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RETURN PERIOD ANALYSIS AS A TOOL FOR URBAN FLOOD PREDICTION IN THE ACCRA PLAINS, SOUTHERN GHANA

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Return period analysis is a common statistical approach used for predicting flooding in urban centers. It is a very important tool for building and designing the safest possible flood control structures. The analysis provides information about when a flood of a given magnitude is expected to occur, be equaled, or exceeded. Flooding is common in urban cities as a result of unplanned development and poor drainage systems and recent flooding in the Accra, Ghana, metropolitan area has been attributed largely to these factors. In this study return period analysis of annual rainfall and maximum 1-month rainfall has been conducted for 30 years of data for the Accra plains. The analysis used the Weibull plotting position. The prediction equations were used to forecast flood magnitudes for return periods of 5, 10, 20, 25, 50 and 100 years. The highest rainfall occurred between May and June. Annual rainfall of 1223.5 mm and maximum 1-month rainfall of 420.6 mm are expected to occur every 31 years. Extrapolation of the return period based on a linear regression model suggests that a maximum 1-month rainfall and maximum annual rainfall of 550.5 mm and 1612.98 mm is expected to occur every 100 years, respectively. The study recommends that urban planners and structural engineers take into account all necessary statistically derived flood magnitudes as inputs during the design of drainage systems in the region.

INTRODUCTION

The city of Accra, the capital of Ghana, is situated on the Atlantic coast about 25 km west of the Greenwich Meridian. The city's settlements occupy an area of approximately 751 km^2 (Yankson et al., 2004 unpublished data) with a population of 1.7 million in 2002 projected to reach 4 million people by the year 2020 (Yankson et al., 2004).

Flooding refers to the inundation of an area by unexpected rise of water by both dam failure or extreme rainfall duration and intensity in which life and properties in the affected area are under risk (Nyarko, 2002). The city of Accra suffers from urban flooding principally as a result of poor drainage (uncoordinated and poorly maintained drainages) that has been aggravated by uncontrolled urban growth rather than heavy rains (Afrol News, 2007).

The development of urban infrastructure leads to the removal of forest cover that can result in the lowering of the infiltration capacity to a point where rainfall intensity significantly exceeds the water infiltration rate thereby causing floods (Dunne and Leopard, 1978). The replacement of pervious by impervious surfaces which is a natural consequence of urbanization, has been found to result in peak surface discharges on the order of 100 to 300 percent greater than those of undeveloped areas (Espey et al., 1969). Changes in the urban landscape not only lead to increased peak flows but to increases in sediment loads in basins, along streets and storm channels, resulting in changes in channel morphology (Gobo and Abam, 2006). Urbanization, especially in cities of third world countries, also results in the building of structures along waterways, inadequate storm drains, dumping of refuse in drains and drainage paths, uncoordinated physical development, and the absence of storm sewers.

The procedure for estimating the frequency of occurrence (return period) of a hydrological event such as flood is known as flood frequency analysis. Though the nature of most hydrological events (such as rainfall) is erratic and varies with time and space, it is commonly possible to predict return periods using various probability distributions (Upadhaya and Singh, 1998). Flood frequency analysis was therefore developed as a statistical tool to help engineers, hydrologists, and watershed managers deal with this uncertainty. Flood frequency is utilized to determine how often a storm of a given magnitude is expected to occur and hence is a very important tool for building and design of the safest possible flood control structures (e.g. dams, bridges, culverts, drainage systems etc.).

The purpose of this study is to use flood frequency analysis to predict flood magnitudes for different return periods within the Accra metropolitan area. It is expected that the flood magnitudes with their respective return periods developed in this study will be used by structural engineers and hydrologists in designing flood control structures in the region.

STUDY AREA

Accra is located within longitude 0.03º and 0.25º west and latitude 5.30º and 5.35º north (Twumasi and Asomani-Boateng, 2002). The topography of the area is generally gentle with occasional hills. The general elevation of the area is about 75 m above sea level. Mean monthly temperature ranges from 24.7º C in August to 28.1º C in February. The major rainfall peak is in May – July and the minor one in August-October with annual mean rainfall of 846 mm. Although annual mean rainfall is 846 mm, the city has been experiencing dry spells with annual rainfall in 2004 not exceeding 600 mm (Data from the Ghana Meteorological Department). Natural streams in a valley network and artificial drains drain the area (Nyarko, 2002). Most of the natural drains including Densu, Nima, Odaw, Osu Klottey, Kpeshie, Mahahuma, Lador and Dzorwulu rivers/drains originate from the Akwapim ranges (Twumasi and Asomani-Boateng, 2002). Accra accommodates major institutions, industries and government ministries and also attracts migrants from various parts of the country and the entire world. The city has been experiencing a high rate of urbanization over the last four decades (Boadi and Kuitunen, 2003) marked by a proliferation of concrete structures by private estate developers in flood plains (Nyarko, 2002).

The city also suffers from insufficient drainage capacities and poor maintenance of gutters and other drainage outlets. Twumasi and Asomani-Boateng (2002) have identified six major causes of flooding in the city. This includes widespread rains characteristic of the May-July wet season, Accra's low elevation, the clay nature of its soil, inadequate and undersized drains, the dumping of refuse into drains and water bodies, and the development of environmentally sensitive areas. A combination of all these factors has resulted in the city experiencing periodic flooding that has affected properties and lives (Nyarko, 2002). Between 1955 and 1997, about 300 billion cedis (equivalent to $33,000,000) worth of property has been destroyed, 100 lives lost either during the flood period or after the floods and 10,000 people displaced from their homes (Adinku, 1994 unpublished thesis; Gyau-Boakye, 1997 unpublished data).

In recent years however, most of the flooding in the city has been attributed mainly to poor drainage and improper drainage designs. To this end an effective flood management in the region should take into consideration design and construction of drainage systems and other engineering structures that would be able to contain such devastating flooding regimes. Even though few studies have been carried out to map out areas within Accra that are susceptible to flooding (e.g. Nyarko, 2002; Twumasi and Asomani-Boateng, 2002), nothing is known of the frequency of occurrence of such events. Figure 1 shows a GIS map of areas within the metropolis that are highly susceptible to flooding.

MATERIALS AND METHODS

The data for the study include a 30 year maximum daily rainfall record from 1975 to 2004 collected from the Ghana Meteorological Department. Maximum monthly rainfall values were used because flood related problems are considered in terms of worst or extreme situation (Gobo and Abam, 2006).

Predictions of recurrence events are usually computed in terms of return periods. The return period of a given event is the average number of years within which an event is expected to be equaled or exceeded (WMO, 1983). A hydrological event (such as rainfall) has a return period of T years if its magnitude is equaled or exceeded once on the average every T years. Thus the probability P of exceedance of such an event is the reciprocal of P (i.e. $P=1/T$). In computing the return period, the data is usually ranked from the largest to the smallest. The Weibull plotting position (equivalent to P) is computed using the relation $P = m/(n+1)$, where m is the rank of the observation beginning with $m+1$ for the largest value and n is the number of years of record. Hydrological frequency analysis can be made with or without any distributional assumption. If no distributional assumption is made, observed data are plotted on any kind of paper (not necessarily probability paper). The magnitude of the past or future events of various return periods is determined using the best fit line of the resultant plot.

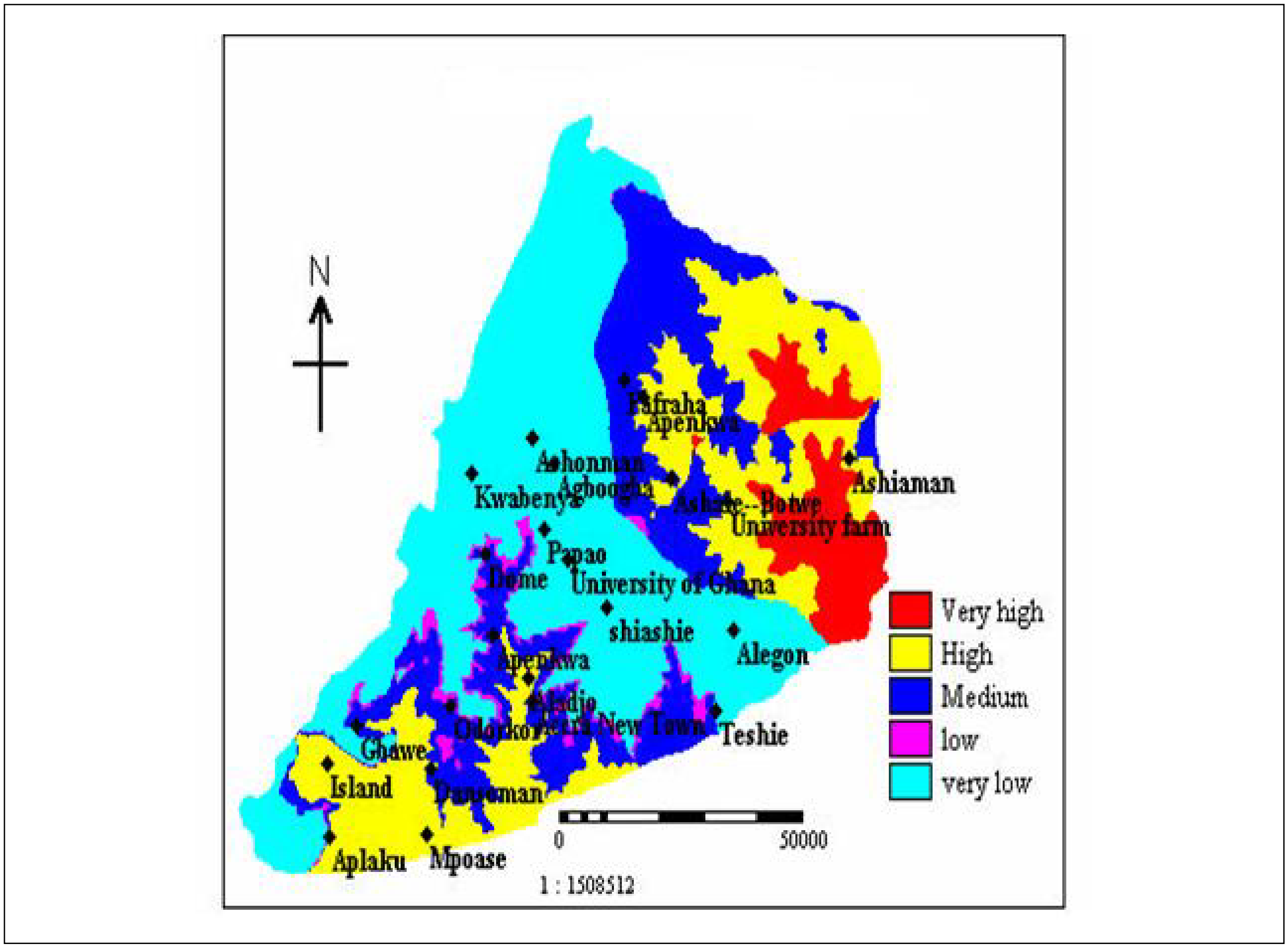

Figure 1. A GIS map of the Accra metropolitan area showing susceptibility to flooding (modified after Nyarko, 2002).

RESULTS AND DISCUSSION

Initial examination of the raw monthly data showed that maximum rainfall occurred between the months May and June. The return period for a maximum total 1-month rainfall (mm) using the 30 years of rainfall (from 1974-2004 inclusive) for Accra using the Weibull plotting position is shown in Table 1 and plotted as Figure 2. Table 1 and Figure 2 show that flood magnitude increases with increase in return period. The line of best fit of Figure 2 was obtained by fitting a log line through the original data points. It is important to mention that an analysis of one day maximum rainfall and two to five consecutive days rainfall for the Accra area follows a lognormal distribution (Xeflide and Ophori, 2007). These relationships can be empirically expressed as $y = 91.2 \text{ Ln } (x)+30.5$ with a coefficient of determination $R^2 = 0.906$. The results of the Weibull plotting position show that a maximum 1-month rainfall magnitude of 420.6 mm is expected to occur on the average every 31 years. Further, a maximum monthly flood of 212.7 mm is expected to have a return period of two years in the region.

Table 2 shows the annual rainfall data of Accra based on the Weibull plotting position. The relationship between the return period and the annual rainfall is plotted in Figure 3 (the line of best fit is obtained by fitting the original data points with a log function). As per Table 2 it would take 31 years for a maximum 1-year rainfall of 1223.5 mm to occur. Further it would take 2.1 years to obtain a maximum annual rainfall of 669.7 mm whilst a maximum annual rainfall of 333.1 mm is expected to occur every year in Accra. The equation relating the maximum annual rainfall y and the

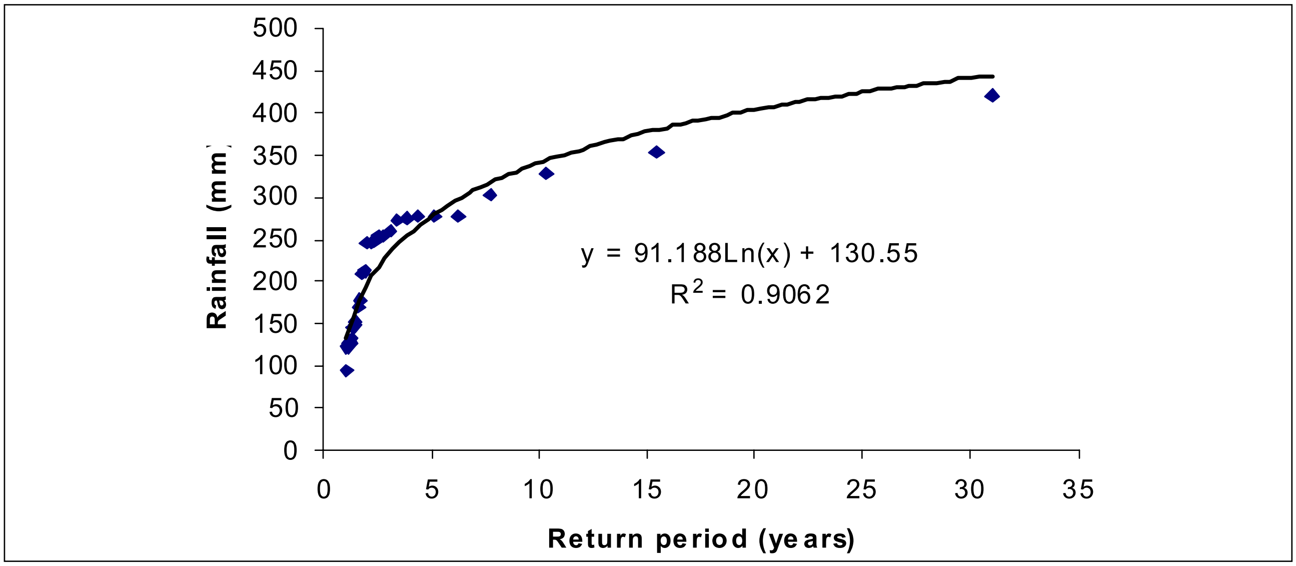

Figure 2. A plot of monthly rainfall versus return period of Accra, Ghana.

Table 1. Maximum 1-month rainfall values for Accra (1975-2004).

m	Year	Rainfall (mm)	*P*=*m*/*n*+1	*T*
1	2002	420.6	0.032258	31
2	1997	353.3	0.064516	15.5
3	1999	327.3	0.096774	10.33333
4	2003	302	0.129032	7.75
5	1995	278.3	0.16129	6.2
6	1982	278	0.193548	5.166667
7	1991	277.7	0.225806	4.428571
8	1987	275.8	0.258065	3.875
9	1975	271.4	0.290323	3.444444
10	1978	260	0.322581	3.1
11	1979	256.2	0.354839	2.818182
12	1988	254.9	0.387097	2.583333
13	2001	246.7	0.419355	2.384615
14	1996	246.1	0.451613	2.214286
15	1980	245	0.483871	2.066667
16	1985	212.7	0.516129	1.9375
17	1998	208.9	0.548387	1.823529
18	1994	178.1	0.580645	1.722222
19	1992	171.1	0.612903	1.631579
20	1983	152.3	0.645161	1.55
21	1989	148.7	0.677419	1.47619
22	1981	144.6	0.709677	1.409091
23	1986	144.1	0.741935	1.347826
24	1976	132.9	0.774194	1.291667
25	1990	127.8	0.806452	1.24
26	2000	127.1	0.83871	1.192308
27	1984	122	0.870968	1.148148
28	2004	121.5	0.903226	1.107143
29	1977	121.3	0.935484	1.068966
30	1993	96.2	0.967742	1.033333

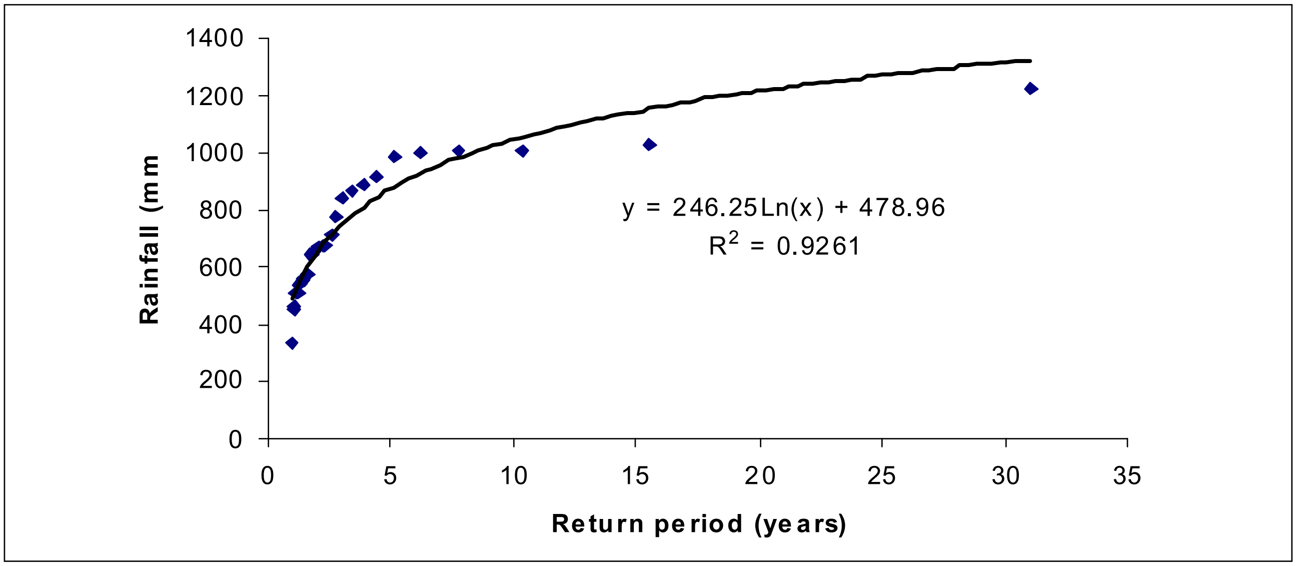

Figure 3. A plot of annual rainfall versus return period of the Accra plains, Ghana.

Table 2. Annual rainfall values for Accra (1975-2004)

m	Year	Rainfall (mm)	*P*=*m*/*n*+1	*T*
1	1997	1223.5	0.032258	31
2	1995	1029.8	0.064516	15.5
3	2002	1009.9	0.096774	10.33333
4	1991	1008	0.129032	7.75
5	1980	1000.8	0.16129	6.2
6	1988	988.9	0.193548	5.166667
7	1979	917.4	0.225806	4.428571
8	2003	887	0.258065	3.875
9	1975	869.9	0.290323	3.444444
10	2001	837.6	0.322581	3.1
11	1982	774	0.354839	2.818182
12	1996	716.6	0.387097	2.583333
13	1984	680.6	0.419355	2.384615
14	1985	680.6	0.451613	2.214286
15	1981	669.7	0.483871	2.066667
16	1989	656.7	0.516129	1.9375
17	1999	641.8	0.548387	1.823529
18	1987	640.8	0.580645	1.722222
19	2004	573.8	0.612903	1.631579
20	1990	568.6	0.645161	1.55
21	1992	557	0.677419	1.47619
22	1976	549.6	0.709677	1.409091
23	1994	547.9	0.741935	1.347826
24	1978	537.4	0.774194	1.291667
25	1998	513.6	0.806452	1.24
26	2000	512.2	0.83871	1.192308
27	1993	509.3	0.870968	1.148148
28	1986	462.1	0.903226	1.107143
29	1977	454.7	0.935484	1.068966
30	1983	333.1	0.967742	1.033333

return period x can be expressed as $y = 246.25\text{Ln}(x) + 478.96$. The coefficient of determination that gives an indication of the strength of the relationship is $R^2 = 0.926$.

Flood frequency analysis for the purposes of engineering design is usually made based on 2 to 100 year return periods. The annual maximum 1-month rainfall and the annual 1-year rainfall values corresponding to a return period of 5 to 100 years are based on the respective regression equations and are shown in Table 3. These values are approximate critical values that must be used during engineering design for flood control works in Accra.

Table 3. Modeled rainfall corresponding 2 to 100 years return period

Return Period	Modeled 1-month maximum rainfall (mm)	Modeled Annual maximum rainfall (mm)
2	193.8	649.6475
5	277.3	875.2841
10	340.5	1045.972
20	403.7	1216.659
25	424.1	1271.608
50	487.3	1442.296
100	550.5	1612.98

CONCLUSIONS

For the purposes of mitigating the perennial flooding in Accra, this study has highlighted the need for basic statistical analysis of hydrometeorological data and application of the results for engineering design to achieve desired flood control objectives. Analysis of maximum 1-month rainfall and annual rainfall for Accra shows a maximum annual rainfall of 1223.5 mm and maximum 1-month rainfall of 420.6 mm with return period of 31 years for Accra. Extrapolation of the return period based on a linear regression model shows a maximum 1- month rainfall and maximum annual rainfall of 550.5 mm and 1612.98 mm are expected to occur every 100 years respectively. Since the recent flooding in the Accra metropolitan area has been attributed to poor drainage, it is recommended that structural engineering practices in the region (in relation to drainage capabilities) take into account all necessary statistically derived flood magnitudes in the structural design process for drainage systems. Further, it is recommended that routing take place through specific drainages in flood prone areas to help mitigate devastating flooding in the area.

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