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(Research Article)

GIS-based analysis of filling stations in Onitsha north and south local government areas in Anambra State, Nigeria

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Abstract

The rapid growth driven by urbanization has increased the demand for vehicles and machines, leading to more fuel usage and the establishment of additional filling stations. While filling stations are essential, they can also pose safety risks and have strict location guidelines. This study utilizes Geographic Information System (GIS) tools to analyze the placement of fuel stations in Onitsha North and South local government areas, Anambra state. The objectives include gathering spatial and attribute data, creating a functional spatial database, and conducting spatial and attribute queries for locational analysis while ensuring compliance with petroleum safety regulations. The methodology involved acquiring primary and secondary data, importing georeferenced digital imagery into ArcGIS for road network digitization, and performing GIS analysis such as buffering operations and spatial queries. The results of the analysis showed a clustered pattern of filling stations, with 45% adhering to the 15-meter setback rule from roads and 55% not in compliance. Additionally, 13 filling stations complied with the 400-meter spacing rule, while 104 did not. 95% of the filling stations were less than 50 meters away from residential buildings. Many lacked essential safety equipment, with 82% missing fire extinguishers at each pump and 70% lacking sand buckets at each pump. In conclusion, the study recommends that regulatory bodies conduct frequent inspections of filling stations to ensure compliance with recommended safety measures and the installation of necessary equipment.

Keywords: GIS Analysis; Filling Stations; Database; Spatial; Query

1. Introduction

Fuel demand is one of several demands that are created by the rise of the urban population and the number of cars and other equipment's/machines. Long urban routes and unnecessary trips consume a significant amount of motor fuel. Since engines are built to use petroleum products and filling stations are the locations where fuel is sold, an increase in automobiles has resulted in an increase in demand for fuel and, by extension, fuel stations [1]. In addition, the petroleum industry has been significantly impacted by technological development in the automotive sector, which has led to the construction of petrol service stations (Petrol Filling Stations) in key areas to meet the demand of vehicular operations. Petroleum products play important roles in every economy as is well known. In addition to industrial growth, the transportation industry is thought to be the biggest consumer of fuel to support human movement patterns around the world [2].

Any land, building, or piece of equipment used for the sale or dispensing of fuel for motor vehicles, or for purposes related thereto, is referred to as a filling station, petrol station, gas station, or petroleum outlet [3,1]. This definition covers the entirety of the land, building, or equipment, whether or not the use as a petrol station is its primary use or only a portion of it. The majority of gas stations sell gasoline or diesel, but a few also sell specialized fuels such liquefied petroleum gas (LPG), natural gas, hydrogen, bio-diesel, kerosene, or butane. The remainder also have stores in addition

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to their main operations[3,1]. In other words, petrol filling stations are the stores in Nigeria where petroleum products are sold to end users. According to requirements of the Petroleum Amendment Decree No. 37 of 1997, the Department of Petroleum Resources (DPR) is required by law to issue licenses and monitor the functioning of filling stations. In the same vein, petrol has been described as a highly volatile compound [4]. Also, [5] pointed out that in spite of the fact that gas stations might go by different names depending on where they are located, and frequently house significant amounts of hazardous materials (hazmat), their primary function is always the same: to sell petroleum products to drivers and other users.

The presence of filing stations within a locality is an example of accessibility to a form of major utility because of the increase in consumption of petroleum products. Although it has been acknowledged that, petroleum is a key driver of industrial activities[1], transportation sector have been a major consumer of fuel, in that, it is more of a necessity to facilitate man's movement. All over the world, there has been a widely known increase in the number of filling stations. For instance, there are currently 17,281 fuel stations in the Asia-Pacific region, up from 342 in 1996 and 10,938 in 2012, respectively [6]. Similar trends may be seen in North America, where the number of gas stations rose from 47 in 1996 to 1,919 in 2017 [6]. In Nigeria, there are over 7,000 registered filling stations [7] and this is not expected to reduce in the future because as population increases, rates of consumption increases due to increase in the number of automobiles [3]. Filling stations has been a major incorporation in the urban environment and a necessity, such that, its growth has been a major influence in the environment as well as safety and vulnerability to hazards.

1.1. Study Area

Onitsha is found in Anambra State, which is one of the five states in the nation's southeast geopolitical region. Onitsha is situated in the Anambra North senatorial district of Anambra state between latitudes 06°07'30" and 06°11'0"N and longitudes 06°45'45" and 06°50'0"E. It covers around 52 sq. km and is located on the River Niger's eastern bank. Onitsha is a prospective industrial and commercial growth center in Nigeria because of its position, which includes access points to both roads and waterways. Onitsha is divided into two local governments, Onitsha North and Onitsha South. Both districts are bordered by the local governments of Ogbaru to the south, Idemili North and Oyi to the east, Anambra East to the north, and the River Niger to the west. According to NPC (2006), Onitsha is said to be populated with 263,103 residents, with Onitsha North having 125,912 residents and Onitsha south with 137,191.

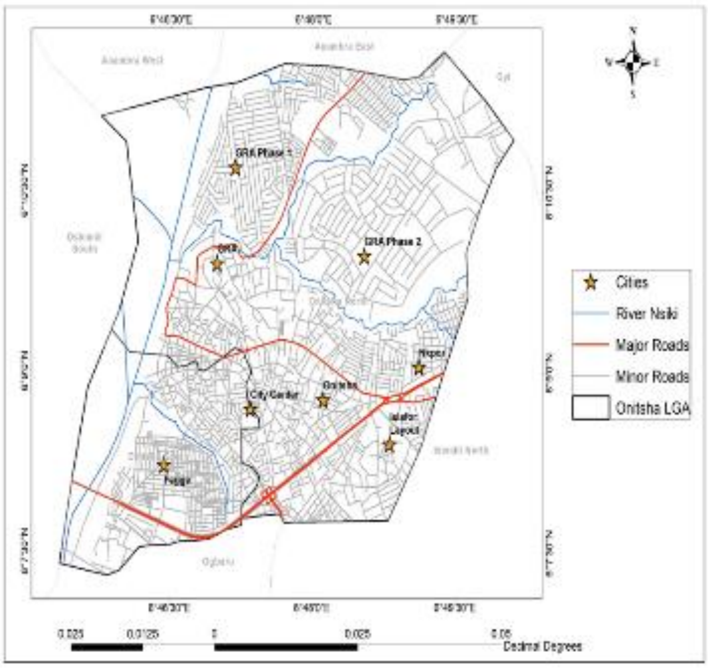

Figure 1 Map of Study area

2. Methodology

The research methodology is centred on building a geodatabase, carrying out GIS based analysis on filling stations in Onitsha North and South. The methodology comprises three key components; (1) data acquisition/collection, (2) Database modelling and creation, and (3) Data processing analysis. These components are strategically designed to address the research objectives.

2.1. Data acquisition

Table 1 Sources and Types of Data

Data type	Source	Purpose
List of petrol filling stations	Department of Petroleum Resource (DPR)	Names and Number of filling stations
Coordinates of filling stations	Handheld GPS	Deriving point location of filling stations
Environmental standards for siting petrol filling stations	DPR	To determine compliance to planning standards
High resolution Satellite image	Digital Globe Imagery	To derive buildings (residential, industrial or commercial)
Facilities (point data)	Google Earth	To be used in measuring standard to DPR compliance
Population	NPC	To be used in measuring standard to DPR Standards

2.2. Database Creation

2.2.1. Conceptual Data Modelling

A Conceptual modelling of the spatial database would be performed. This process involves:

- The identification of entities relevant to the study areas database.
- Identification of attributes of each entity in the study area which will serve as a guide in the collection of data.
- Determination of the relationships between the entities present in the attribute table.

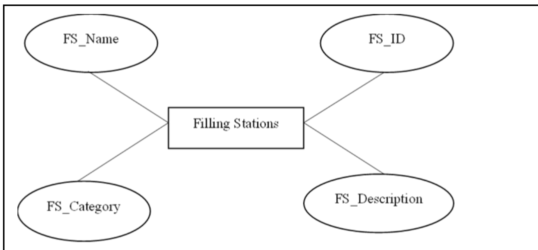

Figure 2 Filling Station Entity and attributes

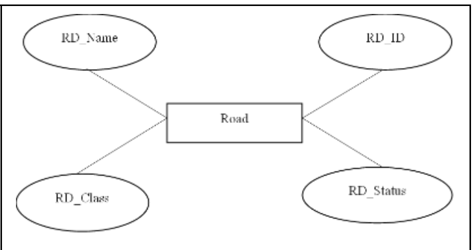

Figure 3 Road Entity and attributes

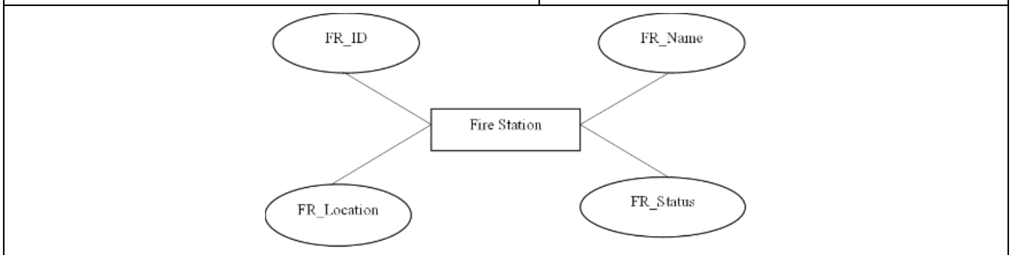

Figure 4 Fire Station and attributes

2.2.2. Logical Data Modelling

The conceptual model schema is consolidated, refined and converted to a system-specific logical schema in this stage, the conceptual schemas was mapped manually into logical schema.

2.3. Physical Design and Creation

All the data gathered through, Ground truthing, satellite imageries, etc. were used as basis for GIS creation and modelling of the study area.

3. Results

3.1. Spatial Distribution and Locational Patterns of Filling Stations in Onitsha North and South Local Governments

To determine the distribution pattern of fuel stations within the study area, a multi-faceted spatial analysis approach was employed, including the Nearest Neighbor Analysis, Spatial Autocorrelation, and Ripley's K-Function Analysis. In Figure 4.1a, the significant level of the distribution being clustered is (0.01 - 0.10) or less than -2.58, while for random it is equal, whereas for dispersed it is greater than 2.58. From the Nearest Neighbour Analysis, the above calculation of the Nearest Neighbour Index gave a Nearest Neighbour Ratio of 0.638854 (less than 1) and a z-value of -7.44 which signifies that there is less than 1% likelihood that this clustered pattern could be the result of random chance and according to the Nearest Neighbour Analysis anything less than one (1) signifies that the spatial distribution of the phenomena under study is clustered. Another observation can be found where the Observed Mean Distance between fuel stations in the study area was 183.5551 Meters, whereas the supposed Expected Mean Distance should be 287.3196 Meters. This signifies that Fuel stations in the study area are in close proximity to one another. From this study, given that our Nearest Neighbour Ratio is 0.638854 it therefore shows that the Spatial Distribution Pattern of Fuel stations in the study area is clustered

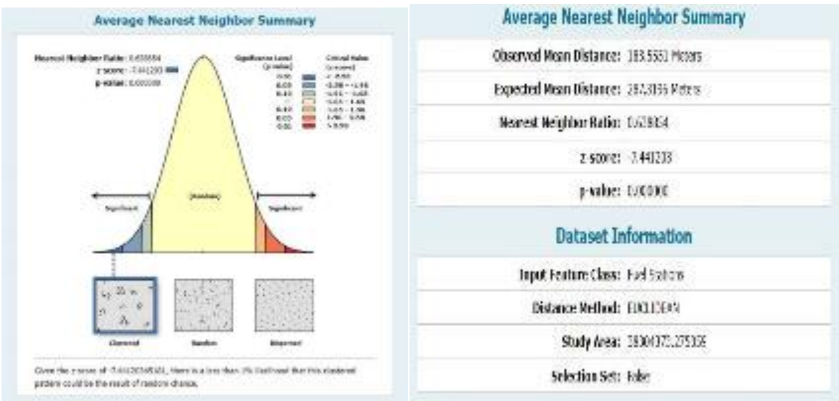

Figure 5 NNA Result

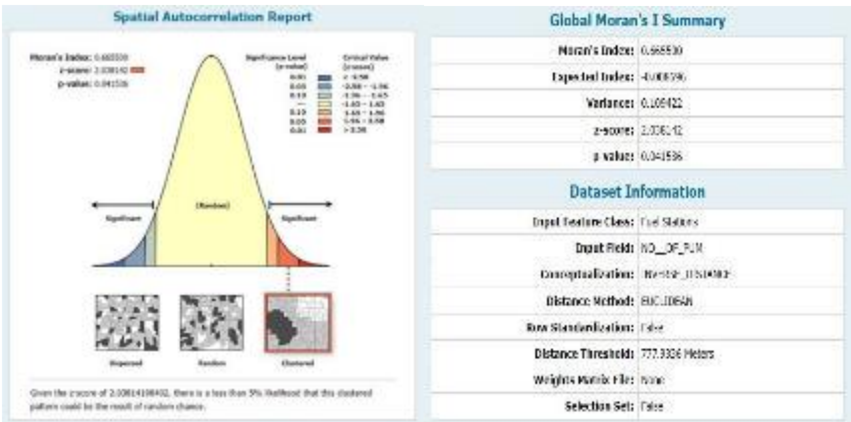

Figure 6 Spatial Autocorrelation (Moran's I) Result

A Spatial Autocorrelation Analysis (Moran's I index) was also conducted on the fuel stations to assess whether they tend to cluster together or disperse across the study area. The results, as depicted in Figure 4.1b indicate that the pattern leans toward clustering. Specifically, the Moran's I index value is calculated as 0.665500, which suggests a positive spatial autocorrelation in the placement of the fuel stations. This means that these fuel stations are not randomly scattered across the area but instead tend to cluster together in certain regions.

To further confirm the distribution pattern of the fuel stations in the study area, a K-function analysis was conducted, as depicted in Figure 4.7. The observed K measures how far apart, on average, the fuel stations are at various distances. The results consistently showed that the observed K values were higher than the expected K values. This indicates that there is a non-random pattern in the distribution of fuel stations.

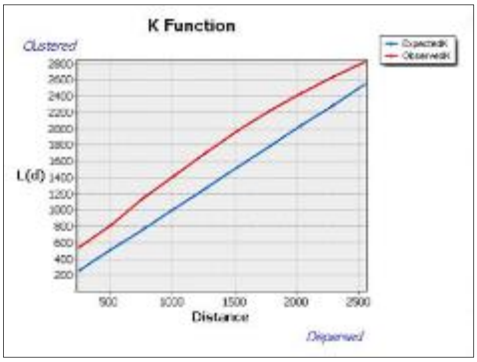

Figure 7 Ripley's K-Function Result

3.2. Compliance with the Physical Planning Standards of the Department of Petroleum Resources (DPR)

According to the standards established by DPR, it is stipulated that the distance between a road and a filling station should not be less than 15 meters. Figure 4.2a provides a visual representation of those fuel stations that adhere to this regulation and those that do not. Figure 4.2a further illustrates the compliance rates, revealing that 53 fuel stations (45%) comply with the 15-meter setback requirement, while 64 fuel stations (55%) fall short of meeting this stipulated distance. Additional analysis revealed that among the fuel stations that did not meet this requirement, 15 of them (23%) were found in Onitsha South, while the remaining 49 fuel stations (77%) were located in Onitsha North.

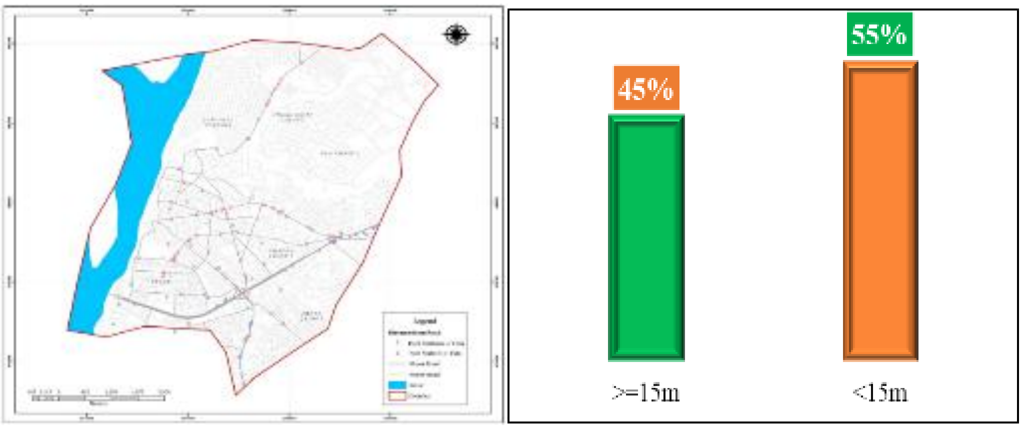

Figure 8 Fuel stations that adhered to the DPR Standards (>=15m to road)

According to the Department of Petroleum Resources (DPR), fuel stations are supposed to be at least 400 meters apart from each other to make things safer, prevent fires, and keep traffic moving smoothly. In Figure 4.2b, it is evident that among the total of 117 fuel stations, 104 did not adhere to this regulation, while only 13 did. This shows that a majority, about 89% of the fuel stations in the study area, didn't meet the DPR's requirement of being 400 meters apart.

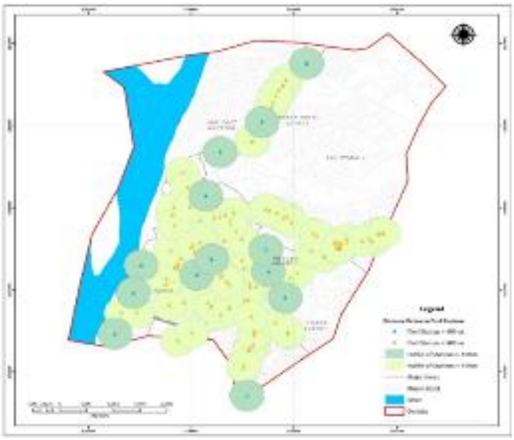

Figure 9 Buffer Analysis Result for the Distance Between Fuel Stations

3.3. Fire Hazard Safety Preparedness of Fuel Stations

The analysis of 117 fuel stations in the study area highlights compliance issues with DPR regulations. While all stations have fire extinguishers, only 3 lack sand buckets, both of which are required per pump. Only 18% of stations meet this standard. Furthermore, 82% of stations lack fire extinguishers on each pump, and 70% lack sand buckets. Only 5% adhere fully to DPR standards. The study also notes only 3 fire stations in the area, primarily in the south, posing potential delays in response to fires in the northern region.

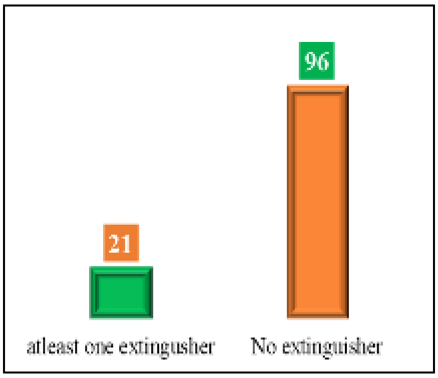

Figure 10 Fire extinguisher per pump

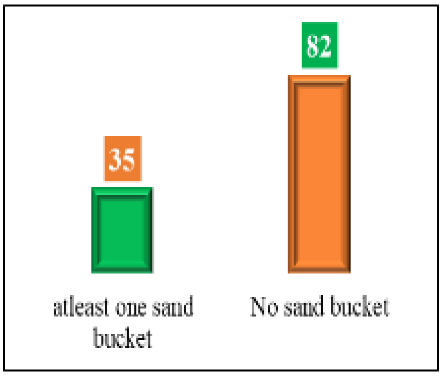

Figure 11 Sand buckets per pump

4. Conclusion

This study explored the spatial distribution of filling stations in Onitsha North and South. The key finding is the presence of a clustered pattern, indicating that not all neighborhoods in these areas have an equal chance of hosting a filling station. This unequal distribution results in uneven accessibility to filling station services for residents. Furthermore, it's evident that many filling stations in Onitsha do not comply with the guidelines established by the Department of Petroleum Resources (D.P.R) for their location. This non-compliance raises concerns about safety, environmental impact, and regulatory adherence. To address these issues, it is imperative that the Department of Petroleum Resources takes proactive measures to ensure strict compliance with the necessary criteria for establishing and operating filling stations within the city. This action will not only enhance regulatory compliance but also promote safety and a more equitable distribution of filling stations.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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