International Journal of Scientific & Engineering Research Volume 11, Issue 2, February-2020
ISSN 2229-5518

Applicability of HEC-HMS Hydrologic Modelling in Arid and Semi-Arid Regions Case Study: Wadi El-Melaha, Sinai, Egypt

Walid Al-Sayed Mohamed

Associate Prof. of Irrigation and Hydraulics. Faculty of Engineering, Al-Azhar University

Abstract – Wadi El-Melaha is one of the catchments that had experienced several devastating floods. It was chosen to be the subject of this paper because it is a sub- basin of Wadi Sudr, which is one of the most important catchments in Sinai. The current thesis focuses on experimental catchments located in Sinai (Sudr, Feiran, and El-Gudirat). These catchments were established by the Water Resources Research Institute (WRRI) in Sinai as an extensive monitoring effort to improve the understanding of the hydrologic processes in Sinai's arid and semi-arid basins. The purpose of this study is to simulate rainfall-runoff in the semi-arid region of Wadi El-Melaha watershed through the employing of HEC-HMS model. In this paper, the storms are used for the meteorological model, the SCS curve number is selected to calculate the loss rate and the SCS unit hydrograph method has been applied to simulate the runoff rate. All of the above was done on two different storms in two different years (1994 & 2011). After calibration and validation, the simulated peak discharges were very similar to the observed values.

Key Words: Wadi El-Melaha; Surface Runoff; Semi-Arid; Hydrologic Model; HEC–HMS.

◆

1. INTRODUCTION

The problem of floods in arid and semi-arid areas indicates the need to look for ways to establish a relationship between the characteristics of basins and the occurrence of floods by determining the factors influencing the hydrograph of these basins; and then accurately predicting the size and shape of these hydrographs, to function as a floods warning (in terms of time or intensity), or for protection works. Since the process of drawing the hydrograph of the basins requires recorded rain data or flow data which is not available in arid and semi-arid regions (The rainfall data may be available while the flood data is hard to find due to the spread of rainfall gauged stations), hydrologists have resorted to the geomorphological characteristics of the basins known for their stability in order to derive the hydrograph of these basins. It is known that after the occurrence of any rainstorm, the rate of flow within the basins will be affected by several factors; including evaporation, soil moisture, vegetation and other factors whose data can't be obtained, while the characteristics of the basins are visible when the streams arrive at the outlet of the basins. The most important one of these factors is the hydro morphology of the basins represented by the natural characteristics; such as area, shape, slope and length, due to its large interference in determining the response time difference between the peak period of the rainstorm and the top of the discharge peak.

Floods can be considered as the most important natural disaster in our world, and Flash floods happen very suddenly with large amounts, which causes many disasters such as damage to buildings, roads and loss of life. Flash floods occur because of the high rainfall intensity, steep slopes in the catchment, poor vegetation cover, high velocity, etc.

Storms and floods are a normal and inevitable part of climate variability that must be managed. We cannot always control floods. Therefore, we must learn how we can live with them while minimizing risks to human lives and infrastructure. Flash floods are especially common in mountainous areas where rapid snowmelt or heavy rainfalls are quickly transformed into runoff. Rainfall-runoff relationship plays a vital role in many aspects of watershed management. Hydrological studies are often aimed at establishing rainfall-runoff relationships [Wheater H., Sorooshian S., Sharma K.D.]. Rainfall-runoff models can be categorized according to the model type. According to [Clarke R.T, (1973)]and [Shah S. M. S. (1996)], the hydrological models can be classified in to four main categories: Determinist or stochastic, global or semi-distributed, kinematic or dynamic and finally empirical or conceptual. The selection of the model depends on the watershed and the objective of the hydrological forecast in the watershed. In this study, the conceptual approach is adopted for the hydrologic modeling, we use a semi distributed hydrologic model of HEC-HMS (Hydrologic Engineering Center- Hydrologic Modeling System) was developed By US Army Corps of Engineers, in order to investigate the rainfall-runoff interactions in the semi-arid Ain Sefra watershed of southwestern Algeria. It is applicable in diverse geographic areas for solving the widest possible of problems. Many scientists have conducted important hydrologic studies using HEC-HMS model, which proved its ability to simulate and forecast streamflow. As example: Sintayehu L.G. used HEC-HMS model employing Snyder unit hydrograph and exponential recession method to simulate the runoff of upper Blue Nile river Basin [Ambroise B., 1998.]. Norhan A. and al. modeled rainfall-runoff relations using HEC-HMS in arid environment at Wadi alaqiq, Madinah, Saudi Arabia [Sintayehu L.G, 2015.]. Sampath and al. modeled the rainfall-runoff relations using HEC-HMS in tropical catchment in Sri Lanka [(6) Norhan A., Saud T., Fahad A., Kamarul A. (2016)]. F. Meiling W. and al. employed the HEC-HMS to simulate runoff in the semi-arid region of northwestern China [Lin, X 1999]. Laouacheria F. and Mansouri R. used HEC-HMS model by employing Frequency Storm to simulate the runoff in a small urban catchment in the North East. Figure (2) shows the regions suffering from flash floods in Egypt and Wadi El-Melaha (research case study) is one of these regions.

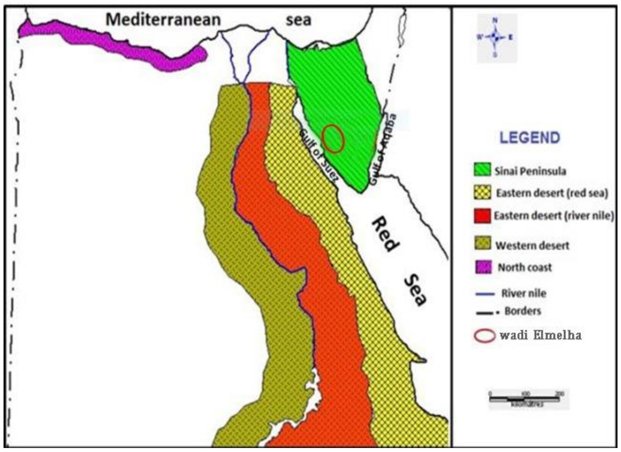

Fig -2: The regions suffering from flash floods in Egypt and Wadi El-Melaha.

Many researchers have developed rainfall runoff models that attempt to accurately predict runoff hydrographs, peak flow rates and peak times. The main applications of hydrologic modeling are for planning purposes, management practices, and rainfall-runoff prediction (Singh, 1995). On the other hand, flash floods are a poorly understood phenomenon (Lin, 1999) and though it is difficult to control floods, yet it is possible to minimize its risks to human lives and infrastructures.

Over the last few decades, a large body of knowledge has been developed about the hydrological processes in arid and semi-arid environments (Yair and Lavee, 1985; Schick, 1988; Abrahams et al., 1988). Rainfall-runoff numerical models have become widely recognized as tools for studying hydrological processes, predicting hydrologic impacts of human activities, and assessing available water resources. A large number of such models with different degrees of complexity are available for humid catchments (Singh, 2002). So many researchers developed a lot of models to visualize this process.

(Eman A. Hassan, 2007) created a comparison between the performance of three infiltration methods (SCS curve number, initial/constant, Green and Ampt) with rainfall and runoff data collected on a 450 km**2** catchment area located in west part of Sinai Peninsula. HEC-HMS model was setup and the optimization trials, different objective functions selected. The calibration process was done included six different objective functions corresponding to runoff volume and peak flow conservation. Finally, the results of calibration and validation described as a following:

- Peak-Weighted RMS Error and Time-Weighted RMS Error gave minimum error values for the three infiltration methods.
- Green and Ampt's method ranked the best because of its accuracy in the simulation of runoff volume and peak flow.

(Punit Kumar Bhola and Ashish Singh, 2010) mentioned the methods used to calculate the runoff are (SCS-CN Method and (ANN)). Based on the analysis performed in ANN and SCS-CN method following conclusions are described:

- SCS-CN method considers the infiltration losses and soil properties. Also, it requires too many field data e.g. topography, Soil type, Moisture condition etc., which are sometimes not known so a lot of assumptions are to be made.

- (ANN) showed satisfactory results in comparison with SCS-CN method, it can be used for prediction of discharge at the remote places where the establishment of stations economical.
- For the learning curve ANN can use both the rainfall and runoff data of previous years while the input parameter in the SCS-CN method can only be rainfall and CN, thus gives better results.

(Haitham Saad et al, 2013) used (FORM) in order to investigate the effect of the uncertainty of CN and Tlag. From the investigation, it was ensured that the SCS-CN method is highly uncertain when the rainfall average value is low. Egypt is the research case study and they used actual rainfall data and values for CN obtained from satellite data in order to determine the regions of acceptance of the SCS-CN method.

Finally, the results showed that SCS -global methodology should be avoided when the coefficient of variation of rainfall is low (PCOV < 0.50) and SCS – CN used when the combination of Pmean and PCOV range between 0.02 and 0.04.

This paper presents a methodology of rainfall–runoff model by using HEC-HMS program integrated with DEM data as an input for basin model in semi-arid environment to simulate the pick discharges for 2 storms 1994 and 2011 in Wadi El- Melaha, Sinai, Egypt.

So, the purpose of this study (Wadi El- Melaha) is: investigating the applicability of hydrologic modelling in arid and semi-arid regions to simulate rainfall-runoff of through the employing of HEC-HMS model using Soil Conservation Services (SCS) curve number (CN) and SCS Unit Hydrograph (UH).

Wadi El- Melaha was chosen in this research, as it is a sub-basin of Wadi Sudr as shown in figure (1).

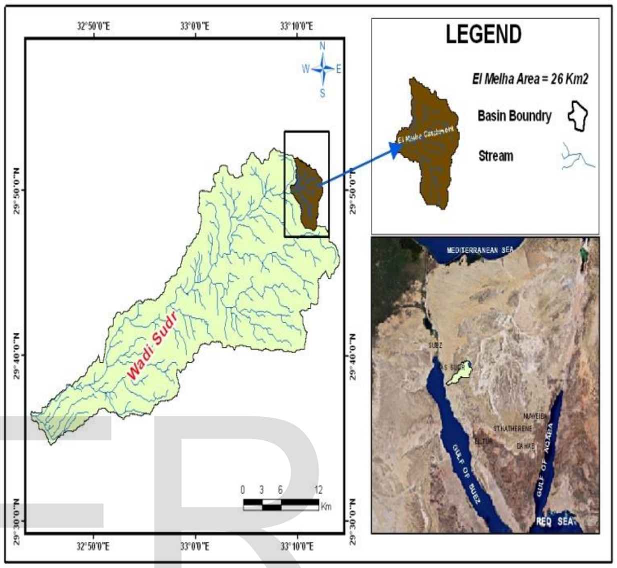

Fig -2: the general layout of Wadi Sudr and El Melaha catchment.

2. MATERIALS AND METHODS

2.1. Rainfall Data

Rainfall time series data are collected from (WRRI) for two different storms 1994, 2011. The recording rainfall gauges are available within the watershed area, one weather station and few storage gauges. However, data from storage gauges will not be considered due to its poor data quality and resolution. Recording rainfall gauges are used to measure the intensity, duration for the watershed. Storage gauges are used to provide a basic data for the determination of the mean rainfall for periods of one day or more.

In 2008, some of these gauges were damaged and replaced by digital rainfall gauges. There is only one runoff monitoring stations with water level recorder located at the outlet of the watershed. Figure (3a-b) shows the locations of all the rainfall gauges, weathering station, and the water level recorder before and after year 2008.

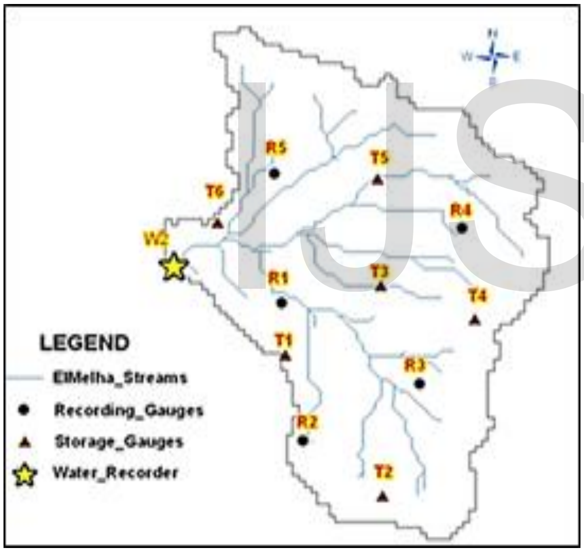

Fig -3-a: Before 2008.

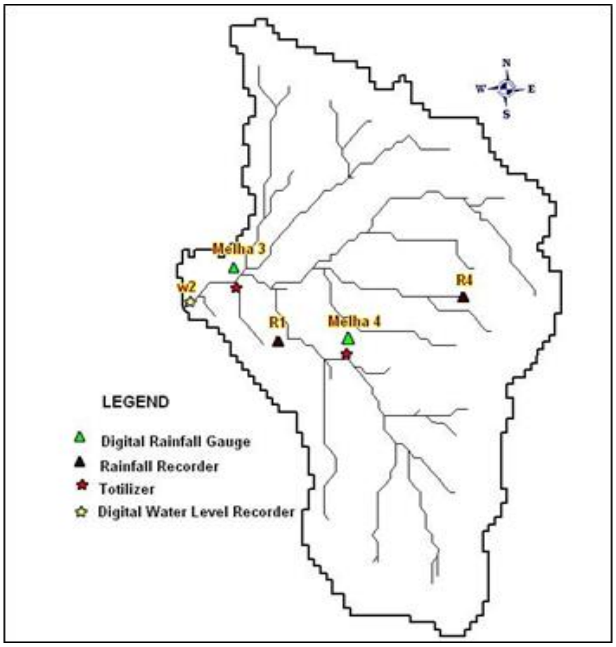

Fig -3-b: After 2008.

2.2. Methods

This objective is to examine the rainfall-runoff relationship in (Wadi El- Melaha) watershed. The methodology is based on meteorological and physical data processing in the geospatial environment.

This methodology can be separated into six main stages:

1-Description and geographic location of the study area.

2-Digital Elevation Model (DEM) processing, defining stream network, topography, and watershed characteristics using Watershed Modeling System (WMS).

3-Define geological and soil characteristics of the watershed, to compute the runoff curve number (CN).

4-Importing the catchment physical characteristics data to HEC-HMS model.

5-Run the rainfall/runoff simulation, and compare compute and observes flows.

6-Calibration and validation of the model.

2.3. Description of Study Area

Wadi El-Melaha is a sub-basin of Wadi sudr which is considered one of south-west Sinai wadis and covers a total area of about 600 km2 and it drains directly in Gulf of Suez at Sudr town. Wadi El- Melaha covers an area of about 26 km2, and extends between latitudes 29° 52' 30" and 29° 47' 30" N, and longitudes 33° 08' 30" and 33° 12' 30" E. Wadi Sudr is monitored by Water Resources Research Institute (WRRI) for Rainfall and runoff measurements since 1989 till now. The Basin slope is computed from Digital Elevation Model (DEM) by using the surface analysis tool available in Arc GIS software. It ranges from (0) degree to (87.4) degree, as shown figure (4). The slope classes according to Canadian system of soil classification, 3rd edition, 1998.

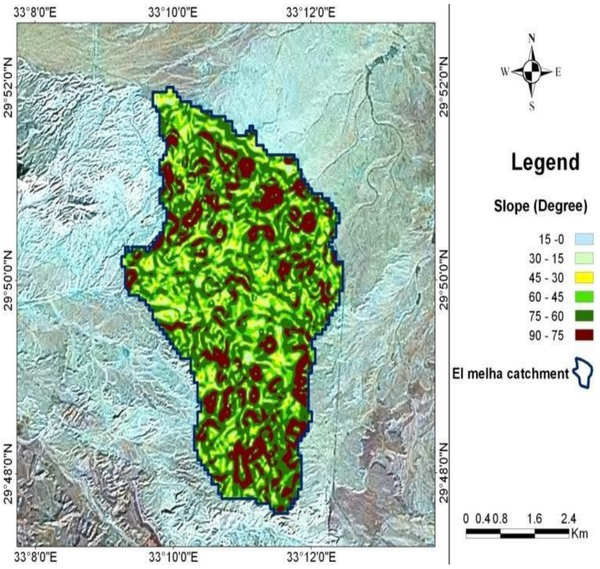

Fig -4: The slope map for El- Melaha Catchment

2.4. Topography of Wadi El- Melaha watershed

The study area (Wadi El-Melaha) is located in the west central part of the Sinai Peninsula. Wadi El Melaha is one of the main sub catchments of Wadi sudr which is considered one of the main wadis in Sinai peninsula wadis group draining to the gulf of Suez in the west, this region is characterized by rocky terrain with high mountains peaks spreaded, which are considered part of south Sinai mountains, such as Gabal El – zarafa peak (686m), Gabal Al Disa peak (681 m) and Gabal Al Risha peak (528 m) and also high plateaus such as El Tih plateau where study area is considered part of the western edge for this plateaus. These mountains and high plateaus cut a network of drainage water represented in the collection of old dry wadis filled by water when heavy rains occur causing flash floods.

The max elevation of the Wadi is 575 m at the first reaches at Ras el-Gindi (old Fort) and reduces to the west until reaching an elevation of 470 m near the outlet of the Wadi, figure (5).

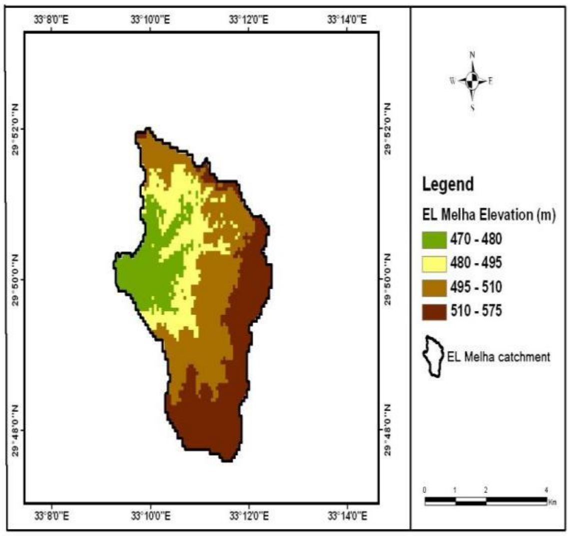

Fig -5: Digital Elevation Model for El –Melaha Catchment

2.5. Geology of Wadi El- Melaha watershed

The geological characteristics of the study area play an important role in the surface water and groundwater studies. Surface water losses are variable from one area to another according to the geological units covering the area. On the other hand, the ground water movement and direction depend on the geological characteristic of the area. The tertiary rocks cover most of the study area especially Sudr formation which covers the catchments and thalwegs of Wadi El- Melaha. The geological units of the area, figure (6) ranging from Quaternary to Upper Cretaceous. Sudr Formation (Cretaceous-Paleocene) white to pale grey chalk, marly near top fossiliferous.

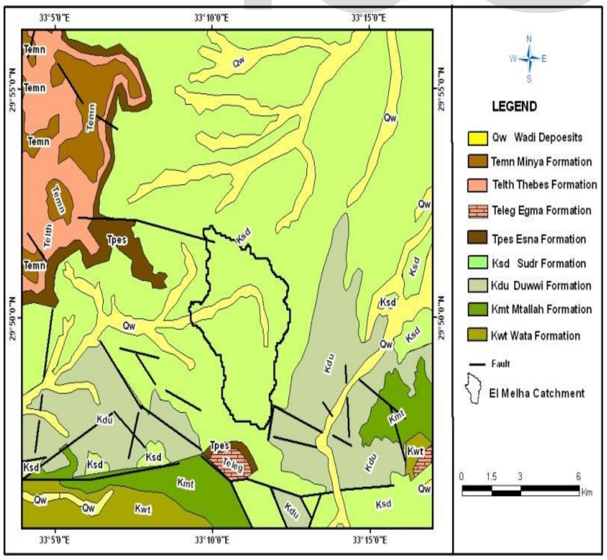

Fig -6: The superficial geological map showing the distribution of different soil types in Ras Sudr region.

2.6. Land Use and Soil Type of Wadi El- Melaha

Over 95% of the watershed area is desert land, and the rest of the area is bush land as shown in figure (7). Land use of the watershed is obtained by digitizing the areas boundaries from satellites images. Figure (8) Pictures shows some feature of Wadi El-Melaha.

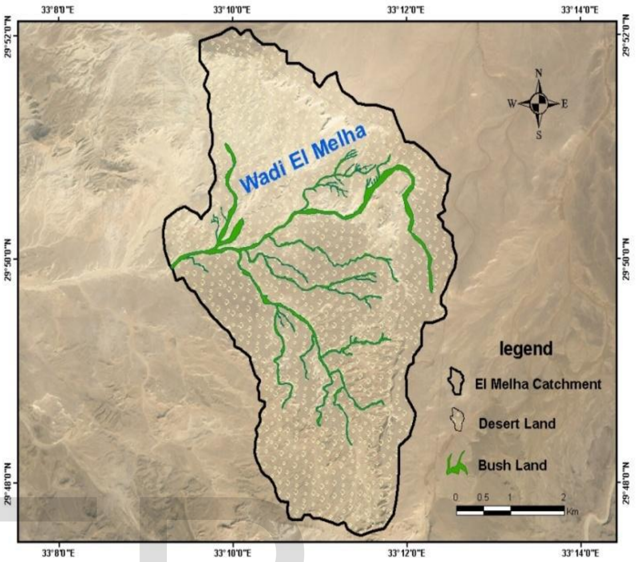

Fig -7: The land use map for El- Melaha catchment

Fig -8: Pictures shows some feature of Wadi El-Melaha

2.7 Climatic

The climate in Sinai Peninsula is similar to those which characterize desert areas in other parts of the world. It includes extreme aridity, long hot rainless summer months and mild winter. During the winter months some areas of Sinai had high intensity of rainfall that causes flash floods. Most rainfall is falling during the period from December to May. The rainfall in this region is subject to the influences of the Red Sea, Indian Ocean and the Mediterranean Sea, because the study area is located in the west-central Sinai Peninsula it's affected by the Mediterranean Sea due north and the red sea and Indian Ocean due south weather conditions. Observed rainfall characterized with short duration and high intensities events.

3. HEC-HMS Model

3.1Model Description

The Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems [US Army Corps of Engineers 2013]. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, and system operation [US Army Corps of Engineers 2013]. HEC-HMS Model setup consists of four main model components: basin model, meteorological model, control specifications, and input data (time series, paired data, and gridded data). An assortment of different methods is available to simulate infiltration losses (Deficit and constant, Exponential, Green and Ampt, number, Smith Parlange and Soil Moisture Accounting (SMA). Seven methods are included for transforming excess precipitation into surface runoff (Clark unit hydrograph, Kinematic wave, ModClark, SCS unit hydrograph, Snyder unit hydrograph, User specified graph and user specified unit hydrograph). Six methods are included for routing model (Kinematic wave Routing, Lag Routing, Modified Puls Routing, Muskingum Routing, Muskingum-Cunge Routing and Straddle Stagger Routing). For the meteorological model eight methods are included (Frequency Storm, Gage weights, Gridded precipitation, Inverse distance, HMR52, SCS storm, Specified hyetograph, Standard project storm)

3.2 Model Structure

In this study, SCS Curve Number (CN) Loss method will be used to determine the hydrologic loss rate, the SCS unit hydrograph (UH) method will be used to calculate the runoff rate, and the simulating process is done by using Frequency storm for the meteorological model.

3.3 Data precipitation

The Hydrological model was built using HEC-HMS software and all the input data were prepared such as;

the characteristics of Wadi EL- Melaha, rainfall data, runoff data, CN value and Lag time. HEC-HMS model is applied to El- Melaha watershed using 2 real storms (1994 and 2011). Figure (9) shows the rainfall distribution during these two storms.

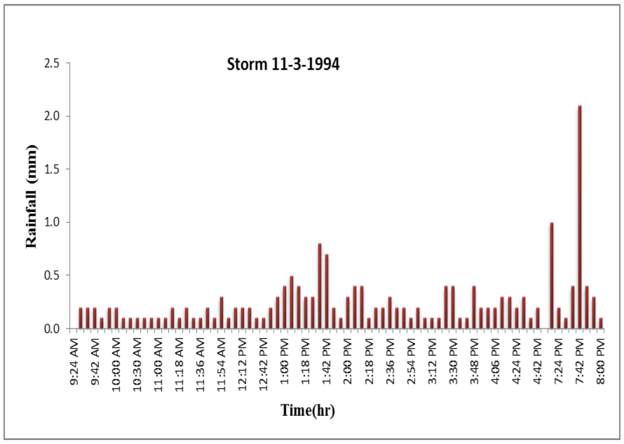

Figure (9-a) Rainfall distribution storm 11-3-1994.

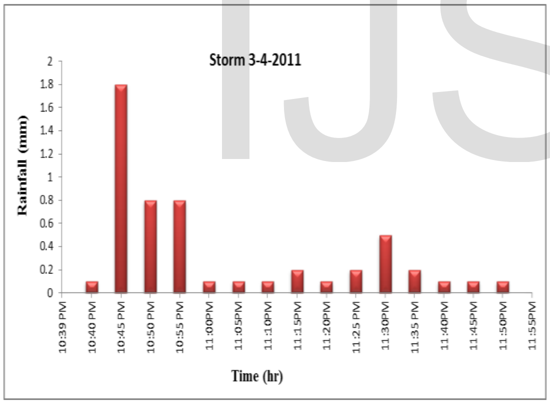

Figure (9-b) Rainfall distribution storm 3-4-2011.

3.4 Infiltration

Soil sampling for infiltration estimate have been done in different site in Wadi El –Melaha. As shown in figure (10). Criteria of selection soil samples are based on the watershed surface geology (Hasanein A. M.1989). This Wadi consists of two geological units. Wadi deposits and sudr formation as shown in figure (10). Samples are taken at two different depths; 30 cm and 60 cm. Sieve analysis and soil classification are carried out for all samples. The infiltration data is analyzed to estimate Green and Ampt parameters to establish a preliminary model setup (ogden and Saghafian, 1995).

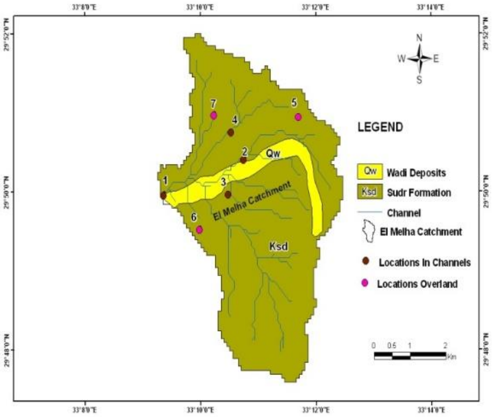

Fig -10: Location of infiltration sites in EL-Melaha.

3.5 Loss Method SCS Curve Number (CN).

Estimation of rainfall losses and represent one of the main inputs to the hydrological model, so the next paragraphs describe the methods for determination these inputs. First and about rainfall losses; the SCS Curve Number method was used for estimation these losses. The application of this method Soil Conservation Service (SCS) (1972) developed a method for computing rainfall losses as shown in the next equations and figure (11).

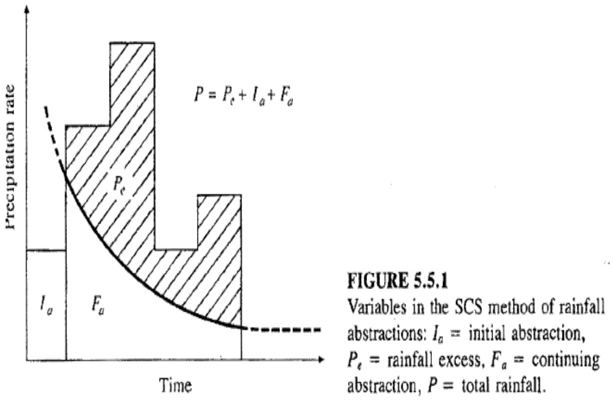

Fig -11: Schematic of the abstraction from rainfall storm (Chow et al, 1988).

There is some amount of rainfall called initial abstraction (Ia) when there is no runoff, the runoff is P - Ia. The approximation of the method is that equal the ratios between the two potential quantities, as shown in the next equations:

$$\frac{Fa}{S} = \frac{Pe}{P - Ia} \qquad (1)$$

From the continuity principle

$$P = Pe + Ia + Fa \qquad (2)$$

Combining (1) and (2) to solve for Pe gives

$$P_e = \frac{(P - Ia)^2}{P - Ia + S} \qquad (3)$$

P: Areal Average Precipitation.

I_a: Initial abstraction.

P_e: Depth of excess rainfall or direct runoff.

Fa = continuing abstraction,

S: potential maximum retention.

Equation (5) is the essential equation for computing the depth of rainfall excess. By studying many small experimental catchments, an empirical relation is created.

$$Ia = 0.2s \qquad (4)$$

On this basis

$$P_e = \frac{(P - 0.2\,S)^2}{P + 0.8S} \qquad (5)$$

The curve number and S are related by

$$S = \frac{1000}{CN} - 10 \qquad (6)$$

Plotting the data for P and Pe from many watersheds, the SCS found curves of the type shown in Figure (12). This figure shows CN relationship with cumulative rainfall and runoff and it is defined as 0 < CN < 100.

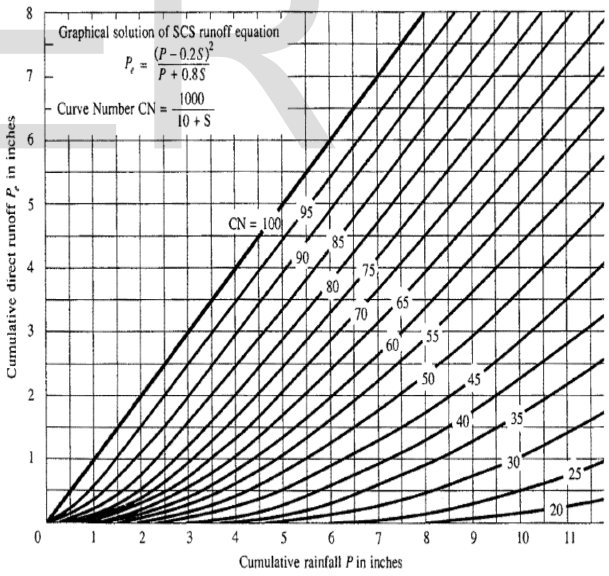

Fig -12: CN relationship with cumulative rainfall and runoff (Chow et al, 1988).

Applying curve number method requires defining the soil type and land use. Therefore, soils are classified into four groups A, B, C and D based on the infiltration rate and other characteristics. Following is a brief description of four hydrologic soil groups:

- Group A: this group is classified as deep sand and aggregated silts. These soils having high infiltration rates.
- Group B: this group is classified as sandy loam. These soils having moderate infiltration rates.
- Group C: this group is classified as Clay loams. These soils having low infiltration rates.
- Group D: this group is classified as heavy plastic clays and rocks. These soils having low infiltration rates (Chow et al., 1988).

After that, it should define the condition of the soil according to the type of AMC (I, II, III), where AMC I represents dry condition and CN (I) can be calculated from equation (7); While AMC II represents normal condition and AMC III for wet condition which has highest runoff potential. CN (III) can be estimated from equation (8).

$$\mathrm{CN(I)} = \frac{4.2\mathrm{CN(II)}}{10-0.058\mathrm{CN(II)}} \qquad (7)$$

$$\mathrm{CN(III)} = \frac{23\mathrm{CN(II)}}{10+0.13\mathrm{CN(II)}} \qquad (8)$$

Where:

P: Areal Average Precipitation.

$I_{a:}$ Initial abstraction.

P_e: Depth of excess rainfall or direct runoff.

S: potential maximum retention.

CN (I): Curve number for normal condition.

CN (II): Curve number for dry condition.

CN (III): Curve number for wet condition.

Finally, Curve numbers CN are based on their land use/covers, soil types, and hydrologic soil groups by using appropriate approaches in Watershed Modeling System WMS. According to Wadi EL- Melaha, the soil type was defined using (the surface geological map for Wadi El-Melaha, (WRRI 2010) and it included Alluvial, Sandstone, Limestone and Basement rocks. And the CN values were determined for each type of soil to be (77 storm1994, 90 storm 2011) and according to the classification of the land use (Chow et al., 1988, Hasanein 1989). Accordingly, the average curve number values for Wadi El- Melaha were calculated.

3.6 Run Off

El- Melaha catchment has high-resolution rainfall and runoff measurements. The criteria of selecting storms of this study is isolating storm event with high rainfall and resulting in high peak flow rate. A storm event was considered to be over when it has a period of at least 6 hours without rainfall. HEC-HMS was applied on two real storms1994 and 2011. Figure (13) shows stage hydrograph at El –Melaha watershed outlet for storm 11-3-1994 and storm 3-4-2011.

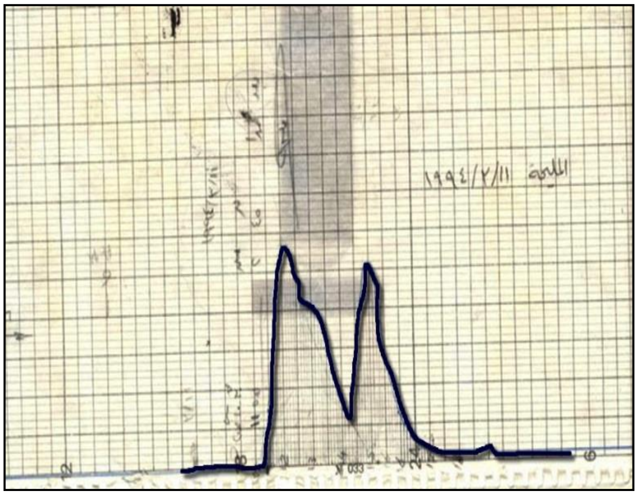

Fig -13: Water level recorded at the watershed outlet during (11-3-1994) storm

4. RESULTS AND DISCUSSION

HEC-HMS model is applied to El- Melaha watershed using two real storms (1994 and 2011). The output hydrographs of HEC-HMS were compared to the observed flow hydrographs.

4.1 Calibration Process

Model calibration is a systematic process of adjusting model parameter values until model results match acceptably the observed data. The precipitation-run-off models, this function measures the degree of variation between computed and observed hydrographs. The purpose of calibration is to identify the parameters whose variation causes significant changes in the outputs of the model. For the calibration of the generated simulation in the present study, we have to choose the CN, Impervious, and Lag time parameters. Two real storms for El-Melaha watershed were selected to perform the sensitivity analysis, storms 11-3-1994 (Double peak) and 3-4-2011 (Single peak). Model calibration process were used thought fourteen methods (first lag autocorrelation, maximum absolute residual, mean absolute residual, mean squared residual, nash Sutcliffe, peak weighted RMS error, percent error peak, percent error volume, RMS error, RMS log error, sum absolute residuals, sum squared residuals, time weighted error and variance absolute residuals)

The base values that were used in this study were presented in table (1, 2) Figures (14, 15) show the comparison between their simulated and observed hydrographs.

The performance of the HEC-HMS model is evaluated using the Peak Weighted RMS Error. This method gives the best results means a good agreement between the observed and predicted hydrographs.

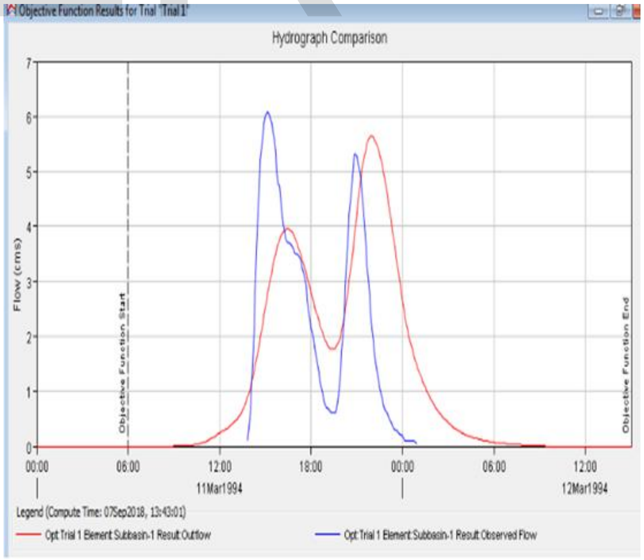

Fig 14-a: Hydrographs of storm (11-3-1994) peak-weighted RMS error methods.

`parameter	unit	Initial value	Optimized value	Objective function
Curve Number		77	68.35	-0.64
Lag Time	min	162.6	160.61	-0.89

Table (1-a) Model parameter values used for sensitivity analysis

Storm (11-3-1994) peak-weighted RMS error method

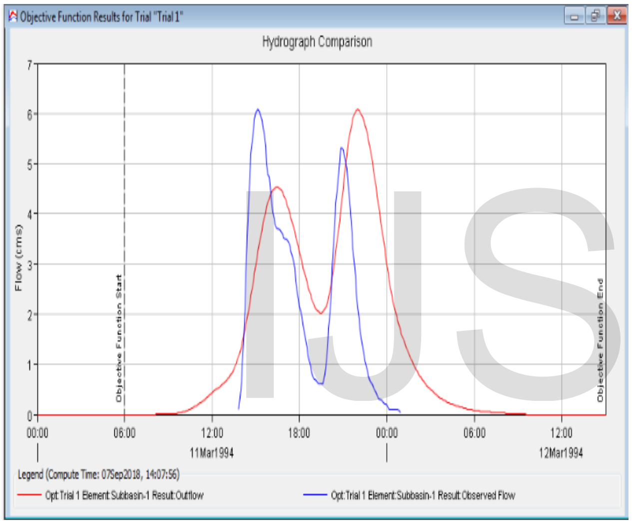

Fig 14-b: Hydrographs of storm (11-3-1994) percent error peak method.

parameter	unit	Initial value	Optimized value	Objective function
Curve Number		77	69.60	0.78
Lag Time	min	162.6	163.33	0.07

Table (1-b) Model parameter values used for sensitivity analysis

Storm (11-3-1994) percent error peak method.

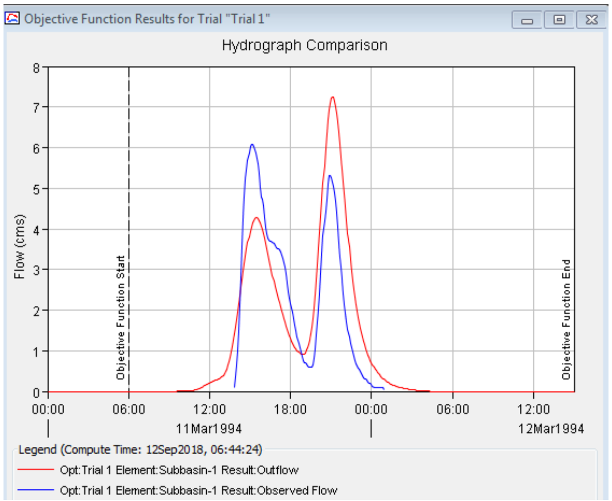

Fig 14-c: Hydrographs of storm (11-3-1994) Nash Sutclitte method.

parameter	unit	Initial value	Optimized value	Objective function
Curve Number		77	66.846	4.85
Lag Time	min	162.6	99.98	0.33

Table (1-b) Model parameter values used for sensitivity analysis

Storm (11-3-1994) Nash Sutclitte method.

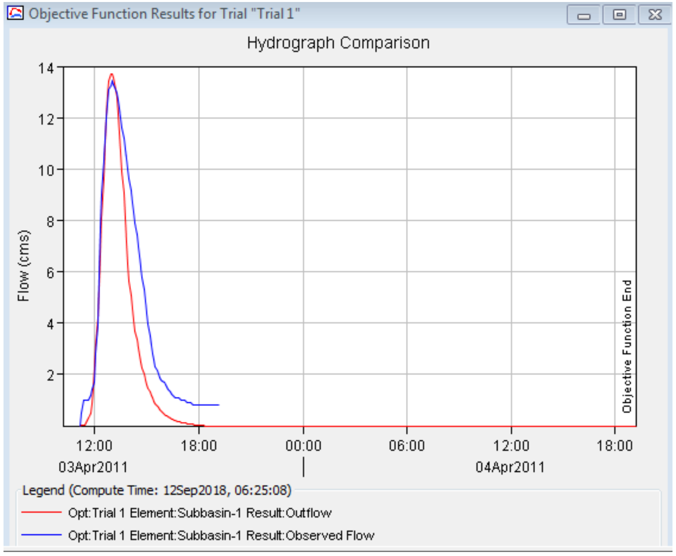

Fig 15-a: Hydrographs of storm (3-4-2011) peak-weighted RMS error methods.

parameter	unit	Initial value	Optimized value	Objective function
Curve Number		93	99	-23.34
Lag Time	min	162.6	75.51	-2.29

Table (2-a) Model parameter values used for sensitivity analysis

Storm (3-4-2011) peak-weighted RMS error method

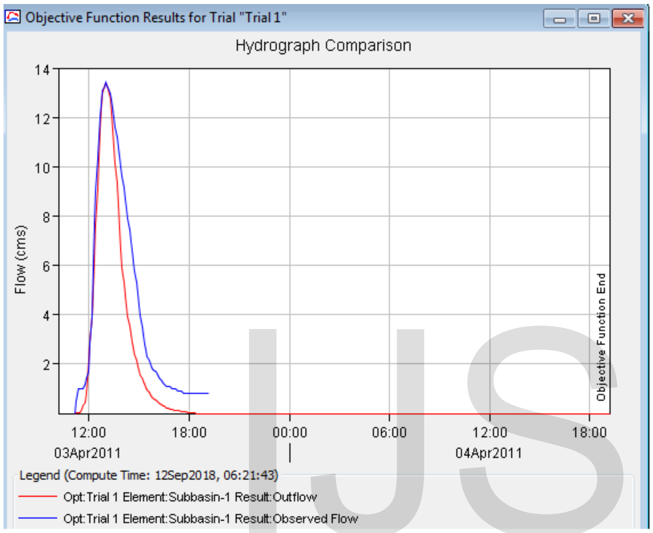

Fig 15-b: Hydrographs of storm (3-4-2011) percent error peak method.

parameter	unit	Initial value	Optimized value	Objective function
Curve Number		93	99	99.18
Lag Time	min	162.6	75.45	79.98

Table (2-b) Model parameter values used for sensitivity analysis

Storm (3-4-2011) percent error peak method.

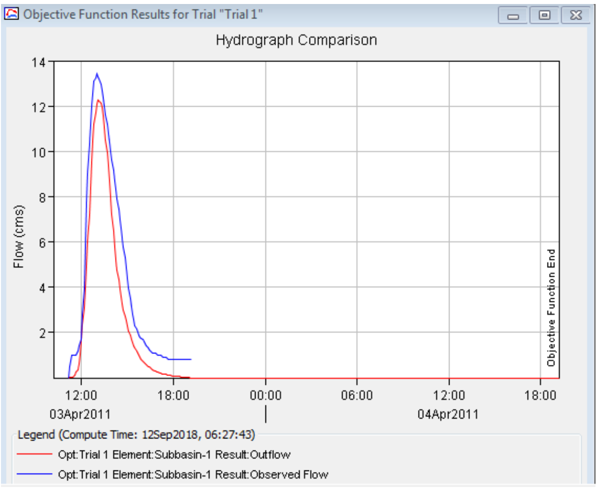

Fig 15-c: Hydrographs of storm (3-4-2011) Nash Sutclitte method.

parameter	unit	Initial value	Optimized value	Objective function
Curve Number		93	99	-48.13
Lag Time	min	162.6	85.063	-0.24

Table (2-c) Model parameter values used for sensitivity analysis

Storm (3-4-2011 Nash Sutclitte method.

In order to assess the HEC-HMS model sensitivity to different parameters, a series of sensitivity analyses were performed. Sensitivity analyses were highly needed to evaluate the impact of model parameters on the simulated hydrographs.

Performing sensitivity analyses is a method to identify model parameters that have the highest impact on model prediction. Different model parameters were studied, as each parameter was allowed to vary, all others were held constant. The effect of varying the parameters was evaluated in terms of impacts on the peak flow rate, the time to peak, the runoff volume and the overall hydrograph shape.

The sensitivity analysis focused on the following parameters (CN, T_{lag}).

The effect of the initial moisture content and the spatial variation in rainfall information were also considered. The sensitivity analyses is applied to two different storms, the first one has hydrograph with double peak and the second storm has hydrograph with only single peak to study the variation occurred in hydrograph in different storms shape.

5. Conclusions

In this study, DEM data of 30 m resolution was used for Wadi El–Melaha watershed delination and catchment characteristics using the WMS. Geological, soil and land use data used to well-understand the nature of the watershed. The HEC-HMS hydrologic modeling software was applied to Wadi El–Melaha located in Sinai to predict the surface runoff. The SCS curve number loss method was used to determine the hydrologic losses from the study area and SCS unit hydrograph method was used for effective rainfall transformation. The model parameters were calibrated against measured runoff event of 2 storm 1994 and 2011. The peak-weighted RMS error methods was used to estimate the goodness of fit between the observed stream flow and modeled stream flow.

After all, although the results suggest the possibility of conducting this model on the ungauged wadis in the semi-arid regions, it's recommended not to generalize this until these results get documented by applying the model on more storms happening in these regions.

REFERENCES

Ambroise B., La dynamique du cycle de l'eau dans un bassin versant. Processus, Facteur, Modèles. H.G.A. (Ed.), Bucarest, 1998.

Chow, V. T. Maidment, D. R. and Mays, L. W, 1988, "Applied Hydrology, McGraw-Hill, New York, U.S.A".

Clarke R.T., A review of some mathematical models used in hydrology with observations on their calibration and use. Journal of hydrology, 1973.

Eman A.H. El-Sayed, 2007, "Runoff Simulation Using Different Infiltration Models", presented at the V Regional Conference on Civil Engineering Technology & V International Symposium on Environmental Hydrology, Cairo, Egypt. Sept. 3-5, 2007.

Haitham Saad, et al, 2013, "Reliability Assessment of Water Structures Subject to Data Scarcity Using the SCS-CN Model", Hydrological Science Journal 61(4), 696-710.

Hasanein A. M. 1989, "Geology of water Resources in Wadi sudr - Gulf of Suez Region , Sinai , Egypt , M. Sc Thesis , Fac. of Sc. Ain Shms Uni. Egypt.

Lin, X 1999: Flash floods in arid and semi-arid zones, IHP-V Technical Documents in Hydrology, no. 23, 1999.

Norhan A., Saud T., Fahad A., Kamarul A., Arid hydrological modeling at wadi Alaqiq, Madinah, Saudi Arabia. Jurnal Teknologi. 2016.

Ogden F.L., and B.Saghafian, 1995, Green and Ampt Infiltration with Redistribution, ASCEJ. Irrigation and Drainage Engineering123 (5):386-393.

Scharffenberg W. A. and Fleming M. J.,“Hydrologic Modeling System HEC-HMS v4.2: User’s Manual, US Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA,

Shah S. M. S., O'Connell P. E. and Hosking J. R. M. Modelling the effects of spatial variability in rainfall on catchment response: Formulation rainfall field model. Journal of hydrology, 1996.

Sintayehu L.G., Application of the HEC-HMS Model for Runoff Simulation of Upper Blue Nile River Basin. Hydrol Current Res 6, 2015.

Sonbol, M. A. Mtalo, F. El-Bihery, M. and Abdel-Motteleb, M, 2005, "Watershed Modeling of Wadi Sudr and Wadi Al-Arbain in Sinai, Egypt", Proceedings of the International Conference of UNESCO Flanders fust FRIEND/NILE project towards a better cooperation, UNESCO 12-14 November.

US Army Corps of Engineers 2013, HEC-HMS hydrologic modeling system User’s Manual, Hydrologic Engineering Center (HEC), US Army Corps of Engineers 609 Second Street Davis, CA 95616 - 4687, USA.

Wheater H., Sorooshian S., Sharma K.D., Hydrological modelling in arid and semi-arid areas. Cambridge University Press, Cambridge UK

WRRI, 2010," Flood atlas in Sinai", Water Resources Research Institute WRRI, Delta-Barrages, Cairo, Egypt.

Yair, A and Lavee, H. 1985. Runoff generation in Semiarid and Arid Areas. In: Hydrological Forecasting, Chap.8: 183-220. Eds. Anderson M.G. & Burt, T.P. Wiley.