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A Comparative Evaluation of Multi-Criteria Decision Analysis Techniques for Selecting the Appropriate Vector Management Strategy in the Northern Zone of Plateau State, Nigeria

Nanlok Henry Nimlang[1*], Gilles Dusserre[1], Sandrine Bayle[1], Kivanc Ertugay[1], Stefan Janaqi[1]

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ABSTRACT

Accurate assessment of the complexity of malaria transmission dynamics requires the selection of appropriate Multi-Criteria Decision Analysis (MCDA) techniques that enable thorough analysis of risk factor parameters and structuring of decision problems into well-defined outcomes. A comparative study and analysis of multi-criteria decision-making methods such as TOPSIS, PROMETHEE II, MAUT and COPRAS was carried out using the reference rankings of MULTIMOORA and MOOSRA to evaluate the consistency of the results of these techniques and to rank the risk factors according to the vulnerability of mosquito breeding habitats and the risk of malaria transmission in the study area. The results indicate that TOPSIS ranked the alternative similarly to the reference ranking, while PROMETHEE II, MAUT, and COPRAS were ranked equally according to the weighted Spearman correlation coefficient and the weighted sum rank similarity coefficient analysis. The degree of consistency with which the risk factors in the study area were analyzed through this comparative study shows that the TOPSIS technique is suitable for its application in malaria epidemiology to determine the appropriate intervention measure for vector management in the northern zone of up to certain Plateau State.

INTRODUCTION

Malaria, along with other diseases such as anaemia, remains a major public problem in developing countries, with socioeconomic consequences for children (Quadri *et al.*, 2022; Youssefi *et al.*, 2022). In most rural areas with limited healthcare facilities, traditional medication with herbs such as Parkia biglobosa is also often used as primary care, in addition to hospital visits for diagnosis and treatment (Ibrahim *et al.*, 2023). In malaria epidemiology, Multi-Criteria Decision Analysis (MCDA) is a valuable tool employed in evaluating different malaria risk factors and guiding the selection of suitable vector management strategies. The selection of MCDA techniques is critical for assessing the intricacy of malaria transmission dynamics by thoroughly analysing the parameters of the risk factor into simple, and structured decision-making problems that guarantee accurate outcomes(Kassaw *et al.*, 2018; Zhao *et al.*, 2020). Various MCDA approaches have been applied to various fields of applications based on how well they transform data into expert results (Diaby *et al.*, 2013; Guarini *et al.*, 2018). The choice of these techniques in solving any decision problem are influenced by a number of factors such as the complexity of algorithms, criteria weighting methods, representation of preference evaluation criteria, handling of uncertain data, and data aggregation type (Bączkiewicz *et al.*, 2021; Taherdoost & Madanchian, 2023). Since the evaluation of different MCDA techniques in solving decision problems often yield disparate transformations that produce disparate results, decision-makers are frequently faced with the challenge of selecting the best MCDA technique for analyzing these decision problems(Sałabun *et al.*, 2020; Yildirim *et al.*, 2021). Thus, when comparing these techniques, it is imperative to ensure that the results are consistent and logical, as the results often impact real-life decisions (Wieckowski & Szyjewski, 2022). Additionally, it is crucial to analyse the consistency of the results obtained from the comparison of MCDA techniques since decision-makers frequently depend on them to choose the best course of action for reducing the prevalence of malaria. Most often, the main objective of using MCDA techniques is to choose the best option from a set of alternatives by establishing a preference ranking among different decision options based on their performance against a variety of criteria (Steele *et al.*, 2009).

Based on database searches, our study found that the AHP is the most often utilized MCDA method in the field of malaria epidemiology. Thus, there is a need to evaluate other MCDA techniques to ascertain their applicability in malaria epidemiology, particularly in mapping and modelling malaria transmission risk. A Web of Science database search conducted with the keywords "Malaria AND Multi-Criteria Decision Analysis OR Multi-Criteria Decision Method AND Analytic Hierarchy Process" indicated 2,806 studies that have been carried out in various fields related to malaria. However, only 1,151 studies utilizing other MCDA techniques were carried out after AHP was removed from the query. This indicates that AHP is the method most frequently employed to assess data related to malaria that influences decision-making processes in this domain. Therefore, it is essential to compare other MCDA techniques on the basis of consistency in order to determine which other

[1] Laboratory for Science of Risk (LSR), IMT Mines Ales, France
[*] Corresponding author's e-mail: nanlock.nimlang@mines-ales.fr

approaches are appropriate for assessing malaria risk factors and comprehend their applicability to vector management practices.

To the best of our knowledge, no study has conducted a comparative evaluation of MCDA techniques using different risk factors to assess malaria transmission risk in the study area. In endemic areas such as the northern zone of Plateau State, comparative analysis of MCDA techniques is essential to influence the selection of MCDA technique for analysis and assessment of various malaria risk factors and consequently improve the quality of decision making in managing the burden of the disease.

This study aims to compare various MCDA techniques in terms of their consistency, leveraging on the most prominent malaria risk factors in the Northern Zone of Plateau State. Thus, the study will guide and enhance the effectiveness of vector management practice in the region. Preference Ranking Organization Method for Enrichment Evaluation II (PROMETHEE II)(Goswami, 2020), Multi-Attribute Utility Theory (MAUT)(Taufik *et al.*, 2021), Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Chakraborty, 2022), and Complex Proportional Assessment (COPRAS) (Lu *et al.*, 2021) were used to evaluate the most prominent malaria risk factors identified in the Northern Zone of plateau State.

Previous research has employed a comparative analysis of various MCDA techniques for practical applications, such as the evaluation of laptops (Wieckowski & Szyjewski, 2022), choosing the optimal technique for identifying areas susceptible to erosion (Patel *et al.*, 2023), sustainable transport(Broniewicz & Ogrodnik, 2021), choosing cameras(Bączkiewicz *et al.*, 2021), real estate and land management practices(Guarini *et al.*, 2018), etc.

The article is structured as follows: Section 2 evaluates the study area, different malaria risk factors, expert consensus on selecting risk factors, assessment of various MCDA techniques, ranking references, and analysis of correlation coefficients. Section 3 examines the assessment of various MCDA techniques, while Section 4 discusses the results of the analyzed data and draws a conclusion.

MATERIALS AND METHODS

Study Area

The Northern Zone of Plateau State, Nigeria consists of six Local Government Areas (L.G.As), namely Bassa, Barkin Ladi, Jos East, Jos North, Jos South, and Riyom. The region is spatially located at latitude 9°20' to 10°20'N and longitude 8°30' to 9°50'E. Bauchi State borders it to the northeast, Kaduna State to the northwest and Mangu and Bokkos L.G.As to the south. Climatic conditions are divided into two distinct seasons: the rainy season, which is typically influenced by the West African monsoon and lasts from May to October, and the harmattan (dry) season, which originates in the Sahara and often lasts from November to April. The annual average rainfall and temperature are 1200 mm and 24 °C, respectively (Binbol *et al.*, 2020). The altitude includes the few regions in Nigeria that are above 1000 m. The most distinctive hydrological feature of the study area is its watershed, which drains rapidly into existing water bodies (static and flowing) during rainfall (Emma Martin & Burgess Neil, 2022).

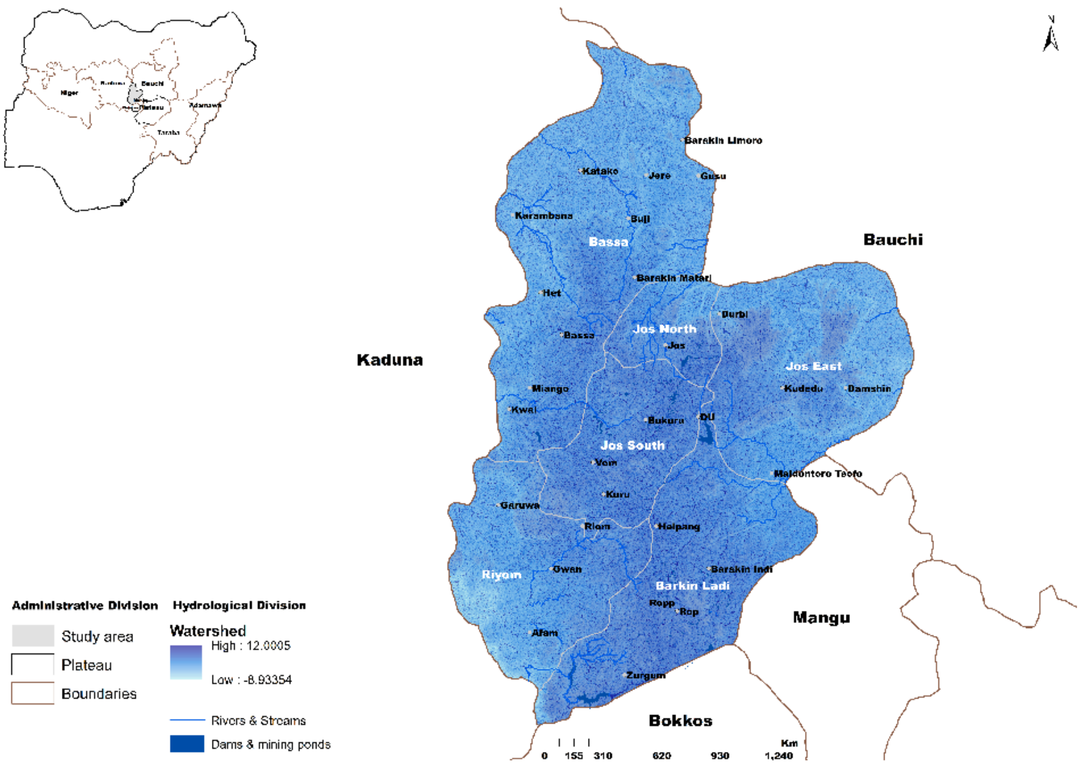

Figure 1: Map of study area showing its hydrological control

Data Collection

Malaria risk factors ranging from environmental (Vegetation Health Index, waterbody distribution, and landuse, landcover classes), climatic (ambient temperature and rainfall), and socioeconomic (population density) were identified as some of the most prevalent risk factors influencing malaria transmission in the study area through experts' consensus and literature review.

Rainfall and temperature data was collected from the Jos meteorological weather station, while the vegetation health indices and landuse/landcover data were extracted from Landsat 8 OLI/TIR image (https://earthexplorer.usgs.gov/). The distribution of water bodies (static and flowing) was extracted from 0.5 metres-resolution Google Earth image using QGIS extensions. Whereas the population density data was collected from the National Population Commission.

Data Analysis

The interpolation tool was used to analyze the ambient temperature and rainfall. Analysis of the vegetation health index was done using the Landsat 8 image. Similarly, the Landsat 8 image was classified into 6 classes with the maximum likelihood supervised classification technique based on the propensity of the different classes to transmit malaria: bare surfaces, rock outcrops, settlements, cultivated areas, forested areas, and water bodies. Lastly, the spatial distribution analysis of population density was also carried out. The risk factor's parameter used in this study was further reclassified into six classes based on the vulnerability of mosquitoes breeding habitats and malaria transmission risk.

Five experts with at least five years of experience in malaria-related fields evaluated and compared the relative importance of the risk factors using a 9-degree pairwise comparison matrix. Furthermore, the weights of these factors were calculated based on the factors' vulnerability to malaria risk.

Furthermore, the identified malaria risk factors were assessed using TOPSIS, MAUT, PROMETHEE II and COPRAS techniques and then ranked based on their propensity for malaria transmission in the study area. Multi-Objective Optimisation by Ratio Analysis plus Full Multiplicative Form (MULTIMOORA), and Multi-Objective Optimisation on the basis of Simple Ratio Analysis (MOOSRA) were used as reference ranking. Using the reference rankings of MULTIMOORA and MOOSRA, a comparative analysis of TOPSIS, PROMETHEE II, MAUT, and COPRAS was conducted to determine the reliability of the consistency results of these techniques in ranking the risk factors.

Lastly, the correlation between TOPSIS, PROMETHEE II, MAUT, and COPRAS techniques was ascertained through weighted Spearman correlation coefficient and weighted sum (WS) rank similarity coefficient analysis.

RESULTS

The analysis of the weight of risk factors based on the propensity of the factors to malaria transmission, performed by pairwise comparison matrix calculations in Table 1, is presented in the following order: Rainfall (C4) in millilitres > LULC(C5), scaled 1-6 > Population (C3) > Vegetation health index (C2) > Water bodies (C1) in kilometres > Temperature (C6) in degrees Celsius.

Table 1: Weights of malaria risk factors and the classification of criteria into cost and profits

	C_1	C_2	C_3	C_4	C_5	C_6
Weight	0.047	0.079	0.125	0.445	0.271	0.033
Type	Cost	Profit	Profit	Profit	Cost	Profit

The calculation of MCDA techniques used in the alternatives ranking analysis and preference ranking of MULTIMOORA and MOOSRA is shown in Table 2. The alternative ranking order showed that PROMOTHEE, MAUT and COPRAS were ranked equally, while TOPSIS ranked the alternatives similarly to the reference ranking. On the other hand, the reference ranking of MULTIMOORA and MOOSRA showed an equivalent placement of the alternatives with TOPSIS. Furthermore, the correlation analysis of MCDA techniques shows that PROMETHEE, MAUT and COPRAS in Figure 1 and Table 3 had a negative correlation and relationship with the reference ranking of MULTIMOORA and MOOSRA in terms of assessing the malaria risk factors used in this study. While TOPSIS showed a positive correlation and relationship with the reference ranking when evaluating the different risk factors.

Table 2: TTOPSIS, PROMETHEE, MAUT, COPRAS, MULTIMOORA and MOOSRA ranking for malaria risk factor selection

Ai	TOPSIS	PROMETHEE	MAUT	COPRAS	MULTIMOORA	MOOSRA
C_1	1	6	6	6	1	1
C_2	2	5	5	5	2	2
C_3	3	4	4	4	3	3
C_4	4	3	3	3	4	4
C_5	5	2	2	2	5	5
C_6	6	1	1	1	6	6

The analysis of the weighted Spearman correlation coefficient and the weighted sum similarity coefficient (WS) presented in Figure 1 shows that PROMETHEE, MAUT and COPRAS were equally correlated with a value of 1.0, indicating that they are equal in terms of evaluation of the alternatives are equal to the various risk factors, while TOPSIS on the other hand showed the negative correlations and relationships in assessing the risk factors of the above MCDA techniques.

However, TOPSIS showed a positive correlation, relationship, and equal ranking in evaluating the alternatives as the reference ranking techniques of MULTIMOORA and MOOSRA, as shown in Table 3.

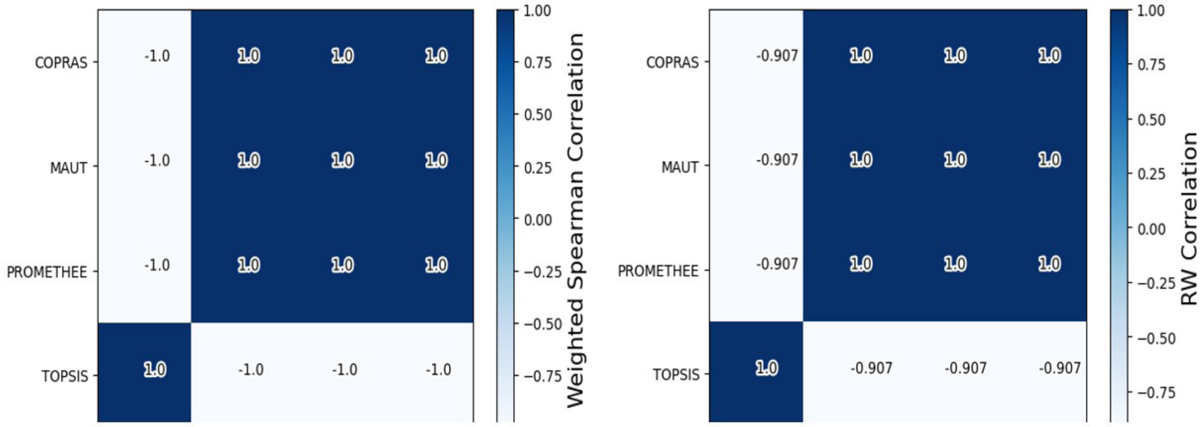

Figure 2: Correlation analysis for TOPSIS, PROMETHEE, MAUT and COPRAS MCDA techniques ranking

Table 3: Correlation analysis of TOPSIS, PROMETHEE, MAUT, and COPRAS with preference ranking of MULTIMOORA and MOOSRA techniques

	TOPSIS	**PROMETHEE**	**MAUT**	**COPRAS**
RW	1	-0.907	-0.907	-0.907
WS	1	-1	-1	-1

DISCUSSION

The criteria weight analysis of malaria risk factors used in this study suggests that rainfall is the key factor contributing to malaria transmission risk, accounting for approximately 44%. Furthermore, because the risk factor ranking analysis used the same weights for all MCDA techniques, only TOPSIS showed similarity to the preference ranking. This means that TOPSIS ensured a high level of consistency in determining the impact of risk factors affecting malaria transmission risk in the study area. Because the various risk factors used in this study were evaluated in such a logical and consistent manner, this decision-making method is helpful in prioritizing the various risk factors and determining the disease hotspot for malaria transmission. In addition, the evaluation of the method based on the ranking of risk factors makes it clear which important intervention measures need to be implemented. Analysis of criteria weights by TOPSIS indicates that priority is given to vector management interventions that address vector distribution around bodies of water, particularly during the rainy season. This is in addition to maintaining good sanitary conditions around settlements and adhering to protective measures against the vectors, such as: E.g., constant use of insecticide-treated nets (ITNs), indoor residual spraying (IRS), etc.

In addition to AHP, which has been demonstrated to be extensively utilized in the field of malaria epidemiology for the assessment of various risk factors impacting the disease's transmission as well as the identification of appropriate vector management strategies. The comparison of TOPSIS, PROMETHEE, MAUT and COPRAS shows that TOPSIS had similarities and correlations with the preference ranking of MULTIMOORA and MOOSRA, suggesting that it is a useful tool for assessing malaria risk and identifying appropriate vector interventions. Also, this indicates that TOPSIS showed consistency in comparison to the other MCDA techniques used in determining the relative importance and ranking of the malaria risk factors, based on the analysis of the malaria risk factors used in this study. The degree of consistency with which the risk factors in the study area were analyzed through this comparative comparison demonstrates that the TOPSIS technique is suitable for its application in malaria epidemiology to determine the suitability of the appropriate vector management intervention measure for application in the Northern Zone of to be determined Plateau State. The negative correlation and relationship shown by PROMETHEE, MAUT and COPRAS with the preference ranking of MULTIMORA and MOOSRA suggests that there are differences in the evaluation of the criterion weights or the ranking of the alternatives of the malaria risk factors. However, the positive correlation and relationship between TOPSIS and the preference ranking of MULTIMOORA and MOOSRA implies that there is concordance in the assessment of the weights and risk factors. This relationship is crucial for selecting appropriate MCDA techniques in malaria risk analysis and consequently improves decision-making processes in managing the malaria burden in the study area.

Although leveraging the intuition of experts in the field of malaria is crucial for decision-makers in combating the scourge of the disease, the evaluation of MCDA techniques with the reference ranking of MULTIMOORA and MOOSRA in this study has some limitations in terms of being subjected to degree of bias or subjectivity since it relies mainly on some assumptions in determining the relative importance and ranking of the criterion weights of the various risk factors. In addition, the numerical values of the different risk factors used to determine the weights and to calculate the rankings established by the different MCDA techniques were considered chronologically, ranging from the smallest to the highest value indicating the maximum potential of the attributes. The lack of randomness attributed to the data set used to determine risk factor weights is also a limitation as it affects the arrangement of the rankings produced using these methods. The lack of randomness attributed to the data set used to determine risk factor weights is also a limitation as it affects the arrangement of the rankings produced using these methods.

CONCLUSIONS

MCDA has proven to be a useful tool in the field of malaria epidemiology, helping to select the most appropriate vector management strategies by assessing various malaria risk factors. Based on the vulnerability of mosquito breeding habitats and the risk of malaria transmission, this study assessed the main malaria risk factors in the northern region of Plateau State, ranging environmental, climatic, and socioeconomic factors. A comparative comparison and analysis of TOPSIS, PROMETHEE II, MAUT, and COPRAS was conducted using the reference rankings of MULTIMOORA and MOOSRA to establish the reliability and consistency of the results obtained from the ranking of risk factors.

The evaluation of the different risk factors within the study area showed that TOPSIS ranked the alternatives similarly to the reference ranking, whereas PROMOTHEE, MAUT, and COPRAS were ranked equally in the evaluation of the alternative ranking. The TOPSIS technique assessed the various risk factors used in this study in such a logical and consistent manner that this decision-making method is helpful in prioritizing the various risk factors and determining the disease hotspot for malaria transmission.

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