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Comparative Mapping of Smellscape Clusters and Associated Air Quality in Kano City, Nigeria: An Analysis of Public Perception, Hotspots, and Inclusive Decision Support Tool

Abstract

Few studies have effectively analysed the spatial patterns of urban smellscapes, public perception, exposure risks, or design an inclusive decision-support system. The current study coupled multiple methods to measure, map, and compare notable smell emitting spots, associated air quality indices, and public perception in Kano, Nigeria. It has revealed how urban informal activities generate both pleasant and offensive smells that contaminate the air more than the city's transportation and manufacturing. Notably, the most perceived odour hotspots coupled with highly hazardous sites with AQI value of >1200 which were found around the city's main abattoir. Conversely, the most commonly distributed pleasant smell spots are beef and chicken grills whose charcoal burning generate hazardous air quality. The novelty of this study includes its ability to use empirical data to design an inclusive decision support tool that identifies pathways for individuals, vulnerable groups, policymakers, and civil society groups to respond to various exposure risks. The study has identified informality, urban spatial inequalities, densification, and poor spatial planning which appeared to be the key drivers of the observed clustering of pleasant/unpleasant smellscapes juxtaposing with sites of worst air quality.

Keywords: Informal, Urban, Odour, Planning, Exposure, Air Quality Index

1. Introduction

Since the beginning of the 21st century, urban planners, city leaders and policymakers have underscored the need to make cities more liveable and resilient. This is expressed in research, innovation, and policy initiatives directed at improving the quality of urban physical and social environments. Urban air quality as an indicator of urban environmental quality has received considerable attention of researchers who discreetly and systematically set limits and standards suitable for human life and wellbeing (Ortolani and Vitale, 2016; Ulpiani et al. 2021; Chen et al. 2022; Sun et al. 2022). The worsening air quality particularly in urban areas is attributed to rapid urbanisation which drive changes in the built environment through technological, industrial, social and economic activities (Yang et al., 2018; Kilinc, 2019; Wang et al., 2020). Such modifications often negatively impinge on the quality of human life and the environment. However, these challenges can be more daunting in countries with low capacity to address them through functional planning, technological and environmental governance systems (Baldasano et al., 2003; Mannucci and Franchini, 2017; Gulia et al., 2020).

Odour is often considered more as a nuisance rather than public health risk or environmental hazard (Kitson et al., 2019). Human socioeconomic activities in cities generate both good and bad smells on daily basis. Exposure to smell is inevitable in people's daily lives and can be particularly high in cities (Xiao et al., 2018). Odours shape our experiences of places and influence our decisions to visit or avoid certain locations within cities (Xiao, Tait, & Kang, 2020); as in the case of Sheffield railway station and bus interchange; influence people's behavior; affect emotional state and decision-making patterns (Hodson, 2022; Liu et al., 2022), or where people decide to relocate, reduce traffic times, and outdoor stays or make use of protective materials. Researchers have established that smell is directly linked to emotional memories of humans, and it assist in influencing memories; and addition, smell can increase physiological stress, particularly for those with post-traumatic stress disorder (Khamsi, 2022). A decade ago, a study considered ordour as a problem of little concern for most urban dwellers in the low-income countries (Rheinländer et al., 2013). However, it is important to investigate the situation given the nature of rapid urbanization and how it confounds multiple risks for people and the environment. A recent study emphasized the need for researchers, practitioners, policy-makers and planners to consider the role of smell experiences in improving human wellbeing (Bentley et al. 2023). This makes it important to construct some decision support tool that supports individuals, groups, practitioners, and policymakers.

IPCC (2022) hinted that about a billion global residents of informal settlements are likely to be subjected to greater amounts of odour pollution because poor water and sanitation which can generate both health hazards and poor odours. This makes the concept of the geographies of smell vital, and Śliwa and Riach, 2011 also noted its importance in explaining urban transitions and transformation and in understanding meanings and people's attachment to urban spaces. Thus, some researchers explored some other theories to explain the importance of smellscapes in tourism, identity, and heritage studies (Boswell, 2008; Davis and Thys-Şenocak, 2017). For instance, Kate (2015) found that walking along a typical urban route exposes one to the drifting smells that could be light, ephemeral, and subtle. The author also observed that through a smell walk in Singapore one could encounter smells of fresh laundry, perfume, urine, food, exhaust, garbage, food, gas, spices, sweet which could be strong, weak and for short or long time. Considering that Singapore is ranked as one of the cities with highest level of urban environmental quality (Addie et al. 2019), it becomes imperative to investigate the state of urban smellscapes in the less-planned and informal cities.

In many large cities of low and middle-income countries, the features of urban informal settlements include: poor planning, low-rise buildings, high density, poor infrastructure, poor healthcare system, and low living standards (Fan et al. 2022), which leads to poor air quality and exposure to unpleasant odours. In the case of Africa where informal settlements account for more than 55% of all human settlements (Habibi et al. 2022), small and largely informal cities will provide some examples that could help researchers to gain insights into the criticality and association of urban smells and air quality risks. This is because unregulated land use activities in informal and dense spaces are likely to emit smells and also contaminate the ambient air. Therefore, this assumption makes it imperative to establish if any correlation exist between the smells of informal settlements and air quality of African cities. The World Health Organization - WHO (2021) has cautioned that 80% of urban residents in Africa are exposed to air quality levels above the established levels. Kano, an ancient city in Nigeria is not an exception as its urban air quality is rated poor (Abdullahi et al., 2020). A recent study on the situation in urban Kano revealed that due to poor planning, the city records largest proportion of PM2.5 and PM10 values at various neighbourhoods and thus exposing the residents to the risks of serious health hazards (Sadiq et al. 2022).

A number of studies measured smells using olfactometry instruments to detect and model environmental odour annoyance (Lucernoni et al., 2016; Hsieh et al., 2017; Szalata et al., 2021). However, insensitivity to some odour offensiveness and decreased sensitivity due to continued simulations are amongst the widely reported limitations of olfactometers (Belgiorno et al., 2012). Furthermore, the use of human olfactory system (respondents' sensitivity to smell) to rank and assess odour annoyance impact has gained scholarly recognition amongst researchers due to its reliability and effectiveness (De Feo et al., 2013; Sówka et al., 2018; Carlson et al., 2020). Therefore, this study is interested in combining the two techniques in assessing smell/odour so as to overcome weakness of using a single technique.

Many studies focused on investigating urban air pollution from landfills, industry and vehicles (Atari et al., 2009; Rotko et al, 2020). Attention is often on measuring air pollution variables such as particulate matter (e.g. PM2.5, PM10, SO_2, NO_2) whose health implications or risks are easily established once they are measured. However, studies on mapping smell hotspots or activities that generate the smells and options for decision-making are lacking in most African cities. As many countries strive to achieve SDG11- for sustainable human settlement; it becomes necessary to identify and key smell hotspots and decision-making options that strengthen or assist in building response to poor air quality spots and associated smellscapes that cause harm and discomfort to urban residents. Smellscapes can be considered as important aspects of liveability of cities because they contribute to understanding sense of place and human well-being. It is also likely to correlate with other aspects of environmental quality such as air pollution, water pollution, waste, presence of green and blue spaces, all of which have both positive and negative implications for human health. Smells are understudied because maybe because they are not visible, and hence rarely seen as a critical urban environmental problem and perhaps because it can only be measured subjectively.

The study is guided by the following research questions: What is the nature of urban smellscapes and how are they associate with urban air quality and residents' perception of the dual risks an African city? What inclusive strategies are needed to address the dual risks? The five sections of the paper start with an introduction, study context and a description of the study area. This is followed by detailing the methods used, results and discussion of the findings and conclusion. This study contributes towards drawing attention of researchers and policymakers to the nexus of publically perceived smellscapes, air quality, health risks and informality in rapidly urbanising cities. It also highlights the need for deploying demystified decision support tool for multiple stakeholders including at the grassroots level in cities with urban planning deficiencies.

2. Materials and Methods

2.1 Study Area

The city of Kano is the second largest urban agglomeration in Nigeria in terms human population. The population of Kano city is around five million inhabitants while the population of the core city and periphery is around two million. Kano's urban population is dominated by the younger people aged 16-30+ (National Bureau of Statistics 2017). Urban Kano covers an area that comprises the old walled city of Kano and its peripheries which sits between latitudes 11°50′and 12°07′N and longitudes 8°22′and 8°47′E respectively in an area covering approximately 100 km^2 (Mohammed et al. 2019). Historically, Kano developed as a compact and very densely built city. More recently, informal settlements have increased and expanded rapidly both factors have directly contributed to poor air quality. Kano is located roughly 800 km from the edge of Sahara Desert to the north and some 1,000 km from the Atlantic Ocean in the south (Figure 1).

The natural vegetation of Kano city and its surrounding falls under the Sudan savannah which is characterised by sparse and medium-height trees with umbrella-like tree crowns. However, vegetation cover in Kano is now dominated by exotic trees that have been planted and maintained for specific purposes (Barau et al. 2015). The climate of urban Kano is tropical wet and dry marked by seasonal rainfall that falls between April–October and a mean annual temperature of over 30°C. At the same time, recent meteorological records suggested that the changing climate and land use in the city drives the diurnal temperature for the hottest months (April/May) to reach up to 40°C which is higher than two to three decades ago (Mohammed et al. 2019). This is attributed to densification of human settlement and decline in open spaces and wetlands (see Barau et al. 2015).

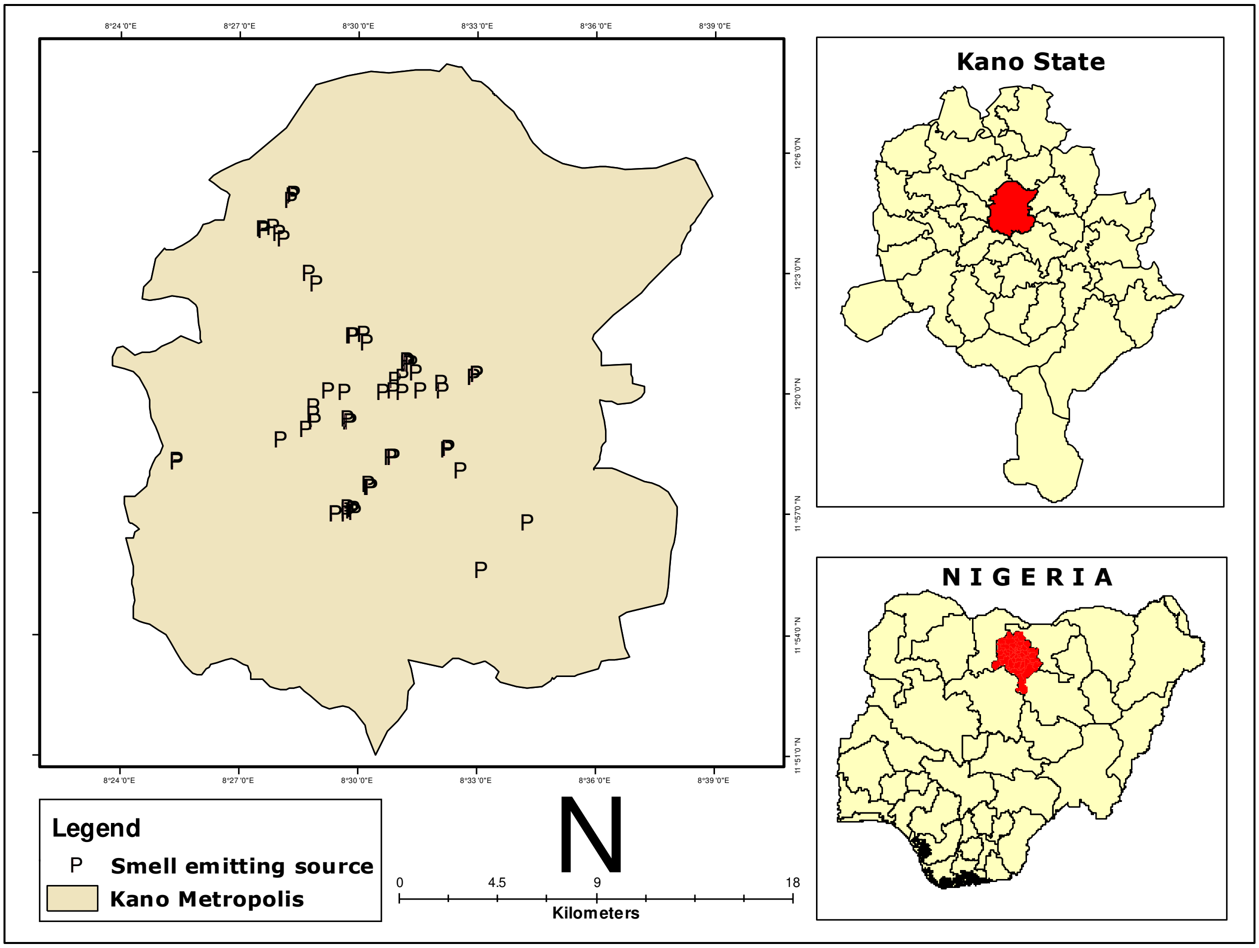

Figure 1: Sampling points within clusters of planned and unplanned areas for smell perception and air quality observations in urban Kano.

2.2 Data collection: Smell Sources Identification and Sampling

Identification of smell sources is considered as the first most important step in smell impact assessment studies (Capelli et al., 2011). It is thus suggested that smells can shift across four different land use types namely: industrial, commercial, landfills and agricultural land use types. This study adapted this proposition while still being mindful of the dominance of informality and unplanned areas. For this study to overcome the confusion of the seamlessness of informal activities and spaces, the authors referred to a Kano land use map produced at the Bayero University Urban Planning Studio (2018) to identify the main areas that matched the four land use types (Table 1). This guided the study fieldwork process to identify smellscapes from the purposively sampled four land use types with clusters of different socioeconomic activities that generate different types of smells. Therefore, the selection of sites was based on multistage sampling where in the first instance 10 sites of each of the four land use types were identified and selected to guide the process of stratified sampling of the clusters of smell emitting activities. Figure 2 summarises the methodological flowchart that encompasses the major tools and data used in the study.

Table 1: Distribution of different land use types based on smell emitting activities

S/N	Activity types	Land Use
1	Slaughtering, fueling and lubrication services, leather processing, bakery, food selling, food selling, dying	Commercial
2	Liquid waste, solid waste dump,	Landfills
3	Insecticides manufacturing, carpet manufacturing, fertilizer manufacturing, mattress manufacturing, plastic manufacturing, vegetable oil processing	Industrial
4	Poultry, livestock market, hides and skins burning, fruit and vegetables market	Agro-allied

In the second stage, based on convenience and availability of different smell emitting activities on ground, the study team observed, selected and confirmed (by asking individuals) regarding the availability and function of the clusters of activities in the area. Consequently, the team randomly selected 65 different smell-emitting clusters from across the city. Each smell source location was recorded using a handheld GPS device, and its type, associated activities that define the clusters for measuring both air quality and smells, and public perception of smell type. Although measurements were recorded at points (five to ten per cluster) mapped on planed, semi-planned and unplanned parts of the city. The smell was broadly categorized into two smell typologies – good smell (pleasant) and bad smell (odour). The source typology was necessary to allow for accurate mapping and easy assessment of smell impact (Bockreis & Steinberg, 2005).

2.3 Measurement of Public Perception of Urban Smells

A questionnaire was designed to elicit public perception on smells from the sites where air quality was measured (see Appendix 1). The instrument has 13 questions, out of which five are on the demographic data, three questions on smell intensity perception, and the other five on the perceived health impact of smells. With exception of the demographics, the questions were designed on a five-point Likert scale (Strongly Agree, Agree, Moderately Agree, Disagree, and Strongly Disagree). Respondents for the research comprises of those working or residing within the smell spots. Male respondents constituted 67% and females accounted for 33% while respondents in the age bracket of 20- 49 on one hand and those aged 50 and above formed 58% and 42% respectively.

The study used purposive-random sampling to distribute 250 questionnaires to the respondents within and around the 48 selected clustered smell sites based on their land use types. Some recent urban environmental studies that used multiple methods as in the current study measured public perception as complementary and confirmatory data only and hence used smaller samples. For instance, Wang et al (2022) used 30 respondents while Zabetian and Zavi (2022) used 100 respondents in their respective studies. The criteria that guided sampling frame was based on the following: (I) Only people who reside, work or whose businesses are carried out within 50m radius of a smell emitting source; (II) only adults within the ages of 20 and above were considered for smell perception ranking. The choice of younger adults and older adults was informed by some studies that suggested that older adults exhibit decreased sensitivity to both pleasant and unpleasant smells (Zelano 2007; Joussain et al., 2013).

2.4 Smellscape Perceptibility Ranking

To arrive at the smell perceptibility ranking, the study followed the Atari et al., (2009) method where perception of smells concentration was analysed based on temporal, environmental and health impact indicators to determine the perceived smell intensity (see Figure 2 and Appendix I).

Thus, a 13-level intensity scale was used to rank the smellscape perceptibility: 0: Not perceptible, 1: Very weak, 2: Weak, 3: Distinct, 4: Strong 5: Very strong, 6: Extremely strong). In this method of smell ranking, pleasant smells are assigned negative values while odorous smells are assigned positive values intensity scale. This method was adopted from the widely used German Standard VDI 3882 for smell intensity scaling (Belgiorno et al., 2012). Smell categories were weighed and averaged to arrive at the smell ranking (Figure 2).

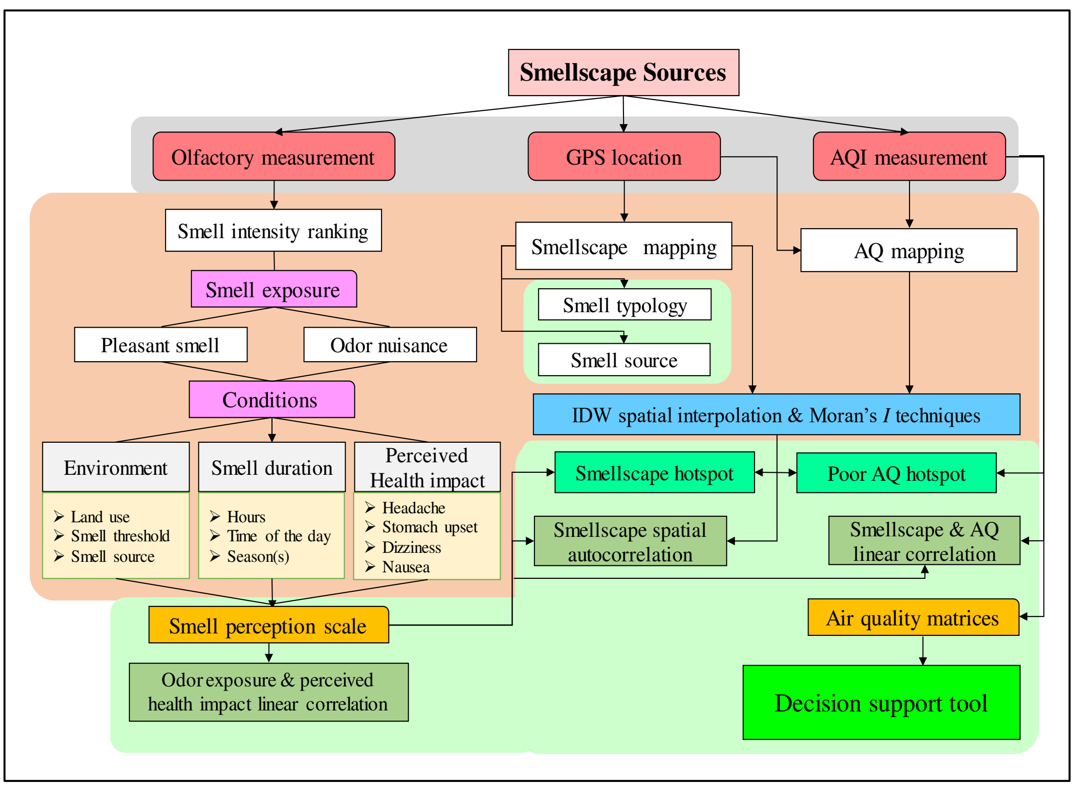

Figure 2. Graphical depiction of multiple methods and tools used for data collection and analysis used in the study.

2.5 Air Quality Measurement

The study team used IQAir sensor to measure the air quality of designated smell-emitting points that within each cluster from a particular land use type. IQAir is a hand held wireless sensor for monitoring ambient air quality based on the US Air Quality Index (AQI). It monitors real-time air quality (AQI, PM2.5 and CO_2). It can also measure meteorological parameters like relative humidity and temperature (Schneider et al., 2017). The AQI values run from 0 to ≥500 but the IQAir sensor can also measure values above the AQI scale. The AQI is divided into six scales: (0 - 50: good, 51 - 100: moderate, 101 - 150: unhealthy for the sensitive group, 151 – 200: unhealthy, 201 – 300: very unhealthy, ≥ 300, hazardous). The higher the AQI value, the greater the level of air pollution and the greater the health and safety concerns.

Air quality measurements were taken at the study locations over a two-year period to determine the mean measured air quality. The measurements were taken during dry, cold, and wet seasons in Kano between the end of 2020 and 2022, mostly during the day when people are outdoors and business activities are at their peak. We also avoided night time measurement for security and safety concerns. Measurements were taken at intervals of 1 to 3 months in the study years 2020 and 2022 at each of the 65 sampled spots to calculate the mean readings. This was done to obtain the average annual air quality in relation to the perceived smell concentration of the activity area, which also takes into account temporal dimensions.

2.6 Mapping Smellscapes and Air Pollution Hotspots

To generate hotspot maps of smellscapes and air quality concentrations in metropolitan Kano, the study executed spatial interpolation using the inverse distance weighted (IDW) technique using ArcGIS 10.5. The technique was used because it models data in continuous surface based on the assumption that nearby values are more related than distant points (Bhunia et al. 2018). Each interpolated point has a weight proportional to its distance from the known point i.e. more weight are assigned to closer points than farther ones from a known point (Al-Mamoori et al., 2021).

Similarly, the higher the concentration of smell or pollution in space, the closer the source of emission. Therefore, IDW will produce a better estimation of smellscape and air quality compared to other techniques. There are quite number of equations that explain the IDW principle, but the commonly used equations that estimate the unknown point is called the Shepard method and it uses weight function *wi* given below (Azpurua & dos Ramos, 2010).

$$w_i = \frac{h_j^{-p}}{\sum_{i=0}^{n} h_j^{-p}} \qquad (1)$$

Where p is an arbitrary positive real number called power parameter (typically $p = 2$) and h_j = the distance from dispersion point to the interpolated point, given by

$$h_i = \sqrt{(x - x_i)^2 + (y - y_i)^2} \qquad (2)$$

Where (x, y) = coordinates of each interpolated (unknown) point, while (x_i, y_i) = coordinates of each dispersion point.

2.7 Mapping patterns of smell-source clusters for spatial ineqaulites

To understand the pattern of smellscape concentration in metropolitan Kano, the study carried out spatial autocorrelation using the Moran's index. The index is important not only in understanding the spatial pattern exhibited across the smellscape but also in understanding the locational impact (positive or negative) of smell-source clustering on one another and the surrounding environment based on the Moran's Index (I) following Fan & Myint (2014). This mapping procedure supported the researchers to identify the spatial inequalities based on differences between planned, semi planned and unplanned areas.

2.8 Design of Decision Support Matrix for Smell and Poor Air Quality Response

Urban sustainability hinges on the ability to develop solutions or best management practices. Hence, the study proposes smellscape and air quality matrices and decision taxonomic hierarchy to guide decision support for addressing citywide air pollution for individuals, community and policymaker's response. The matrices are designed in 6 x 7 and 6 x 5 cells based on six AQI ranking against 12-level of smell hedonic scale in order to come up with air pollution concern levels. Many studies have utilized matrix model to guide decision support and policy formulations (Tseng et al., 2018; Tang & Liao, 2021; Kafi et al., 2021; McFerran et al., 2022).

3.0 Results

3.1 Spatial Distribution of Sources of Smell and Air Contamination

The spatial distribution and classification of urban smellscapes in Kano are presented in Figures 4 and 5 respectively. It is evident that the identified activities were distributed across the city's formal, informal and semi-formal areas in other words planned, semi-planned and unplanned areas. Appendix II gives details of the distribution and activities that cause air quality contamination while Appendix III pictorially depicts examples of some of the major smell emitting activities.

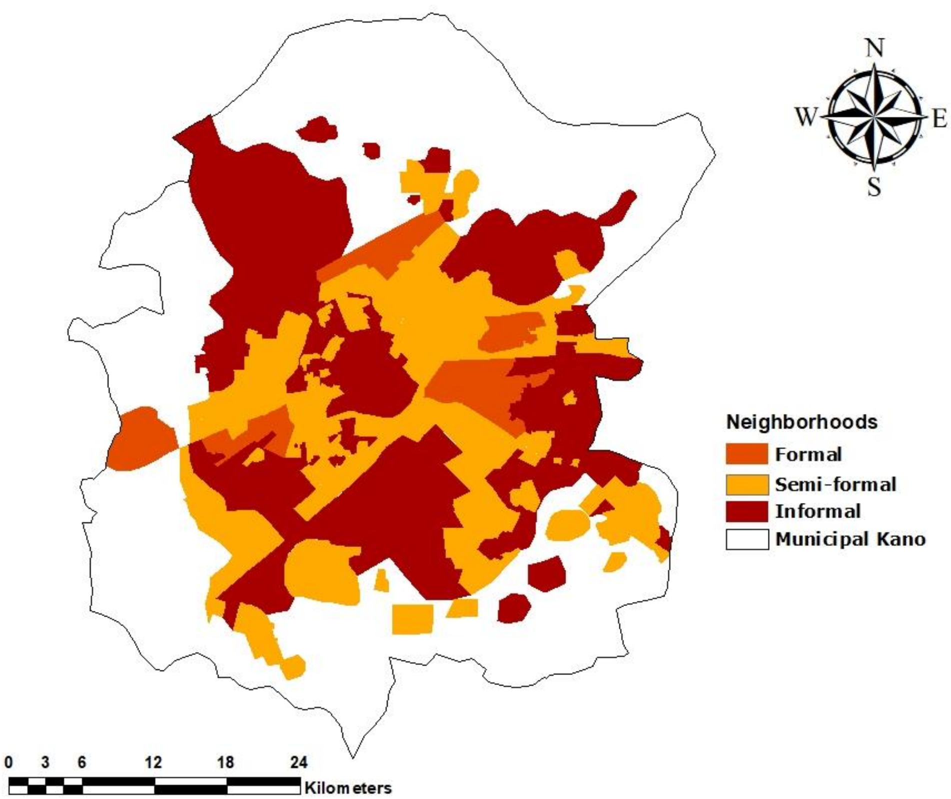

Figure 3: Settlements status based on residential densities and design patterns of neighborhoods of urban Kano. The formal represents the planned areas that have lowest population density and lived by the most

affluent and have less concentration of odours. Semi-formal areas have medium population densities and mixed concentration of smell typologies while informal area are the unplanned areas with higher clustering of smell activities.

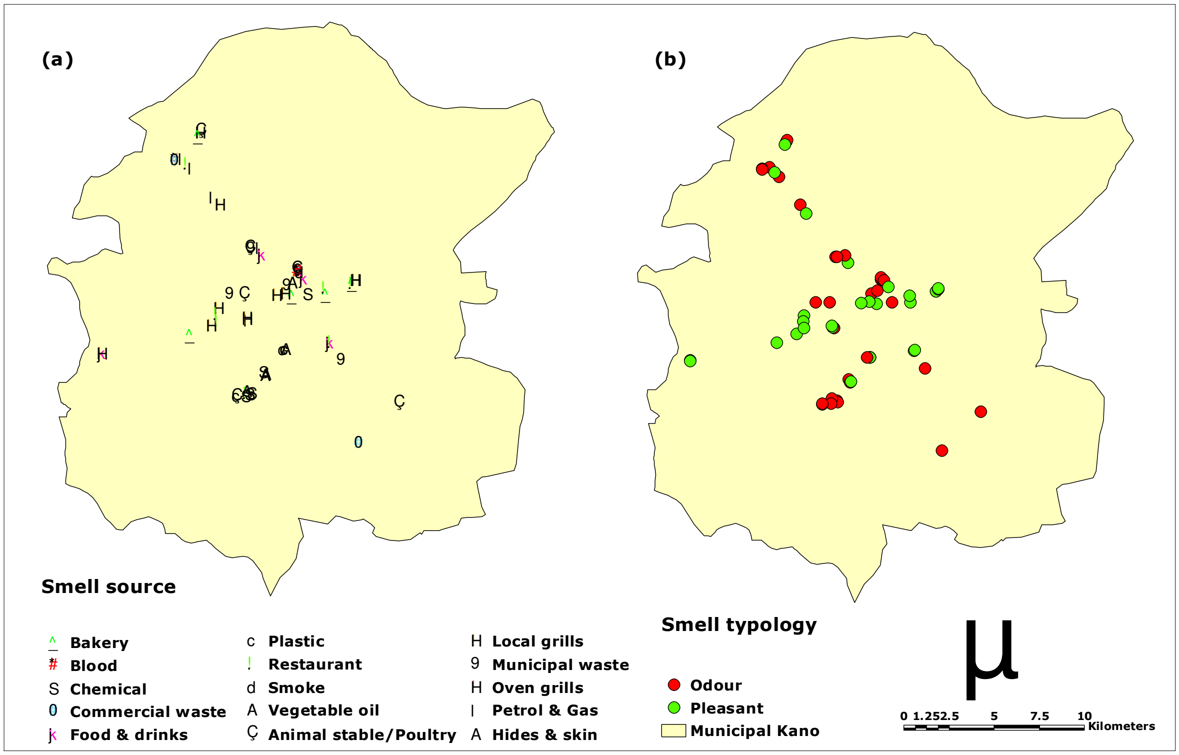

Figure 4a: spatial distribution of clusters of smellscapes based on types of business and commercial activities

Figure 4b: Smellscape typologies and their locations based on data collected in 2020-2022 shows a mixed distribution of good and bad smell points all over the city

3.2. Smellscape Hotspots

The results of the spatial interpolation of smellscape and air quality are shown in Figures 5. Evidently, the concentration of pleasant smellscape appeared to be outside the more traditional and highly densified parts of the city. On the other hand, pleasant smells concentrated mostly within the medium and low density residential areas and commercial areas as depicted on the hotspots map. Activities with pleasant smells include beef/chicken grill spots, bakeries, popcorn and candy making sites, perfume shops, gardens and others.

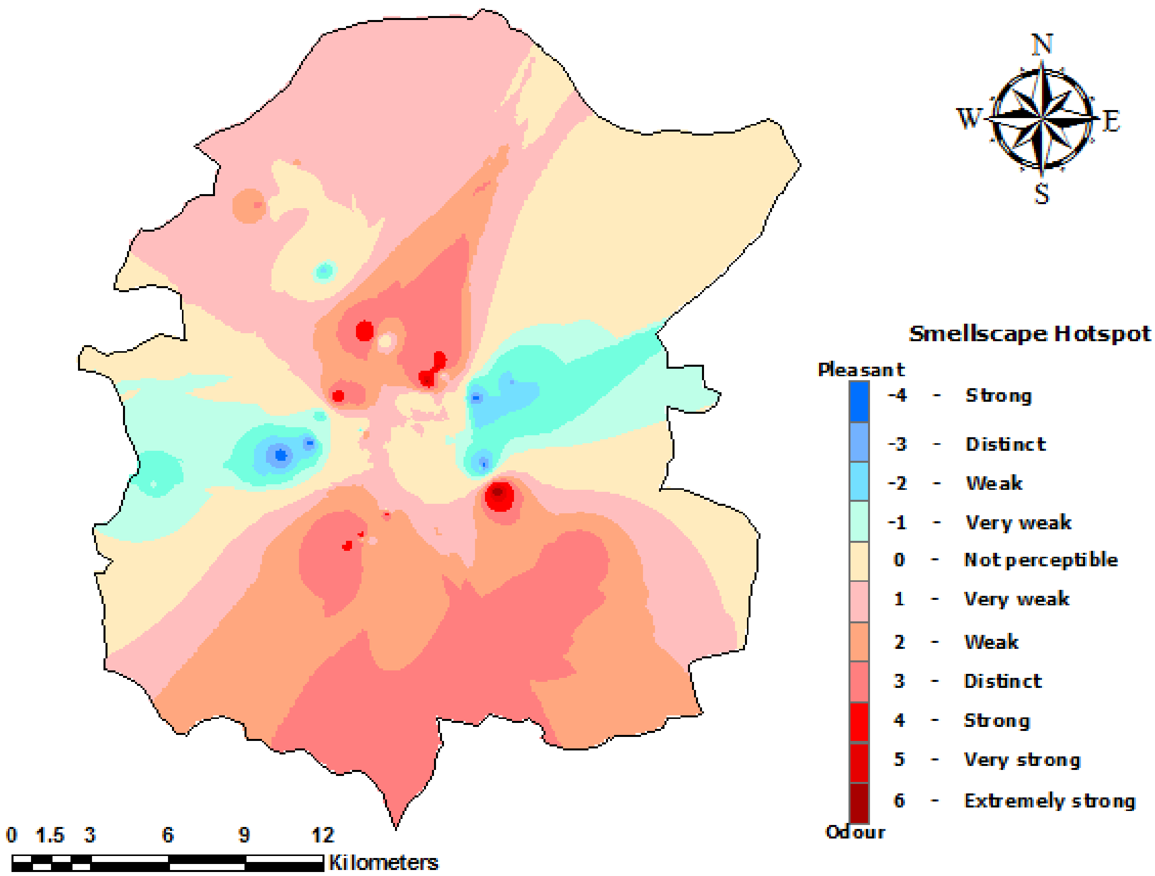

Figure 5: Smellscape hotspots based on 13-level hedonic intensity scale representing public perception of the situation from across clusters

Based on Figure 5, public perception measure revealed that odour hotspots are mostly found within the unplanned and high density areas of this highly densified city. As example, burning of hides and skin, municipal waste, poultry farming and artisanal works such as leather works are associated with informal spaces. Places leading this category of smellscape include the abattoir, local markets, and sites of small enterprises. Another ordour hotspot under this category include waste dumping sites which exhibited highest perception threshold as shown in Figure 5. Unlike odour hotspot that were found to have a wider diffusion, pleasant smells were observed to have a characteristically low perception thresholds, with their smell concentrations usually within a few meters away from their emitting sources.

3.3 Poor Air Quality Hotspots

Previous studies have established that the mean measured air quality shows high and varying AQI values (Plants, 2017; Schneider et al., 2017; Dutta et al., 2021). The same situation played out in this study where a total of five smell emitting sources were identified as AQI hotspot areas (Figure 6). The area with high pollution concentration and "hazardous" ranking is the abattoir. It records AQI value of 1200 far above the worst ranking threshold ≥300 (see Appendix 1). This was directly traced to the animal skin burning activities that emit thick and offensive smoke within and around abattoir (see Appendix I). Other hotspot areas with "Hazardous" AQI ranking are local meat grill spots for selling roasted beef and chicken. These spots of both good and pleasant smells corresponded with hazardous sources of air contamination and this is attributed to their charcoal burning. These spots are the most common and widely distributed sources of smell and air quality threatening activities across the clusters. Indeed, the in-situ mean measured AQI and the hotspot mapping reveals the air quality ranges between 101– 200 (see Figure 6).

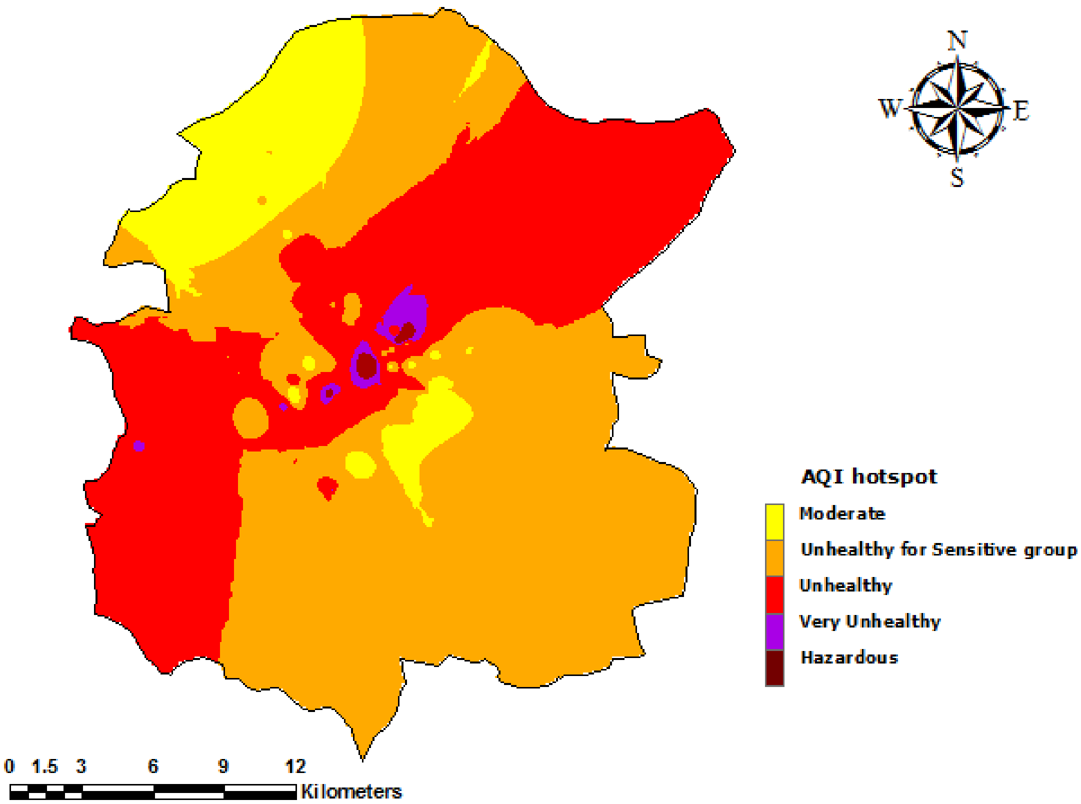

Figure 6: Poor air quality hotspot based on mean measure AQI values associated with individual activities or land use types

3.4 Spatial Correlations of Urban Smellscapes Distribution

To understand the pattern of smellscape concentration in metropolitan Kano, the study run spatial autocorrelation using the Moran's index (*I*). Moran's *I* is important not only in understanding the spatial pattern exhibited across the smellscape but also in understanding the impact (positive or negative) of smell-source clustering on one another and the surrounding environment following Fan & Myint (2014). The result of the Moran's Index is shown in Table 2, the summary of the Moran's coefficient (*I*), expected *I*, variance and critical value (z-Score) were statistically computed to show how dispersed, random or clustered the distribution pattern of smellscape is within Kano metropolis (Figure 7). The Moran's *I* was 0.199 - less than 1, which implies that the smellscape exhibited a clustered pattern. Furthermore, with a combined z-score of 8.760, greater than the critical value 2.58, and *P-value* of 0.000, less than the standard 0.01, the result is statistically significant with less than 1% probability of showing a random distribution (Vojteková et al., 2019; Kafi et al., 2021).

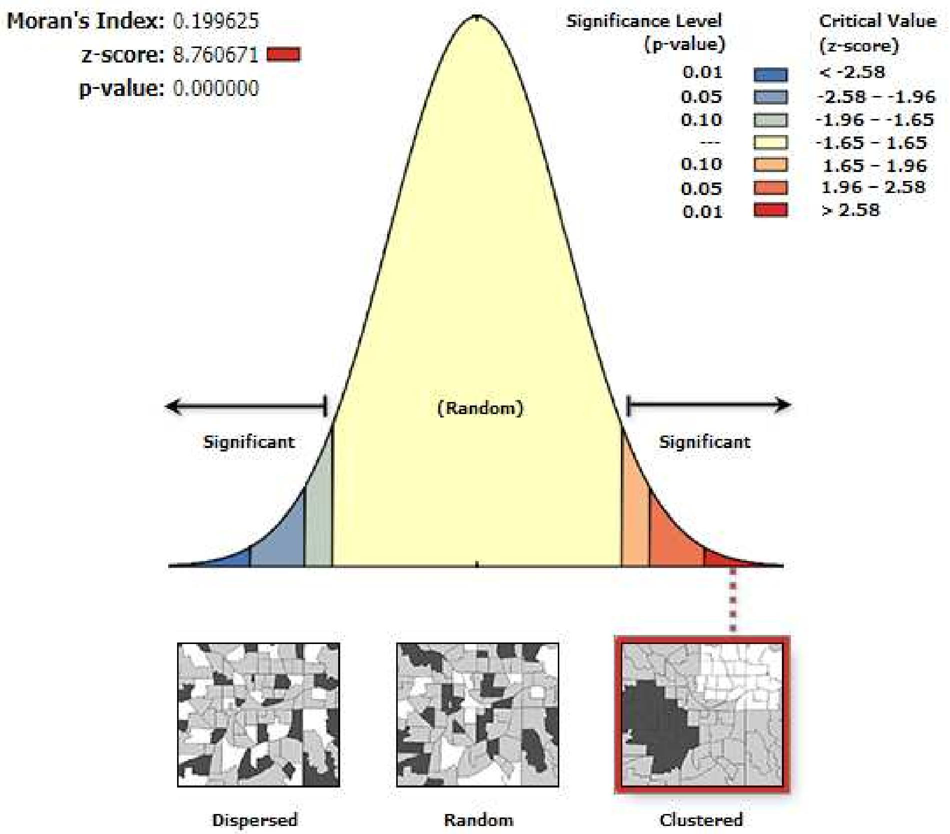

Figure 7: The overall pattern of spatial patterns of Kano smellscapes based on Moran's *I* statistical analysis exhibits clustering of smellscape types

Table 2: Moran's Index Spatial correlation for Kano urban smellscapes

Moran Coefficient	0.1996
***p*-Value**	0.0000
z-Score	8.7607

3.5. Correlation between Urban Smell and Air Quality

To assess the relationship between smell and air quality, a correlation analysis was carried out and displayed in scatter plots (see Figure 8). The scatter plot represents the functions of the mean measured AQI of each of the identified smell emitting sources against their corresponding mean perceived smell intensity, ranked based on human olfactory system. The correlation analysis was performed differently for each of the two smell typologies considered in this study. Each of the smell-source clusters were color-coded distinctively in the scatter plot to better understand the source, intensity and its corresponding air quality ranking. The correlation analysis between smell and air quality showed non-significant results, with p-values of 0.075 (for pleasant) and 0.23 (for odor), both exceeding the standard P-value of 0.05. This indicated no correlation between smell and air quality based on aggregation of all the sources (emitting activity) and types (pleasant and odour). This is further supported by the values shown in Figure 8 and Appendix II, which showed that changes in the perceived smell intensity did not cause any significant change in the mean measured air quality, and vice versa.

Although there is no statistically significant correlation between overall smell and air quality, some activities that emit smoke such as hides and skin burning and local grill spots do emit odour and pleasant smells a varying degree of poor AQI values. Thus, the correlation between smell and air quality is apparent at activity level rather than at a landscape level.

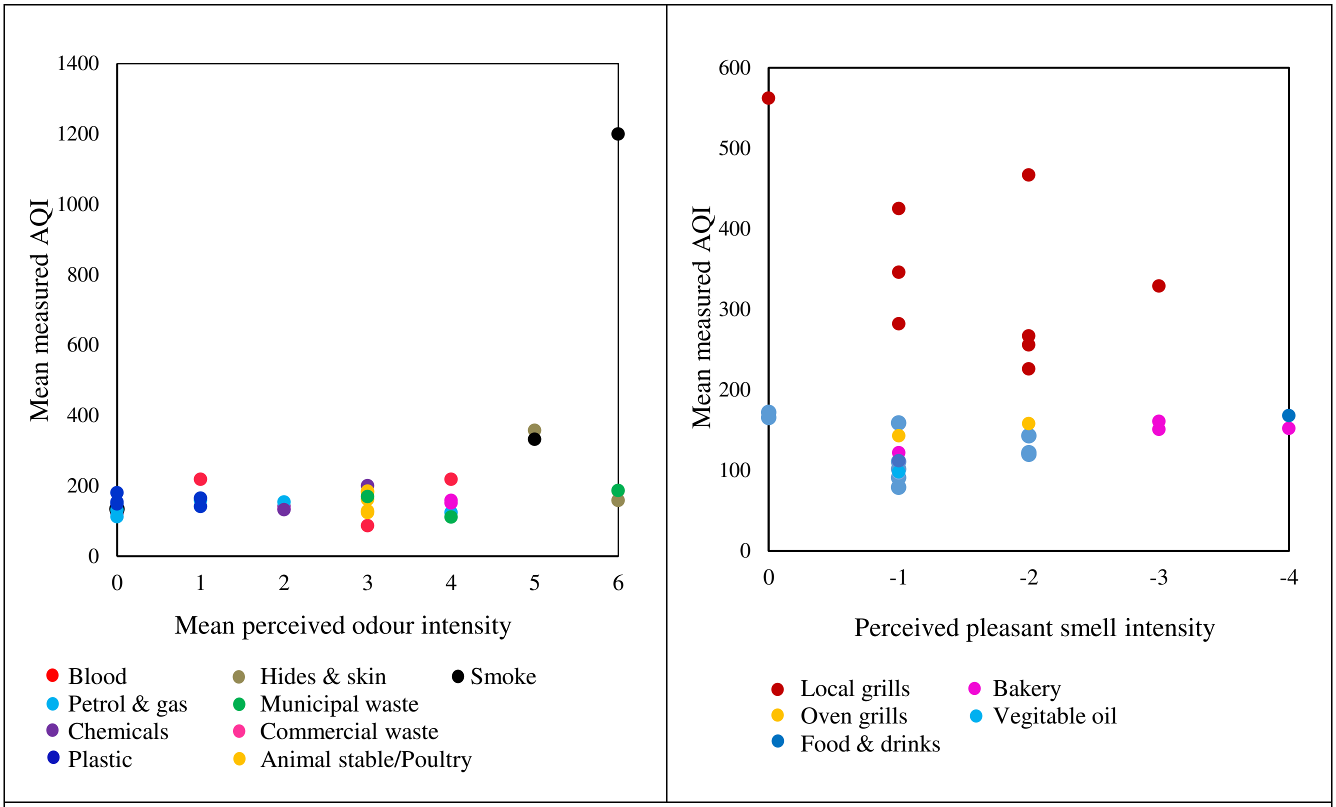

Figure 8: Scatter plot showing correlation between perceived smell intensity scale across source typologies and their mean measured air quality

On the other hand, to assess the relationship between odour exposure and perceived psychological and health impact, a simple linear correlation analysis was computed and presented in scatter plot (see Figure 9). A statistically significant relationship was found ($P < 0.000$), with an $R^2 = 0.75$, which indicates a strong positive correlation between odour exposure and perceived psychological and health impact.

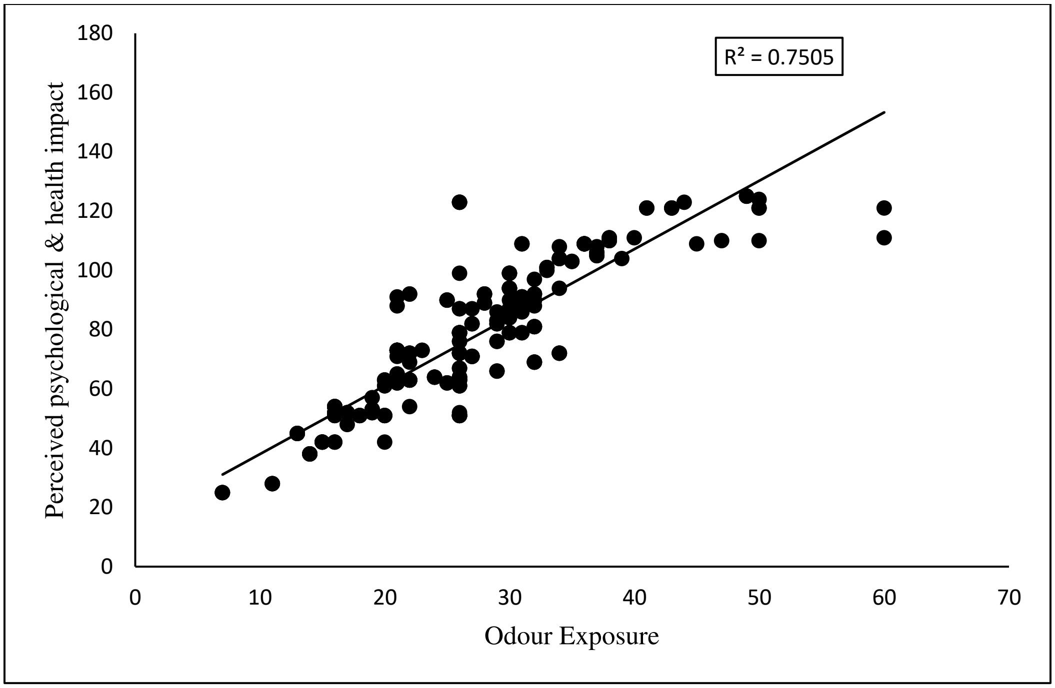

Figure 9: Linear correlation between odour exposure and perceived psychological and health impact based on interview with residents of Kano City

3.6 Decision Support Tool for Urban Smell and Management of Air Quality

The decision support tool (DST) is based on results from smell intensity perception and mean measured AQI values observed from the field. Each smell category is presented distinctly in a separate matrix for the purpose of distinguishing between air pollution concern rating for pleasant and odour smell spots (Figure 10 and 11). Each matrix gives a breakdown of observations under different air pollution cases observed in this study.

	Air quality index → / Unpleasant smell scale ↓	Good	Moderate	Unhealthy for sensitive group	Unhealthy	Very unhealthy	Hazardous
		0 - 50	51 - 100	101 - 150	151 - 200	201 - 300	> 300
0	**Not perceptible**	-	-	5	2	-	-
1	**Very weak**	-	-	1	2	1	-
2	**Weak**	-	-	3	1	-	-
3	**Distinct**	-	1	3	5	-	-
4	**Strong**	-	-	2	1	1	-
5	**Very strong**	-	-	-	-	-	2
6	**Extremely strong**	-	-	-	-	4	1

Figure 10: Matrix for air contamination based on measured air quality index and perceived unpleasant smell hedonic scale

Although the study found that air pollution concerns are always higher and more associated with odor-emitting activities, not all pleasant-smell emitting locations are safe or do not contaminate air quality. It was discovered that none of the 65 smell emitting spots under study are rated "safe." However, 30 smell-emitting spots (17 odour spots and 13 pleasant spots) are rated as "Unsafe." Furthermore, 12 smell emitting spots (eight odour spots and four pleasant spots) are rated "Very unsafe". Lastly, the study observed that the number of smell emitting spots with "Hazardous" rating are 19, with odour emitting spots having 10 and pleasant smell-emitting spots having 9, as shown in Figure 10 and 11.

	Air quality index → / Pleasant smell scale ↓	Good	Moderate	Unhealthy for sensitive group	Unhealthy	Very unhealthy	Hazardous
		0 - 50	51 - 100	101 - 150	151 - 200	201 - 300	> 300
0	**Not perceptible**	-	-	-	2	-	1
-1	**Very weak**	-	-	6	1	1	2
-2	**Weak**	-	-	3	1	3	1
-3	**Distinct**	-	-	-	2	-	1
-4	**Strong**	-	-	-	2	-	-

Figure 11: Matrix for air contamination based on measured air quality index and perceived pleasant smell hedonic scale

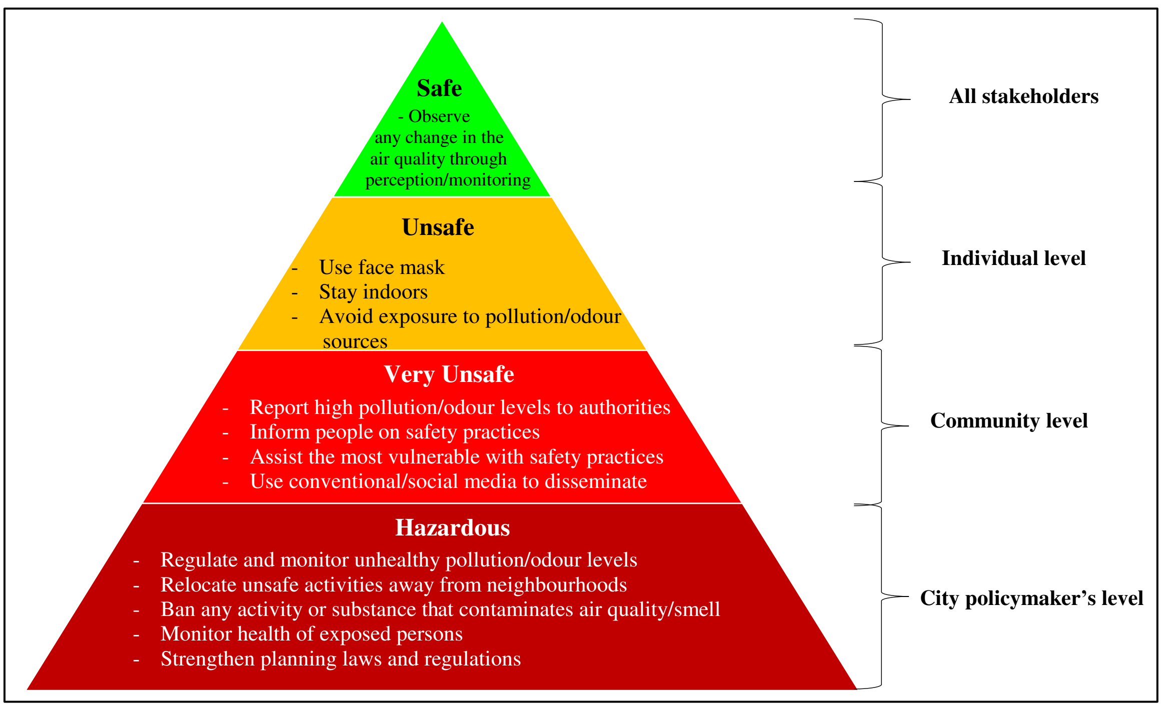

Figure 12: Range of options to support various stakeholders to decide on best practices for city level air pollution or offensive urban odour. The application of this DST is based on the assumption that people and authorities can have access to AQI values which is available online and use such data to take decision on daily basis.

4. Discussion

This section outlines the key implications of the study especially in relation to the study research questions. This study has successfully mapped the distribution patterns of urban smellscapes in a typical high population and unplanned African city. Mapping is an important leveraging factor for improved understanding of smellscapes and air quality spatialities in the lived environment. Ordinarily, it is assumed that cities lacking standard urban planning would experience a mixed smellscapes as in the case of Kano. However, variations in population density and urban poverty show that areas loved by the poor for residence and livelihood record worst smell activities.

Based on the study results of public perception and AQI analysis, urban environmental quality monitoring and standards are lacking in the city. The results have shown an evidence of poorly perceived smell and air quality parameters. Yet, even from within the span of two years of this study, there is no evidence of any action taken recently or previously by the policymakers or any other stakeholder to address the issue effectively. Studies from different parts of the world have underscored the point that odours with or without health risks constitute nuisance to city dwellers (Badach et al 2018; Kitson et al., 2019). However, in the interest of public safety and wellbeing, researchers are concerned that the challenge of urban smell needs to be addressed by planners, policymakers, and practitioners (Bentley et al. 2023). Indeed, further studies are needed to establish health risks associated ordours in the same way health risks of air pollution are known (Fisher et al. 2019; Sadiq et al., 2022).

Another insight relates to the clustering of smell sources and hotspots of air contamination and odours. It is pertinent to add that rapid urbanisation experienced in Kano has resulted in densification at various degrees in low and high density areas which witness increased disappearance of open spaces and green areas (Barau et al. 2015). The prevalence of offensive smells in the informal and high density unplanned areas as revealed by this study corresponds to the vulnerability characteristics of informal settlements as highlighted by Fan et al. (2022). Hence, it is possible to assume depletion of green and open spaces reduces air circulation and cleansing

There is an assumption that sees urban smells as more of nuisance than a health risk (Kitson et al. 2019). However, this study has established that even smells perceived as pleasant could be hazardous to public health and especially their associated poor air quality. On the other hand, it is worth mentioning that, residents can hardly take decisions on that because it is beyond their capacity. This is especially because informal activities exist independent of any existing urban planning and management system. The extent of information in public domain about the state of the environment and especially the ambient air dictates how they respond. Hence, there is need for alarmist campaigns on the negative impacts of urban smell and air quality. In particular, municipalities, civil society groups and individuals should pay attention to monitoring and sharing data and information on air quality.

The hotspots analysis illustrates an aspect of spatial inequality in exposure to pollution and odours. The concentration of odour around informal settlements and types of activities that the poor engage in for their livelihoods is a key indicator of this assertion. The exposure of urban poor to polluting smell spaces is another justification for the manifestation of spatial inequality to exposure risks. On other hand, the richer urban residents' direct exposure to such risks could be limited because they do not operate under such working environments. The lower density rich people's residences are greener and more open and which make them to experience less concentration of both forms of pollutants.

With respect to contributions to methodology, this study builds on previous studies on air quality challenges in urban areas of developing countries where the focus is on urban transport generated air pollution (Sadiq et al., 2022). This study has expanded the frontiers by directing its searchlight on specific spot or object-based pollution and smell sources and how they are clustered. By doing that, it shifts attention to small and informal business-driven pollution. Nevertheless, it is undebatable that it is difficult to separate sources of air pollution but the point specific measurement to sufficient extent address such fears. This study has also shifted attention to building and identifying solutions that target individuals and communities including the most vulnerable inhabiting cities. This has been achieved through design of a disaggregated decision support tool and this is contrary to traditional solution pathways designed by scientists which often target science and policy communities.

5. Conclusion

This study has clearly shown the importance of coupling empirically and subjectively driven data in mapping and understanding how socio-economic activities in largely informal cities affect and contributes to deterioration of urban air quality. While the global science and engineering community is yet to create smell sensitive machines that differentiate good and bad smells, this study reveals that some perceived bad or good smell may correspond to points of hazardous air contamination. It is apparent from this study that using AQI to understand and measure air quality needs to be complemented by public perception measures especially as it related to urban pleasant and unpleasant smells. Furthermore, this study has demonstrated the critical importance of urban planning in cities and towns of developing countries where its absence and weaknesses are more likely to result in the sort of situation that this paper has revealed in Kano. Similarly, this study reveals that in as much subjectivity varies between person to person in smell perception; variation could also occur between air quality measurements between points of smell emission and clusters of smell emissions. On the basis of this weakness, more detailed data are needed for future studies.

More studies are also needed to establish which materials and substances actually contribute to bad odour or contaminate the air at each spot or cluster of spots. This is because some perceived pleasant spots correspond to points of hazardous air quality. Given, the poor state of urban planning in the rapidly growing cities of the developing world, this study recommends strengthening of nature based solutions. Some studies found urban greening in particular as invaluably useful in addressing multifaceted urban air quality challenges. The novelty of this study is in its ability to use empirical data to design an inclusive decision support tool that identifies pathways for individuals, vulnerable groups, policymakers, and civil society groups to respond to various exposure risks. Finally, this study underscores the need for stakeholders interested in mainstreaming and streamlining sustainability and resilience in cities to strengthen transdisciplinary and solution-oriented research. Studies of this nature are also vital for supporting cities to respond to or implement global urban sustainability instruments such as SDG 11, New Urban Agenda, Paris Agreement and many others.

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Appendix I

Gender	○ Male	○ Female			
Age of the respondent	> 20 years 21 -30 years	31 – 40 years 41 – 50 years	61 and above		
Educational Level	Primary Secondary Tertiary Others _____				
Place of residence					
Place of work					
What is the degree of the smell perception?	○ Pleasant	○ Less offensive	○ Moderately offensive	○ Very offensive	○
At what time of the day do you perceive the smell more?	○ Morning	○ Afternoon	○ Evening	○ Always	○
At what season is the smell more?	○ Dry	○ Winter	○ Rainy		
If I am exposed to unpleasant smell, I feel dizzy	○ Strongly Agree	○ Agree	○ Moderate	○ Disagree	○ Strongly Disagree
If I am exposed to unpleasant smell, I feel headache	○ Strongly Agree	○ Agree	○ Moderate	○ Disagree	○ Strongly Disagree
If I am exposed to unpleasant smell, I feel nauseous	○ Strongly Agree	○ Agree	○ Moderate	○ Disagree	○ Strongly Disagree
If I am exposed to unpleasant smell, It affects my mood	○ Strongly Agree	○ Agree	○ Moderate	○ Disagree	○ Strongly Disagree
If I am exposed to unpleasant smell, It get me stress up	○ Strongly Agree	○ Agree	○ Moderate	○ Disagree	○ Strongly Disagree

Appendix II

S/N	Business activity	Source of smell	Process	Smell Type	Mean Perceived Smell Intensity	Mean measured Air Quality Index
1	Abattoir Slaughter Area	Blood	Slaughtering	Odour	3	87
2	Old Abattoir Slaughter Area	Blood	Slaughtering	Odour	1	218
3	Old Abattior Blood	Blood	Liquid waste	Odour	4	218
4	Old Abattior Burning Area	Smoke	Animal skin burning	Odour	6	1200
5	Dye - Pit (Marina)	Chemical	Fabrics dying	Odour	0	121
6	Gongoni	Chemical	Insecticides manufacturing	Odour	3	200
7	Jay Kay Carpet & Rug	Chemical	Carpet manufacturing	Odour	0	134
8	Olam Fertilizer	Chemical	Fertilized Manufacturing	Odour	2	141
9	Royal Foam	Chemical	Mattress manufacturing	Odour	2	134
10	A.A Sadiq Oil & Gas	Petrol & Gas	Fueling & lubrication services	Odour	0	112
11	A.Y Mai Kifi Oil & Gas	Petrol & Gas	Fueling & lubrication services	Odour	1	158
12	Kokiya Petroleum	Petrol & Gas	Fueling & lubrication services	Odour	0	131
13	Oando Petroleum	Petrol & Gas	Fueling & lubrication services	Odour	4	124
14	Alaj Petroleum	Petrol & Gas	Fueling & lubrication services	Odour	2	154
15	Salasar	Petrol & Gas	Fueling & lubrication services	Odour	6	185
16	Local Tannery (Majema)	Hides & skin	Leather processing	Odour	6	158
17	Loquat Tannery	Hides & skin	Leather processing	Odour	5	358
18	Nabegu Tannery	Hides & skin	Leather processing	Odour	6	158
19	Poultry Farm	Animal stable/Poultry	Poultry farming	Odour	3	128
20	Poultry Farm	Animal stable/Poultry	Poultry farming	Odour	3	124
21	Yan Dabbobi	Animal stable/Poultry	Livestock market	Odour	3	161
22	Yan Awaki	Animal stable/Poultry	Livestock market	Odour	3	181

23	Old Abattior Kara	Animal stable/Poultry	Livestock market	Odour	3	185
24	B & B Leather	Plastic	Manufacturing	Odour	1	141
25	K & H	Plastic	Manufacturing	Odour	1	165
26	M C Plastic	Plastic	Manufacturing	Odour	0	180
27	Super Sack	Plastic	Manufacturing	Odour	0	154
28	B.B.Y Super Sack	Plastic	Manufacturing	Odour	0	148
29	Refuse Dump Site	Municipal waste	Solid waste dumps	Odour	6	187
30	Refuse Dump Site	Municipal waste	Solid waste dumps	Odour	3	169
31	Refuse Dump Site	Municipal waste	Solid waste dumps	Odour	4	111
32	Refuse Dump Site	Municipal waste	Waste burning	Odour	5	332
33	Yan Lemo	Commercial waste	Fruits market	Odour	3	150
34	Abattior Waste Area	Commercial waste	Solid waste dumps	Odour	2	132
35	Old Abattior Waste Area	Commercial waste	Solid waste dumps	Odour	4	158
36	Dowells Eatery	Food & drinks	Oven roasting	Pleasant	-2	143
37	Hilder Suya	Oven grills	Oven roasting	Pleasant	-1	159
38	Ilham Suya	Oven grills	Oven roasting	Pleasant	-2	158
56	More N More Shawarma	Food & drinks	Oven roasting	Pleasant	-1	143
39	White House Suya	Local grills	Smoke roasting	Pleasant	-2	267
40	Yan kilishi	Local grills	Smoke roasting	Pleasant	-1	282
41	Gurasa Suya	Local grills	Smoke roasting	Pleasant	-1	425
42	Ali Kaza Suya	Local grills	Smoke roasting	Pleasant	-1	346
43	Mai Takobi Eatery & Suya	Local grills	Smoke roasting	Pleasant	-2	467
44	Murtala Eatery & Suya	Local grills	Smoke roasting	Pleasant	-3	329
45	Hamdala Suya	Local grills	Smoke roasting	Pleasant	0	562
46	K.A.K Suya	Local grills	Smoke roasting	Pleasant	-2	226
47	Lajawa Suya	Local grills	Smoke roasting	Pleasant	-2	256
48	See Sweet & Bakery	Bakery	Bakery	Pleasant	-4	152
49	Two One Two	Bakery	Bakery	Pleasant	-4	168
50	White Light Bakery & Snacks	Bakery	Bakery	Pleasant	-3	161
51	Maroosh Bakery & Snacks	Bakery	Bakery	Pleasant	-3	151
52	A.A.A Bread	Bakery	Bakery	Pleasant	-1	112
53	Mansur Bakery & Snacks	Bakery	Bakery	Pleasant	-1	122
54	Shaba'an Eatery	Food & drinks	Food selling	Pleasant	-1	79
55	Down Town Eatery	Food & drinks	Food selling	Pleasant	-1	111
57	Lamid Eatery	Food & drinks	Food selling	Pleasant	-2	122
58	Yan Nono	Food & drinks	Food selling	Pleasant	0	166
59	Royal Taste Eatery	Food & drinks	Food selling	Pleasant	-1	97

60	Kangiwa Eatery	Food & drinks	Food selling	Pleasant	-1	102
61	Sharp Sharp Eatery	Food & drinks	Fast food	Pleasant	-1	91
62	Havilah Eatery & Snacks	Food & drinks	Fast food	Pleasant	-2	120
63	Dala Food Nig Ltd	Food & drinks	Food selling	Pleasant	0	172
64	Yakasai Oill Mill Nig Ltd	Vegetable oil	Food processing	Pleasant	-1	98
65	Alh Baita Oil Mill	Vegetable oil	Food processing	Pleasant	-1	112

Appendix III

	
Fig x. Animal skin burning area, Old Abattior (Kofar Mazugal)	Figure x. Animal Horn burning Area (Kofar Mazugal)
	
Figure x. Animal stable (Unguwa Uku)	Figure x. Blood passage way (kofar Mazugal)

Figure x. Court Road refuse dump site

Figure x. Old Abattior Slaughter Area (Kofar Mazugal)

Figure x. Poultry farm (Kofar Ruwa)

Figure x. Hilder Suya (Ungogo)