Review Article

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Optimal siting of a nuclear power station in Nigeria using fuzzy grey relational analysis

Abstract

One of the primary causes of Nigeria's underdevelopment is a lack of electricity to power the country's industries. Rather than relying solely on fossil fuels to generate electricity in Nigeria, a variety of other sources, such as nuclear energy, must be considered. A Nuclear Power Plant's (NPP) location is a critical step in its development. This paper thus presents a methodology for resolving the issue of NPP site selection. For this project, the fuzzy Grey Relational Analysis (GRA) method was chosen. To assess the feasibility of the approach, one of Nigeria's six south-south states was chosen as the location of a hypothetical nuclear power plant. According to the findings, the NPP would be best located in Delta State, which had the highest gray relational grade of 0.7897.

Keywords: Fuzzy GRA, Nuclear Power Plant, Decision criteria, Sites, Location

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Introduction

Most industries in Nigeria are forced to rely on expensive, stand-alone power generators since the national grid's supply is so uneven and unreliable. Renewable and non-renewable energy sources, such as nuclear, are needed to meet Nigeria's energy demands instead of just relying on fossil fuels.[1] 17 % of the world's nuclear power plants, situated in more than 30 countries, supply the world's electrical energy demands.[2] NPP placement is an important phase in the development of nuclear power plants because it minimizes costs and protects individuals and the environment from the unwanted consequences of construction or operation.[3]

The problem of NPP site selection has been addressed successfully using MCDM tools in a few countries around the world. Fuzzy SWOT, Ekmekçioglu et al.[4] investigated Fuzzy AHP, and Fuzzy TOPSIS to see if they could be used to select the best location for a nuclear power plant in Turkey. Erol et al.[5] combined Fuzzy Entropy with Fuzzy Compromise Programming to solve another NPP site selection problem in Turkey. Kurt[3] utilized Fuzzy TOPSIS to investigate the site selection problem for Turkey's nuclear power plant.

Kassim et al.[6] adopted the AHP to determine the best location for a nuclear power plant in Yemen.

Wang et al.[7] advocated for the use of the Fuzzy ANP and TOPSIS approaches in determining the best location for a nuclear power plant in Vietnam. Wu et al.[8] used Type 2 fuzzy AHP and Type 2 fuzzy PROMETHEE II to solve China's nuclear plant site selection problem. Peng et al.[9] investigated the application of Z-number linguistic variables, the Best Worst Method (BWM), DEMATEL, and TOPSIS. The results of their analysis showed that more MCDM technologies, such as fuzzy GRA, can be employed to augment the effort and close the gap. To my knowledge, there is no research on the MCDM method for Nigeria's NPP site selection, hence this method should be investigated further. This study proposed a fuzzy GRA approach for selecting the optimal state in Nigeria's south-south region for the NPP's location. Due to the complexity of traditional MCDM tools used to handle NPP site selection challenges, fuzzy GRA approaches were chosen as a solution. It has also been used in literature to investigate multi-criteria decision issues, such as machining parameter optimization.[10,11] Conceptual design appraisal,[12] and supplier selection.[13] Because it has not previously been documented in the literature, the MCDM method needs to be studied further. In this paper, a fuzzy GRA technique is proposed to select the best state in Nigeria's south-south region to house the NPP.

Because of their computational simplicity in comparison to other MCDM tools, fuzzy GRA techniques were chosen to support in the solution of the NPP site selection problem. It has already been shown in the literature to be a valuable tool for solving a variety of complex multicriteria decision problems, such as machining parameter optimization,[10,11] conceptual design evaluation,[12] and supplier selection.[13]

A Number of multicriteria decision tasks have been studied using the fuzzy GRA technique, including machining parameter optimization, conceptual design evaluation, and supplier selection.[10-13] The MCDM approach should be investigated further because it has not been previously documented in the literature. To find the ideal location for the NPP in Nigeria's south-south zone, a fuzzy GRA technique is proposed in this research. Fuzzy GRA techniques were chosen to help solve the problem of NPP site selection because they are computationally simpler than other MCDM tools. In the literature, it has already proven to be a valuable tool for solving a variety of complex multi criteria decision problems, such as machining parameter optimization,[10,11] conceptual design evaluation,[12] and supplier selection.[13]

Methodology

Figure 1 depicts the proposed method for determining which of Nigeria's six south-south states is the best location for a nuclear plant (NPP). As shown, the next step is to establish criteria for evaluating each state's performance after determining the goal of locating the NPP in the best possible state. Here, in Table 1 are the criteria that we used to make our final decision. The states are ranked using the Fuzzy GRA technique, and the state with the highest fuzzy GRA performance values is chosen.

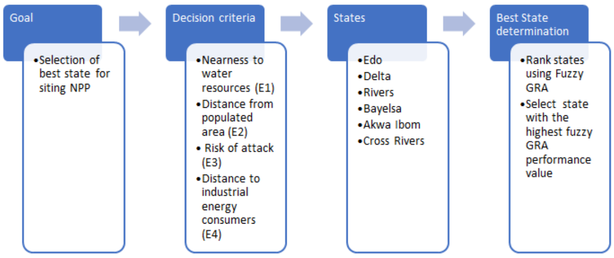

Figure 1 NPP site selection decision chart.

Fuzzy GRA method

The Fuzzy Set Theory (FST) and the GRA method are combined in the fuzzy GRA method. Julong[14] developed the GRA technique for analyzing multi criteria decision problems. The degree of similarity between the reference alternative value and each comparison alternative value determines the ranking principle.[15] One disadvantage of the GRA method is the use of only exact data in decision analysis, which is ineffective in practice. FST and GRA can be used to model ambiguity in the decision-making process, though. Multi-criteria decision-making has been made easier with the fuzzy GRA. Hydrogen energy storage technique selection was dealt with by Gumus et al.[16] using the method. To identify the most advanced manufacturing system, Goyal and Grover[17] used the fuzzy GRA. When using the fuzzy GRA approach; linguistic variables are employed by decision-makers to award scores to potential NPP sites based on decision criteria. Fuzzy triangular numbers (TFNs) are created from the linguistic variables and consist of three real numbers, l, m, and p. Tables 2 and 3 provide the linguistic scale for assigning fuzzy scores to alternate NPP locations and criteria, respectively.

Protocol for implementing the Fuzzy GRA algorithm

The Fuzzy GRA algorithm implementation is divided into five stages.[18]

(1) Determine the fuzzy decision matrix

The first step in applying the fuzzy GRA methodology is for decision-makers (DMs) to assign fuzzy ratings to alternative NPP sites against decision criteria using the fuzzy scale in Table 2.

If k DMs assign ratings to alternative NPP sites I based on decision criterion j, the DMs' combined rating can be calculated as follows:[19]

$$\tilde{\mu}_{ij} = \frac{1}{k}\left[\tilde{\mu}_{ij}^{1} + \tilde{\mu}_{ij}^{2} +,\ldots\tilde{\mu}_{ij}^{k}\right] \quad (1)$$

Where $\tilde{u}_{ij}^{k}$ is the fuzzy rating of the ith alternative site by the kth decision maker (DM) against the jth criterion? If more than one DM is involved in the decision-making process, k number of DMs is asked to assign fuzzy weights to decision criteria. The obtained integrated fuzzy criteria weights are expressed as follows:[20]

$$\tilde{w}_{j} = \frac{1}{k}\left[\tilde{w}_{j}^{1} + \tilde{w}_{j}^{2} +,\ldots\tilde{w}_{j}^{k}\right] \quad (2)$$

Where $\tilde{w}_j^k$ is the fuzzy weight of criterion *j* assigned by *k*th DM.

Fog matrixes are formed by adding together the various choice criteria's integrated fuzzy weights with the integrated fuzzy ratings of probable NPP locations.[19]

$$\tilde{U}_{ij} = \begin{bmatrix} \tilde{u}_{11} & \tilde{u}_{12} & \ldots & \tilde{u}_{1n} \\ \tilde{u}_{21} & \tilde{u}_{22} & \ldots & \tilde{u}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{u}_{m1} & \tilde{u}_{m2} & \ldots & \tilde{u}_{mn} \end{bmatrix}; \tilde{w}_j = \left[\tilde{w}_1 + \tilde{w}_2 +,..,\tilde{w}_n\right],\ j = 1,2,3,\ldots,n \quad (3)$$

Where $\tilde{u}_{ij}$ is the alternative NPP sites, *i*, rating with respect to criterion *j* and $\tilde{w}_j$ indicate fuzzy weight of criterion *j* and $\tilde{u}_{ij} = \left(l_{ij}, m_{ij}, q_{ij}\right)$

(2) Normalise the fuzzy decision matrix

Equation (4) is used to transform the fuzzy decision matrix into a normalised fuzzy decision matrix, R.

$$\tilde{\gamma}_{ij} = \left(\frac{l_{ij}}{q_j^{+}}, \frac{m_{ij}}{q_j^{+}}, \frac{q_{ij}}{q_j^{+}}\right) i = 1,2,\ldots,m;\ j = 1,2,\ldots,n \quad (4)$$

Where $q_j^{+} = \max_i\left(q_{ij}\right)\ i = 1,2,\ldots,m$

(3) Evaluate the reference series

The individual criterion reference number is obtained as follows

$$\tilde{R}_o = \left[\tilde{r}_{o1}, \tilde{r}_{o2}, \ldots, \tilde{r}_{on}\right]\ where\ \tilde{r}_{oj} = \max\left(\tilde{r}_{ij}\right)\ j = 1,\ldots,n \quad (5)$$

(4) Determine the distance matrix

The distance $\tilde{\partial}_{ij}$ between the reference value and the individual comparison value is expressed as:

$$\partial_{ij}\left(\tilde{r}_{oj}, \tilde{r}_{ij}\right) = \sqrt{\frac{1}{3}\left[(r_o^{l} - r_{ij}^{l})^2 + (r_o^{m} - r_{ij}^{m})^2 + (r_o^{q} - r_{ij}^{q})^2\right]} \quad (6)$$

(5) Evaluate grey relational coefficient (GRC)

The GRC, is evaluated as:

$$\sigma_{ij} = \frac{\tilde{\partial}_{min} + \pi\tilde{\partial}_{max}}{\partial_{ij} + \pi\tilde{\partial}_{max}} \quad (7)$$

Where, $\tilde{\partial}_{min} = min\left(\tilde{\partial}_{ij}\right), \tilde{\partial}_{max} = max\left(\tilde{\partial}_{ij}\right)$ and π is the revolving coefficient which has a value of 0 to 1.

(6) Defuzzification of fuzzy criteria weight

The fuzzy criteria weights, $\tilde{w}_j$ $\left\{\tilde{w}_j = \left(l_j, m_j, q_j\right)\right\}$ is generally transformed into crisp values through defuzzification as follows:

$$Crisp\left(\tilde{w}_j\right) = w_j = \frac{l + 2m + q}{4} \quad (8)$$

(7) Evaluate grey relational grade (GRG)

The GRG, ϕ_i of the alternative NPP sites are evaluated as follows:

$$\varnothing_i = \sum_{j}^{n} w_j \sigma_{ij}\quad ,i = 1,2,\ldots,m \quad (9)$$

Where w_j is the crisp weight of the *j*th criterion

Based on the GRG, φ_i the different NPP sites are ranked, and the site with the maximum value is optimal.

Case study

A real-world example of selecting the best state in Nigeria's south-south region to locate a nuclear power plant was used to test the efficacy of the proposed fuzzy GRA technique. There are six states in

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Nigeria's south-south region: Edo, Delta, Rivers, Bayelsa, Akwa Ibom, and Cross River (all in the south-south). Each state was rated based on four criteria: proximity to water resources (E1), distance from densely populated areas (E2), and low attack risk (E3), and distance from significant industrial energy consumers (E4) (E4). For proximity to water resources, each state received an E1 rating (E4). Table 2 shows the fuzzy scale ratings for the DM, while Table 4 shows the ratings for each alternate site. In the fuzzy GRA approach, weights analysis is also required for decision-making. The DM assigned weight to each decision criterion using the fuzzy weighting scale shown in Table 3, and the criteria weights are also shown in Table 4. Table 5 highlights how the DM linguistic ratings are converted into TFN.

The fuzzy decision matrix in Table 5 must be normalized as a first step in performing a fuzzy GRA analysis by solving Equation (4) for values in Table 6. The distance between each alternate site and the reference series is calculated using Equation (6). As can be seen in Figure 2, the results are as follows. Equation (7) is used to analyze the GRC, as illustrated in Figure 3, and the results may be seen. Decided criteria weights are essential to GRG calculation.

Table 1 Description of decision criteria

Decision criteria	Description
Nearness to water resources (E1)	For effective cooling of NPP large volume of water is required, thus NPP should be sited near sea or big river
Distance from populated areas (E2)	The appropriate site for locations of NPP should not be near populated areas in order not to expose people to radioactivity
Risk of attack (E3)	NPP should be located in the place that is safe from any form of attack be it internal from (Boko haram, militant, and any other pressure group) or external
Distance to industrial energy consumers (E4)	To reduce energy loss on transmission line the site for location of NPP should be close to large industrial energy consumers

Table 2 Linguistic variables for rating alternatives[3]

Linguistic variables	TFN
Very poor (VP)	0,0,1
Poor (P)	0,1,3
Medium poor (MP)	1,3,5
Fair (F)	3,5,7
Medium good (MG)	5,7,9
Good (G)	7,9,10
Very good (VG)	9,10,10

Table 3 Linguistic variables for rating criteria[3]

Linguistic variables	TFN
Very Low (VL)	0,0,0.1
Low (L)	0,0.1,0.3
Medium Low (ML)	0.1,0.3,0.5
Medium (M)	0.3,0.5,0.7
Medium High (MH)	0.5,0.7.0.9
High (H)	0.7,0.9,1

Table 4 DM linguistic rating of alternative NPP sites

Alternative NPP sites	Proximity to water resources	Distance from densely inhabited areas	Low attack risk	Distance from significant industrial energy
Edo	MG	G	VG	F
Delta	VG	G	P	G
Rivers	VG	VP	P	VG
Bayelsa	G	F	P	P
Akwa Ibom	MG	VP	G	F
Cross River	G	VG	G	F
Criteria fuzzy rating	H	H	ML	M

Table 5 DM TFN rating of alternative NPP sites

Alternative NPP sites	E1	E2	E3	E4
Edo	(5,7,9)	(7,9,10)	(9,10,10)	(3,5,7)
Delta	(9,10,10)	(7,9,10)	(0,1,3)	(7,9,10)
Rivers	(9,10,10)	(0,0,1)	(0,1,3)	(9,10,10)
Bayelsa	(-7,910)	(3,5,7)	(0,1,3)	(0,1,3)
Akwa Ibom	(5,7,9)	(0,0,1)	(7,9,10)	(3,5,7)
Cross River	(7,9,10)	(9,10,10)	(7,9,10)	(3,5,7)
Criteria fuzzy rating	(0.7,0.9,1)	(0.7,0.9,1)	(0.1,0.3,0.5)	(0.3,0.5,0.7)

Table 6 Normalised fuzzy decision matrix

NPP alternatives	E1			E2			E3			E4		
Edo	(0.5,	0.7,	0.9)	(0.7,	0.9,	1)	(0.9,	1,	1)	(0.3,	0.5,	0.7)
Delta	(0.9,	1,	1)	(0.7,	0.9,	1)	(0,	0.1,	0.3)	(0.7,	0.9,	1)
Rivers	(0.9,	1,	1)	(0,	0,	0.1)	(0,	0.1,	0.3)	(0.9,	1,	1)
Bayelsa	(0.7,	0.9,	1)	(0.3,	0.5,	0.7)	(0,	0.1,	0.3)	(0,	0.1,	0.3)
Akwa Ibom	(0.5,	0.7,	0.9)	(0,	0,	0.1)	(0.7,	0.9,	1)	(0.3,	0.5,	0.7)
Cross River	(0.7,	0.9,	1)	(0.9,	1,	1)	(0.7,	0.9,	1)	(0.3,	0.5,	0.7)

The DM's fuzzy criteria weight score is defuzzified using Equation (8). Using defuzzification, we get decision weights of 0.3095, 0.3095, 0.1429, and 0.2381 for each of E1 through E4, respectively.

Figure 4 shows how GRG can be determined using Equation (9). Delta, Cross River, Rivers, Edo, Bayelsa and Akwa Ibom are the alternate NPP locations shown in Figure 3. Because Delta state having the highest GRG score is the best site for NPP location.

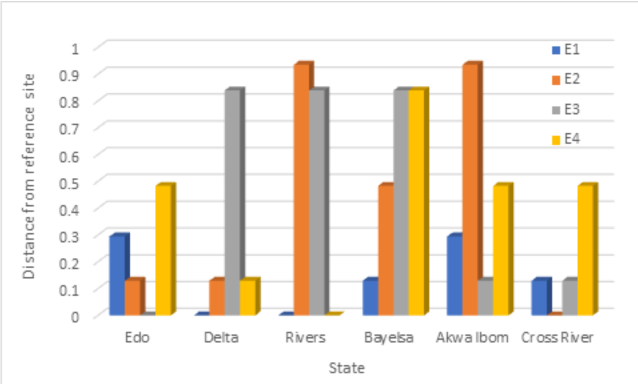

Figure 2 Distance of each alternatives from the reference site.

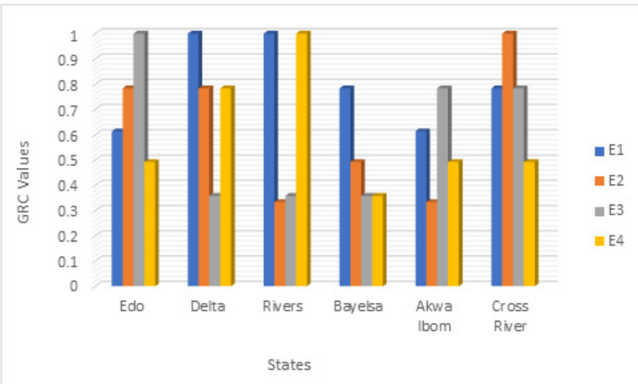

Figure 3 GRC of alternative NPP sites.

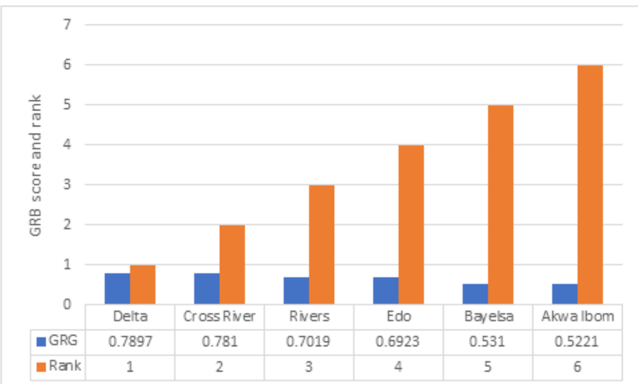

Figure 4 GRG of alternative NPP sites and corresponding rank.

Conclusion

The objective of this paper was to use the fuzzy GRA technique to select the optimal NPP site from the possibilities of Edo, Delta, Rivers, Bayelsa, Akwa Ibom, and Cross River. Each state's performance (NPP sites) was evaluated using four-choice criteria. According to the study's findings, the state of Delta is the optimal location for the NPP among the six states. In analysing the NPP site selection problem in Nigeria, other choice criteria such as public acceptability and the convenience of nuclear fuel supply can be included in future work.

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Conflicts of interest

The authors state that there is no conflict of interest.

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