


Correlation between flooding and settlement planning in Nairobi

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ABSTRACT

Globally, climate change triggers flooding through unpredictable, intermittent and incessant precipitation. Flooding in Nairobi is multi-factorial in causation. This has raised the question of necessary interventions in the design of urban settlements in order to reduce the impacts of extreme rainfall events that result in floods. This paper seeks to analyse the reciprocal correlation between settlement planning and pluvial flooding in Nairobi. Censuses data were obtained from the Kenya National Bureau of Statistics (KNBS) and daily rainfall records from the Kenya Meteorological Department spanning from 1961 to 2018. Other key parameters were drawn from extensive thematic content analyses of the existing literature. The data were subjected to trend and correlation analyses using the Stata and SPSS software to determine patterns and possible causal relationships. The results showed that there was an insignificant but positive relationship between the two variables with Pearson and Spearman coefficients of correlation of 0.211 and 0.111, respectively. The results of this study repudiate the perceived notion that occurrences of pluvial flooding in Nairobi have increased due to erratic precipitation patterns and improper planning of settlements. The null hypothesis is therefore upheld at 95% confidence level.

Key words: flooding, precipitation, settlements, settlement planning

HIGHLIGHTS

- The empirical scientific evidence in this study catapults the scientific debate on the need for necessary interventions in the design of urban settlements in order to reduce the impacts of extreme rainfall events that result in floods.
- The major contribution is the upholding of the null hypothesis at 95% confidence level on the nexus between settlement planning and flooding in Nairobi from 1961 to 2018.

1. INTRODUCTION

Pluvial flooding has continued to wreak havoc in Nairobi in recent years due to erratic precipitation patterns and demographic changes (Simperler *et al.* 2019). Anthropogenic forces have led to urbanization and changes in global climate (Onwuemele 2015). Urban environmental risks such as flooding have increased in complexity, nature and scale due to steady development of urban settlements (Ziervogel *et al.* 2016; Salami *et al.* 2017). Ill-structured development planning coupled with unplanned land use have led to a higher vulnerability of settlements located in flood-prone areas (Niyongabire & Rhinane 2019). Shareef & Abdulrazzaq (2021) note that exponential increase of urbanization and ‘mismanagement of land utilization’ have greatly contributed to flooding in urban areas. Urban flooding has cascading effects on drainage systems, mobility, waste collection services and power (Barreiro *et al.* 2021).

A plethora of scholars have carried out research on climate change, flooding and physical planning of Nairobi in general and independently but a settlement-based approach is missing. Other studies have concentrated on the encyclopaedical approach of documenting the historical urbanization, social and cultural problems of the city without suggesting remedies. Oyugi *et al.* (2017) analysed land use and land cover dynamics on the environmental quality of Nairobi. Mwaniki *et al.* (2015) have highlighted the housing challenge without addressing the totality of settlements. Opiyo (2009) examined the historical planning mistakes for Nairobi and resultant pollution from transportation, housing, energy and industrial sectors. Burra (2005) investigated slum upgrading, its possibilities and constraints. Manda (2007) researched on access to land and

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housing fund for the poor. [Mundia & Aniya \(2007\)](#) analysed urban expansion of Nairobi. However, the above researchers failed to address the nexus between settlement planning and flooding in Kenya's capital city. Thus, the impact of assessments of settlements and the related uncertainty of urban flooding is the crux of the research presented in this paper.

This paper is structured into four major sections. Section 1 introduces the study topic, problem statement, research gap and aim. Section 2 discusses the methodology employed. Section 3 analyses and presents key findings. Section 4 provides the conclusion and recommendations of the study.

2. MATERIALS AND METHODS

To analyse the relationship between flooding events and settlement planning in Nairobi, two measurable variables were used as proxies for the two phenomena. Monthly average number of extreme events was used as a proxy of flooding events and urban population growth rate was used as a proxy of settlement planning. The Kenya Meteorological Department (KMD) provided daily rainfall data from 1961 to 2018. Population data were retrieved from censuses of 1962, 1969, 1979, 1989, 1999, 2009 and 2019 conducted by the Central Bureau of Statistics (prior to 1972) and the Kenya National Bureau of Statistics (after 1972). The study used Pearson and Spearman correlation coefficients to establish the relationship between the two variables. Other key parameters were drawn from an extensive thematic content analyses of the existing literature of Nairobi's settlements.

2.1. Assumptions

Two major assumptions for standard parametric technique for correlation analysis are absence of outliers and normality distribution. These assumptions were first tested on both variables to establish whether or not they passed for parametric analysis.

2.2. Study area

The study area shown in [Figure 1](#) lies within latitudes 1°16'30"S and 1°6'0"S and longitudes 36°39'0"E and 37°10'30"E within Nairobi and Kiambu counties, in Kenya. The catchment covers an area of 965.03 km². The area slopes from 2,380 m at the head waters to 1,440 m at the outlet of the Nairobi river. The study area was chosen due to the extent and magnitude of flooding as well as dense location of settlements in flood-prone areas along the tributaries of the Nairobi river.

2.3. Sample and sampling procedures

According to the KMD, any rainfall less than 5 mm was categorized as light. A range of 5–20 mm was categorized as moderate. A range of 21–50 mm was categorized as heavy. Any record above 51 mm was categorized as very heavy rainfall. In this study, any rainfall event with above 21 mm of precipitation was used as a proxy for flooding while population was used as a proxy for settlements. Correlation analyses were used to reveal the existence of relationships between settlement planning and flooding. The Pearson and Spearman coefficients were used to determine linear relationships between the variables. Any coefficient value greater than 0.05 implied that the coefficient was not statistically significant at 95% confidence level.

3. RESULTS AND DISCUSSION

3.1. Historical overview of Nairobi

Nairobi takes its name from the Maasai phrase '*enkarē nairobi*', which means 'a place of cool waters'. The area was originally a grazing land and a livestock watering point and there was no permanent settlement ([Schlyter & Freeman 2006](#)). Nairobi was first settled as a transport depot in 1896. Its main attractions were cool climate and clean water. The city of Nairobi owes its early development and growth to the Kenya–Uganda Railway which was constructed between 1895 and 1905. It was considered to be a halfway point between Mombasa and Port Florence (currently Kisumu). The railhead reached Nairobi in May 1899 and by July it had become the headquarters of the Kenya–Uganda Railway ([Syagga et al. 1999](#)). This led to Nairobi's growth as a commercial and business hub of the British East Africa protectorate.

In 1902, a bubonic plague epidemic struck the Indian bazaars in Nairobi after a private company that was contracted to offer sanitation services failed in its duties ([Pollitzer 1951](#)). In 1904, a second plague struck. Consequently, a commission was set up in 1906 to investigate Nairobi's sanitary conditions. The commission found Nairobi to be unsuitable for further development and recommended its relocation. However, due to lack of political goodwill, its relocation was shelved. In 1912, a third plague struck the then Nairobi town. Simson Commission was thereafter formed and it recommended racial segregation

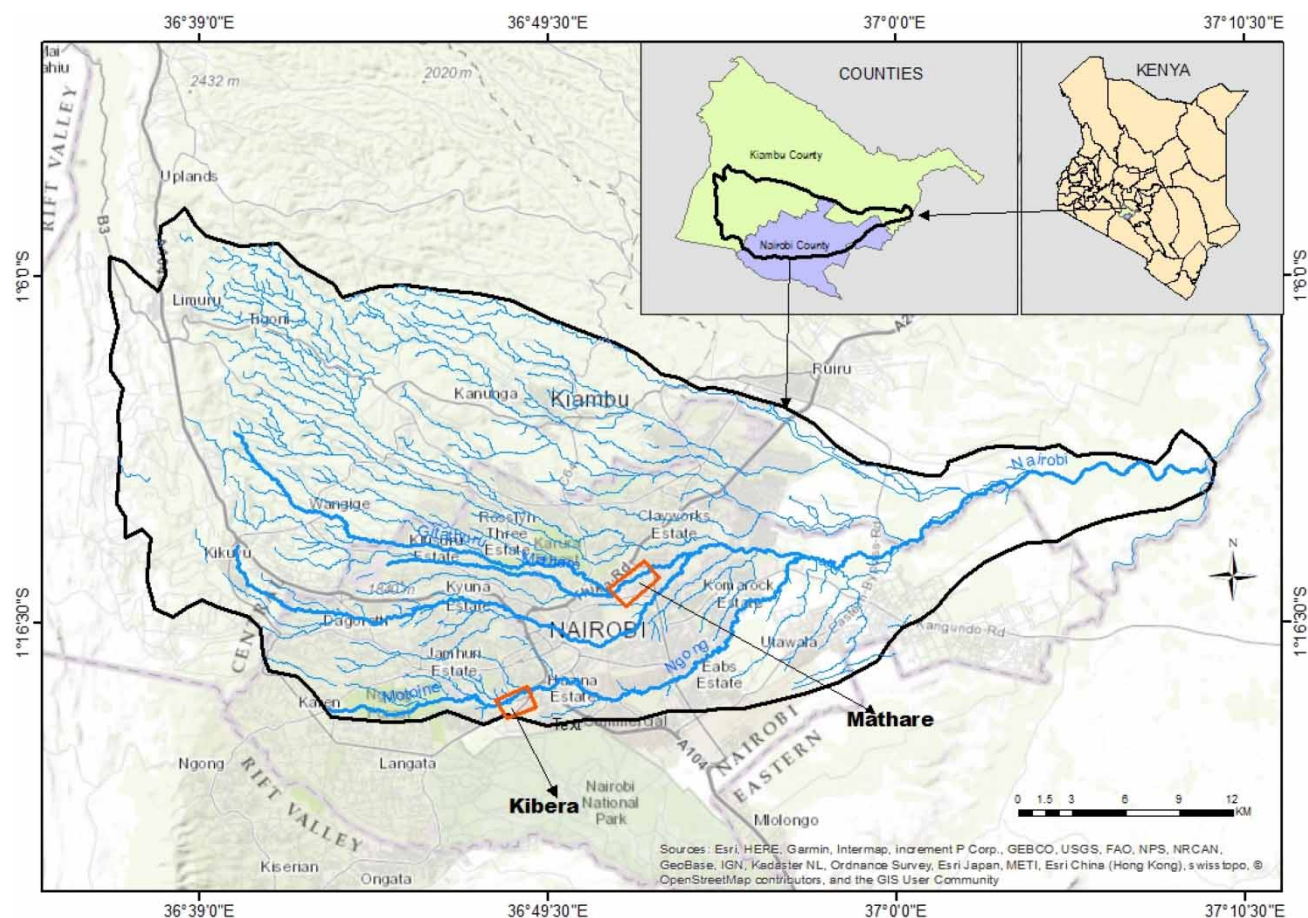


Figure 1 | Study area. (Sources: ESRI, HERE, Garmin, Intermap, Increment P Corporation, GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, 2018.) Inset: Location of study area within Kiambu and Nairobi counties in Kenya.

whereby Europeans, Indians and Africans were to live in separate quarters (Amis 1984). In 1919, a full-fledged Nairobi Municipal Council was established after the municipal committee was disbanded (Olima 2001).

3.2. Settlement planning and spatial development in Nairobi

This section has detailed the process of settlement planning and spatial development in Nairobi from 1901 to date. The population of Nairobi had risen to 10,000 inhabitants during the town's founding period of 1899–1903 (Mitullah *et al.* 2001). Racial segregation was the basis of the Nairobi settlement plans of 1905, 1927 and 1948 (Mitullah *et al.* 2001).

In 1905, the Nairobi city plan covered an area of 18 km² (see [Figure 2](#)) and it was predominantly a railway town ([Mwaniki et al. 2015](#)). Nairobi exhibited segregation between the central business district (CBD) together with European, Asian and African residential areas based on its historical spatial patterns. By 1906, Nairobi had the following functional zones: railway centre, railway workers' quarters, European business and administrative centre, Indian bazaar, washer man's quarters and military barracks outside the town. It became the administrative capital of Kenya in 1907. By 1909, much of the internal structure especially the road network had been developed.

In 1927, a second city plan was prepared which made Nairobi to be a settler capital. According to [Van Zwanenberg \(1972\)](#), Nairobi was the headquarters of the European settlers. It was both a collection centre and distribution point for exports produced in the highlands. The boundary of Nairobi was extended to cover 30 square miles (77 km²) mainly as a result of the rapid growth of the urban centre in terms of population and infrastructure. Transport networks were extended to service newly acquired land. In 1928, Justice Feedham Commission reviewed the town's structure and development. It proposed a change in the boundary which then led to the creation of the Nairobi Extra Provincial District of 1928. Later in 1950, Nairobi

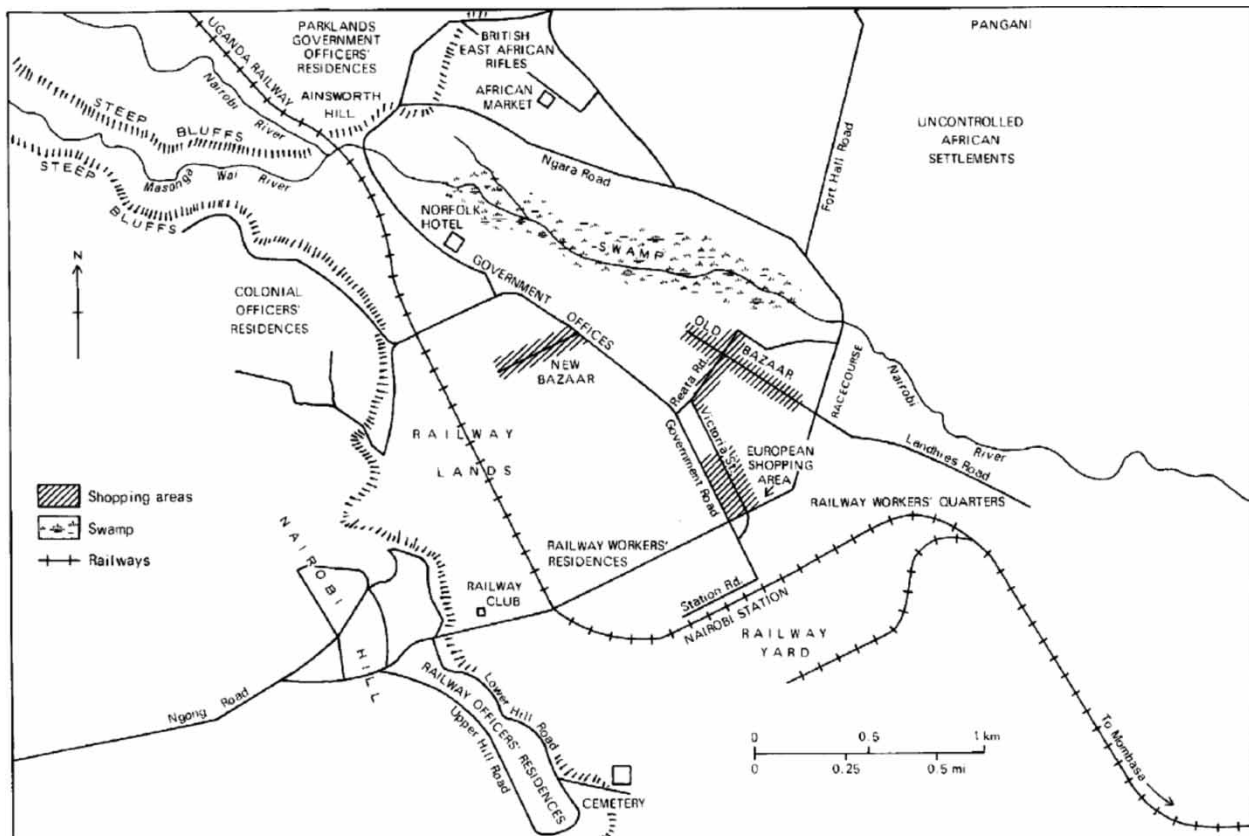


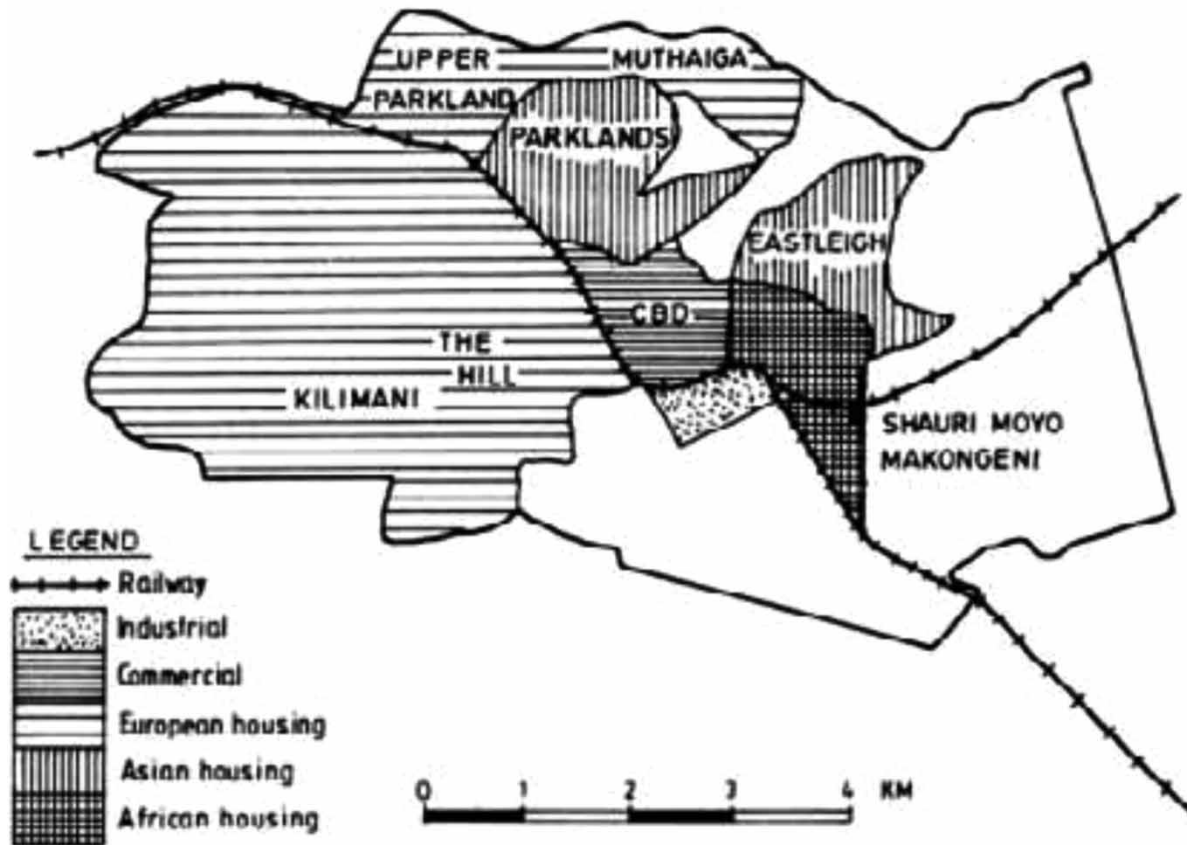
Figure 2 | Nairobi city plan (1905). Sources: [Martin & Bezemer \(2019\)](#); [Schlyter & Freeman \(2006\)](#). Detail from W.T.W. Morgan. *Nairobi City and Region*. Nairobi, Oxford University Press.

became a city. From 1928 up to 1963, this boundary remained the same with only minor additions and excisions taking place ([Makworo & Mireri 2011](#)).

Thorton-White prepared the 1948 Nairobi Master Plan (refer to [Figure 3](#)). The city size increased to 83 km². Functionalism was its ordering principle. According to [Vogel \(2008\)](#) and [Nairobi City County \(2014\)](#), the new zones were Kenya centre, official housing, residential, industry, official buildings, business and commerce, railway, open space, and forest reserve and park zones. It was based on the European model of urban form rather than the traditional African settlement pattern ([Obudho 1997](#)).

The master plan was inspired by the colonial planning approach and it advocated for racial segregation ([Muraya 2006](#)). The British model of the garden city informed the development of Nairobi. The European housing occupied the western and north western side of the city where soils were red, and rent and land values were high. Africans were designated to settle next to industrial areas on the eastern and southern side of the city. Asians settled in the north eastern side.

The population grew to 118,579 in 1948 ([Rakodi 1997](#)). The Nairobi Municipal Committee Regulations of 1960 defined the initial boundaries for the then Nairobi town as 'the area within a radius of one and a half miles from the offices of the sub-commissioner of the then Ukambani province' ([Mitullah et al. 1999](#): p. 2; [Obudho & Aduwo 1992](#): p. 51). By 1962, the city had a population of 343,500 people, although some of this could be attributed to extension of the city's boundaries ([Syagga et al. 1999](#)). Between the 1948 and 1962 censuses, the population grew at an average rate of 5.9% per annum, compared with 7.6% in the previous 12-year period. According to [Amis \(1984\)](#) and [Huchzermeyer \(2008\)](#), Africans were required in Nairobi mainly for their labour. Colonialists viewed Nairobi as 'no man's land' thus [Oyugi & K'Akumu \(2007\)](#) note that they gave leases with a validity period of up to 999 years. [Amis \(1984\)](#) and [Van Zwanenberg \(1972\)](#) note that the city plans of Nairobi of 1905, 1927 and 1948 had high planning standards to the extent that most Kenyan residents could not manage to stay in well-planned estates due to the tough economic conditions they faced at that time.



Source: Nairobi Municipality 1948. Eighteenth Annual Report of the Medical Officer of Health, 1947
Nairobi DL Patel Press (African Urban Quarterly Vol 7 Nos 1&2: 1992: 56)

Figure 3 | Nairobi municipality (1948). Source: Mitullah *et al.* (2001).

In 1963, the boundary of Nairobi was extended to cover an area of approximately 688.9 km². No boundary changes have taken place since then. From 1986, the city's functions have evolved and widened such that currently it is still dominating the political, social, cultural and economic lives of the people of Kenya and the wider Eastern Africa region (Mitullah *et al.* 2001; UN-HABITAT 2003).

Figure 4 illustrates the boundary changes that took place from 1900 to 1963 after which they have not changed. The population of the town, however, changed significantly. Its main sources of growth were in-migration especially from the former Central province (currently Kiambu county). The long-distance sources were mainly from the former Eastern, Nyanza and Western provinces of Kenya (Obudho & Aduwo 1992: p. 58). Other sources of the population growth were the boundary changes and natural growth factors.

By 1963, the Africans who formed a major part of the population lived in the eastern parts, while the Europeans and Asians lived in the western suburbs with access to better services. This position is reflected today not so much in terms of race, but rather in terms of incomes as well as population densities. The people living in the western suburbs are generally the more affluent while the lower and middle-income elements of society dominate the eastern suburbs. Nairobi displays a complex surface structure, making it difficult to decipher the city surface into distinct land uses. Inevitably, there are wide variations in population density reflecting different land utilization patterns within what Obudho & Aduwo (1988) see as six distinct and different land use divisions, namely the CBD, industrial area, public and private open spaces, public land, residential areas and undeveloped land. The spatially divided internal structure is based on land uses and income levels (Olima 2001).

According to Mabogunje (1970), the three main categories of government housing policies are laissez-faire, restrictive and supportive policies. Laissez-faire policies tend to pump financial resources to other development sectors and totally disregard

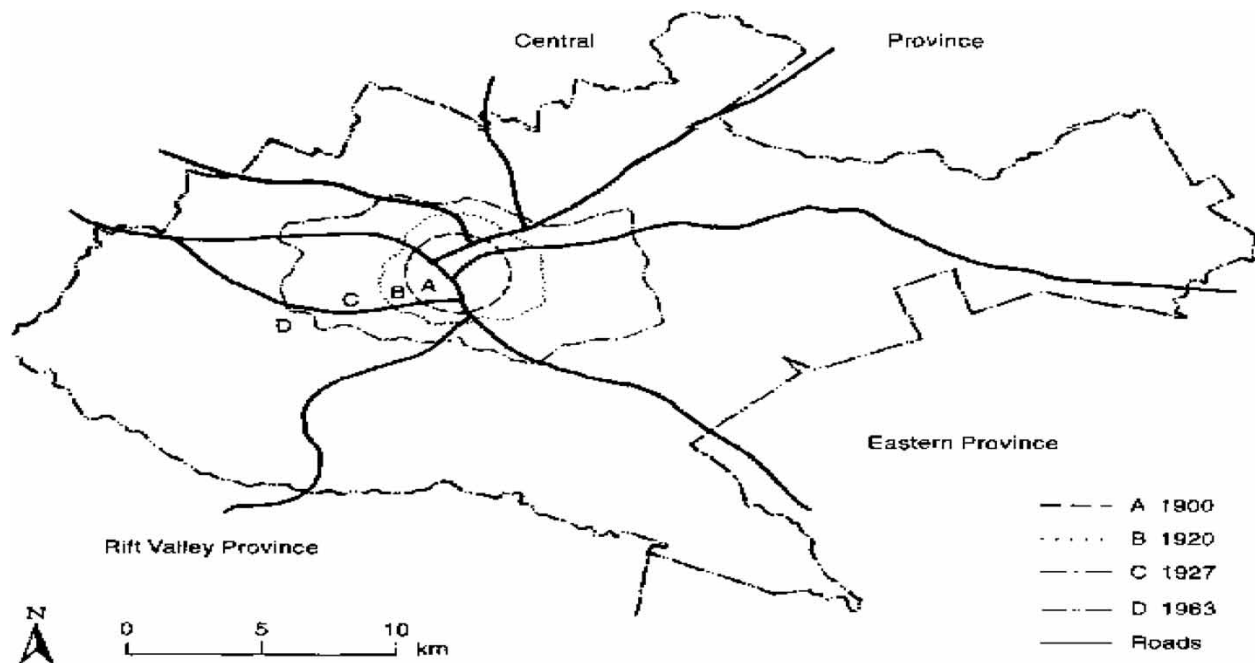


Figure 4 | Nairobi spatial expansion (1906–1963). Source: Obudho & Aduwo (1992: p. 53).

the housing problems. Between 1901 and 1963, the government of Kenya had a laissez-faire attitude towards urban housing problems. It was up to the employers of the private sector to resolve the housing challenge.

Between 1963 and early 1970s, the government policy changed to restrictive. Restrictive policies tend to do away with low-income neighbourhoods through exclusion from urban services such as water, electricity, sewerage systems, educational and health care facilities to discourage residents from residing in those areas. This can be achieved through relocation programmes or complete demolition of communities at short notice.

Between late 1970s and to date, the policy has been supportive. Supportive policies aim at uplifting the standard of living for the low-income cadre of the society. The government has provided land and built complete dwelling units with public facilities. Examples of supportive policies are site-and-service schemes, public-housing projects and community upgrading programmes (Obudho & Aduwo 1989).

Colonial policies and laws which curtailed the migration of Kenyans to Nairobi were relaxed when Kenya became independent in 1963. Consequently, California estate in Pumwani/Majengo area of Nairobi was the first public-housing programme that began in early 1960s. Ziwani, Starehe and Makongeni followed as among the first housing estates to be planned for Africans in Nairobi, according to Obudho & Aduwo (1989). The principle used was a 'Neighbourhood Unit' which had a social centre, beer shop, schools, clinic and shops. Settlement schemes such as Kariokor, Mariakani, Jerusalem, Lumumba and Jericho were built in early 1960s. However, the upsurge in population in Nairobi meant that these estates were inadequate to accommodate all Africans; thus, slums and squatter settlements sprung up. Mathare Valley and Kibera can be traced to as early as 1940s since they were near employment centres.

A Central Housing Board through the Housing Ordinance was established by the Colonial Government in 1953 to promote the development of houses for Africans. In 1959, Europeans and Asians were incorporated into the Board's activities. The National Housing Corporation (NHC) was established after an amendment of Housing Ordinance of 1953. To date, it is the government's main agency through which public funds for low-cost housing are channelled.

Sessional paper No. 5 of 1966–1967 was the housing policy developed after the United Nations Technical Assistance (UNTA) national housing survey was done in 1964. The land planning act of 1968 advocated for town plans in order to control urban development (Mwaniki *et al.* 2015). The town plans, however, were not effective since the machinery of preparation and details of town plans were not clearly articulated. Secondly, there was no public participation. Obudho & Aduwo (1989) observed that 70% of the urban population comprised of the lowest-income group. They lacked housing

since the constructed houses were for the middle-income group. This led to proliferation of unplanned urban settlements built using any available material.

The Nairobi Metropolitan Growth Strategy was developed in 1973 (Mitullah *et al.* 2001). It was to guide the development of Nairobi up to the year 2000. In 1984, the then city commission developed the 1984–1988 Nairobi City Commission Development Plan which grouped the needs of Nairobi residents into sectors. These included housing, transport and public works, social services, health and environment, sewerage, manpower development and financial management (Nairobi City Commission, 1985).

A forum of stakeholders was held in 1993 dubbed the Nairobi City Convention which grouped its recommendations into political, administrative and legal issues; the physical environment and use of space issues; social sector issues and services provision problems (Karuga, 1993). In 1995, 'Code 95' by-law was initiated by the state. The aim was to deal with typical realities of poor households, use of innovative building materials, alternative building technologies and minimize space standards aimed at reducing overall building costs. Studies by Anderson (1977), Devyer (1981) and Syagga (1993) advocated for the use of local materials such as compacted hardcore in mesh cage formwork for foundation; stabilized soil blocks for walls; stabilized earth for floors; alternative binders, for example, pozzolanas from rice husks and ash (RHA) and fibre concrete tiles (FCR) for roofing in order to save on construction costs. However, these recommendations required parliamentary approval for them to be legally operational. Unavailability of legislation on innovative alternative construction materials has constrained their permissibility in the building sector. The physical planning act of 1996 followed. It provided for the preparation of regional and local physical development plans. However, according to Mwangi (1997), landlords and tenants did not participate in the development of the plans.

In 2004, a new housing policy was formulated since the Nairobi metropolitan growth strategy had expired in 2000. The policy promoted funding of low-cost building materials and construction techniques through creation of a Housing Development Fund to be financed through budgetary allocations and development partners (GoK 2004). It advocated for harmonization of urban development laws and embraced integrated strategies in scaling-up housing production, shifting towards pro-poor approaches and slum upgrading (Mwaniki *et al.* 2015).

Kenya's Vision 2030 launched in 2007 aimed at increasing the annual production of housing units from 35,000 to 200,000 annually (GoK 2007). One of its flagship projects for housing and urbanization was the metropolitan plan for six regions, among them was Nairobi. Thus, the Nairobi Metropolitan Region (NMR) was created in 2008 that extended the boundary to cover northern Kajiado, western Machakos and southern Kiambu counties. This brought the new total area of Nairobi Metropolis to 32,000 km². The spatial development plan took into consideration economy, transport, physical infrastructure, land use, social demography, environment, landscape, urban design and institutional framework (GoK 2012). The 'Nairobi metro 2030: a world class African metropolis' strategy document formulated an approach based on three parameters: space as a field of activity, space structuring for sustainable co-existence and space quality best suitable for different activities. The proposed spatial pattern for the NMR combined three patterns; polynucleated development, bi-polar corridor development and corridor-cum-ring development. Consequently, six levels of settlement hierarchy were proposed: regional centres, sub-regional centres, priority towns (new town), growth centres, market centres and basic villages.

Polynucleated development is characterized by polycentric network of nodes with none dominating the other. It is advantageous in that it accelerates growth of regional towns and ensures stronger connectivity among the regional centres. Its main disadvantage is deceleration of growth of Nairobi. Bi-polar corridor development has minor settlements along transport corridors connecting two nodes. It is advantageous in that it has strong axial development and high technology transport networks that can be developed along the corridors. However, its weakness is that it leads to neglect of the rest of the urban areas. Corridor-cum-ring development is characterized by settlement developments along the corridors and rings. It is advantageous in that it has high intensity development along city centres and a medium-capacity transport system. However, its weakness is that massive investments on the transport infrastructure are required (GoK 2012).

In 2013, a spatial planning concept for Nairobi metropolitan region (SPCNM) was formulated (GoK 2012; NCC 2013). It aimed at providing settlement pattern, settlement hierarchy and land use guidelines. The outcome was the unveiling of the Nairobi integrated urban development master plan 2014–2030 (NIUPLAN) to be the city's development framework from 2014 to 2030.

On 12 December 2017, the government identified 'affordable housing' as one of its four main agendas. The aim currently is to provide 500,000 decent, affordable housing units by 2022 in three main housing levels namely social housing (income of

KSh.1–14,999), low cost (income of KSh.15,000–49,999), and middle to high income range (income of KSh.50,000–99,999) (GoK 2018, 2019).

3.3. Relationship between population growth rate and number of extreme rainfall events in Nairobi

The average number of extreme rainfall events has been fluctuating from a minimum of zero (0) to a maximum of 19.42 with a mean of 5.78. On the other hand, urban population growth rates seem to have been fairly stable throughout the time interval. Urban population growth rates have been fluctuating fairly from a minimum of 4.04 to a maximum of 8.17 with the mean of 5.43. Table 1 presents the summary of selected statistics to describe the variables of study.

Trends of the two variables can clearly be seen when the variables are plotted against the time interval. Furthermore, graphs were produced to clearly display the variables' properties over time. The graph provided an easy way of assessing how the variables are trending over time (see Figures 5 and 6).

Figure 5 shows that the monthly average of extreme rainfall events has been fluctuating between 0 and 20 throughout the entire period of study. However, the fluctuations seem to have been declining from above 10 in 1960s and 1970s to below 5 from 2010 to 2018. The trend of extreme rainfall events has been decreasing at a rate of 0.0981 per year from 1961 to 2018. Similarly, studies by Kilavi *et al.* (2018); Parry *et al.* (2012), concur with the findings of this study by noting that 17 major events occurred in Kenya between 1964 and 2004.

On the other hand, the Nairobi population growth rate seems to have been exponentially increasing at a rate of 70,517 people per year from 1963 to 2019 with a correlation coefficient of 0.9401. However, the inter-censal growth rate declined from 2.9 during the 1999–2009 period to 2.2 during the 2009–2019 (Kenya National Bureau of Statistics 2019: p. 6). A study by Muthoni (2016), concurs with the findings of this study by noting that Nairobi had one of the highest growth rates in Africa at 4.1%. Table 2 shows the population density of Nairobi between 1906 and 2019. Nairobi as at 2019 had a total population of 4,397,073 people (Kenya National Bureau of Statistics 2019: p. 7).

Table 1 | Relationship between variables

Variable	N	Mean	Maximum	Minimum
Number of extreme rainfall events	44	5.78	19.42	0.00
Population growth rate	57	5.43	8.17	4.04

Source: Authors' computation from field data, 2019.

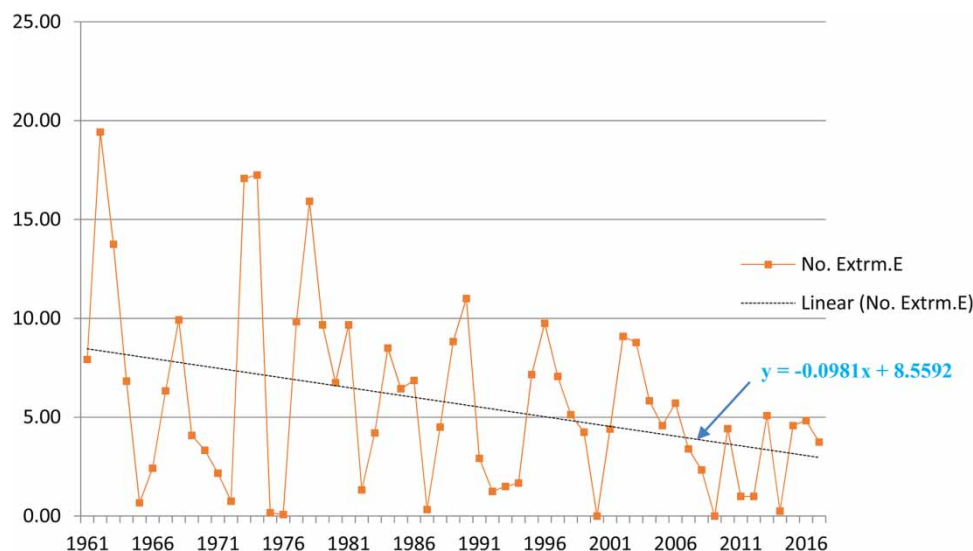


Figure 5 | Monthly average number of extreme rainfall events. Source: Authors' computation from field data, 2019.

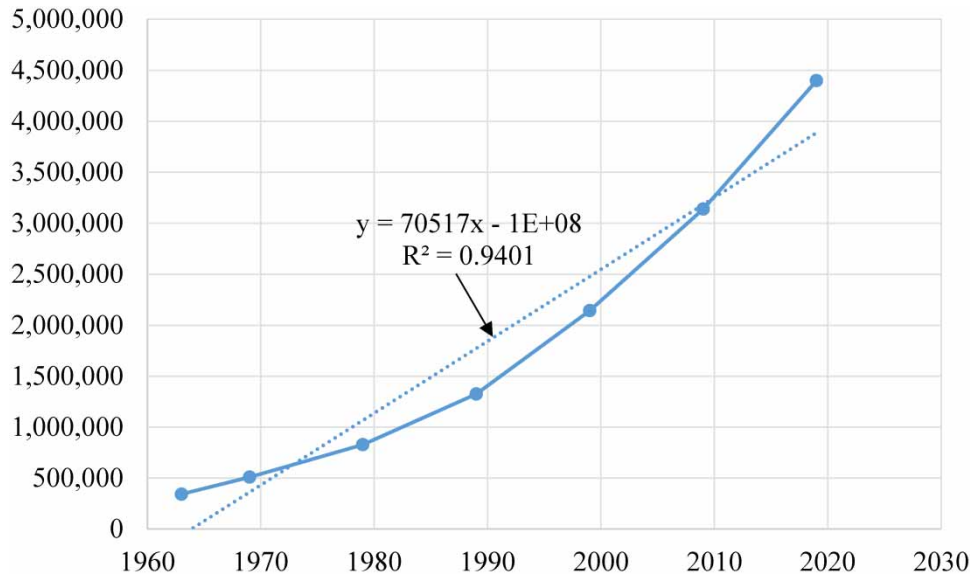


Figure 6 | Nairobi population's growth rate. *Source:* Authors' computation from field data, 2019.

Table 2 | Population of Nairobi (1906–2019)

Year	Area (hectares)	Population	% Increase in population	Density (persons per hectare)
1906	1,813	11,512	–	6
1928	2,537	29,864	159.4	12
1931	2,537	47,919	60.5	19
1936	2,537	49,600	3.5	20
1944	2,537	108,900	119.6	43
1948	8,315	118,976	9.3	14
1963	68,945	342,764	188.1	5
1969	68,945	509,286	48.6	7
1979	68,945	827,755	62.5	12
1989	68,945	1,324,570	60.0	19
1999	68,945	2,143,254	61.8	31
2009	68,945	3,138,369	46.43	45.52
2019	68,945	4,397,073	40.1	63.78

Sources: Olima (2001); GoK (2010); Kenya National Bureau of Statistics (2019).

3.4. Relationship between flooding events and settlement planning in Nairobi

Figure 7 shows that the annual rainfall trend was decreasing at a rate of 1.267 per year from 1961 to 2018. This result is consistent with the findings of Kilavi *et al.* (2018). Correlation analysis was used to analyse the relationship between flooding events and settlement planning. The analysis helps in understanding whether or not there exists a significant relationship between the variables. If a relationship does exist, the analysis also helps to understand the nature (positive or negative) and the significance of the relationship.

However, there exists some pre-conditions to be considered before performing the analysis depending on the nature of data and the correlation technique/coefficient to be used. These conditions ensure that the analysis does not give spurious results. The conditions are further discussed in subsection 3.4.1.

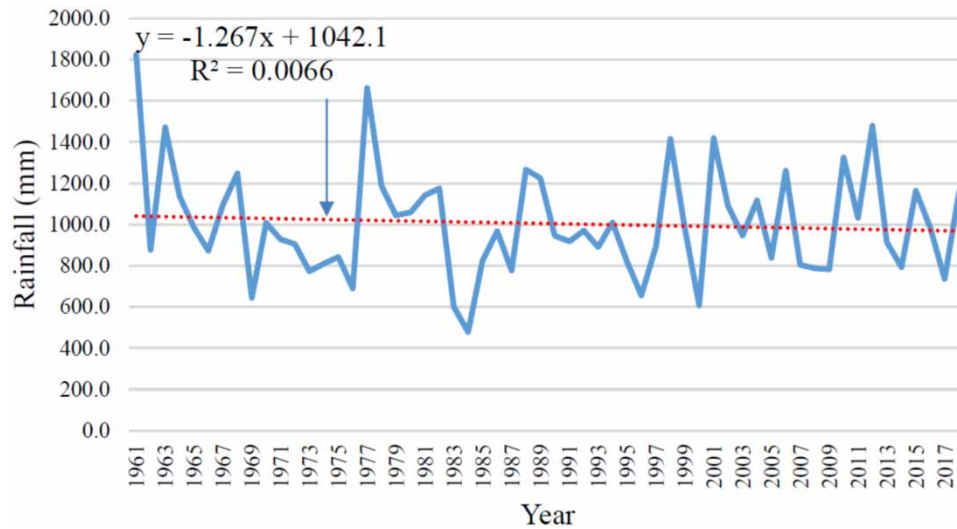


Figure 7 | Total annual precipitation. *Source:* Authors' computation from field data, 2019.

3.4.1. Stationarity tests

Since both variables are time series, it is required that the correlation coefficients are produced with stationary series. Therefore, both variables were tested for stationarity and differenced (if not stationary) until stationarity was achieved to satisfy the condition for the used correlation coefficients. The Phillip Perron test was used to test the stationarity of the variables. Table 3 presents the results of stationarity tests for both variables.

Stationarity was tested on both variables at level, and the results in Table 3 show that only average number of extreme events was stationary at level. The urban population growth rate was not stationary at level. The non-stationary variable was then subjected to first differencing in an attempt to stationarize it. The results in Table 4 show that urban population growth rates became stationary after first differencing. Further analyses can therefore be done between average number of extreme events and the first differenced urban population growth rates.

3.4.1.1. Outliers. Box plots were used to check whether the variables contained potential outliers.

The plot for each variable was produced and potential outliers are presented by a star (*) while non-potential outliers are presented by a circle (○). Figures 8 and 9 present the box plots for average number of extreme events and first differenced urban population growth rates, respectively. Figure 8 shows the variable, average number of extreme events, contained only one outlier corresponding to observation number 58. Since the identified outlier was non-potential, this variable passes the assumption of no outliers. Additionally, Figure 8 shows that the variable, first differenced urban population

Table 3 | Test of stationarity at level

Variable	$Z(t)$	p -value	Comment
Number of extreme events	-4.357	0.0004	Number of extreme events is stationary
Population growth rate	-1.292	0.6327	Population growth rate is not stationary

Source: Authors computation from field data, 2019.

Table 4 | Test of stationarity after first differencing

Variable	$Z(t)$	p -value	Comment
Population growth rate (d1)	-6.166	0.000	Population growth rate (d1) is stationary

Source: Authors computation from field data, 2019.

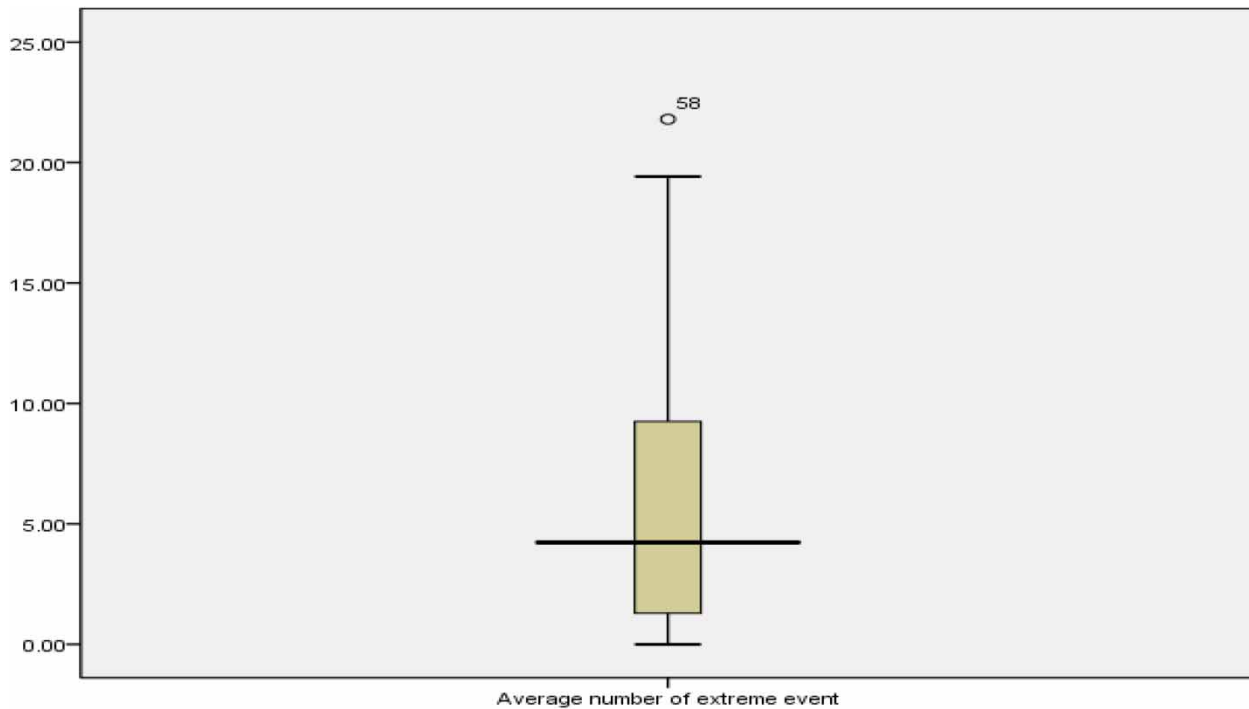


Figure 8 | Box plot for average number of extreme events. *Source:* Authors' computation from field data, 2019.

growth rates, contained some potential outliers. The box plot outlined these potential outliers to correspond to observation numbers 10, 30, 3, 11, 21 and 20. The total number of observations were 56 which was large enough to allow dropping the six outliers without potentially decreasing the total number of observations. The box plot was then produced to see whether the

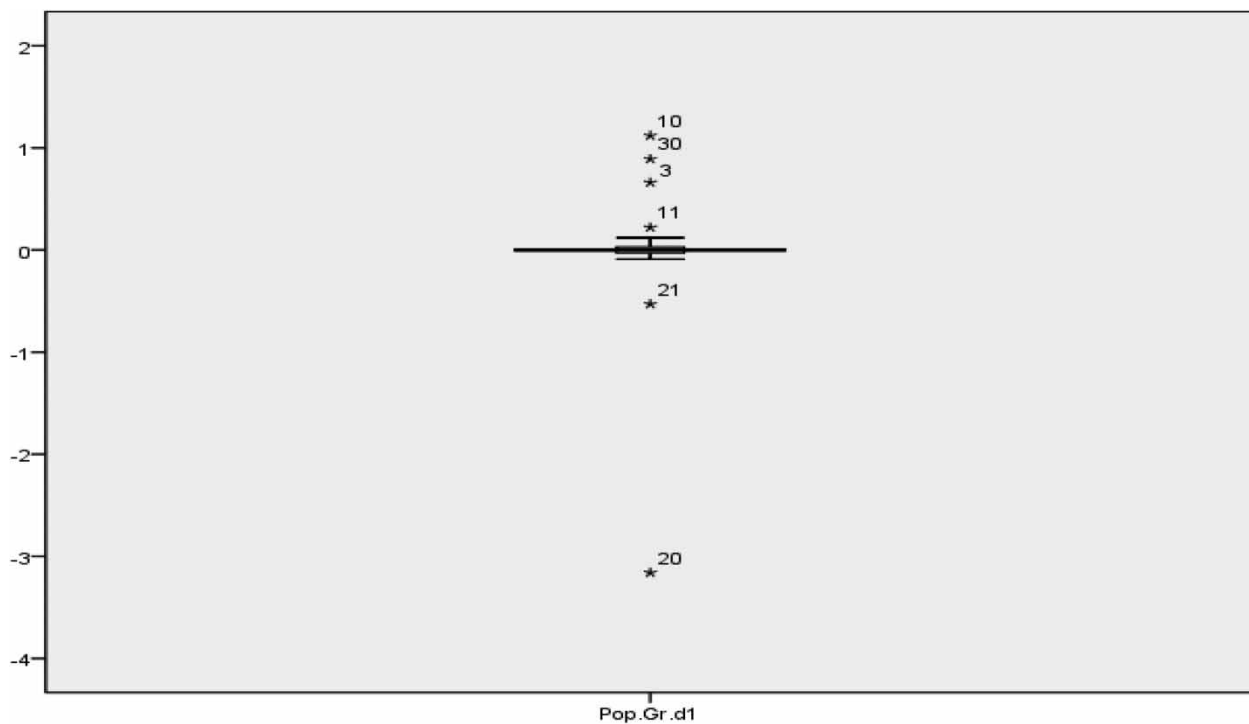


Figure 9 | Box plot for first differenced urban population growth rates. *Source:* Authors' computation from field data, 2019.

variable no longer contained potential outliers after dropping the pre-identified outliers. Figure 10 shows that the first differenced urban population growth rates no longer contained potential outliers and hence passed the assumption.

3.4.1.2. Normality distribution. Observations in each variable were tested on whether or not they followed a normal distribution using the Shapiro–Wilk test. Results of the normality test are presented in Table 5 which shows that both variables population growth rate (d1) and number of extreme events are not normally distributed. However, the variable (number of extreme events) can easily be normalized using the natural logarithm transformation.

3.4.1.3. Correlation coefficients. Spearman's correlation coefficient is a non-parametric technique for studying relationships between variables. This coefficient was used since both variables were found to have non-normal distribution before transformation. The non-parametric technique was thus appropriate for untransformed variables.

Pearson's correlation coefficient was applicable under the assumption that, the variable population growth rate (d1) was approximately normally distributed. This allowed the parametric analysis to be done because the variable (number of extreme events) was found to be normally distributed after transformation as presented in section 3.2.2.2.

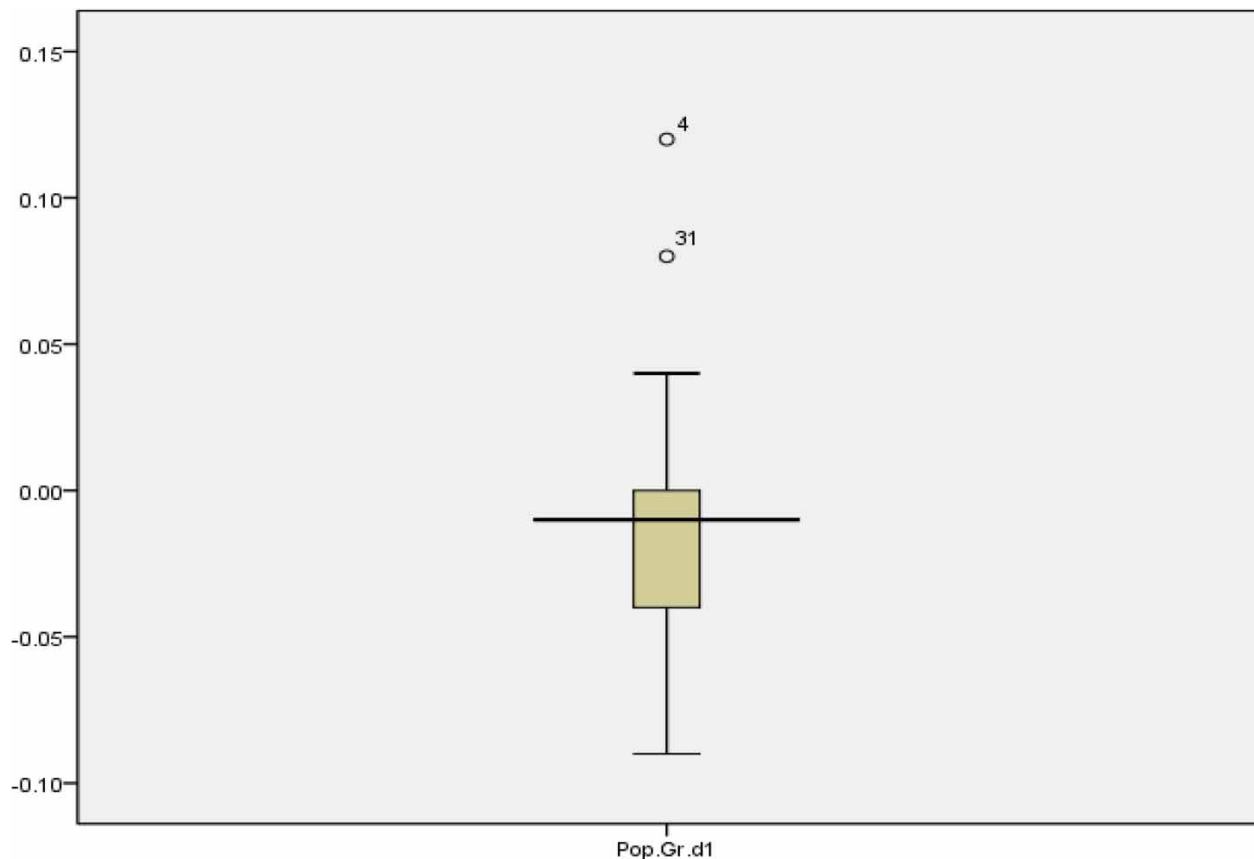


Figure 10 | Second box plot for first differenced urban population growth rates. *Source:* Authors' computation from field data, 2019.

Table 5 | Shapiro–Wilk test of normality

	Statistic	Sig. value	Comment
Population growth rate (d1)	0.925	0.008	Not random
Number of extreme events	0.067	0.000	Not random
Log of average number of extreme events	0.950	0.073	Random

Source: Authors' computation from field data, 2019.

Therefore, parametric coefficient was produced using variables population growth rate (d1) and log of average number of extreme events while non-parametric coefficient was produced using variables: population growth rate (d1) and number of extreme events. For each set of variables, a scatter plot was first produced to give a picture on how the variables relate.

Both Figures 11 and 12 suggest that no linear relationship exists between the sets of variables. To further investigate this, both parametric and non-parametric correlation coefficients were produced and presented in Table 6.

Under these techniques, the null hypothesis tested claims the non-existence of significant correlations. The coefficients of 0.211 and 0.111 suggest the existence of an insignificant positive relationship between the variables. Additionally, their corresponding significance values of 0.239 and 0.519, respectively, which are greater than 0.05 indicate that the coefficients are not significant at 95% confidence level.

4. CONCLUSIONS AND RECOMMENDATIONS

Both parametric and non-parametric techniques produced insignificant coefficients of correlation between population growth rate and average number of extreme rainfall events. The study therefore concludes that there is an insignificant but positive relationship between flooding and settlements from 1961 to 2018. Precipitation data from the KMD revealed that rainfall amounts had been declining steadily from 1961 to 2018. However, the paradox was that flooding continued to pound the city. Floods have been more pronounced with higher intensity and severity in recent years.

Nairobi lacks an approved master human settlement plan as documented in Oyake *et al.* (2007). Thus, urbanization is occurring rapidly in a planning vacuum. The only approved plan for Nairobi is the 1948 masterplan. The 1973 version was never approved, according to NEMA (2003). As an incontrovertible consequence, this has contributed to the negative effects of improper settlement planning, such as haphazard development. An increase in settlements due to rapid population growth has led to significant concretization and hard landscaping of once permeable ground surfaces thus making them impervious mainly due to construction of housing, commercial, educational, transportation infrastructure and industrial developments. The consequential change in the land use pattern has led to higher flood peaks and volumes even for short-duration low-intensity rainfall. Thus, rapid unplanned urbanization has adversely intensified the hydrological cycle in Nairobi leading to a flooded urban environment.

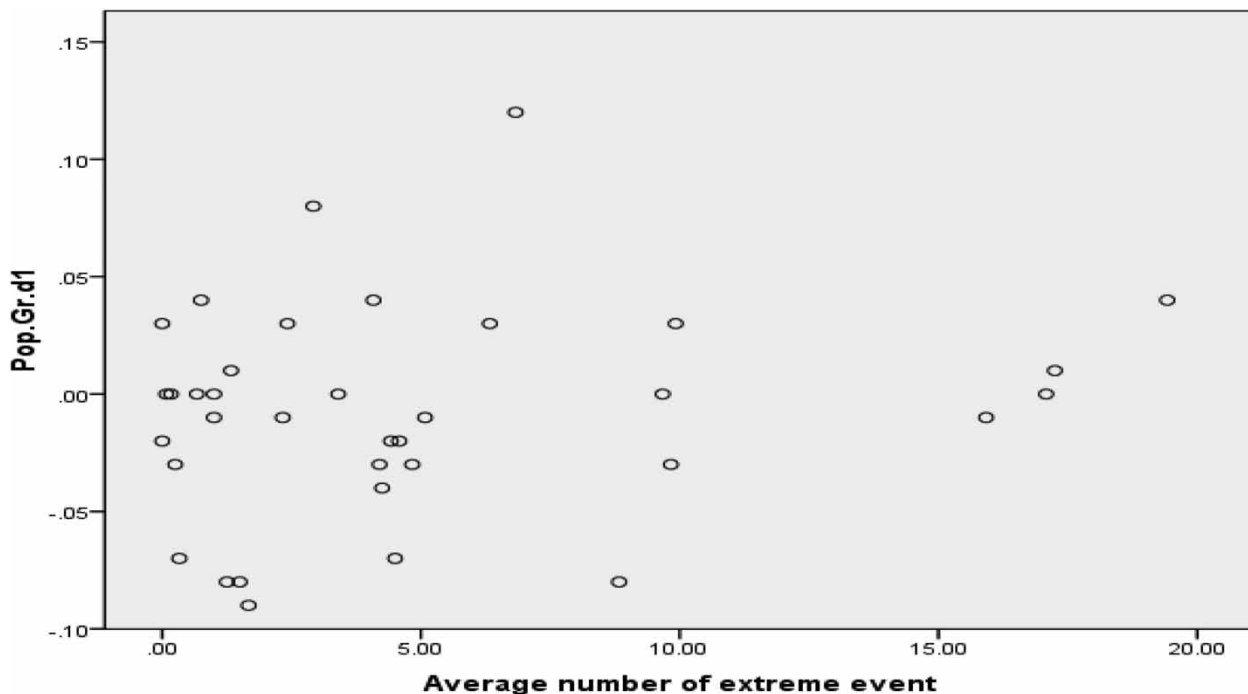


Figure 11 | Scatter plot for urban population growth rates (Pop.Gr.d1) against average number of extreme events (No.Extrm.E). *Source:* Authors' computation from field data, 2019.

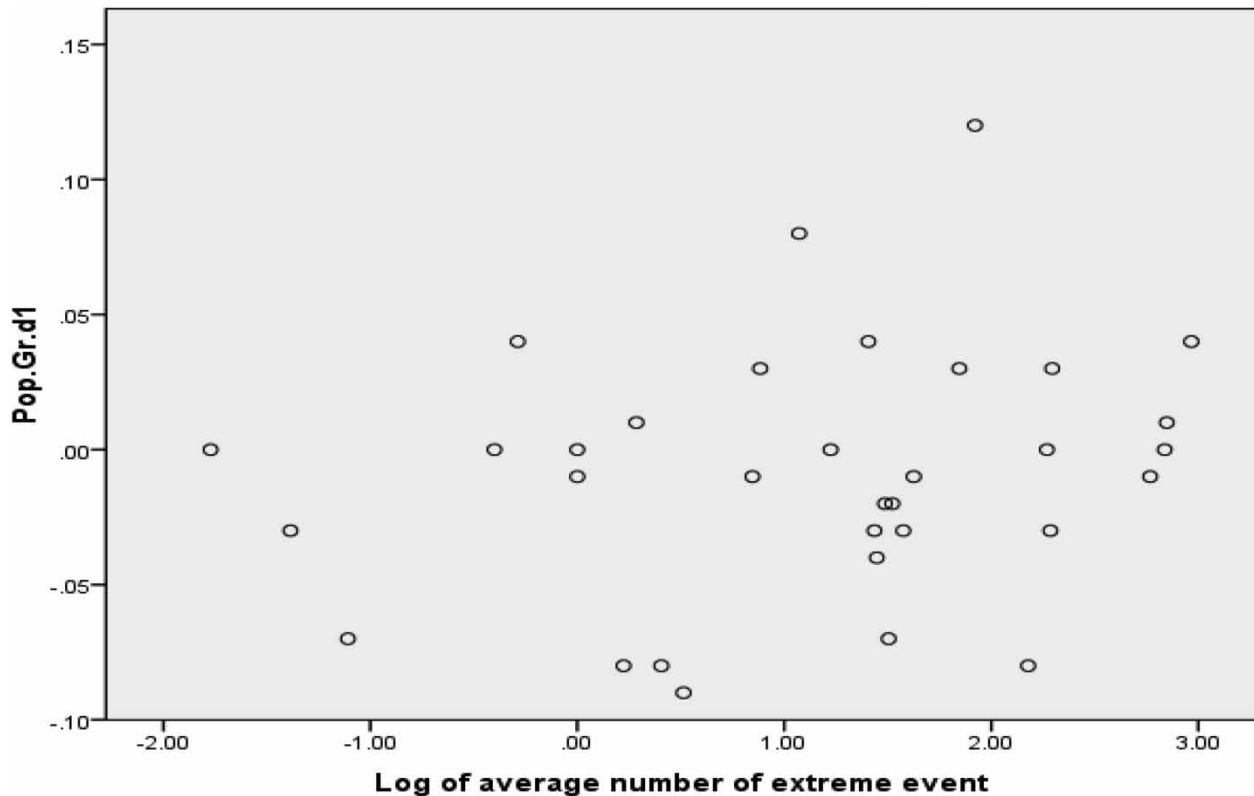


Figure 12 | Scatter plot for urban population growth rates (Pop.Gr.d1) against log of average number of extreme events Ln.No.Extrm.E.
Source: Authors' computation from field data, 2019.

Table 6 | Correlation coefficients

	Coefficient	Sig. value	Comment
Pearson	0.211	0.239	Weak and not significant
Spearman	0.111	0.519	Weak and not significant

Source: Authors computation from field data, 2019.

The findings of the [Institute for Climate Change & Adaptation \(ICCA\) \(2016\)](#) show that there was a very high population density along the stretches of rivers of Nairobi, thus flooding impacts were severe in the informal settlements. 56% of Nairobi city residents live in 150 congested informal settlements as identified by [Wangari & Makau \(2015\)](#) which are mostly located along the banks of Nairobi river and its tributaries. This makes them highly susceptible to flooding.

This study recommends that settlement planning of Nairobi should precede development and flood risk zones should be clearly mapped in future settlement plans based on hydrologic modelling, topographical analysis and ground-truth field visits. The results of this study can be used by policy-makers to make planning intervention strategies in other jurisdictions globally.

CONFLICT OF INTEREST STATEMENT

The authors certify that they are not affiliated with or involved with any organization or entity with any financial or non-financial interest in the subject matter or materials discussed in this paper.

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DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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