

Development of storm hyetographs for flood forecasting in the Kingdom of Saudi Arabia

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Abstract This paper presents the derivation of the design storm hyetograph patterns for the Kingdom of Saudi Arabia based on real rainfall events from meteorological stations distributed throughout the Kingdom. Two thousand twenty-seven rainfall storms for a 20–28-year period were collected and analyzed covering 13 regions of the Kingdom. Four distinct dimensionless rainfall hyetograph patterns have been obtained over the Kingdom, while two patterns have been obtained for each individual region because of the lack of data for long-duration storms in individual regions. The resulting dimensionless rainfall patterns for each region can be used to develop storm hyetographs for any design duration, total rainfall depth and return period. It has been shown that the developed storm hyetographs have different features from other storm patterns that are commonly used in arid zones. The study recommends using these curves for the design of hydraulic structures in Kingdom of Saudi Arabia and regions alike.

Keywords Rainfall patterns · Dimensionless hyetograph · Design storm · Kingdom of Saudi Arabia · Arid zone

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Introduction

Hyetographs and storm-depth distributions are important elements in hydraulic design. Design hyetographs are used in conjunction with unit hydrographs to obtain peak discharge and hydrograph shape for hydraulic design. Hyetograph basics and the relation of hyetographs to hydraulic design are discussed in numerous hydrologic engineering books (e.g. Chow et al. 1988 and Haan et al. 1994). Currently, Natural Resources Conservation Service storm hyetographs (e.g. Type I, Type II and type IA), previously called Soil Conservation Service (SCS), are commonly used to construct synthetic temporal distributions of storm rainfall depths whenever runoff hydrographs are required. It is also common to describe these hydrographs in dimensionless forms. A dimensionless hyetograph has the units of time (storm duration) and cumulative rainfall depth (storm depth) expressed in percentages of the respective totals.

Many studies describe the development of hyetographs. Al-Asaadi (2002), Asquith (2003), Asquith et al. (2003) and Thompson et al. (2002) describe hyetographs in various areas. Soil Conservation Service (1973) developed a hyetograph model related to the intensity–duration–frequency curve and a “balanced-storm” or “alternating-block method” (Chow et al. 1988). The method provides dimensionless hyetographs classified into four types that depend upon specific regions of the United States. The Type I and II hyetographs are represented in elsewhere in the United States. The Type II hyetograph is applicable for the most intense cases and is commonly used in many countries even in arid and semi-arid regions.

Huff (1967) developed a methodology for obtaining the temporal distribution of rainfall on the basis of 261 storms, of durations ranging from 3 to 48 h, observed at 49 recording gauging stations located in the state of Illinois, USA. In Huff's method, the temporal distribution is achieved by relating the percentiles of total precipitation with percentiles of total duration, with storms grouped by their maximum duration. The

calculated dimensionless mass curves are associated to selected exceedance probabilities to constitute a synthetic picture of temporal distribution of storm rainfall over the region.

Pani and Haragan (1981) classified storms into four quartile categories depending upon which quarter of dimensionless storm time had the greatest change in storm depth. They analyzed 117 storms that occurred during May 15 through July 31 for a 3-year period (1978–1980) over the High Plains Cooperative Program (HIPLEX) rain-gage network. The network was in the southern High Plains of Texas near the town of Big Spring and covered about 2,600 square miles. The data consisted of 15-min rainfall values. Pani and Haragan (1981) determined that the relative frequencies of the quartiles were 13, 41, 32, and 14 % for the first, second, third, and fourth quartiles, respectively. These frequencies indicate that most storms (73 %) are characterised as second or third quartile in the area. This observation differs from Huff (1967, 1990) who found that most storms (66 %) are characterised as first or second quartile. Pani and Haragan (1981) provided median dimensionless hyetographs for only second- and third-quartile storms. First- and fourth-quartile hyetographs are not provided because of small sample sizes.

Although dimensionless rainfall storm hyetographs are a must for hydrological applications, such curves have not been established yet in Kingdom of Saudi Arabia (KSA). Some of the recent research work in KSA is focusing on rainfall analysis (e.g. Subyani and Al-Dakheel 2009) and flood analysis such as Subyani (2011). However, these works and others do not consider hyetograph analysis. The hyetographs patterns

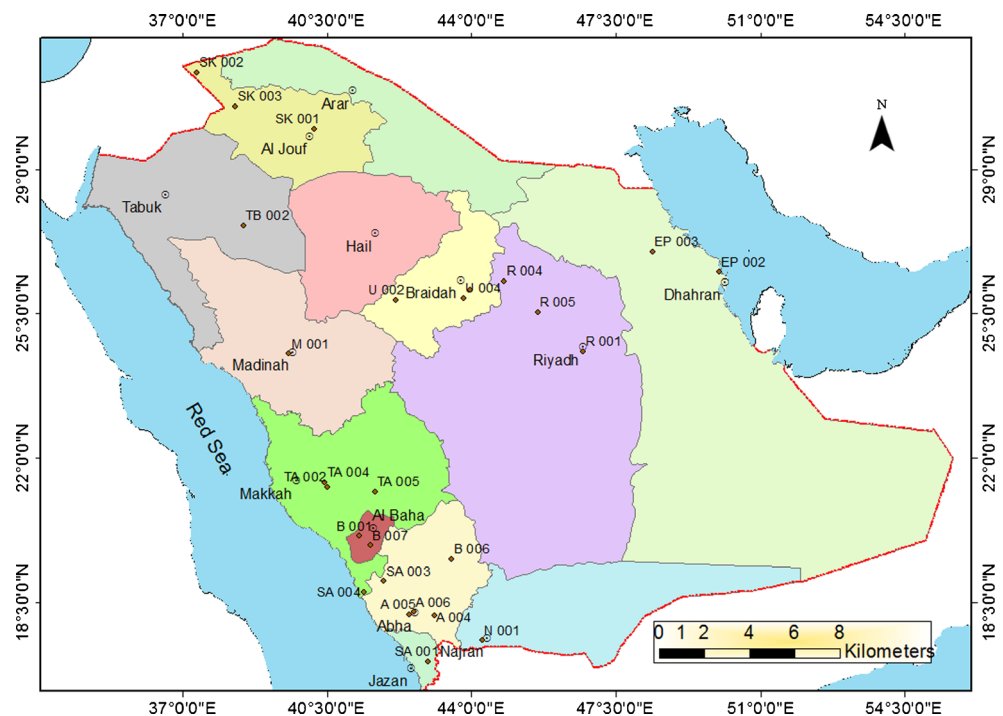
are crucial for flood mitigation measures and water resources engineering designs. Establishing such relationships requires good, long historical data set which is normally not available in an arid zone.

The current paper aims at developing dimensionless rainfall storm hyetographs for the Kingdom of Saudi Arabia based on measured rainfall events from meteorological stations distributed throughout the Kingdom. Representative tables have been developed to estimate the distribution of storm depth over 13 regions in Saudi Arabia. To the best of the authors' knowledge, this is the first attempt to derive such curves in KSA.

Study area

With the exception of the south western region of Saudi Arabia, it has an arid environment characterised by extreme heat during the day, an abrupt drop in temperature at night, and slight, erratic rainfall. The region of Asir (Fig. 1) is subject to Indian Ocean monsoons, usually occurring between October and March. An average of 300 mm of rainfall occurs during this period (about 60 % of the annual total). Additionally, in Asir and the southern Hijaz, condensation caused by the higher mountain contributes to the total rainfall. For the rest of the country, rainfall is low and erratic. The entire year's rainfall may consist of one or two torrential outbursts that flood the wadis. The average rainfall is 100 mm per year.

Fig. 1 Locations of rainfall stations in Saudi Arabia



In the present study, Saudi Arabia is divided into 13 districts. Each district has one to four recording rainfall gauges (Fig. 1).

Methodology

Continuous rainfall data were collected from the rainfall gauge network that covers the Saudi Arabian region from 1975 to 2003. The data collected for each station include the zone name, station number, station symbol, years of records, coordinates and number of storms (Table 1, Fig. 1).

Two thousand twenty-seven rainfall storms are collected for a 20–28-year period from the 13 regions covering Saudi Arabia. Only 599 rainfall storms have detailed rainfall temporal distribution from the 28 rainfall gauges (Table 1).

Criteria to identify rain events often rely on threshold values for selected properties of rain events. For instance, the duration and intensity of rain events may serve to identify events (see

e.g. Dunkerley 2008b). Commonly, the minimum event depth serves to identify rain events or to classify a series of rain observations as a single event. Huff defines a “storm” as a “rain period separated from preceding and succeeding rainfall by 6 h or more” (Huff 1967). Dunkerley (2008a, b) reviewed a large number of criteria and reported that the minimum event depth varies from the measurable amount that is the detection threshold of the rain gauge to 13 mm. Dames and Moore (1985) took 10 mm as a threshold for runoff studies for Sinai wadis in Egypt.

The storms used in the current analysis are the ones that could produce runoff. Therefore, only storm depths more than a threshold value of 10 mm are considered. According to this criterion, 269 rainfall storms out of 599 rainfall storms were selected for further analysis.

A frequency histogram relates the number of rainfall events to the corresponding rainfall event durations from all stations are shown in Fig. 2. The figure shows that about 52 % of the

Table 1 Stations used in the current study

Zone	Station number	Station name	Station symbol	Recorded storms		Coordinates		Storms > 10 mm	Total number of storms
				From	To	Longitude	Latitude		
Abha	12	Serat Abida	A 004	1975	2002	4306'00"	18 10'00"	12	19
	13	Abha	A 005	1975	2003	4229'00"	18 12'00"	27	28
	14	Sir Lasan	A 006	1975	2000	4236'00"	18 15'00"	20	21
Bishah	61	Al Mundak	B 001	1975	2003	4117'00"	2006'00"	16	21
	66	Tathlith	B 006	1975	2003	4331'00"	19 32'00"	9	18
	67	Bliljorshi	B 007	1975	2002	4133'00"	19 52'00"	25	27
Eastern province	138	Qatif	EP 002	1975	2002	5000'00"	26 30'00"	6	27
	139	As Sarrar	EP 003	1975	2002	4823'00"	26 59'00"	8	19
Hail	186	Hail	H 001	1975	2001	4138'00"	27 28'00"	4	26
Jeddah	214	Mudaylif	J 001	1975	2001	4103'00"	19 32'00"	6	19
Al Medinah	366	Al Medna Farm	M 001	1975	2002	3935'00"	24 31'00"	8	28
Najran	405	Najran	N 001	1975	1999	4415'39"	17 34'00"	12	23
Riyadh	452	Ritadh	R 001	1975	2003	4643'00"	24 34'00"	11	29
	455	Zilfi	R 004	1980	2003	4448'00"	26 17'00"	21	24
	456	Hutah Sudair	R 005	1975	2003	4537'00"	25 32'00"	15	15
Sabya	496	Malaki	SA 001	1975	2003	4257'00"	17 03'00"	12	23
	498	Kwash	SA 003	1975	2003	4153'00"	19 00'00"	8	22
	499	Kiyat	SA 004	1975	2002	4124'00"	18 44'00"	5	15
At Taif	625	Hema Saysid	TA 002	1975	2000	4030'00"	21 18'00"	22	27
	627	At Taif	TA 004	1980	2003	4027'00"	21 24'00"	9	19
	628	Turabah	TA 005	1975	1997	4140'00"	21 11'00"	15	15
Tabuk	770	Tayma	TB 002	1975	1995	3829'00"	27 38'00"	4	17
Unayzah	786	Unayzah	U 001	1980	2003	4359'00"	26 04'00"	19	24
	787	Uclat As Suqur	U 002	1982	2003	4211'00"	25 50'00"	2	16
	848	Quraa Almarw Atajarob	U 004	1975	2003	4348'51"	25 52'46"	6	18
Sakakah	592	Sakakah	SK001	1975	2002	4012'00"	29 58'00"	8	26
	593	Qurayyat	SK002	1975	2002	3721'00"	31 20'00"	6	17
	594	Tabarjal	SK003	1975	2002	3817'00"	30 31'00"	7	16

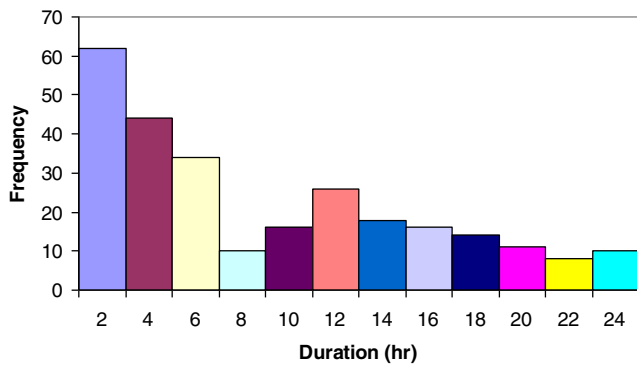


Fig. 2 Frequency histogram of storm durations from the 28 stations

storms have durations less 6 h, and 19 % of the storms have durations between 6 and 12 h. The rest of the storms which constitute about 29 % have durations more than 12 h of which 18 % have durations of 12 h to 18 h, and 11 % have durations of 18 to 24 h.

Storms can be grouped either to maximum intensity or duration. Comparison of the effect of the grouping paradigm is ongoing. Storms, in the present study, have been grouped according to their total durations. Storms with durations less than 6 h represent the first quartile storms, and storms characterised by durations between 6.1 to 12 h represent the second quartile storms. The third and fourth quartile storms are in the interval between 12.1 and 18 h and 18.1 and 24 h, respectively.

It should be emphasised that enough data for all quartiles are not often available. Storms that have been derived for the first and second quartiles are based on 192 storms, while the third and fourth quartiles are based on 77 storms. Therefore, the curves of the first and second quartiles are more reliable than those of the curves for the third and fourth quartiles. Consequently, the third and fourth quartiles are considered for the overall Saudi Arabia where statistically reliable data could be obtained; however, for individual region, only first

and second quartiles are derived which has been supported by Viessman et al. (1977).

Construction of synthetic temporal distribution of precipitation assumes homogeneity over the region, in addition to a large collection of storm events. In order to construct these distributions in the Kingdom of Saudi Arabia, 269 storms have been selected among those observed at the 28 stations. Bonta (2004) has presented the details of construction of dimensionless mass curves since the methodology is not presented clearly in the literature. For the sake of completeness, the construction of the dimensionless mass curves and hyetographs are presented below:

1. Selecting the reliable rainfall events from the rainfall storm records.
2. Grouping the storms according to their total durations as follows:

Quartile storm	Duration (h)
First	≤6
Second	6.1–12
Third	12.1–18
Fourth	18.1–24

3. Constructing a mass curves for each storm. Figure 3 shows the mass curve for storms in rainfall station R004 in Riyadh region. The horizontal axis is the time elapsed from the beginning of the storm, and the vertical axis is the cumulative rainfall depth collected at each elapsed time during the storm event.
4. Transforming the mass curve of each event into a dimensionless mass curve by dividing the rainfall depth at each time by the total rainfall at the storm duration and dividing the time elapsed since the storm begins by the maximum duration of the storm. Figure 4 shows the dimensionless

Fig. 3 Cumulative mass curves of storms at station R004 at Riyadh region

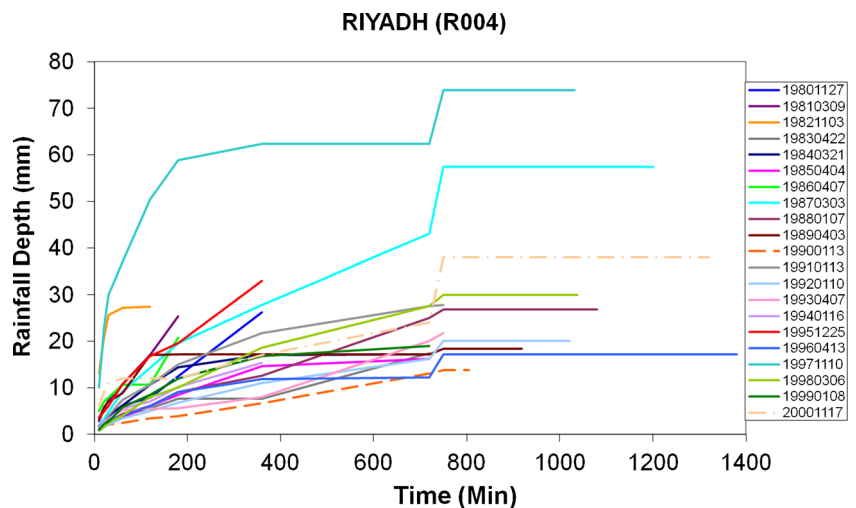
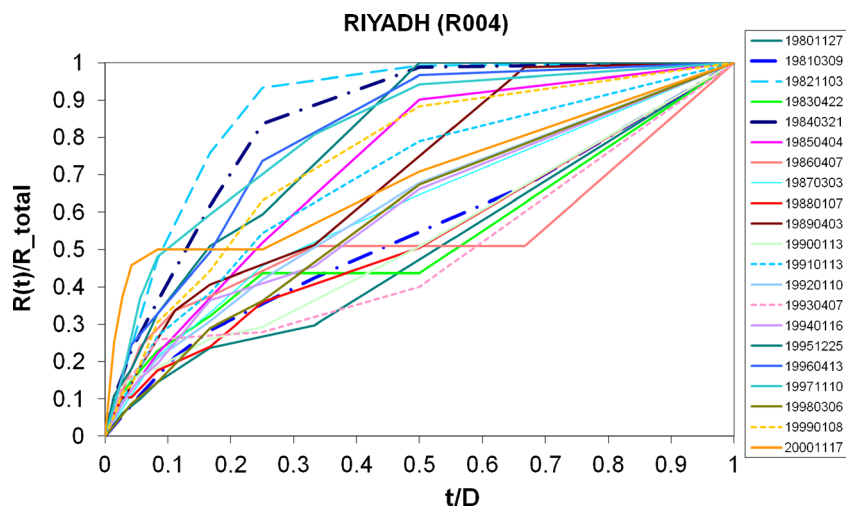


Fig. 4 Dimensionless cumulative mass curves of storms in station R004 at Riyadh region



- mass curves for station R004 in Riyadh region. Figure 5 shows the pointwise dimensionless mass curves for station R004 which will be used to calculate percentiles.
- For each percentile (0.01, 0.02, 0.03..., 0.99) of the total duration on the horizontal axis, one calculates the percentiles of total precipitation on the vertical axis.
 - Graphing and tabulating the first and second quartile storms for each region and the four quartiles for the Kingdom as a whole (Figs. 6 and 7 and Appendix 1).
 - Graphing the third and fourth quartile storms for the Kingdom as a whole as shown Fig. 8.
 - Calculating the incremental curves by computing differences in mass curves.

Results and discussion

Time distributions of storm rainfall in Fig. 8 presents the dimensionless rainfall cumulative hyetographs as families of curves derived from storms classified as first,

second, third and fourth quartiles. The figure shows the probability levels from 50 % level (median), 10 % and 90 % levels. The first quartile represents most severe storms while the fourth quartile corresponds to the mildest storms (Huff 1967), the second and third are somewhat in between in terms of storm severity.

All storm quartiles have storm pattern with greater portions of rainfall occurring during the early minutes of the storm for the 50 % and 90 % storms. For the 10 % storms, the first and second quartile storms have major bursts at the beginning of the storm. For the third quartile, the major burst moves to the end of the storm time, while finally, in the fourth quartile, the major bursts are distributed over the end of the storm.

Tables 2 to 4 provide median time distributions for each quartile-type storm in Saudi Arabia.

Interpretation of the curves can be illustrated by referring to the four quartiles storm distributions in Tables 2, 3 and 4. The 50 % curves (median) are storms in which the rainfall pattern may occur in 50 % or less of the storms as shown in Table 2. It

Fig. 5 Pointwise dimensionless cumulative mass curves of storms in station R004 at Riyadh region

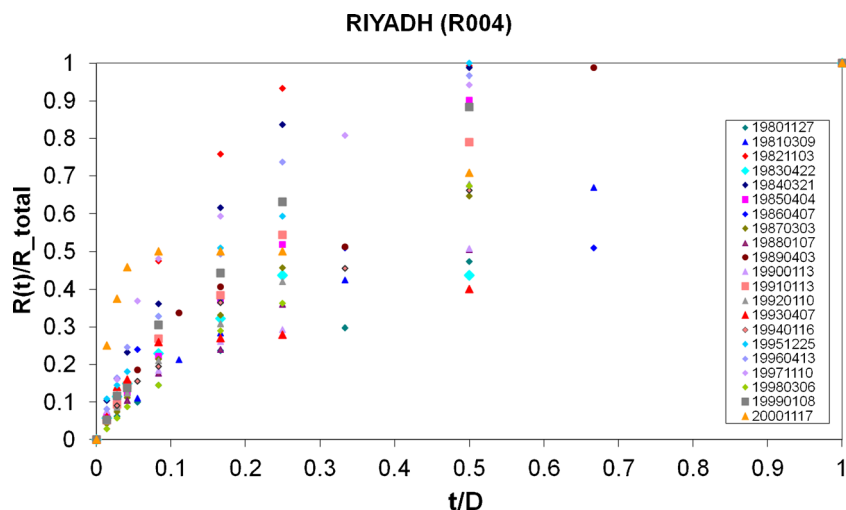
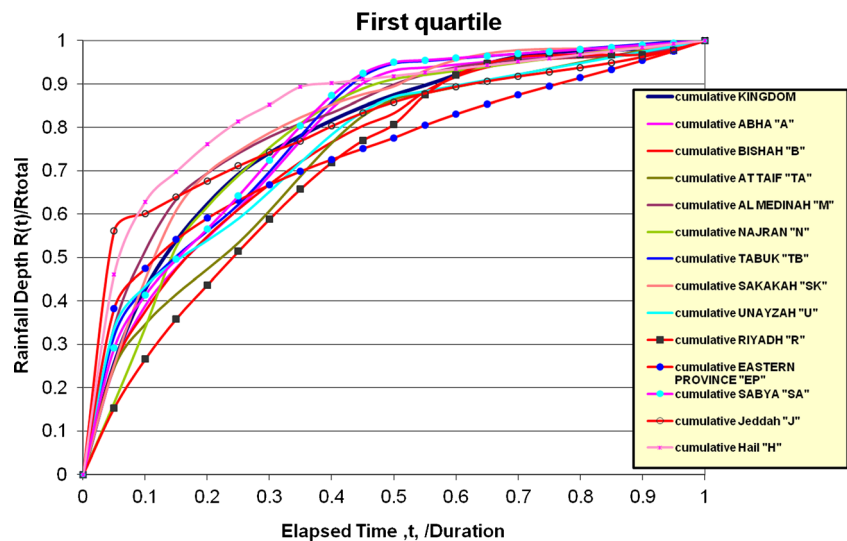


Fig. 6 Dimensionless of the median of the first quartile (durations less or equal 6 h) cumulative mass curves for the 13 regions in Kingdom of Saudi Arabia and the Kingdom curve



indicates that, on average, five first-quartile storms out of every ten will have at least 69 % of its rainfall in the first quarter of the storm period. More than 67 %, 50 % and 56 % of rainfall occur in the first quarter of the duration of such storms in the second, third and fourth quartiles, respectively. In the first half duration of such storm, more than 88 % of rainfall occurs in the first quartile, while 86 %, 74 % and 74 % of rainfall occur in the second, third and fourth quartiles, respectively.

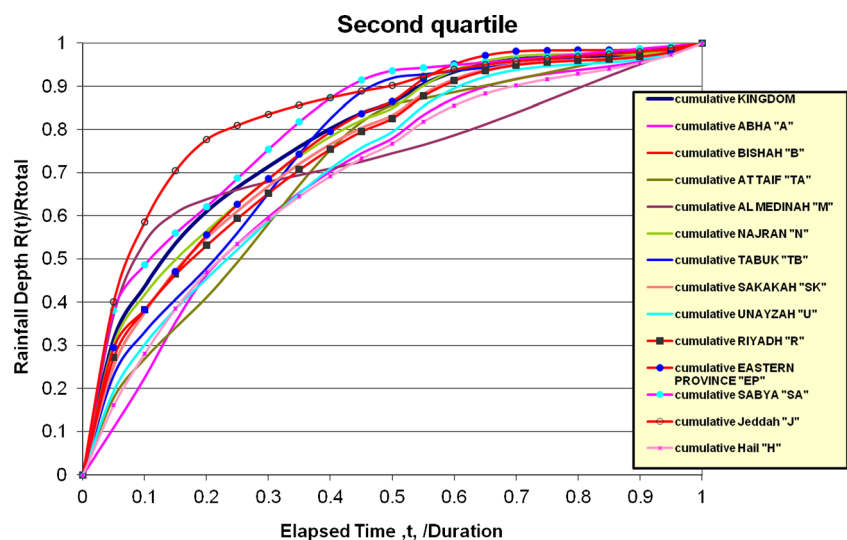
The 10 % probability level storms are the rainfall storm pattern that may occur in 90 % or less of the storms as shown in Table 3. The first quartile storms are typical of prevailing thunder storms in which the rainfall is concentrated in an unusually short portion of a storm. It indicates that, on the average, one first-quartile storm out of every ten will have at least 43 % of its rainfall in the first quarter of the storm period. More than 46 %, 34 % and 27 % of rainfall occur in the first

quarter of such storms in the second, third and fourth quartiles, respectively. More than 63 % of rainfall will occur in the first half of such storm. The 63 %, 53 % and 43 % of rainfall occur in the first half of such storms in the second, third and fourth quartiles, respectively.

The 90 % curves shown in Fig. 3 represent storms that occur in 10 % or less of the storms. These curves show that, in 25 % of the storm durations, 91 % of the rain occurs in the first, second and third quartiles of the storm while more than 84 % occurs the fourth quartile of the storm. To further illustrate the difference between the median curve and the 10 % and 90 % curves for every percentile of storm duration, a reference is made to Tables 2, 3 and 4.

It should be remembered that a particular storm may fall into any of the four quartile types. For most purposes, the median curves are probably most applicable to design. The extreme curves (10 % or 90 %) can be useful when runoff

Fig. 7 Dimensionless of the median of the second quartile (storm durations between 6 to 12 h) cumulative mass curves for the 13 regions in Kingdom of Saudi Arabia and the Kingdom curve



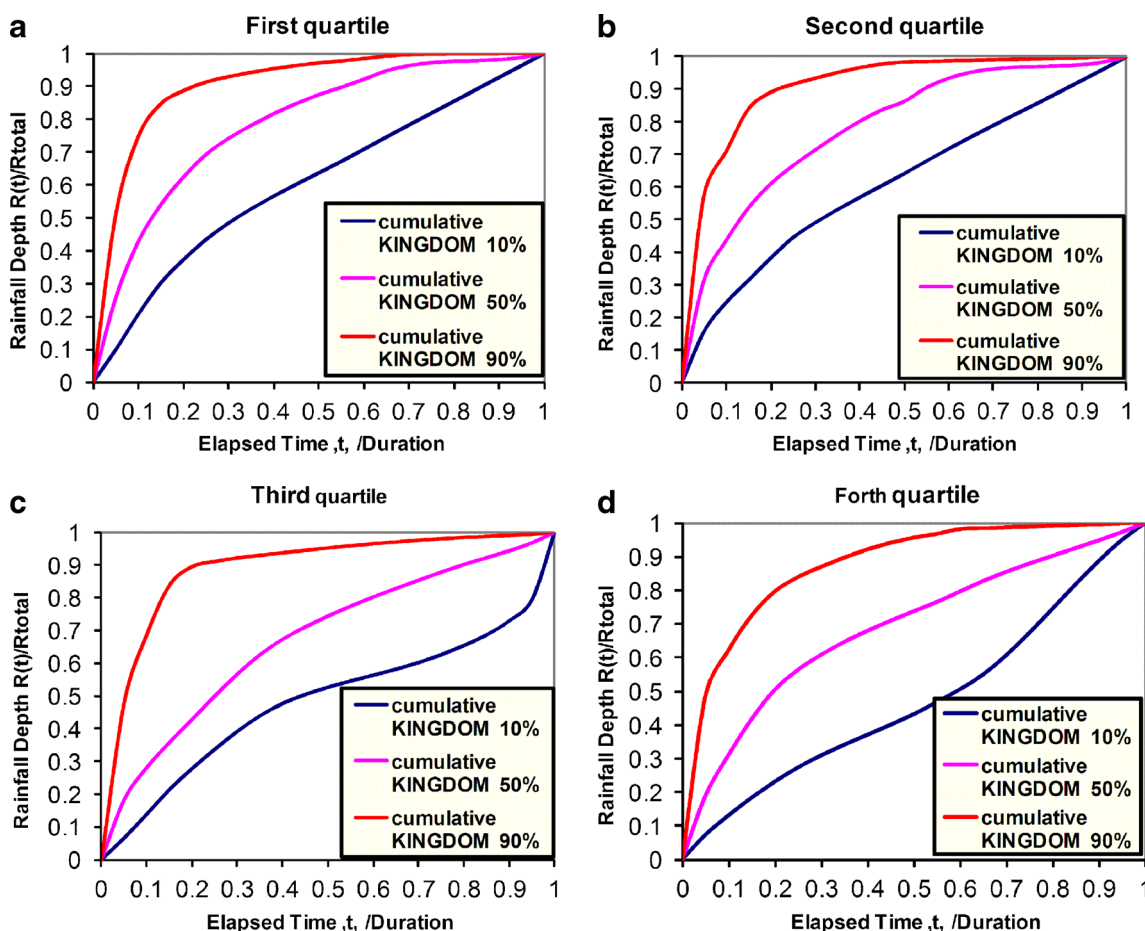


Fig. 8 Time distribution of the 10 %, 50 % and 90 % storms for the four quartiles derived from 269 storms of 28 stations in KSA: **a** first quartile, **b** second quartile, **c** third quartile and **d** fourth quartile

estimates are needed for the occurrence of unusual storm conditions.

1. Comparison of design storms in the four quartiles

Design storms quantify the location of a major burst of rainfall. Comparing the location of the major bursts of rainfall from the four quartiles shown in Fig. 9 revealed that the entire major bursts are located in the first 10 % of the storm time. Such shape of storm indicates a convective storm pattern. This means that most storms are thunder storms usually resulted in flash flood.

In Fig. 10, the second quartile tends to first quartile and the third quartile converges to the fourth quartile. This is may be due to the fact that most duration of the storms of the second quartiles are not far from 6 h while the duration of the fourth quartile storms are close to 18 h.

2. Comparison with other distributions in the literature

SCS (Types I, II and IA) and Huff (1967) dimensionless mass curves are superimposed on the KSA four quartile hyetographs in Fig. 10. It is obvious that the SCS Type hyetographs are not similar in shape to any of the fourth quartile storms of KSA. To quantify the

location of the major burst of rainfall design storm, hyetographs are deduced from the mass curves of the KSA four quartiles Huff (1967), and SCS type II as shown in Fig. 11. It is apparent that the major burst of rainfall is located in the beginning of the storm in the first quartile, while the major burst is in the middle for SCS type II curve. Such locations of major bursts are typical shapes of convective and cyclonic storms, respectively. The location of the major burst of rainfall deduced from Huff distribution, shown in Fig. 11, moves from the beginning in the first quartile to the end at the fourth quartile. Thus, the developed KSA curves do not correspond to the most commonly used type II curve in the hydrologic design in arid zone.

Conclusion

Analysis of the characteristics of storm patterns in the Kingdom of Saudi Arabia has been performed. Percentiles of the design storm hyetograph in dimensionless form for

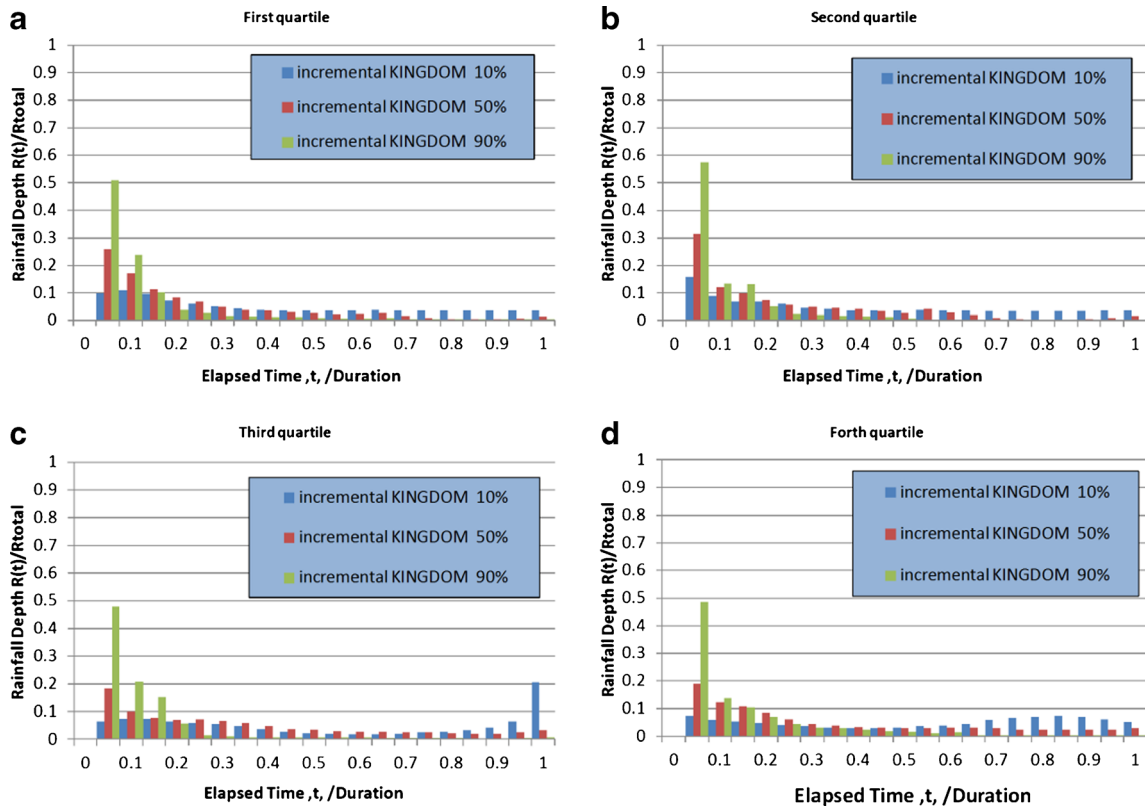
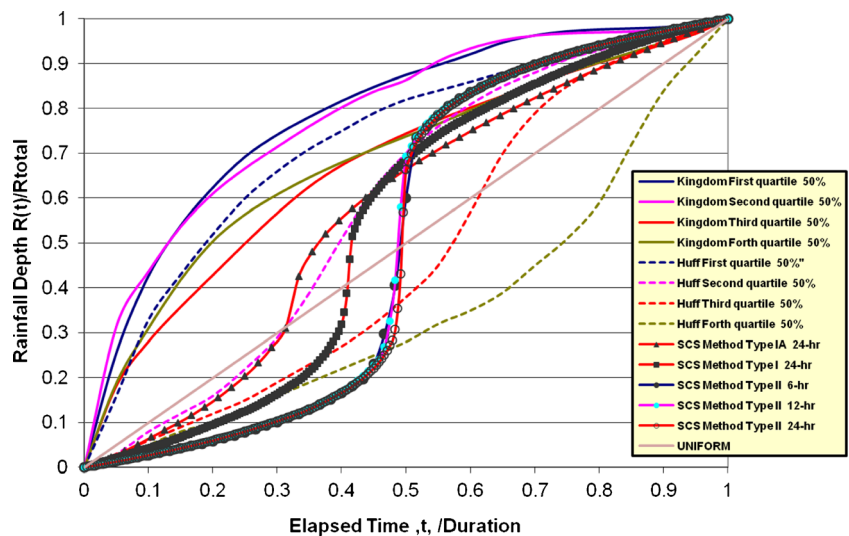


Fig. 9 Design storms hyetographs for 10 %, 50 % and 90 % storm patterns for the Kingdom of Saudi Arabia

storm durations of 0 to 6 h, 6 to 12 h, 12 to 18 h and 18 to 24 h for KSA are developed. Tables for mass curves and incremental temporal distributions for the first and second quartiles for 13 regions of KSA are presented in Appendix “A”. Comparisons of design hyetographs from different methods

(such as Huff (1967) and SCS types) are carried out. Results indicate that major bursts of rainfall are located in the first time of the storm period in all quartiles typically for connective thunder storms. The dimensionless cumulative hyetographs for KSA are now readily available for hydrologic design

Fig. 10 Dimensionless cumulative hyetographs for KSA compared with Huff (1967) and SCS Types I, II and IA



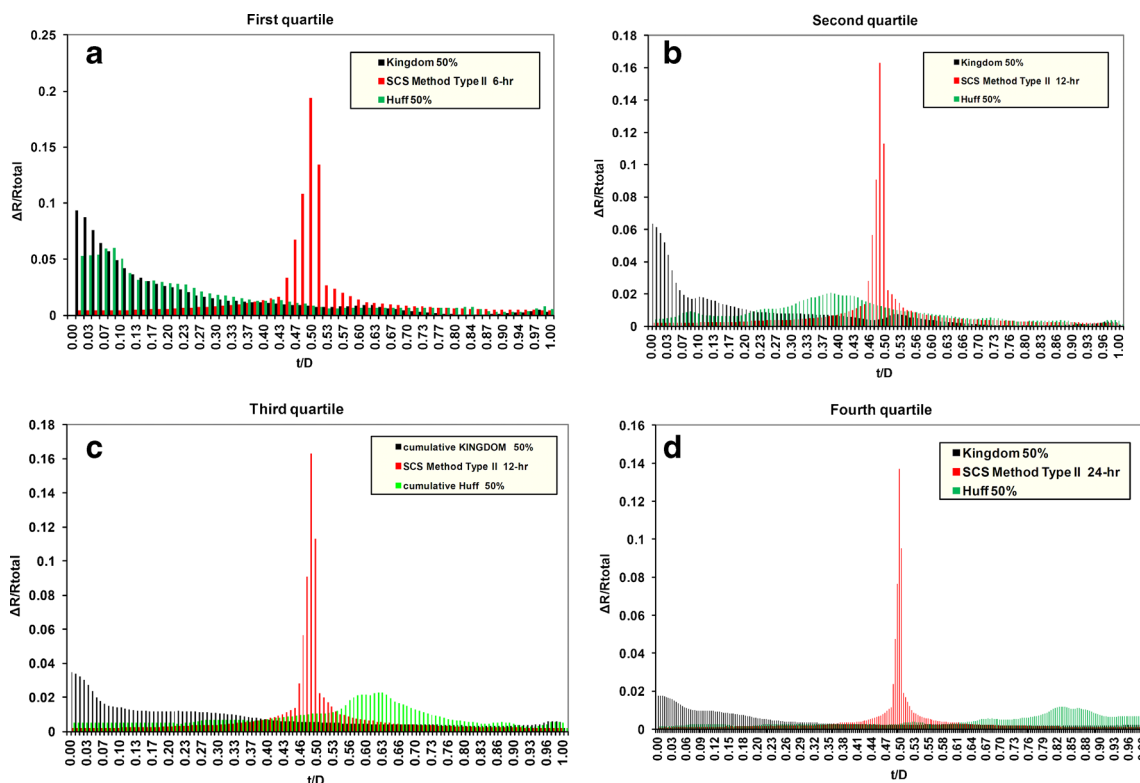


Fig. 11 Comparison of design storm hyetographs of KSA, Huff and SCS Type II

applications in the Kingdom of Saudi Arabia. The hyetographs and tables presented are intended to enhance watershed design practice applicable in Kingdom of Saudi Arabia.

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Appendix

Table 2 The 50 % probability level (median) time distributions of rainfall storm in Saudi Arabia

t/D	Cumulative Kingdom 50 % (R(t)/Rtotal)			
	First quartile	Second quartile	Third quartile	Forth quartile
0	0	0	0	0
0.05	0.2567	0.3155	0.1828	0.1892

Table 2 (continued)

t/D	Cumulative Kingdom 50 % (R(t)/Rtotal)			
	First quartile	Second quartile	Third quartile	Forth quartile
0.10	0.4274	0.4371	0.2813	0.3112
0.15	0.5396	0.5369	0.3585	0.4183
0.20	0.624	0.6107	0.4288	0.5044
0.25	0.6927	0.6667	0.4995	0.5639
0.30	0.7419	0.7147	0.5667	0.6084
0.35	0.7815	0.7609	0.6262	0.6465
0.40	0.8171	0.8028	0.6734	0.6798
0.45	0.8484	0.8379	0.7108	0.7097
0.50	0.8751	0.8636	0.7443	0.7379
0.55	0.8969	0.9053	0.7747	0.7657
0.60	0.9213	0.934	0.8026	0.7968
0.65	0.9472	0.9523	0.8287	0.8282
0.70	0.9632	0.9627	0.8539	0.8556
0.75	0.9721	0.9677	0.8787	0.8801
0.80	0.9763	0.9698	0.9021	0.9029
0.85	0.9785	0.9716	0.9226	0.9252
0.90	0.9815	0.9756	0.9433	0.948
0.95	0.9878	0.9842	0.9671	0.9726
1.00	1	1	1	1

Table 3 The 10 % probability level time distributions of rainfall storm in Saudi Arabia

t/D	Cumulative Kingdom 10 % (R(t)/Rtotal)			
	First quartile	Second quartile	Third quartik	Forth quartile
0	0	0	0	0
0.05	0.0986	0.1584	0.0655	0.0735
0.10	0.2064	0.2478	0.1389	0.1313
0.15	0.3023	0.3157	0.2139	0.1843
0.20	0.3731	0.384	0.2785	0.232
0.25	0.4334	0.4459	0.3371	0.274
0.30	0.4836	0.4916	0.3923	0.31
0.35	0.5268	0.5322	0.4401	0.3417
0.40	0.5657	0.5694	0.477	0.3713
0.45	0.6018	0.6054	0.504	0.4008
0.50	0.6366	0.6419	0.5262	0.4324
0.55	0.6717	0.681	0.5453	0.4683
0.60	0.7087	0.7185	0.563	0.5057
0.65	0.7461	0.7546	0.5812	0.5497
0.70	0.7828	0.7897	0.6016	0.6072
0.75	0.819	0.8243	0.6259	0.674
0.80	0.855	0.8585	0.654	0.7458
0.85	0.8909	0.8929	0.6866	0.8185
0.90	0.9269	0.9277	0.7298	0.8879
0.95	0.9632	0.9633	0.7948	0.9498
1.00	1	1	1	1

Table 4 The 90 % probability level time distributions of rainfall storm in Saudi Arabia

t/D	Cumulative Kingdom 90 % (R(t)/Rtotal)			
	First quartile	Second quartile	Third quartile	Forth quartile
0	0	0	0	0
0.05	0.5092	0.5748	0.4789	0.4854
0.10	0.7473	0.7095	0.6877	0.622
0.15	0.8476	0.8405	0.8383	0.7253
0.20	0.8866	0.8913	0.8955	0.797
0.25	0.9128	0.9155	0.9111	0.8395
0.30	0.9294	0.9341	0.9218	0.8704
0.35	0.9424	0.9516	0.9298	0.8978
0.40	0.9538	0.9666	0.9372	0.9214
0.45	0.9635	0.9777	0.9447	0.9409
0.50	0.9714	0.9836	0.9517	0.9563
0.55	0.9774	0.9853	0.9583	0.9672
0.60	0.9844	0.987	0.9644	0.9816
0.65	0.9923	0.9887	0.97	0.984
0.70	0.9967	0.9904	0.9751	0.9864
0.75	0.9984	0.9921	0.9798	0.9888
0.8	0.9984	0.9938	0.9837	0.9912
0.85	0.9992	0.9955	0.9867	0.9936
0.90	0.9996	0.9972	0.9898	0.996
0.95	0.9998	0.9989	0.9936	0.9984
1.00	1	1	1	1

Table 5 The median of the first and second quartiles of the incremental distribution curves for 13 regions of KSA

t/D	Abha “A”		Bishah “B”		Attaif “TA”		Al Medinah “M”		Naj Ran “N”		Tabuk “TB”		Sakakah “SK”	
	First quartile	Second quartile	First quartile	Second quartile	First quartile	Second quartile	First quartile	Second quartile	First quartile	Second quartile	First quartile	Second quartile	First quartile	Second quartile
0.00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.05	0.2471	0.11	0.2456	0.3514	0.2464	0.1791	0.3405	0.3724	0.1655	0.3032	0.32	0.2315	0.2523	0.2526
0.10	0.1423	0.1154	0.1407	0.1408	0.1004	0.0903	0.1754	0.1664	0.1739	0.1151	0.1106	0.1	0.1982	0.1243
0.15	0.0874	0.1297	0.1034	0.104	0.0692	0.0724	0.1185	0.0682	0.1859	0.0808	0.0725	0.0761	0.1589	0.0969
0.20	0.0698	0.1092	0.0896	0.0732	0.0576	0.0702	0.0604	0.0316	0.0925	0.0663	0.0586	0.0713	0.0859	0.0754
0.25	0.0669	0.0709	0.0859	0.0537	0.0608	0.0813	0.046	0.0224	0.0721	0.0625	0.0611	0.0827	0.0503	0.0625
0.30	0.076	0.063	0.0676	0.0473	0.0739	0.0896	0.0379	0.0182	0.0644	0.0582	0.0757	0.0918	0.0426	0.0576
0.35	0.0805	0.0561	0.0606	0.0411	0.0801	0.0895	0.0307	0.0156	0.0556	0.0525	0.0828	0.0912	0.0355	0.0519
0.40	0.0742	0.0491	0.0736	0.0344	0.0763	0.0811	0.0246	0.0151	0.0456	0.0456	0.0175	0.0811	0.0292	0.0453
0.45	0.0574	0.042	0.0533	0.0275	0.0622	0.0644	0.0326	0.0162	0.0343	0.0375	0.0595	0.0615	0.0235	0.0311
0.50	0.0297	0.0346	0.036	0.0203	0.0379	0.0392	0.0324	0.0194	0.0217	0.0281	0.0291	0.0323	0.0183	0.0291
0.55	0.0067	0.0537	0.0215	0.0393	0.0142	0.0149	0.0234	0.0192	0.0095	0.0523	0.0056	0.0081	0.0363	0.0493
0.60	0.0067	0.0389	0.0099	0.0263	0.0142	0.0149	0.0161	0.0225	0.0095	0.0353	0.0056	0.0081	0.0245	0.0342
0.65	0.0067	0.0268	0.0013	0.0157	0.0142	0.0149	0.0105	0.0251	0.0095	0.0215	0.0056	0.0081	0.0149	0.0221
0.70	0.0067	0.0179	0.0005	0.0076	0.0142	0.0149	0.0064	0.0269	0.0095	0.011	0.0056	0.0081	0.0077	0.0128
0.75	0.0067	0.0118	0.0005	0.0021	0.0142	0.0149	0.0039	0.0282	0.0095	0.0038	0.0056	0.0081	0.0028	0.0065
0.80	0.0067	0.0087	0.002	0.001	0.0142	0.0149	0.0032	0.0286	0.0095	0.0003	0.0056	0.0081	0.0006	0.0033
0.85	0.0067	0.0085	0.002	0.0006	0.0142	0.0149	0.0041	0.0282	0.0095	0.0004	0.0056	0.0081	0.0005	0.0028
0.90	0.0067	0.0112	0.002	0.0007	0.0142	0.0149	0.0065	0.0273	0.0095	0.0004	0.0056	0.0081	0.0002	0.0054
0.95	0.0067	0.0169	0.002	0.0009	0.0142	0.0149	0.0106	0.0255	0.0095	0.0079	0.0056	0.0081	0.0057	0.0109
1.00	0.0084	0.0256	0.002	0.0121	0.0074	0.0088	0.0163	0.023	0.003	0.0173	0.0022	0.0076	0.0121	0.0194

t/D	Unayza “U”		Riyadh “R”		Eastern province “EP”		Sabya “SA”		Jeddah “J”		Hail “H”	
	First quartile	Second quartile	First quartile	Second quartile	First quartile	Second quartile	First quartile	Second quartile	First quartile	Second quartile	First quartile	Second quartile
0.00	0	0	0	0	0	0	0	0	0	0	0	0
0.05	0.3374	0.1944	0.1529	0.2726	0.3827	0.2948	0.2913	0.3818	0.5613	0.4017	0.4608	0.1611
0.10	0.0965	0.1082	0.1128	0.1097	0.0918	0.0885	0.1221	0.1041	0.0396	0.1841	0.1678	0.1198
0.15	0.0591	0.0826	0.0932	0.0821	0.0666	0.0868	0.0828	0.0735	0.0389	0.1192	0.0697	0.1044
0.20	0.0468	0.0701	0.0782	0.0669	0.0497	0.0852	0.0701	0.062	0.0371	0.0722	0.0635	0.0838
0.25	0.0503	0.0673	0.017	0.0625	0.0411	0.071	0.076	0.0658	0.0345	0.0329	0.0529	0.065
0.30	0.0625	0.0667	0.0745	0.0591	0.0362	0.0598	0.0819	0.0673	0.0311	0.0258	0.0381	0.0587
0.35	0.0613	0.0634	0.0695	0.0543	0.031	0.0575	0.0797	0.0637	0.0268	0.0209	0.041	0.0528
0.40	0.0642	0.0573	0.0614	0.048	0.0272	0.0515	0.0696	0.0549	0.0342	0.0173	0.0082	0.0467
0.45	0.0528	0.0484	0.0508	0.0401	0.0252	0.0418	0.0513	0.0412	0.0305	0.0148	0.0082	0.0408
0.50	0.0335	0.0368	0.0372	0.0308	0.0249	0.0288	0.0252	0.0224	0.0246	0.0134	0.0082	0.0346
0.55	0.013	0.0592	0.0674	0.0513	0.0289	0.0515	0.005	0.0063	0.0197	0.0208	0.0082	0.0505
0.60	0.013	0.0413	0.0454	0.0356	0.0256	0.0342	0.005	0.0063	0.0157	0.0156	0.0082	0.0376
0.65	0.013	0.0268	0.0216	0.0229	0.0231	0.0202	0.005	0.0063	0.0127	0.0113	0.0082	0.0273
0.70	0.013	0.0159	0.0141	0.0134	0.0212	0.0095	0.005	0.0063	0.0109	0.0083	0.0082	0.0194
0.75	0.013	0.0084	0.0047	0.0069	0.0199	0.0022	0.005	0.0063	0.01	0.0061	0.0082	0.0143
0.80	0.013	0.0045	0.0003	0.0034	0.0194	0.0005	0.005	0.0063	0.0101	0.005	0.0082	0.0116
0.85	0.013	0.004	0.0003	0.0031	0.0195	0.0002	0.005	0.0063	0.0113	0.0051	0.0082	0.0115
0.90	0.013	0.0072	0.0005	0.0057	0.0203	0.0003	0.005	0.0063	0.0135	0.0061	0.0082	0.0141
0.95	0.013	0.0137	0.0101	0.0114	0.0218	0.0005	0.005	0.0063	0.0166	0.0081	0.0082	0.0192
1.00	0.0126	0.0238	0.0221	0.0202	0.0239	0.0152	0.005	0.0066	0.0209	0.0113	0.0078	0.0268

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