SPATIAL PATTERN AND PLANNING COMPLIANCE OF PETROL FILLING STATIONS IN KEFFI, NIGERIA: A GIS-BASED PUBLIC-SAFETY ASSESSMENT

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ABSTRACT
Rapid urban growth of second-tier cities in Nigeria has increased patronage of petroleum retail services and exacerbated land-use conflicts and public-safety problems. This study examined the spatial pattern and planning performance of petrol filling stations in Keffi Local Government Area, Nasarawa State. Cross-sectional geospatial design integrated an inventory from the petroleum regulator with field verification and GPS survey. A total of 43 operational and non-operational stations were overlaid on ArcGIS 10.5 and classified according to road hierarchy. Average Nearest Neighbour analysis examined if the pattern was different from spatial randomness. Euclidean buffers compared three planning standards described in the source thesis (i.e. 15 m pump-to-road setback; 400 m inter-station separation and 100 m healthcare facility separation). Stations tended to cluster along eight road corridors; Keffi-Akwanga (10 stations), Abuja-Keffi (eight stations) and Nasarawa Bypass (eight stations), representing 60.5% of all stations. The distribution was significantly clustered (nearest-neighbour ratio = 0.534; observed mean distance = 317.7605 m; expected mean distance = 595.3249 m; z = -5.849; p < .0001). Settlements and highway-oriented commercial activity produced corridor clustering and poor planning performance (79% set back compliance; 83% healthcare-facility buffer compliance). Inter-station separation was reportedly poor (only 4%) however the non-compliance rate reported in the thesis appears inconsistent with the spatial layer. Accordingly, commercial accessibility and highway-oriented activity shape corridor clustering and poor planning efficiency. A common geospatial permitting data base, pre-approval spatial screening, risk-based inspection and unified enforcement by petroleum and planning authorities are proposed.
Keywords: *Petrol Filling Stations, Spatial Distribution, Regulatory Compliance, GIS, Public Safety, Urban Planning.*

1. Introduction

Car petrol filling stations are a central element of the urban transport and the petroleum-distribution system. On the one hand they deliver energy to a broad spectrum of users (private, commercial and public transport). On the other hand they accommodate store and transfer highly inflammable products into built-up areas. Hence their siting poses a planning issue between commercial accessibility, on the one hand, and traffic safety, environment protection, emergency planning and land use compatibility issues, on the other hand.

This balancing is particularly relevant to proliferating secondary cities. Spatial growth propagates along arterial roads, where trade, dwellings, educational and medical facilities, and transport nodes vie for available sites. Permitting regimes that are inconsistent or regulation that is unenforced can result in clustering around busy roads or flight paths, or

in close proximity to sensitive uses. Considerations include subsequent increases in turning conflicts, roadside queues, vapour inhalation, spill risk, and the severity of consequences following fire or equipment malfunction. Benzene within petroleum products has both subsequent and long-term influence on health, including haematological consequences and cancer, which justifies the prudent management of hazard exposure around fuel retailing establishments (WHO [World Health Organization], 2019).

The Nigeria's Petroleum Industry Act took powers from the technical and commercial regulation of midstream and downstream petroleum activities from the department of Petroleum Resources to the Nigeria Midstream and Downstream Petroleum Regulatory Authority (NMDPRA). Petrol-station development is subject to 'state and local planning systems'. Thus, control requires the intervening agencies of petroleum regime, environmental institutions, urban-development agencies, fire-protection services and agencies of traffic-management. Ambituuni et al. (2014) found that 'Institutional and implementation problems constrain safety and environmental protection regulation in Nigeria's downstream petroleum sector. Spatial information can clarify where non-compliance and thus accompanying corridor risk accumulation occurs.

Existing Nigerian literature of a similar nature have focused on the distribution of an agreement with siting standards for the entire metropolitan area or segments of the road network (Akinsulire & Fadare, 2020; Ulakpa et al., 2022). However, as evidence have been sparse on Keffi, a relatively small sized and fast growing town with historical relationship with the Federal Capital Territory (FCT), Abuja and other cities in North-Central Nigeria; this study aims to answer three research questions: How has the available filling station stock been distributed across the town's road corridors? How far does the point pattern of current ISs depart from spatial randomness? How well does the existing stock conform to predetermined road, inter-station and health centre to station distance criteria?

The paper presents a case-specific spatial audit of petroleum retail infrastructure. It deals with a set of distances and end compliance measures, and stands on a separate analytical plane with the companion article that applies the same thesis data to a different paper on location-selcorce factors, hazards perceptions, and mitigation priorities.

2. Literature Review and Analytical Framework

Filling-Station Location as an Urban-Planning Problem

Location theory elucidates the preference of service facilities for accessible locations with appropriate market thresholds. Central Place Theory correlates the distribution and spacing of services with consumer distance, range and threshold populations (Christaller, 1966). While the theory's premise of uniformly-shaped space is arguably outdate in modern cities, it is still effective in understanding the draw of high-traffic road corridors and nodal sites for fuel retailers. Transport routes, land access, market opportunity, site form and visual prominence distort the idealized, regular urban pattern into corridor clustering.

Facility-location research has progressed from single-criterion accessibility analysis to multi-criteria decisions including environmental, social, economic and safety factors (Farahani et al., 2010). For hazardous or risky-to-mix land uses, the most commercially desirable site location may also be the most unsafe. Ajman et al. (2021) found a 1.7 fold disparity between a locally-acceptable site location on the one hand and a more conservative international safety benchmark on the other based on GIS-based suitability analysis to novel farming land uses, for example. Such analysis is encouraged to guide site approval decision-making, rather than rely on after-the-fact inspection.

Spatial Clustering and Cumulative Risk

Clustered pattern is not testimony to illegality; it simply observations that stations are located more closely than would be predicted by spatial randomness. Clustering may result from mutual attraction to highways, motor parks, commercial nodes, settlements/plots and high-volume traffic

flows. It may, however, lead to aggregate planning effects: several accesses in close proximity may be combined into multiple turning movements; overlapping queues may be generated in times of shortage; vapour and traffic emissions may be concentrated.

Average Nearest Neighbour (AVGNN) measures the actual average distance from each feature to its nearest neighbor against the average distance expected for a random spatial process. An index of less than 1 indicates clustering, an index equal to 1 indicates randomness and an index of greater than 1 indicates dispersion. The statistical reading of the results is dependent on the accompanying z-score and p-value. This methodology (AVGNN) describes pattern; the reasons for it must be supported elsewhere. Possible explanations may be found in the hierarchy of roads, land-use patterns or interviews with residents.

Regulatory Compliance and Institutional Coordination

Siting criteria utilize separation distances and setbacks as direct planning tools. Road setbacks offer protection from conflicts between station activity and the carriageway. Inter-station separation offers a tool to limit corridor saturation and, in turn, interaction between traffic and other risk effects. Buffers around hospitals and other sensitive installation provide opportunities to reduce exposure and protect populations that cannot be evacuated or otherwise remain serviceative during emergencies.

The extent to which they are effective, also depends upon a clear legal basis, the application of a consistent methodology, documented findings, transparency in the permitting process and implementation of conditions. Institutional theory is applicable since regulation outcomes are a function not only of formal rules but of the organisation‘s ability and motivation to comply (North, 1990). In Nigeria, duplication of mandates, connection of mandates and poor exchange of information can result in a technically licensed facility that does not adhere to the land-use plans. A common spatial database can portray licensed and proposed sites to all approval agencies and identify cumulative effect that issuance of paper may not identify.

Empirical Gap

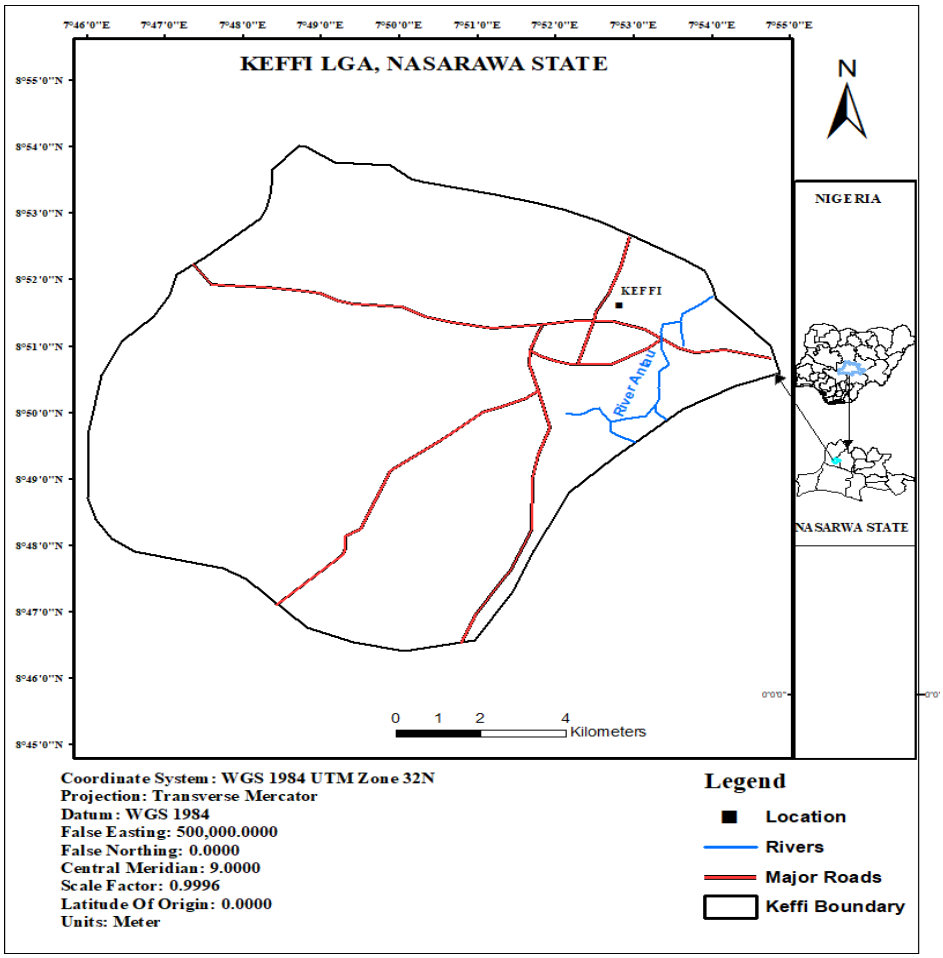
While the literature documents the usefulness of GIS for station-location audits there are three remaining gaps. First, numerous studies have described non-compliance without providing a statistical assessment of the overall point pattern. Second, corridor-level aggregation of the data is often given without relating it to other forms of distance compliance. Finally, smaller secondary cities are less documented than metropolitan conglomerates despite experiencing rapid peri-urban change and having generally less bureaucratic capacity and regulatory will. This study fills these gaps in Keffi via a comprehensive station inventory, road-corridor typology, Average Nearest Neighbour analysis, and Buffer analysis using the criterion.

3. Materials and Methods

Study Area

Keffi Local government area of Nasarawa State is situated in North-Central Nigeria about 57 km from Abuja and about 128 km from Lafia. The thesis has identified the latitude of the area to be about 8 47’ and 8 54 N and the longitude to be about 7 46’ and 7 55’ N. The area has a land mass of about 140 km 2. It is located on the routes between Abuja, Akwanga, Lafia, Makurdi, Nasarawa and Kaduna (see figure). As such, it is a transit point with a heavy flow of vehicles and is also a big market for petroleum dispensing.

Fig. 1: Study Area



Source: Authors Analysis, (2025)

Research Design and Data

The research used a cross-sectional geospatial inventory design. The list of filling stations was acquired from the then Department of Petroleum Resources and certified by reconnaissance and comprehensive field observation. The locations and attributes of filling stations were acquired with a hand-held global positioning system receiver. The source thesis identified 43 functioning and non-functioning filling stations located along eight corridor roads.

Secondary spatial data was a Keffi street map (digitised and georeferenced) and satellite imagery. The street map was scanned and loaded into ArcGIS. 10.5 and was used to georeferenced and digitised. A Universal Transverse Mercator projection and Minna datum, Zone 32N, were used throughout. Road layers and land use layers were combined with point station layers.

Spatial Analyses

Three analyses were completed. First, stations were counted by road corridor and road hierarchy to illustrate concentration. Second, the Average Nearest Neighbour statistic was calculated by Euclidian distance, with the null hypothesis that stations were randomly distributed in space. Third, the proximity buffers and spatial queries were used to evaluate the three criteria described in the thesis:

A minimum 15 m distance between the road and dispensing-pump area.

A minimum 400 m distance between neighbouring stations.

A minimum 100 m distance between stations and healthcare facilities.

The manuscript shows the standards as applied in the thesis used in archives. Since regulations documents and local implementation may change, the standards in force will have to be confirmed with NMDPRA and the Nasarawa Urban Development Board

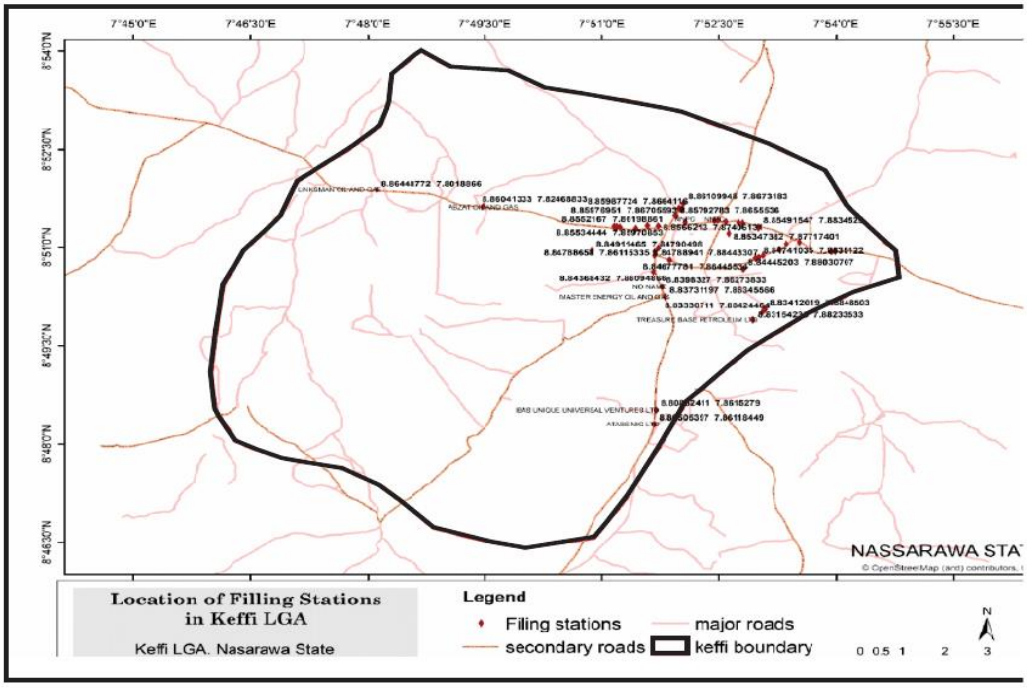
prior publication or before enforcement.3.4 Data-quality safeguards and limitations. The station inventory is a census of facilities identified at the 2025 fieldwork; it is not a sample. However, the combination of operational and non-operational stations warrants an explicit disclosure of the status date when the spatial database is released. The thesis states that “more than 90%” of stations failed the 400 m threshold, but also mentions that 4% met the threshold; 90% and 4% are not mathematical complements, and this article employs the latter figure and notes the inconsistency for resubstitution from the point layer. The analysis also omits modeling of population exposure, traffic, predominate wind, subsurface tank integrity, and actual measured pollutant levels; buffers therefore represent planning proximity, not defined individual risk.4. Results4.1 Distribution by road corridor. The 43 stations were inequitably spread across eight corridors, as shown in table 1. The Keffi-Akwanga Highway and the highest number of stations, followed by the Abuja- Keffi Highway, and the Nasarawa Bypass. These three corridors comprised 26 stations (60.5%) of the inventory. Two stations were located on each of the minor roads that served the Palace of the Emir, and the market.

Table 1. Distribution of filling stations by road corridor

No.	Road corridor	Road class	Stations, n	Share (%)
1	Abuja-Keffi	Highway	8	18.6
2	Keffi-Akwanga	Highway	10	23.3
3	Keffi-Kaduna	Highway	5	11.6
4	Nasarawa Bypass	Highway	8	18.6
5	Old Nasarawa Road	Major road	3	7.0
6	Old Keffi-Akwanga Road	Major road	7	16.3
7	Emir’s Palace Road	Minor road	1	2.3
8	Market Road	Minor road	1	2.3
	Total		43	100.0

Source: Field survey (2025)

Figure 1: Distribution of Filling Stations by Road Corridor



The pattern in the map was of a corridor type with the highest concentrations of stations tending to follow the north-eastern road network and some of the main exit roads. The majority of the western and southern parts of LGA lacked coverage from the stations.

Nearest-Neighbour Pattern

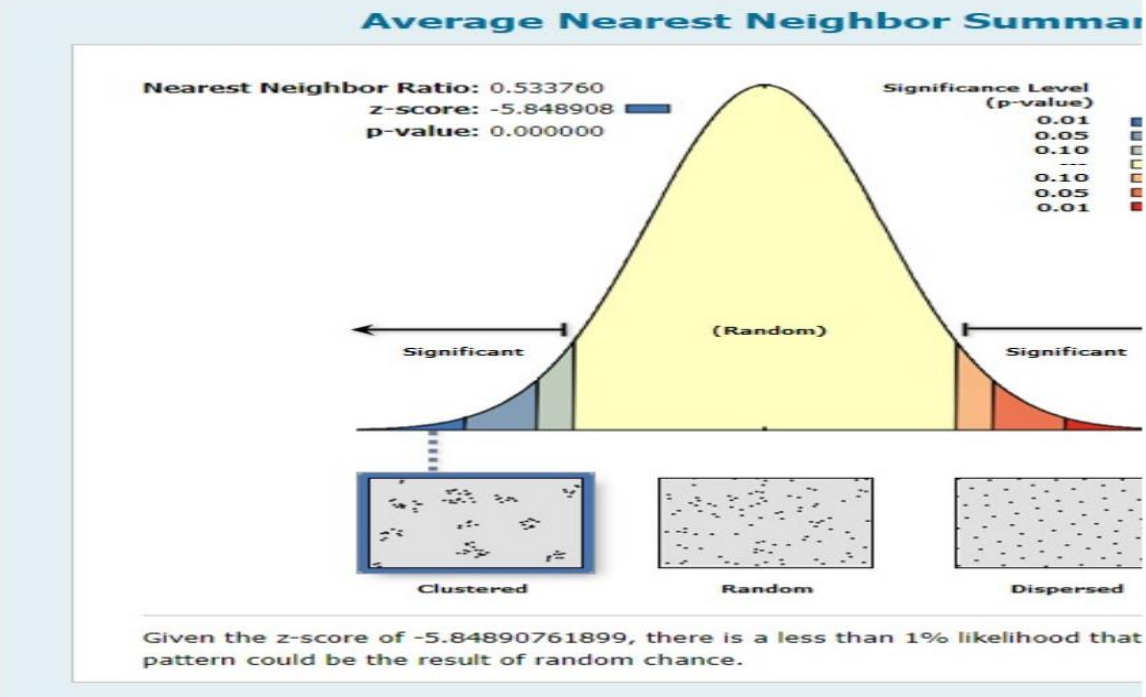
Average Nearest Neighbour gave 317.7605 m as the observed mean distance between the observations and 595.3249 m as the expected mean distance if they were randomly spatially distributed. The ratio of 0.533760 states that the initial distribution of nearest-neighbour distances was about 53% less than that calculated from an random spatial distribution; the negative z-value and the very low p-value and point to a very significant deviation from the null hypothesis of complete spatial randomness (Table 2).

Table 2. Average Nearest Neighbour results

Statistic	Result
Observed mean distance	317.7605 m
Expected mean distance	595.3249 m
Nearest-neighbour ratio	0.533760
z-score	-5.848908
p-value	< .001
Interpretation	Statistically significant clustering

Source: Authors' GIS analysis (2025).

Figure 2: Average nearest Neighbour Results



Compliance with selected Distance Criteria

Percent compliance with differing criteria (Table 3) also showed wide variability. Most stations reportedly had satisfied the road-setback and healthcare-facility buffers; most failed on inter-station spacing.

Table 3. Reported compliance with selected siting criteria

Criterion applied in thesis	Reported compliance (%)	Reported non-compliance (%)	Interpretation
At least 15 m from road to pump area	79	21	Majority compliant
At least 400 m from nearest station	4	Not consistently reported	Severe clustering/non-compliance;

			recalculate
At least 100 m from healthcare facilities	83	17	Majority compliant, but sensitive exceptions remain

Source: Authors' Analysis (2025).

Finally, the 17% of stations located in the healthcare -facility buffer are critical, as only a few exceptions could disturb all delicate services, so the level of compliance could not just be used as an average for the system at large; every non-compliance point should be inspected site by site.

4. Discussion

The fact that 60.5% of the stations are located along three major corridors argues in favor of the idea that interurban traffic and access to markets are the primary factors in the spatial organization of petroleum retailing. This pattern is in line with location theory: firms will need visibility, continuous flows of customers and easy accessibility. It also reveals why a universe of evenly spaced points, a common assumption of CPT, rather than the elongated shapes of actual urban spaces is needed. The road system funnels demand points onto linear corridors, leading to a clustered rather than evenly distributed service system.

The nearest-neighbour result offers an objective quantification of this clustering. The ratio of 0.533760 and the z-score of - 5.848908 show the assemblage very unlikely to be the result of random chance. While the result does not imply regulatory failure per say, shared attraction to highways can cluster otherwise sensibly located stations. Read in conjunction with the reported 4% inter station compliance it indicates corridor saturation and cumulative planning pressure.

This also highlights the differences in the three compliance measures. Road setback and health care separation both had fairly high compliance rates. It suggests that the criteria which are visible at the level of individual plots may be given more consideration in development control. Inter-station spacing requires decision makers to consider the location of the proposed site with respect to the existing set of health services, as defined by the entire and up-to-date inventory. This is more problematic where records are scattered, or residents can only identify their location by the coordinates. It is also more difficult where separate agencies may have authorized different elements of the development. The pattern therefore indicates it is an information-governance as well as an enforcement issue.

Healthcare-buffer exposures reported, suggest policy for prudence. WHO (2019) cites the presence of benzene in petroleum products as a significant health risk. This research did not measure benzene or any other chemicals and cannot substantiate health findings or outcomes to any station. However, the presence of hospitals close by presents planning issues of idiosyncratic users, emergency access, evacuation limits and ongoing healthcare service delivery. The adequate measure is to undertake risk-based site inspection/exposure measurements and not years later claiming of illness observed.

The results support a transition from paper-based, parcel-by-parcel permitting to a cumulative spatial evaluation. A new station concept might meet internal site layout requirements, yet reduce corridor access density or encroach on the risk envelope of existing facilities. GIS-based suitability evaluation can incorporate roads, sensitive land uses, existing stations, population density, drainage, emergency access, and development plans prior to approval (Ajman et al, 2021).

5. Conclusion and Planning Implications

The petrol filling stations in Keffi were very concentrated along primary roads and exit corridors. While most petrol filling stations satisfied the road-setback and healthcare-buffer requirements used in the thesis, there was a huge amount of inconsistency with inter-station distances. This suggests that commercial viability has been more of a priority than balanced spatial distribution and that inconsistency in records has hampered analysis of cumulative coverage.

Four planning procedures are taken from the results. First, the NMDPRA and the Nasarawa Urban Development Board need a common, intersection-based station register that indicates licensure, operation status, approval date, inspection record and surrounding sensitive uses. Second, all applications should have inbuilt automated buffer and corridor-saturation screening prior to site approval. Third, the inspection process should focus on clusters, those stations with proximity to health facilities and unsafe access geometry. Fourth, development plans should formally designate appropriate petroleum-service zones, and regulation within heavily saturated corridors should require a planning reasoned exception.

Prior to submitting a journal article, rebalance the 400 m compliance calculation within the original GIS feature class, check that the legal basis and current applicability of each distance criterion, and update the station operating-status field. This will improve reproducibility and ensure policy conclusions do not depend upon an internally inconsistent percentage.

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