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The Potential Use of the SCS-CN Method to Estimate Extreme Floods in the West Bank Data-scarce Catchments

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Abstract: In the West Bank, extreme floods are becoming more frequent. This can be attributed to the expansion of urban areas together with the climate change impacts (the increasing rainfall intensity). This situation worsens given the lack of proper hydraulic infrastructures required to safely dispose of the accumulated floods. Thus, it becomes essential to estimate extreme flood values so as help decision-makers in formulating proper corrective and preventive strategies. This study utilizes the SCS-CN approach to estimate extreme flood values at the different West Bank data-scarce catchments. Maximum annual daily rainfall (MADR) values were used to obtain extreme rainfall daily grids for different selected return periods (10, 25, 50, and 100 years). The GIS was heavily used to apply the SCS-CN method for the entire West Bank catchments. Results show that extreme daily rainfall values are increasing with the increase of the return period. Further, catchments draining into the west (into the Mediterranean Sea) have more extreme daily rainfall values than those draining to the east (into the Dead Sea and the Jordan river) and as such, the expected extreme floods in these catchments are high for the selected return periods. Moreover, based on the average expected extreme flood values, a flood hazard map was developed that classifies West Bank catchments into 5 flood hazard zones. By area, about 42% of the total West Bank catchments are under high to very high flood hazard zone. The results of this research can be adapted to realize any administrative strategy changes for cohesive catchment-based extreme flood hazard management and to prioritize flood remedial plans at the different West Bank catchments.

Keywords: SCS-CN method, Extreme Floods, Flood Hazard, Data-Scarce Catchments, West Bank, Palestine.

Introduction

Worldwide, flood is one of the most frequent and destructive natural hazards, which in most cases, leads to catastrophic consequences to natural resources, and loss of human beings and assets (Khan et al., 2011; Jonkman & Dawson, 2012, Yashon & Ryutaro, 2014; Kazakis et al., 2015; Jain et al., 2018). Urbanization in many regions of the world will amplify potential flood hazards, which implies pressure on landuse planning (Yashon & Ryutaro, 2014; Hanif et al., 2019). Urbanization has direct impacts on hydrological characteristics (e.g., infiltration decrease, runoff increase) that will increase the frequency and magnitude of floods (Alaghmand et al., 2010). Moreover, the predicted global climate change and the accompanying severe weather conditions (e.g., increasing rainfall intensity) will also increase the occurrence of flash (extreme) floods (Dihn et al., 2012; Mishra et al., 2018).

Flash floods caused by extreme rainstorm events combined with climate change have increased in the past few years (IPCC, 2013; Merz et al., 2014; Yin et al., 2018). Hence, the development and implementation of mitigation measures to reduce flash flood impacts and protect people and civil infrastructures are essential. In this sense, hydrological models have been found to be reliable tools for extreme flood estimation (Shadeed, 2008; Jorge et al., 2020). Worldwide, hydrological models have been widely applied to simulate rainfall-runoff processes and to describe extreme flood dynamics at the catchment level (Jain et al., 2018). In the West Bank, Palestine, extreme weather conditions are becoming more frequent due to the potential impacts of climate change (Shadeed, 2019). This situation has geared up the urgent need to assess/estimate potential extreme floods by the proper and possible hydrological models.

Hydrologic models can be broadly classified into empirical, and physically-based models. Empirical models are simply based on studying observed input and output data (e.g. rainfall, runoff). As named, physically-based models have been developed based on the understanding of the physical processes of the hydrologic cycle elements and their parameters and state variables may be directly measured in the field (Beven, 2011). One has to compromise between the easy use of empirical models and the use of physically-based models that are more accurate but intensive data demanding (Shadeed, 2008; Shadeed & Masri, 2010, Stephen & András, 2020).

Extreme floods estimation is essential for assessing flood hazards in the likely flood-vulnerable catchments and accordingly proposing proper mitigation actions (Coppock, 1995; Black & Burnes, 2002; Nyarko, 2002; Dewan et al., 2007; Daniel et al., 2015; Nerantzis et. al., 2015; Shadeed, 2019). In the West Bank as an arid and semi-arid region, the dominant flood generation mechanism is the infiltration excess overland flow (IEOF) where rainfall intensity is greater than the infiltration capacity rate of the soil (Horton, 1933). Shadeed (2008) studied runoff generation in the Faria catchment (one of the main catchments draining to the Jordan River) using a physically-based spatially distributed model (the TRAI-ZIN model). He figured out that rainfall intensity highly influenced the runoff generation mechanism in the West Bank. Moreover, he concluded that applying physically-based

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models in the West Bank catchments (such as the one of the Faria) will not be possible given the hydrologic data scarcity.

In between the empirical, and physically-based models, Shadeed and Masri (2010) applied the SCS-CN (Soil Conservation Service-Curve Number) method to estimate flood depth for some selected rainfall events in the Faria catchment with reasonable results. The SCS-CN method (SCS, 1985) is one of the most commonly used methods for the estimation of the runoff depth from a given rainfall event. The CN is a dimensionless catchment parameter that is a function of land use and hydrologic soil group (HSG) and ranges from 0 (no runoff) to 100 (runoff equals rainfall). The SCS-CN is an easy-to-use method that provides a rapid way to estimate runoff change due to land use change (Schulze et al., 1992; Shrestha 2003; Zhan and Huang 2004). Therefore, the use of the SCS-CN method is seen as valuable to estimate extreme floods in the West Bank data-scarce catchments. The SCS-CN method has been discussed and used to estimate runoff depth at different catchments worldwide (Hjelmfelt, 1991; Hawkins, 1993; Ponce & Hawkins, 1996; Bonta, 1997; Yu, 1998; Grove et al., 1998; Moglen, 2000; Mishra et al., 2003; Mishra & Singh, 2004; Mishra et al., 2006; Geetha et al., 2007; Shadeed & Masri, 2010; Singh & Goyal, 2017; Zelelew, 2017; Uwizeyimana, et al., 2019; Atie, et al., 2019; Pankaj & Ojha, 2022).

In developing countries, the lack of reliable rainfall and runoff data has constrained the application of proper hydrological models to estimate extreme floods (Boongaling et al., 2018; Kristian, et al., 2018). The ability of the hydrological models to mimic the hydrological mechanisms in data-scarce catchments, like Palestine, is uncertain (Shadeed, 2008). Subsequently, the application of hydrological models in data-scarce catchments is subjected to high results uncertainty, even after successful calibration and validation processes have been accomplished (Shadeed, 2008; Shadeed and Masri, 2010; Acero Triana et al., 2019). Furthermore, modeling results may not improve the basic understanding of the hydrological processes and systems (e.g., runoff generation mechanism, transmission loss, etc.) in data-scarce catchments (Shadeed, 2008; Johnston and Smakhtin, 2014; Jorge et al., 2020; Khader, et al., 2023).

This research aimed to evaluate the potential use of the SCS-CN method to estimate extreme floods in the West Bank data-scarce catchments. The methodology and outputs from this research will be of high value for the policy-makers to improve the in-place flood emergency response of different actors to outline specific policies and mitigation measures to support any managerial changes toward the proper implementation of a sustainable flood management strategy in Palestine.

Materials and Methods

Study Area

In the West Bank, there exist 33 catchments (wadis) (See Figure 1) at which surface water drains either to the Mediterranean Sea (western wadis) or to the dead sea and the Jordan river (eastern wadis). Most of these catchments are ungauged where streamflow (flood) data are not available. For these catchments, it was estimated that the long-term annual average streamflow is about 169 mcm (Palestinian Water Authority, PWA, 2003). The catchments draining to the west accounts for 51% of the total West Bank area whereas, the annual flood from these catchments represents about 73% (122.7 out of 169 mcm). This can be attributed to the general rainfall distribution in the West Bank, which is increased north-west and decreased east-south. The West Bank climate can be generally described as a Mediterranean one that experiences extreme seasonal variations. The climate varies from hot and dry in summer to wet and cold in winter with short transitional seasons (UNEP, 2003). The rainy season usually extends from October to April. In winter, more than 80% of the annual rainfall commonly occurs (Shadeed, 2012). In general, rainfall is characterized by its high temporal and spatial variability. Based on the available data from the Palestinian Meteorological Department (PMD, 2018) for 113 raingauges distributed in the West Bank (See Figure 2), the long-term annual average rainfall ranges from less than 150 mm in the Jordan Valley to more than 700 mm in the central mountains of the West Bank with an average value of about 420 mm.

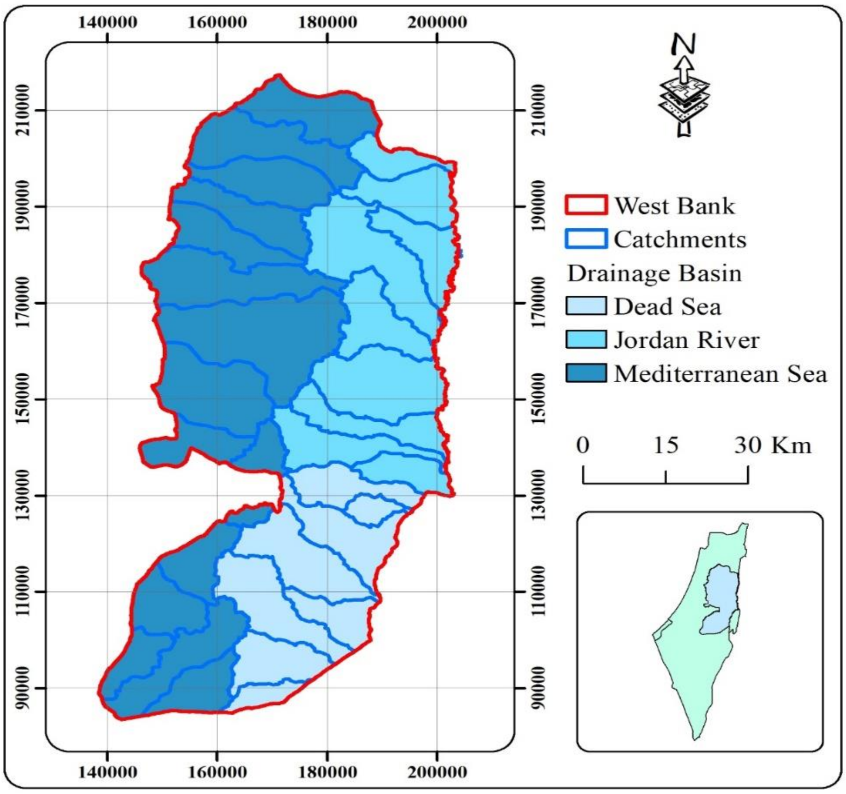

Figure (1): Surface water catchments in the West Bank.

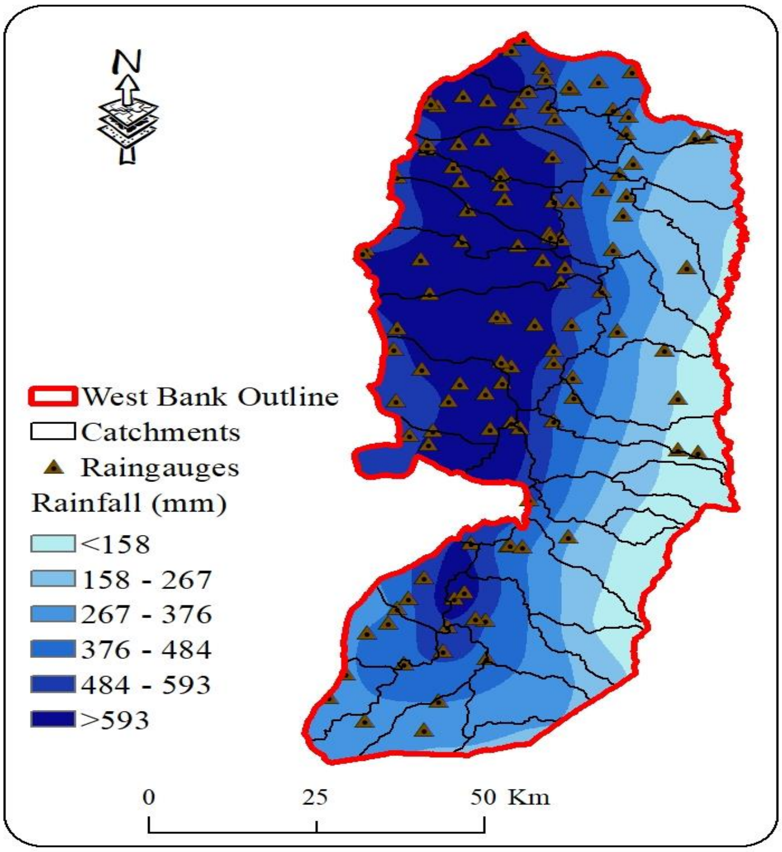

Figure (2): Long-term annual average rainfall distribution in the West Bank.

In the West Bank, extreme rainfall events and the expansion of urban areas are increasing the potential occurrence of extreme floods (Shadeed, 2008, Shadeed & Lange, 2010). This situation is becoming worse given the lack of proper hydraulic infrastructures (e.g., culverts) required to safely dispose of the accumulated floods. For instance, in the winter of 2012, an extreme rainfall event occurred, followed by unexpected extreme floods. Accordingly, three people passed away in the Tulkarm governorate and many roads across much of the West Bank areas were flooded (Shadeed, 2019). However, extreme floods have never been estimated for the entire West Bank catchments.

Methodology

For this study, the SCS-CN approach was used to estimate extreme floods in the West Bank catchments. Shadeed and Masri (2010) applied the SCS-CN method to four selected rainfall events and they found that the accuracy ranged between 7% and 20%. The estimated and observed runoff depths of the four events were close enough to assume the applicability of the SCS-CN approach for the different West Bank catchments. The standard SCS-CN method is based on the following relationship between rainfall, *P* (mm), and runoff, *Q* (mm) (SCS-USDA 1986; Schulze et al. 1992):

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \; for \; P > 0.2S$$

$$Q = 0 \; for \; P \leq 0.2\mathrm{S}$$

$$S = \frac{25400}{CN} - 254$$

Where P is the daily (event) rainfall (mm), S is the potential maximum soil retention (mm), and Q is the daily (event) runoff (mm).

The general methodology used in this research to apply the SCS-CN method to estimate extreme flood values for the different West Bank catchments is depicted in Figure 3.

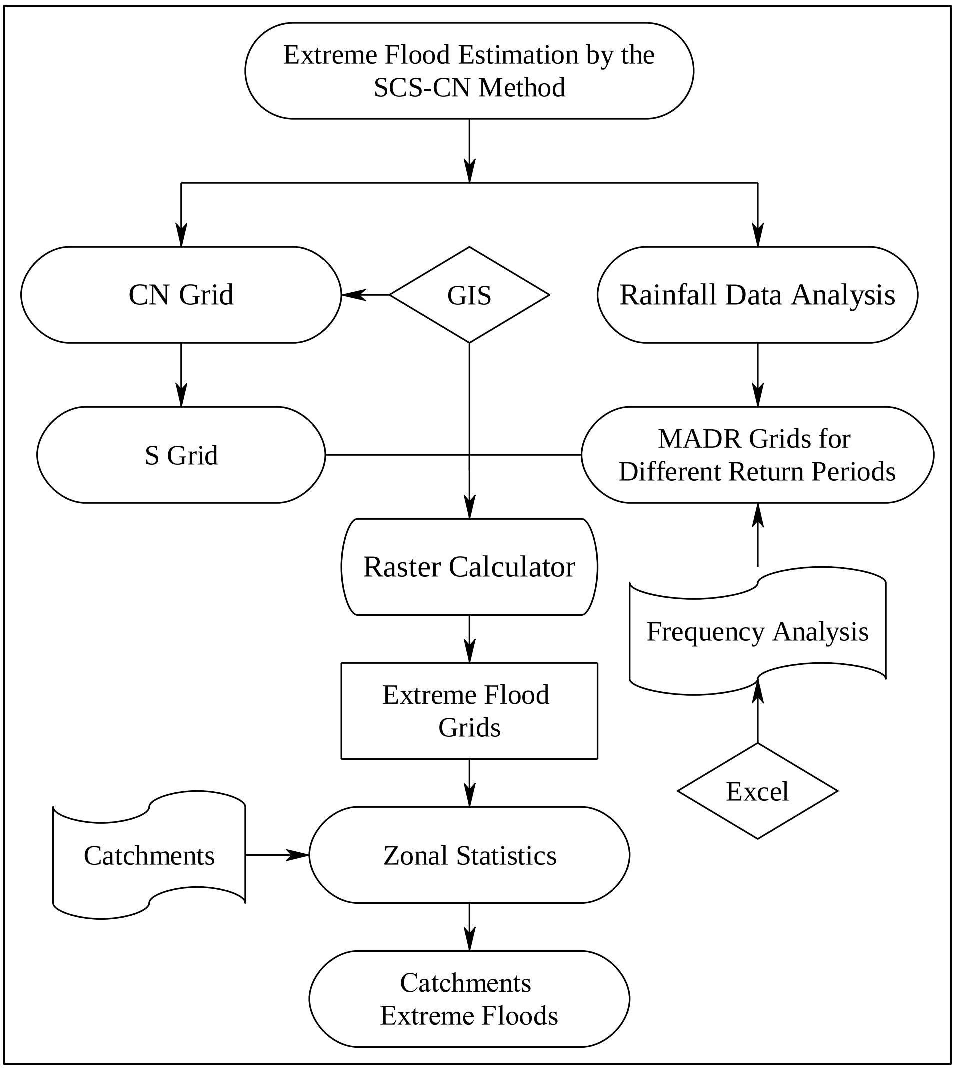

Figure (3): General methodology flowchart.

As seen in Figure 3, the methodology was based on (1) the utilization of the available CN grid and (2) the analysis of the maximum annual daily rainfall (MADR) values for different return periods. GIS (ArcMap 10.8) was heavily used in this research. Details of the two main steps are presented in the following sub-sections.

The Curve Number (CV)

Shadeed and Masri (2010) developed a GIS-based SCS-CN map for the entire West Bank (See Figure 4, a). From the map and assuming average conditions, the CN for the West Bank is ranging from 39 to 87 with an average value of about 69. This in turn indicates the high flood potential in the different West Bank catchments. Extreme rainfall events accompanied by extreme (flash) floods are getting more frequent in the study area (Shadeed, 2008). Moreover, based on the developed CN map, the potential maximum soil retention (S) was also developed for the West Bank (See Figure 4, b).

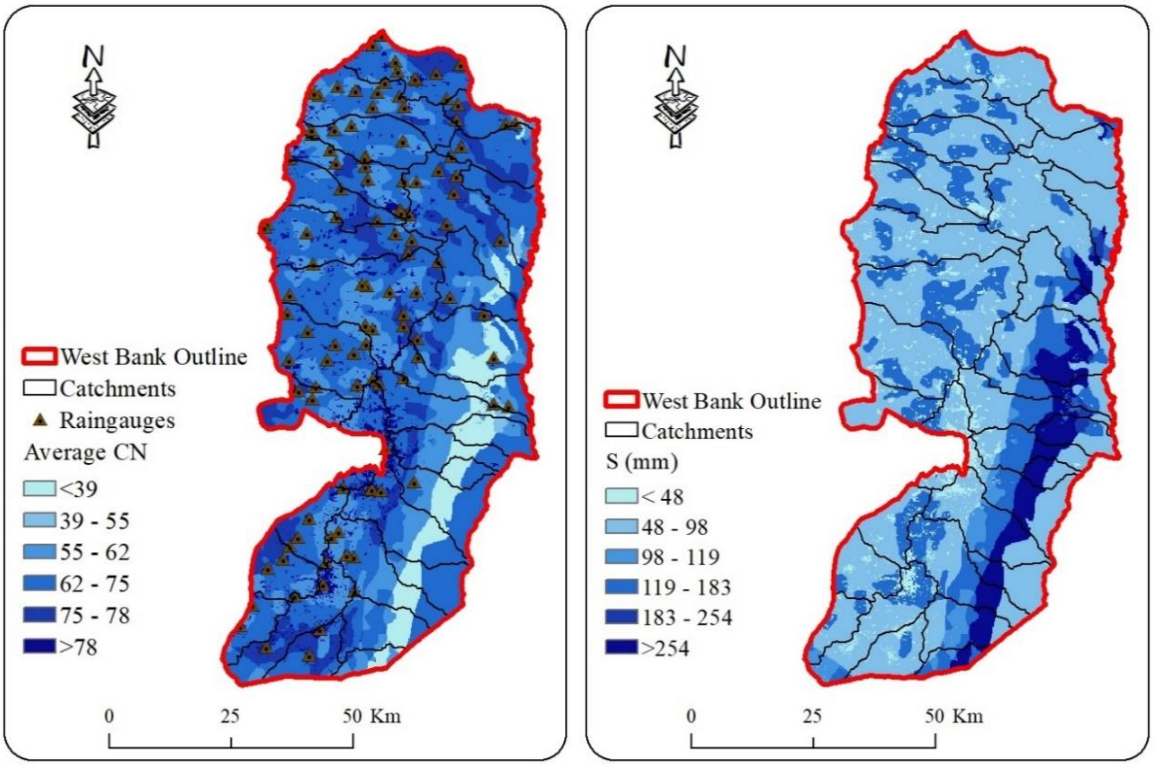

Figure 4: The distribution of (a) average CN and (b) potential maximum soil retention (S) in the West Bank Catchments.

Rainfall Data Analysis

In the West Bank, the availability of rainfall data is very limited, and historical fine-resolution data (e.g., hourly) are missing. As such, actual rainfall intensity duration frequency (IDF) curves, which are commonly used for the prediction of floods for different durations and return periods, are not available. In this research, the extreme (maximum) daily rainfall values were used. The daily available rainfall data at the Nablus rainfall station (which has a long historical daily rainfall time series) has been available from the Palestinian Meteorological Department (PMD) for a period of 46 years (from 1975 to 2020). From this, the maximum annual daily rainfall (MADR) values were obtained as listed in Table 1.

Table (1): MADR values of Nablus rainfall station for the period from 1975 to 2020.

Year	MADR (mm)	Year	MADR (mm)	Year	MADR (mm)
1975	65	1991	86.2	2006	105
1976	58	1992	111	2007	43.3
1977	65	1993	39.5	2008	76.8
1978	46.2	1994	59.9	2009	68.4
1979	115	1995	45.9	2010	83.4
1980	98.8	1996	73.8	2011	46
1981	51.4	1997	77	2012	74.8
1982	59.7	1998	76.2	2013	123
1983	72.9	1999	53.3	2014	55
1984	79.3	2000	80.2	2015	82.5
1985	52.9	2001	70	2016	73.8
1986	87.8	2002	68.9	2017	45
1987	37.1	2003	68.9	2018	89.5
1988	75.3	2004	67.9	2019	116.9
1989	60.4	2005	95	2020	52.8
1990	37.7				

Frequency analysis was used to relate the magnitude of a MADR value with its frequency of occurrence (return period) through probability distribution. To do so, the two common probability distribution functions (Weibull and Gumbel) used for most sample data, including rainfall data, were tested. Results are tabulated in Table 2.

Table (2): MADR values versus return period (Tr) for Weibull and Gumbel functions.

MADR (mm)	Tr		MADR (mm)	Tr	
	Weibull	Gumbel		Weibull	Gumbel
123.0	47.0	82.4	68.9	2.0	2.0
116.9	23.5	29.6	68.9	1.9	1.9
115.0	15.7	18.0	68.4	1.8	1.8
111.0	11.8	13.0	67.9	1.7	1.7
105.0	9.4	10.1	65.0	1.7	1.7
98.8	7.8	8.3	65.0	1.6	1.6
95.0	6.7	7.0	60.4	1.6	1.6
89.5	5.9	6.1	59.9	1.5	1.5
87.8	5.2	5.4	59.7	1.5	1.5
86.2	4.7	4.8	58.0	1.4	1.4
83.4	4.3	4.4	55.0	1.4	1.4
82.5	3.9	4.0	53.3	1.3	1.3
80.2	3.6	3.7	52.9	1.3	1.3
79.3	3.4	3.4	52.8	1.3	1.3
77.0	3.1	3.2	51.4	1.2	1.2
76.8	2.9	3.0	46.2	1.2	1.2
76.2	2.8	2.8	46.0	1.2	1.2
75.3	2.6	2.6	45.9	1.1	1.1
74.8	2.5	2.5	45.0	1.1	1.1
73.8	2.4	2.4	43.3	1.1	1.1
73.8	2.2	2.2	39.5	1.1	1.1
72.9	2.1	2.1	37.7	1.0	1.0
70.0	2.0	2.0	37.1	1.0	1.0

To judge whether Weibull or Gumbel fits the rainfall data of Nablus, the data presented in Table 3 were plotted and the best fit (logarithmic one) was obtained (See Figure 5).

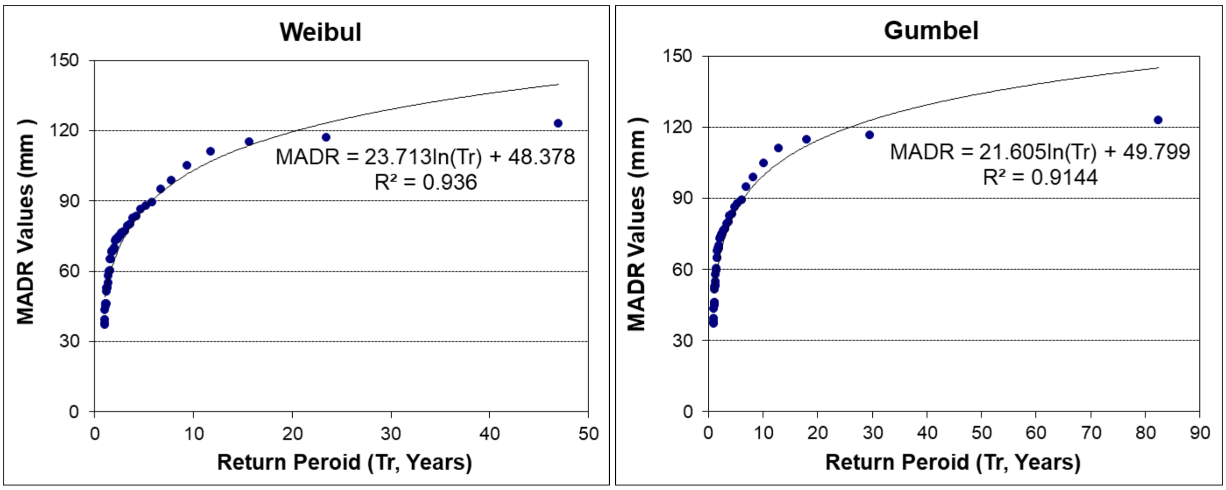

Figure (5): Weibull and Gumbel probability distribution functions for MARD of Nablus station.

From the figure and based on the goodness of fit measure (R^2) (Kinnison, 1989), it is noted that both functions fit the rainfall data of Nablus (R^2 greater than 90% for both) but Weibull is the most suitable one. As clear from Table 2, MADR values corresponding to a return period of up to about 50 years (from Weibull) can be interpolated from the given data. For return periods of more than 50 years, the Weibull function is used to extrapolate the MADR values corresponding to selected return periods. As a result, MADR values for Tr of 10, 25, 50, and 100 years were obtained as listed in Table 3.

Table (3): MADR values of Nablus for Tr of 10, 25, 50, and 100 years.

Tr	10	25	50	100
MADR (mm)	103.0	124.7	141.1	157.6

Based on the availability of historical rainfall data for the existing 113 raingauges located in the West Bank (See Figure 2), it is not possible to accomplish frequency analysis to estimate the MADR values for the different raingauges for the selected return periods. Instead, the following approach was used:

1. The long-term annual rainfall values are divided by the one of Nablus raingauge (660 mm) to estimate correction rainfall coefficients for the different raingauges.
2. Coefficients obtained from the previous step are then multiplied by the MADR values of Nablus (See Table 3) to obtain MADR values for the different raingauges as presented in Table 4.
3. This approach is tested based on the available MADR values of Ramallah raingauge for 26 years (1992 – 2017) and the result is very promising as the percentage of error is within ± 2% (See Table 5).
4. The MADR values for the 113 raingauges were interpolated by the inverse distance weighting method (IDW) within the GIS environment to obtain rainfall grids for the selected return periods (See Figure 6). The IDW is one of the most commonly used methods to interpolate rainfall data (Shadeed, et al., 2022).

Table (4): MADR values for the 113 raingauges located in the West Bank.

Raingauge	AAR (mm)[1]	CRC[2]	MADR (mm)			
			Tr = 10	Tr = 25	Tr = 50	Tr = 100
1	513.0	0.78	80.0	96.9	109.7	122.5
2	606.0	0.92	94.6	114.5	129.6	144.7
3	488.0	0.74	76.1	92.2	104.4	116.5
4	596.0	0.90	93.0	112.6	127.5	142.3
5	591.0	0.90	92.2	111.7	126.4	141.1
6	606.0	0.92	94.6	114.5	129.6	144.7
7	637.0	0.97	99.4	120.4	136.2	152.1
8	658.0	1.00	102.7	124.3	140.7	157.1
9	658.0	1.00	102.7	124.3	140.7	157.1
10	660.0	1.00	103.0	124.7	141.1	157.6
11	611.0	0.93	95.3	115.4	130.7	145.9
12	606.0	0.92	94.6	114.5	129.6	144.7
13	503.0	0.76	78.5	95.0	107.6	120.1
14	596.0	0.90	93.0	112.6	127.5	142.3
15	596.0	0.90	93.0	112.6	127.5	142.3
16	606.0	0.92	94.6	114.5	129.6	144.7
17	627.0	0.95	97.8	118.5	134.1	149.7
18	606.0	0.92	94.6	114.5	129.6	144.7
19	369.0	0.56	57.6	69.7	78.9	88.1
20	611.0	0.93	95.3	115.4	130.7	145.9
21	611.0	0.93	95.3	115.4	130.7	145.9
22	632.0	0.96	98.6	119.4	135.2	150.9
23	642.0	0.97	100.2	121.3	137.3	153.3
24	369.0	0.56	57.6	69.7	78.9	88.1
25	333.0	0.50	52.0	62.9	71.2	79.5

Raingauge	AAR (mm)[1]	CRC[2]	MADR (mm)			
			Tr = 10	Tr = 25	Tr = 50	Tr = 100
26	416.0	0.63	64.9	78.6	89.0	99.3
27	585.0	0.89	91.3	110.5	125.1	139.7
28	596.0	0.90	93.0	112.6	127.5	142.3
29	647.0	0.98	101.0	122.3	138.4	154.5
30	524.0	0.79	81.8	99.0	112.1	125.1
31	611.0	0.93	95.3	115.4	130.7	145.9
32	606.0	0.92	94.6	114.5	129.6	144.7
33	606.0	0.92	94.6	114.5	129.6	144.7
34	570.0	0.86	88.9	107.7	121.9	136.1
35	529.0	0.80	82.5	100.0	113.1	126.3
36	658.0	1.00	102.7	124.3	140.7	157.1
37	457.0	0.69	71.3	86.4	97.7	109.1
38	333.0	0.50	52.0	62.9	71.2	79.5
39	359.0	0.54	56.0	67.8	76.8	85.7
40	333.0	0.50	52.0	62.9	71.2	79.5
41	436.0	0.66	68.0	82.4	93.2	104.1
42	493.0	0.75	76.9	93.2	105.4	117.7
43	534.0	0.81	83.3	100.9	114.2	127.5
44	395.0	0.60	61.6	74.6	84.5	94.3
45	441.0	0.67	68.8	83.3	94.3	105.3
46	380.0	0.58	59.3	71.8	81.3	90.7
47	652.0	0.99	101.7	123.2	139.4	155.7
48	395.0	0.60	61.6	74.6	84.5	94.3
49	261.0	0.40	40.7	49.3	55.8	62.3
50	364.0	0.55	56.8	68.8	77.8	86.9
51	585.0	0.89	91.3	110.5	125.1	139.7
52	621.0	0.94	96.9	117.3	132.8	148.3
53	663.0	1.00	103.4	125.3	141.8	158.3
54	601.0	0.91	93.8	113.6	128.5	143.5
55	632.0	0.96	98.6	119.4	135.2	150.9
56	673.0	1.02	105.0	127.2	143.9	160.7
57	194.0	0.29	30.3	36.7	41.5	46.3
58	627.0	0.95	97.8	118.5	134.1	149.7
59	668.0	1.01	104.2	126.2	142.9	159.5
60	483.0	0.73	75.4	91.3	103.3	115.3
61	704.0	1.07	109.8	133.0	150.6	168.1
62	447.0	0.68	69.7	84.5	95.6	106.7
63	601.0	0.91	93.8	113.6	128.5	143.5
64	534.0	0.81	83.3	100.9	114.2	127.5
65	544.0	0.82	84.9	102.8	116.3	129.9
66	472.0	0.72	73.6	89.2	100.9	112.7
67	575.0	0.87	89.7	108.6	123.0	137.3
68	683.0	1.03	106.6	129.1	146.1	163.1
69	534.0	0.81	83.3	100.9	114.2	127.5
70	601.0	0.91	93.8	113.6	128.5	143.5
71	436.0	0.66	68.0	82.4	93.2	104.1

Raingauge	AAR (mm)[1]	CRC[2]	MADR (mm)			
			Tr = 10	Tr = 25	Tr = 50	Tr = 100
72	277.0	0.42	43.2	52.3	59.2	66.1
73	133.0	0.20	20.8	25.1	28.4	31.8
74	117.0	0.18	18.3	22.1	25.0	27.9
75	215.0	0.33	33.5	40.6	46.0	51.3
76	513.0	0.78	80.0	96.9	109.7	122.5
77	153.0	0.23	23.9	28.9	32.7	36.5
78	652.0	0.99	101.7	123.2	139.4	155.7
79	308.0	0.47	48.1	58.2	65.9	73.5
80	405.0	0.61	63.2	76.5	86.6	96.7
81	462.0	0.70	72.1	87.3	98.8	110.3
82	606.0	0.92	94.6	114.5	129.6	144.7
83	621.0	0.94	96.9	117.3	132.8	148.3
84	611.0	0.93	95.3	115.4	130.7	145.9
85	256.0	0.39	39.9	48.4	54.7	61.1
86	673.0	1.02	105.0	127.2	143.9	160.7
87	385.0	0.58	60.1	72.7	82.3	91.9
88	302.0	0.46	47.1	57.1	64.6	72.1
89	549.0	0.83	85.7	103.7	117.4	131.1
90	596.0	0.90	93.0	112.6	127.5	142.3
91	457.0	0.69	71.3	86.4	97.7	109.1
92	411.0	0.62	64.1	77.7	87.9	98.1
93	596.0	0.90	93.0	112.6	127.5	142.3
94	580.0	0.88	90.5	109.6	124.0	138.5
95	405.0	0.61	63.2	76.5	86.6	96.7
96	452.0	0.68	70.5	85.4	96.7	107.9
97	596.0	0.90	93.0	112.6	127.5	142.3
98	616.0	0.93	96.1	116.4	131.7	147.1
99	585.0	0.89	91.3	110.5	125.1	139.7
100	529.0	0.80	82.5	100.0	113.1	126.3
101	591.0	0.90	92.2	111.7	126.4	141.1
102	498.0	0.75	77.7	94.1	106.5	118.9
103	380.0	0.58	59.3	71.8	81.3	90.7
104	513.0	0.78	80.0	96.9	109.7	122.5
105	575.0	0.87	89.7	108.6	123.0	137.3
106	606.0	0.92	94.6	114.5	129.6	144.7
107	323.0	0.49	50.4	61.0	69.1	77.1
108	647.0	0.98	101.0	122.3	138.4	154.5
109	632.0	0.96	98.6	119.4	135.2	150.9
110	380.0	0.58	59.3	71.8	81.3	90.7
111	632.0	0.96	98.6	119.4	135.2	150.9
112	529.0	0.80	82.5	100.0	113.1	126.3
113	452.0	0.68	70.5	85.4	96.7	107.9

[1] Annual average rainfall

[2] Correction rainfall coefficients

Table (5): Estimation of MADR values of Ramallah from Ramallah and Nablus rainfall data.

Tr	Ramallah data	Nablus data	Error (%)
10	103.1	105.0	1.9
25	127.1	127.2	0.1
50	145.3	143.9	-0.9
100	163.4	160.7	-1.7

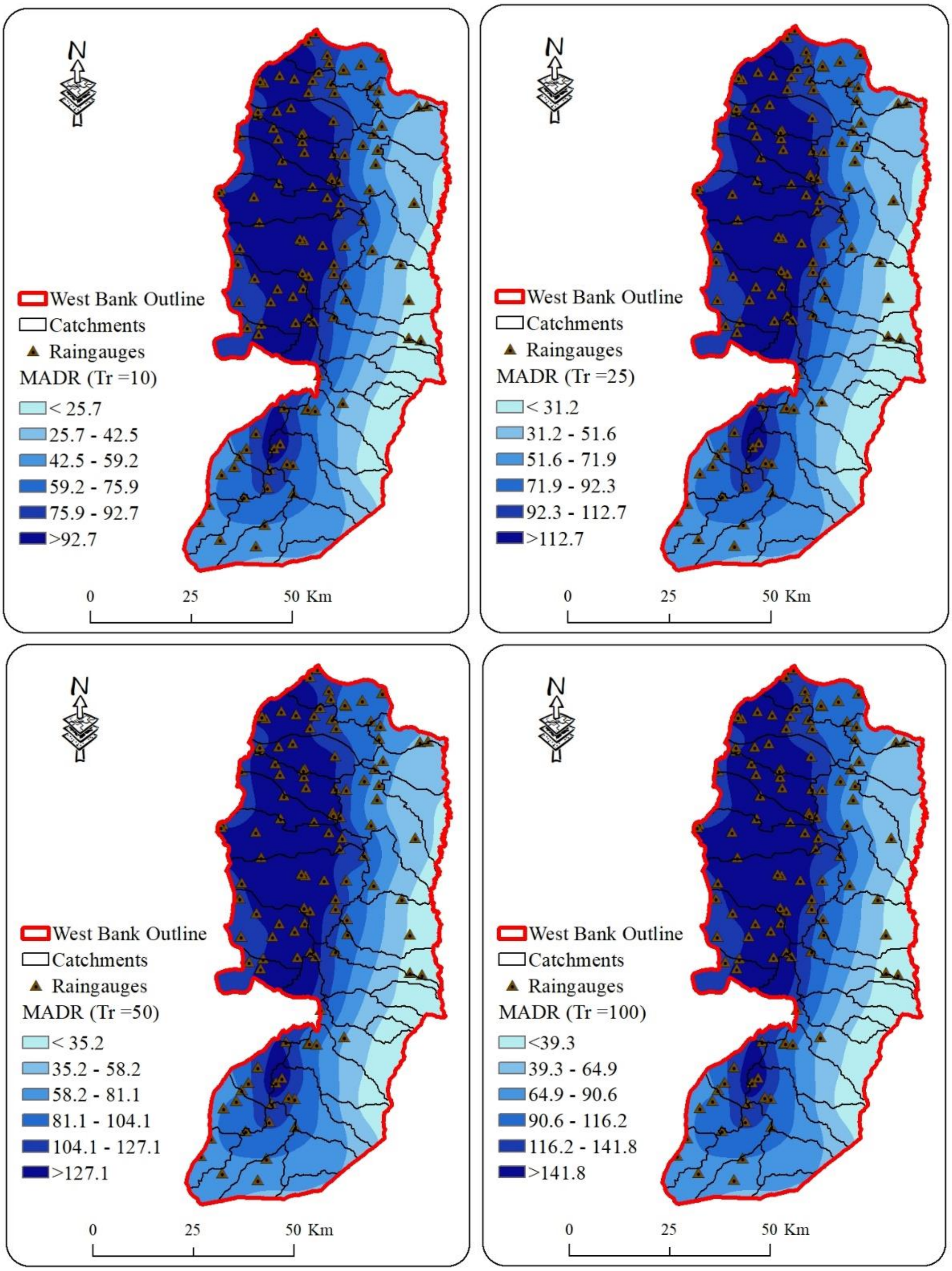

Figure (6): MADR grids (in mm) for the return periods (Tr) of 10, 25, 50, and 100 years.

Results and Discussion

Extreme flood values for the different West Bank catchments and for different return periods are illustrated in Figure 7 and tabulated in Table 6.

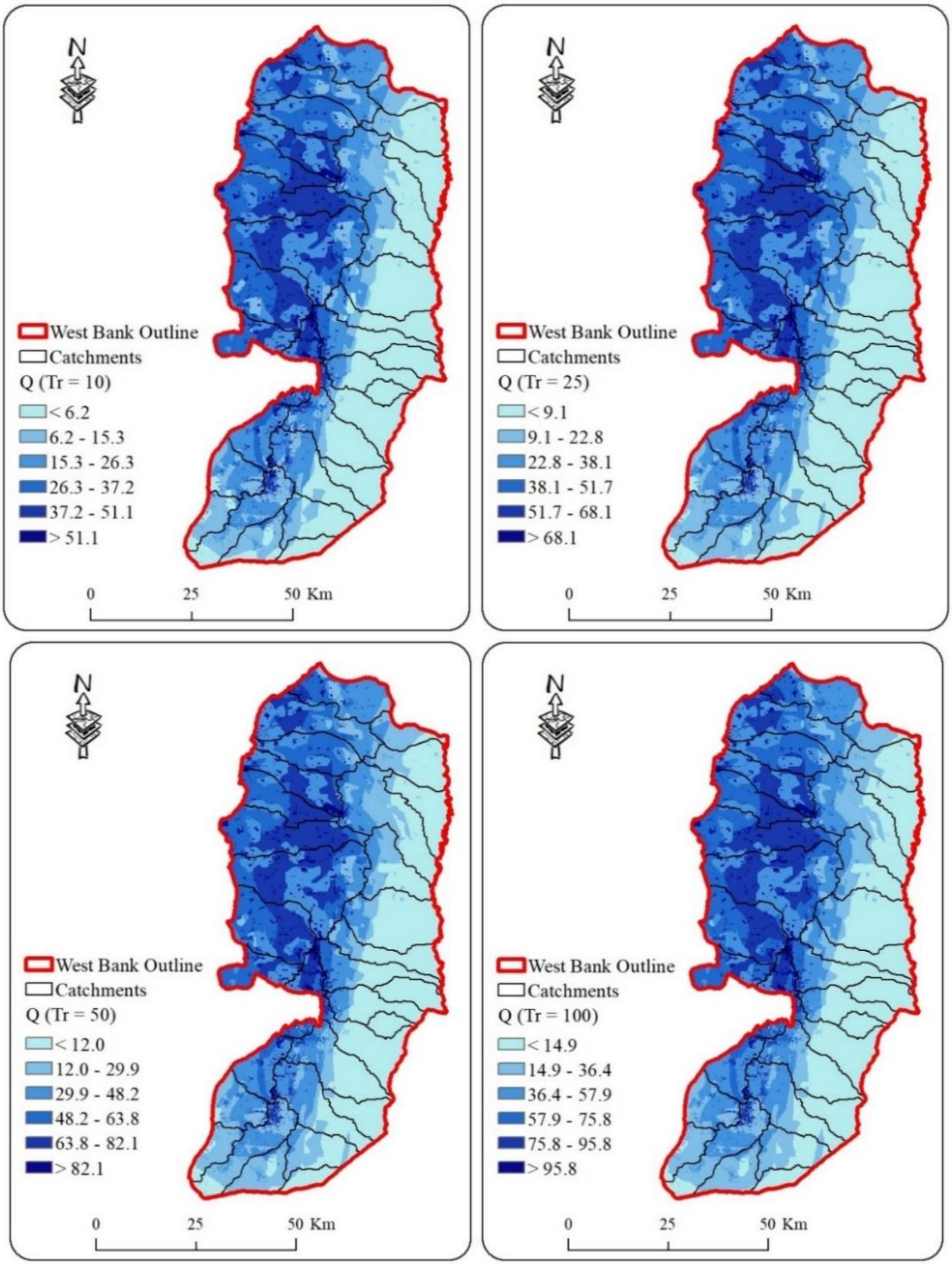

Figure (7): Q (extreme flood depth in mm) at different West Bank catchments for return periods (Tr) of 10, 25, 50, and 100 years.

Table (6): Average extreme flood depth (Q) at the different West Bank catchments for the selected return periods.

Catchment	Area (km^2)	Average CN_{II}	Average MADR Values (mm)				Average Flood Depth, Q (mm)			
			Tr = 10	Tr = 25	Tr = 50	Tr = 100	Tr = 10	Tr = 25	Tr = 50	Tr = 100
Qishon	205.7	74.0	77.6	93.9	106.3	118.7	24.7	35.8	44.7	54.2
Hadera-Abu Na	247.5	69.7	86.9	105.3	119.2	133.0	25.2	36.9	46.5	56.6
Hadera-Massin	187.6	69.8	92.2	111.7	126.4	141.1	28.6	41.5	52.0	63.0
Alexander-Zeimar	172.5	70.1	96.6	117.0	132.5	147.9	32.3	46.1	57.3	69.1
Alexander-Abra	155.6	73.2	95.1	115.2	130.4	145.6	35.5	50.2	61.9	74.1
Qana	280.4	73.2	96.1	116.4	131.8	147.1	36.3	51.1	63.0	75.4
Sarida	466.2	70.6	94.8	114.9	130.0	145.1	31.4	45.1	56.1	67.7
Al-Dilb	275.0	71.8	96.1	116.4	131.8	147.1	34.0	48.4	60.0	72.1
Salman	119.4	71.8	93.1	112.8	127.6	142.5	31.7	45.4	56.4	67.9
Soreq	66.6	74.8	99.2	120.1	136.0	151.8	41.6	57.5	70.1	83.2
Malih-Shu-bash	88.8	73.6	49.9	60.5	68.4	76.4	9.5	14.9	19.5	24.5
Malih	160.8	74.4	39.1	47.3	53.6	59.8	5.2	8.7	11.7	15.1
Faria	333.5	71.6	52.1	63.1	71.4	79.7	11.2	17.0	21.8	27.0
Abu Sidra	146.4	72.0	29.6	35.9	40.6	45.3	1.9	3.6	5.1	6.9
Al'Ahmar	181.0	70.1	47.7	57.8	65.4	73.0	8.4	13.1	17.1	21.4
Auja	290.8	60.7	38.7	46.9	53.1	59.2	4.5	7.0	9.2	11.6
Nueima	150.9	63.8	42.0	50.9	57.6	64.3	5.8	9.1	11.9	15.0
Qilt	172.1	67.6	56.9	68.9	78.0	87.1	14.8	21.4	26.8	32.6
Marar	97.6	55.9	20.6	24.9	28.2	31.5	0.0	0.0	0.1	0.2
Mukallak	137.8	65.2	41.2	49.9	56.4	63.0	6.1	9.3	12.0	15.1
Qumran	46.6	55.3	22.4	27.1	30.7	34.2	0.0	0.1	0.3	0.6
Nar	189.2	65.0	30.6	37.1	42.0	46.9	4.0	5.9	7.5	9.2
Soreq Al-sara	27.0	78.1	81.8	99.0	112.1	125.1	33.8	46.9	57.4	68.2
Daraja	234.4	67.1	48.5	58.8	66.5	74.3	9.4	14.1	18.1	22.4
Lakhish-Saint	126.8	72.0	83.1	100.6	113.9	127.1	25.4	36.9	46.3	56.2
Lakhish	136.1	73.3	64.7	78.4	88.7	99.0	16.6	24.7	31.5	38.6
Hasasa	107.3	66.5	31.4	38.0	43.1	48.1	1.0	2.2	3.4	4.8
Ghar	227.2	65.7	67.3	81.5	92.3	103.0	14.0	21.2	27.1	33.5
Besor	120.4	75.3	48.8	59.1	66.9	74.7	10.2	15.7	20.3	25.2
Abu Mura-din	54.0	56.5	43.8	53.0	60.0	67.0	1.4	3.0	4.5	6.2
Abu El-hay-yat	149.7	63.3	51.7	62.7	70.9	79.2	6.3	10.3	13.7	17.4
Besor-Nar	203.5	73.5	61.9	75.0	84.8	94.7	16.1	23.7	30.0	36.8
Shiqma	88.5	72.1	55.0	66.5	75.3	84.1	10.3	16.2	21.2	26.6

From Figure 7 and Table 6, the following general points can be noticed:

1. Extreme daily rainfall values (MADR) are increasing with the increase of the return period.
2. Catchments draining into the west (into the Mediterranean Sea) have more extreme daily rainfall values than those draining to the east and as such, the potential extreme flood hazard in these catchments is also high.
3. The expected extreme flood values are high for catchments that have high CN and MADR values for the selected return periods.

Moreover, and based on the average expected extreme flood values presented in Table 6, a flood hazard map was developed that classify West Bank catchments into 5 flood hazard zones (based on the natural breaks, Jenks in the GIS) as shown in Figure 8 and Table 7. The developed flood hazard map for the selected extreme rainfall values aims to identify high-potential flood hazard-prone areas based on catchment units. The estimation of a catchment-based potential flood hazard is valuable and essential to prioritizing flood remedial plans at the different catchments.

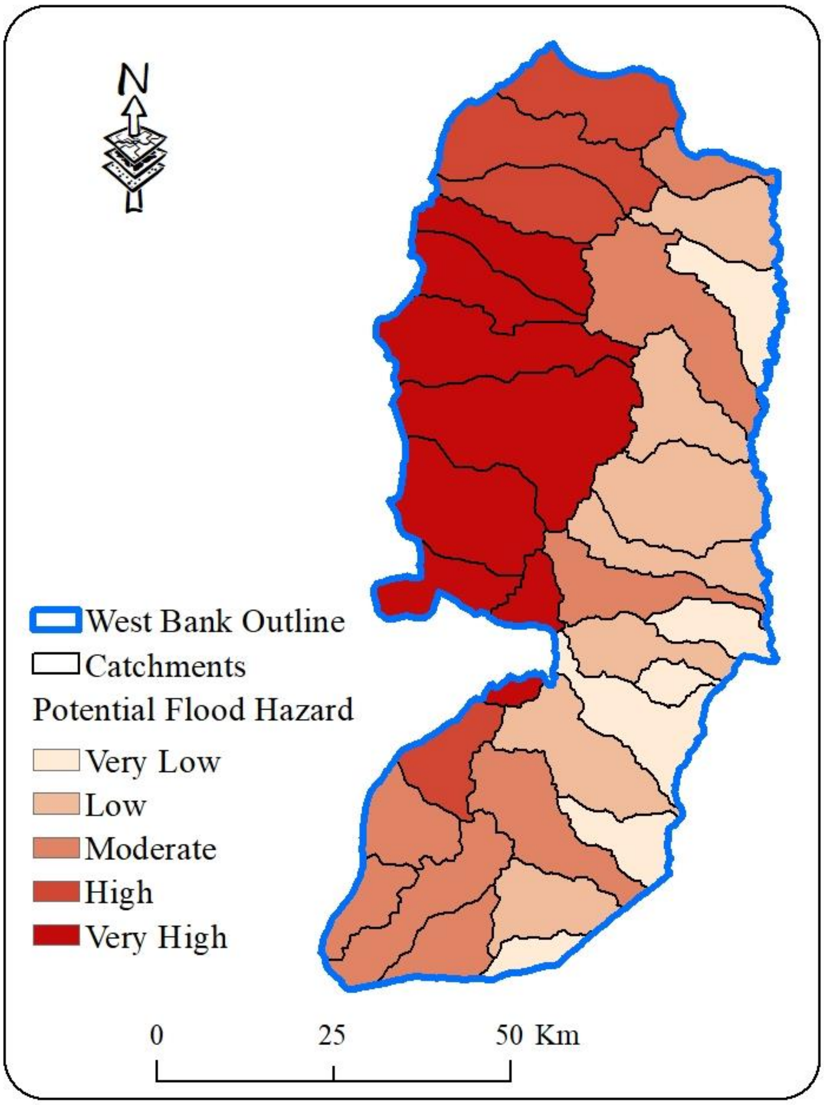

Figure (8): Potential flood hazard map for the West Bank catchments based on the MADR values for the different return periods.

Table (7): West Bank catchments flood hazard categories.

Flood Hazard Class	Area (km^2)	Area (%)
Very Low	641.5	11.4
Low	1304.5	23.1
Medium	1370.2	24.3
High	767.7	13.6
Very High	1562.8	27.7

Although the utilized SCS-CN approach for extreme flood estimation and assessment in the West Bank data-scarce catchments is very promising, the obtained results are subjected to several uncertainties. As such and to overcome such uncertainties and obtain more reliable extreme flood estimation results in the different West Bank catchments, potential decision-makers (e.g. PWA) have to seek to build a national and reliable hydrologic model that fits and mimic the runoff generation mechanism in Palestine as mostly classified as arid to a semi-arid region where extreme floods are becoming more frequent. In the selection and adoption of a proper hydrologic model, the following points have to be considered:

1. The selected hydrologic model has to be physically based and spatially distributed (e.g. the TRAIN-ZIN model of Faria catchment) or at least to be physically based and semi-spatially distributed (e.g. the HEC-HMS model).

2. The distribution of raingauges has to be considered and raingauges have to be properly distributed to cover the prevailing spatial rainfall variation in the West Bank. As such, new gauges have to be installed mainly in the catchments draining to the east. Additionally, the existing raingauges (mostly daily ones) have to be replaced by a recording type (e.g. Tipping Buckets) to collect rainfall intensities. Proper rainfall data (in time and space) is the key input parameter for the successful utilization of any hydrologic model.

3. Streamflow gauges are essential to collect runoff data that is very essential to calibrate and validate flood models. Hence, streamflow gauges have to be installed in some selected catchments. The catchments need to be clustered according to hydrological and meteorological similarities. For instance, three clusters can be considered; catchments draining into the Mediterranean Sea, the dead Sea, and the Jordan River. For each cluster, at least one streamflow gauge is to be installed.

4. The soil map of the West Bank has to be updated and the most important parameters for flood generation (the soil texture and soil depth) have to be properly identified.

5. The landuse/land cover map has to be updated dynamically to capture the ongoing and potential landuse changes that might affect potential flood generation. The impact of urbanization has to be addressed in the national hydrologic model to assess the potential impact of future flood generation mainly in the catchments where urbanization in the upper parts highly influences flood generation in the lower parts. For instance, Alexander-Zeimar is one of the catchments draining into the Mediterranean Sea where the increased urbanization in the upper part of the catchment (in Nablus west) highly influences the flood inundation in the lower part (in Tulkarm east).

6. The effect of relevant future climate change scenarios on the occurrence of extreme flash floods in Palestine has to be also considered in the developed hydrologic model.

7. The effect of the transmission loss function (wadi bed losses) that might attenuate peak streamflow has to be addressed.

Based on the aforementioned points, and once a national hydrologic model is successfully calibrated and validated, an early flood warning system can be established at which the nowcasted and forecasted weather data can be integrated to forecast the flood. This in turn can help decision-makers to outline precise policies and mitigation measures to support any managerial changes toward the proper implementation of a sustainable flood management strategy in Palestine.

Conclusions

This study applied the SCS-CN approach to estimate extreme floods in the data-scarce catchments to be used for flood hazard assessment in the West Bank. The results showed that this approach is suitable to estimate extreme floods from extreme daily rainfall (MADR). The approach used in this research facilitated the estimation of extreme flood values for different selected return periods (10, 25, 50, and 100 years) in catchments where robust monitoring of rainfall and runoff networks is not available. Despite the assumptions that long-term rainfall and runoff data are required to build a robust hydrologic model and establish a flood forecasting system, the obtained results from adopting of the SCS-CN approach can cope with data scarcity and pave the way for flood research and the establishment of flood monitoring/forecasting systems in West Bank catchments. This in turn indicates that even under data-scarce catchments and limited resources yet much can be performed to assist the decision-makers by providing even rough estimates of the expected extreme flood values mainly in the highly potential flood hazard-prone catchments. Thus, to formulate proper corrective and preventive strategies including but not limited to early warning and emergency preparedness plans, flood control engineering structures enhancements, and floodplain management protocols. Finally, for further and detailed extreme flood research studies, collaborative efforts have to be concentrated on how to integrate the obtained results with other techniques such as hydrological models once the rainfall and runoff networks are established and the required data become available.

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Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The raw data required to reproduce these findings are available in the body and illustrations of this manuscript.

Author's contribution

The paper was authored by just one author. As such, the author (Sameer Shadeed) confirms his contribution to all parts of the paper. The author reviewed the results and approved the final version of the manuscript.

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The author declares that there is no conflict of interest regarding the publication of this article

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