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Finding the design storm hyetograph for the Suez Gulf area

Ahmed Adel Saleh[1], Ashraf El Moustafa[2], Ahmed Ali Hassan[3]

[1](The corresponding author) Assistant researcher, Water Resources Research Institute, National Water Research Center, e-mail: Norahmed1@gmail.com.
Tel:+2 01062782686

[2]assistant professor, irrigation and hydraulics department, faculty of engineering, ain shams university, e-mail: elmoustafa010@yahoo.co.uk.

[3]professor, irrigation and hydraulics department, faculty of engineering, ain shams university, e-mail: ahmad9657@yahoo.co.uk.

الملخص:

التوزيع الزمني لهطول أمطار العواصف لهو من العناصر الأساسية التي تتحكم في خصائص الفيضانات الناتجة. لكن عدم توفر القياسات الدقيقة للأمطار في الكثير من الأماكن يضطر الهمتخصصين للإعتماد على توزيعات إفتراضيه لتهاطل الأمطار خلال مدة العاصفة. في هذه الدراسة، تمت المحاكاة الهيدرولوجية لأحد احواض المياه لتمثيل عاصفة تصميمية ذات زمن تكراري ٢٥ و ٥٠ و ١٠٠ سنة، لتمثيل أربعة توزيعات لكل زمن تكراري (اثنان إفتراضيتان، واثنين بناء على مراجعة العواصف السابقة). وتمت المقارنة بين العواصف المختلفه من حيث أقصى تصرف للسيل المتولد عنها. في حالة العاصفة ذات الزمن التكراري ١٠٠ سنه كانت التصرفات الناتجه عن عواصف ذات توزيع زمنى مماثل لعواصف سابقة أكثر ب ١٤% من العواصف ذتا التوزيعات الافتراضية. بينما لم تكن هناك فروق ملحوظة بين التوزيعات الزمنية المختلفة لعواص الأزمنة التكرارية ٢٥ عاما و ٥٠ عاما. ومن ثم أظهرت النتائج أفضلية الاعتماد على التوزيعات الزمنية للعواصف بناء على القياسات السابقه بدلا من التوزيعات الإفتراضية خاصة عند تصميم أعمال هندسية بناء على أزمنة تكرارية كبيرة. بينما لا يمثل التوزيع الزمني مشكلة عند تصميم منشئات هيدروليكية بناء على أزمنه تكرارية قصيرة.

Abstract:

The temporal distribution of storm precipitation controls the generated flood characteristics. The common lack of detailed measurements in many places makes hydrologists rely on synthetic temporal distributions. In this study, a hydrological simulation of a selected watershed is used to simulate 25, 50 and 100 years return periods design storm, each with four different distributions (two synthetic, and two historical storms). They were compared based on the generated peak discharge to determine which is able to generate the worst-case scenario. For 100-year storm, the historically based temporal disruption generated a peak 14% more than the synthetic based disruption. On the other hand, generated flood peaks were almost similar among all temporal distribution for 25-years and 50-years return period storms. Results recommend depending on real historical storms for designing structures with a long return period. On the other hand, applying synthetic storm is accepted for designing protection structures according to short recurrence intervals.

Keywords:
Flash floods, Design hyetograph, Wadi hydrology, Surface hydrology.

1. Introduction

Design storms' hyetographs (i.e., the graphical representation of rainfall changing in the storm duration) is an essential requirement for predicting peak discharge of flash floods.

Then it is possible to design many hydraulic structures such as culverts and drain channels. These hyetographs are usually determined using observed (chosen among historically recorded rainfall events) or synthetic storms (constant intensity, triangle, SCS, etc.) (Musy et al., 2014; Richard H. McCuen, 1989).
Some of the synthetic storms are simple geometric shapes such as rectangular, triangular and exponential hyetographs. Also, a common group of synthetic hyetographs is generated based on long historical records all over the united states. These generated hyetographs (SCS) were developed by the U.S. Dependent of Agriculture, Soil Conservation Service (now called the National Resources Conservation Service -- NRCS). This class of hyetographs, as shown in Figure 11, represent storms of six and 24 hours duration that mainly exists in the USA, furthermore, these hyetographs are also accepted worldwide. (Chow et al., 1988; Prodanovic and Simonovic, 2004).

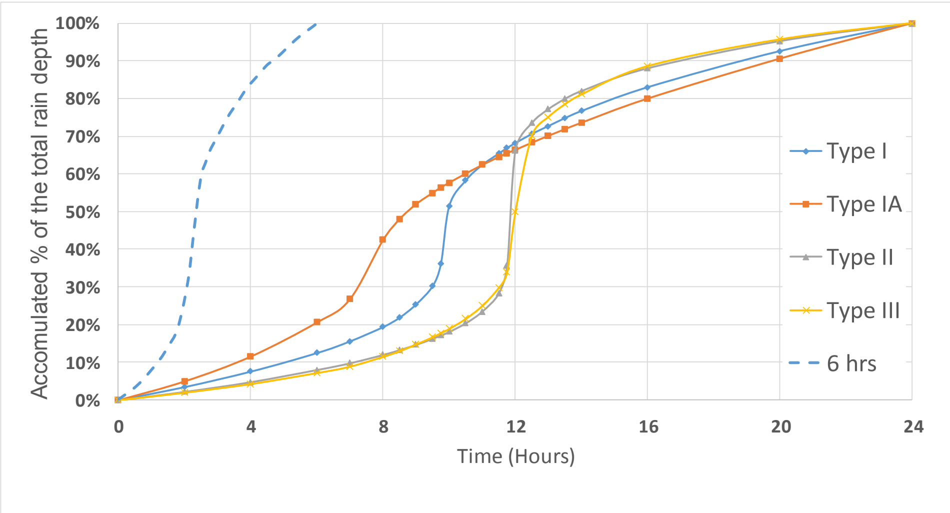


Figure 11 Cumulative SCS Hyetographs for the duration of 6-hours and 24-hours (type I, type IA, type II, and type III). Source: (Chow et al., 1988)

Suitability of applying these SCS-hyetographs to Arabian arid regions is Questionable. In addition, it is required to know the temporal storm disruption that generates the worst possible peak flow. Finally, whether applying synthetic hyetographs is accepted instead of historically based measurements, is also a common question.
Suitability of SCS synthetic hydrograph to represent flash floods in Saudi Arabia is discussed in (Asaad, 2013; Awadallah and Younan, 2012; Elfeki et al., 2013). They found that SCS is not suitable for that environment and some modifications are suggested in this literature to generate more reliable peak discharge. Assad (Asaad, 2013) concluded the need to modify SCS for the short storms in Saudi Arabia. (Awadallah and Younan, 2012) Suggested and tested some modification to the shape of the SCS synthetic hyetograph, they found the results are more suitable to estimate the most dangerous flood peak flow.
Also, (Terranova and Iaquinta, 2011) used a large amount of rain data to modify Huff's standard hyetographs to local conditions in Calabria, Italy.
(Prodanovic and Simonovic, 2004) Applied many synthetic storms on the Upper Thames River basin, England. They determined the storm duration limitation for each hyetograph. Their conclusion limited applying SCS 24-hours for only short and intense storms. Similar efforts were done by in (2005) to check the suitability of SCS synthetic

hyetographs in Texas and found that SCS doesn't fit there. They found that observed storms produce more useful hydrographs than synthetic ones.

Alfieri et al., (2008) compared the succession of different synthetic hyetographs to produce design floods. The application is ideal river basin in Italy. They found rectangular hyetograph underestimate flood's peak. A trial to develop a synthetic hyetograph with a triangular shape for central Tunisia was done by (Ellouze et al., 2009), good flood estimation was observed for storms with a duration between 2 and 4 hours.

The goal of the paper is to find out the temporal distribution of the design storm that produces the most danger flash flood peak flow.

2. Materials and Methods

2.1. Data collection

The chain of mountains along the coasts of the Red Sea faces flash flood events periodically. Therefore, a study area of similar geologic and topographic features as may be found in many watersheds in that region will be selected. Hence, "Wadi Araba" is selected because enough data sources are available, and also it represent many such features of large numbers of watershed in the region. "Wadi Araba" is located north of Egyptian eastern desert. Its stream flows mainly from west to east (Figure 12). The watershed has a large area of about ٤٢٠٠ km2. It is formed of steep rock mountains down to flat sandy land. Its mainstream finally intersects with several main roads.

Close to the selected watershed, there are three rain gauges provide total daily rainfall records that are located in Suez, Abu Redis, and Bani Suef. These rain gauges provide total daily data. While detailed data is only provided by the "Sidr" station (Figure 12). The length of records for these stations is 101, 30, 46, and 23 respectively. To make the best use of the available data, design rainfall depth with a certain probability of exceedance and spatial distribution of the rain over the catchment are estimated using the total daily rain stations. In addition, analysing storm pattern is done using Sidr station.

The highest storms recorded in "Sidr" happened on 11th of March 1994 and on 4thof February 2004. The first storm started at 9 a.m. and stayed for 11 hours with a total rain of about 30mm. The rain gradually increased for 3.5 hours, then it felt down rapidly for 2.5 hours, then for four hours, it felt down slightly; at the end of the storm, about ten mm felt down within an hour. The other storm started at 9:30 p.m. and lasted for 21 hours, about 30mm has fallen down in this storm. The rain had a very high intensity for 4.5 hours, and then it continued as repetitive periods of low and high rates of rainfall. Figure 13 shows the hyetographs for each observed storm.

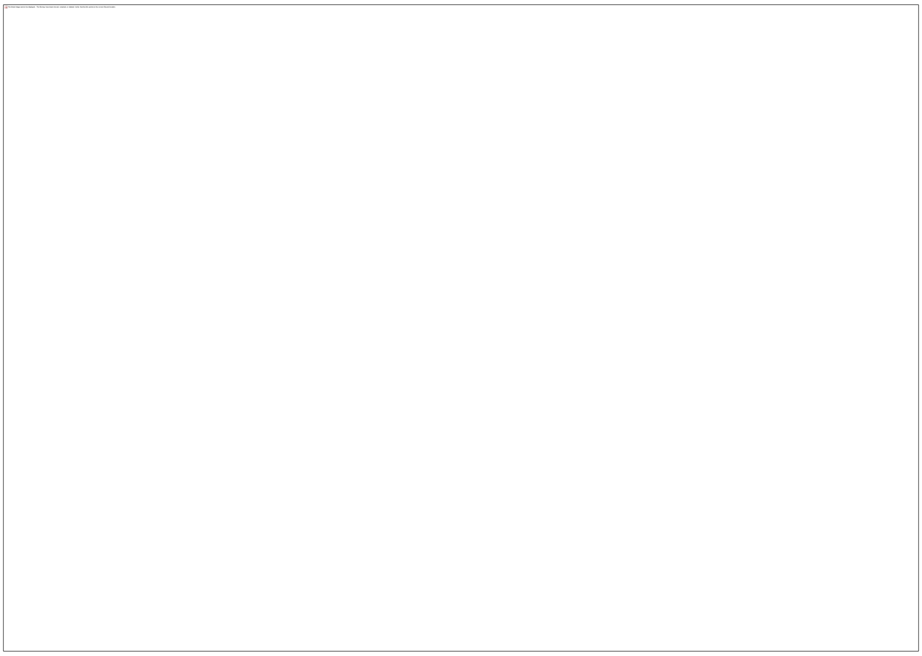


Figure 12 Location map of the study area "Wadi Araba" in Egypt's Eastern Desert, and available rain gauges of Non-Recording (red squares) and Recording (blue circle) Types. Source: (Water Resources Research Institute, 2015)

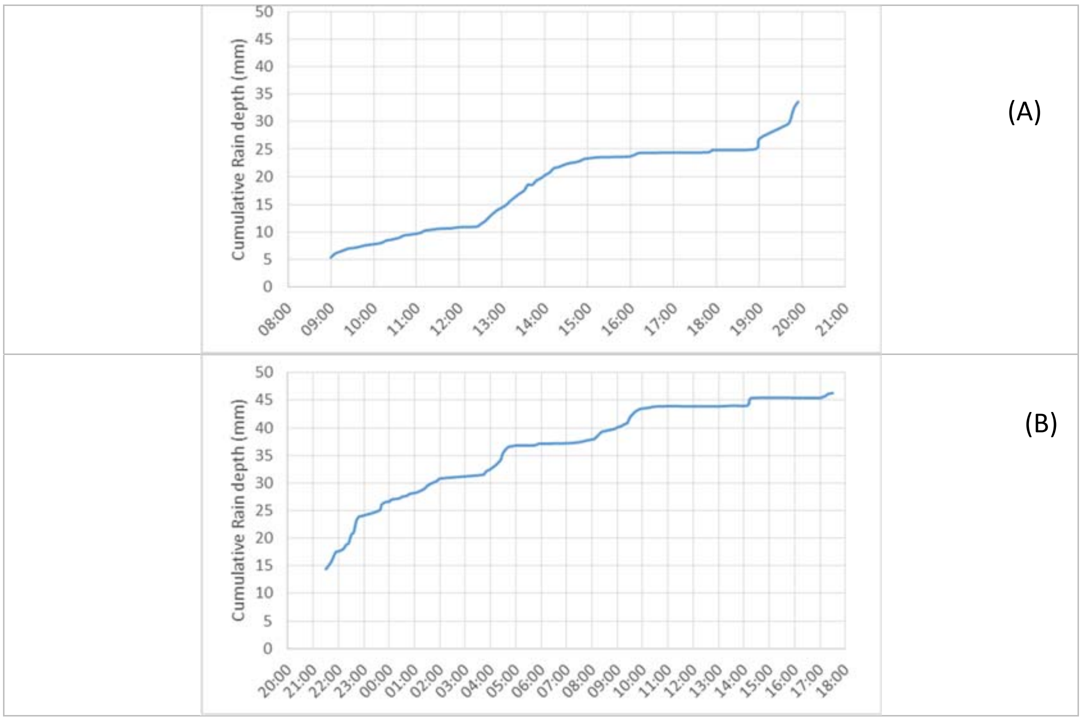


Figure 13 Cumulated hyetographs of the heaviest two storms were recorded close to the study area: (A) 11 hours, 28 mm storm occurred on 11 March 1994. (B) 20 hours , 32 mm on 4 February 2004. source: (Water Resources Research Institute, 2015)

In addition, to the selected storms, the SCS-II type curve and uniform distribution curves are selected as synthetic hydrographs. It should be noted that the SCS-II type curve is the closest among four types of SCS to the characteristics of the study area

(Chow et al., 1988). The selected synthetic hydrographs are compared with historical events.

Figure 14represents the cumulative percentage of four design storms in this study. The x-axis represents a 24 hours' time in minutes, and the y-axis represents the cumulative change from zero to hundred percent. The two solid lines represent the observed storms of 1994 and 2004. In addition, the two dotted lines represent the uniform and the SCS-II synthetic design storms. The uniform storm's line rises gradually (linearly) till the end of the storm. The SCS-II curve smoothly takes S-shape, as most of the storm occurs at the middle of the storm.

Opposite to the standard storms, both recorded storms consist of a number of jumps and steadiness. The 1994-storm starts by rapid rain period followed by heavier rain periods then four hours of low rains and ended by a big jump. Lastly, the 2004-storm had high intensity of rain for 12.5 hours followed by 7.5 hours of drizzling.

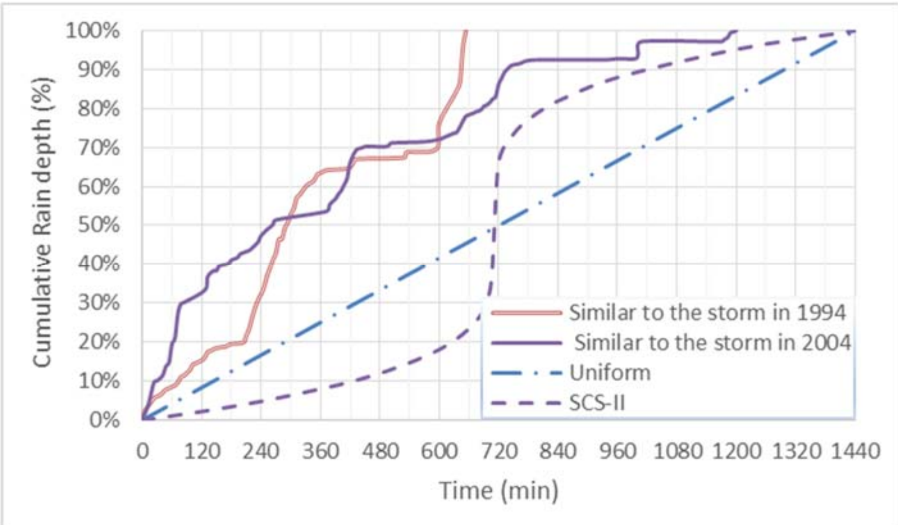


Figure 14 hyetographs that used in this study: Measured hyetographs of the 1994 and 2004 storms (solid lines); and synthetic standard accumulative hyetographs of uniform and SCS-II (dotted lines).

Model

The Watershed Modeling System (WMS) (Aquaveo, 2015) is utilised here to simulate rainfall-runoff of the selected case study "Wadi Araba". The topographic data was identified using the SRTM DEM of 90m spatial resolution, and then WMS has delineated the basin and calculate its attributes. In addition, soil and land use maps were read by WMS that calculated the composite curve number of 63.

Then, among the eight different hydrological models available within WMS, the HEC-1 was applied to subtract rain losses and predict flood hydrograph. HEC-1 applied the SCS method that estimates peak flow by the equation:

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \quad \text{Equation 9}$$

After running the model several times using a different standard and synthetic hyetograph, all generated hydrographs were compared. Finally, the resultant hydrographs were compared in regards to determining the effect of changing storm pattern on flood peak discharge.

3. Results

A rainfall-runoff model was developed for the study area using the WMS, and it was run for 12 times, the only variables were rainfall pattern and depth. These variables represent three-design storms (25, 50 and 100 years return period), each using four different rainfall temporal patterns. The generated hydrographs Figure 5 are compared to identify the relation between storm characteristics and the estimated flow peak discharge. Table 1 summarises the differences among hydrographs while Figure 6 displays these differences in a graphical form.

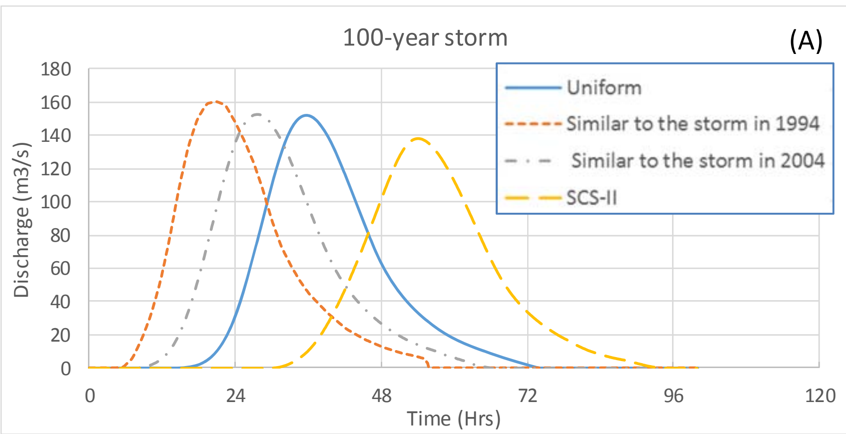
The results show when design storm is 100-years (Figure 5-A) that the total flooding period for all cases is about three days. The peak discharge is 140 to 160 m3/s for hyetographs of the SCS-II storm and the storm of 1994, respectively. Flow peaks due to the other two hyetographs are similar and equal to about 150 m3/s.

The flooding period of the second scenario, 50-years design storm, reduced to about two days (Figure 5-B). In addition, results show that estimated peak discharges of both observed and synthetic design storms are almost the same and equal to 40 m3/s. However, the SCS-II method produces a peak that is slightly less than 40 m3/s.

The last scenario (design storm of 25 years return period), caused flooding period of two days (Figure 5-C) which is the same as the second scenario. Also, all generated estimated flood peaks for all hyetographs are less than one m3/s.

A summary of the differences in the peak flows is displayed in Table 1. The first two rows show synthetic cases while last rows are for the observed storms. The lowest peak discharge is produced by SCS-II in 100-year and 50-year storm scenarios. Whereas, the highest peak discharge is produced by hyetographs that are similar to the storm of 1994. All peak flows are similar for the 25-year storm scenario.

For the design storm with 100-years return period, it is found that the SCS-II hyetograph produces peak flow that is less than the uniform hyetograph, the 2004-based hyetograph, and the 1994-based hyetograph by 9%, 10% and 14% respectively. Those differences are reduced with 50-year return period storm to be 3%, 3% and 5% respectively. Lastly, flood peaks are equal for the 25-year return period storm.



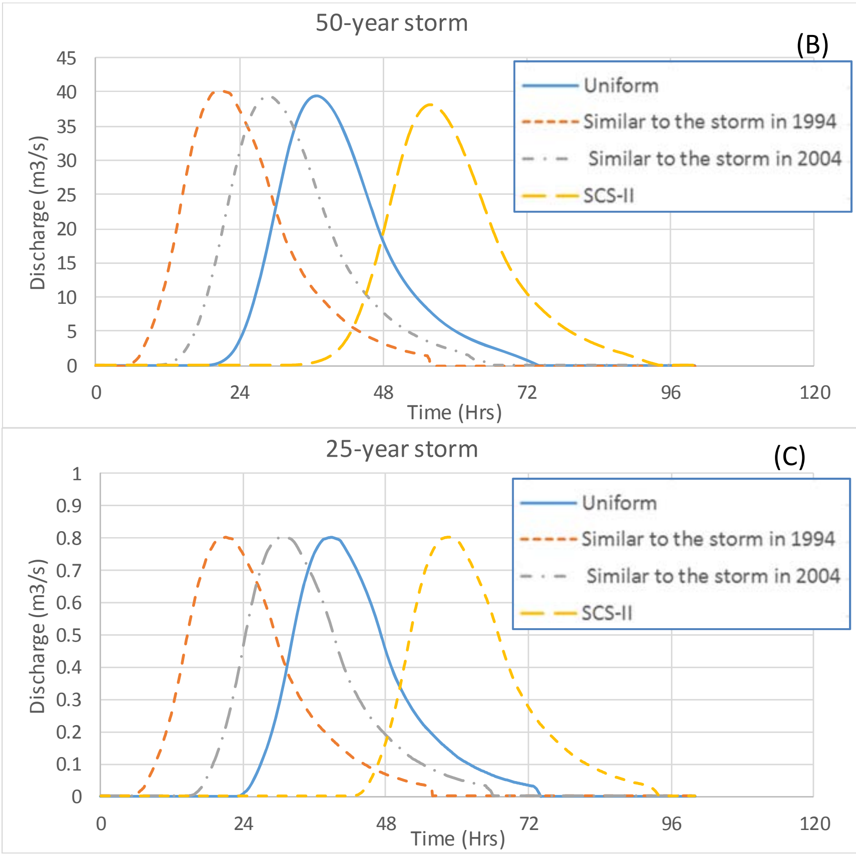


Figure 15 compares Hydrographs estimated by the hydrologic model w.r.t. hyetograph: (A) 100-years return period. (B) 50-year return period. (C) 25-year return period. Dotted lines and solid lines represent hydrographs caused by observed and synthetic hyetographs respectively.

Table 4 comparing estimated peak discharges for the developed hydrological model with changing

	100 yrs.	**50 yrs.**	**25 years**
Uniform	152.04	39.42	0.80
SCS-II	137.72	38.08	0.80
1994	159.80	40.20	0.80
2004	152.50	39.43	0.80

hyetographs and storm return period

The differences among the highest and lowest estimated flood peak discharges for each return period is displayed in Figure 16. It displays clearly that these differences increase enormously with the increasing if the return period.

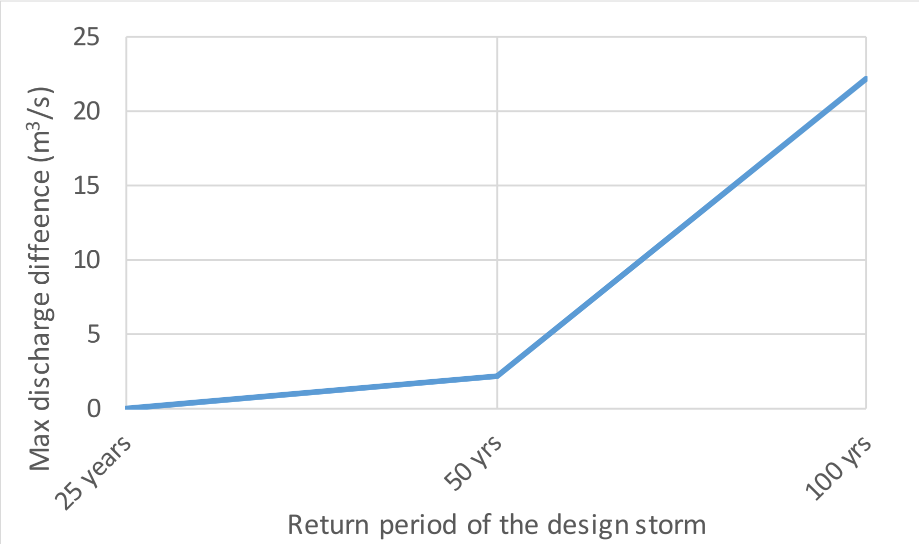


Figure 16 differences in estimated peak flow among compared hyetogeaphs. It increases with the increase of design storm return period.

4. Discussion

It is hypothesised that synthetic hyetographs are not suitable to be used in the arid region for designing flood protection structures (e.g., culverts, spillways, road protection, etc.). A numerical model was built in WMS environment to simulate and compare multiple historically based and synthetic hyetographs. Differences among produced hydrographs (directly proportional to the design storm return period) provide evidence to evaluate the appropriateness of using standard hyetographs.

The differences noticed here between uniform and SCS-II agree with Alfieri et al., (2008) who found significant hydrograph differences based on the selected synthetic hyetograph. Also, the unsuitability of SCS to catch the highest peaks agrees with work introduced in (Awadallah and Younan, 2012; Elfeki et al., 2013) and extends what they researched in Saudi Arabia.

Soil infiltration consumes a similar amount of rainfall whatever rain amount is, which raise its influence in events of short return period storms. Therefore, for watersheds with a high percentage of low soil permeability such as Saint Catherine, Sinai or south Red Sea mountains, it is expected that difference among hyetographs would be clear even in short return period storms.

The limited number of rain gauges and lack of detailed measurements increase significantly results uncertainty.

5. Conclusions and recommendations

SCS 24-hour synthetic hyetograph is generally accepted and widely applied in flood protection studies in addition of being embedded in most of the all hydrological modelling tools. They usually yield good results for humid areas, however, for arid conditions SCS 24 hyetograph failed to provide an accurate estimation of flash flood peaks.

Comparing synthetic methods with hyetographs extracted from observed large storms allows us to determine their suitability to estimate critical discharges required in estimating expected hazards to flood protection works. Differences among peaks are noticeable in long return periods floods. Therefore, until officially agree on modified standard methods to local conditions, factors of safety to increase calculated flood peaks should be considered.

According to this research, it is not recommended to use the SCS method if enough historically detailed rain data are available. Otherwise, the estimated peak discharge should be increased especially for long design return periods. In addition to the SCS-II method, this work is limited to only uniform rain distribution; it may be very useful to study in depth different simple and/or complex shapes of hyetographs.

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