ORIGINAL PAPER

Rainfall variability, floods and adaptations of the urban poor to flooding in Kumasi, Ghana

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Abstract Flood is a normal ecosystem phenomenon and a natural hydrological feature of most river systems. Climate variability may also bring about precipitation events that cause floods. However, recent floods in most areas may be anthropogenically induced and are on a spatial and temporal increase. This study assessed rainfall variability, flooding and the adaptations of slum residents to floods in Kumasi, Ghana. Rainfall data of Kumasi were collected from the Meteorological Services Department, Accra. Basic descriptive statistics of rainfall data were used to evaluate the rainfall variability. The Mann–Kendall test was used to assess rainfall trends. A survey of residents of flood-prone suburbs was conducted to assess their vulnerability and adaptations to floods. The results show that rainfall in March and November is significantly decreasing. The floods in Kumasi are not due to climate change but bad spatial development practices. Most people will pump out water and build embankments around their houses as adaptations to the floods. Flooding in Kumasi will continue to outwit local government initiatives of storm drain construction because the floods are predominantly due to development of effluent streams and less from flash floods.

1 Introduction

Floods are part of the ecosystem and a natural hydrological feature of most river systems. They provide benefits to humans through maintenance of ecosystem functioning such as sediment and nutrient inputs to renew soil fertility in floodplains, providing floodwaters to fish spawning and breeding sites (Brinson 1993; Casanova and Brock 2000). However, this important natural phenomenon mostly causes disasters because human settlements are getting increasingly closer to the floodplains of river channels, such that, communities are

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more vulnerable and/or unprepared for these floods. Recent floods in most areas are therefore preventable or anthropogenically induced and are on a spatial and temporal increase (Intergovernmental Panel on Climate Change [IPCC] 2007; Millennium Ecosystem Assessment 2005).

It is known that urban dynamics are the result of physical, biological and social forces (Millennium Ecosystem Assessment 2005; Adelekan 2010). A major factor affecting the urban dynamics and its vulnerability to climate is urbanisation, particularly, in the developing world. Increasing urbanisation means that the impacts of climate change on human settlements, if they occur, will increasingly affect urban populations (IPCC 2007; Adelekan 2010). A significant part of the activities to achieve Goal 7 of the Millennium Development Goals and climate change mitigation and adaptation will therefore be played out in the urban environments (Secretariat of the Convention on Biological Diversity 2007). The hazards to which some cities are exposed to are likely to become either more severe or more frequent, and so the increased risk should be anticipated, if not predicted (Fedeski and Gwilliam 2007; IPCC 2007). However, urban areas are still understudied, and much less attention has been devoted to the study of the impacts of global environmental change on urban areas and the people who live in them. Particularly critical are the more than 70 % of the urban population living in slum conditions in Sub-Saharan African cities (Rietbergen et al. 2002; Sánchez-Rodríguez et al. 2005).

The extent to which urban centres are vulnerable to changes in climate is influenced by a variety of factors such as topography, housing, infrastructure and preparedness. However, this vulnerability could be mediated through social and economic interventions and the ability of stakeholders and institutions to address the challenges. Research shows that West Africa is among the most vulnerable regions to climate change worldwide (Niasse et al. 2004; Millennium Ecosystem Assessment 2005; IPCC 2007). However, the information and capacity needed to meet these challenges are lacking, not only in Ghana but in developing countries as a whole (Sánchez-Rodríguez et al. 2005). It is also known that climate change affects water resources (Jenerettea et al. 2006) and may cause flooding in many areas (Fedeski and Gwilliam 2007; IPCC 2007). However, no studies have been conducted on climate change effects and adaptations by the vulnerable urban communities as in Kumasi, Ghana.

Relevant research conducted in Kumasi has been on pollution and peri-urban agriculture (Brook and Dávila 2000; Keraita et al. 2002, 2003; Cornish and Kielen 2003), livelihood changes in peri-urban environments (Holland et al. 1996; Danso et al. 2002, 2006; Quansah et al. 2005; Drechsel 2006; McGregor et al. 2006), urban planning (Mabogunje 1990), land and land tenure (Blake and Kasanga 1997; Botchie et al. 2007). There is certainly a shortfall in depth and direction of research that would provide the basis for climate mitigation and adaptation for disaster risk reduction in the urban environment in Kumasi, Ghana.

Kumasi has experienced floods in recent years with increasing scale and cost of destruction. Without any research backing, newspaper reports have attributed it to climate change and the city authorities blame it on obstruction of waterways. Whatever the cause of floods may be, most of the residents of the flood-prone suburbs are not ready to relocate. An investigation into their adaptations to the floods could be very important for future flood management and adaptation strategies. Milly et al. (2008) advocate for a "predictable uncertainty" of flooding as a step towards adaptations to flood disasters. The prediction of this uncertainty can be done in Kumasi only after specific local conditions are assessed to determine future hydrological conditions based on past climate records. This paper

therefore seeks to investigate the relationship between flooding and rainfall variability or change and the vulnerabilities and adaptations of slum dwellers of Kumasi to floods.

2 Methodology

Kumasi is the second largest city in Ghana and lies within latitudes 6°38′ north and 6°45′ north and longitudes 1°41′ west and 1°32′ west in the forest zone of Ghana with a climate described as wet sub-equatorial type (Fig. 1). Like many growing cities in developing countries, the city's wetlands are highly anthropogenically impacted (Campion and Venzke 2011). The suburbs being studied have relatively large portions of informal or slum settlements with haphazardly arranged houses built from wood or block. There is little or no drainage network. Most houses directly release their domestic waste water through small channels to the open which finds its way into surrounding streams. Most of the lands used for these houses are originally designated as "natural areas" according to the land use plan of the city and therefore not to be built upon. However, the land owners secretly sell out small portions of these natural areas leading to a gradual habitation of such zones. Alleys are very narrow or virtually non-existent because of the continual encroachments and erection of illegal structures. These communities also have high population densities with very little social infrastructure. Water is drawn from shallow manual dugout wells. Local entrepreneurs take advantage of the dearth in services to provide substandard facilities to these depraved communities. There are several private primary schools and churches mostly housed in wooden structures. Also, there are no culverts or bridges linking communities on either side of the water channel in these suburbs. Wooden foot bridges are constructed across the streams and rivers through local efforts. There is no thoroughfare in most areas so vehicular movement in such communities is limited.

These study suburbs were chosen from a list of most frequently flooded suburbs that receive media coverage. Because of the density and demographic characteristics of these suburbs, they are media and political hotspots. The data on flooding, vulnerabilities and adaptations to floods were obtained from administering 128 structured questionnaires to household members randomly chosen within the 100 m stream/river buffer range set by the Water Resources Commission (2008). Interviews were conducted with officials of the Kumasi Metropolitan Assembly (KMA), Town and Country Planning Department (TCPD), the Regional Office of the National Disaster Management Organisation (NADMO), key informants and some sub-chiefs.

Monthly mean rainfall data on Kumasi from 1961 to 2010 were collected from the Meteorological Services Department, Ghana. Basic descriptive statistics were used to evaluate the temporal variability in rainfall. The Mann–Kendall test, Z, was also used to determine annual and monthly rainfall trends and trends in rainy days per year (Modarres and da Silva 2007; Batisani and Yarnal 2010). Positive values of Z indicate increasing trends whilst negative Z indicates decreasing trends. When testing either increasing or decreasing monotonic trends at a p significance level, the null hypothesis is rejected for absolute values of $Z > Z_{1-p/2}$. The standard significance levels of $p = 0.05$ are applied. The true slope of the linear trend, Q (change in rainfall per year), was estimated with the nonparametric Sen's method (Gilbert 1987). The Sen's method uses a linear model to estimate the slope of a linear trend. The slope can be computed efficiently and is insensitive to outliers; it can be significantly more accurate than simple linear regression for rainfall data which may be skewed and heteroscedastic. Therefore, for measuring seasonal environmental data, the Sen's slope estimate has been proposed as preferable (Leroy and
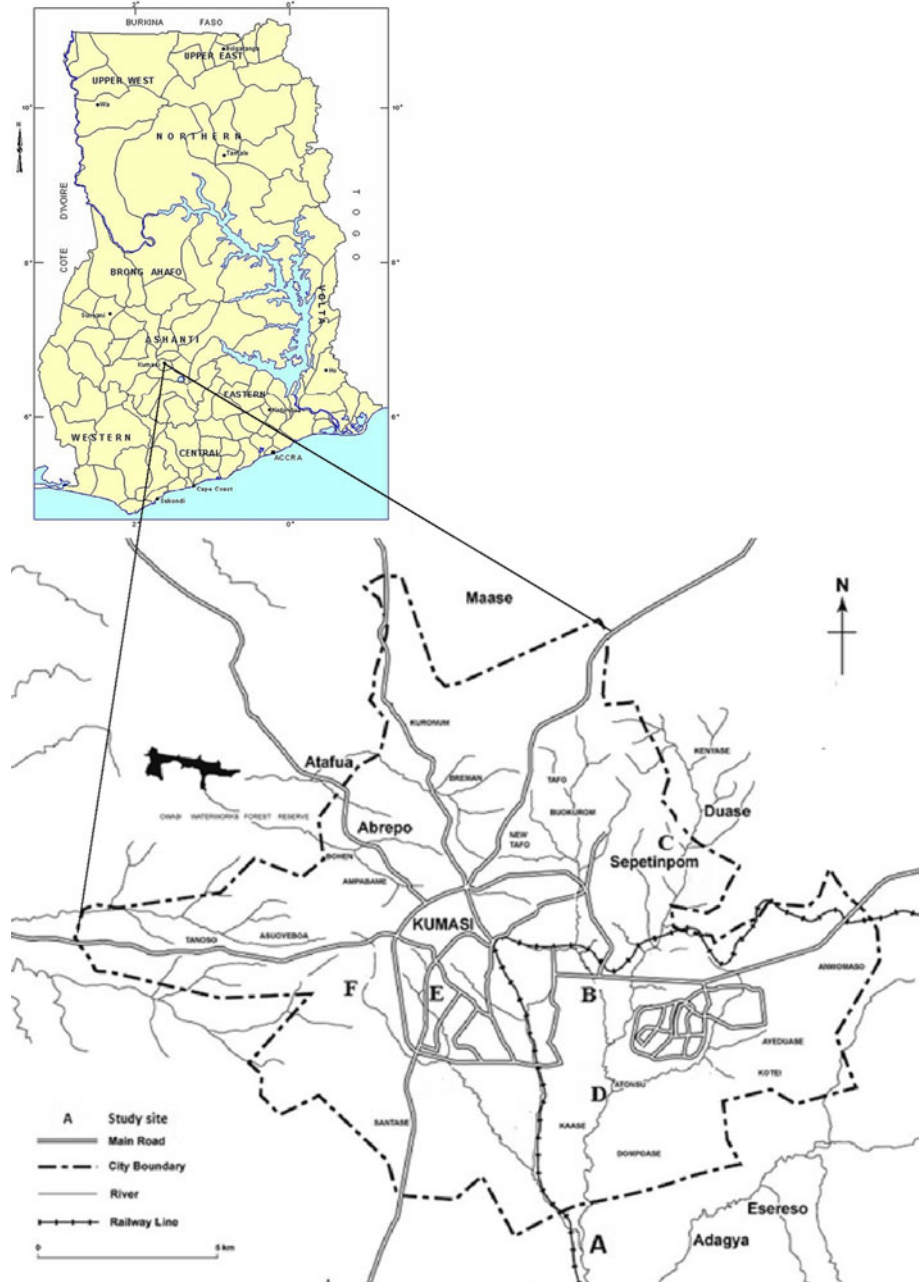
Fig. 1 Map of Ghana with an insert showing and the flood-prone study suburbs: Atonsu (*A*), Ahensan (*B*), Asokore Mampong (*C*), Atonsu (*D*), Dakwadwom (*E*) and Kwadaso Estates (*F*) within the limits of the Kumasi metropolitan assembly

Rousseeuw 2003). The relationship between total rainfall and number of rainy days (rainfall ≥1 mm/day) and heavy rainfall events (rainfall ≥31 mm/day derived from an estimate of the 95th percentile of the rainfall events of 1963 [chosen at random among first 3 years of Kumasi's rainfall data]) was assessed using correlation. This was to assess if Kumasi's rainfall is explained more by the total number of days with rain or by individual heavy rainfall events.

3 Results

The annual rainfall pattern of Kumasi is weakly bimodal with an annual average of 1,374.8 mm. The first and major rainy season starts from a relatively dry period in January with an average rainfall of 18.9 mm and peaks in June with an average of 211.7 mm. The second rainy season starts from August with an average rainfall of 87.7 mm and peaks at an average of 168.9 mm in September and drops to an average of 23 mm in December.

The descriptive statistics of the rainfall from 1961 to 2010 is presented in Table 1. Within these 50 years, there were 15 January months and 6 December months without rainfall. All the other months had rainfall. The months with the highest variability in rainfall distribution are the rainy season months between April and October. The rainfall distribution for these months is also characterised by relatively high coefficients of variation and that for August and September is significantly peaked over the normal distribution (kurtosis of 6.98 and 5.50, respectively). All the monthly rainfall distributions have positive skew values. That is, several extreme rainfall values lie to the right of the mean. Skewness for August is the highest (2.06).

The nonparametric Mann–Kendall (Z) and Sen's slope (Q) tests could not generalise either an increasing or a decreasing trend for the given set of data. Rainfall for January and September shows no trends. April and August are experiencing an increasing trend in rainfall, whilst that of February, May, June, July, October and December is decreasing. In both instances above, the trends were not significant. Only rainfall for March and November had significantly decreasing trends over the period ($Z = -2.44$, $Q = -1.20$ and

Table 1 Descriptive statistics of the monthly rainfall pattern of Kumasi from 1961 to 2010

Variable	Minimum	Maximum	Mean	SD	Variance	Skewness	Kurtosis	Mann–Kendall Z	Sen's slope Q
January	0	111	18.92	25.85	668.05	1.52	1.97	0.00	0.000
February	1	135	55.75	40.03	1,602.44	0.43	−0.92	−1.31	−0.546
March	36	310	119.12	53.61	2,874.49	1.21	2.31	−2.44*	−1.200
April	45	311	146.32	64.54	4,165.61	0.80	0.03	0.90	0.631
May	46	307	174.79	63.93	4,086.88	0.43	−0.56	−1.15	−0.715
June	41	377	211.73	83.00	6,889.14	0.26	−0.66	−0.47	−0.490
July	18	446	146.62	98.14	9,630.74	1.10	1.20	−0.74	−0.562
August	7	400	87.70	69.71	4,859.20	2.06	6.98	0.49	0.304
September	15	535	168.89	87.10	7,586.15	1.80	5.50	0.00	−0.004
October	43	336	156.12	63.55	4,038.46	0.77	0.73	−0.50	−0.378
November	3	213	62.38	47.33	2,240.15	1.20	1.24	−2.90*	−1.145
December	0	116	26.40	26.60	707.48	1.37	1.81	−0.26	−0.025

* $p = 0.05$

$Z = -2.90$, $Q = -1.15$, respectively, at a statistical significance level $\alpha = 0.05$). That is, the average rainfall for these 2 months was decreasing at 1.20 and 1.15 mm per year, respectively. The annual total rainfall also showed a decreasing trend with a slope of 0.59 mm/year although not significant (Fig. 2). The heavy rainfall trends for the two flood-prone months of June and July are varied. Whilst the heavy rainfall events are decreasing for June ($Z = -0.78$, $Q = 0.00$), that for July is increasing ($Z = 0.91$, $Q = 0.00$) but both are not significant. In general, for all the trend analyses, the residuals are more positive and randomly distributed for most of the months. The Sen's slope estimate and Mann–Kendall tests therefore reflect data that are random and from the same distribution.

The first rainy peak of the year (May, June and July) has always been associated with floods in the selected study suburbs of Kumasi. Table 2 provides an extract of rainfall events that have been reported in the media to have caused floods and documented by the NADMO Office in Kumasi for 2009. June and July were the months with the most reported incidence of floods. These rainfall events were categorised into rainy days and heavy rainfall events. Except for the flood that occurred on 9 June 2009, all others occurred during or after heavy rainfall events. The relationship between all rainfall events and the total monthly rainfall was measured by correlation. The results showed that total monthly rainfall is explained more by heavy rainfall events than the number of rainy days in the month (85 % and 72 % of variance in common between heavy rainfall events and rainy events with total rainfall, respectively). A trend analysis of heavy rainfall events showed that annual heavy rainfall events are decreasing in trend, although not significant ($Z = -0.10$, $Q = 0.00$). The heavy rainfall trends for the two flood-prone months are varied. Whilst the trend in heavy rainfall events is increasing for June ($Z = 0.53$, $Q = 0.00$), that for July is decreasing ($Z = -0.13$, $Q = 0.00$).

Various types of houses were identified within 100 m from the water channel (Fig. 3). These were permanent block structures in the form of multifamily residential facilities commonly called compound houses, single-family self-contained structures (detached or semi-detached), L-shaped detached or single-room structures and wooden structures (Fig. 4). The wooden structures were found in Aboabo, Ahensan, Atonsu and Dakwadwom. Occupants had lived less than 10 years in these facilities. When the economic conditions of these residents improve, most of them transform the wooden structures to more permanent block structures. The predominant housing types for respondents from Aboabo are compound, wooden or L-shaped detached houses. The houses in Aboabo, unlike those of Kwadaso Estates, are mostly multifamily permanent compound structures with relatively large numbers of residents even at the household level. Those in Kwadaso Estates are mostly single-family accommodations. Majority of the respondents (62 %) either own the houses or are part of the extended family and do not pay rent. The largest proportion of home owners is those in wooden and permanent single-room structures in Ahensan and Atonsu. Most of the multifamily residential facilities like the compound, detached and semi-detached houses have tenants who are completely separate households. There is also a relatively high tenant turnover in these areas. Most tenants who did not know of the annual floods usually moved out after one or two flood experiences. The relationship between length of stay and prevalence of flood was assessed using the Pearson's correlation. There was no relationship between number of years of stay in an area and presence or absence of floods ($r = -0.135$).

The estimation of the number of days the flood waters take to recede in the suburbs depended on the location of respondents' houses. The predominant number of days the people lived under flood conditions is more than 20 days in a year for all the suburbs (Fig. 5). For some suburbs like Ahensan, Atonsu and Dakwadwom, it took more than
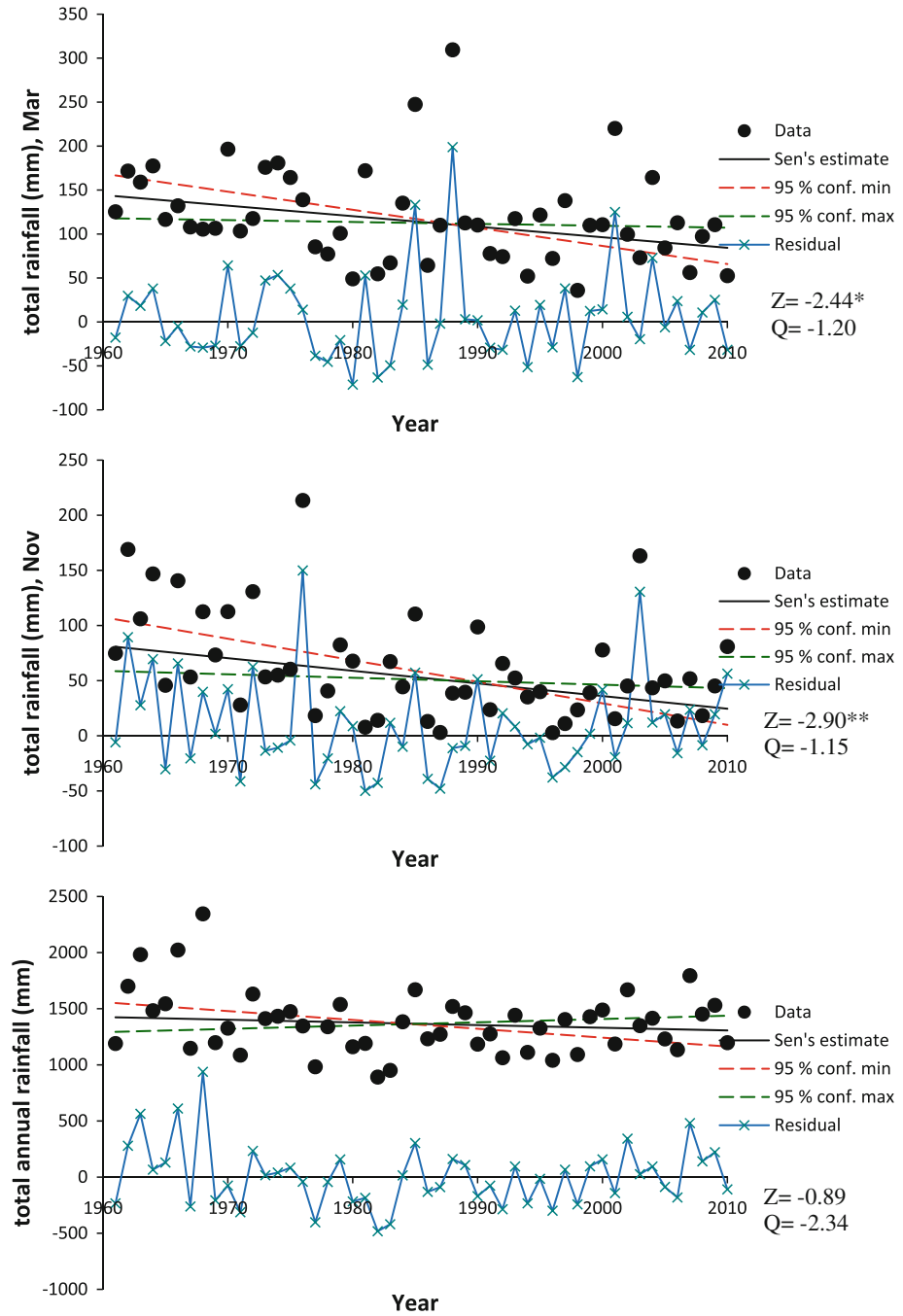
Fig. 2 Trends in total annual rainfall and the 2 months with significantly changed rainfall trend in Kumasi

Table 2 Rainfall events and reported floods in some suburbs of Kumasi in 2009

| Flood conditions			Antecedent conditions	
Date	Amount of rainfall (mm)	Flood location	Date of last rainfall	Amount of rainfall (mm)
09/06/2009	27.8	Aboabo, Anloga, Oforikrom, Ahensan, Kwadaso Estates, Dakwadwom, Bomso, Sisaso, Atonso	08/06/2009	3.1
11/06/2009	60.4		10/06/2009	0.1
15/06/2009	43.3		13//06/2009	19.1
26/06/2009	90.3		25/06/2009	17.3
04/07/2009	53.4		03/07/2009	12.8
09/07/2009	72.7		08/07/2009	27.6
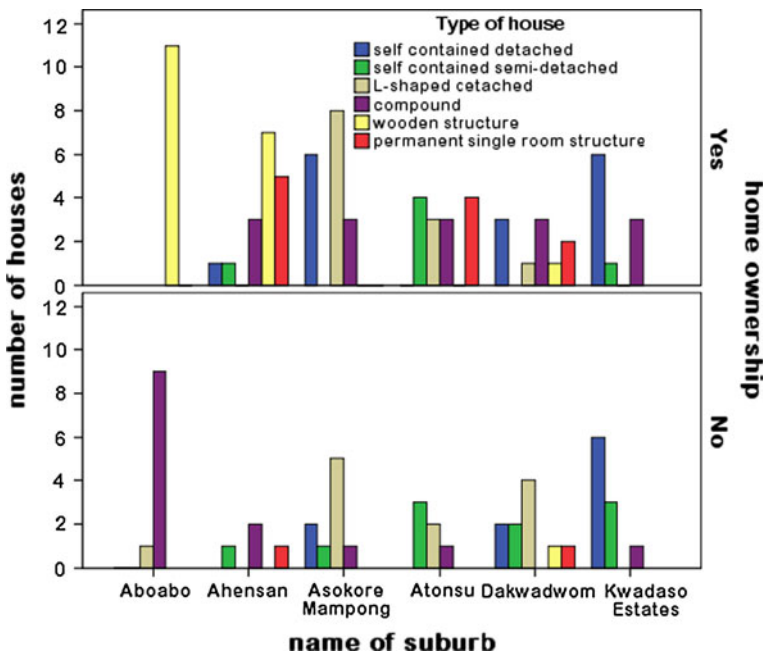
Fig. 3 Homeownership and residential types of respondents of the various suburbs of Kumasi

1 month for the water to recede in some areas, especially, those closer to the water channel (Fig. 6). The estimation of the loss by various institutions and the newspaper reportage of damage keeps rising year after year and varies depending on the interest and capacity of the person or institution making the estimates.

The action a resident takes in times of flood is very much dependent on the person's previous flood experiences (Fig. 7). Most first time rent paying tenants of these suburbs do not know that their houses are flood prone. These first time residents are usually shocked and annoyed at the non-disclosure that the area or house is flood prone. They then attempt to retrieve their rent (rent is usually paid 2–5 years in advance) in order to relocate. When the rent retrieval fails, the coping strategies of such first time flood victims are usually egocentric, for example, move out till the conditions improve; seal or open vents in

Fig. 4 Cluster of different house types close to a stream bank in one of the study suburbs in Kumasi
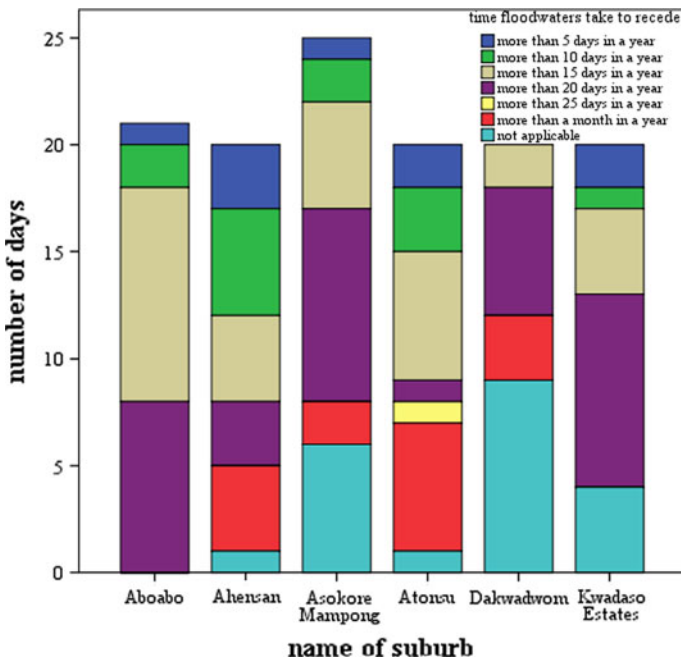

Fig. 5 Recession time of water at the various flood-prone suburbs of Kumasi

building to block water or allow for flow of water as may be deemed appropriate; build embankments around apartment (Fig. 8); and/or complete relocation of (movable) property; and complain to the city authorities. Most of these individual efforts often bring conflicts between the person and the landlord or neighbours. Some of the conflict issues were disagreements on the direction of a new drainage channel created by the individual;

Fig. 6 Flood scene in a suburb of Kumasi, Ghana. Note the channel used to drain off the water from the neighbourhood

perception of the individual as being a free rider or proud for not participating in communal efforts; and the individual's refusal to contribute in cash or in kind to community efforts.

Residents, who have lived in these suburbs for a while, respond differently to the floods: they are more accommodating to their landlords. Together with landlords and other tenants, they employ more communal adaptations to floods. This category of residents mobilises and participates in the construction of new drainage channels and (re)dredging of streams; construction of networks of raised walkways to the various houses or compounds (Fig. 9). They help the landlords by providing labour or sometimes technical expertise or financial assistance to build embankments or major modifications around houses (Figs. 10, 11). Direct financial assistance to landlords is usually not paid back but rather absorbed as an extension of the rent. These old residents do not make complaints to the city authorities because they know it will have little or no effect. Also, in these poor suburbs, there is a very strong sense of belief in the mercies of God and reliance on political promises to reduce future floods. They believe the situation will soon improve when the political promises to improve their neighbourhoods are fulfilled. After making all these preparations or inputs in any given year, most people accept the flood as an inevitable annual incident and do nothing except wait for the dry season. KMA's responses to these floods have been reactionary. It identified the obstruction of waterways by houses and waste as the main causes of the floods. However, nothing is done until each major flash flood event and the KMA responds by demolishing houses on waterways (Fig. 12) and the construction or desilting of storm drains.

4 Discussion

The rainfall pattern for Kumasi, as described above, is due to its dependence on convection following the movements of the Intertropical Convergence Zone (ITCZ). This is the dominant mechanism producing rain in this region (Barbé et al. 2002). After September, the ITCZ is receding and there is less penetration of moisture laden winds to cause rainfall,
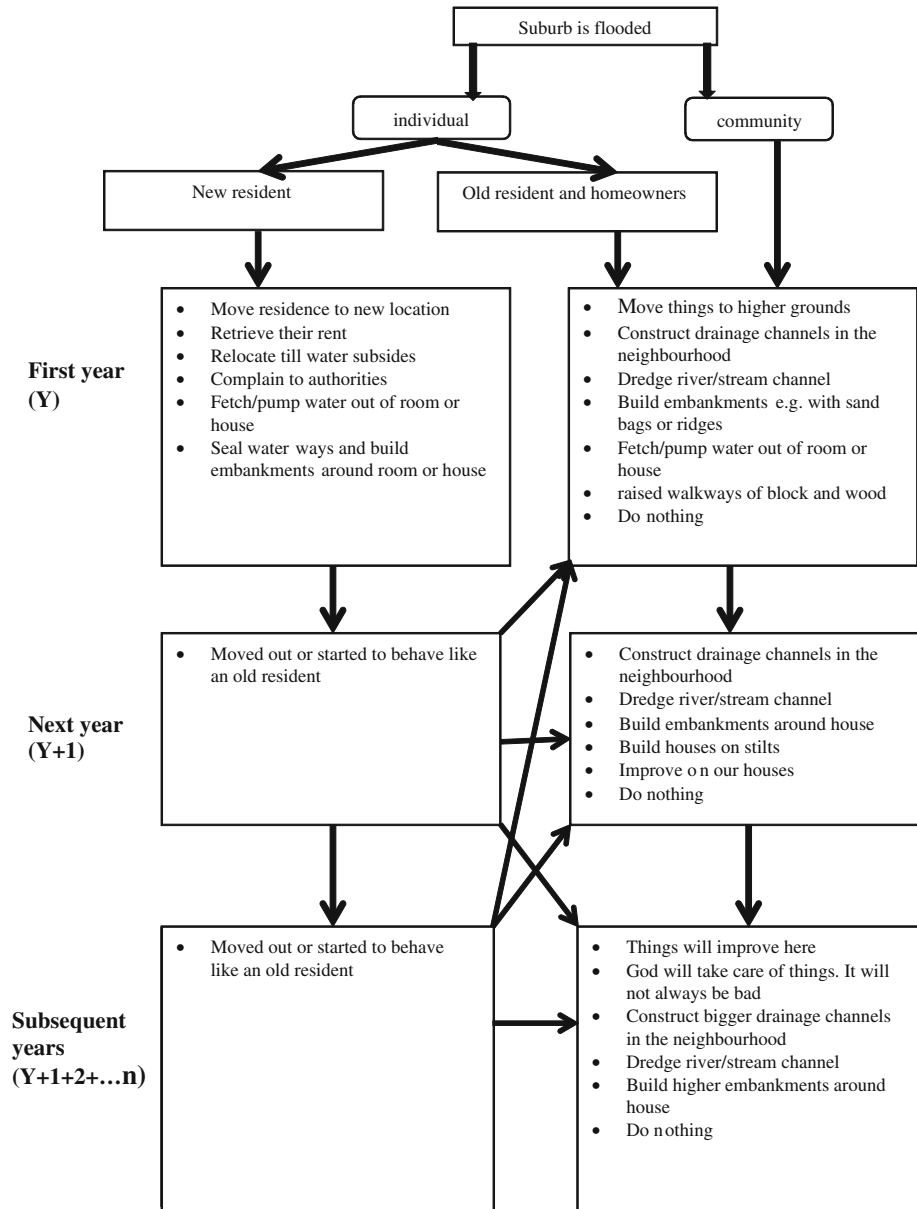
Fig. 7 Flood response of new and old residents of flood-prone suburbs of Kumasi

hence the weaker second peak. The higher statistical variations of the rainy season months may be due to inconsistencies in quantity and temporal distribution in the rainfall as shown by the skewness and kurtosis. Positive skew values mean that the larger proportions of the rainfall for those months are a result of extreme rainfall events (Barbé et al. 2002; Modarres and da Silva 2007; Batisani and Yarnal 2010). This is also shown in the correlation analysis. The results of the statistical analyses of rainfall for July, August and September, which are the peaks of the rainy season and floods in Kumasi, are therefore not

Fig. 8 An individual adaptation to flood by building a wall around the door to a room in a compound house

Fig. 9 Adaptation to flood by raised walls and raised wooden walkways between two houses in Kumasi

surprising and could be due to heavy rainfall events as shown by the correlation results. Even though this analysis did not consider time between rainfall events, an antecedent condition such as date of last rainfall event could have affected the probability of occurrence and duration of floods. For example, rainy days preceding heavy rainfall events could increase the probability of flooding due to soil saturation and rise in water table leading to increased overland flow. November and March are in the dry season. The effects of the significant decrease in rainfall in these months on the incidence floods in June are not known. However, these dry months may decrease the water table and reduce stream flows. Because these streams are not being directly used by the people, this threat is insidious.

Fig. 10 Adaptation to floods by building a wall around house. Note the raised car ramp and staircase into the house

Fig. 11 Adaptation to floods by construction on a house on stilts in a flood-prone suburb in Kumasi

Even though the floods occurred during or after heavy rainfall events, the relatively long time it takes for the flood waters to recede may indicate that not all the floods are flash floods. These suburbs and houses are situated on lands, hitherto, considered as wetlands. This is evidenced by the prevalence and dominance of vegetation adapted to growing in water and saturated soil conditions (Campion and Venzke 2011). The experiences of these flood-prone neighbourhoods are, therefore, consequences of the spread of physical urban developments into wetlands. The clearing of vegetation, surface compaction and expansion of such compacted areas due to urbanisation may increase overland flow and produce flash floods as

Fig. 12 A house marked for demolition by the KMA in a flood-prone suburb of Kumasi

described by Griggs and Paris (1982) and the United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction (2005). However, the rising of the water table during the rainy season (peaking in June) creates a network of surface streams called effluent streams in large parts of these suburbs. The discharge of an effluent stream is sustained by groundwater for long periods of time between runoff-producing rainfall events. The rainfall recorded each year increase the groundwater levels and therefore trigger the flow and extended duration of these effluent streams in June and July. Effluent streams, rather than flash floods, best explain the delay of the flood waters from drying out in the neighbourhoods. Also, the networks of raised walkways and drainage channels could only be an adaptation to protracted effluent stream flows rather than flash floods.

Also, these flood-prone suburbs are predominantly inhabited by the urban poor and new rural–urban immigrants. Even though there is no spatial poverty profile of the residents of Kumasi, the physical location and characteristics of the poor are undeniably obvious in the housing landscape: an agglomeration of dilapidated structures without social infrastructure and amenities. However, estimated economic losses from the floods keep rising year after year irrespective of the scale of the floods in accordance with findings of Golnaraghi et al. (2009). Because the type and quality of houses identified in these suburbs are among the worst in the city, the reported increases in economic losses may be due to improvement in the economic conditions of these slum residents leading to increase in acquisition of precious and capital goods and services which are easily destroyed by the floods. Also, after living in such environments for several years, there is increased resilience by residents and general losses may decrease except for the occasional flash floods. Almost all heavy rainfall events produce flash floods which is increasingly making it difficult for residents to predict and work within previously known weather estimates. Also, there is usually the perception and anticipation of help or a craving for public sympathy by these victims and therefore the tendency to exaggerate their losses due to floods. Either way it is difficult to independently verify these claims or accurately estimate the value of properties destroyed by the floods.

In recent years, the notion of adaptation has become a significant component of climate change literature and international negotiations on climate (Niasse et al. 2004; World Meteorological Organisation 2006; IPCC 2007; Ireland 2010). This study describes individual and communal coping strategies rather than the expected proactive and concerted efforts by city authorities at managing floods. Rather than depending on the city authorities or complaining, the old residents might have developed strong social ties in the community and with their landlords and are therefore motivated and responsible to contribute to solving the problem. For these people, the pull forces to remain therefore transcend the push effect of annual floods. Also, when calls for assistance are made, there is relatively little from the city authorities because most of these landlords in these flood-prone areas have problematic relationships with the KMA. The KMA's flood management strategy is to increase the free flow of flood water through the construction of storm drains and removal of illegal structures in the waterways (KMA 2006). Therefore, many houses in these neighbourhoods have no building permits and have been marked for demolition. Yet, according to the United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction (2005), the KMA is to act with all stakeholders to reduce these risks. Community resilience to these floods could therefore be improved if city authorities, like the KMA, harness their efforts with local efforts and know-how rather than single handily and repeatedly demolishing the ever mushrooming houses in these flood-prone areas.

5 Conclusions

This study sought to investigate the rainfall variability, causes of floods and adaptation strategies of the poor to floods in Kumasi, Ghana. The total annual rainfall is decreasing but not significant. Only rainfall for March and November is significantly decreasing over the period considered. The analyses show that total monthly rainfall of Kumasi is explained more by heavy rainfall events than the number of rainy days in the month. However, there is no significant change in trends of heavy rainfall events for the two flood-prone months of June and July. The floods in Kumasi could therefore not be attributable to changes in climate. There are two types of floods that affect the suburbs studied: flash floods and effluent stream floods. The flash floods arise from overland flow due to heavy rainfall events. Effluent stream floods are due to a rise in the water table during the peak rainy season of June–July causing relatively long-term surface inundation. The adaptations to floods in these suburbs include dredging of streams, erection of embankments around houses, moving property to higher grounds, building a network of raised walkways and building houses on stilts. These are adaptations to the long lasting seasonal effluent stream floods rather than unexpected flash floods. Collaboration between city authorities and residents of these neighbourhoods could reduce the effects and improve their resilience to the annual floods.

References

Adelekan IO (2010) Vulnerability of poor urban coastal communities to flooding in Lagos, Nigeria. Environ Urban 22:433–450

Barbé L, Lebel LT, Tapsoba D (2002) Rainfall variability in West Africa during the years 1950–90. J Clim 15:187–202

Batisani N, Yarnal B (2010) Rainfall variability and trends in semi-arid Botswana: implications for climate change adaptation policy. Appl Geogr 30:483–489

Blake B, Kasanga K (1997) Kumasi natural resources management research project report. Natural Resources Institute, The University of Greenwich, UK and University of Science and Technology, Kumasi, Ghana

Botchie G, Akabzaa T, Gyasi E, Sarpong DB (2007) Land tenure, land use and environment in Ghana. ISSER technical publication series 72. Legon, Ghana, p 78

Brinson MM (1993) A hydrogeomorphic classification for wetlands. Wetlands Research Program Technical Report WRP-DE-4. Army Engineer Waterways Experiment Station, Vicksburg, MS

Brook RM, Dávila JD (eds) (2000) The peri-urban interface: a tale of two cities. School of Agricultural and Forest Sciences, University of Wales and Development Planning Unit, University College London, London pp vii + 251

Campion BB, Venzke J-F (2011) Spatial patterns and determinants of wetland vegetation distribution in the Kumasi Metropolis, Ghana. Wetlands Ecol Manag 19(5):423–431

Casanova MT, Brock MA (2000) How do depth, duration and frequency of flooding influence the establishment of wetland plant communities? Plant Ecol 147:237–250

Cornish GA, Kielen NC (2003) Wastewater irrigation—hazard or lifeline? Empirical results from Nairobi, Kenya and Kumasi, Ghana. In: Scott CA, Faruqui NI, Raschid-Sally L (eds) Wastewater use in irrigated agriculture: coordinating the livelihood and environmental realities. IWMI, IDRC, Ottawa

Danso G, Drechsel P, Wiafe-Antwi T, Gyiele L (2002) Income of farming systems around Kumasi, Ghana. Urban Agric Mag 7:5–6

Danso G, Drechsel P, Wiafe-Antwi T, Gyiele L (2006) Income generated by farming systems in and around Kumasi. In: van Veenhuizen R (ed) Cities farming for the future: urban agriculture for green and productive cities. RUAF Foundation, IDRC and IIRR, Ottawa, pp 205–207

Drechsel P (2006) Learning from rapid urban growth and reflection in Kumasi. Case study 25: Ghana. In: Hague C et al (eds) Making planning work. A guide to approaches and skills. Intermediate Technology Publishing, London, pp 74–75

Fedeski M, Gwilliam J (2007) Urban sustainability in the presence of flood and geological hazards: the development of a GIS-based vulnerability and risk assessment methodology. Landsc Urban Plan 83:50–61

Gilbert RO (1987) Statistical methods for environmental pollution monitoring. Van Nostrand Reinhold, New York

Golnaraghi M, Douris J, Migraine JB (2009) Saving lives through early warning systems and emergency preparedness. Risk Wise. Tudor Rose Publishing, Leicester, pp 137–141

Griggs GB, Paris L (1982) Flood control failure: San Lorenzo River, California. Environ Manag 6(5): 407-419

Holland MD, Kasanga RK, Lewcock CP, Warburton HJ (1996) Peri-urban baseline studies, Kumasi, Ashanti region, Ghana. Final technical report for project R6448, NRI, Chatham

Intergovernmental Panel on Climate Change (2007) Climate change 2007. Fourth assessment report. Cambridge University Press, Cambridge

Ireland P (2010) Climate change adaptation and disaster risk reduction: Contested spaces and emerging opportunities in development theory and practice. Clim Dev 2(4):332–345

Jenerettea GD, Marussicha WA, Newell JP (2006) Linking ecological footprints with ecosystem valuation in the provisioning of urban freshwater. Ecol Econ 59:38–47

Keraita B, Drechsel P, Huibers F, Raschid-Sally L (2002) Wastewater use in informal irrigation in Urban and Peri-urban areas of Kumasi, Ghana. Urban Agric Mag 8:11–13

Keraita B, Drechsel P, Amoah P (2003) Influence of urban wastewater on stream water quality and agriculture in and around Kumasi, Ghana. Environ Urban 15(2):171–178

Kumasi Metropolitan Assembly (2006) A profile of Ashanti region of Ghana. KMA, Kumasi

Leroy AM, Rousseeuw PJ (2003) Robust regression and outlier detection. The Wiley-Interscience Paperback Series, 360 pp. ISBN-10: 0471488550

Mabogunje AL (1990) Urban planning and the post-colonial state in Africa: a research overview. Afr Stud Rev 33(2):121–203

McGregor D, Simon D, Thompson D (eds) (2006) The peri-urban interface: approaches to sustainable natural and human resource use. Earthscan/James & James, London pp xxiv + 336

Millennium Ecosystem Assessment (2005) Ecosystems and human well-being: current state and trends. Island Press, Washington

Milly P, Betancourt J, Falkenmak M, Hirsch R, Kundzewicz Z, Lettenmaier DP, Stouffer RJ (2008) Stationarity is dead: whither water management? Science 319:573–574

Modarres R, da Silva VR (2007) Rainfall trends in arid and semi-arid regions of Iran. J Arid Environ 70:344–355

Niasse M, Afouda A, Amani A (eds) (2004) Reducing West Africa's vulnerability to climate on water resources, wetlands and desertification: elements for a regional strategy for preparedness and adaptation. IUCN, Gland pp xviii + 66

Quansah C, Drechsel P, Bakang JA (2005) Participatory communication strategies to improve natural resources management in peri-urban Kumasi, Ghana. In: Mear A (ed) Food and water for millions. Participatory communication for land and water management. IDRC, Ottawa, pp 81–88

Rietbergen S, Bishop J, Mainka S (2002) Ecosystem conservation—a neglected tool for poverty reduction. World Summit on sustainable Development. UNDP, IIED, Opinion

Sánchez-Rodríguez R, Seto KC, Simon D, Solecki WD, Kraas F, Laumann G (2005) Science plan: urbanization and global environmental change. IHDP report no. 15. International Human Dimensions Programme on Global Environmental Change (IHDP), Bonn, Germany

Secretariat of the Convention on Biological Diversity (2007) Cities and biodiversity: achieving the 2010 biodiversity target. Mayors' meeting on the contribution of cities to the achievement of the 2010 biodiversity target. Curitiba, Brazil, 26–28 March 2007. UNEP/CBD/Cities/1/3

United Nations Inter-Agency Secretariat of the International Strategy for Disaster Reduction (2005) Hyogo framework for action 2005–2015: building the resilience of nations and communities to disasters. World conference on disaster reduction 18–22 January 2005, Kobe, Hyogo, Japan (A/CONF.206/6)

Water Resources Commission (2008) Buffer zone policy for managing river basins in Ghana. Accra, Ghana

World Meteorological Organisation (2006) Environmental aspects of integrated flood management. The Associated Programme on Flood Management (APFM) technical document no. 3. Flood Management Policy Series, Geneva, Switzerland