GIS-BASED RISK ASSESSMENT IN THE TRANSPORTATION OF HAZARDOUS PETROLEUM PRODUCTS BY ROAD ACROSS A DENSELY POPULATED URBAN CENTRE IN NIGERIA

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Abstract

Hazmat products transportation requires safe condition without significant risk to human and environmental health. This research employed Geographical Information System (GIS) a risk-based model for the identification of the least-risky routes in the transportation of hazardous petroleum products across the city of Ogbomoso, Oyo State, Nigeria. The risk considered in the model is basically population exposure since the safety of lives and properties is paramount. Global Positioning System (GPS) device was used to track the freight route to identify potential risk points in the study area. ArcGIS 10.5 was used to plot the tracked point data, performed buffer operation to determine the different risk level at 800meters (m) and query distance measurement. The produced risk map was overlay over Land Use Land Cover (LULC) types to determine the level of population exposure. Kernel density was used to calculate a magnitude per-unit area from point or polyline features using a kernel function to fit a smoothly tapered surface to each point or polyline. Valued attributes were selected and assessed using a buffer area of 800metres. The results revealed that substantial number people living within the exposure area are at risk of hazardous material disaster in addition to loss of properties of high economic value. The study developed alternative routes to reduce the population exposure risk to be use in the transportation of hazardous materials across the city. The result of this study could enhance sustainable planning of transporting hazardous hydrocarbon products within metropolis at minimal risk level.

Key words: *Hazardous; Materials; Road; Transport; Risk; Assessment; GIS; Population*

Introduction

Over the years, the rate of domestic consumption of refined petroleum products has increased in Nigeria. According to the Nigerian National Petroleum Corporation (NNPC) annual report (2014), the average daily refined petroleum product distribution increased from 29.9 million litres in 2008 to 58.6 million litres in 2013. The 2008 figure was more than doubled in 2014, giving an average of 64.4 million litres. In Oyo state where the study was carried out, the total distribution to the state in 2014 was 1.35 billion litres, giving an average of 3.7 million litres daily (NNPC 2014 Bulletin). In Nigeria, the distribution of dangerous petroleum products to the various filling (gas) stations is mainly done by road. This is as a result of poor connection of rail transport with consuming areas. In Nigeria, refined petroleum products are transported from the refineries through a network of pipelines, coastal (marine) vessels, road trucks and rail wagons to the Twenty One (21) regional storage/distribution depots, spread across the country. It is from these depots that the various marketing companies obtain their supplies. The major marketers account for 70% of products distributed in 2008, according to data from the Nigerian National Petroleum Corporation (NNPC, 2008). Given the volume of petroleum product consumed in the country and the use of road as major mode of transportation, societies have become a source of concern, considering the hazards associated with the product freight. Cases of burn arising from frequent accidents of the vessels are now a common scenario resulting in loss of life and alteration of the environmental chemistry including soil and water resources (Chen, Wood, and Zhao, 2019).

Dangerous goods are hazardous substances defined by the Dangerous Substances Act as dangerous (Workplace Health and Safety Act, 2008). Dangerous and hazardous goods are classified on the basis of immediate physical or chemical effects that may impact on people, property or the environment – explosive, flammable, corrosive, chemically reactive, highly combustible, acutely toxic, radioactive or infectious. These hazardous and dangerous goods pose a certain risk either to people, property or the environment.

Risk is the probability (likelihood) of harm or damage occurring from exposure to a hazard, and the likely consequences of that harm or damage. Dangerous goods are a specific part of all goods. A lot of dangerous goods in Nigeria are transported as transit goods by different modes. According to Batarlienė (2008), about 25% of goods transported by roads are hazardous. In case of rail, it is about 55%; by pipeline, it is100 %; by water transport, it is 55 % while only about 1% of goods transported by air are dangerous.

Hazardous or dangerous goods are such goods that have the potential to cause harm to people, property, or the environment (Erkut, et.al., 2007; Khan, et.al., 2021). They include highly flammable petroleum products like petrol, diesel liquefied natural gas, corrosive substances like acids, factories' toxic wastes, and various air and water pollutants (Oasmaa, et.al., 2012). In Nigeria, the movement of hazardous petroleum products is known to be associated with several life-threatening risks. An account that perfectly captures this situation was the Ibadan tanker truck explosion, one of the worst ever multi-vehicle accidents, killing about 200 people near Ibadan on November 5, 2000. The accident occurred outside Ibadan, on a stretch of motorway connecting Ibadan and Ife to the Eastern Nigeria. Another recent tanker explosion accident happened in Nigeria in the megacity of Lagos on the Otedola Bridge where nine (9) lives were lost with fifty four (54) vehicles burnt beyond recognition on July 2, 2018 (FRSC, 2018).

Considering the Nigeria tanker traffic situation as highlighted earlier, statistics show that whilst the number of deaths from crashes involving buses fluctuates each year, estimates of casualties of tanker explosions have remained on the increase in recent times. Transportation risk analysts have blamed this scourge on the over-reliance of the Nigerian National Petroleum Corporation (NNPC) and Pipeline and Products Marketing Company (PPMC) on the road mode for the distribution of petroleum products without giving due consideration to the environmental consequences.

Fuel tanker transportation, otherwise known as fuel trucking, is an important dimension of cargo transport in Nigeria. It has become, more or less, an indispensable medium for transporting domestic and industrial fuel. Therefore, tankers and other trucks provide important freight transport services across Nigeria with a greater number carrying highly inflammable products like kerosene, petrol diesel, liquefied natural gas, ethanol, thinner, and other spirits (Okoli and Atelhe, 2015). The near collapse of alternative means of cargo transport such as railway and pipeline systems has necessitated the dominance of tank-truck transport in Nigeria. Therefore, tank trucking is a non-negotiable imperative.

Statement of the Research Problem.

Transportation of petroleum products by road truck creates numerous opportunities for hazardous materials to be accidentally released into the environment. Depending on the volume upon Loss of Containment (LOC), chemical properties, sensitivity to the host environment and proximity of human presence, such releases have safety and environmental consequences (Ambituuni et al., 2015). This is especially a problem in developing countries where towns and villages are often situated very close to major roads serving as key transport corridors, thereby increasing accident vulnerability. Furthermore, when these accidents occur and the transported products spilled, the closest settlement to the road becomes more vulnerable depending on the chemical composition of the transported products (Huang, Wang, Pei, Xu, Huang, and Luo, 2018; Chen et al., 2019; Mrozik, Rajaeifar, Heidrich, and Christensen, 2021). This accident resulted to the contamination of the immediate environment of the scene of the occurrence.

According to Ajide (2020); Sa'ad, Omaye, Adama, Dotti, and Usman (2022), about 80% of freight movements are done by road and there has been a steady growth in number of heavy goods vehicles. An average of about 5,000 tankers are involved in wet cargo haulage, moving about 150 million litres of fuel and 2,500 trailers in dry cargoes plying Nigeria roads daily (Olagunju, 2011). In case of the

study area, at least about 200 fuel tankers each carrying 33,000 litres of refined petroleum products move across the city daily.

Fuel tanker explosion has been a common occurrence of road transport mishap in Nigeria. The incidence and prevalence of this phenomenon have been alarming over the years. Most flammable fluids (usually gasoline, diesel, fuel oil, and other related liquid hydrocarbon compounds) are transported in tanks of articulated vehicles. It compromises the structural integrity of the road thereby making it susceptible to rapid degradation. In effect, fuel tanker disaster has been identified as a major contributor to road collapse in Nigeria (Dare et al, 2009).Apart from violating the structural integrity of the road, fuel tanker disaster leads to physical destruction of road infrastructure. This includes damage of road signs, lightening facilities, and buffer-divide. These damages translate into huge material values and financial costs (Sumaila, 2013).

There has been growing concern regarding the safety of Nigerian roads for transporting petroleum products to the retail points in recent times. Amidst this concern, many and, more human lives and economic resources are being lost daily. While other stake holders opined the need to develop a sustainable means of transporting petroleum products in the country, the alternative of pipe line transportation is already failing from the recent figures of the NNPC report on the crude theft and activities of bunkering on the existing pipe line network. Thus, the use of pipeline transportation is not suggested as a better and viable alternative to road transportation in addition to the poor door-to-door limitation as a medium of transportation (Hongfang, Xin, Huang, Fu, Lingdi, and Mohammadamin 2020). Literatures from the scientific community including; Merem, Twumasi, Wesley, Isokpehi, Fageir, Crisler, Romorno, Hines, Ochai, and Leggett (2018); Ofualagba (2020); Olujobi, Olujobi, and Ufua (2020); Sa'ad et al. (2022) implemented varying measures that could improve the safety of transporting petroleum products in Nigeria with degree of success. However, safety in terms of spill and contaminations of the environment and population exposure risk were not critically examined. To effectively manage the risk associated with this scenario, the chemistry of the transported products, the environments and water resources is considered to determine the spatial risk aspect of the affected communities.

Emerging from the limitation of the existing studies was the application of Geographic Information System (GIS) technique that has an excellent spatial analysis capability. The application of GIS based techniques in accessing the risk of petroleum product transportation provides the potency of the spatial information about areas likely to be affected. Studies in this dimension include; Njoku and Alagbe (2015); Chukwuma, Okey-Onyesolu, Ani, and Nwanna (2021); Zhang, Cheng, and Gai (2022); Wang, Roy, and Zhang (2023) among several others. These studies effectively provide methods in applying GIS in studying transportation of petroleum product to assess its risk. However, aspect of population exposure risk spread associated with the petroleum products is less presented. The spatial extent of petroleum product spill during freight and accident is critical to effectively manage the risk associated with the product on the environments, community and population.

Ogbomoso area have been experiencing high rate of petroleum products tanker accidents which has resulted in loss of life and properties as well as gridlock on the major road (Adagunodo, Sunmonu and Oladejo, 2014; Korter, Olubusoye and Salisu, 2013). The aim of this research is to assess the exposure to risks associated with the transportation of petroleum products in Ogbomoso, Nigeria using geospatial technology.

The specific objectives of the research include:

i. To identify the major freight route of petroleum products in the metropolis,
ii. To determine the risk areas of the petroleum product spills area during freight using geospatial buffering operation and
iii. To develop an alternative freight route in the metropolis using GIS and results from (ii).

Review of Related Literature

The Research Model of assessing the Impact Area

The impact area is considered from the point of view of the affected population centre. This is modeled as a point on the plain, where all inhabitants of the population centre experience the same impact from a hazmat incident on a road segment nearby. The impact point depends on the distance

between the point and the incident location. A GIS enables these researchers to represent the spatial distribution of population density more accurately within different concentration levels rather than using aggregate points.

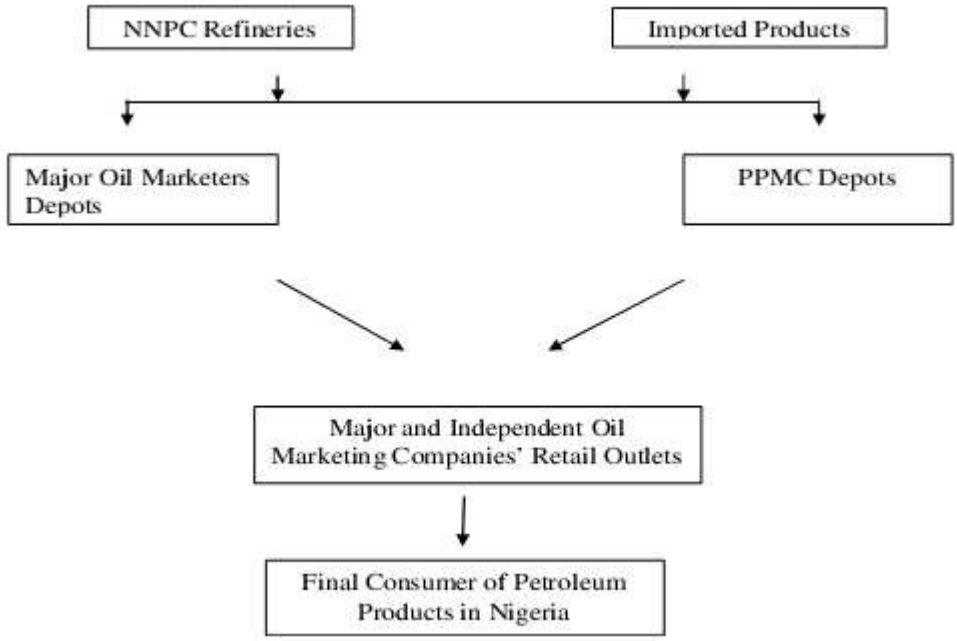

Figure 1: Physical flow of petroleum product Framework in Nigeria (NNPC/PPMC Bulletin, 2010).

Risk Theory of the Research

The research is based on risk theory, which has also been used in describing accident causation. Risk can be defined as the effect of uncertainty on objectives whether positive or negative. Its management is followed by coordinated economical application of resources to minimize, monitor, and control the probability and impact of unfortunate events or to maximize the realization of opportunities. Risks can come from uncertainty in financial markets, project failure, legal liabilities, credit risk, accidents, natural causes and disasters, and deliberate attacks from an adversary.

Risks can also be seen from four perspectives: These are the rationalist, realist, constructionist and middle positions. The rationalist sees risks as real-world phenomena to be measured and estimated by statistics, prioritized by normative decision theory and controlled by scientific management. The realist sees risks as objective hazards or threats that can be estimated independently of social and cultural processes but that may be distorted or biased through social and cultural frameworks of interpretation. Rather, the constructionist sees what we understand to be a risk as the product of historically, socially and politically contingent ways of seeing. Proponents of the middle positions between realist and constructionist theory see risk as an objective hazard or threats that are inevitably mediated through social and cultural processes and can never be known in isolating from these processes. Therefore, the research work intends to assess the risk involved in the daily movement of volumes of petroleum products across Ogbomoso, Nigeria.

According to Okoli and Atelhe (2015), hazardous or dangerous goods are such goods that have the potential to cause harm to people, property, or the environment. They include highly flammable fluids like petrol, corrosive substances like acids, radioactive materials like uranium, toxic wastes from factories, and various forms of air and water pollutants. Petroleum products constitute a typical instance of hazardous goods in view of their highly flammable nature. The haulage of these products by road through tank trucking has been associated with series of mishaps with disastrous outcomes in Nigeria. In this regard, Oluwatuji and Ileri (2013) observed that in recent time, especially in the developing countries such as Nigeria, cases of petrol tanker disaster are rampant. The aftermath of petrol disaster has led to loss of life and properties worth millions of Naira. Fuel tanker explosion

disaster has been a recurring occurrence in Nigeria over the recent years. It has virtually become an every-year occurrence.

Zhang *et. al* (2000) modeled the probability of an undesirable consequence as a function of the concentration level, using the traditional expected consequence representation of transport risk. They adopted a raster GIS framework that approximates the plane with a set of discrete points. Thus, the concentration level was constructed without making the linearity assumption which ignores atmospheric stability conditions. This method assumes a pre-specified wind direction and speed. Verma and Verter (2003) used the Gaussian plume model in estimating spatial distribution of the toxic concentration level. It was found that concentration increases with release rate of the hazardous materials and decreases with distance from the accident site and wind speed. At a given distance from the point of release, the maximum concentration is observed at the downwind location. In addition, Verma and Verter (2003) also used the Immediately Dangerous to Life and Health (IDLH) concentrate level of the hazmat materials being transported to determine the threshold distance for fatality and injuries. According to the model, the impact area around the accident site depends on the type and volume of hazmat released. In light of the foregoing, it is evident that fuel tanker disaster poses a serious risk to road safety, public safety and human security in Nigeria. The implication is that such a phenomenon threatens Nigeria's national security and must be properly acknowledged as such (Okoli and George, 2015).

The application of remote sensing data, ground control points data and GIS ushered in a nexus for assessing the risk factor of a scenario on a spatial scale. The application of GIS-Based risk factor assessment is largely favored by the ability of the system to accommodate heterogeneous spatially referenced multilayer information and the advances in the development of computer technology that allowed for the processing of large amount of information. Application of GIS-based risk mapping is evident in the work of Zhijun, Jiquan, and Xingpeng (2009); Leite, Mantovani, Dokic, Yan, Chen, and Kezunovic (2019); Huang, Li, Li, and Zhang (2019); Noguchi, Omachi, Seya, and Fuse (2021) in hydrocarbon transportation risk assessment, Three-Dimensional (3D) GIS for the simulation of fire hazard from hazardous product transportation along highway and grassland fire disaster with high level of success. Furthermore, Chukwuma, Okonkwo, Ojediran, Anizoba, Ubah, and Nwachukwu (2021); Zhou, Su, Arnbjerg-Nielsen, Ren, Luo, Ye, and Feng (2021); Chen (2022); Gupta and Dixit (2022) applied GIS-based technique in mapping of flood risk areas with high degree of reliability. Recent advances in geospatial technology is the combination of geospatial technology and computing power of the computer algorithm that provides highly versatile literature for the integration of multilayer information in risk assessment studies.
Many of these applications offer a useful conceptual framework for relating phenomenon to a spatially referenced point and the spread of this scenario into the outer space with higher efficiency. The possibility of the geospatial approach in this dimension is largely favored by the development of spatial analysis tools including *kridgin,* various kinds of surface interpolation techniques and different methods of image processing that offered a robust data for such studies. Many GIS practitioners have since utilized this window in developing a risk assessment and mitigation for sustainable environmental management. Inference from the foregoing indicated that GIS is a suitable tool for risk mapping using spatially referenced data that aid mitigation and emergency response.

Methodology

For the purpose of this research, geospatial analysis map of the study area was generated from a topographic map of Ogbomoso on a scale of 1:500,000. The topographic map was scanned using a 3D lesser scanner as arcmap document in TIF format. The scanned image was georeferenced on geographic coordinate system on World Geodetic System (WGS) to allow validation from Google earth image. Four control points were created and mapped coordinates were inscribed and a Root Mean Square Error of the entire process was evaluated at 0.000012 (0.0012%) representing 99.99% accuracy of the entire process. The Area of Interest (AoI) was extracted by mask and features of interest were then digitized in the study area map. The road networks were digitized as; access road coverage and routes of petroleum products within the metropolis and for the overlay of other features considered critical to this study.

A Handheld Global Positioning System (GPS) device was used to tracked enroute spill point in the study area. The collected GPS points were imported into ArcGIS environment as dbf file. ArcGIS 10.5 was used to subset Ogbomoso regions from the whole Oyo State's administrative and local government map on a scale of 1:500,000 and WGS 1984 projection. To analyze the human population exposure risk associated with the transportation of hazardous petroleum products, a buffering operation analysis tool in ArcGIS 10.5 was used over the generated points to identify the risk extent. The implemented buffer size used for the study was adapted from Lownes and Rahman (2013) who adopted the 1996 HazMat Routing Guide (USDOT 1996). With petroleum products being the focus of this study, a buffer size of 800m (0.5miles) was selected for analysis.

The obtained result from the buffering operation was further overlayed on the classified satellite imagery in ArcGIS environment. To complement the overlay results of the buffering operation, Sasplanet imagery was used to subset the high-resolution imagery of the study area to determine the accuracy of the classified remote sensing imagery. A good impression of the combination is given at a glance. A buffer operation creates zone of exclusion among and between spatial features. Feature to point creates a feature class containing points generated from the representative locations of input features. Kernel density was used to calculate a magnitude-per-unit area from point or polyline features using a kernel function to fit a smoothly tapered surface to each point or polyline. Query operations were carried out using the designed database. Valued attributes were selected and assessed. To achieve this, a conversion tool extension of ArcGIS 10.5 was used to convert the building polygons to point as seen in the map above. Furthermore to generate a vulnerability map for the area the point feature was deployed into the Kernel density tool which calculates a magnitude-per-unit area from point or polyline features using a kernel function to fit a smoothly tapered surface to each point or polyline. The result is the severity of exposure map which shows areas of low, medium and high densities.

Location of the study area

This study considered the transportation of petroleum products from Ibadan depot across the densely populated city of Ogbomoso, Oyo State, South-Western Nigeria, located on latitude $8^{0}08$'N and longitude $4^{0}15$'E (Figure 1). The population of the city was approximately 299,535 according to 2006 population census and currently estimated to be 395,386 using an annual growth rate of 3.2%. The Federal highways which crisscross through Ogbomosho city is known for the heavy presence of tankers carrying petroleum products to other towns outside the city.

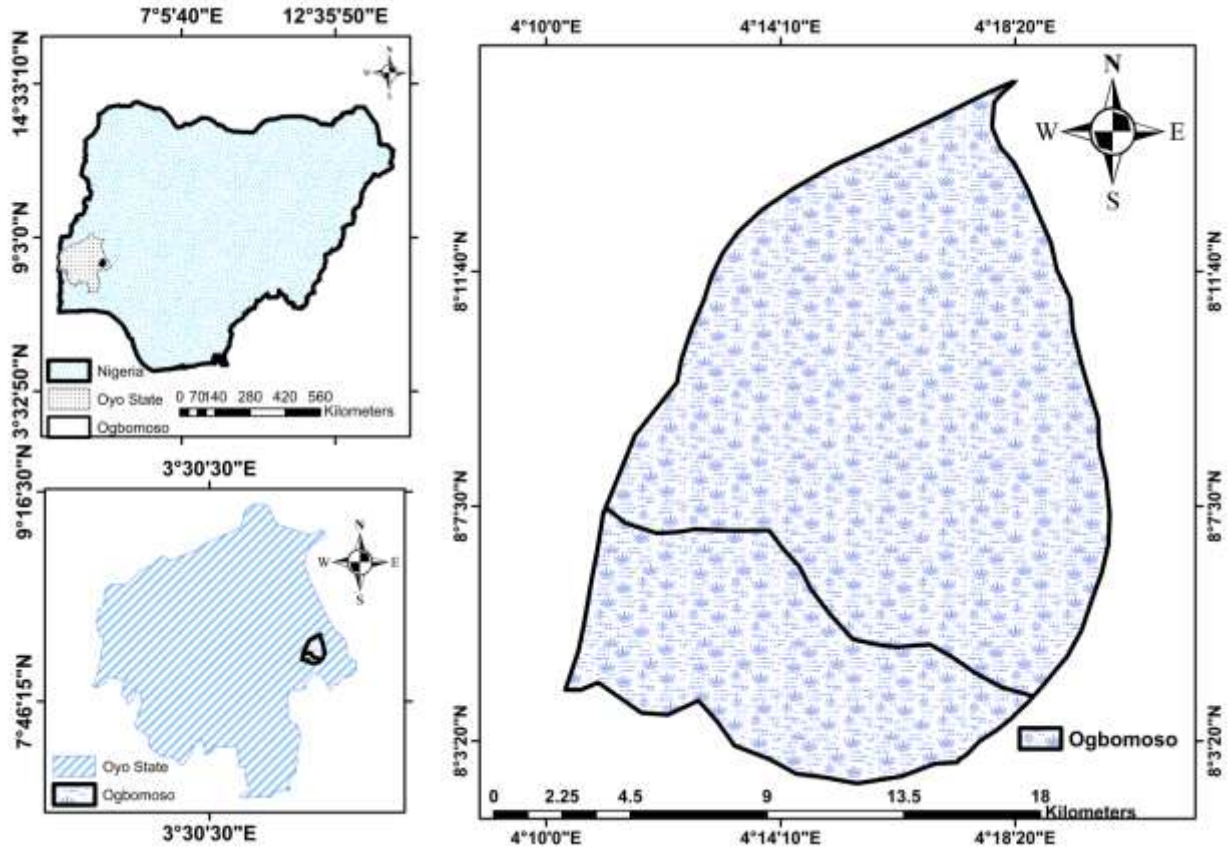

Figure 1: Map of Nigeria, inset Oyo state and Ogbomosho as the study area

4.0 Result and Discussion

4.1 Identification of the Major Freight Route of Petroleum Products in the Metropolis

The results from this study identified different kind of petroleum products spills in four major routes in Ogbomosho metropolis (Figure 2). The study shows the existence of two major spill as; enroute petroleum spills and spill due to accident on the routes that constitute population exposure risk. Another hazard identified by this study is the case of a fire outbreak that is common either along the routes, during accidents and collusion with other going vessel on the routes. It was observed that there is a high population of people living in high density areas compared to areas with low number of buildings.

The result revealed that most of the spills are most common along the metropolitan route that the petroleum tankers pass through with their products which provides a link to the state capital and other neighboring areas. Furthermore, the study revealed that enroute spill were of less significant in terms of the product quantity spilled but tend to be more volatile during accidents on the route resulting to the spill of high quantity of the products thereby affecting wider area close to the routes within the metropolis. The severity of the risk of the spilled products on the metropolis was observed from the evidence of the spot and trace on the properties along the route. The effects could also be observed from the quality of the environments where affected spilled region were completely devoid of any urban grasses thereby exposing the metropolitan surfaces and population to the direct effect of acidic precipitation that could transport the spilled products away from the point occurrences (Kanno and McCray, 2021; Ukhurebor, Athar, Adetunji, Aigbe, Onyancha, and Abifarin, 2021; Dong, Asif, Shi, Zhu, and Chen, 2022).

The impact of rainfall in the transportation of the spilled products exert significant threat to both human live, environment, water resources (surface and subsurface) and biodiversity either terrestrial or aquatic lives. Furthermore, amidst global climate change scenario, this is an indication that food

security may be threatening and population socioeconomic activities is likely to be affected thus, hampering economic growth of the metropolis (Akinro, Opeyemi, and Ologunagba, 2008; Ukhurebor *et al.*, 2021; Dong *et al.*, 2022). The study further reviled risk associated with ownership of properties along these major routes of petroleum product freight to include destruction of properties by fire which sometimes occurred with high casualty of lives and properties and sometimes caused structural damages to both nearby buildings and the road network in the metropolis.

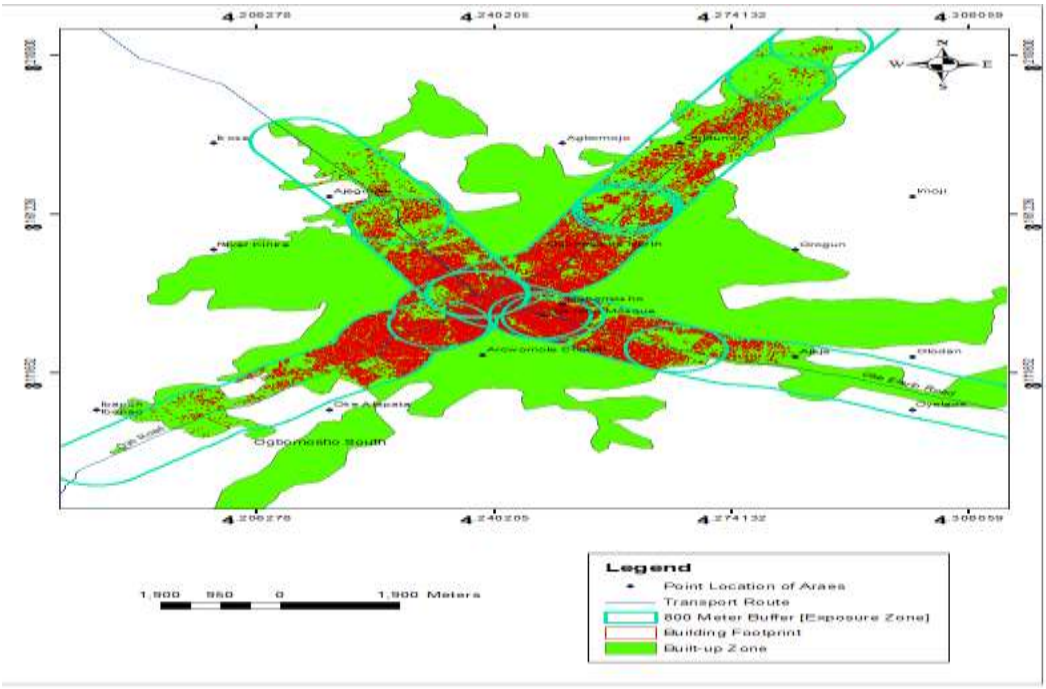

Figure 2: Major freight route of petroleum products in the metropolis

The risk of the petroleum product spills area and exposure during freight using geospatial buffering operation

To assess the level of risk in the metropolis through population exposure, the result of 800 metres (m) operation from the two main roads running through Ogbomoso city were used as presented in Figure 3. The major thoroughfares are Oyo road running from the South-West towards the North-East and Oke-Elerin road running down from North-Western side to South-Eastern part of the map. These highways are plied by tankers to supply commodities in and out of Ogbomoso. A buffer analysis was employed to visualize the exposure zone from the centre of the highways both right and left; the map above shows the pattern exhibited by the buffer. The final vulnerable result was classified into three (3) discrete categories from low density vulnerable areas to highly vulnerable zones of hazard within the 800m exposure zone considering the closeness and population of building properties.

The result of the 800m buffering analysis shows many of the structures along the freight routes to be vulnerable to petroleum products spill. The level of vulnerability increases as one move closer to the route and reduces outward. The low density vulnerability zones conformed to the 800m fringes usually farther away from the routes. This zone is mostly occupied by residential areas and some small isolated commercial shops within the neighborhoods with low economic impacts during hazards. The next level of risk is the medium vulnerability usually between 400 to 600m zones away from freight route in the metropolis towards the North East route. This zone have dominant of commercial and residential buildings with some isolated educational centers. Although, risk level and population exposure at this zone appeared to be moderate, hazard such as fire and spilling of products exert the potency of spreading to this area except early emergency response is in place to cut the menace of the hazard. Due to the difficulty in decongesting these developed areas arising from Nigeria's land use act system and the cost of resettlement, the study revealed the need for route

diversion through the development of alternative path that will cope with the impact of the oil spill during freight.

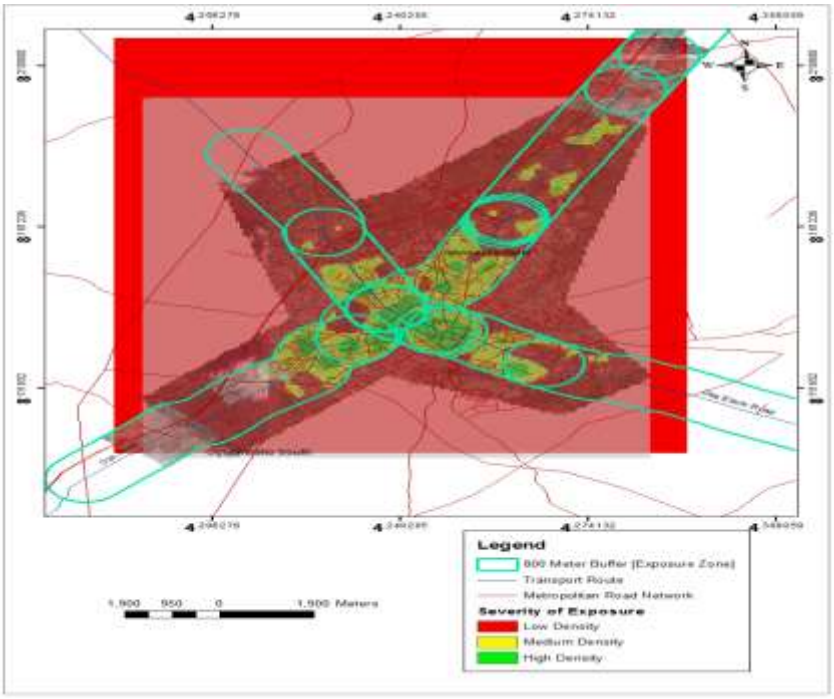

Figure 3: Population exposure zones along road transport route in Ogbomoso.

4.3 Development of an Alternative Freight Routes in the Metropolis

The research based on the result of the 800m buffering operation performed develop an alternative route for freighting of petroleum products as a measure for reducing risk associating with the products. Three alternative routes were developed based on the buffering operation (Figure 4). The major route is the use of Oyo road passing through Ogbomoso North, the second route is a road linking the Oyo road through the North West and the final route is an adjourning route on Oyo road passing through Ogbomoso South and connecting the Oke-Ilorin road.

The major route passing through Ogbomoso North will provide inlet through which petroleum products can be delivered to the metropolis at lesser hazards while the metropolis enjoyed adequate supply. The advantage of this route is based on the fact that only waybill meant for the metropolis supply will play this route. Thus, reducing the number of petroleum products transporting trucks at the metropolis ensures safety of lives and properties. The second route that passes through the Oyo Road will divert freight meant for distribution to the neighboring South-West State while other distribution to the Northern part of Nigeria will use the Oyo route through the Ogbomoso South and connect the Oke Ilorin route.

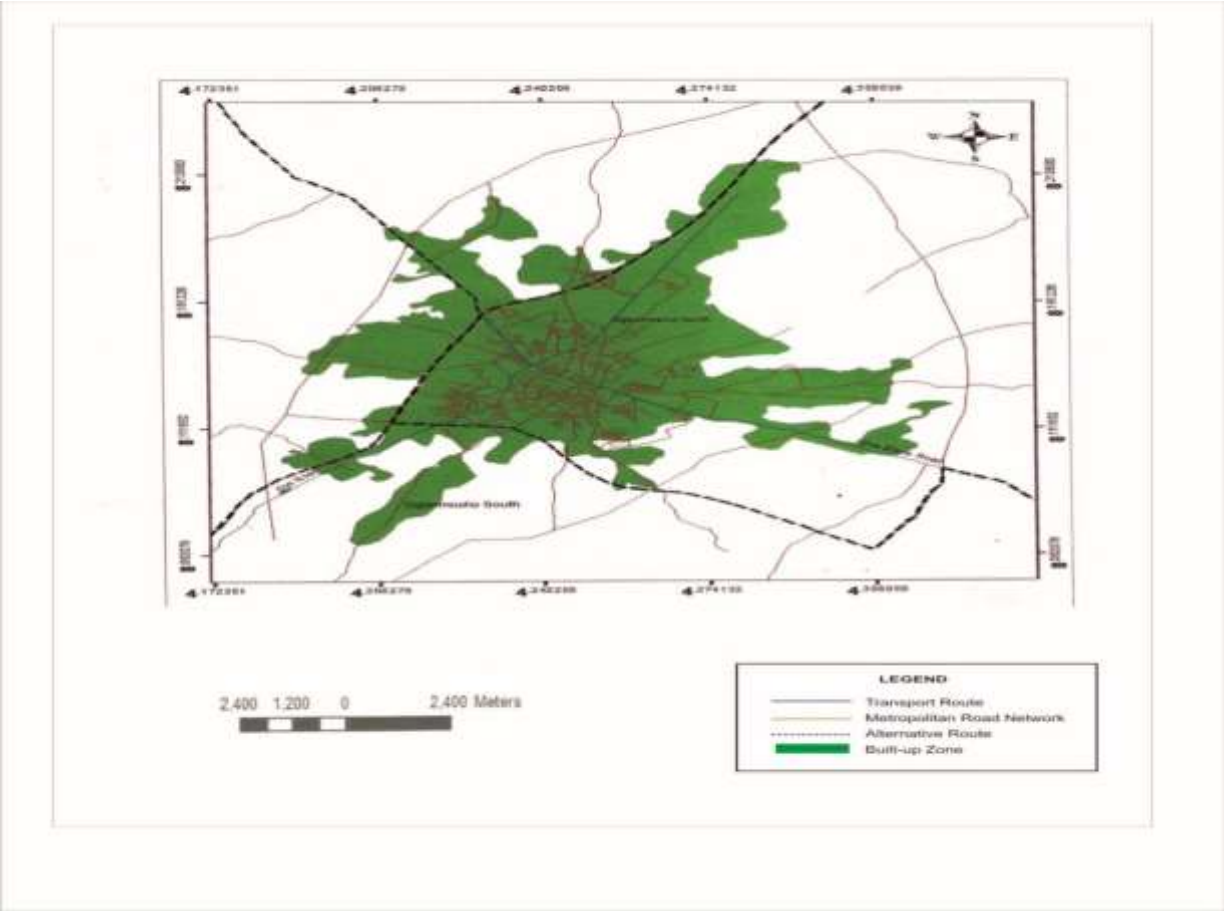

Figure 4**:** Alternative routes for the transportation of petroleum products across Ogbomoso

4.4 Summary of the Research Findings

From the result of the overlay of the 800 metres buffer over the satellite imagery, it made it possible to digitize out all the building footprints which fall within the buffered area i.e 800 metres both left and right of the transport route. This gives us an idea of the buildings exposed to hazards along the major transport route. A number of 27,478 buildings were successfully traced out and identified as at risk of hazard should there be any disaster in the ring of incidence at any point on location of the route. Using the World Bank Standard of 6 - 7 occupants per dwelling unit, we can therefore estimate the average number of people or the average population living within the 27,478 buildings digitized. Thus 27,478 buildings multiplied by 7 gives 192,346. Therefore, an average number of 192,346 represent the population of people living within the exposure zone. The same process was carried out along the alternative routes that pass through Ogbomoso-Ilorin expressway and link up with Oke Elerin-Owode road, bypassing the densely populated city centre. The average population exposed to risk was reduced to 71,078.

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Conclusion

The assessment of the population of people at risk evidenced some critical situations of the road transportation on the highways crossing the city of Ogbomoso. There is need to speed up the completion of the on-going construction of Oyo-Ogbomoso expressway running parallel to the highway. This will serve as alternative route for the trucks and heavy vehicles. The government should make provision for emergency management through the provision of prompt action vehicles such as fire service vehicles to cater for eventuality. Heavy toll can be introduced to restrict movement of goods along densely populated areas. There is need for urgent reformation of other modes of transportation such as rail and pipelines for the movement of hazardous materials in Nigeria. It is important to note that this analysis treats population exposure as a static parameter and does not account for the movement of people throughout the day. A further research investigating daytime, evening and weekend population movement would provide a more complete picture of the hazmat risk exposure. Finally, attempt can be made to analyse the cost-risk trade off in the context of road Transportation as well as identifying the environmental risks associated with the trucks.

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