Assessment of the Frequency and Return Period for Extreme rainfall Causing Floods Inmecca, Saudi Arabia

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Abstract: *Different types of geological hazards such as earthquake, volcanic eruption, flooding, rock falls, sand problems, and subsidence will endanger people and their properties in Saudi Arabia. Identification, evaluation and mitigation of geo-hazards are a vital task that should be considered in the city planning, so, estimating the frequency, magnitude and recurrence are considered the ways that help to mitigate the effects of the natural hazard to people and assets.*

In arid regions, flash floods often occur. Rainfalls which cause flash floods are a deadly and costly event that can be exacerbated in arid environments.Consequence of excessive rainfall occasionally causing major loss of property and life, floods are large events of relatively short duration.

In this study,the history of rainfall data are collected and analyzed to get an idea about the floodbehavior in Makkahduring the previous years, the Weibull distribution is used for this purpose.The collected data for flooding in Saudi Arabia for period from 19664G to 2004 G are used to analyze and get prepared for the flooding hazard in the future.

I. Rainfall in Makkah Region

Makkahregion is the most populous region in Saudi Arabia. It is located in the Western region of Saudi Arabia and has an extended coastline. It has an area of 153,128 km² and a population of 6,915,006 (2010 census). Its capital is Mecca (also transliterated as Makkah), the holiest city in Islam, Figure 1 shows the location of Makkah area.

Makkah features a hot desert climate. Mecca retains its hot temperature in winter, which can range from 18 °C (64 °F) at night to 30 °C (86 °F) in the day. Summer temperatures are extremely hot, often being over 40 °C (104 °F) during the day, dropping to 30 °C (86 °F) at night. Makkah is at an elevation of 277 m above sea level, and approximately 80 km inland from the Red Sea. Flash floods are common during winter season even though the amount of precipitation is low. Since Mecca is located in a desert, dust storms are common in the city. (Mecca weather and temperature, 2016). Rain usually falls in Makkah in small amounts between November and January. The rainfall, as scant as it is, also presents the threat of flooding and has been a danger since the earliest times. According to Al-Kurdī, there had been 89 historic floods by 1965, including several in the period. In the last century the most severe one occurred in 1942. Since then, dams have been constructed to ameliorate the problem.

Taking place immediately after a heavy short rainstorm,flash floods are one of the most catastrophic phenomena.They are fairly common in arid regions and present apotential hazard to life, personal properties, and structures such as small dams, bridges, culverts, wells, and dykes along the valley“Wadi” courses. Flash floods form rapidly andflow down over watercourses that are nearly or alreadyextremely dry.

A flash flood is a rapid flooding of geomorphic low-lying areas: washes, rivers, dry lakes and basins. It may be caused by heavy rain associated with a severe thunderstorm, hurricane, tropical storm, or melt water from ice or snow flowing over ice sheets or snowfields.

Figure1.The location of Makkah

Flash floods are distinguished from a regular flood by a timescale of less than six hours. The temporary availability of water is often utilized by foliage with rapid germination and short growth cycle, and by specially adapted animal life.
Floods are the most frequently encountered natural disaster in Saudi Arabia. They have been the cause of 7 of the 10 most damaging natural disasters in the history of the country between 1900 and 2004.

This problem is originated due to the geography of some of the most populated cities in Saudi Arabia. Cities, such as Makkah, are on low ground and are surrounded by mountains. When rains fall on these mountains, water runs in valleys towards these cities. With poor drainage systems, this continuous flow of water could easily lead to a flash flood.

Although the average rainfall in the coastal areas of the Kingdom is very small, rainstorms on the nearby mountains can generate flash floods that damage properties and result in loss of lives.

Figure 2 (Subyani, 2011)indicatesthe probable maximum rainfall of 24 h for 100-year return period.

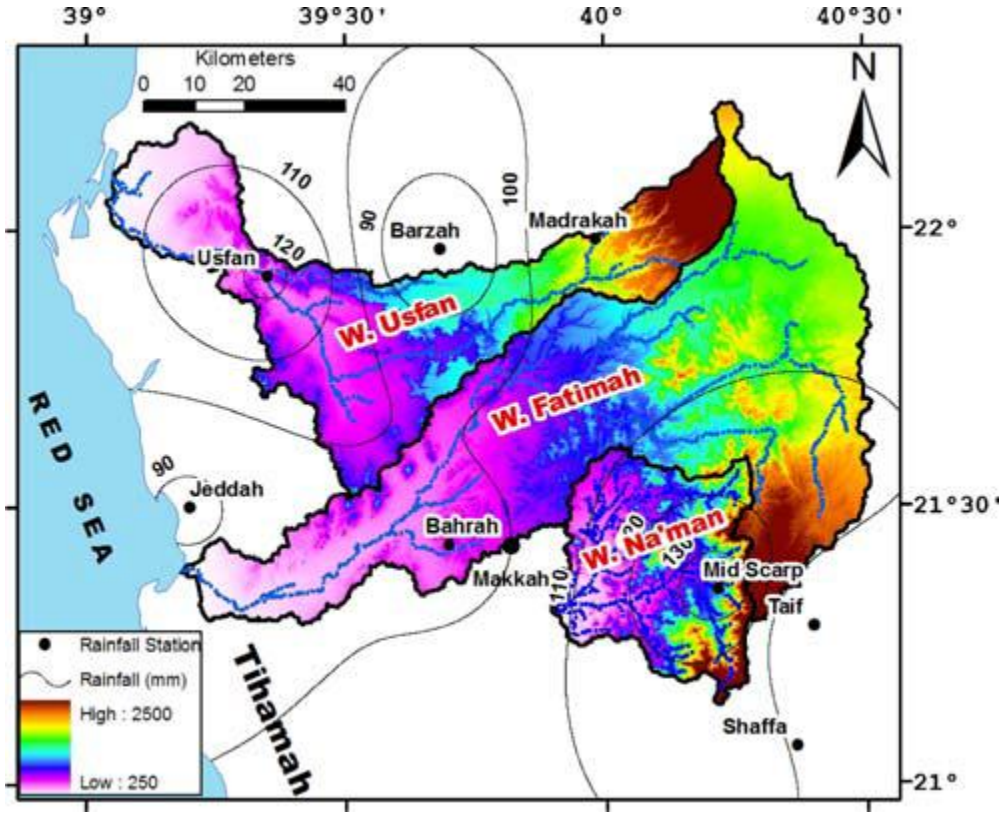

Figure 2.Probable maximum rainfall of 24 h for 100-year return period.

Since Makkah is located in a low-lying region, it is threatened by seasonal flash floods despite the low amount of annual precipitation. There are less than 110 millimeters of rainfall during the year, mainly falling in the winter months. Temperatures are high throughout the year and in summer it may reach 45 °C(Mecca Climate - Britannica Online Encyclopedia, 2016). Figure 3 shows the climatic graph of Makkah, the average temperature and the average precipitation (Climate Data.Org, 2016). The following are extreme weather events in Mecca and the surrounding area:

- In November 2009, Makkah Province was badly affected when record-breaking rainfall of 90 millimetres (3.5 in) hit the province causing flash floods all over the province. It was the worst flood in 27 years.
- In November 2010, a thunderstorm killed 3 people in Makkah city following heavy rainfall. Most of the city remained under flood warning the entire night (New Straits Times on Line (2016).
- In December 2010, once again the city was flooded when light to moderate intensity rainfall battered the holy city, claiming the lives of 4 people. While condition in Makkah Province was also comparable to the provincial capital
- In January 2011, heavy rainfall created flood like situation in the provinces especially Jeddah where 111 millimeters occurred in just 3 hours killing four people.
- On May 8,2014 rainfall of more than 50mm created flood like situation with extreme lightning (Arab News, 2016).

Figure 4 and 5 show some pictures of extreme lightening and rainfall in Makkah.

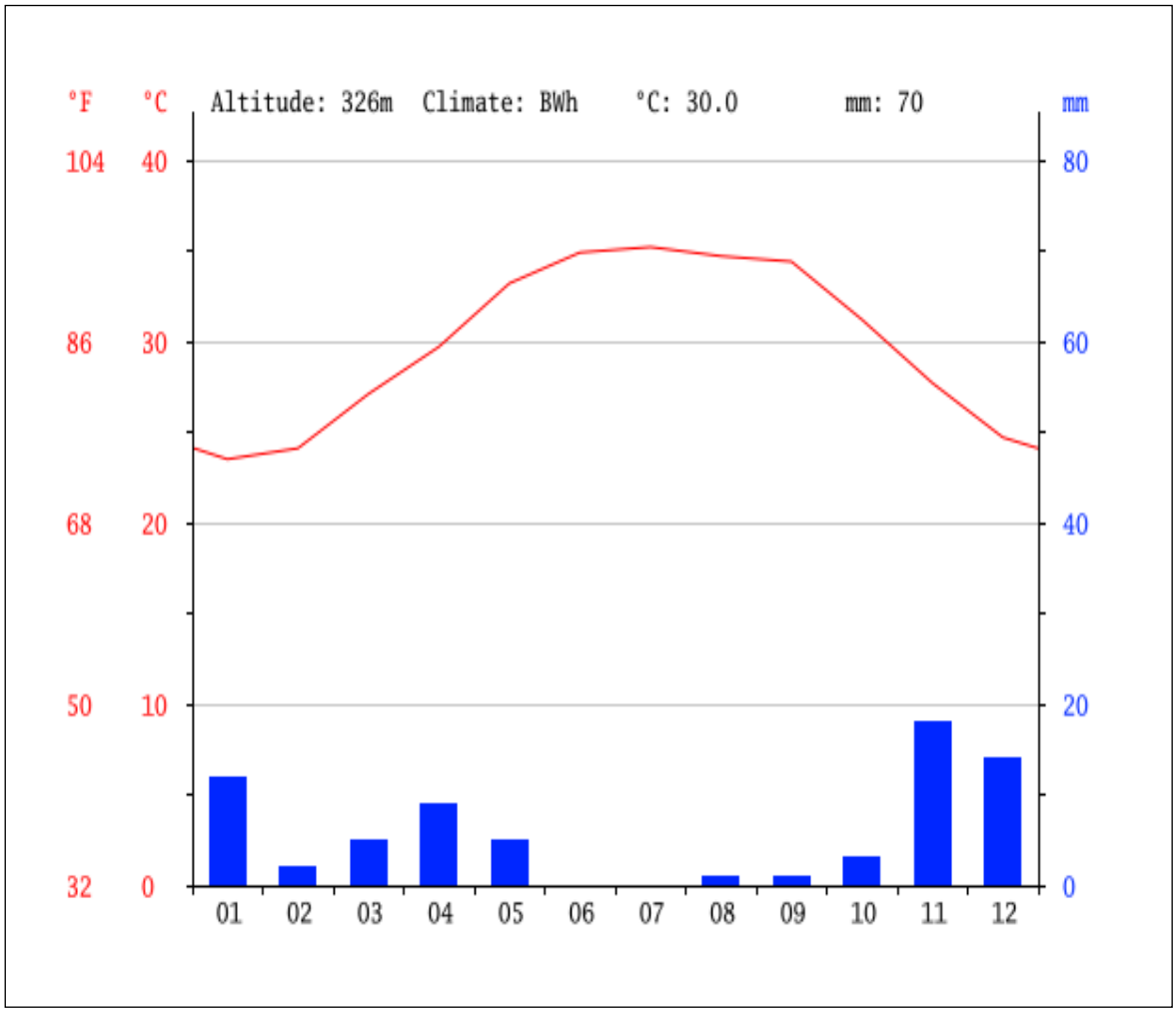

Figure 3.Climatic graph of Makkah.

II. Leteruture Review

Flood occurrences are complex since they depend on interactions between many geological and morphological characteristics of the basins, including rock types, elevation, slope, sediments transport, and flood plain area. Moreover, hydrological phenomena, such as rainfall,runoff, evaporation, and surface and groundwater storage can affect floods(Farquharson et al., 1992; Flerchinger and Cooly, 2000; Şen 2004; Nouh, 2006). The "Wadis" course has been negatively affected by man-made objects, such as extending barriers, levees, and farms, that increase the risk of flood behavior.

Statistics of extremes have played an important role in engineering the water resource design and management (Katz et al., 2002; Tingsanchali and Karim, 2005). In western Saudi Arabia, flood discharge from the Wadi basins that drain toward the Red Sea can become dangerous and threaten coastal cities, towns, villages, and engineering structures.

Figure 5. Extreme rainfall in Makkah.

A previous report (ACSAD/AFESD/KFAED, 1986) documented that the average surface water flow into the Red Sea zone can be estimated to be about 39.8m^3/s, of which 27 m^3/s (70%)occurs south of Jeddah, 8.2 m^3/s (21%) north of Jeddah, and the remaining 4.6 m^3/s (9%) aroundJeddah city.
Alyamani and Subyani (2001) studied and collected runoff hydrographs and sediments load transport from some major Wadis in western Saudi Arabia.

Nouh (1988) obtained data from 32 arid catchments from different parts of the Kingdom to derive regional equations for flood estimation. Results from this study indicated that theweighted estimate is more accurate than the estimate offlood through the calibrated regional method. Nouh (2006) used real data on Wadi flood flows from theArabian Gulf States and Yemen to develop methodologies for predicting annual maximum flow.Three methods were investigated. In the first method, regional curves weredeveloped and used along with the mean annual flood flow, which was estimated from characteristics of the drainage basin, to estimate the flood flows at a particular locationwithin the basin. The second method involved fitting data using different probability distribution functions; the best fit was used for the flood estimate. In the final method, onlyfloods over a certain threshold were considered and modeled.

III. Rain Fall Analysis

The Weibull distribution which is a continuous probability distribution will be used for the analysis. It is named after Swedish mathematician WaloddiWeibull, who described it in details in 1951, although it was first identified by Fréchet (1927) and first applied by Rosin &Rammler (1933) to describe a particle size distribution.

The magnitude of the extreme rain fall at Makkah area are shown in columns 1 and 2 in table 1,Presidency of Meteorology and Environment "PME" (2016). Most extreme event analysis is concerned with the distribution of annual maximum or minimum values at a given site. These events are given a rank, *m*, starting with $m = 1$ for the highest value, $m = 2$ for the next highest and so on in descending order. Each Rainfall magnitude is associated with a rank, *m*, with $m = 1$ given to the maximum magnitude over the years of record, $m = 2$ given to the second highest magnitude, $m = 3$ given to the third highest one as shown in table 1.

T (years) = $(n+1)/m$ …….. (1)

Where: *m* = event ranking (in a descending order), and
n = number of events in the period of record.
The percentage probability (annual exceedence probability) for each magnitude in any year is calculated using the inverse of the Weibull equation as follows:

P (per cent) = 100.*m*/(*n*+1) …………………………………….. (2)

The collected data for rainfall magnitude in Makkahfor different years is the highest reading per year of the rainfall is shown in the third column of Table 1.

Table 1: Magnitude, probability and return period for the Rainfall at Makkah.

Rank (m)	Year	Magnitude (mm)	Probability (P%)	Return Period (T)	ProbabilityP_t In Ten Years
1	1969	318.5	2.5%	40	0.22
2	1992	252.9	5%	20	0.40
3	1996	240.4	7.5%	13.3	0.54
4	1968	202,0	10%	10	0.65
5	1989	180.2	12.5%	8	0.74
6	1975	147.8	15%	6.7	0.80
7	2004	136.0	17.5%	5.7	0.85
8	1997	134.9	20%	5	0.89
9	1978	128.3	22.5%	4.4	0.92
10	1998	127.8	25%	4	0.94
11	1985	123.5	27.5%	3.6	0.96
12	1979	122.5	30%	3.3	0.97
13	2002	122.0	32.5%	3	0.98
14	2001	118.0	35%	2.8	0.99
15	2000	112.0	37.5%	2.6	0.99
16	1982	111.0	40%	2.5	0.99
17	1977	109.8	42.5%	2.4	
18	1970	108.8	45%	2.2	
19	1999	97.5	47.5%	2.1	
20	1983	92.7	50%	2	
21	1966	86.4	52.5%	1.9	
22	1991	82.0	55 %	1.8	
23	1988	70.9	57.5%	1.7	
24	1967	69.9	60%	1.67	
25	1971	64.6	62.5%	1.6	
26	1972	62.4	65%	1.54	
27	1994	58.0	67.5%	1.48	
28	1981	57.9	70%	1.4	1.00
29	1973	57.0	72.5%	1.37	
30	1993	56.1	75%	1.33	
31	1995	43.3	77.5%	1.29	
32	1986	40.1	80%	1.25	
33	1984	38.3	82.5%	1.2	
34	1987	36.9	85%	1.17	
35	1990	35.2	87.5%	1.14	
36	1976	29.8	90%	1.1	
37	2003	28.0	92.5%	1.08	
38	1974	14.7	95%	1.05	
39	1980	3.8	97.5%	1.02	

IV. Probability and Return Period

4.1 Probability

Probability is the measure of the likelihood that an event will occur.Probability is quantified as a number between 0 and 1 (where 0 indicates impossibility and 1 indicates certainty), or as a percent.The higher the probability of an event, the more certain we are that the event will occur. The exeedence probability curve as a function of the magnitude is shown in Figure 3.

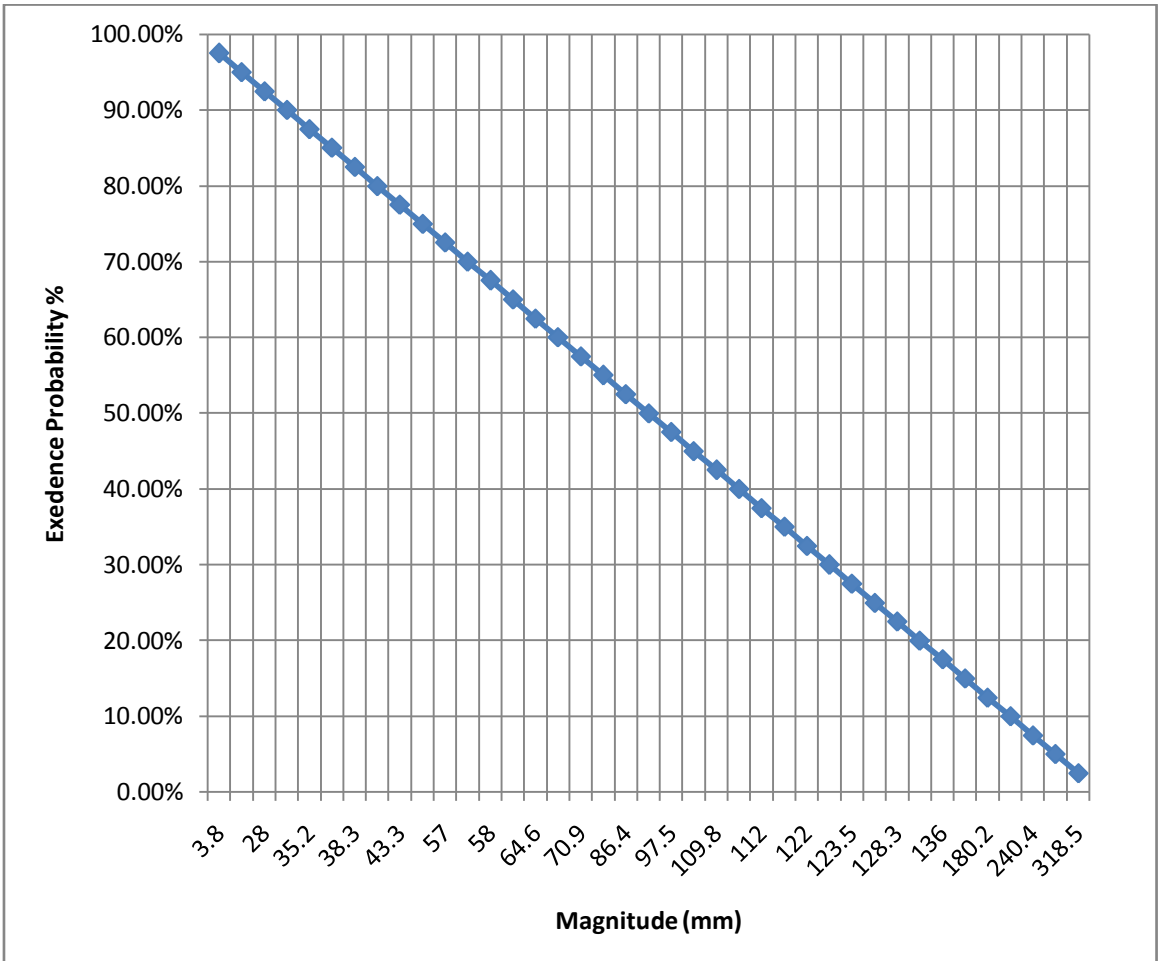

Figure 3.Probability of the Rainfall in Makkah.

4.2 Return Period

A return period, also known as a recurrence interval (sometimes repeat interval) is an estimate of the likelihood of an event, such as an earthquake, flood or a river discharge flow to occur. It is a statistical measurement typically based on historic data denoting the average recurrence interval over an extended period of time, and is usually used for risk analysis (e.g. to decide whether a project should be allowed to go forward in a zone of a certain risk, or to design structures to withstand an event with a certain return period), Figure 4.

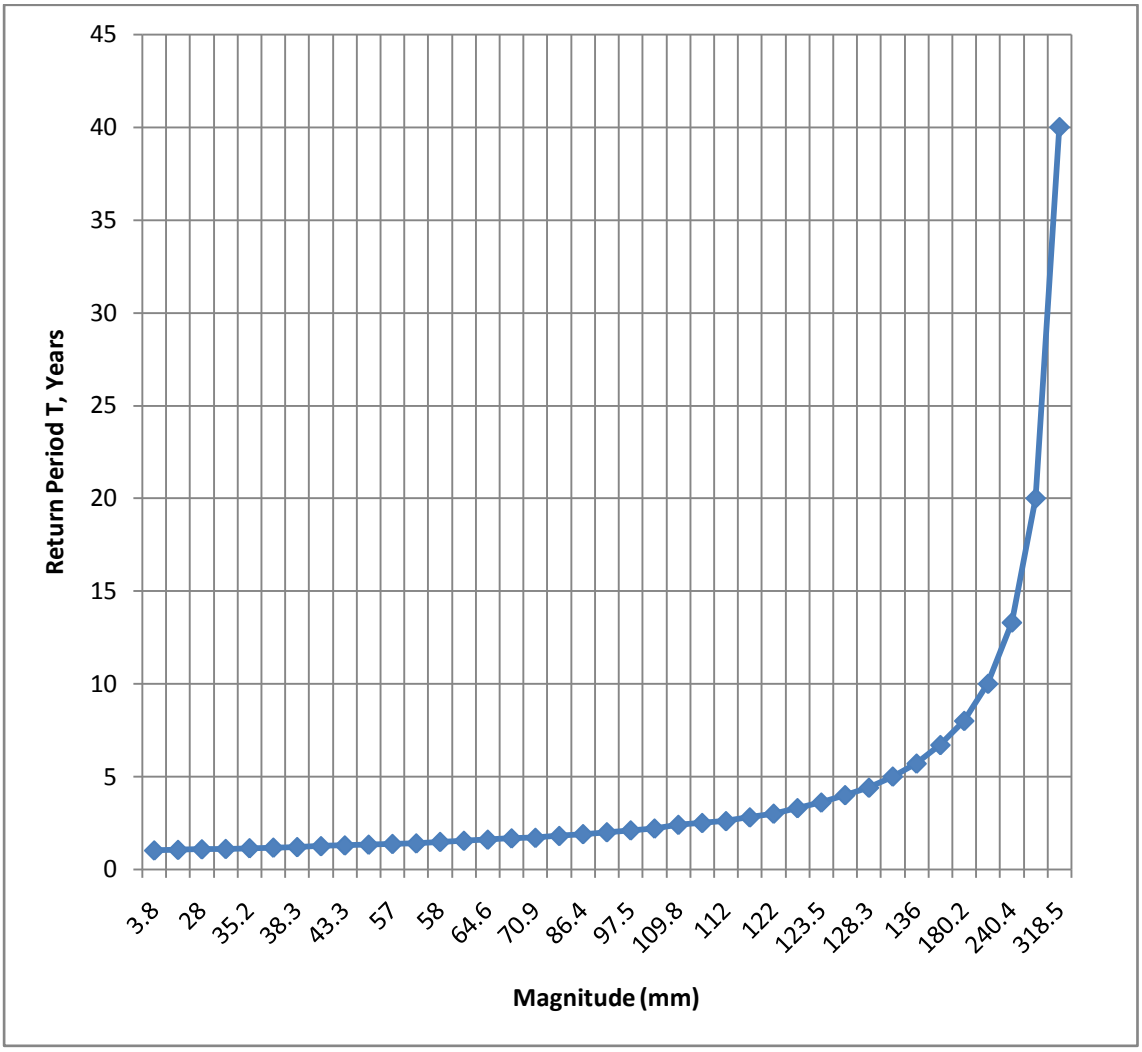

Figure 4.Return period of the Rainfall in Makkah.

4.3 The Probability During a Time Period

The probability of a certain-magnitude rainfall-flood occurring during any period ***t*** can be calculated using the following equation:

$P_t = 1-(1-P)^t$…….. (3)

Where P_t is the probability of occurrence over the entire time period, *t*, and *P* is the probability of occurrence in any year.

Anauthorized person considering the costs of reinforcing buildings and facilities against rainfall will want to know how the risk varies during an average mortgage span of 10 years**.** Last column in Table 1 andFigure 5 shows the earthquake probability and earthquake magnitudes in a time span of 10 years. A rainfall of magnitude 180 mm for example, has a 74 % probability of occurrence but, any rainfall of magnitude less than 11 is chosen, the probability reaches 100 %.

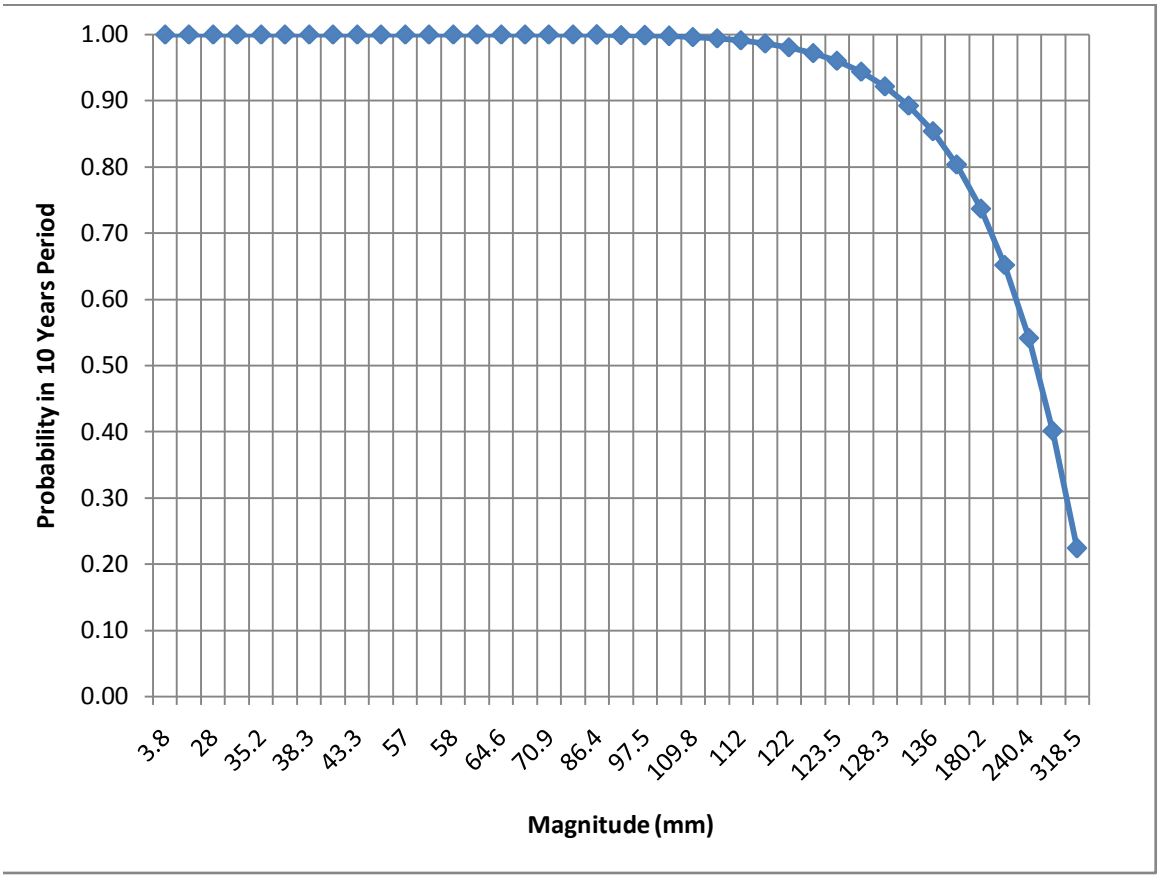

Figure .5Rainfall probability and magnitudes in a time span of 10 years.

V. Conclusions and Point of the Future Study

5.1 Conclusions

In Makkah area in western Saudi Arabia, flash floods often take place as a consequence of excessive highly intense rainfall. Urban areas and major Valleys (Wadis) are subject todestructive floods.

Makkahis considered as the most holy place in the Islamic world.The study of the rainfall risk main parameters like probability and recurrence will help to mitigate hazards and keep the townin safeconditions in case of natural hazard like heavy rain which will cause the floods in the area. The estimation of the probability and the return period will give us the time to prepare ourselves and take the correct actions before, during and after the hazard action.

5.2Points of Future Researches

To study the positive impacts of the natural hazard like floodsin Makkah city in order to get benefits of the rainfall.For example, it can be utilized in producing the clear energy that will feed the city with the necessary electrical power.

To study the negative impacts of the natural hazard like floodsin Makkah city. For example todesign of buildingsto help reduce losses during the floods and rain falls.

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