Rainfall, Runoff and Erosion Analyses in a Sandy Desert Watershed under Mid-Latitude Cyclones Using the Kineros2 Model

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***Abstract*-Yamin Plain as the host of the national radioactive waste disposal in near surface repositories is very sensitive to erosion during flood events. To estimate the runoff and erosion Kineros2 model was used. For the period of 2012-2015, twelve related rainfall and runoff events were recorded from a centrally-located recording rain gage and separate runoff station at the outlet of the Nahal Yamin watershed, located in the northeast of the Negev Desert, Israel. Four of the storms, associated with mid-latitude cyclones were analysed due to the assumed relatively homogeneous distribution of rain. Three runoff parameters-peak discharge, time to peak and runoff volume were used to compare the computed with the measured hydrograph. In two events the fit was 2.16 and 3.67 for Root Mean Square Errors of 0.48 and -0.54 for Nash-Sutcliffe coefficients. The erosion rate calculated by the model of a few millimetres per event were in the same of order of magnitude as found by different techniques. In this limited application, the Kineros2 model provided valuable insight into the hydrological functioning of a critical arid watershed.**

Keywords- Kineros; Hydrograph; Hydraulic Conductivity; Arid Zone; Erosion Rate

I. INTRODUCTION

Floods are a major cause of losses in infrastructure, property and life in many arid regions around the world. In addition, floods play a primary role in modifying the fluvial desert environment [1]. Still many arid watersheds lack the data necessary to predict the runoff volume, discharge and erosion from the characteristically highly spatially and temporally variable precipitation that falls within these watersheds, further decreasing data reliability. Hydrological data in arid and hyper-arid areas are generally poorly documented. Only some ephemeral streams have hydrometric stations, and these are very hard to maintain. During intensive flooding, the stations can be destroyed, leading to incomplete or non-existent data. This is true for the Negev Desert in southern Israel, where floods have been studied extensively [2-6]. Sometimes you need only few events, where the hydrometric station recorded the full flood without any disturbance, and the rainfall was homogenous, in order to model the watershed. This is the case in Yamin Plain. Therefore, the ability to reconstruct a flood hydrograph by using a model is one of the ways to deal with that problem. The main motivation for the current study was derived from the existence of waste disposal facilities in near surface repositories. The site will be under institute control period of 300 years starting from the closure. According to the statutory duty, evaluation of the changes in the environment due to climate changes should be done. Modelling of the rainfall/runoff relationship and the erosion will allow running different scenarios including extreme rain events.

Models dealing with the prediction or reconstruction of flood hydrographs are common, among them rainfall-runoff process simulation and flood routing [7-17]. In the field of rainfall-runoff modelling, the focus is often on flood hydrograph prediction. A simple approach to rainfall-runoff modelling was proposed by Sherman [18] based on the unit hydrograph method, which hypothesizes that a watershed has a unique hydrological response function that is reflected by a unit hydrograph. Many researchers have described flood hydrographs and the recession limb as part of flood-routing procedures [16, 19-23]. In general, flood hydrograph analysis provides a simple method for estimating runoff volume in a watershed in response to storm patterns [24-27] or physical characteristics of the drainage area [10, 11, 15, 28, 29]. However, in both cases, there is a need for many variables and complicated equations.

The present study demonstrates the use of the Kineros2 (K2) model for analysing runoff and erosion in a sandy watershed in the Yamin Plain (YP), located in the Negev Desert. The YP is dominated by the Subtropical ridge (latitude of 20-30^{0}N), and is classified as arid zone. The YP has been designated as a national radioactive waste site for the last approximately 50 years. The depth of the waste facilities are only few meters below surface and according to IAEA [30], it is classified as near surface disposal. Therefore, knowing and understanding the natural processes in the watershed, mainly geomorphology, floods, surface erosion rate are very important for managing and maintaining the waste facilities. Previous research has determined erosion rates for 300k-year periods in the YP using optical stimulated luminescence (OSL) [31] and cosmogenic isotopes [32].

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However, calculation of erosion rates for single flood events does not exist for this watershed. We chose to apply the K2 runoff and erosion model to the acquired data, since it was physically-based, well-suited for the individual and isolated rain/runoff events characteristic of arid areas, and has runoff and erosion capabilities.

The two main goals defined for the current research were to analyse the runoff hydrograph and to calculate the erosion rate during the flood events caused by the Cyprus Low associated with regional mid-latitude cyclones. This will allow us to reconstruct events when the runoff gage fails to record the runoff event.

II. THE STUDY AREA

The YP is situated northeast of the Negev Desert in Israel. The 30 km^2 Nahal Yamin (NY) watershed is located in the southern part of YP (Fig. 1). Geologically, the YP is located in an asymmetric syncline which is part of the Syrian Arch system [33, 34]. The syncline was filled during the Miocene era essentially with sand, to a depth of 80-150 m [35, 36]. At the depth of 80 m in the base of Hazeva Gr. a small fossil aquifer existed [37]. The topography is described as mainly flat plain, ranging from a peak elevation of 472 m a.s.l. to the lowest elevation of 392 m a.s.l. along the south edge of the plain, where the runoff gage is located. Meteorologically, two types of synoptic systems are associated with precipitation in the southern part of Israel [38]. The first are mid-latitude cyclones arriving from Europe which dominate the months of December to March, and the second are small, convective rain cells resulting from the Red Sea Trough (RST), dominating the precipitation during October-November and April to May. The average annual precipitation of NY is 72 mm, falling during the autumn, winter and spring seasons (October through May) on an average of 10 days per year. Snow in the study area is very rare. The precipitation is highly variable, where rain amounts for a single rain event have varied up to 100% over a distance of 2 km, Table 1 shows the rain data of the winter 2013-14. As seen the event of 20.3.14, the rain gage got 5.5 mm, while rain gage 8 located 2 Km to the north got 12.5. Water flow in the watershed is ephemeral, with flow in the channels occurring only in response to specific rain events.

TABLE 1 HIGH VARIABILITY OF RAIN EVENTS AS MEASURED IN 3 DIFFERENT RAIN GAGES LOCATED IN THE WATERSHED

date	rain gage 5	rain gage 6	rain gage 8	average	STDEV
15.12.13	10	7	9	8.67	1.53
31/12/13	21	22	23	22	1.0
9/1/14	13	15	12	13.33	1.53
16/2/14	28	18	16	20.67	6.43
10/3/14	7	9	7	7.67	1.15
20/3/14	7	5.5	12.5	8.33	3.69
7/5/14	26	21.5	30	25.83	4.24
total	112	98	109.5		

The plain is dominated with perennials of *Artemisia sieberi, Retama raetam, Atriplex halimus, Zygophllum dumosun, Anabasis articulate and Calligonum comosum.* The common annual plants are *Erucaria pinnata. Stipa capensis, Anthemis melampodina* [39]. The sandy soil throughout the NY watershed is mainly composed of quartz with the most frequent grain size of 0.5 mm [40, 41]. The soils are classified as sandy soil [42]. Part of the YP area was closed administratively during the late 1950's and cattle grazing were stopped. Since then, the sands have been stabilized by perennial plants and patches of biological soil crust (BSC), both of which changed the ecology and the hydrology of the study area [40, 43-45]. Today, aeolian processes in YP have been found to be negligible since the closure of the study area. Specifically, Hetz [40] measured the hydraulic conductivities over tens of plots and reported that infiltration rates can vary by one order of magnitude in the same plot, depending on the presence and activity of the BSC [45-48].

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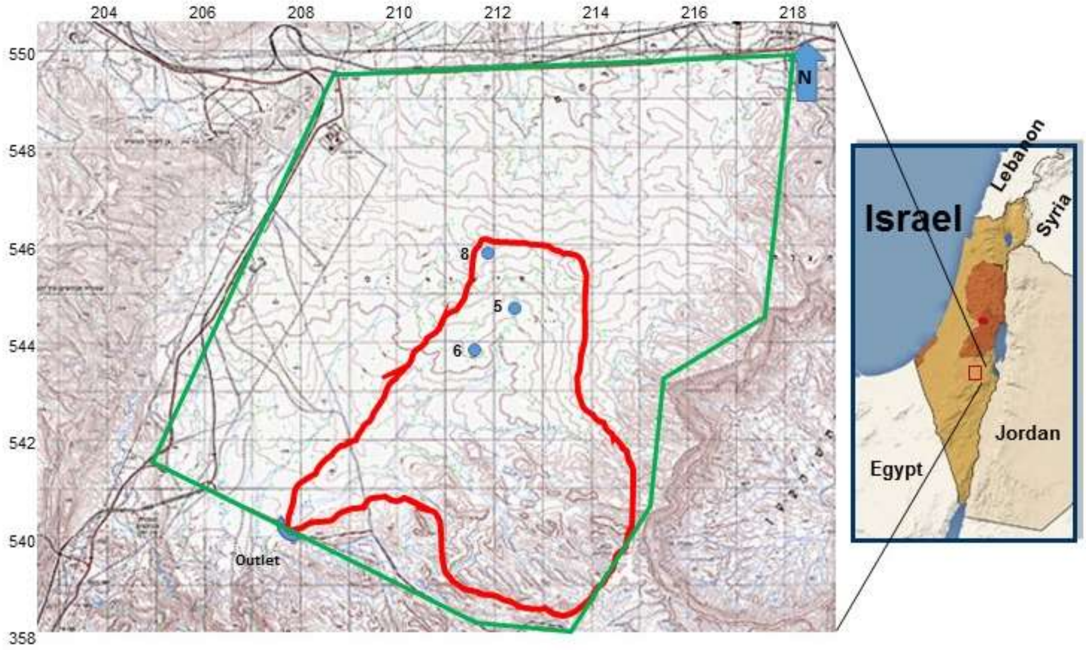

Fig. 1 Map of the Yamin Plain (YP) borders (green), the Nahal Yamin (NY) watershed (red), recording rain gage, runoff gage, and total depth rain gages (5, 6, 8). The recording rain gage and total depth gage 6 are located in the same place (ITM coordinates)

III. MATERIAL AND METHOD

A. Kineros2

Kineros2 (K2) is a physically-based, distributed runoff and erosion prediction model [49]. It is an event model (able to account for soil moisture for only short periods of time without rain), well-suited for the infrequent, short duration and high intensity precipitation events characteristic of arid areas. Nevertheless, the utility of K2 has been demonstrated in tropical and temperate regions with higher and longer precipitation events. In addition, the utility of K2 has been demonstrated in various settings ranging from urban developments to remote mountain watersheds [50, 51]. As an event model, there is no accounting for evapo-transpiration during an event, neither can K2 account for precipitation in the form of snowfall nor snow accumulation on the land surface. In K2, the watershed is discretized into a series of overland and channel flow planes, over and through which flow is routed, using the kinematic wave model. The degree of discretization (i.e., size and shape of model plane and channel elements) is a balance between capturing the realistic routing of water over and through the basin and the existence of data characterizing the salient features of the watershed spatial heterogeneity. Parameters input to characterize plane elements are assumed to be time-invariant throughout the modeled event, and surface flow is assumed to be unidirectional. Various channel geometries can be accounted for. Erosion and sediment transport is modeled using a mass balance approach accounting for both splash and hydraulic erosion on overland flow planes, and for hydraulic erosion and lateral inputs of sediment in channel elements [52].

K2 generates and routes water flow given the spatial and temporal conditions of a precipitation event. K2 includes a spatiotemporal precipitation interpolator given time-depth precipitation data for more than one gage. The initial soil moisture condition can also be spatially specified. The spatial variability of saturated hydraulic conductivity can be varied throughout a watershed through the discretization of the overland flow planes, but sub-plane spatial variability can also be specified if multiple measurements exist. The three parameter Smith-Parlange equation is used to model infiltration during an event. K2 is considered an interactive infiltration model in that the infiltration of water is accounted for during each flow calculation time step.

While K2 has seen successful application in a variety of settings, it has been considered a parameter-intensive model - a drawback for data-sparse applications. But this again, is dependent on the degree of discretization deemed necessary to capture watershed features and on model objectives. Nevertheless, K2 has been adapted for GIS applications and data formats, if point data are sparse or unavailable, although that adaptation was not used for the NY application. Both versions of K2 are PC-based. K2 is public-domain software developed by the USDA (U.S. Department of Agriculture) Agricultural Research Service. The documentation and source code are available on-line [53].

Data needed to run the model include precipitation data intensity or depth for each rain gage and, for each element, initial soil moisture and values for parameters such as hydraulic conductivity, Manning roughness coefficient, canopy cover, interception, and grain size distribution. In case of unknown values for any parameters, default values suggested by the model documentation were used.

The watershed was divided into six planes and two channels, based on the physiographic pattern of the watershed (Fig. 2). The area, length and slope for each plane and channel were calculated from a 1:50,000 topographic map. Once runoff element parameters were specified, various degrees of watershed discretization were examined.

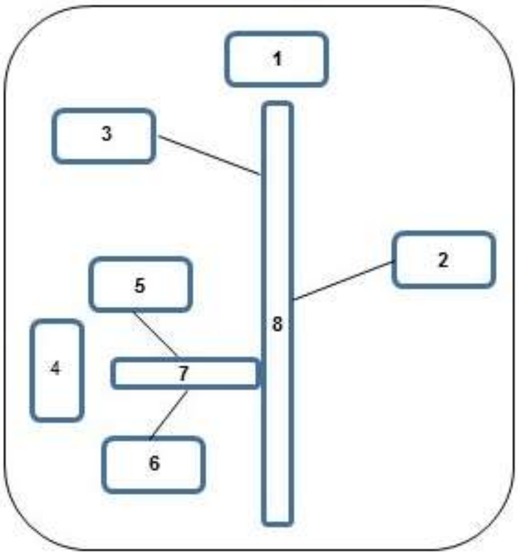

Fig. 2 Schematic layout of the planes and channels in the NY watershed

B. Data

A full meteorological station, including a Campbell Scientific TE525 tipping bucket electronic recording rain gage with a resolution of ±0.1 mm and unlimited capacity, is located close to total depth rain gage 6 (Fig. 1). Three total depth rain gages (5, 6 and 8) are covering only the northern part of NY watershed (Fig. 1).

A runoff gage was setup and operated since 2011 by the Israel Hydrological Service (see location in Fig. 1). The station has a known steady cross section. The flow depth is measured by a Shlumberger mini diver-CDX (pressure transducer), defining the lowest point of the watershed at the channel outlet cross section. The minimal discharge threshold value is 0.012 m^3/s. No other devices exist at that location.

The saturated hydraulic conductivity (K_s) was measured at 60 locations throughout the YP, using the Decagon mini portable tension infiltrometer, while only 38 were located in the northern part of the NY north watershed. Calculated K_s values ranged from 0.3 to 4.5 mm/hr with an average of 1.49 mm/hr. The grain size distribution used in the model, and canopy cover of 20%, were taken from Hetz [40].

The initial ambient surface soil moisture saturation of 0.18 was calculated based on gravimetric measurements [40, 41]. Length, width and slope of the NY watershed were calculated based on a 1:50,000 scale topographic map. Due to the sparsely of data, several assumptions were necessary to implement K2. Although K2 can account for the spatial and temporal variability of precipitation input, only one electronic recording rain gage and three total depth rain gages are located in the basin, covering only the north parts of the basin (Fig. 1). The recording rain gage is considered reliable but insufficient, alone, to capture the spatial variability of rain and storm movement during an event. The total depth rain gages require readings immediately following an event, thus can be unreliable. However, the total depth rain gages were only used to indicate the homogeneity of the event. The three total depth rain gages do not represent precipitation for the entire watershed. Since there was only one rain gage to record precipitation for a 30 km^2 area, all data representing convective precipitation belonging to the RST and associated runoff were eliminated from this study.

Fig. 3 shows the total rain depth in the three rain gages. We assumed that if the rain in the total depth rain gages appeared varied, rain throughout the watershed was varied; however, homogeneity of rain depths in the gages did not imply homogeneity of precipitation throughout the watershed. Unfortunately, rain radar data were available for only one event.

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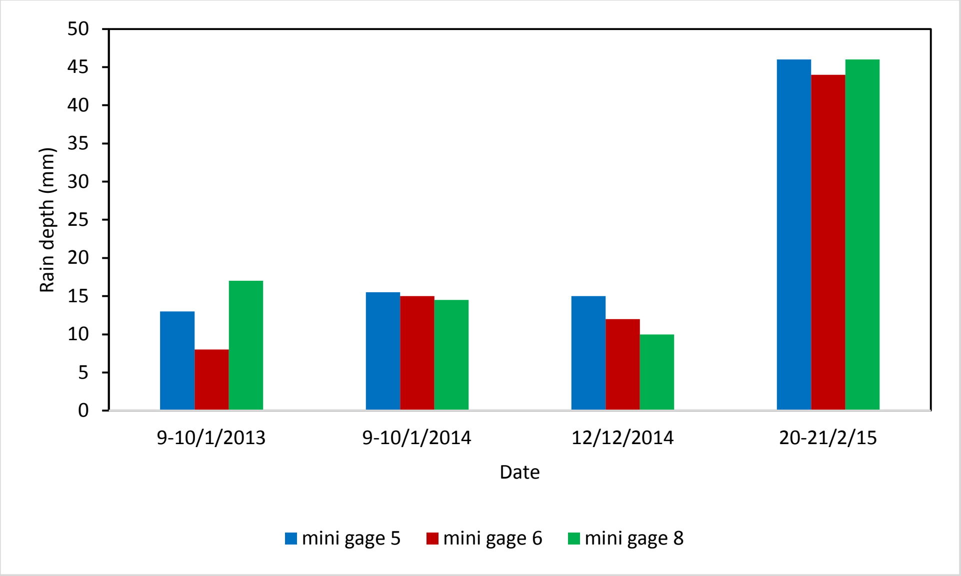

Fig. 3 Total depths according to the total depth rain gages for four mid-latitude cyclonic events

Coordinated rain and runoff data exist for four events belonging to mid-latitude cyclone were analyzed within the NY watershed (Table 2). Due to the scarcity of data, this was a non-calibrated runoff model study.

TABLE 2 RECORDED FOUR FLOW EVENTS CAUSED BY MID-LATITUDE CYCLONES

Event No.	**Beginning of flow**		**End of flow**		**Flow duration**	**Volume**
	Date	**time**	**date**	**time**	**(hr:min)**	**m^3 (x1000)**
1	08/01/2013	21:20	10/01/13	19:40	46:19	12
2	09/01/2014	23:10	10/01/14	07:45	8:34	55
3	12/12/2014	20:00	13/12/14	14:55	18:55	92
4	20/02/2015	10:25	21/02/15	18:40	32:15	73

The variability of the K_s is expressed by the CV (CV=STDV/Average). The K_s measurements done by Hetz (2009) were not taken systematically from the whole watershed, but from the north part only. Yet because of the same geology, ecology and soil formations, we expect the CV value to represent adequately the whole watershed. Nevertheless, the effect of the CV values between 0 and 3.5 on the peak discharge was tested.

C. Model Fitting Measures

Table 3 presents the physical parameters and variables of the basin used in the model.

TABLE 3 PARAMETERS AND VARIABLES USED FOR OVERLAND FLOW PLANE 1*

Parameter/variable	**Value**	**Unit**
grain size	0.5, 1.25, 2	mm
Density	2.65, 2.6, 2.6	gr/cm^3
Fraction	06, 0.3, 0.1	ratio (sum to 1)
Porosity	0.3	-
Slope	0.04	-
Relief	2	mm
Manning roughness coefficient	0.1	
Saturated hydraulic conductivity	1.49	mm/hr
Coefficient of Variation (CV) of K_s	2.22	-
Temperature	15	^0C
Interception	0.9	mm
Canopy	0.2	Ratio

* The values of some parameters and variables may differ values among planes and channels.

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Model fit was assessed using root mean square error (RMSE) and the Nash-Sutcliffe efficiency coefficient. The RMSE values range from 0 to ∞, where RMSE=0, indicating perfect fit. Equation 1 expressed the RMSE:

$$RMSE = SQRT((O_d - C_d)^2/n) \tag{1}$$

Where O_d and C_d are measured and computed discharge, respectively.

The Nash–Sutcliffe (1970) model efficiency coefficient (Equation 2) was used to assess the predictive power of hydrological models. It is defined as:

$$E = 1 - \frac{\sum_{t=1}^{T}(Q_0^t - Q_m^t)^2}{\sum_{t=1}^{T}(Q_0^t - \overline{Q_0})^2} \tag{2}$$

where $\overline{Q_0}$ is the mean of measured discharges, Q_m^t is modelled discharge and Q_0^t is measured discharge at time *t*. Nash–Sutcliffe efficiency can range from -∞ to 1. An efficiency of 1 ($E = 1$) corresponds to a perfect match of modelled discharge to the measured data. An efficiency of 0 ($E = 0$) indicates that the model predictions are as accurate as the mean of the measured data, whereas an efficiency less than zero ($E < 0$) occurs when the measured mean is a better predictor than the model [54].

IV. RESULT AND DISCUSSION

Rain runoff and erosion were studied carefully in NY watershed, although the uncertainty, lack of data, which almost built in research under desert conditions. The new hydrometric station allowed us to use runoff and erosion model like K2. Twelve events were recorded but only 4 of them belonging to mid-latitude cyclones were analysed. This was done to reduce as much as possible the uncertainty of the spatial distribution of the rain.

A. Planes and Channels

The determination of the level of discretisation (i.e., the size and number of watershed planes and channels) necessary to characterize the watershed is an important consideration in model application as the need to capture salient runoff features is balanced with available data. The numbers of the elements (planes and channels) were changed from two to 18, while the rest of the variables stayed constant. In this process, we used the same rain event and peak discharge was chosen to be tested. With two and four elements, the peak discharge was too low compared to the measured runoff. Using more than eight up to 18 elements, no improvement in the results was achieved.

B. Runoff Modelling

Four mid-latitude cyclonic events were analysed and used for model input (Table 4). The model simulations used the same parameters over the four events.

TABLE 4 COMPARISON BETWEEN MEASURED AND COMPUTED HYDROGRAPHS

Event No.	Event date	Peak discharge (m^3/s)		Time to peak (min)		Volume (m^3)	
		Measured	Computed	Measured	Computed	Measured	Computed
1	09/01/2013	**0.82**	**0.23**	445	440	**12,000**	**222**
2	09/01/2014	12.64	12.66	130	120	55,000	86,071
3	12/12/2014	9.65	10.26	90	130	92,000	57,081
4	20/02/2015	**5.85**	**45.8**	1210	1310	**73,000**	**338,617**

Fig. 4 represents the rain and runoff event of 8-10/01/13. Significant differences between the hydrograph peaks are apparent where the predicted runoff was much lower than the measured runoff event (Fig. 4b). In this case, the total depth precipitation data based on the three total depth rain gages (Fig. 3) indicate that the rain distribution may not homogeneously distributed, and the precipitation data from the recording rain gage was not representative of the entire watershed.

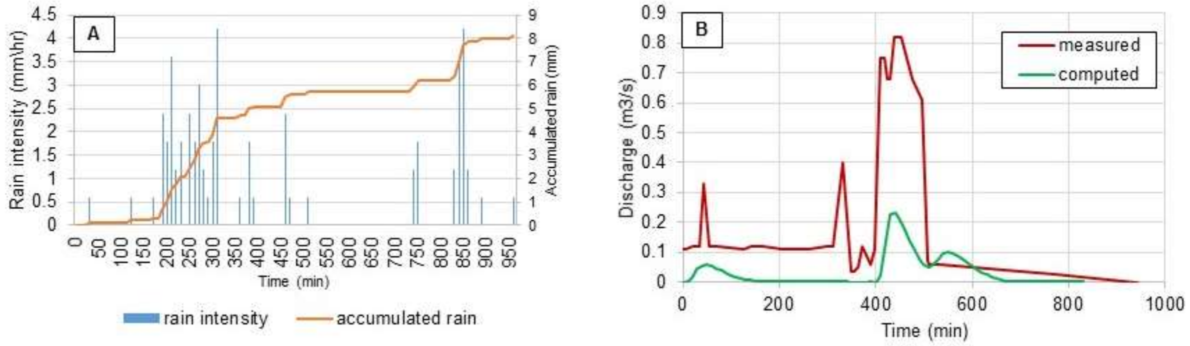

Fig. 4 (a) Rain event and (b) Measured and computed hydrographs for rain event 9-10/01/13

Fig. 5 represents the input rain data and the output hydrographs of rain event 20-21/02/15. This rain event was unusually large (42 mm), more than half the average annual total (72 mm). The computed peak discharge is about 45 m^3/s, while the measured is about 11 m^3/s (Fig. 5b).

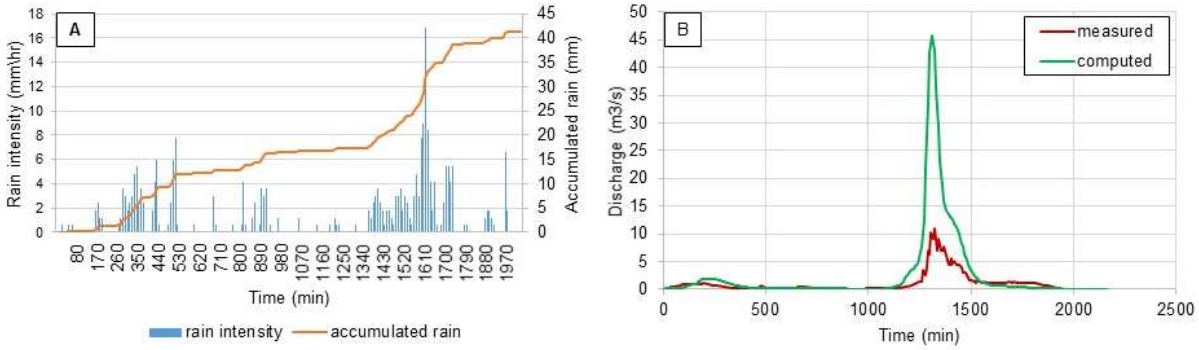

Fig. 5 (a) Rain event and (b) Measured and computed discharge occurred in rain event 20-21/02/15

Using the three total depth rain gages (Fig. 3) located in the north part of the watershed (Fig. 1), the rain distribution could be considered homogenous. However, additional rain radar data obtained for this event show a decreasing rain trend toward the southeast part of the watershed (Fig. 6). Around half of the watershed received 20-30 mm of rain; while the other half received only 15-20 mm, resulting that recorded runoff lower than runoff modelled assuming a homogeneous rain distribution (Fig. 5b).

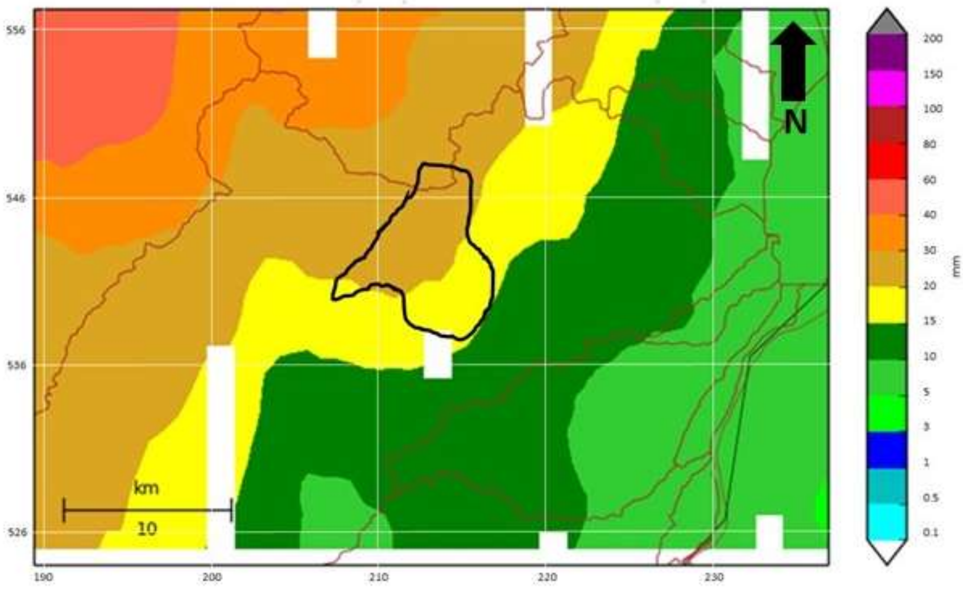

Fig. 6 Computed accumulated rain map based on rain radar. The boundaries of the NY watershed are shown in black

Fig. 7 represents the input rain data and the output hydrographs, for the rain event at 9-10.1.14. The measured hydrograph

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(Fig. 7b) has sharp fluctuations, which probably occurred due to measurement interference during the flow event, but the peaks are similar. The rain for this event was considered relatively homogeneous and the modelled runoff matched the observed fairly well, therefore we choose this event to run with CV=0 in order to test the case where all Ks measurements yield the same value. In both events, the peak discharge was much lower by factor of 2.5-3 as shown in Figs. 7b and 8b.

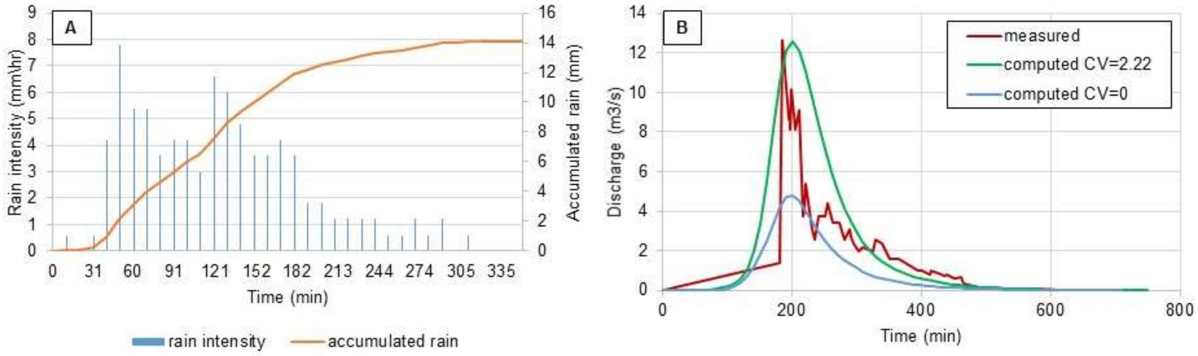

Fig. 7 (a) Rain event and (b) Measured and computed hydrographs for rain event 9-10/01/2014

Fig. 8 represents the input rain data and the output hydrographs of rain event 12/12/14. Here again, the computed peak discharge with CV=0 is lower compared to a computed hydrograph using CV=2.22.

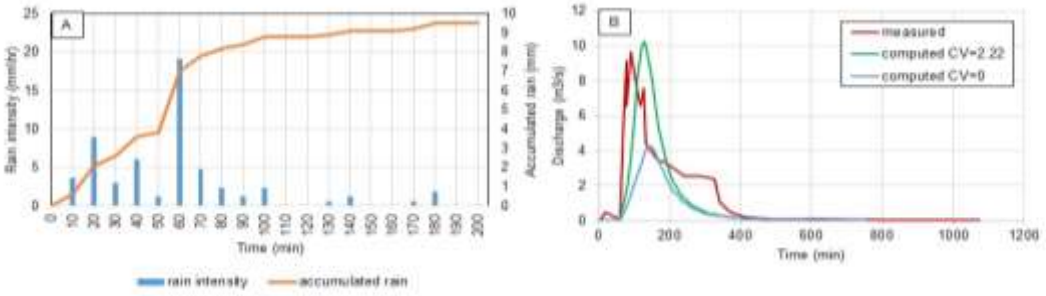

Fig. 8 (a) Rain event and (b) Measured and computed discharge occurred in rain event 12/12/2014

Taking into account the uncertainty of the rain characteristic over the watershed in events 2 and 3 (Table 4), the RMSE indicating the agreement between simulated and measured peak discharges are 2.16 and 3.67, and Nash-Sutcliffe values of 0.48 and -0.54, respectively (Table 5). In this case, since the similar between the measured and computed hydrograph, we assumed that the rain was relatively homogenous over the watershed as indicated by the total depth rain gages. As shown in Fig. 4b (event no.1 in Table 4) the measured peak discharge is much higher than the computed one. This may be because that part of the watershed received more rain as recorded by the total depth rain gage 8 (Fig. 3). In event 4 (Fig. 5b), the computed peak discharge is much higher than the measured, likely due to the fact that the southeast portion of the basin received less rain. In all four events (Table 4), the time to peak between measured and computed hydrographs was tested too with RMSE of 44 min.

TABLE 5 RMSE AND NASH-SUTCLIFFE FOR THE TWO EVENTS

Event	RMSE	Nash-Sutcliffe
09/01/14	2.16	0.48
12/12/14	3.67	-0.54
9-10/01/13	0.36	-0.2
20-21/0215	8.12	-49.14

Saturated hydraulic conductivity (K_s) and its spatial distribution are a major control on infiltration in runoff analyses [50], [55-57]. K_s measurements were available for the larger YP area (n = 60) of which 38 were located in NY in the north part of the watershed, with a calculated (spatial) CV of 2.22. To test the effect of the spatial variability on the NY, simulations were carried out with the general area mean K_s of 1.49 mm/hr in two events, using CV = 0 up to CV=3.5 (Fig. 9). The CV (K_s) parameter was altered to assess the unaccounted for but probable variability in K_s due to soil texture, vegetation effects and crusts both physical and biological. From Fig. 9 we learn that the peak discharge increases as the value of CV grows. The

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relationship is not linear but asymptotic.

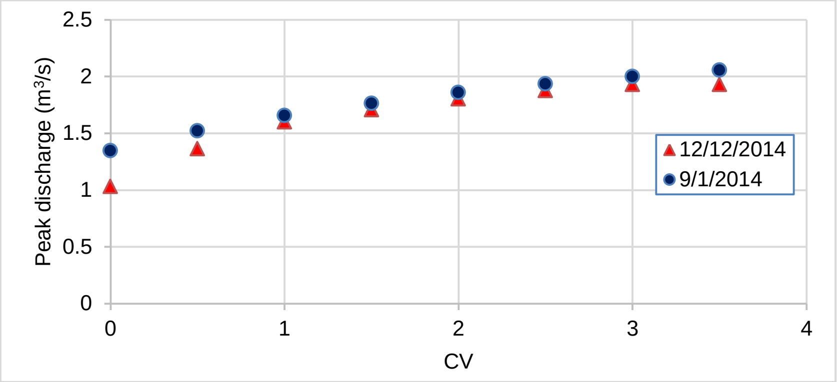

Fig. 9 The effect of the coefficient of variation about Ks on modelling peak discharge

C. Erosion

Erosion rates or bedload sediments were studied in the Negev area very intensively [57-60]. The entire mentioned article reported that bedload sediments were very high. The erosion rates in YP were studied in different techniques during 300 Ky; OSL [31], cosmogenic isotope [32], and qualitatively analyses using aerial photos and satellites images [40]. In the current research, the erosion was calculated for the two fit events and presented in Table 6. Average erosion was calculated by dividing the total erosion (m^3) by the area of the watershed (m^2). This average value is needed to compare with previous studies mentioned before.

TABLE 6 THE EROSION FOR THE TWO FIT EVENTS

Date	Total erosion		Erosion peak	Average erosion
unit	kg	m^3	gr/m^2	mm
09/01/14	267000	103000	8.88	3.46
12/12/14	143000	54800	4.700	1.83

In general, the combination of rain parameters and the physical characteristic of the watershed, influencing the peak discharge and the time duration of the flood and the bedloads sediments transport. In a given watershed, the higher rain intensity, the higher peak discharge, the higher kinetic energy and higher erosion is expected. Table 7 shows the rain and discharge peaks and the ratio between them for the two events. High ratio means low erosion and vice versa.

TABLE 7 PEAKS OF RAIN AND DISCHARGE FOR THE TWO FIT EVENTS

Event	Rain peak (mm/hr)	Computed peak discharge (mm/hr)	Specific discharge ($m^3/s/km^2$)	Rain/Discharge Ratio
09/01/14	4.68	1.5	0.42	3.12
12/12/14	11.52	1.14	0.32	10.10

V. SUMMARY AND CONCLUSIONS

Research in desert environments is challenging in many aspects. Collecting reliable data of flood events is particularly challenging. Lack of data or poor quality may leads to a situation that statistically, one does not have enough events to analyse to get the full picture. Although the uncertainty that the decision to analyse the flood events using K2 model was made, mainly because it deals with the two important topics (runoff and erosion) rose in the introduction.

Yamin Plain is composed by sandy soil; therefore the area is very sensitive to surface erosion mainly during flood events. The fact that YP is also hosts the national facilities for near surface radioactive waste disposal, makes the erosion topic even more critical. The current study is the first step to get a better understanding about surface erosion during flood events. Because the lack of the data the authors awarded that the results and conclusions are limited and more work should be done in the future.

Only one reliable recording rain gage in the arid 30 km^2 NY watershed was available. It is obvious that neither the spatial nor temporal variability in rain input can be captured, variability essential to predicting runoff, as was shown in the analysis. But this situation is likely quite common throughout the dry lands of the world which, nevertheless, may require some knowledge about runoff and erosion within and leaving a watershed. Thus, addition of simple total depth rain gages, properly used, can increase the reliability of a more costly single recording rain gage. Rain data based on radar should be a better way to solve the fact of spatial and temporal variability.

Four events associated with mid-latitude cyclones were analysed but only in two of them the peaks hydrographs were similar. The RST events were excluded from the analysis since by definition, they have high spatial variability. In two events, the likely heterogeneity of the rain over the watershed yielded wrong calculated hydrographs. We think that the spatial variability of the rain is the reason. This situation could be resolved with more than one recording rain gage or spatial data from radar. In case that part of the basin gets more rain compared to the recording rain gage, the measured hydrograph will be larger than the computed and vice versa if part of the basin gets less rain compare to the recording rain gage, then the computed hydrograph will be bigger than the computed one.

As a part of dealing with lack of Ks measurements, the model run with different values of CV of the Ks measurements to learn its influence of runoff hydrograph. The main conclusion is that higher CV, yield higher discharge. The number of the elements (planes and channels) could affect the hydrograph as found here. In less than eight elements, the peak discharge was lower than expected.

Erosion as stated before is very important topic. Since the erosion is a function of the discharge, we analysed only the two fit events. Few mm of erosion computed per single flood are in the same of order as found in different methods reported in previous studies.

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