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Air Pollution Exposure Mapping by GIS in Kano Metropolitan Area

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ABSTRACT: Because of the pinch of air pollution on human health and its environment, it has become necessary to monitor and map out the peaks and lows threat places of air pollution in different land use across a city. In this regard, air pollution exposure mapping of Kano metropolis based on land use classifications namely industrial, residential, commercial and institutional was carried out for interpretive and assessment of health hazard associated with the selected pollutants. The observations for ambient air quality parameters (CO, SO_2, H_2S, NO_2, and PM_{10}) monitored with portable digital air pollution detecting devices for creation of data. Geographic Information Systems (GIS) technique was applied to create spatial distribution maps of urban air quality of the metropolitan area. The results of pollution index map of ArcGIS extrapolation indicated that neighbourhoods in the vicinity of Bompai and Sabon Gari industrial and commercial zones, respectively were found to be highly exposed and liable to ailments associated with air pollution, while places nearby Dorawa and School of Technology were air pollution-ease zones but could experience bioaccumulation over long exposure time. Therefore, the study reveals that variability of air quality was strongly related to predominant land use in particular areas within the metropolis and could help in estimate and valuation of likely health challenges associated with poor air quality due to air pollution. Besides, the observed spatial variation for air quality could serve as hot spot identifier and as an informant for rational decision on air quality control strategies for environmental management.

Keywords: Microenvironment, health burden, urban environment, urbanisation-pollution nexus.

INTRODUCTION

In the recent past, air pollution is one of the most pressing issues to all of the urbanite and has added tremendously to the disease burden of most nations especially the developing nations which Nigeria is not an exception. Air pollution describes the state of the atmosphere with predominant presence of hazardous substances that are harmful to humans and animals (Reinmuth-Selzle *et al.,* 2017; Ghorani-Azam *et al.,* 2016). Atmospheric pollution hampers human breathing and influences life quality. Furthermore, it becomes a critical factor of anticipated cardiopulmonary health associated problems, most especially on the issues of ambient air quality and air quality level in houses and places of work. The air-borne pollutants impair the air quality and continuous exposure to polluted air may lead to several health problems such as cardiopulmonary disease, bronchitis, asthma, wheezing and coughing

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etc (Ghorani-Azam *et al.,* 2016; Rumana *et al.,* 2014). An average composition of the atmosphere below 25 km indicates that nitrogen, oxygen, water vapour, carbon dioxide, methane, nitrous oxide, and ozone are the major constituents and their balance is important to the maintenance of the Earth's biosphere (Cassia *et al.,* 2018; Portmann *et al.,* 2012). A balanced distortion of these constituents for a considerable long time may lead to serious implications on weather and climate in term of air quality.

Urban environment has over the years faced adverse air pollution challenges, which largely emanated from socio-economic and transport-related situations. The urban population growth, economic development, energy consumption forms, growing transportation demand and living standards have been playing major role in the pollution of atmospheric environment (Avtar *et al.,* 2019; Aliyu & Amadu, 2017; Guttikunda & Bhola, 2012). For example, due to persistent high rate of immigration from other parts of Northern Nigeria, industrial artisanal, commercial activities, high demand of transportation, squatter settlement proliferations and utilisation of poor quality fuels, Kano metropolitan area has been experiencing severe air quality problems in the last several decades. Besides, a rapidly growing population and unplanned residential expansion in the city caused more harm to the air quality prevalently.

Several studies suggest that current levels of particulate pollution in urban air associated not only with short-term, but also long-term increases in cardio respiratory morbidity and mortality (Hoek *et al.,* 2013). However, the real exposure of persons and places to ambient pollution cannot be accurately estimated with the most commonly practice of sampling of points in study areas. Besides, the costs of stationary measuring stations and of their maintenance limit the knowledge to specific point(s) in study areas (Hoek *et al.,* 2013). So, in order to identify and map out the widely spread of air pollution proficiently in urban area like Kano metropolis, GIS spatial analysis can be used to identify and map out air pollution levels in relation to land use in the metropolis. In this context, pollutants concentration dataset is usually computed into ArcGIS software to create their spatial distribution maps for delineation of interpretive hazard maps of the pollutants in study areas. The principle applied here is based on the proximity approach for assessing human exposure to air pollutants. Proximity models measure the proximity of a receptor to a pollution source (Watson & Chow, 2015; Zou *et al.,* 2009; Briggs *et al.,* 1997). This model is based on the assumption that exposure at locations nearer to an emission source are higher relative to positions further from the source. The proximity is used as a proxy for exposure estimation. The Geographical Information Systems (GIS) are increasingly used in estimating proximity exposure to air pollution, and have been recently recognised as a potential method to minimise the exposure misclassifications, which is vital to the accuracy of exposure assessment produced by proximity models (Kirby *et al.,* 2017; Chang *et al.,* 2014; Zou *et al.,* 2009).

During the past several decades, air quality in Kano metropolis has been the subject of several studies in Nigeria. However, several research work on air pollution in relation to air quality focused on the assessment of the effects of air pollution characteristically dwelled on monitoring the ambient concentration of CO, NOx, SOx, CO_2, lead (Pb) and particulate matter (PM) at some specific points, while studies on air pollution levels of Kano metropolis in terms of georeferenced spatial data analysis in relation to land use has not been undertaken profusely. Although several research studies investigated the pollution distributions, most of them were based on interpolation or extrapolation methods (Kumar *et al.,* 2016; Beaulant *et al.,* 2008; Wong *et al.,* 2004; Jensen, 1998). These methods do not take into account the morphological and structural characteristics of urban areas. Therefore, to evaluate the exposition to atmospheric pollution, an accurate knowledge of the spatial distribution of air pollution exposure over an urban area is required. Although several tools exist to perform such evaluation, but the most state-of-the-art approach for air quality monitoring and exposure is by space time budget of air pollution exposition over a designated area of study. For that reason, recent advances in new and modern technologies such as remote sensing, geographical information systems and global positioning system has made it possible to not only look to spatial distribution of air pollution, but also to see and monitor the critical areas in air pollution point of concerns.

Accordingly, this study was aimed and undertaken to provide the scientific evidence based on proximity approach to portray the extent and levels of exposure of air pollution in the commonly land use forms in Kano metropolis in spatial arrays. Geographical Information Systems (GIS) mapping technique was used to give good predictions of gravity of exacerbation of air pollution exposure in the metropolis, which even covered the unattended or unmeasured sampling points and/or places.

MATERIAL AND METHODS

The study area was Kano metropolis, Nigeria (Fig. 1). Kano is the biggest commercial and industrial centre in Northern Nigeria. It has 43 existing marketplaces and over 400 privately owned manufacturing industries (Ibrahim, 2014). The study locations used for this research work are Dorawa Street, Sabon Gari Market, Bompai Industrial Area and School of Technology in Kano metropolitan area.

Dorawa is located in the heart of Kano municipality within the coordinate of 11^{o}58'17"N and 8^{o}33'31"E and is a residential area that is moderately populated. The area is a high income residential area with lots of greenery and serene environment. The area is characterised by good road network within the residential area. Sabon Gari Market is situated between 12^{o}00'45"N and 8^{o}32'23"E, the busiest commercial area in the city of Kano. It has in it lots of traders trading variety of goods and services from perishables, non-perishable and consumables. Sabon Gari is densely populated during the day time due to the traders that come from far and wide to trade their goods and also buyers who come from far places also.

Bompai is an industrial area with traceable coordinate of 12^{o}00'41"N and 8^{o}33'21"E, which is home to several industries that are involved with the processing of industrial materials. These places are characterised with lots of manufacturing industries with heavy duty machines. However, School of technology which is an institutional area situated between 11^{o}59'28"N and 8^{o}32'28"E. It is an academic environment characterised with high traffic of people coming in and out of the college and thus, considered very important to the study.

The sampling was done at industrial, commercial, residential and institutional locations in the study area and the average values for respective parameter readings were recorded at each identified sampling point using calibrated sampling devices. The assessed parameters included carbon monoxide (CO), Sulphur dioxide (SO_2), hydrogen sulphide (H_2S), nitrogen dioxide (NO_2) and particulate matter (PM_{10}). All measurements were done in one-hour triplicates (i.e. repeated three times-morning, afternoon and night) per day based on the air pollution monitoring guideline set by the United States Environmental Protection Agency (USEPA) and the Nigerian Federal Ministry of the Environment (FMEnv).

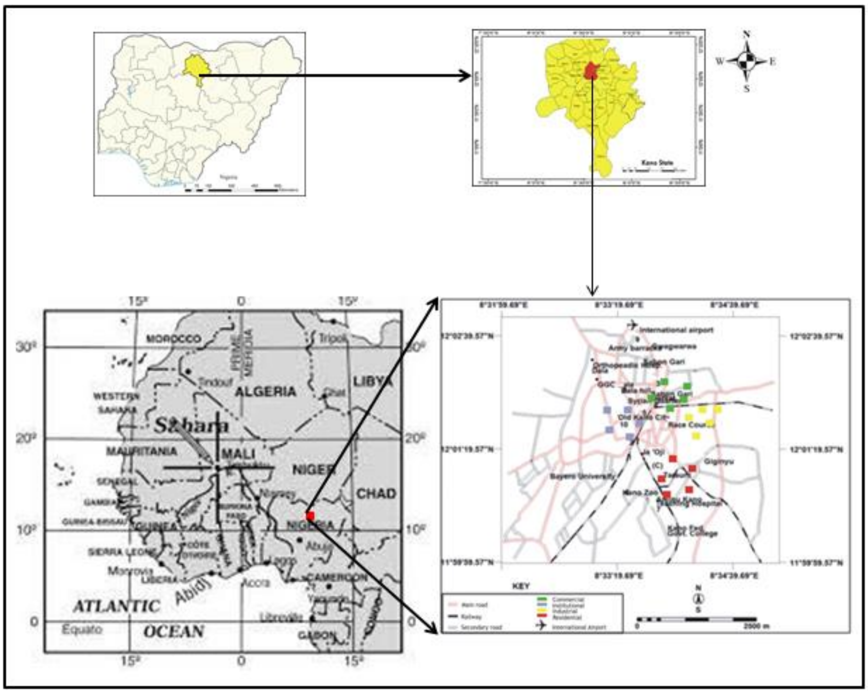

Fig. 1. Map of Kano municipal area and the sampling locations.

For the purpose of this study, purposive and random sampling techniques were employed in the study. The air sampling was performed continuously on daily basis in each of the four (4) land use air monitoring locations, three times per day (morning, afternoon and evening) covering a period of thirty (30) days. A total of sixty (60) samples were collected daily covering morning, afternoon and evening, fifteen (15) for each land use i.e. industrial, residential, commercial and institutional represented by Bompai, Dorawa, Sabon Gari Market and School of Technology, respectively.

Exposure assessment describes the damages to the human health, plant ecosystems and sensitive areas like hospitals, schools, residential area. Air pollution exposure modelling on human is very complex and time-based dynamic process. Simulation is therefore necessary for simplification and plays a key role in implementing exposure modelling (Ferreira *et al.*, 2006; Gulliver *et al.*, 2005). GIS provides an effective way to implement exposure modelling. Exposures are estimated for each location, at each time interval, by cross-reference to the pollution concentration raster for that time period as shown in equation 1.

$$Eijk = Cij \times Wk \quad (1)$$

where E denotes the exposure of an individual during time i, at location j, in exposure environment k. C denotes pollutant concentration during time i at location j and W denotes the weighting factor for exposure environment k, relative to ambient environment. Modelling exposure uses raster-based calculation.

A geographic information system (GIS) is a computer-based tool for mapping and analysing geographic phenomenon that exist and occur on earth. In this approach, the obtained readings of pollutants concentration with their respective coordinates were computed into ArcGIS software and distribution maps were obtained using pre-defined ranges for the respective air quality parameters. The maps were presented as coloured gradients representing the distribution pattern of the respective ranges of the parameters.

Therefore, GIS was utilised to study the community level pollutant concentrations and associated health risks. It was explored by Air Quality System and National Emission Inventory for identifying risks of exposure to air pollutants at the community level. GIS basically integrates baseline data and unique visualisation of geographic analysis on the maps. It was used to acquire the pollutant spatial distribution, variations and characteristics information.

The maps is embedded with distinct hues/coloration which segregates the zones into the various Environmental Air Quality Standards (GB3095-2012) and WHO (2001) of hazardous 360m from source of pollution, very unhealthy 500m from source, unhealthy 740m from source, unhealthy for sensitive groups 950m from source and 950m above for moderate and good, as a compromise between the need for spatial precision and the limited accuracy of exposure thus giving a resolution similar to or higher than that of previous studies (Dolk *et al.,* 2010; Fielder *et al.,* 2000).

RESULTS AND DISCUSSION

The display of the air pollution exposure mapping in terms of spatial distribution of the examined pollutants at Bompai industrial layout in Kano metropolis is presented in Fig. 2. The result outcome demonstrates the pollution exposure zones in Bompai industrial location. The dark reddish-brown colour shows the maximum concentration of the examined pollutants, which describes the hazardous delineated zone. In the study location of Bompai, the areas under the hazardous zone are Wacot Rice Company, Bagudu Textile and Northern Textile Manufacturers Company. For the very unhealthy zone, it consisted of Bompai Mosque, First Bank, Unity Bank and CBN estate, whereas unhealthy zone includes areas such as Tahir guest house, eHealth Africa, GTB and parts of of Badawa market. In the unhealthy zone, the sensitive groups includes Green Palace Hotel, Bompai police station, Doctors Clinic, Golden penny and Nigeria Spinners and Dyers Company. However, moderate and good zones were Gado guest house, Turkish airline, Bompai Juma'at Mosque and Nimar guest homes. The level of pollution in the hazardous zone was highly dangerous for human habitation and thus, people leaving in this zone are likely to be plagued with various respiratory and cardiovascular ailments. Similar results were reported in the literature (Portier *et al.,* 2013; Briggs & Elliot, 1995; Stewart *et al.,* 1991). It has been reported that those living closer to an industrial chimney are at more prone to air pollution related ailments (Mosley, 2013; Ko & Hui, 2012; Reif *et al.,* 2003). The very unhealthy zone falls within 360m-500m from the dangerous/hazardous zone, which deemed not healthy for residential areas, unfortunately CBN estate is located within this zone with a sizeable human population and thus are constantly being exposed to dangerous air pollutants concentrations.

However, for those captured within the unhealthy zone, people living in this zone may begin to experience health effects in related to respiratory and cardiovascular diseases exacerbated by air pollution exposure. It has been reported that people residing in the zone lies between 740m-950m might not be intensely affected, however it can be very lethal for people who are very sensitive or allergy to pollution heightened in such areas (D'amato *et al.,* 2015; Floret *et al.,* 2003; Perlin, 2001). Conversely, the buffer areas are those that fall in moderate and good zones, which spans from 950m and above from the core source of the pollution and are considered as an environmentally safe locations against the inhalation of poor air quality resulted from air pollution. So, since exposure is defined as concentration, amount or intensity of a particular environmental agent that reaches the target population, organism, organ tissue or cell over time and space (WHO, 2011;

Session, 2001; IPSC, 1993). Thus, compared with levels of pollutants concentrations, exposure assessment seems as a more accurate measure of population contact with pollution, and therefore, air pollution exposure estimation can be integrated to be part of the critical component of health risk assessment.

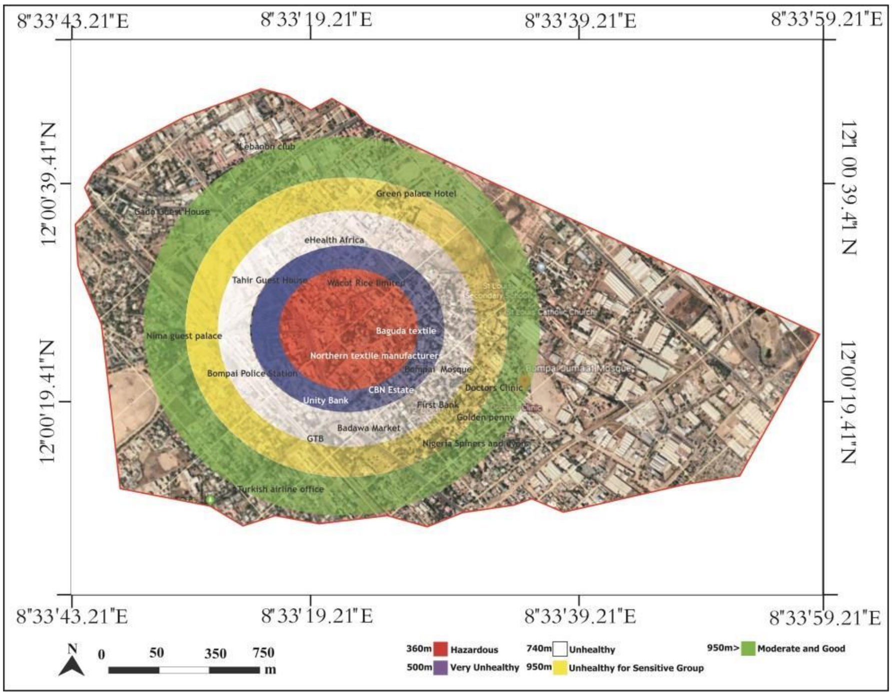

Fig. 2. GIS Map showing exposure zones for Bompai (Industrial layout).

The air pollution exposure mapping based on proximity models relative to Sabon Gari commercial land use pattern is displayed in Fig. 3. The air pollution exposure assessment in Sabon Gari zone created distinct environmental layers of demarcations for pollution exposure spatially. The hazardous zone include Sabon Gari police station, Zenith Bank. The very unhealthy zones are Russel avenue, LAPO microfinance bank, while unhealthy zone are Sky Bank, Union Homes, International hospital and unhealthy for sensitive people zone are Our Lady Secondary School, Doctors quarters, Masalachi Sani Abacha. For moderate zones are Saint Thomas Secondary School and Kano Pillars stadium. Hazardous zones are areas exposed to high concentration of CO, NO_2 and H_2S, as well as an unhealthy level of PM_{10} and the levels of these pollutants were beyond the WHO permissible limit. This could possibly emanate from high traffic congestion and increased fossil fuels used in generators. Bellander *et al.* (2001) discovered that people leaving very close to heavy traffics are vulnerable to increased risk of air pollution. Very unhealthy zones are at very serious health crisis, as air pollutants plume are blown from the market towards LAPO and Russel Avenue and for this reason, it is inferred that residential proximity to commercial sources of air pollution expose resident to high concentration of pollutants, particularly CO, SO_2 and PM_{10}. Those within the unhealthy zone are also people susceptible to be harmed due to harmful emission from Sabon Gari commercial zone. Unhealthy zones, for sensitive people, are areas where people residing and are sensitive to pollution and can easily fall sick due to the emission from the pollution source. Comba *et al.* (2003) found that people sensitive to the risk of soft tissue sarcomas are those residents in the neighborhood of air pollution sources occasioned by high commercial and transportation activities. This directly indicates that the GIS spatial distribution of air pollution exposure over time soiled the interactions between the pollution in microenvironment and its impact on humans exists there in. It further reveals that concentration only assumes some abundance of pollutants in the microenvironment, but makes no assumption about whether a human or population is exposed to the pollution or not. However, with the development of air pollution exposure risk model, air pollution exposure assessment with GIS provides eventual information on the factual interaction between pollution source points and the nearby microenvironment.

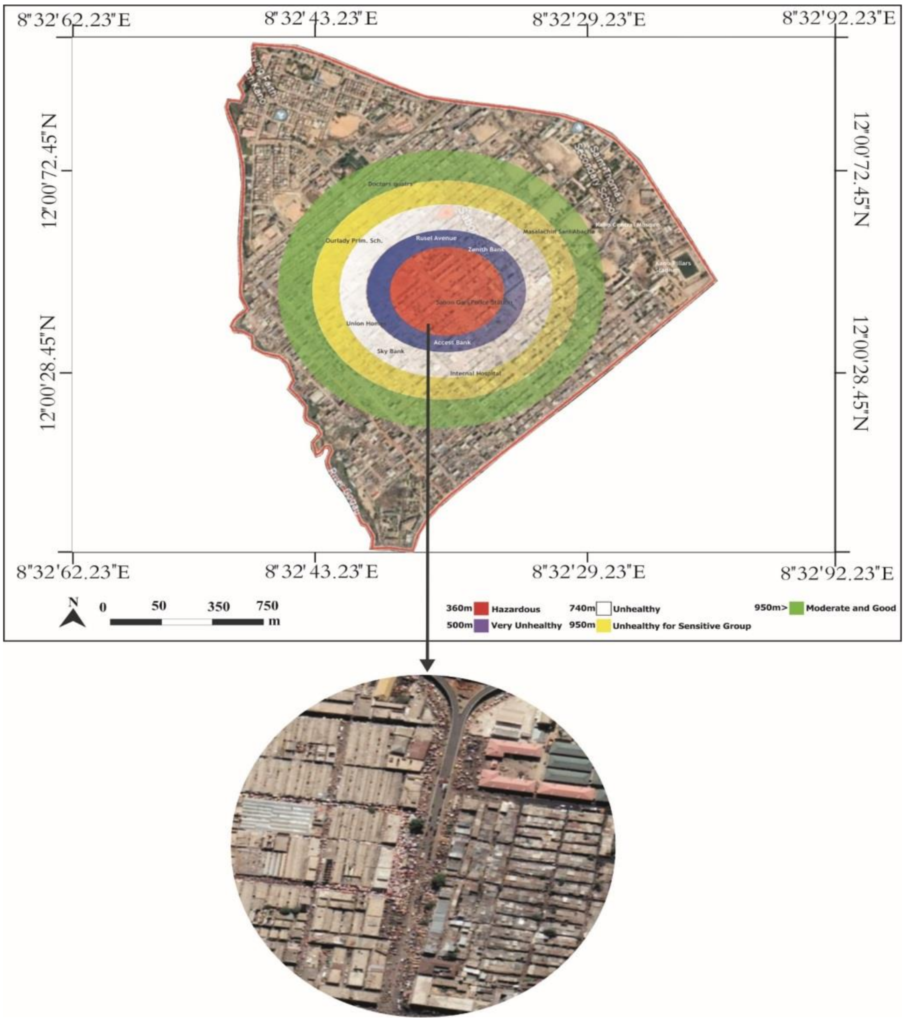

Fig. 3. GIS Map showing exposure zones for Sabon Gari (Commercial zone).

The estimate exposure to air pollution in institutional area of Kano metropolis is presented in Fig. 4. The map detailed exposure to air pollution distribution over the large area provides a localised aggregated air quality index in the studied area. The GIS pollution map exposes the susceptible places in zonal site of School of Technology in the metropolis. Under the hazardous exposure zones were student hostel, staff quarters, and administrative office, while under the very unhealthy zone are Bubura, Capital School and other residential houses. The unhealthy zones comprised of Maintama House, CBN Entrepreneurship Development Center, Summit Lodge and Gardens and Government Technical College, whereas sensitive for people are Arafat building, Amkas motors and Zaki car dealers. Those fall within the moderate zones are Sky Masjid, Iyka and railway club. The very worrisome area of hazardous zones are basically due the influx of cars in and out of the school premises and also due to a major access road passing through the front of the school, which commonly emit some levels of CO, NOx, and SO_2. The main sources of the air pollution levels in this area are energy generators and motor vehicles. In the area, thousands of vehicles circulate on an average daily basis in and around the proximity of the school. This might partly explain the observed elevation of pollution levels in the area. This is in agreement with the study conducted by NRC, (1991), who reported human exposure assessment for airborne pollutants mainly caused by vehicular emissions.

The positioning of student hostel, staff quarters, and administrative office of the School of Technology under the hazardous exposure zone may attributed to mobile air pollution sources such as proximate road traffic, which affected perhaps the concentration levels of the pollutants in those places and resulted in their fall under the hazardous zone. Dominant wind direction may be responsible for the observed high elevation of pollutant concentration levels. Similar observation was also reported (Bozyazi *et al.,* 2000). Therefore, from the perspective of this mapping analysis, student hostel, staff quarters, and administrative office of the School of Technology were in the offing the most susceptible places to risk of air pollution based on the air quality index mapping and as a result, periodical monitoring of the air quality of these places deserve an attention of the pollution regulatory and management agencies in the state.

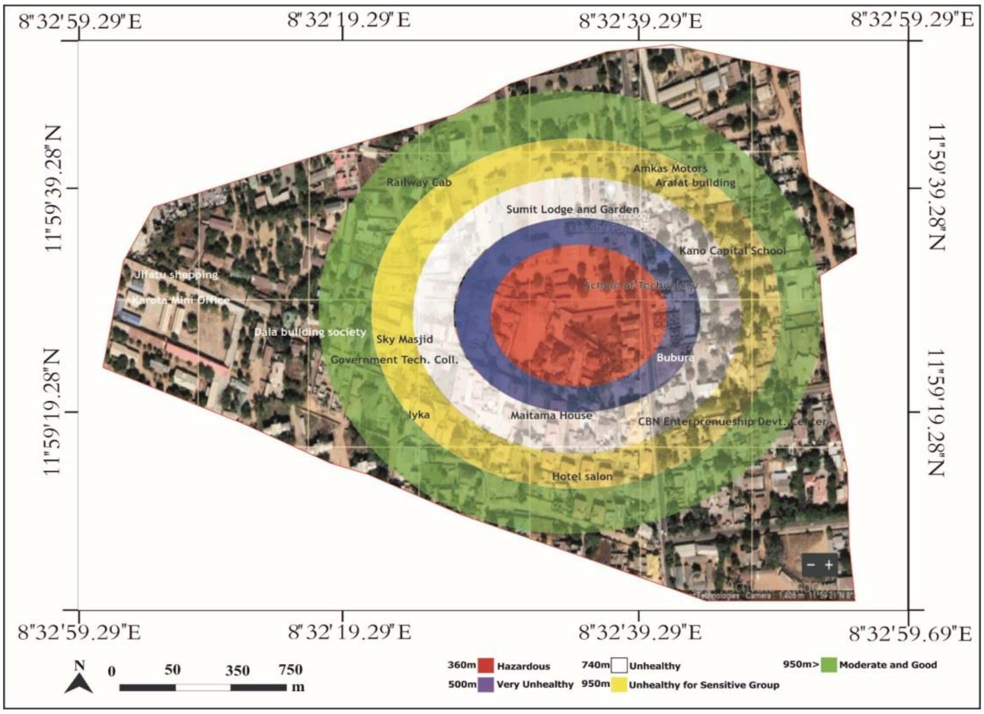

Fig. 4. GIS Map showing exposure zones for School of Technology (Institutional area).

Figure 5 shows the derived air pollution exposure map of Dorawa, the representative residential area of the metropolis. The GIS Map displays air pollution exposed places in Dorawa residential zones. From the displayed map, places under the hazardous zones are Aisha International Model School, Sahaba

Mosque, Federal College of Agriculture, and residential houses, while those under very unhealthy zones are Baffa Mosque, Grass-root Microfinance Bank, and residential houses. For the unhealthy zones for sensitive people are the Public Complain and Anti-corruption Agency and Darul Noor International Schools, whereas the moderate zones made up of Standard Specialist Hospital, Taurani Market, International Schools Kano, Azman filling station and Universal Circuit Company. The falling of Aisha International Model School, Sahaba Mosque, Federal College of Agriculture, and residential houses under the hazardous zone may incurred the maximum cost to health impact. Although the severity of pollutants index recorded in this study location was not as high as other study areas, but long regime of exposure could lead to air pollution related illnesses. Even though the impact of pollution exposure on people residing in this area might not be significantly manifested momentarily, but over time they could be inflicted with illnesses associated with air pollution exposure due to continuous openness to air pollution. In addition, on the review of health effects of residence near hazardous waste landfill sites, it was found that bioaccumulation of hazardous air pollutants over time influenced a lot health risk to inhabitants (Vrijheid, 2000).

From this spatial air pollution exposure mapping, it is obvious that people violated the urban plan agenda and encroached non-residential layouts for their shelter are the recipients of follow up attendant consequences of urban air pollution. Accordingly, the spatial air pollution exposure mapping of the residential land use informed the most vulnerable places in the entire area. The urban planning and development could serve as a soft-land tool for remedying or controlling urban air pollution problem. Therefore, the overall urban planning and development policies should certainly include stringent measures to control population explosion, unplanned urban expansion, private vehicles, and unnecessary air pollution for the preservation of community health and environmental quality.

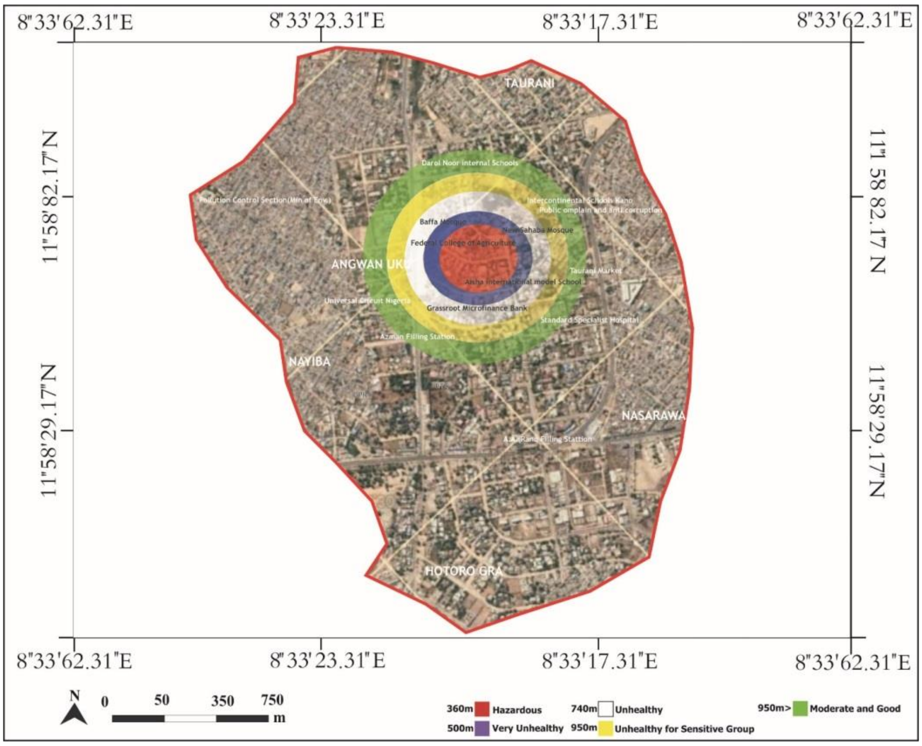

Fig. 5. GIS Map showing exposure zones for Dorawa (Residential area).

CONCLUSION

The results of the GIS spatial distribution of air pollution exposure mapping of this study clearly illustrate the importance of spatial mapping of urban air quality relative to air pollution. The approach confirms the marked variation in levels of exposure to air pollutants in different land use which may occur over small distances within the metropolitan area. At the same, the approach presents information on the spatial relationship between pollutant emission sources and the extent of exposure amongst the places in different land use patterns within the metropolis.

The spatial variations in air pollution exposure levels seen in this study have considerable implications, both for air pollution monitoring and management and environmental epidemiology. In addition, spatial phenomenon revealed hidden facts and can be a significant contribution in designing the urban planning and management policy strategies. GIS mapping provides an idea of not only the extent of pollutant influence but also its impact based on the difference on land use lines. Accordingly, the air pollution maps presented here consistently gave good predictions of gravity of exacerbation of air pollution exposure in the metropolis, which even covered the unattended or unmeasured sampling points and/or places. Consequently, an accurate knowledge of the spatial distribution of air pollution exposure over an urban area is achieved. Hence, the use of a Geographic Information System (GIS) approach permits an environmental assessment of air pollution exposure analysis through the pictographic data across the various demographic land use in the designated metropolis, and the exposure mapping leaks vulnerable populations under the impact zones which could assist the concerned authorities in making appropriate decision for control and management based on informed results and choices.

So, as the extent of air pollution exposure cannot accurately be estimated with the most commonly practice of sampling of points in study areas, likewise concentration alone cannot determine the extent of exposure to air pollutants in an urban area. However, GIS mapping provides a veritable and state of the art tool which can be used to determine the extent of exposure of humans and other physical structures within an area, thereby not only reducing man hours-labour but also resources needed to properly carryout air pollution exposure assessment in an urban area of large land mass. Thus, the practice can be adopted sustainably by ministries, departments and agencies saddled with environmental quality management responsibility.

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CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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