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Urban development and stormwater

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Introduction

Nairobi is the capital of Kenya as well as the largest city in East Africa (Kenya, Uganda and Tanzania). It has become the centre of local national, regional and international organisations including those of the United Nations system, international research institutions and also the headquarter for East and Central African-based multinational and transnational corporations. The city has grown considerably since it was founded in June 1899 as a railway depot roughly halfway between Mombasa and Kisumu for the then Uganda railway. By 1907, Nairobi had become the capital of Kenya a position it has maintained to date. During the second world war, its position not only became established as a military base but also as a centre for European settlement. The city was planned to cater for various racial groups including the European, Asian, Arabs and Africans among others (Table 1). With the growth of population, the city boundary was increased from 76.8 kilometers square in 1927 to cover approximately 680.9km² in 1963.

The population of the city doubled between 1976 and 1986 to a total of approximately 1 million people. This increase in population has been due to natural increase as well as immigration of the rural folk to urban areas in order to seek employment there. With such an increase of population a lot of stress has been laid on the provision of public services including health, transport, water supply and also on the maintenance of these infrastructures. Each residential area is distinguished by its population density, the quality of its environment and by the economic level of its population. The high-class low-density residential areas are situated in the northern and western portions of the city. This

includes housing for transient European expatriates and some wealthy Africans and Asians and a large population of domestic servants accommodated in separate "quarters" built on each site. A much higher proportion of Africans live in eastlands and southlands. These housing estates are comprised of Municipal housing and some English New-Storey terraced and semi-detached houses with rendered block walls and tiled double-pitched roofs, all with individual services. Almost 80 percent of the city's residential land has less than 20 percent of the population.

An urban development usually starts with the removal of vegetation from an area. Vegetation facilitates a continuous downward movement of water through infiltration process. In addition, vegetation protects the soil from sealing under the impoundments of raindrops. Vegetation cover also retains some water on the leaves and branches in the form of interception storage is small, vegetation reduces also the impact of rain drops from causing erosion, provides the litter that has a "blotter effect" of rain water and supplies humus to the soil when the plants' leaves decay. The city of Nairobi used to have abundant swamps, ill-drained river valleys and flood-prone regions. Grading and filling eliminated these swamps and have reduced the natural catchment storage, increased surface runoff and decreased groundwater storage and base flows.

The weather of Nairobi is influenced by south west trade winds and the north east trade winds. The north east trade winds, laden with little moisture from the Indian subcontinent prevails between December to March. This subsiding airmass is usually dry. However, orographic effects tend to create an occlusion as a result of a cold airmass from Aberdare Mountains (Ref.2). The storms caused by this airmass

Table 1. The Trend of Population Growth in Nairobi Since 1906

Year	Africans	Europeans	Asians	Total
1906	6,351	579	3,582	11,512
1926	19,112	1,492	9,260	29,864
1931	26,761	5,195	15,988	47,919
1949	65,939	10,830	21,476	118,579
1962	155,388	21,476	87,454	266,795
1969	421,079	19,186	67,189	509,286
1979	695,353	33,511	108,911	887,775

Source: Ref. 1

approaches the city either from the south or north east. The south east trade winds on the other hand obtain their maximum intensity between April and May. This system is repeated, although weakly, in the months of September to November. An analysis of low-level wind during the rainy season shows that wind direction rotate 360° each day. It begins from the south west in the morning, backing and increasing until sunset, with a combination of backing through north and south west again by next morning.

Major storms occur between November and May. The long rains begins in Mid-March and continues to the end of May while the short rains occur between October and December although some storms have been recorded in the dry months of January and February. The storms of the long rainy seasons occur in the evenings and early mornings. Without relegating the impact of the mean events, it is the intense storms, so characteristic in Nairobi that causes flooding and are also of sedimentologic effect. Such storms occur in the evenings (1200-2400 hours) and nearly 50% of the total rainfall occurs in 10-15% of the total duration. 90% of the total rainfall occurs in 30-35% of the total duration.

Engineers sometimes oversimplify the design of storm sewers by assuming a flat rate of rainfall. Although these calculations are based on wide experience, the result does not take account of variations in intensity that are associated with storm duration. Most designs in the city has adopted a flat rate of 65 mm/hour to 75mm/hour for current designs. Floods are

devastating because most intensive storms come after the ground has reached field capacity. There is a probability of a total monthly rainfall of 220 mm with a recurrence interval of 2 years. Devastating wet years such as 1961-2 had a monthly return period ranging from 10-50 years (figure 1).

Flood Analysis

The floods result from intense storms that occur during the long and short rainy seasons. The magnitude of the flood depends on basin factors such as on the percentage area of pavements, slope of the land and soil characteristics, the antecedent conditions and also the characteristics of rainfall. Most of the wettest months are preceded by relatively wet ones. The peak flow of flood is a simple function of the contributing area. This geomorphological fact has been the basis for flood planning for many years. This method is known as the "Rational Method" and it is attributed to Dickens (Ref.3). Dickens expressed the flood intensity, Q , as a linear function of the catchment area, a , in the form:

$$Q = ka^i$$

in which k and i are constant and exponent respectively.

The rainfall gradually decreases in the rather drier eastern and southern part of Mairobi. The low values of runoff may be explained partly by the low slope and partly due to low lag time. The low lag time is contributed primarily by smooth verges and grassed contributory area.

In the high cost single-house residential areas the total runoff

Table 2: Rainfall - Runoff Relations of Eastern part of Nairobi

Months:	Jan.	Feb.	Mar.	April	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec
Rainfall (mm)	35	35	75	145	100	30	10	10	15	35	90	55
Runoff (mm)	5	5	10	30	20	20	0	0	0	5	15	5
Ep.* (mm)	220	215	240	165	140	130	130	130	170	190	170	180

potential evapotranspiration.
Source: Ref.3.

range between 26 percent and 42 percent because of the large gardens and sometimes, non-lined channels the paved surface is sometimes less than 5 percent. The deep weathered volcanic soils have high infiltration rates that absorb most of the rain water. For this reason, the hydrology of high cost single-house residential units behave in a similar way as rural catchments. The lat time that water takes to drain from the catchment to the outfall is about 1.2 hours (Ref.4). Under such conditions of long lag time, the rainfall intensity does not affect the flood peak much.

In areas with more than 28% pavement the total runoff percent ranges from 31% to 95% especially in the city centre, Industrial Area, and Pangani. In dense low cost residential areas the percent paved area is about 18% and the total runoff from single storms range between 26% to 84%. The wide variation is due to nearly a flat surface inclined towards the east to a tributary of the Nairobi River.

There is a high lat time for flow concentration in Industrial Area. Reasons for this high lat time is probably due to the manner in which the storm sewer system is laid and partly due to the type of development there. The paved areas within Industrial area drain westwards under the roads while most of the unpaved areas drain eastwards. The unpaved areas have rough surfaces or semi-derelict under-developed factory sites that possibly retard runoff.

The relationship between rainfall for individual storms and runoff does not yield satisfactory correlation, partly because such a

relationship does not distinguish between rainfall intensity and duration and partly because catchments have long lag times in which case the effectiveness of rainfall intensity is minimal.

Drainage, Sediment Sources and Flooding

The storm drainage system in Nairobi is constituted of a combined sewer-storm system in City Centre and separated systems in the other districts. The separate system has been useful, especially with frequent flooding problem because the waste water treatment plants are inadequate to handle such quantities of water. The conduits used includes earth channels in exclusively high-class residential areas and also in low-class areas. Lined channels, pipes and culverts are also used in different parts of the city. The choice of any conduit depends on the area, aesthetic considerations and cost. The layout of the storm drainage system vary also. There are open systems, open systems with piped gulley connections, partially piped systems and completely piped systems. Each type of layout influences flood concentration time and peak runoff.

Sediment is produced whenever soil is exposed to rainfall energy and flowing water. Increased runoff from paved areas and buildings help to channels the flow rapidly and also increases the flood peak and erosive capability of such a flood. Sediment sources are from erosion of roads and footpaths, and from gardens, construction sites, earth channels and masswasting. The roads without kerbs and those with poor drainage erode relatively quickly than those with kerbs and are well drained. Because of steep slopes, erosion along the road sides

without kerbs increase rapidly. Erosion reduces the life of such roads by more than one half. Gullies are common also along unpaved foot-paths.

Pot holes are common on many roads after the rains. The pot holes are formed as a result of poor drainage that allows water to saturate the clays that form the foundation. Typical in soils with high clay minerals, they swell when wet and crack when dry. The cracks facilitate rain water into the bases and as vehicles move over the affected surface, silt mixed with water is pumped out and filled again with water. The process, acting, as a diaphragm, undermines the foundation and the asphalt surface collapses. The problem becomes cyclic in time as the asphalt and the silt clogg the drainage becomes cyclic in time as the asphalt and the silt clogg the drainage outlets allowing more water to infiltrate into the road bases.

The flower gardens along the streets and farms adjacent to river valleys contribute sediment during storms. Tree nurseries and potatoes, vegetables, and maize/banana gardens are typical feature that one observes along the Nairobi rivers. Such farming practices increase sediment discharge rates 4 or 9 times that on undisturbed surface. In one way the erosion from the channel banks are deposited within the natural channels and riverain vegetation thrives well in such banks. On the other hand riverain crops and vegetation reduce channel conveyance and cause flooding.

Construction sites and mass wasting are two major sources of sediments into the drainage network. In Kenya where there is no bye-law governing construction industry, many contractors move large quantities of soil any time of the year and with rather less consideration on the magnitude of pollution that their activities may generate. It is evident taht soil heaps may be seen in ridges, road sides, and anywhere before the long rains come. But when the rains come, most of the loose soil is washed into the drains. A survey of areas susceptible to mass wasting revealed that unlined channels natural rivers and, to an extent,

lined channel contributed a lot of debris into the drainage network after the rains.

Conclusion

Most of the urban centres are growing at an average rate of 6 percent per annum. As urban centres grow, the percent area covered by concrete increases the runoff magnitude and flood frequency. In areas where expansion is currently proceeding storm water drainage need to be planned appropriately. In built-up areas, new drainage methods could be established in the process of modernisation or redevelopment of the city centre. One way of doing this is that as new roads are surfaced, new institutions and recreation centres are built, planners and engineers must incorporate storm water detention points within their respective plans.

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