.98%
Sum=		517	100%

Rainfall   Seven rainfall gauges were installed within the boundary of Sarida watershed which was used to represent the rainfall distribution in the Sarida Catchments (Table 7).

Generally, the rainfall distribution in the seven rainfall gauges has the same distribution with some variation in daily rain data. Figure 9 shows the rainfall distribution of two stations, Birzeit and Salfit, for years 2008 to 2015.

Potential evapotranspiration   The monthly average potential evapotranspiration values were obtained from the Palestinian Meteorological Department (2016). These values were used to represent the potential evapotranspiration for all models of the sub-catchments (Table 8).

Model calibration and validation

Model calibration is the process of systematically adjusting the values of some or all of a model's parameters until reaching the smallest difference between the model's output variables of observed data. The calibration is generally performed after the design of the model where a number of simulation runs are needed to achieve calibration. In Sarida watershed, no storm water gauges where installed and the amount of stormwater generated were still unknown. Accordingly, making standard calibration based on measured records was not applicable. Alternatively, the operations from locals during storm events as well as the results obtained from models developed for similar
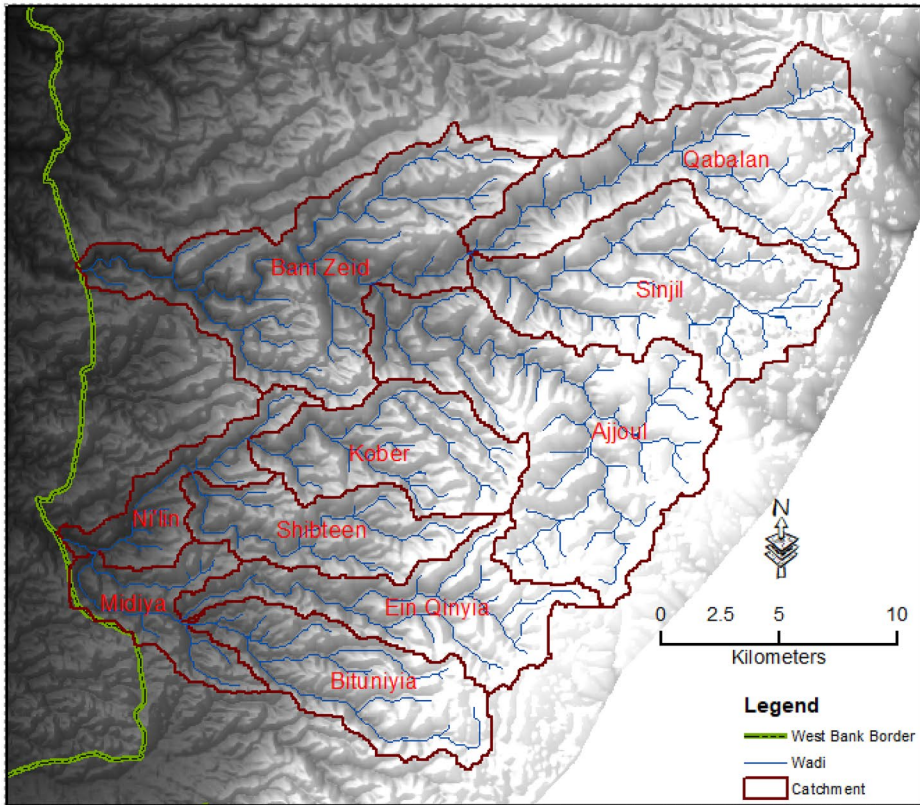
(a) DEM for the area

(b) Sarida sub-basins

◄ **Fig. 7** Basin delineation. **a** DEM for the area. **b** Sarida sub-basins

watersheds in the West Bank and Jordan were used for model calibration and comparing the results. Consequently, an intensive literature review was conducted for other similar studies. The main studies were found similar and used during model development was as follows:

1. Shadeed (2008) developed a model for Al Far'ah Watershed in the eastern slopes of the north-eastern part of the West Bank. The model was developed for both event and continuous based

using physically-based and spatially distrib-uted hydrological TRAIN-ZIN model during the period 2005–2007. The runoff coefficient in this watershed ranged between 0.2 and 8%, tak-ing into consideration that it receives less rainfall (amount and intensity) than the rest of the study area.

2. In Jordan, a hydrological model for Wadi Kafrein was developed using the TRAIN-ZIN application. The rainfall-runoff coefficients range between 4% in dry seasons to 11% in very wet seasons (Al Khoury, 2011).

3. Two other watersheds (Al Qilt and An Nueima) in the eastern slopes of the West Bank were

Table 5 Sarida catchments.

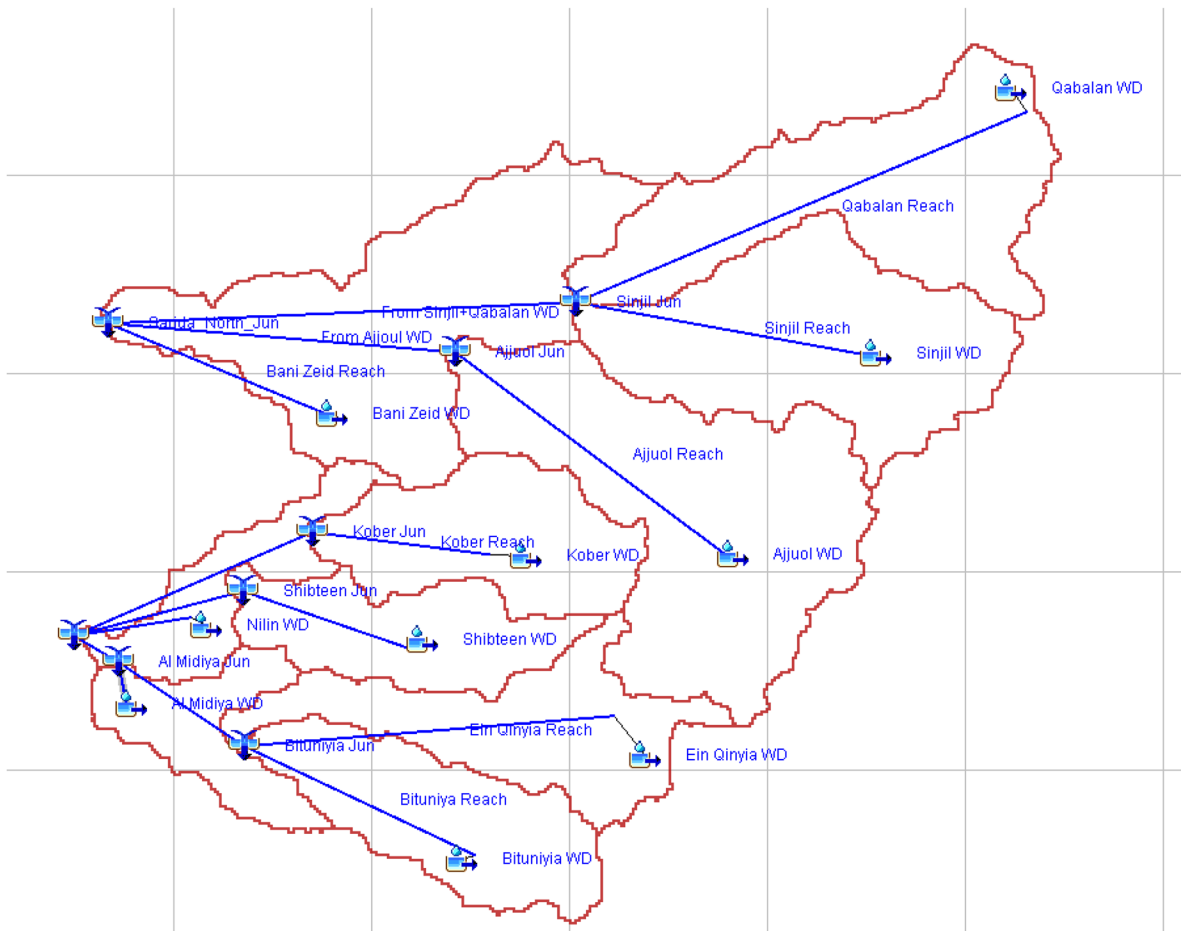| Sub-Basin	Catchment Name	Area (Km^2)
	Qabalan	76.6
	Sinjil	76.3
Sarida North	Ajjoul	101.8
	Bani Zeid	94.2
	Sub-Total=	348.9
	Ni'lin	24.4
	Midiya	23.8
	Ein Qinyia	48.3
Sarida South	Shibteen	36
	Bituniyia	45.2
	Kober	44.5
	Sub-Total=	222.2
Sum=		571.17

Fig. 8 Sarida model, schematic diagram by HEC-HMS

also modelled for the seasons 2011/2012 and 2012/2013 by (Ries et al., 2016). Accordingly, the runoff coefficients ranged between 2.4 and 6.4% for both watersheds. However, the runoff coefficient for single storm events showed higher values reaching 13%.

Models analysis

The modelling results can be provided in sensitive conceptual principles for understanding the runoff mechanisms in the watershed. The annual generated runoff and runoff coefficients versus the annual rainfall for both northern and southern parts of Sarida watershed are shown in Table 9. The average generated storm water over the seven seasons (2008/09 to 2014/15) is 23.16 and 13.44 Mm^3/year for northern and southern sub-basins, respectively.

High seasonal variations of the amount of generated runoff or runoff coefficients (Fig. 10). However, the annual rainfall in the seven seasons almost located within the same range with an average of 572 mm and standard deviation of 115 mm for the northern sub-basin and the generated runoff amounts are completely have different distributions with an average of 23.16 Mm^3/year and a standard deviation of 21.13 Mm^3/year. This implies that the generated runoff is not correlated with the annual rainfall amount.

Table 6 Model parameters as estimated by WMS/GIS and literature review

Catchment	Losses in watershed			Lag time (Min)	Reaches		
	Maximum deficit (mm)[1]	Constant rate (mm/h)[2]	Impervious (%)		Manning's n	Losses/gain rate (m^3/s/1000 m^2)	Slope
Qabalan	150	1.99	2.42	249.63	0.05	0.0005–0.0007	0.01–0.015
Sinjil		1.716	2.01	185.68			
Ajjoul		1.39	3.22	302.49			
Ein Qinyia		1.64	5.54	216.72			
Beitunyia		1.5	2.9	163.47			
Al Midiya		3.12	2.59	228.20			
Kober		1.99	2.21	150.26			
Shibteen		2.71	2.05	178.72			
Bani Zeid		1.81	2.19	283.21			
Nilin		2.83	2.15	132.65			

[1]The maximum deficit is estimated based on the average soil depth and porosity.

[2]The constant rate is estimated based on soil distributions in each catchment and the hydraulic conductivity of each soil type.

Sensitivity analysis

Two types of data were used for sensitivity analysis of the developed model: the first type was the physical properties of the watershed (e.g., impervious and constant rates) and the rainfall intensity (i.e., rainfall storms with different intensities). The sensitive analysis for physical properties of the watersheds was conducted by changing their values by $\pm 10\%$ and then compares the model results with the baseline model. The main finding that except the impervious factor, the model is not highly sensitive to the change (i.e., runoff coefficient is changed by $\pm 0.6\%$ as a result of changing physical parameters by $\pm 10\%$). The mode shows high sensitivity to the change in impervious factor which lead to change by 8–12% change in runoff coefficient as a result of increasing or decreasing it by 10% of their original values. This indicates that the runoff amount in all sub-watersheds will be highly impacted of urbanization (an increase in paved roads, green houses, or/and buildings). The daily rainfall distribution is the main parameter that controls the generated runoff. For this reason, the daily rainfall, the accumulated rainfall, and the number of rainy days per storm versus the runoff coefficients were analyzed. Figure 11 shows the rainfall/runoff coefficient versus the accumulated rainfall amounts at the end of the rainfall storm for Sarida North sub-watershed. It shows that runoff coefficient is proportional to the amount of rainfall, and its value is very low (i.e., < 5%) when the storm has an accumulated rain lesser than 60 mm, while it has higher and random values whenever storms have rainfall more than 60 mm. These values are controlled by two factors:

1. The initial conditions of the watershed prior to the storm: if the watershed is wet at the start of the storm, then the runoff coefficient is high.
2. If the storm has a long period (several days of rainfall) with high intensity rain especially at its end, then runoff coefficient is high and vice versa.

The following two events clarified the determination of runoff coefficients based on the rainfall storm characteristics:

Table 7 Rainfall stations as distributed within the watershed catchments.

| Sub Basin	Rainfall gage
Ajjuol WD	Attara
Al Midiya WD	Biet Ur
Bani Zeid WD	Salfit
Bituniyia WD	Bitunyia
Ein Qinyia WD	Bitunyia
Kober WD	Birzeit
Nilin WD	Rantees
Qabalan WD	Qarout
Shibteen WD	Birzeit
Sinjil WD	Sinjil

Storm 4–10 January 2013:

This storm was started on the 4th of January 2013 and ends on the 11th of January 2013. The total rainfall over the northern part of Sarida watershed was 282 mm. This storm had three main days: the 4th of January with average rainfall of 63 mm, which was used to wet the soil with very low runoff coefficient followed by two major days 7th and 10th of January with an average rainfall exceeded 100 mm per each day. Consequently, the majority of rainfall in these 2 days was converted to runoff (Fig. 12). The average runoff coefficient in this storm was 51.5%

Storm 28 January 2011 to 8 February 2011:

3This storm was extended over 12 days with total rainfall 135 mm. However, it had small runoff coefficient (i.e., 1.87%). This is due to several reasons (Fig. 13):

1. It came after dry period.
2. Rainfall was not uniformly distributed over the entire catchment.
3. The maximum day rain was 67 mm in the third day flowed by low rainfall days.

Moreover, to analyze the runoff coefficient variations between seasons, the highest and the lowest
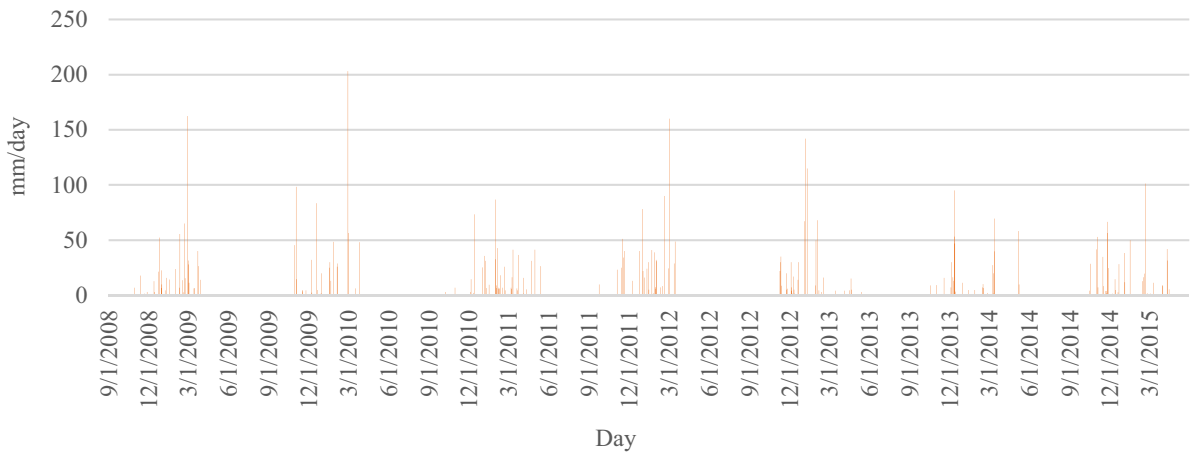
a: Daily rainfall for Birzeit station
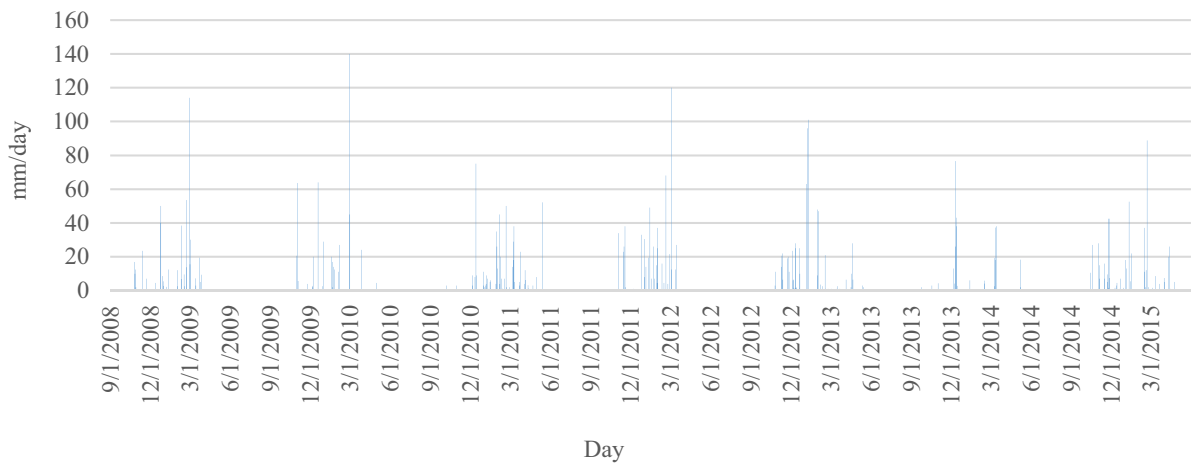
b: Daily rainfall for Salf it station

Fig. 9 **a** Daily rainfall for Birzeit station. **b** Daily rainfall for Salfit station.

runoff coefficients were analyzed (i.e., seasons 2010/2011 and 2012/2013 with runoff coefficient of 1.78% and 23.88% respectively). The accumulative rainfall for the two mentioned seasons is illustrated in Fig. 14 and clarified the following:

1. The rainfall in season 2010/2011 was uniformly distributed over the season without any major storms during the season.
2. In season 2012/2013, there are two major storms; one accumulated rainfall of 285 mm and generated a significant amount of storm water.

3. Generally, the 2012/2013 season had higher rainfall.

Generated runoff per catchment

The runoff is generated at sub-catchment level, and it was outlined at the outlet of each sub-catchment. This will help decision makers to establish storage infrastructures where appropriate.

Table 8 Potential evapotranspiration use for the model

Month	Evapotranspiration (mm)
January	110
February	104
March	157
April	195
May	238
June	232
July	252
August	228
September	127
October	128
November	63
December	55

Qabalan and Sinjil Catchments

The outlets of both Qabalan and Sinjil catchments are combined at Khirbet Qeis before flowing to Bani Zeid catchment. The average generated storm water at this junction was estimated at 10.41 Mm^3/year over the seven modelled seasons (2008–2015) (Table 10).

Table 9 Rainfall versus runoff coefficients during the modelled period

Sub-basin	Season	Rainfall (mm)	Runoff coefficient (%)	Storm water (Mm^3)
Sarida North	2008/2009	562	10.73%	21.03
	2009/2010	527	6.72%	12.36
	2010/2011	569	1.78%	3.53
	2011/2012	746	18.66%	48.54
	2012/2013	677	23.88%	56.42
	2013/2014	386	2.78%	3.75
	2014/2015	534	8.87%	16.50
Average		572	10.49%	23.16
Sarida South	2008/2009	531	8.75%	10.32
	2009/2010	612	7.65%	10.40
	2010/2011	493	0.63%	0.69
	2011/2012	783	15.89%	27.64
	2012/2013	713	21.39%	33.90
	2013/2014	466	3.27%	3.39
	2014/2015	682	5.10%	7.72
Average =		611	8.95%	13.44

Ajjoul Catchment

Ajjoul outlet is flowing to Bani Zeid catchment at Qarawet Bani Zeid, and the average generated storm water during the model period was 9.16 Mm^3/year (Table 11).

Bani Zeid Catchment

The generated storm water from Bani Zeid and the coming flow from Ajjoul, Sinjil, and Qabalan watersheds are leaving the West Bank border at the west of Deir Balout Village toward the Mediterranean Sea. The average flow over the modelled period is 23.18 Mm^3/year (Table 12).

Ein Qiniyia and Betuniyia Catchments

The generated storm water from both catchments is flowing to Midyia catchment with an average storm water of 6.86 Mm^3/year (Table 13).

Al Midiya Catchment

The generated storm water from Al Midiya catchment is summed up with the flow generated in both Ein Qyniyia and Betuniyia Catchments before leaving to Nilin sub-basin. The average sum of the outflow et al. Midiya junction is 7.59 Mm^3/year (Table 14).

Kober and Shibteen Catchments

These two catchments are located in the upper stream of Nilin sub-basin. The generated flow in both catchments flows to Nilin Catchment and the outlets of each catchment. The generated flow in both catchments is illustrated in Table 15.

Nilin Catchment

The flows from Kober, Shibteen, Midiya, Ein Qyniyia, and Betuniyia Catchments as well as the flow from Nilin catchment are leaving the West Bank border at the outlet of Nilin outlet. The average generated storm water during the modelling period is 13.46 Mm^3/year (Table 16).
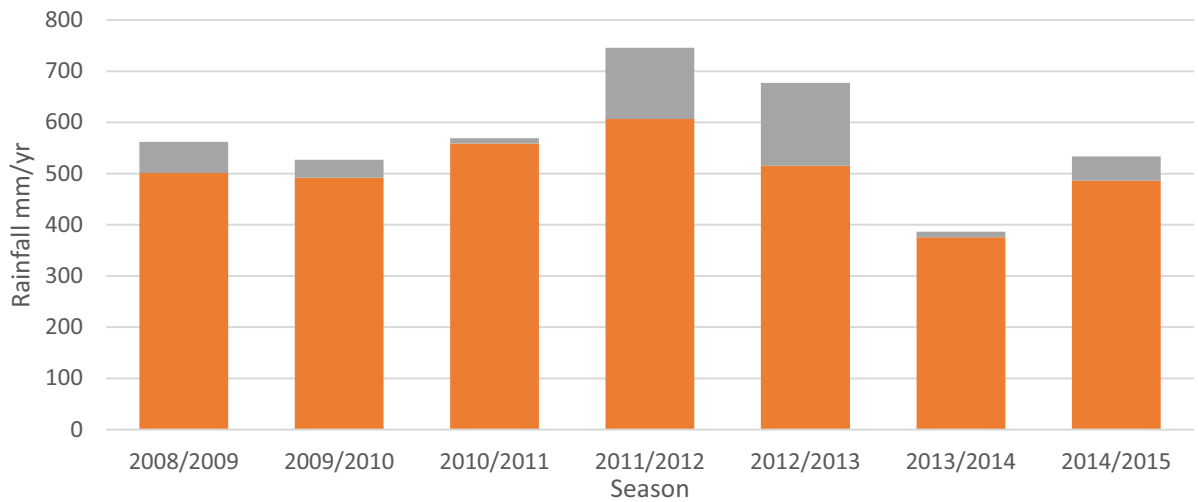
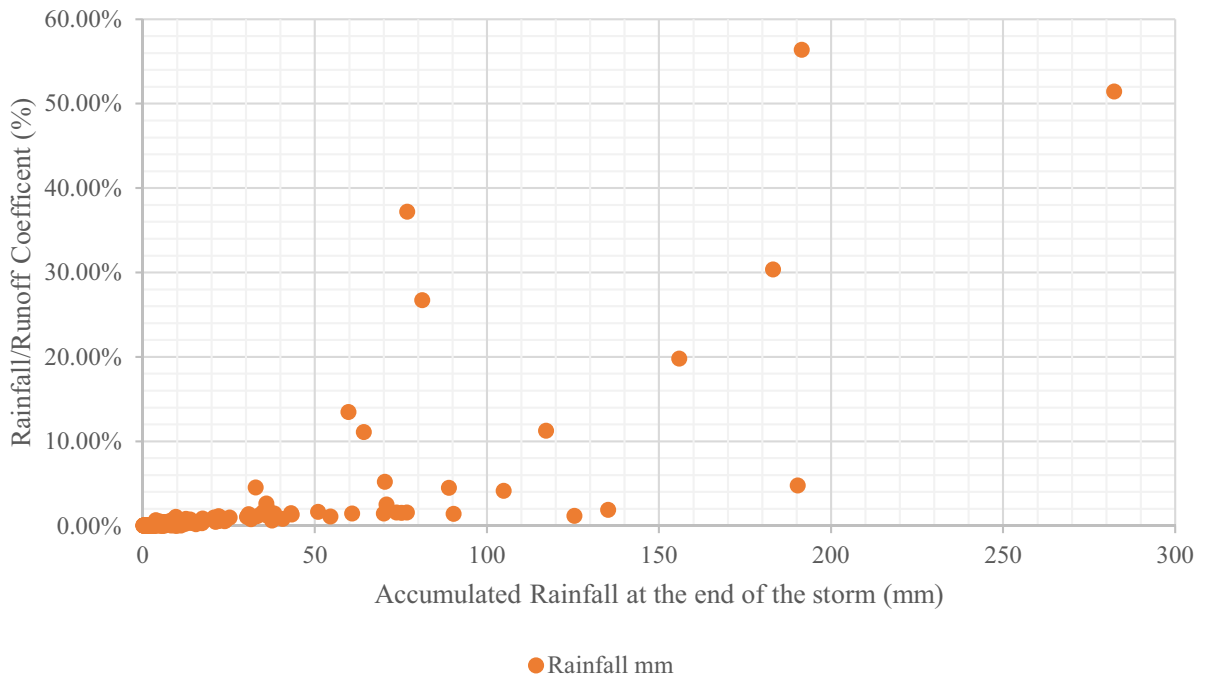**Fig. 10** Rainfall versus Runoff during the modelled period

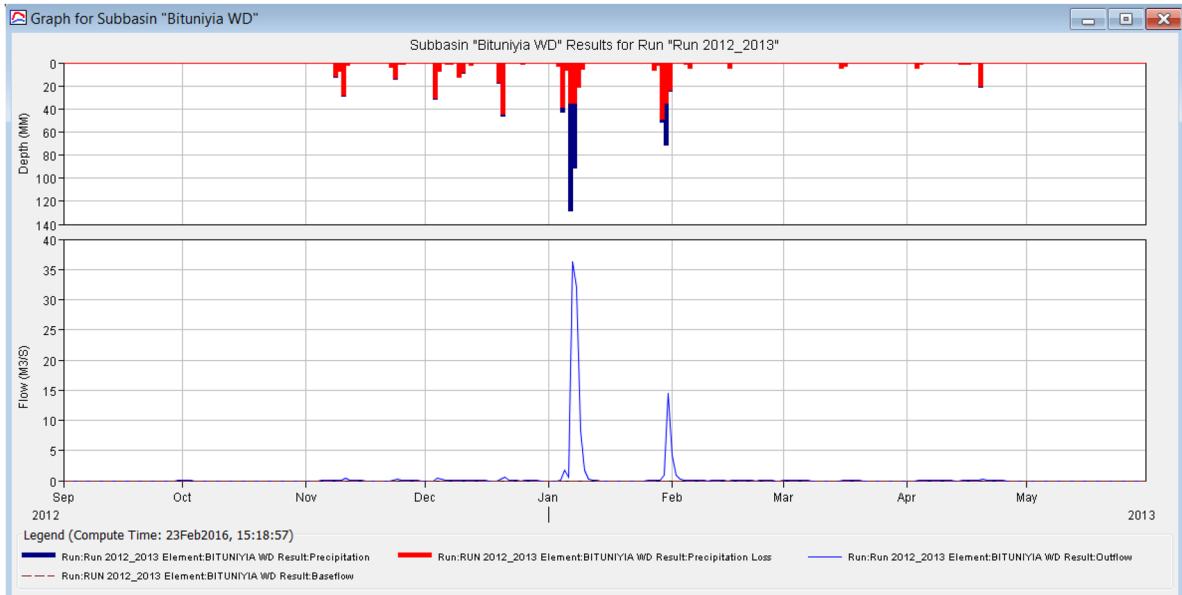**Fig. 11** Runoff coefficients versus Rainfall (Per storm)

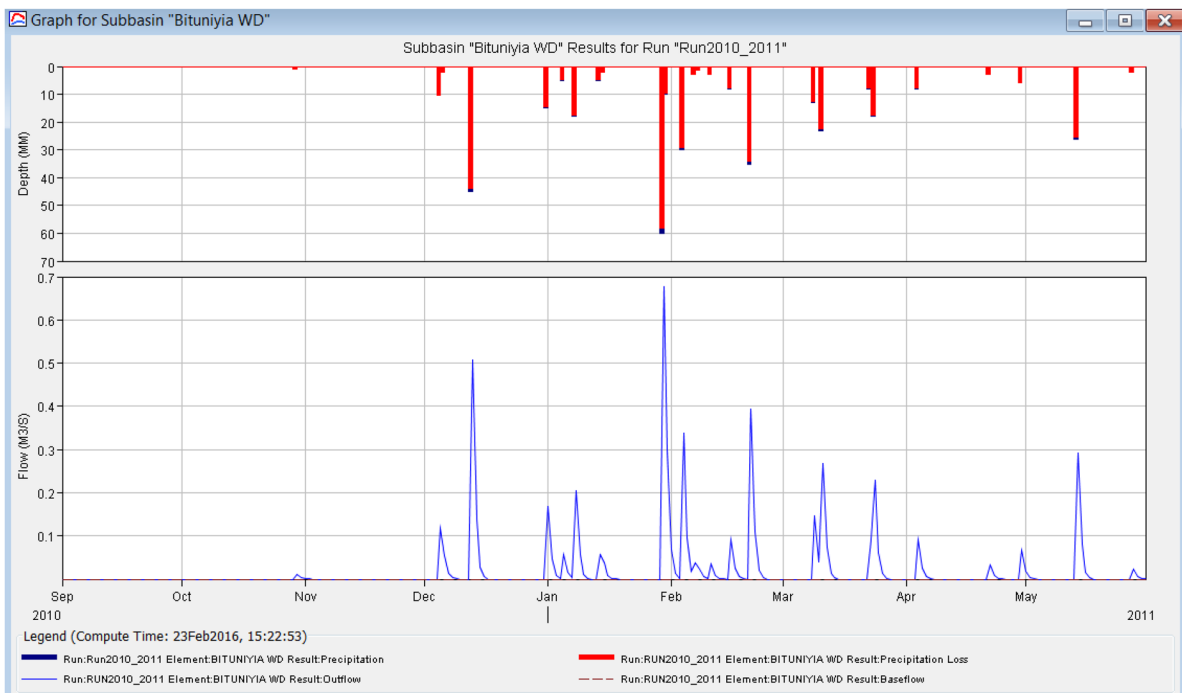**Fig. 12** Runoff versus Rainfall in Betuniyia Catchment, Season 2012/2013

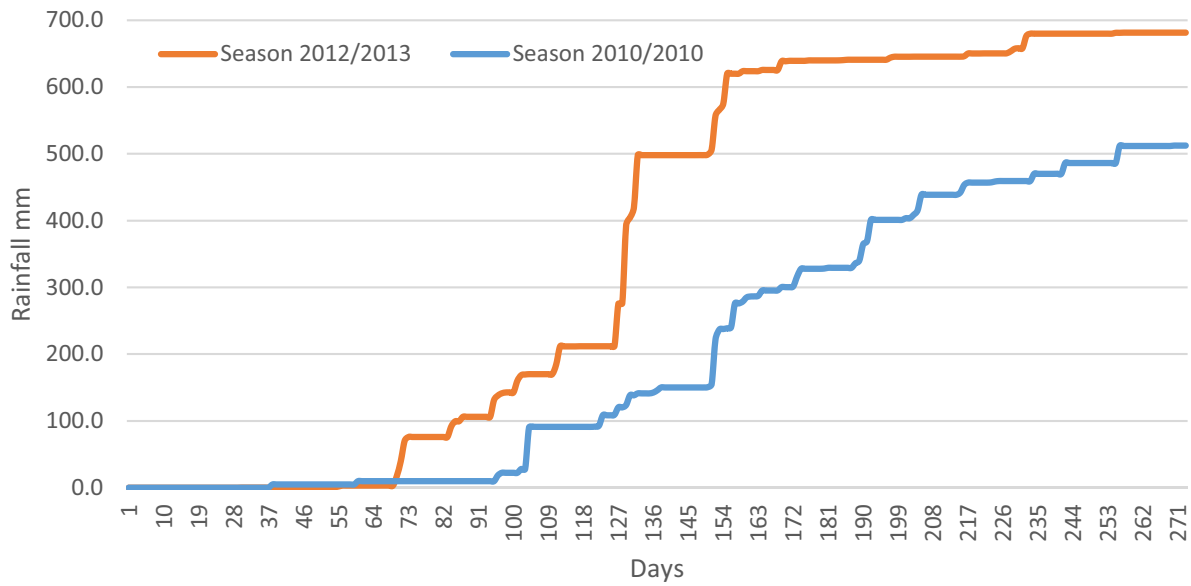**Fig. 13** Runoff versus rainfall in Betuniyia Catchment, season 2010/2011

Fig. 14 Different types of annual rainfall distributions

Table 10 Storm water characteristics at Qabalan and Sinjil outlets

Season	Peak discharge (m^3/s)	Time of peak	Runoff (Mm^3)
2008/2009	97.5	28/02/2009	13.94
2009/2010	33.5	28/02/2010	5.19
2010/2011	1.1	30/01/2011	0.75
2011/2012	129.8	01/03/2012	21.28
2012/2013	84.1	10/01/2013	20.03
2013/2014	2	12/12/2013	0.80
2014/2015	72.7	10/01/2015	10.87
Average =			10.41

Table 11 Storm water characteristics at Ajjoul outlet

Season	Peak discharge (m^3/s)	Time of peak	Volume (Mm^3)
2008/2009	27.9	39,872	4.49
2009/2010	26	01/03/2010	6.14
2010/2011	9.5	11/03/2011	9.00
2011/2012	108.2	02/03/2012	19.07
2012/2013	88.5	07/01/2013	24.98
2013/2014	14.1	13/12/2013	3.24
2014/2015	14.1	13/12/2014	3.24
Average =			9.16

Table 12 Storm water characteristics at Bani Zeid outlet

Season	Peak discharge (m^3/s)	Time of peak	Volume (Mm^3)
2008/2009	118.3	28/02/2009	21.06
2009/2010	49.7	01/03/2010	12.36
2010/2011	6.1	11/03/2011	3.58
2011/2012	210.7	02/03/2012	48.54
2012/2013	155.7	07/01/2013	56.45
2013/2014	14	13/12/2013	3.74
2014/2015	59.1	10/01/2015	16.54
Average =			**23.18**

Table 13 Storm water characteristics at Ein Qinyia and Betuniyia outlets

Season	Peak discharge (m^3/s)	Time of peak	Volume (Mm^3)
2008/2009	26.3	28/02/2009	4.37
2009/2010	2.7	28/02/2010	1.22
2010/2011	1.2	30/01/2011	0.61
2011/2012	85.5	01/03/2012	14.75
2012/2013	69.1	07/01/2013	18.53
2013/2014	11.6	13/12/2013	3.16
2014/2015	17.9	26/11/2014	5.41
Average =			6.86

Table 14 Storm water characteristics et al. Midiya outlet

Season	Peak discharge (m^3/s)	Time of peak	Volume (Mm^3)
2008/2009	53.1	28/02/2009	8.24
2009/2010	2.9	28/02/2010	1.12
2010/2011	0.9	31/01/2011	0.28
2011/2012	79.6	01/03/2012	15.50
2012/2013	73.3	07/01/2013	19.85
2013/2014	11.4	13/12/2013	2.96
2014/2015	17.1	26/11/2014	5.16
Average =			7.59

Table 16 Storm water characteristics at Nilin outlets

Season	Peak discharge (m^3/s)	Time of peak	Volume (Mm^3)
2008/2009	65.2	28/02/2009	10.36
2009/2010	52.6	28/02/2010	10.42
2010/2011	3.2	31/01/2011	0.70
2011/2012	102.7	02/03/2012	27.67
2012/2013	125.6	07/01/2013	33.94
2013/2014	13.1	13/12/2013	3.41
2014/2015	22.7	26/11/2014	7.73
Average =			**13.46**

Table 15 Storm water characteristics at Kober and Shibteen outlets

Kober Catchment

Season	Peak discharge (m^3/s)	Time of peak	Volume (Mm^3)
2008/2009	10.1	28/02/2009	1.50
2009/2010	33.2	28/02/2010	6.03
2010/2011	2.6	30/01/2011	0.53
2011/2012	38	02/03/2012	7.36
2012/2013	32.7	07/01/2013	8.42
2013/2014	2.7	12/12/2013	0.64
2014/2015	7.7	20/02/2015	2.30
Average =			3.82
Shibteen Catchment			
2008/2009	6.1	28/02/2009	0.91
2009/2010	23.6	28/02/2010	3.70
2010/2011	1.1	30/01/2011	0.22
2011/2012	25.7	02/03/2012	4.42
2012/2013	21.2	07/01/2013	4.72
2013/2014	0.7	11/12/2013	0.19
2014/2015	4.1	20/02/2015	0.73
Average =			2.13

Conclusion

While good quality and high-resolution datasets related to physical characteristics and meteorological data are available for Sarida watershed, the measured storm water flow records in the main wadis of the target watersheds are not available in the same way they are for other watersheds within the West Bank. In this research, a watershed model was developed as an initial attempt to estimate the amount of storm water that is "lost" every year to runoff. The model was based on the available data, and the results and experience gained from several models developed in similar watersheds in the region (i.e., in the West Bank and Jordan) as well as based on some observations of some locals during storm events. The developed model should be calibrated and validated in the future after installing runoff gauge stations in the catchment area.

The Sarida watershed modelling results show the importance of storm water as a potential source of water resources. Sarida watershed generates an average of 36.6 Mm^3 of runoff every year. That runoff leaves the West Bank border every year and travels to the Mediterranean Sea, while Palestinians could benefit from this water to fulfil their domestic, agricultural, and

commercial water demands. Governmental and non-governmental institutions can develop different types of storage infrastructures (ranging in scale from household level collection tanks, to retention ponds and diversions) according to the developed sub-catchment characteristics. The main outcome is the spatial and time wise distribution of the annual rainfall in the modelled area, including the annual amounts, intensities, number of rainy days, number of storms, and changes of rainfall behaviours from one sub-catchment to another within the same watershed area. The annual generated storm water varies from year to year. For example, in Sarida North, the rainfall varied from 3.6 to 56.45 Mm^3 in winter season of 2010/2011 and 2012/2013, respectively. This calls on rainwater harvesting designers to select the most appropriate type and size of storage facilities to accommodate storm water annual variations. Furthermore, it is recommended to establish a monitoring network in Sarida catchment as well as other watersheds inside the West Bank to measure storm water from the main wadis in addition to climatic parameters. The resulting measurements will be used to validate and calibrate future rainfall models and to improve the estimation of physical characteristics of the watershed.

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