The Influence of Public Space Characteristics on Odour in Residential Neighbourhoods of Nairobi City, Kenya

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***Abstract*:- Public spaces of planned residential neighbourhoods in Nairobi are characterized with odour associated with rotting garbage, blocked storm water drains, poor surface drainage and broken-down sewerage systems. Whereas urban management agencies are responsible for the delivery of desirable public space environments, this has not been successful. This study was designed to find out whether there could be public space characteristics influencing this problem. Space syntax and structured observation were used in data collection. Multiple regression analysis established that relative depth of axial space, adjacency and permeability; proportion of buildings with setbacks; percentage of space that is tarmacked; plot ratio; frequency of informal businesses; and tree canopy height significantly explain odour in public space. These characteristics should be considered in residential neighbourhood layout to counter the problem of odour and promote public space environmental sustainability.**

Keywords: Public space; space syntax; odour; air pollution; residential neighbourhoods; Nairobi

1.0 INTRODUCTION

The impact of odours, and air pollution generally, on the health and well-being of people in urban settlements has been widely considered in the literature and mostly confined to epidemiological studies (King, 2018). While various ways of ameliorating the impacts have been advanced, the role of public space layout in minimizing odours in residential neighbourhoods is much less clear.

Odours have been defined as sensations which occur when chemical substances, referred to as odorants, are inhaled through the nose (Brancher, et al., 2016). These include sulfur compounds, nitrogen compounds and volatile organic compounds (Leonardos et al., 1969). Exposure to odourous emissions can result in negative effects on public and individual health (Brancher et al., 2016; Schiffman and Williams, 2005; Oltra and Sala, 2014; Manisalidis et al., 2020; Kitson et al., 2019; Njoku et al., 2019), annoyance (Brancher, et al., 2016; Kitson et al., 2019) and depreciation of property values (Brancher, et al., 2016). Further, environmental pollution leads to climate change which affects the geographical distribution of many infectious diseases (Manisalidis et al., 2020).

Green spaces in settlements have been linked to a reduction in air pollution and improvements in mental health (James et al., 2016). However, the focus is a lot more on the particulate matter than odours. Abhijith et al. (2017) and Acero et al. (2012) examine the role of trees, hedges, green walls and larger green spaces on their ability to reduce air pollutants by trapping large particulate matter. King (2018) underscores that some urban vegetation design implementations may increase or decrease air pollution levels based on a wide range of factors: street design, building architecture, plant types, among others. A comparably small number of studies has shown that low-level roadside hedges are more effective than trees in trapping particulate matter and offering better air pollutant protection for roadside footpath users than high-level trees (Abhijith et al. 2017). This has a bearing on urban design in that within a street environment, low-level vegetation rows play the role of securely separating the road from the path, greening an area, and reducing air pollutant dispersion to path users.

A large body of literature on odours in residential neighbourhoods focuses on external sources. These include landfill sites adjacent to the settlements (Njoku et al., 2019; Xiang-zhong, 2005), industrial areas (Naddeo et al., 2012), wastewater treatment plants and composting activities (Brancher, et al., 2016). Alloway and Ayres (1997) point out that wastewater, such as sewage, can be a source of noxious odours, degrade river water quality and contribute to the spread of infectious diseases.

The layout of residential neighbourhoods is concerned with how space is created and functions. This entails the definition of a network of public spaces, concerning buildings and other activities, which in turn contributes to the settlement's spatial form. According to Hillier and Hanson (1984), a settlement's spatial structure presents patterns which carry social information and content. The authors aver that spatial layout, in giving shape and form to the physical world, structures the system of space in which people live and move. Space, consisting of streets and squares, plays a crucial role in influencing human activities and social interaction (Cutini et al., 2020). The layout of residential neighbourhood streets thus presents spatial characteristics that determine the way they are used. This, for instance, explains the distribution of people in public space and their associated behaviour (Jacobs, 1961 and Makworo et al., 2013). The manner of use of the space may result in either promoting or jeopardizing the health and well-being of residents and other street users.

The setting of this study is in the planned residential neighbourhoods of the City of Nairobi. The city is characterized by the rapid growth of human population and increasing pressure on residential public space use and environmental sustainability challenges. Some of the sources of odour in the public space system of residential neighbourhoods investigated include rotting garbage resulting from inefficient systems of solid waste collection; blocked stormwater drains; poor drainage of surface runoff; broken-down sewerage systems, unmaintained public toilets and wrong use of negative spaces. Trancik (1986) defines negative space in a settlement as that part of public space that nobody cares about maintaining. These spaces are ill-defined and fail to connect to other elements of the public space system in a coherent way. These spaces end up being used in the wrong way – as spots for dumping solid waste, and in some cases, urination. With most designers acknowledging that space has a powerful role in shaping social behaviour (Southworth et al., 2012), this study is designed to establish public space characteristics influencing odour in the city's residential neighbourhoods and the extent of the relationship between the characteristics and the odour.

2.0 MATERIALS AND METHODS

This paper generalizes its findings to the entire frame of public spaces of planned residential neighbourhoods in Nairobi. Public space is limited to the residential street and to permit systematic inquiry, the street space is broken down into spatial units referred to as axial spaces which form the units of inquiry. To arrive at a representative sample of public spaces, multi-stage sampling from the level of residential neighbourhoods to axial spaces was necessary.

2.1 Sampling of residential neighbourhoods

The planning of residential neighbourhoods in Nairobi is such that they fall into high-income, middle-income and low-income categories. Based on this stratification, a population frame of planned residential neighbourhoods was defined and then subjected to further stratification using public space structure as the criterion. Application of simple random sampling to each stratum resulted in selection of a representative sample of ten neighbourhoods distributed as follows: three in the high-income stratum (that is Parklands, Mitini and Lavington), four in the middle-income stratum (that is Tena, Pangani, Otiende and Buru Buru V) and three from the low-income stratum (that is Ofafa Maringo, Madaraka and Umoja II).

2.2 Establishment of the parent population of public spaces

Preparation of neighbourhood axial maps was a pre-requisite to establish the parent population of axial spaces in the neighbourhoods. This is done by first finding the longest straight line that can be drawn within a street space of a neighbourhood map and drawing it on an overlaid tracing paper, then the second-longest, and so on until the entire street space is covered and all axial lines that can be linked to other axial lines without repetition are so linked. An axial line defines the axial space. An axial space is therefore a unit of a continuous street space which extends in one dimension and is linked to one or more other units in the street space system of the settlement. Initially, an accurate axial map of each neighbourhood was drawn based on maps obtained from Survey of Kenya and Nairobi City County Government. This was followed by a reconnaissance survey of each neighbourhood to identify any omitted spaces to include them in the respective axial maps. The updated axial maps presented the universe of public spaces, hence the study population. Figure 1 below, the axial map of Otiende, illustrates how this study operationally defined public space.

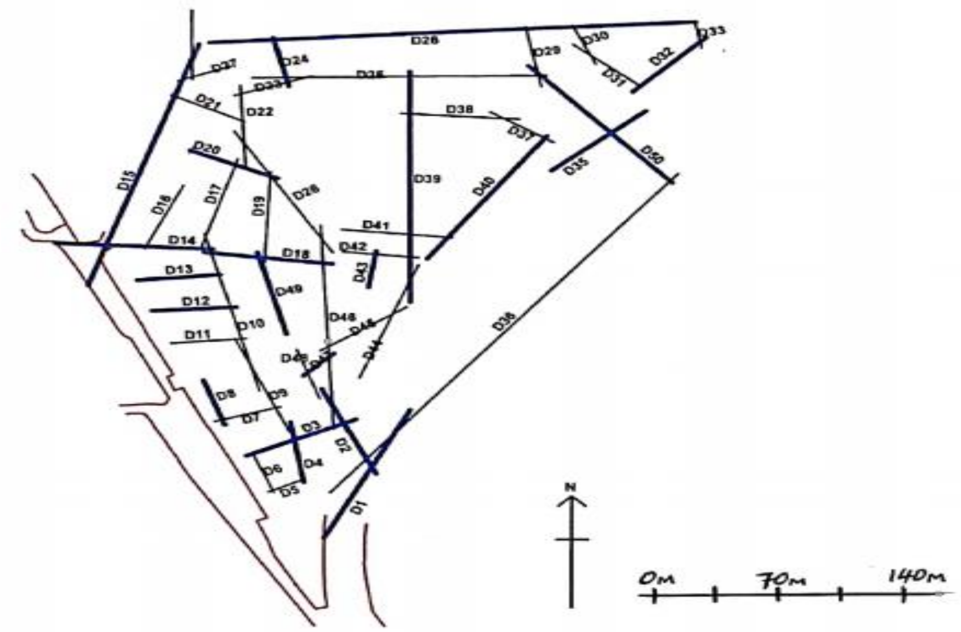

Fig. 1: Axial map of Otiende residential neighbourhood

Source: Author, 2019

The same process was applied to all the sample neighbourhoods to determine the parent population of public spaces. In total, the study realized 369 public spaces in the sampled neighbourhoods.

2.3 Sampling of public spaces

To facilitate sampling of public spaces for inclusion in the study, each public space in the respective neighbourhood axial map was coded uniquely as illustrated in Figure 1. The spaces were then sampled in a two-stage process. In the first stage, a public space survey was conducted in which all the spaces in each neighbourhood were systematically observed to establish the intensity of odour in each axial space. The intensity was scored using a five-point scale. In this scoring, the highest intensity was given a score of five (5) whereas the lowest intensity was given a score one (1). This preliminary assessment was done on a neighbourhood basis to make possible selection of a sample that is representative of the parent population of public spaces. Simple random sampling was then applied in the selection of spaces from each category of scores on a neighbourhood basis. In total, 120 axial spaces were sampled for detailed inquiry in stage two of the study.

2.4 Primary data collection

Axial alpha-analysis and structured observation were used as the main methods of primary data collection. Axial alpha-analysis, a space syntax method of assessing exterior space of a settlement plan, was used to generate data from the axial maps of the residential neighbourhoods under inquiry. Syntactic variables whose data is generated through axial alpha-analysis were assessed regarding their predictive strength of the problem of odour in public space.

Data collected through structured observation was both for non-syntactic variables (that is, public space variables whose data is not collected through axial alpha-analysis) and odour. Non-syntactic variables relate to the physical, social and economic characteristics of space. Odour was measured as intensity using a 5-point scale where the highest intensity was given a score of 5 and the lowest a score of 1. Measurement of odour was carried out on weekdays between 9.00 a.m. and 4.00 p.m., a time frame that is outside the peak hours when people are going to or coming back from work. Delimitation of observation time was necessary for consistency purposes.

The non-syntactic variables to be observed and the style of recording the observations were defined in an observation schedule. Data collected through structured observation was measured quantitatively using either a five-point scale or with the aid of precision instruments which included a measuring wheel, tape and tally counter. A measuring wheel was used for measuring horizontal and long distances whereas a 5-metre long measuring tape was used for measuring short distances, both horizontal and vertical. Standardization of data, where necessary, was done to allow for comparison among spaces of different sizes.

2.5 Data analysis and interpretation

Descriptive statistics (frequencies and percentages) were used to analyse data on the intensity of odour in public spaces of the sampled neighbourhoods. This is the data that was collected in stage one of the study. Multiple regression using the stepwise method was applied in the analysis of data in the second stage of the study. The method was used to establish independent variables that significantly predict the intensity of odour in public space. Independent variables are the syntactic variables and those linked to the physical, social and economic characteristics of space. The intensity of odour in public space comprised the dependent variable. Analysis of variance at a 99 percent confidence level was used to test the significance of the relationship. Data for the study was presented in tables and an analysis report.

3.0 RESULTS AND DISCUSSION

3.1 Stage One of the Study

This stage sought to establish the intensity of odour in public spaces of the sampled residential neighbourhoods. This was measured using the following five-point scale: 1 – Very low; 2 – Low; 3 – Moderate; 4 – High; 5 – Very high. The public space survey established that the intensity of odour varied across and within the neighbourhoods (Table 1).

Table 1: Intensity of odour in public spaces of the sample residential neighbourhoods

S/No	Neighbourhood	Total number of neighbourhood public spaces (N = frequency; % = percentage)	Number of public spaces per score				
			Score 1 (very low)	Score 2 (low)	Score 3 (moderate)	Score 4 (high)	Score 5 (very high)
1	Tena	N = 35	0	3	18	13	1
		% = 100	0	9	51	37	3
2	Pangani	N = 45	2	3	17	12	11
		% = 100	4	7	38	27	24
3	Buru Buru V	N = 41	3	31	6	1	0
		% = 100	7	76	15	2	0
4	Otiende	N = 49	13	28	5	2	1
		% = 100	27	57	10	4	2
5	Umoja II	N = 41	6	8	4	13	10
		% = 100	15	19	10	32	24
6	Madaraka	N = 22	3	11	7	1	0

		% = 100	14	50	32	4	0
7	Ofafa Maringo	N = 37	0	14	11	11	1
		% = 100	0	37	30	30	3
8	Lavington	N = 43	0	42	1	0	0
		% = 100	0	98	2	0	0
9	Parklands	N = 27	0	20	5	2	0
		% = 100	0	74	19	7	0
10	Mitini	N = 29	28	0	1	0	0
		% = 100	97	0	3	0	0

Source: Author, 2019

The survey established that the intensity of odour in public spaces of the sample residential neighbourhoods ranged between 'very low' and 'very high' (Table 1). The worst performing neighbourhoods, those with the highest intensity of odour in public space, were Umoja II, Pangani, Tena and Ofafa Maringo. The cumulative score for 'high' and 'very high' for each of these neighbourhoods was 56%, 51%, 40% and 33% respectively. Umoja II fell in the low-income category whereas Pangani and Tena were in the middle-income category. Inasmuch as the latter two were in the same income category, a further stratification placed Pangani at a relatively lower level (lower middle-income) than Tena which fell in the middle middle-income level. Based on the economic characteristics of these neighbourhoods, the study inferred that odour in public space has an inverse relationship with the income level of a neighbourhood. However, a paradox in this relationship was why Ofafa Maringo, a low-income neighbourhood relatively lower than Umoja II, performed better than the middle-income neighbourhoods. Nonetheless, it was evident that the worst performing neighbourhoods ranged from low-income to middle middle-income categories. Extraneous factors that could be an explanation of the variance of odour in public space are assessed in stage two of this study.

The best performing neighbourhoods, those with the lowest intensity of odour in public space, were Mitini, Lavington, Buru Buru V and Parklands. The cumulative score for intensity of odour under 'high' and 'very high' for each of these neighbourhoods was 0%, 0%, 2% and 7% respectively. The cumulative score for the same neighbourhoods under 'moderate', 'high' and 'very high' was 3%, 2%, 17% and 26% respectively. Mitini, Lavington and Parklands fell in the high-income category although Parklands was relatively lower than the first two. Buru Buru V was in the upper middle-income category. In considering the neighbourhoods in the high-income category, it was evident, just like for the worst performing neighbourhoods, that the intensity of odour in public space is inversely proportional to the income level of the neighbourhood. Again, there arises a paradox in this deduction – why Buru Buru V, an upper middle-income neighbourhood, performed better than Parklands which was in a relatively higher income category. Factors that could be an explanation to this paradox were assessed in stage two of this study. However, the paper infers that the best performing neighbourhoods ranged from the upper middle-income to the high-income categories. The performance of Otiende, an upper middle-income neighbourhood, matched closely with that of Buru Buru V in the cumulative score of 'moderate', 'high' and 'very high'. Madaraka, an upper low-income neighbourhood, performed moderately on odour in public space. It had a cumulative score of 36% under 'moderate' and 'high' and 0% under 'very high'.

3.2 Stage Two of the Study

Stage two of the study sought to establish independent variables that significantly predict the distribution of odour in the public spaces. This was carried out at two levels. Firstly, axial alpha-variables were regressed against the dependent variable to establish the extent to which they explain the distribution. Secondly, all independent variables (that is, syntactic and non-syntactic) were regressed against the dependent variable to present a comprehensive picture of the prediction. The two-tier analysis demonstrates that syntactic variables alone account for a relatively smaller percentage of the variance in the environmental problem in public space whereas a combination of syntactic and non-syntactic variables significantly explain a relatively larger percentage. The two scenarios are illustrated in Table 2 below.

Table 2: Regression results for public space odour

Model 1: Odour in public space using alpha variables as predictors

Var	Uns. B	SE B	B
N10	5.905	1.188	.399
N2	-31.136	8.662	-.289

Constant= 2.595; R= 0.495; R^2= 0.245; Adjusted R^2= 0.232; S_e = 1.124; df= 2,117; F= 18.962; Sig. =0.000

Model 2: Odour in public space using all independent variables as predictors

D42	1.219	.317	.353
B4	.018	.005	.293
F28	-.771	.211	-.314
F17	-8.841	2.986	-.252
B15	-.184	.086	-.179

Constant= 3.937; R= 0.785; R^2= 0.616; Adjusted R^2= 0.588; S_e = 0.823; df= 5, 69; F= 22.110; Sig. =0.000

Where:
R= Multiple correlation coefficient; R^2= Coefficient of determination; S_e= Standard error of the estimate; Uns. B= Unstandardized coefficient; SE B= Standard error of B; β= Standardized coefficient; df= degrees of freedom of the model; F= Analysis of Variance coefficient; Sig. = Significance (p) value of the model.

B_4= Percentage of the area with tarmac; N_{10}=Relative depth of axial space; N_2= Adjacency and permeability per square metre of space; D_{42}= Proportion of buildings with setbacks; F_{28}= Plot ratio for the space; F_{17}= Frequency of informal businesses; B_{15}= Average tree canopy clearance from ground in metres.

Source: Author, 2019

3.3 Modelling Odour in public space

3.3.1 Prediction using axial alpha variables

Multiple regression analysis between the intensity of odour in public space and axial alpha variables demonstrates that 24.5 per cent of the variance in the dependent variable is explained by relative depth of axial space and adjacency and permeability per square metre of space (Model 1 in Table 2). The model, whose prediction is significant at a 99 percent confidence level, is illustrated below.

$$Odour = 2.595 + 5.905N_{10} - 31.136N_2 +/- 1.124S_e \quad \ldots\ldots (1)$$

The relative depth of axial space refers to the level of integration or segregation of a space in relation to all other spaces in the settlement plan system (Hillier and Hanson, 1984). Spaces that are shallow in the settlement layout have low relative depth values whereas deeper spaces have high relative depth values and therefore more segregating in the settlement layout system (Hillier, 1988). On the other hand, adjacency and permeability refers to the constitutedness property of a space. According to Hillier and Hanson (1984), constitutedness of a space is said to exist when adjacent buildings and other bounded areas, such as inhabited plots, gardens and parks, are directly or indirectly permeable to it. Permeability refers to access between the enclosed and public space environments. This access can be either physical through doors or gates, or visual through windows or transparent areas of a perimeter wall. This then suggests that constitutedness is defined by the degrees of permeability, enclosure and transparency. Whereas the variable of relative depth of axial space has a direct relationship with odour, the measure of adjacency and permeability of space has an indirect relationship. This means that an increase in the relative depth value of a space, while holding all other variables constant, leads to a corresponding increase in the amount of odour pollution. It also means that an increase in the constitutedness of a public space, while holding all other variables constant, results in a decrease in the amount of odour.

Spaces that are more integrating in a settlement plan system, that is, spaces that are shallow and therefore have low relative depth values, are characterized with a high intensity of use. Hillier (1988) points out that the more integrating a space is, the higher the number of people or encounter rate in the space. The density of motor vehicles in such spaces, both moving and parked, is also high. Shallow spaces also have better road and lighting infrastructure. Generally, agencies responsible for the management of the public space system of a settlement give priority to spaces that are shallow in relation to the carrier space, that is, the peripheral road system of the settlement. Because of the higher level of activity in such integrating spaces and the higher frequency of attention it receives insofar as provision of public space services is concerned, the level of odour pollution is lower. Conversely, segregated spaces, with their high relative depth values, are less busy with activity and are usually left out when it comes to maintenance of infrastructure and provision of public space services. Because of this, segregated spaces have higher levels of odour. On the other hand, a public space that is constituted by adjacent buildings has fewer odours. Constitutedness of public space promotes the presence of people and motorists in the space (Alexander, 1977; Hillier, 1988; Moirongo, 2011). An increased presence of people and motorists in space promotes surveillance and minimizes wrongful use such as dumping solid waste or urination (figure 2). In effect then, the more constituted a space is, the lower the intensity of odour.

Figure 2: A space with adjacent but impermeable buildings. Such settings have high levels of odour Source: Author, 2019

3.3.2 Prediction using all independent variables

Multiple regression analysis between the intensity of odour and all independent variables as predictors realized that five independent variables significantly explain 61.6 percent of the variance in the dependent variable (Model 2 in Table 2). The model, whose prediction is significant at a 99 percent confidence level, is illustrated below.

$$Odour = 3.937 + 1.219D_{42} + 0.018B_4 – 0.771F_{28} – 8.841F_{17} – 0.184B_{15} +/- 0.823S_e \quad \ldots\ldots\ldots\ldots\ldots (2)$$

Two of the independent variables have a direct relationship with the intensity of odour and include the proportion of buildings with setbacks and the percentage of space that is tarmacked. This means that an increase in any of these variables while holding all other variables constant results in an increase in the intensity of odour. In the neighbourhoods surveyed in this study, public spaces that have a higher percentage of tarmac but do not benefit frequently from public space services, such as garbage collection, have higher intensities of odour. Tarmac is impervious and any water-logged biodegradable matter on it, once it rots, will emit high levels of odour. Low-income and middle-income neighbourhoods were the most affected in this respect because of their dependence on the unreliable garbage collection services by the city authorities. Some middle-income and all high-income neighbourhoods were able to mitigate odours from tarmacked surfaces by engaging private companies in provision of public space services. Similarly, neighbourhoods with a higher proportion of buildings with setbacks have higher odours. Removal of a building off the edge of a public space has the effect of reducing pedestrian flow due to reduced social intercourse between the residents and strangers in the public space. The reduced surveillance from pedestrians results in wrongful use of public space and higher odours. High-income neighbourhoods, with their vast building setbacks, are able to counter odours in their street spaces through effective provision of public space services by private undertakers.

Three of the five independent variables that have an inverse relationship with the intensity of odour include plot ratio, frequency of informal businesses, and average tree canopy clearance from the ground. This implies that an increase in any of the variables while holding all the other variables constant results in a corresponding decrease in the intensity of odour. Higher plot ratios and frequency of informal businesses characterizing a public space have the effect of increasing density of people in the space. Similarly, a section of a public space that has trees with a higher canopy clearance from the ground attracts more people to relax or socialize under shade. Conversely, people tend to keep off from shrubs or planting of canopy clearance from the ground that does not permit social activity under its shade. In the latter case, the space attracts wrongful use and, according to Trancik (1986), such is lost or negative space. It follows that public space with a pattern that promotes density and suffusion of people in the space is integrated and therefore free of elements that lead to the production of odours. This is in line with the finding by Moirongo (2011) that spaces frequented by pedestrians, and more so residents, tend to experience less disintegration and hence lower levels of odour.

4.0 CONCLUSION AND RECOMMENDATIONS

This paper has established that relative depth of axial space, adjacency and permeability, the proportion of buildings with setbacks, percentage of space that is tarmacked, plot ratio, frequency of informal businesses and tree canopy height significantly explain odour in public spaces of Nairobi's residential neighbourhoods. Failure to consider these characteristics in the layout of residential neighbourhoods in the city is thus a significant factor explaining the problem of odour and is a threat to the environmental sustainability of the public space system. This is evidenced in the remarkable break-up of the public space system which results in segregated and unconstituted spaces that attract wrongful use such as dumping of solid waste and urinating. Spaces characterised with constitutedness and a higher degree of integration have a diverse mix of activities that attract both pedestrians and motorists. These help in policing public space and thus protect it from pollution by its users.

To realize sustainable public space environments, free of odours, this study recommends five areas of action. One, there should be adequate provision of public space services by the city authorities. Priority should be accorded to the low-income neighbourhoods because their residents have a relatively lower economic capacity to engage private organizations to do the work. Two, residential neighbourhood layout should be guided by insights emanating from application of space syntax in the study of public space. In this regard, the residential neighbourhood layout should avoid remarkable break-up as this leads to segregated spaces. This means that the depth of public spaces, relative to the peripheral road system of the neighbourhood, should not be so much. Deeper spaces are usually neglected by the city authorities in the provision of public space services, for example, maintenance of roads and street lighting infrastructure. Three, residential neighbourhood planning should provide a rich mix of land use activities fairly well distributed in the settlement. This requires that the residential use is mixed with various commercial activities, such as shops and chemists, well distributed in the entire settlement. This ensures that deeper spaces of the neighbourhood attract presence people most of the time, do not suffer neglect from city authorities and that the public spaces are safe as a result of increased human presence. Four, residential neighbourhood planning and design should ensure that public spaces are adequately constituted. This should be achieved by ensuring that buildings have provisions for a visual connection with the adjacent public space environment. Plot boundaries, in particular, should not be of solid walls but of materials and designs that permit visual surveillance of the public space system. Five, discourage the planting of shrubs in the public space system. Shrubs, besides being points where people answer calls of nature such as urinating, create a favourable setting where criminals can hide. Residential neighbourhood planning and design should encourage planting of trees whose canopy heights do not obstruct the surveillance role of public space users.

By focusing on odour in residential neighbourhoods of Nairobi, this study contributes to the international debate on sustainable cities and communities. It has identified key public space characteristics that influence public space odour. Findings of the study form a useful reference in informing policy and practice in residential neighbourhood planning and design for environmentally sustainable public space environments.

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 10 Issue 09, September-2021

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