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Statistical Analysis of Rainfall Patterns in Jeddah City, KSA: Future Impacts

Mazen M. Abu Abdullah, Ahmed M. Youssef, Fawzy Nashar and Emad Abu AlFadail

Abstract

Recently, the Kingdom of Saudi Arabia (KSA) has been facing significant changes in rainstorm patterns (rainstorm intensities, frequencies, distributions) causing many flash flood events. The city of Jeddah is located in a coastal plain area, in the middle of the western side of the KSA, which represents a clear case of changing rainstorm patterns. Jeddah has been hit by many rainstorm events, which increased dramatically since 2009 (e.g., one in 2009, one in 2011, one in 2015, and another one happened in 2017). However, in 2018 about six rainstorms occurred. Two major flash flood events occurred in the city in November 2009 and in January 2011. There were significant impacts of these two events causing severe flooding. During these events, 113 persons were announced dead (in the 2009 event), and infrastructures and properties were damaged (roads and highways, more than 10,000 homes and 17,000 vehicles). In addition to that, dam failure occurred in the 2011 event. This situation gives clear evidence in changing the climate system that could cause more storms in the future across the KSA. Generally, Jeddah city has a lack of short-duration data in rainfall stations. In addition to that, there are a limited number of studies that have been done in determining rainstorm patterns. Consequently, the approach of the current study will focus on understanding and determining rainstorm patterns in the period between 2011 and 2017 depending on some digital rainfall stations that have been installed recently in Jeddah city. Rainstorm pattern and the method of distribution are the most crucial factors affecting peak flow and volume calculations. Our findings showed that there are two pattern types for the rainstorms in Jeddah city. Finally, a comparison with SCS-type II distribution was carried out.

Keywords: rainfall patterns, floods, impacts, Jeddah, KSA, statistical analysis

1. Introduction

Climate change is a debatable subject these days. Dealing with this topic is considered an enormous challenge of the coming years [1]. There are many definitions of climate; however, the common term of climate is the long-term pattern of meteorological conditions in a specific area [2]. It is measured by evaluating variations in temperature, humidity, atmospheric pressure, wind, precipitation, atmospheric particle, and other meteorological variables. Climate change can have significant impacts on weather conditions around the world, such as storms and heavy rainfall.

Climate changes can occur due to different processes internal to the earth, external forces (e.g., variations in sunlight intensity), and human activities that have been increasing recently. Many shreds of strong evidence in many regions regarding the climate changes and variability that is impacted by anthropogenic activities, industries and natural specifications of climate systems are recently available. Among these factors that caused climate change due to changing of the composition of the atmosphere are the greenhouse gas emissions, CO₂, CH₄, and N₂O [3–5].

Many studies related to climate change have emphasized that there is an increase in the rainfall events recently regarding frequency and intensity [6–14]. Rainfall patterns and rate over a region are reliant on the ambient and global water evaporation and to a significant extent on altitude, latitude, and level of humidity [15]. Warmer conditions brought out from increased emissions of greenhouse gases through industrialization cause evaporation and precipitation with varying degree of intensity on individual regions [16].

Various environmental impacts have been witnessed according to climate change including change in the hydrological cycles, availability of water resources, unprecedented rainfalls and floods, unexpected drought frequencies, and changes in natural ecosystems [5, 14, 17–20]. Rain is an essential natural phenomenon which can influence the human life and properties. There are many factors which affect rainfall, such as geographical position, monsoon, topographic, and other factors. Flash flood frequency and severity in the desert areas are generally unpredictable and vary from year to year due to variability in the rainfall values [21–23]. Rainfall in arid areas is spatially variable than that of humid regions and is often described as “spotty,” and the impacted area is often limited by the radius of the clouds [24].

It is tough for hydrologists to use unreliable hydrological data (rainfall data) in the design of water-related structures. In most cases, the available rainfall data are limited (few records) and contain some gaps in the time series; rainfall stations are far from each other, with no intensity records; and records are not authentic values due to human errors. Previous studies used historical information to carry out the rainfall frequency analysis to understand the flooding behavior [25, 26]. These studies generally show that the use of historical information can be of great value in the reduction of the uncertainty in flood quantity estimators. A frequency analysis of the data is the most commonly applied method. Several studies were found dealing with the analysis of rainfall intensity in many areas [27–32].

A rain gauge is an instrument that measures how much rain falls in a given set time. Automatic rain gauges are rain gauges that electronically start working once it feels rain on the gauge. They automatically record the data, from measuring to removing the rainfall afterward [33]. Automatic rain gauge systems are required to collect rainfall data at remote locations, especially oceanic sites where logistics prevent regular visits [34]. It is usually based on tipping-bucket rainfall sensor and data logger for measuring the rainfall quantity and intensity during a given period and transmits the data through the GSM/GPRS modem to the desired e-mails and server at user-defined time intervals, and records obtained are of high reliability.

The Kingdom of Saudi Arabia (KSA) is one of the other countries that is impacted by severe events of rainfall in the last decade due to climate change. The intensity and frequency of the rainfalls are unprecedented and cause devastating floods in many KSA regions. Due to the lack of short-duration data in the Kingdom in general and in Jeddah in particular, and the limited number of studies that have determined the pattern of rainstorms, the current research will be a cornerstone in establishing rainfall pattern and behaviors. Determination of rainstorm pattern and method of distribution is one of the most critical factors affecting peak flow calculations. In this work, the Jeddah area was chosen as a unique example of unprecedented rainfall events in the last decade. The rainfall rate and patterns of the Jeddah area will be discussed in detail to extract

the adequate rainfall intensity patterns that could be used for future predictions. In the current study, the short duration rainfall data recorded by climate stations of the Saudi Geological Survey during the period from 2011 to 2017, as well as the data available at station J134 of the Ministry of Environment, Water and Agriculture, And the conclusion of the general pattern prevailing in these storms, as well as their comparison with the distribution of SCS-Type II, and the conclusion of the intensity curves based on available data. Many rainfall storms were analyzed in this study. It includes the following events (intensity records) 2011, 2014, 2015, 2016 and 2017. However, in the devastating floods that occur in 2009, we do not have intensity records for that event.

2. Rainfall distribution in the KSA and recent problems

The KSA climate is mainly arid and semiarid, except in the northern and southern areas. The arid and semiarid regions have an extreme continental climate with warm and dry summer and very cold winter especially in the central regions of the KSA. To assess rainfall pattern over the study area, it is necessary to define the dominant climatic patterns that have an influence on rainfall distribution over the western province of the KSA. The climatic pattern can best be described by considering the various air masses that affect the rainfall distribution over the KSA area. The influence of the different air masses and the rainfall patterns over the KSA has been discussed and mapped by several investigators [35–38].

Different air masses, which influence the Kingdom's climate, are illustrated in **Figure 1**. These air masses include (1) the monsoon front during the late autumn (maritime tropical air mass) reaches the area from the south, southwest, and southeast. This front that originates in the Indian Ocean and the Arabian Sea during the autumn brings warm and moist air. Outbreaks of westerly air become more frequent, characterized by medium to high intensity over the western and northwesterly regions of the country. This front often picks up further moisture while moving through the Red Sea Trough. (2) The continental tropical air masses are warm and moist coming from the Atlantic Ocean through the Central and North African continent. (3) The maritime polar air masses are derived from the Eastern Mediterranean

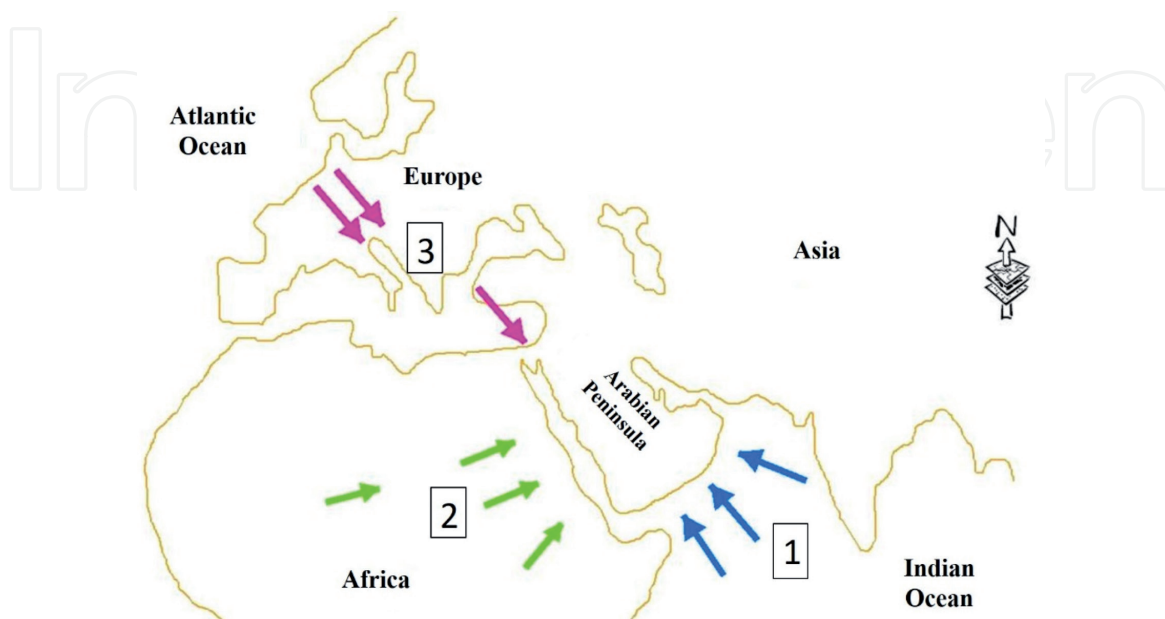


Figure 1. Air masses affecting the climate of the KSA: (1) maritime tropical air masses, (2) continental tropical air masses, and (3) maritime polar air masses [39].

Sea. In early winter the Mediterranean-borne maritime air increasingly disturbs the monsoonal air movement and displaces it in the low altitudes. These maritime depressions draw the tropical continental air masses into the warm sectors, and extreme weather conditions occur that are associated with the passage of a hot sector. Both (2) and (3) move toward the east and prevail in the winter season. During this season, the western region, particularly the coastal area, is characterized by its relatively low rate of rainfall [38], whereas, due to the topographic effects, the highlands receive a considerable amount of rainfall. In spring, the impact of the Mediterranean air movement diminishes, whereas the monsoon from the south takes its place, penetrating the southern part of the Kingdom. During summer, the cyclonic flow sweeps along the Mediterranean Sea from the west toward the east and continues moving over the northern and central regions of the country preventing the maritime air masses of the northeasterly monsoon from penetrating the north regions of the Kingdom. Due to this, the summer season will be somewhat dry in the area considered.

The mean annual rainfall (from 1960 to 2018) over the KSA can be shown in **Figure 2**. The rainfall rate in the KSA (except for the Empty Quarter desert) is 109 mm per year. The southwestern region is characterized by a heavy rainfall compared with the rest of the Kingdom. Rainfall is more than 500 mm per year in some locations. The peaks of the Sarawat Mountains, which extend from the northern part of the Kingdom to the south, parallel to the Red Sea, are the dividing line for the distribution of surface water. The rains that fall in the east of this line take place in the valleys heading east, and in the west, the valleys are steep and flowing towards the Red Sea.

Recently, there is a definite increasing trend in rainfall in frequency and intensity in the KSA. Many areas in the KSA have shown an increasing trend in the annual rainfall and flood events. Most of the rainfall in the KSA occurs during the monsoon. Monsoon is a term derived from the Arabic word “mausim,” meaning season. It was used to describe the seasonal winds of the Arabian Sea. The Jeddah area is characterized by wet and dry seasons that generally occur from November to May and from June to October, respectively. One example is Jeddah city which has shown an increasing trend in the rainfall events. These events cause disasters that result in human, property, and economic loss.

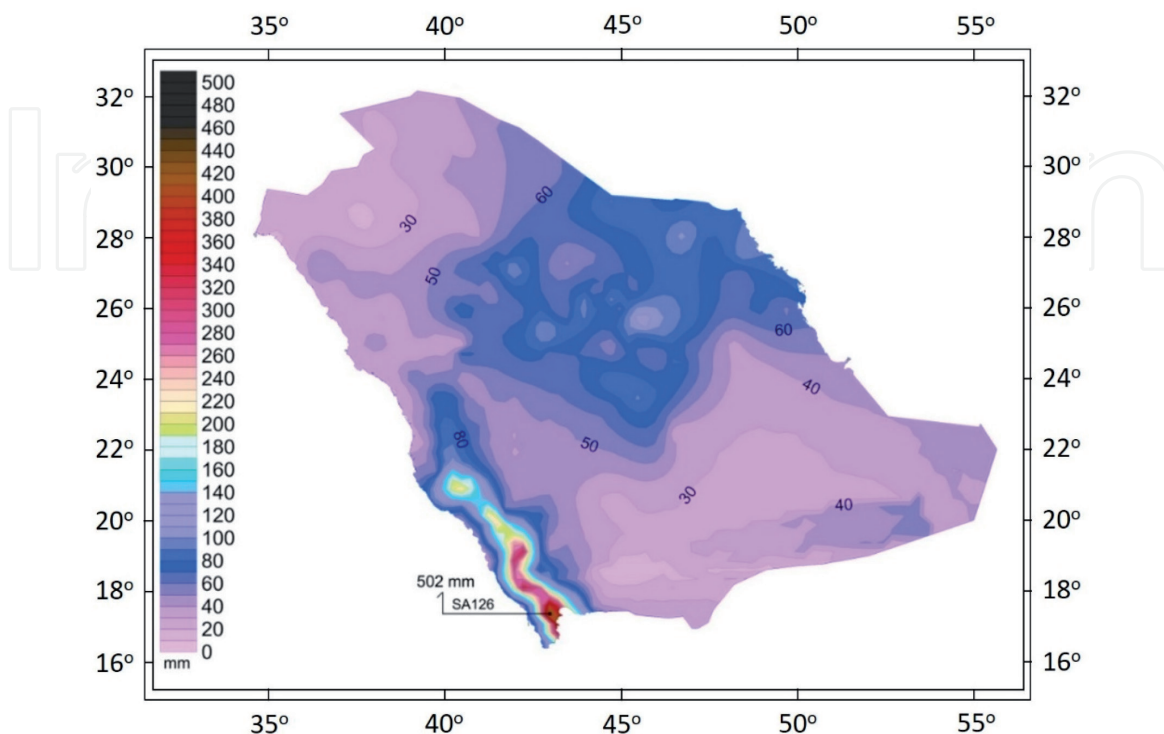


Figure 2. Average annual rainfall values for 270 rainfall stations distributed across the KSA area (from 1960 to 2018).

These unprecedented events have affected the KSA, causing considerable damage to highways, railroads, urban zones, and agricultural areas [39]. Most of the flash flood hazards in the KSA are caused by a combination of natural conditions (heavy rainfall and climate changes) and human interference (poor drainage systems and urban expansion). Recently, heavy rainfall events have triggered flash floods in various areas of the KSA (e.g., Jeddah city flash floods in the years 2009, 2011, 2015, 2017, and 2018 and Al Riyadh flash floods in 2015 and 2018). The severely hit areas are generally in the western part of the KSA, particularly in the city of Jeddah during November 2009 and January 2011 [39, 40]. These events were characterized by 70 and 111 mm of rainfall, respectively, within 3 h and were considered catastrophic flash floods for Jeddah city. They caused a death toll of 113 people in 2009, and, together, they damaged more than 10,000 homes and destroyed approximately 17,000 vehicles. Other areas impacted by flash floods are As Sail Al Kabir area, Taef; Najran city; Ar Riyadh city; Ha'il city; Makkah city; and Tabuk city [41–48].

3. Study area and its characteristics

The study area, the Jeddah area, is located in the western region of the KSA covering an area of $\sim 1731 \text{ km}^2$ and lies between latitudes $21^\circ 15'$ and $21^\circ 57' \text{ N}$ and

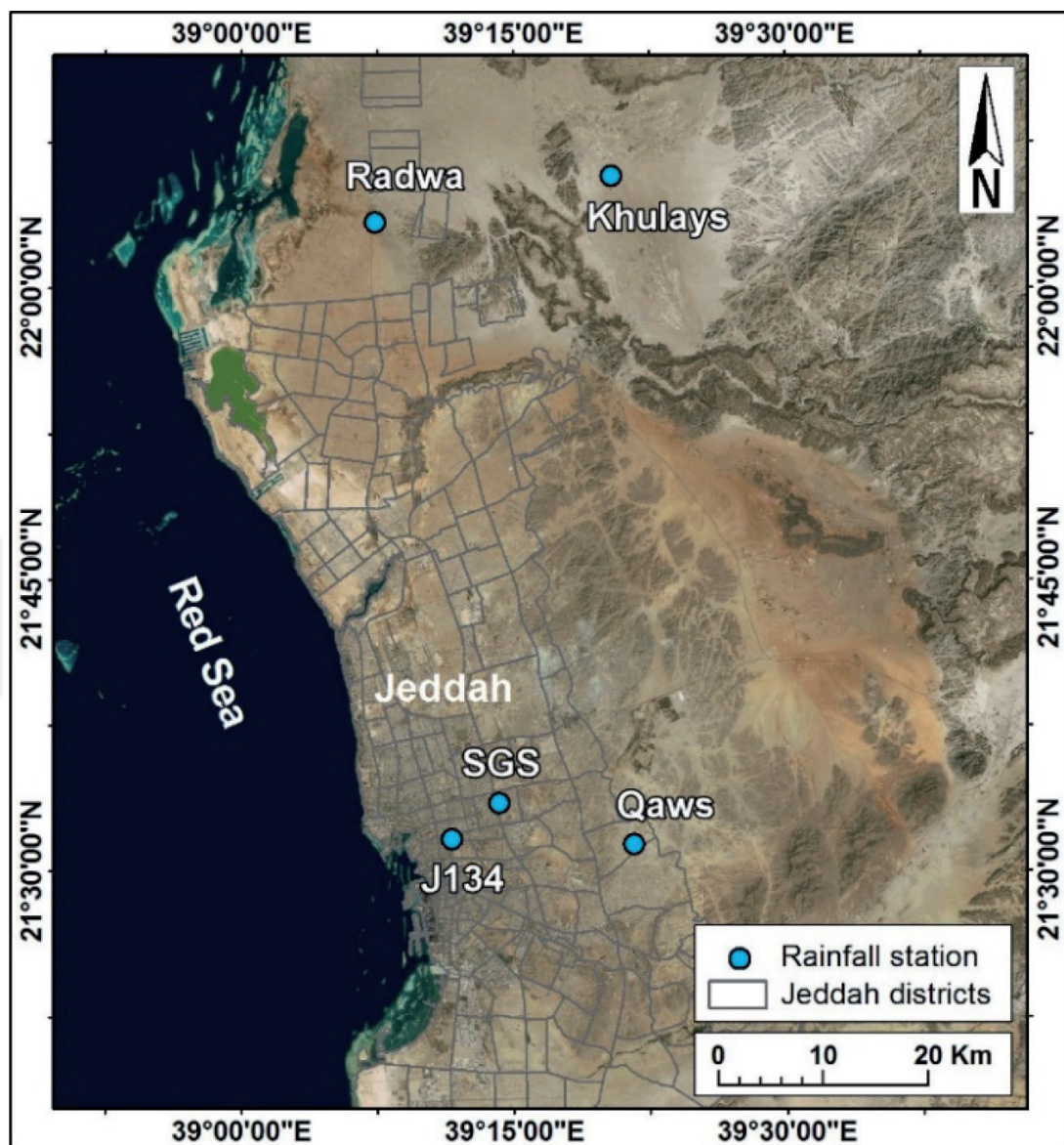


Figure 3.
Study area and its meteorology station locations.

longitudes 39°06' and 39°31'E (**Figure 3**). From the latitude point of view, the Jeddah area is considered to be in the arid zone (Köppen's climate classification). The Jeddah area has different geomorphological features. It represents a part of the Red Sea coastal zone. Jeddah drainage system comes from the east (a series of hills) toward the city which is located to the west. The catchment areas have a variety of landforms such as low- and midsize hills and flattened foothills in some places followed to the west by the floodplain areas. The monthly average relative humidity ranges between ~85% from September to October and ~34% from April to June. The Jeddah area is characterized by scarce rainfalls with high variability, which occur most often in November–December–January (the winter season). Additionally, monsoonal rainstorms take place in March and April due to the moist air currents from the Indian Ocean and the Arabian Sea. The average annual precipitation is ~52.5 mm/year. The maximum rainfall was recorded in 1996, with ~284 mm/year. Recently these thunderstorms increased in their frequencies and intensities causing flash floods and inundation events within Jeddah city.

4. Characteristics

In this study, all the current stations have automatic rain gauges that can record the intensity of the rainfall events (minute-base). This technique did not occur before, and most of the hydrological studies were depending on the daily rainfall data analysis which brings some uncertainty to the hydrological results. The stations used in the current study are shown in **Figure 3**. In the present work, trend and pattern analysis is based on intensity rainfall values for each rainfall station. Detailed analysis and discussion of the different recently occurred storms will be carried out in the following sections. This analysis and comparison work will give us the ability to deduce the general pattern prevailing in the storms in the city of Jeddah. **Table 1** has a list of different storms that will be considered in this study.

4.1 Rainstorm occurred on January 26, 2011

The data recorded by the rainfall station located at the headquarter of the Saudi Geological Survey shows that the precipitation began at 10:56 am on Saturday, January 26, 2011; continued until 12:27 noon, for ~91 min; and remained after a short break until 3:38 pm. The total precipitation is ~112.0 mm. It is difficult

No.	Date	Location	Name	Total rainfall (mm)	Duration (h)
1	January 26, 2011	SGS site	SGS	112.0	4.7
2	November 22, 2014	SGS site	SGS	43.0	10.0
3	November 17, 2015	Radwa farms	Radwa	21.7	2.7
4	November 17, 2015	Khulays, Ad Daff	Khulays	20.6	2.7
5	November 17, 2015	Old Jeddah airport	J134	79.0	3.2
6	November 17, 2015	Wadi Qaws	Qaws	61.0	1.77
7	December 02, 2016	SGS site	SGS	44.91	2.75
8	November 21, 2017	SGS site	SGS	88.04	15.75

Table 1.
Rainstorms occurred between 2011 and 2017 in the Jeddah area and the stations' names.

to distinguish two separate storms, but this rainstorm can be separated into two phases. The first phase of rainfall was ~54 mm, while the second one was ~58 mm. **Figure 4a** shows the rainfall recorded plotted against the whole rainfall time (4.7 h), which shows ~48% of the rainfall depth is fallen in the first phase for a period of ~78 min. The first phase is shown in **Figure 4b**.

4.2 Rainstorm occurred on November 22, 2014

This event was recorded in one rainfall station located at the headquarter of the Saudi Geological Survey. The data recorded by this station shows that the precipitation began at 0:22 am on Saturday, November 22, 2014; continued until 1:03 am, for ~41 min; then resumed at 9:53; and stayed until 10:19 am. The total precipitation is ~42.87 mm. This rainstorm can be separated into two storms. The rainfall of the first storm was ~33 mm, while the second one was ~9.61 mm. **Figure 5a** shows the rainfall recorded plotted against the whole rainfall time (10 h), which shows ~77% of the rainfall depth is fallen in the first storm for a period of ~41 min. The first storm is shown in **Figure 5b**.

4.3 Rainstorm occurred on November 17, 2015

This event was recorded in four rainfall stations including Radwa farms, Wadi Khulays, Station J134, and Wadi Qaws.

The data recorded by the rainfall station at Radwa farms shows that the precipitation began with a slow rate at 8:44 am on Tuesday, November 17, 2015; continued until 9:51 am, for ~67 min; and remained with a moderate rate until 11:25 am of the same day. The total precipitation is ~21.7 mm. The main storm in this event lasted ~41 min and reached a precipitation amount of ~19 mm. **Figure 6a1** shows the rainfall recorded plotted against the whole rainfall time (2.7 h), which shows ~88% of the rainfall depth is fallen at a period of ~41 min (the main storm; see **Figure 6a2**).

The data recorded by the rainfall station at Wadi Khulays shows that the precipitation began at 9:18 am on Tuesday, November 17, 2015; continued until 9:45 am, for ~27 min; and continued intermittently until 12:00 noon. The total precipitation is ~20.6 mm. The main storm in this station lasted ~27 min and reached a precipitation amount of ~18 mm. **Figure 6b1** shows the rainfall recorded plotted against the whole rainfall time (2.7 h), which shows ~87% of the rainfall depth is fallen at a period of ~27 min. The first storm is shown in **Figure 6b2**.

The data recorded by rainfall station J134 (located in the old Jeddah airport) shows that the precipitation began at 10:00 am on Tuesday, November 17, 2015; continued until 12:20 am, for ~140 min; and continued intermittently until

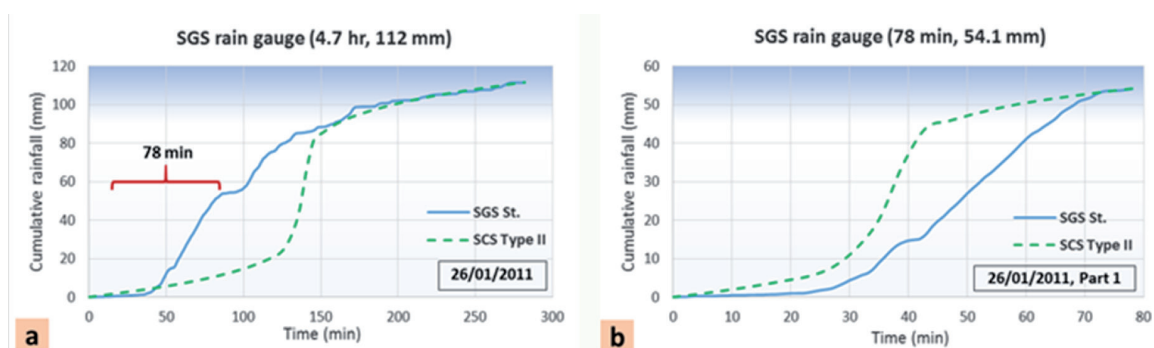


Figure 4. The rainstorm on January 26, 2011, at SGS station. (a) Distribution of cumulative rainfall intensity of the total storm. (b) Distribution of cumulative rainfall intensity of the first phase.

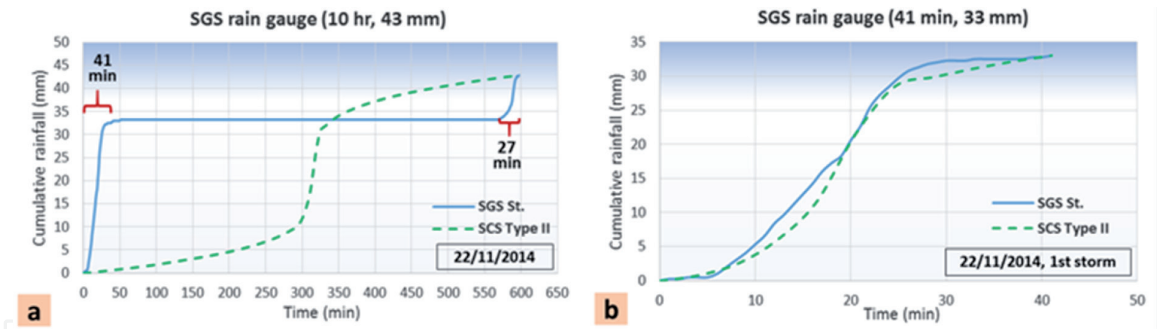


Figure 5. The rainstorm on November 22, 2014, at SGS station. (a) Distribution of cumulative rainfall intensity of the total storm. (b) Distribution of cumulative rainfall intensity of the first storm.

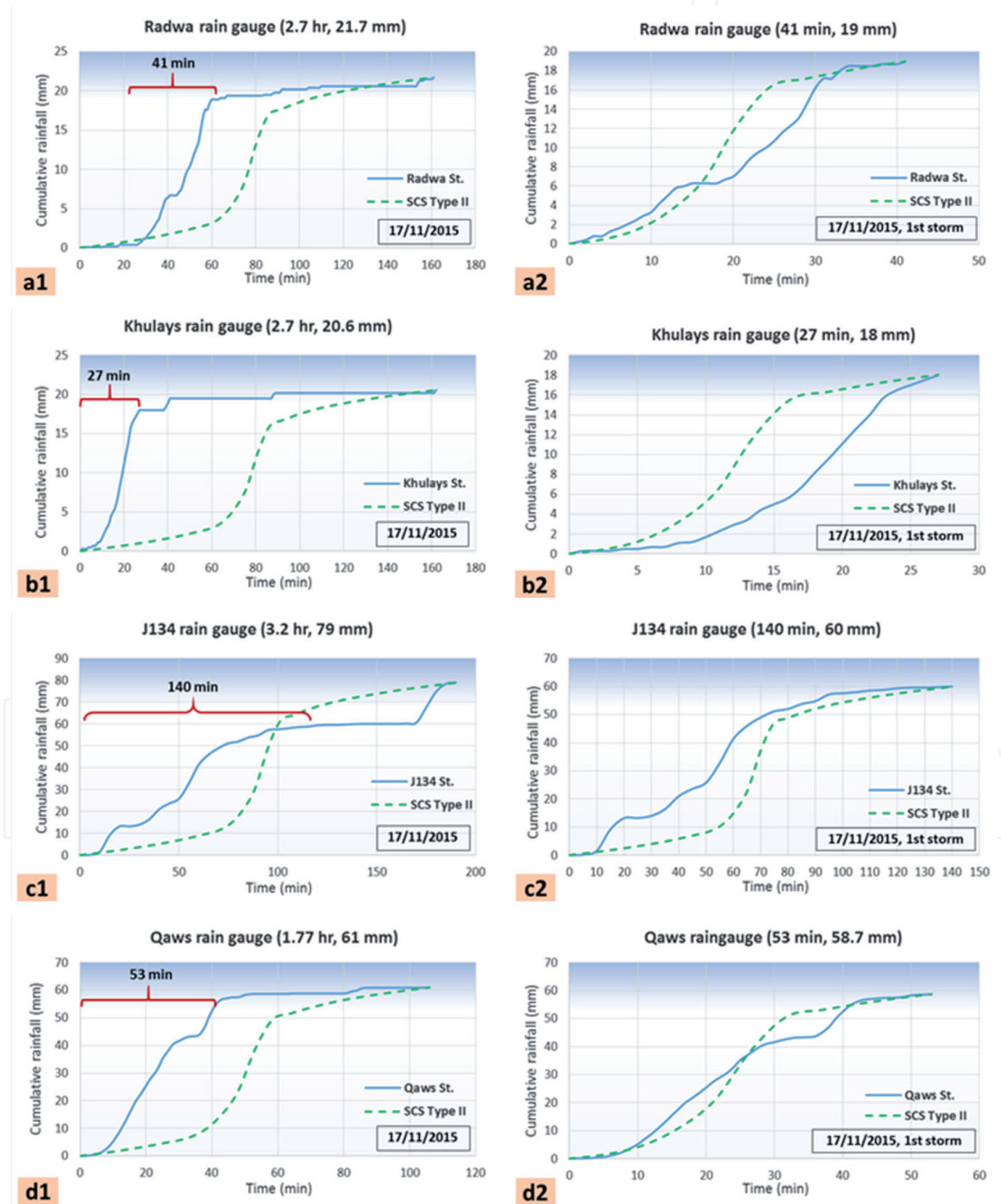


Figure 6. The rainstorm on November 17, 2015, at Radwa, Khulays, J134, and Qaws stations. (a1, b1, c1, d1) Distribution of cumulative rainfall intensity of the total storm. (a2, b2, c2, d2) Distribution of cumulative rainfall intensity of the first storm.

1:10 pm. The total precipitation is ~79.0 mm. The main storm in this station lasted ~140 min and reached a precipitation amount of ~60 mm. **Figure 6c1** shows the rainfall recorded plotted against the whole rainfall time (3.2 h), which shows ~76% of the rainfall depth is fallen at a period of ~140 min. The first storm is shown in **Figure 6c2**.

The data recorded by the rainfall station at Wadi Qaws shows that the precipitation began at 10:48 am on Tuesday, November 17, 2015; continued until 11:41 am, for ~53 min; halted at 12:09; and then continued intermittently until 12:34 pm. The total precipitation is ~61.0 mm. The main storm in this station lasted ~53 min and reached a precipitation amount of ~58.7 mm. **Figure 6d1** shows the rainfall recorded plotted against the whole rainfall time (1.8 h), which shows ~96% of the rainfall depth is fallen at a period of ~53 min. The first storm is shown in **Figure 6d2**.

4.4 Rainstorm occurred on December 2, 2016

This event was recorded in one rainfall station located at the headquarters of the Saudi Geological Survey. The data recorded by this station shows that the precipitation began at 7:18 am on Friday, December 2, 2016 and continued until 7:38 am, for ~20 min; then it resumed at 8:11 and stayed until 8:43 am, followed by a precipitation of 0.25 mm at 10.03 am. The total rainfall is ~44.91 mm. This rainstorm can be separated into two storms. The rainfall of the first storm was ~12.43 mm, while the second one was ~31.47 mm. **Figure 7a** shows the rainfall recorded plotted against the whole rainfall time (2.75 h), which shows ~28% of the rainfall depth is fallen in the first storm for a period of ~20 min and the second storm which lasted 43 min shows 70% of the total rainfall depth. **Figure 7b** shows the main storm which lasted 43 min (the second storm).

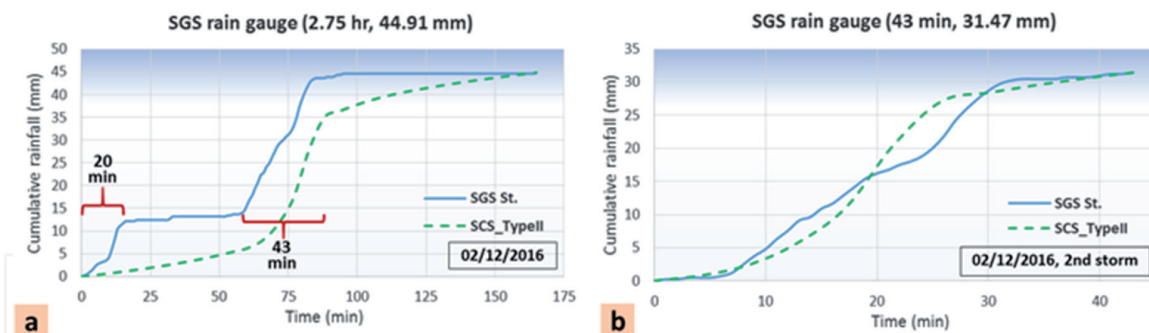


Figure 7. The rainstorm on December 2, 2016 at SGS station. (a) Distribution of cumulative rainfall intensity of the total storm. (b) Distribution of cumulative rainfall intensity of the second storm.

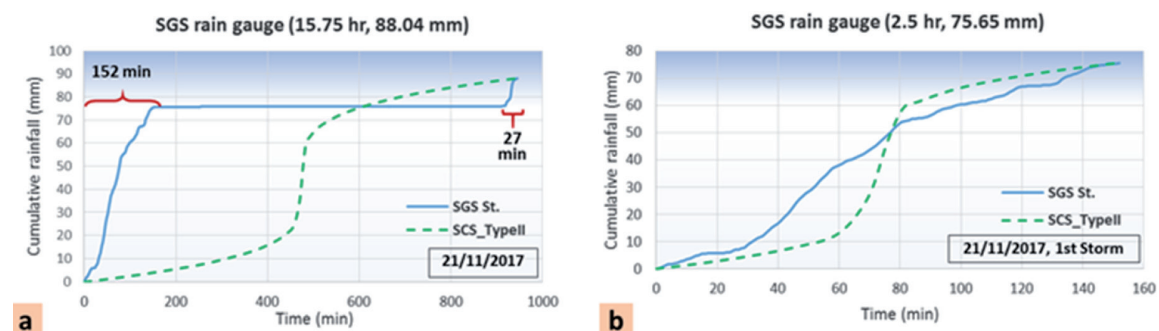


Figure 8. The rainstorm on November 21, 2017, at SGS station. (a) Distribution of cumulative rainfall intensity of the total storm. (b) Distribution of cumulative rainfall intensity of the first storm.

4.5 Rainstorm occurred on November 21, 2017

This event was recorded in one rainfall station located at the headquarters of the Saudi Geological Survey. The data recorded by this station shows that the precipitation began at 8:19 am on Tuesday, November 21, 2017; continued until 10:50 am, for ~152 min; then resumed at 11:30 pm; and continued until 12:01 night. The total precipitation is ~88.04 mm. This rainstorm can be separated into two storms. The rainfall of the first storm was ~76 mm, while the second one was ~12.0 mm.

Figure 8a shows the rainfall recorded plotted against the whole rainfall time (15.75 h), which shows ~85% of the rainfall depth is fallen in the first storm for a period of ~152 min. The first storm is shown in **Figure 8b**.

5. Comparison of different storms

In the current work, a comparison between the storms which occurred in the Jeddah area during the period (2011–2017) was carried out. The results indicated that there is some similarity in the behavior of these storms. The presence of the two main storms characterizes most of them during the rainfall time which is usually separated by a period of partial cessation. The most substantial amount of rainfall always exceeding 70% of the recorded rainfall appears in the first storm. Also, it was found that there is one exception in this rule which seems in the storm recorded on January 26, 2011, at the Saudi Geological Survey Station, which is different from other storms in terms of the amount of precipitation where the rain value reached 112 mm. **Figure 9a** shows a comparison of the major storms that have been occurred in the Jeddah area. **Figure 9b** shows comparison between storms which exceeded a rain value (50 mm). The results also indicated that based on the rainstorm that hit the city of Jeddah on November 21, 2017, with the storms that had a definite impact in the Jeddah city, we find that all these storms exceeded the amount of rainfall 50 mm during the first 100 min (**Table 2**).

The storm recorded at Wadi Qaws station on November 17, 2011, is the highest intensity, followed by the storms occurred at J134 on November 17, 2015; then the station at the headquarters of the Saudi Geological Survey on November 21, 2017; and then the storm recorded at the station at the headquarter of the Saudi Geological Survey on January 26, 2011. However, the storm occurred on January 26, 2011, left a massive damage and problems to the Jeddah area. It caused failure of the Umm al-Khair dam and paralyzed traffic in the province. Maybe the reason for that

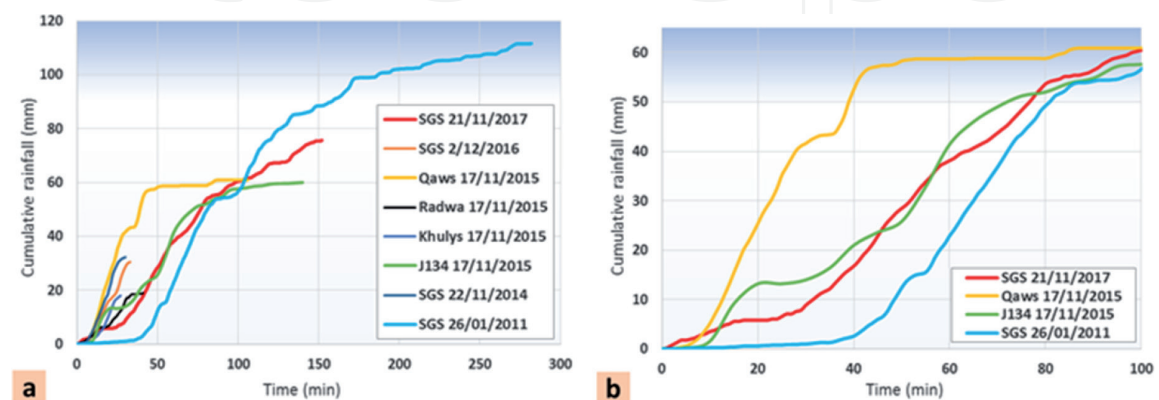


Figure 9.

A comparison between different rainstorms occurred in the period between 2011 and 2017: (a) all storms and (b) storms recorded rainfall more than 50 mm (the first 100 min).

is related to the duration time of the storm on January 26, 2011. The impact of the storm on November 21, 2017, was within the city of Jeddah and led to the flooding of a large number of roads and tunnels, although considers moderate intensity, however, the storm was concentrated in the center of the city, where almost urban areas are located. The lack of a proper drainage system inside the city has increased the impact of this storm.

6. Prevailing patterns of precipitation in Jeddah

To deduce the characteristic patterns of rainfall in the Jeddah area, we need a large number of reordering storms which are not available in the whole KSA. However, in the current work depending on the storms collected in the Jeddah area from the new installed automated rainfall stations, some suggestions can be made to understand the behavior of storms in the Jeddah area. To achieve this, the data available for each storm were converted to dimensionless data (**Figure 10**). The behavior of all possible storms was compared with the SCS-type II distribution curve. It is noticed that these storms can be divided into two groups. The first group represents the storms, which exceeded 50 mm of precipitation (**Figure 11a**). This group is represented by the storms recorded at the headquarters of the SGS station on November 21, 2017; January 26, 2011; and November 17, 2011, in both the Wadi Qaws and J134 stations. The second group represents short-term storms which recorded precipitation quantities less than 50 mm (**Figure 11b**). This group includes the storms registered at the headquarters of the SGS station on November 22, 2014, and December 2, 2016. For both groups, the average curves of each storm set were derived. To verify that these two storm groups are different from each other and have different behaviors, a distribution histogram of the average curve for each storm group was extracted and simplified as shown in **Figure 12**.

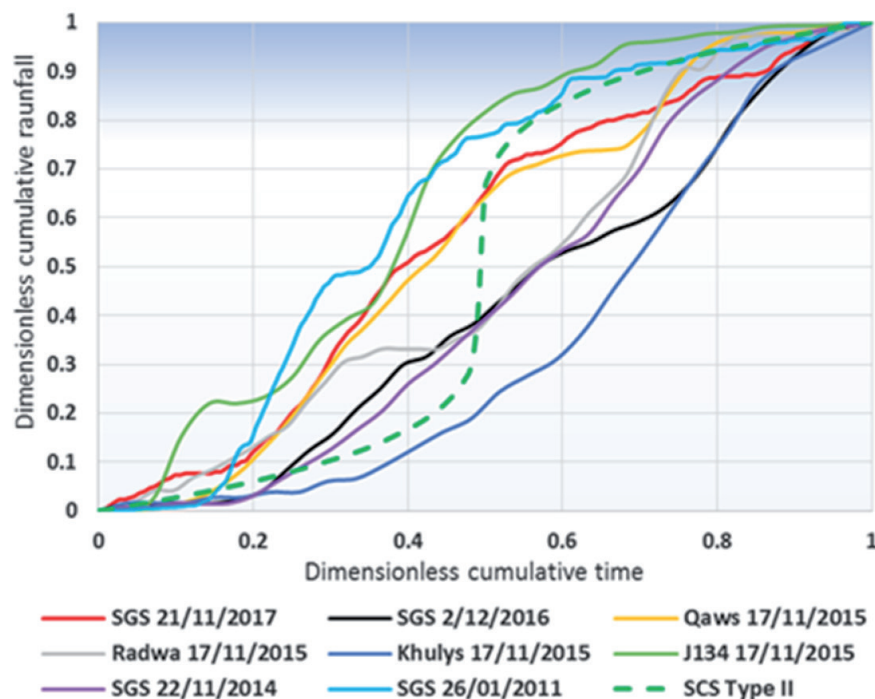


Figure 10.
Cumulative dimensionless hyetographs for rainstorms occurred in the period 2011–2017.

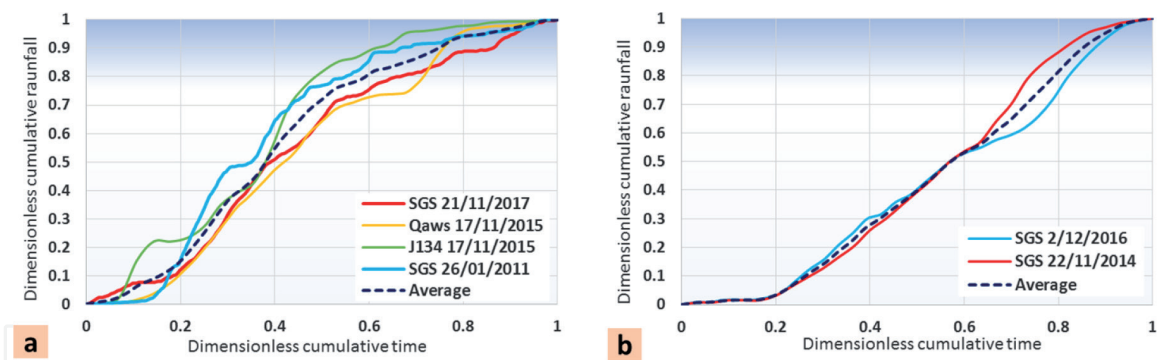


Figure 11. Cumulative dimensionless hyetographs: (a) for storms above 50 mm and (b) for storms below 50 mm.

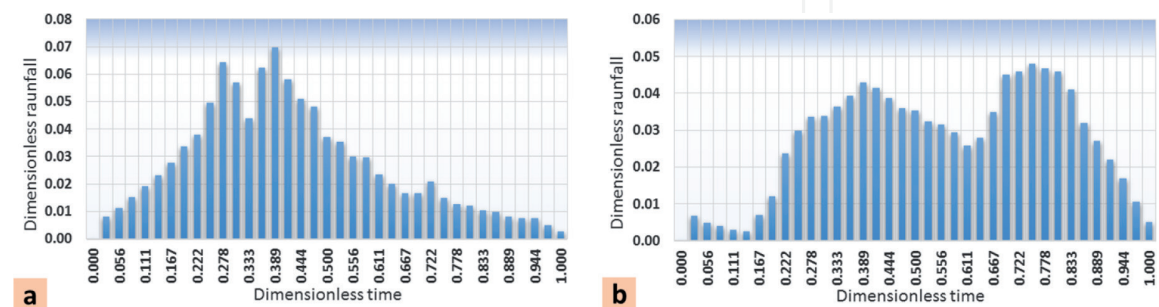


Figure 12. (a) Dimensionless histogram for storms above 50 mm. (b) Dimensionless histogram for storms below 50 mm.

7. The relation of the storms to the depth of the rain calculated for different return periods in the Jeddah area

Rainfall depth of return periods 5–100 years was estimated by the Saudi Geological Survey and AECOM company (Table 2). The values are due to the analysis of the historical records of all rain stations located in and around the Jeddah area. An average value for each return period was calculated and used in the current study.

By comparing the average data of Table 2 with the rainfall amounts recorded in the recent storms, it was found that the storms of the first group, which exceeded the amount of rainfall of 55 mm, fall within the rainfall depth above the 5-year return period. The storm recorded on January 26, 2011, 111.6 mm, falls below the 50-year return period; the storm recorded on November 21, 2017, 88 mm, falls below the rainfall value of the 20-year return period; the storm recorded on November 17, 2015, in the Wadi Qaws, 61 mm, falls under the value of the 10-year return period; and the storm recorded on November 17, 2011, at the J134 station, 79 mm, falls under the storms of the 12-year return period, while in the second group storms, they did not exceed the amount of rainfall of 50 mm, which falls below the return period of 5 years.

Source	Return period				
	5	10	25	50	100
SGS 2016 (mm)	53.1	71.1	93.4	110.0	125.0
AECOM 2011 (mm)	57.6	75.6	98.4	115.0	132.0
Average (mm)	55.4	73.4	95.9	112.5	128.5

Table 2. Rainfall analysis of the historical records for the Jeddah area.

Accordingly, our results indicated that instead of using the SCS distribution curve type II which has happened before in our studies, we can use these new distribution curves. For storms that exceed 50 mm, we can use the distribution curve extracted from the first group (average curve) (**Figures 11a** and **12a**). However, for storms less than 50 mm, we can use the average distribution of the second group (small storm distribution can be applied) (**Figures 11b** and **12b**).

8. Conclusion

Our findings indicated that Jeddah rainfall is characterized by two patterns: one for the rain values less than 50 mm and the other one for the rain values above 50 mm. The study shows that dealing with rainfall data in the Jeddah area required the following points to be considered: (1) it is necessary to pay attention to the details of rainstorms (intensity values) and not only to the recorded daily values. (2) There is a convergence of the nature of storms with impact (greater than 30 mm), which begins to rise after the onset of the storm almost immediately and continue the same tendency to the end of the storm. (3) There is a slight difference between the nature of these storms and the SCS-type II distribution, which assumes that about 60% of the depth of the rain falls in a fraction of the duration of the storm ranging from 8 to 20% and the rest distributed over the rest of the storm. (4) The average length of storms should be considered within the study areas. (5) In short-term storms of less than 2 h or even (with some reservation) up to 3 h, the distribution of SCS type II can be used safely but with duration limited to the same span of the storm rather than 24 h.

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Conflict of interest

The authors declare no conflict of interest.

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Author details

Mazen M. Abu Abdullah^{1*}, Ahmed M. Youssef^{1,2}, Fawzy Nashar³
and Emad Abu AlFadail¹

1 Department of Geological Hazards, Applied Geology Sector, Saudi Geological Survey, Jeddah, KSA

2 Department of Geology, Faculty of Science, Sohag University, Egypt

3 Department of Hydrogeology, Applied Geology Sector, Saudi Geological Survey, Jeddah, KSA

*Address all correspondence to: mazenaa@yahoo.com

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References

- [1] Aerts J, Droogers P, editors. *Climate Change in Contrasting River Basins: Adaptation Strategies for Water, Food, and Environment*. London: CABI Books; 2004. p. 288
- [2] Mander WJ. *Dictionary of Global Climatic Change*. 2nd ed. London: VCL; 1994
- [3] Domroes M, El-Tantawi A. Recent temporal and spatial temperature changes in Egypt. *International Journal of Climatology*. 2005;25:51-63
- [4] Hunt BG. Natural climatic variability and Sahelian rainfall trends. *Global and Planetary Change*. 2000;24:107-131
- [5] Raziei T, Arasteh PD, Saghafian B. Annual rainfall trend in arid & semi-arid regions of Iran. In: ICID21st European Regional Conference; 15-19 May, 2005; Frankfurt (Oder) and Slubice—Germany and Poland; 2005. pp. 20-28
- [6] Ali SA, Aadhar S, Shah HL, Mishra V. Projected increase in hydropower production in India under climate change. *Scientific Reports*. 2018;8:12450. DOI: 10.1038/s41598-018-30489-4
- [7] Coumou D, Rahmstorf S. A decade of weather extremes. *Nature Climate Change*. 2012;2:491-496. DOI: 10.1038/nclimate1452
- [8] Fowler HJ, Cooley D, Sain SR, Thurston M. Detecting change in UK extreme precipitation using results from the climate prediction.net BBC climate change experiment. *Extremes*. 2010;13:241-267. DOI: 10.1007/s10687-010-0101-y
- [9] Kundzewicz ZW, Kanae S, Seneviratne SI, Handmer J, Nicholls N, Peduzzi P, et al. Flood risk and climate change: Global and regional perspectives. *Hydrological Sciences Journal*. 2014;59:1-28. DOI: 10.1080/02626667.2013.857411
- [10] Mosmann V, Castro A, Fraile R, Dessens J, Sanchez JL. Detection of statistically significant trends in the summer precipitation of mainland Spain. *Atmospheric Research*. 2004;70:43-53
- [11] Ogburn SP. Climate Change is Altering Rainfall Patterns Worldwide. *Scientific American*. 2013. Available from: <http://www.scientificamerican.com/article/climate-change-isaltering-rainfall-patterns-worldwide/>
- [12] Xu ZX, Takeuchi K, Ishidaira H. Monotonic trend and step changes in Japanese precipitation. *Journal of Hydrology*. 2003;279:144-150
- [13] Xu ZX, Takeuchi K, Ishidaira H, Li JY. Long-term trend analysis for precipitation in Asia Pacific friend river basin. *Hydrological Processes*. 2005;19:3517-3532
- [14] Yu PS, Yang TC, Kuo CC. Evaluating long-term trends in annual and seasonal precipitation in Taiwan. *Water Resources Management*. 2006;20:1007-1023
- [15] Nayak JK, Prajapati JA. *Handbook on Energy Conscious Buildings*, Pilot Edition. 2006. Available from: <http://www.mnre.gov.in/solar-energy/ch2.pdf>
- [16] Stephen Schneider H. The greenhouse effect: Science and policy. *Science*. 1989;243:771-781
- [17] González-Hidalgo JC, De Luis M, Raventos J, Sanchez JR. Spatial distribution of seasonal rainfall trends in a western Mediterranean area. *International Journal of Climatology*. 2001;21:843-860

- [18] IPCC. Climate Change 2007: Synthesis Report. Spain: Valencia; 2007
- [19] Jiang T, Su B, Hartmann H. Temporal spatial trends of precipitation & river flow in the Yangtze River Basin, 1961-2000. *Geomorphology*. 2006;**85**:143-154
- [20] Piccareta M, Capolongo D, Boenzi F. Trend analysis of precipitation and drought in Basilicata from 1923 to 2000 within a southern Italy context. *International Journal of Climatology*. 2004;**24**:907-922
- [21] Dolman AJ, Gash JHC, Goutorbe J-P, Kerr Y, Lebel T, Prince SD, et al. The role of the land surface in Sahelian climate: HAPEX-Sahel results and future research needs. *Journal of Hydrology*. Feb 1997;**188-189**:1067-1079
- [22] Reid I, Powell DM, Laronne JB, Garcia C. Flash floods in desert rivers: Studying the unexpected. *EOS. Transactions of the American Geophysical Union*. 1994;**452**:75-39
- [23] Warner TT. *Desert Meteorology*. Edinburgh: Cambridge University Press; 2004. p. 612
- [24] Laity JE. *Deserts and Desert Environments*. Oxford, UK: Wiley-Blackwell; 2008. p. 360
- [25] Ouarda TBMJ, Cunderlik JM, St-Hilaire A, Barbet M, Bruneau P, Bobee B. Data-based comparison of seasonality-based regional flood frequency methods. *Journal of Hydrology*. 2006;**330**:329-339
- [26] Parent E, Bernier J. Bayesian POT modelling for historical data. *Journal of Hydrology*. 2003;**274**:95-108
- [27] Dairaku K, Emori S, Oki T. Rainfall amount, intensity, duration and frequency relationships in the Mae Chaem watershed in Southeast Asia. *Journal of Hydrometeorology*. 2004;**5**:458-470
- [28] De Paola F, Giugni M, Topa ME, Bucchignani E. Intensity-duration-frequency (IDF) rainfall curves, for data series and climate projection in African cities. *Springerplus*. 2014;**3**:133. DOI: 10.1186/2193-1801-3-133
- [29] Lu E, Zhao W, Gong L, Chen H, Wang H, Li X, et al. Determining starting time and duration of extreme precipitation events based on intensity. *Climate Research*. 2015;**63**(1):31-41
- [30] Mirhosseini G, Srivastava P, Stefanova L. The impact of climate change on rainfall intensity-duration-frequency (IDF) curves in Alabama. *Regional Environmental Change*. 2013;**13**:25-33. DOI: 10.1007/s10113-012-0375-5
- [31] Wagesho N, Claire M. Analysis of rainfall intensity-duration-frequency relationship for Rwanda. *Journal of Water Resource and Protection*. 2016;**08**:706-723. DOI: 10.4236/jwarp.2016.87058
- [32] Zainudini MA, Sardarzaei A. Analysis of short duration rainfall intensity data of Makoran region-Iran. *Irrigation and Drainage Systems Engineering*. 2014;**3**:123. DOI: 10.4172/2168-9768.1000123
- [33] Goodison BE, Louie PYT, Yang D. World Meteorological Organization. WMO Solid Precipitation Measurement Intercomparison: Final Report. Instruments and Observing Methods Report No. 67 (WMO/TD-No. 872). Geneva: 1998
- [34] Nystuen JA, Proni JR. A Comparison of Automatic Rain Gauges. Miami, Florida: NOAA/Atlantic Oceanographic and Meteorological Laboratory, Ocean Acoustics Division; 1995. DOI: 10.1175/1520-0426(1996)013<0062:ACOARG>2.0.CO;2

- [35] Al-Ehaideb. Precipitation distribution in the southwest of Saudi Arabia [thesis]. USA: Arizona State University; 1985. p. 215
- [36] Al-Qurashi MA. Synoptic climatology of the rainfall in the southwest region of Saudi Arabia [thesis]. USA: Western Michigan University; 1981. p. 97
- [37] Alyamani MS, Sen Z. Regional variations of monthly rainfall amounts in the Kingdom of Saudi Arabia. *Journal of King Abdulaziz University: Earth Science*. 1992;6:113-133
- [38] McLaren International Ltd. Water and agricultural development studies, Arabian Shield South. Report prepared for the Ministry of Water and Agriculture, Riyadh; 1979
- [39] Sen Z. Hydrology of Saudi Arabia. In: *Symposium on Water Resources in Saudi Arabia*; Riyadh, Saudi Arabia: King Saud University; 1983. pp. 68-94
- [40] Youssef AM, Pradhan B, Sefry SA. Flash flood susceptibility mapping in Jeddah city (Kingdom of Saudi Arabia) using bivariate and multivariate statistical models. *Environment and Earth Science*. 2016;75:12. DOI: 10.1007/s12665-015-4830-8
- [41] Youssef AM, Sefry SA, Pradhan B, Abu Al Fadail E. Analysis on causes of flash flood in Jeddah city (Kingdom of Saudi Arabia) of 2009 and 2011 using multi-sensor remote sensing data and GIS. *Geomatics, Natural Hazards and Risk*. 2016;7:1018-1042. DOI: 10.1080/19475705.2015.1012750
- [42] Abdul Karim AAA. Effect of spatial changes of urban growth and land uses on increasing flood risks in the Saudi City: Case study of Ha'il city using geographical information systems and remote sensing (GIS & RS). *Arab Journal of Geographic Information Systems*, Saudi Geographical Society. 2013;6(2)
- [43] Abushandi E. Flash flood simulation for Tabuk City catchment, Saudi Arabia. *Arabian Journal of Geosciences*. 2016;9:188. DOI: 10.1007/s12517-015-2192-x
- [44] Al-Ghamdi K, Elzahrany R, Mirza M, Dawod G. Impacts of urban growth on flood hazards in Makkah City, Saudi Arabia. *International Journal of Water Resources and Environmental Engineering*. 2012;4(2):23-34
- [45] Elkhrachv I. Flash flood Hazard mapping using satellite images and GIS tools: A case study of Najran City, Kingdom of Saudi Arabia (KSA). *The Egyptian Journal of Remote Sensing and Space Sciences*. 2015;18:261-278. DOI: 10.1016/j.ejrs.2015.06.007
- [46] El Shinnawy I, Bestawy A, El Tahawy T. Assessment and Management of flash floods for sustainable development in Al-Sail Al Kabir area, Kingdom of Saudi Arabia. *International Journal of Applied Engineering Research*. 2017;12:2807-2814
- [47] Embaby A, Abu Halawa A, Ramadan M. Integrating geotechnical investigation with hydrological modeling for mitigation of expansive soil hazards in Tabuk City, Saudi Arabia. *Open Journal of Modern Hydrology*. 2017;7(1):11-37. DOI: 10.4236/ojmh.2017.71002
- [48] Sharif HO, Al-Juaidi FH, Al-Othman A, Al-Dousary I, Fadda E, Jamal-Uddeen S, et al. Flood hazards in an urbanizing watershed in Riyadh, Saudi Arabia. *Geomatics, Natural Hazards and Risk*. 2014;7:702-720. DOI: 10.1080/19475705.2014.945101