International Journal of Multidisciplinary Studies
Centre for International Studies, Osmania University,
Hyderabad –500007, (A.P.), India.
Online ISSN: 3349-4132
Print ISSN: 3349-5939
Volume 13. Issue 09. Sept., 2026
Page No.128-134

FROM COMPLIANCE AUDIT TO PREVENTIVE APPROVAL: A GIS-MCDA DECISION FRAMEWORK FOR SITING FUTURE PETROL STATIONS IN KEFFI, NIGERIA

Ummi A. S.
Department of Geography and Environmental Management, Federal University Lafia, Nigeria.
sambo.alhaji@science.fulafia.edu.ng

I. M. Hauwa
Department of Geography Nasarawa State University, Keffi, Nigeria.

A. I. Abdullahi
Department of Geography Nasarawa State University, Keffi, Nigeria.
ibrahimabdullahi2200909@nsuk.edu.ng

Abstract
Retrospective compliance audits will tend to discover poorly sited petrol stations after the money has been invested and before there has been public exposure. This methodology paper translates evidence from a survey of 43 petrol stations in Keffi, Nigeria into a preventative GIS-MCDA framework for screening station proposals for future investments. The paper differs from previous reporting of station clustering and compliance and analysis of stakeholder-claimed locational choices and hazards. The framework segregates land that is legally or technically infeasible from gradient suitability. Stage 1 applies exclusionary criteria for sensitive public uses, minimum inter-station spacing, reserved road space, infeasible land uses and parcels without sufficient area or emergency access. Stage 2 evaluates feasible land using access, traffic demand, road class, junction safety, population/ service need, terrain, drainage, environmental potential, utility access and corridor saturation. Criteria weights will be elicited from Nigerian petroleum regulators, planning authorities, fire and environmental agencies, transport bodies, operators and community groups in a transparent decision process, using the Analytic Hierarchy Process. Testing for internal logical consistency is mandatory, and sensitivity analysis advisable. Stage 3 site-specific validation, traffic impacts, environmental assessment, emergency response appraisal and a multi-agency decision are mandatory. The parent evidence justifies the framework: stations were largely clustered, 60.5% occurred on 3 corridors, compliance reporting was highly inconsistent for different criteria, and commercial locational decisions were biased towards corridors and junctions. The model prevents an agentically attractive criterion from cancelling mandatory safety exclusion. In addition, demand and service equity metrics are provided to prevent further stations from contributing solely to already operate corridors. My paper offers a data schema, workflow map, decision matrix, and validation protocol and governance framework. My paper does not offer a final suitability map due to unavailability of current land use, traffic, and parcel and hazard data. The model is ready for empirical implementation once these datasets and current governance practices are documented.

Keywords: *GIS-MCDA, Petrol-station Siting, Site Suitability, Preventive Planning, AHP, Development Control.*

INTRODUCTION

Petrol-station siting decisions need to reflect accessibility and commercial needs, public safety, environmental issues and integration with urban development. In standard approval systems, a proposed lot is judged by written statements and its appearance when visited in the field, but the site‘s relationship with its neighboring lots, sensitive receptors and corridor capacity is harder to visualize. GIS can make those relationships visual before approval is granted.

The Keffi thesis compiled a geocoded inventory and recorded high levels of spatial concentration and considerable differential compliance. One publication explores retrospective audit, while another studies market-accessibility incentives and perceived risks. A third paper should build on those results. This paper considers a future-oriented concern: how may the available evidence be converted into an explicit, replicable screening system?

GIS-MCDA is apt for this as station suitability is based on many criteria measured in many different units. Ajman et al. (2021) used combination of environmental assessment with AHP for filling-station suitability model while Zhu et al. (2024) showed the importance of multi-objective approach for the compromise between safety and service objectives. It is not that MCDA yields an absolute answer; it is because it makes such assumptions, weights, compromises and uncertainties visible.

CONCEPTUAL AND EMPIRICAL BASIS

Prevention Development Monitoring and Spatial Decision Support

Control is most useful if it can prevent an application being made rather than requiring correction after land purchase, design commitment or building costs. A retrospective audit of a development for compliance is "is it in accordance with current rules"; a prospective appraisal of suitability is "what areas should be filtered out, conditionally screened in or screened early for further consideration?" In the case of petrol stations this can be shown to make large differences since siting decisions involve accessibility, commercial viability, safety considerations, environmental protection, emergency response, land-use compatibility and cumulative impacts from nearby stations.

GIS provides the spatial database and analytical functions necessary to model these relationships, but multi-criteria decision analysis (MCDA) provides the systematic method to compare objectives and preferences. The review by Malczewski (2006) resulted in land-use allocation, facility location, environmental management and infrastructure planning being categorized into the major family of spatial decision-support methods using integrated GIS and MCDA. The integration has not value in automation for automation's sake; rather, its value lies in making the criteria, assumptions, trade-offs, and spatial implications accessible for examination.

Facility-location Theory and the GIS-MCDA Approach

Facility location analysis aims at helping managers decide to determine or analyze the best location for one or more facilities.

Facility-location problems trying to identify places that work "relatively well" when considering demand, accessibility, cost/risk trade-offs, service regions, other firms' facilities or supply chains, and other relevant performance dimensions. Farahani et al. (2010) point out that today's facility location literature is inherently multi-criteria as a "location minimizing the distance travelled by customers can have a high cost, safety, equity, and environmental penalty." The same applies to gas stations: places that are service-effective through traffic and denser housing will have trade-offs in access conflict, sensitive receptor exposure, hazard hazard, corridor and facility saturation, and the bounds of their emergency response area.

GIS-MCDA generally comprises the following stages: problem definition, criteria identification, spatial data collection, standardisation, weighting, aggregation, sensitivity analysis, and validation (Malczewski & Rinner, 2015). The stages are sequential for analysis, because they explicitly distinct descriptive spatial evidence from evaluative criterion. Distances, slopes, land covers and vehicle flows are 'set by calculation'; value proportions placed on them will be a matter of policy. A justifiable model records both.

Constraints, Factors, and Non-compensating Safety Rule

Factors

There are two types of factors which are dependent on the parallel components safety rules Definition of Factors When a factor is present on a component, the component is definitely safe.

The definitional difference is the distinction between constraints and factors. Constraints are Boolean or nominal rules that specify where land is unavailable. Constraints can specify incompatible land uses, verified buffers on incompatible uses, restricted roadway space, minimum parcel size, or infeasible elevations for emergency access (or other factors). Factors specify the variations of favorability among eligible locations for those uses, such as service demands, network access, topography, utility availability, or corridor density. This differentiation keeps the strength of the commercial advantage from offsetting an essential safety requirement.

Similarly, this distinction helps interpret regulations. A back-up should not automatically be added in a model in response to the fact it was used by an earlier researcher, but checked against the legal citation, source of measurement, facility class and validity for the current placement. If requirements differ from those of petroleum planning, road or fire authorities including environmental, attempt to label the disagreement in the model rather than choosing one to be applied. Eligibility becomes a legal-technical decision, while suitability becomes a relative planning judgment.

Criteria Selection, Measurement and Standardization

Criteria should be theoretical, pragmatic, evidence-informed, and limited. Consideration of too many highly correlated criteria can be double counting; omission of a vital hazard or access criterion can make a safety assessment unsafe. Ajman et al. (2021) combined environment-impact criteria with GIS and AHP to determine filling-station siting, underlining the importance of a joint consideration of environmental, social, technical and accessibility criteria. Zhu et al. (2024) out discussed this problem by the intervention of multi-objective optimisation, pointing out that service efficiency and planning constraints may require its operation in a joint manner.

As criterion layers are based on different units they need to be standardised to the same scale prior to aggregation. For benefit criteria, which improve suitability, we expect a positive, monotonic linear function. For cost criteria, which reduce suitability, we expect a negative, monotonic linear function. Nonlinear monotonically decreasing functions of benefit criteria, and nonlinear monotonically increasing functions of cost criteria, or non-continuous, piecewise functions, may more accurately describe a simple threshold or diminishing benefit principle. Justification from regulation, observed behaviour or expert opinion then needs to be tested, as different functions will influence the ranking materially.

Weight Elicitation, AHP and Stakeholder Involvement

The Analytic Hierarchy Process breaks a decision down into a goal, criteria, sub-criteria and alternatives and assigns weights on the basis of pairwise comparisons (Saaty, 1980). Its advantage is that it is transparent and there is a consistency ratio available to reveal internally inconsistent judgements. A consistency ratio of less than 0.10 is generally considered acceptable while the diagnostic does not establish the substantive correctness of the preferences.

For petrol-station siting, weights should not be elicited by a single analyst or regulatory organisation. Petroleum regulators, planning authorities, road agencies, fire services, environmental bodies, transport experts, operators and local populations bring diverse knowledge and priorities. Separate judgement matrices enable conflict to be transparent before aggregation. Providing a statement of the expert panel composition, the elicitation method, individual consistency values and the aggregation rule enhances reproducibility and guards against an ostensibly technical model masking institutional priorities.

Aggregation, Compensation and Uncertainty

Weighted linear combination tends to be popular as it is understandable and relatively easy to use: standardised factors are multiplied by their associated weights and summed. It is a compensatory method, with the weakness that poor performance on one factor can be made up for by good performance on another one. This can only be allowed for once the location-specific rules have eliminated ‘bad’ locations. Where residual criteria are not supposed to fully compensate, outranking, ordered weighted averaging or multi-objective procedures can be used (Malczewski and Rinner, 2015).

Uncertainty occurs in point location, old land-use data, incomplete station records, estimated traffic, subjective weights, buffers, and classification function. Producing one suitability map communicates false precision. Sensitivity analysis can change weights, thresholds, standardisation functions, and uncertain inputs, compare the stability of rankings, and list parcels that are classified in the same value in all plausible alternatives. Suitable parcels are those that are suitable in multiple defensible specifications, not just those given maximum score in a single run.

Validation, Implementation, and Governance

The model validation should consider both internal and external performances. Internal validation considers the consist entities, missing attributes, the projection accuracies, the logical conflicts, programming reproducibility. External validation considers the predicted spatial suitability; the field conditions; the judgement of separate experts; the traffic observations; the parcel feasibility; the performance of existing stations if it is appropriate. Conformity of existing station locations should not be taken as adaptive evidence for model.

Implementation is something more than a final raster: the bottom candidates must be signoffs on the cadastral match, the title check, the zoning, a site visit, a traffic-impact analysis, an environmental impact analysis, an emergency-response analysis, and a community-notice, plus a record of decision that keeps the data version, regulations, sides accounted away, the weights, the sensitivity analysis, field observations, agency comments, approval conditions, and acceptance-or-denial reasons. Making each step traceable turns GIS-MCDA from presentation map to development-control tool.

Empirical Applications to Filling-station Siting

The existing empirical applications to filling-station siting cover a range of approaches. Of the three studies that are available to this author, the first is simple and elegant in its way; the second is a complex application of spatial autocorrelation analysis; and the third implicitly assumes the complex network of influences that determine filling-station siting.

As shown by previous empirical studies, the potential and limits of GIS-based station planning are confirmed. Ajman et al. (2021) proposed an integrated environmental assessment + Analytical Hierarhym Procedures (AHP) to classificate land under various regulatory policies. Peprah et al. (2018) developed a GIS-based compliance based analysis in Ghanan oil and gas filling station planning, which brought the planning standards to detail and revealed how weak enforcement compromised standards. In Nigerian, Mohammed et al. (2014) proposed comparison of locations in metropolitan Kano with physical-planning standards, and Njoku and Alagbe (2015) employed GIS-based availability and proximity analysis in Oyo Town. All these exemplified the potential of inventories, buffers, overlays and multi-criteria evaluation.

The six persistent methodological issues include the validation of existing regulatory thresholds when current status is not checked; inadequate reporting of weights; counting multiple accessibility variables even though they are correlated; inadequate application of sensitivity analysis; the presentation of suitability maps without parcel-level or field validation. Moreover, demand attractive models rather than supply potential models, may only perpetuate existing corridor concentration and fail to reduce service inequity and cumulative access pressure.

The Keffi Evidence and the Research Gaps

The Keffi evidence justifies a preventive approach. Seven existing stations were regrouped rather than randomly; 26 of 43 outlets were concentrated on three major corridors; place markers collectively performed differently on planning factors; and outlet locations reports favored traffic, exit routes and motor parks, junctions, and easy accessibility. They reveal that individual rational commercial actions can collectively escalate corridor and safety management pressures.

Existing published literature supports the use of GIS-MCDA for this problem, however it also calls for a framework that safeguards non-compensatory standards, maps service need and saturation, reveals stakeholder weights, examines uncertainty and maintains an auditable multi-agency decision trail. This is the methodological contribution that the present article makes. It offers an implementation-ready architecture, rather than the final tested suitability map, as reliable, up-to-date standards and parcel, traffic hazard and land use data are necessaries for robust empirical application.

Framework Development Method

The framework was constructed through evidence-to-criterion translation. Relevant thesis variables, identified compliance problems, planning standards, and recent GIS-MCDA literature were synthesized into five key elements goal definition, exclusion constraints, suitability factors, weighting and aggregation, and validation/governance.

Level 1: Exclusion Screening

This feedback limitation bands should be constructed after legal basis and measurement method, that is:

Table 1. Proposed Exclusion Constraints

Constraint	GIS Operation	Required Verification
Sensitive public uses	Buffer hospitals, schools, and other protected uses	Current legally applicable distance and feature definition
Existing stations	Buffer licensed and operational outlets	Current minimum separation and treatment of opposite carriageways
Road and right-of-way protection	Apply parcel/pump setback geometry	Whether distance is measured to parcel, canopy, tank, or pump
Incompatible land use	Reclassify zoning and development-plan layers	Permitted, conditional, and prohibited zones
Parcel adequacy	Exclude parcels below layout requirement	Minimum area, frontage, turning, tanker, and queue-storage needs
Physical/environmental hazard	Exclude floodways, unstable slopes, or protected land	Hazard thresholds and authoritative datasets

Source: Authors' Analysis, 2025

Binary constraint rasters are combined through Boolean intersection. If (C_k(x)) is 1 where location (x) passes constraint (k) and 0 otherwise, eligibility is:

[E(x)=_{k=1}^{m}C_k(x)]

Only cells or parcels where (E(x)=1) proceed to suitability scoring.

Stage 2: Factor Evaluation

Eligible locations are evaluated using standardised factors.

Table 2. Proposed suitability factors

Factor Group	Example Variables	Preferred Direction
Market/service need	Population, registered vehicles, underserved service area	Higher need, higher score
Road accessibility	Functional class, traffic flow, route continuity	Adequate access, higher score

Access safety	Junction distance, sight distance, queue storage	Safer geometry, higher score
Corridor saturation	Outlet density, nearest competitors, driveway density	Lower saturation, higher score
Emergency readiness	Fire-service travel time, alternative access	Shorter response, higher score
Environmental suitability	Slope, drainage, groundwater sensitivity	Lower sensitivity, higher score
Infrastructure	Power, water, communication, service access	Better provision, higher score
Planning compatibility	Conformity with zoning and growth strategy	Stronger conformity, higher score

Source: Authors' Analysis, 2025

Replace values by a common 0-1 scale with monotone value functions, rather than with class breaks. Travel time on the network can be used rather than direct distance when considering fire response and customer access.

Stage 3: Weighting, Aggregation, and Sensitivity

AHP can extract pairwise comparisons from a multi-agency expert panel. Individual stakeholder matrices should be computed, then an aggregation rule documented. Judgements that have a consistency ratio above 0.10 should be examined. The following is the suitability score:

[S(x)=E(x)_{j=1}^{n}w_jv_j(x)]

Where (w_j) is the normalised weight and (v_j(x)) the standardised factor value. After the exclusion constraints are introduced, weighted linear combination is also acceptable.

Conduct sensitivity testing by varying the weights, buffer distances, classification functions and uncertain data. The candidate sites that consistently stay in top ranked position across the possible situations are the more robust candidate sites than the candidate sites ranked highly based on a limited assumption.

Stage 4: Site Verification and Decision

A high GIS score is not approval. Short-listed parcels need cadastral approval, on-site survey, traffic-impact analysis, environment study, fire-service study, drainage and tank-system study, community notification, title search and zoning approval. The decision should include map version, data input, criteria, weighted sum, exclusion, condition and reasons.

Proposed Data Architecture

The system should utilize a parcel-centred geo-database integrated with application and inspection information.

Table 3. Minimum Geo-database Structure

Dataset	Essential Attributes	Update Responsibility
Station register	Coordinates, owner, brand, licence, status, capacity, inspection date	NMDPRA
Parcel/cadastre	Parcel ID, area, frontage, title, application status	Land authority
Planning layers	Zoning, approved layouts, rights-of-way, growth areas	NUDB/local planning authority
Roads/traffic	Class, width, direction, volume, junctions, crashes, queue space	Transport/road agencies
Sensitive uses	Facility type, capacity, operating status	Health, education, planning agencies
Hazards/environment	Flood, drainage, slope, geology, groundwater, protected land	Environmental agencies
Emergency services	Station location, vehicles, network travel time	Fire and emergency services

Source: Authors' Analysis, 2025

All datasets require the addition of metadata, coordinate system referencing information, dates, quality statements and version control. Outputs for public viewing would need to state areas in and out of scope but without revealing operational sensitive information.

Validation Strategy

The framework should be validated four ways. Internal validation validates topology, missing attribute, AHP consistency and computational reproducibility. Retrospective validation validates present sites against modelled site suitability without assuming existing sites are correct. Field validation validates high-, medium- and low-ranked parcels. Outcome validation validates approved sites with time using access conflict, complaints, incidents, queue obstruction, inspection results and environmental monitoring.

If standards, land use, roads or demand change model should be recalibrated. Static map would not remain valid in a rapidly growing secondary city.

DISCUSSION

The framework offers three improvements over the Keffi articles. First, it shifts emphasis from identifying measures to prevent existing non-compliance to strategies that avoid future incompatibility. Second, it separates mandatory barriers from compensatory factors, thus avoiding the perilous outcome of strong commercial demand netting off significant setbacks. Third, it injects service equity and corridor saturation rather than unconditionally channeling all proposals to busy arterial streets.

Ajman et al. (2021) proved material differences in suitability judgments can be obtained when testing different regulatory codes, emphasizing to record details of standards and sensitivity tests. More recent multi objectives research (Zhu et al. 2024) also finds that transparency in balancing accessibility; demand, environmental impacts, and safety are well possible when the objectives are explicit. For Keffi, institutional value is derived from sharing information/data between NMDPRA, NUDB, land, road, environmental, health,1-3 emergency agencies.

The framework will not be supplied as a finished suitability map. The provided thesis has the station locations and buffers and basic parcel geometry but not the two recent sets of traffic volumes, the full land use database, flood and groundwater sensitivities, fire-service travel times, and documented current, regulation standards. Creating these would be to introduce an unquantifiable degree of false accuracy, the best contribution will be an explicit, ready-to-apply design and statements of data needs.

CONCLUSION

Keffi retrospective evidence; the clustering of station locations, oversaturation of high appeal corridors and variable merits of criteria, reveals reasons for preventive site selection. A justifiable approval process for land use should eliminate unsuitable lands before prioritising suitable parcels through following merits: demands, accessibility, access safety, corridor oversaturation, response ability, environmental factors, infrastructure preparedness and land use planning compatibility.

Offered is a GIS-MCDA framework complete with equations, criteria, architectural specification, weighting protocols, sensitivity analysis, and a validation scheme. The short-term policy benefit is procedural: every decision can be traced and every cumulative outcome seen. The short-term research programs is to make the elicited authoritative layers, normalize standards, convene a multi-agency weighting panel, and publish the resulting suitability and uncertainty maps.

References

Agoma, A. (2023). Old Stand-up Comedy, Orality, Subject Matter and the New Media: A Study of Alibaba's 2016 January 1st Concert Performance. Ama: Journal Of Theatre And Cultural Studies, 14(1).

Agoma, A. (2023). SOLO PERFORMANCE AND THE RESTRUCTURING OF THE THEATRE CURRICULUM: A STUDY OF TUNJI SOTIMIRIN'S PERFORMANCE IN SOLO AFRICA. Ama: Journal Of Theatre And Cultural Studies, 15(1).

Agoma, A. (2025). Writing Solo Plays in Nigerian Theatre: Using Sotimirin's Molue, Mbajiorgu's The Prime Minister's Son, and Binebai's Karina's Cross as Paradigms. Abuja Journal of Humanities, 6(2), 370-384.

Agoma, A. (2026). Solo Performance and the Superfluity of Facial Make-Up: A Study of Ipe, as Performed by Daniel Olamide, and Molue, as Performed by Tunji Sotimirin. Abuja Journal of Humanities, 7(1), 211-223.

Ajman, N. N., Kadir, T. A. A., & Mukhtar, A. (2021). An integrated land suitability analysis of filling stations using GIS-based multi-criteria decision making. Sustainability, 13(17), 9859. https://doi.org/10.3390/su13179859

Awaritoma, A. (2009). Stand-up Comedy in Nigeria.

Baba, A. A. Current Development.

Farahani, R. Z., SteadieSeifi, M., & Asgari, N. (2010). Multiple criteria facility location problems: A survey. Applied Mathematical Modelling, 34(7), 1689-1709. https://doi.org/10.1016/j.apm.2009.10.005

Ismail, N. A., & Ali, B. A. (2026). Teaching Classical Arabic (Fuṣḥā) Beyond Grammar: Language, Culture, and Pedagogical Meaning-Making in Nigeria. Abuja Journal of Humanities, 7(1), 161-176.

Jajere, Z. M. (2009). Family Planning and Abortion in the Face of the Shari'ah. Unimaid Journal of Women Studies, 2, 85.

Jajere, Z. M. (2026). FAITH-BASED RESOURCES AND DURABLE SOLUTIONS: ISLAMIC SOCIAL FINANCE AND THE PROTECTION OF INTERNALLY DISPLACED WOMEN AND CHILDREN IN BORNO STATE, NIGERIA. Multi-Disciplinary Research and Development Journals Int'l, 8(2), 1-36.

Jajere, Z. M. (2026). Gender Inequality in Maiduguri: An Islamic Perspective. Spanish Journal of Innovation and Integrity, 51, 23-29.

Jajere, Z. M., & Abdullahi, A. S. (2025). Muslim Women in Environmental Stewardship: Afforestation Initiatives and Socioeconomic Impact in Muslim-Majority Regions Sahel Region of Africa. African Journal of Earth and Environmental Science, 7(1).

Jajere, Z. M., & ISHAQ, R. N. (2024). ISLAMIC VIEW ON ORPHANS, WIDOWS AND LESS PRIVILEGE IN ECONOMIC HARDSHIP. EKERE JOURNAL OF RELIGION (EJR), 2(1), 71-86.

Jajere, Z. M., & ISHAQ, R. N. ISLAMIC VIEW ON ORPHANS, WIDOWS AND LESS PRIVILEGE IN ECONOMIC HARDSHIP. EKERE JOURNAL OF RELIGION (EJR), 85.

Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. International Journal of Geographical Information Science, 20(7), 703-726. https://doi.org/10.1080/13658810600661508

Malczewski, J., & Rinner, C. (2015). Multicriteria decision analysis in geographic information science. Springer. https://doi.org/10.1007/978-3-540-74757-4

Mohammed, M. U., Musa, I. J., & Jeb, D. N. (2014). GIS-based analysis of the location of filling stations in metropolitan Kano against the physical planning standards. American Journal of Engineering Research, 3(9), 147-158.

Njoku, C. G., & Alagbe, A. O. (2015). Site suitability assessment of petrol filling stations in Oyo Town, Oyo State, Nigeria: A geographic information systems approach. IOSR Journal of Environmental Science, Toxicology and Food Technology, 9(12), 8-19. https://doi.org/10.9790/2402-091230819

Peprah, M. S., Boye, C. B., Larbi, E. K., & Opoku Appau, P. (2018). Suitability analysis for siting oil and gas filling stations using multi-criteria decision analysis and GIS approach: A case study in Tarkwa and its environs. Journal of Geomatics, 12(2), 158-166.

Saaty, T. L. (1980). The analytic hierarchy process. McGraw-Hill.

Zhu, J., Zhang, H., Wang, Y., & Li, X. (2024). Multi-objective optimization of urban gas-station site selection using GIS and improved decision analysis. ISPRS International Journal of Geo-Information, 13(11), 375. https://doi.org/10.3390/ijgi13110375