Multi-Criteria Decision Analysis for Malaria Control Strategies Using Analytic Hierarchy Process: A case of Yola North Local Government Area, Adamawa State Nigeria

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Abstract **- There has been significant interest over the last few years in the application of multi-criteria decision analysis (MCDA) in the field of healthcare. This study determined weights that will prioritize the alternative strategies for malaria control. These strategies (Alternatives) and criteria (factors) for assessing the control strategies have been identified and then used to develop a 9-point scale, which helped to elicit responses of the three medical doctors in grading the criteria and alternatives. Analytic Hierarchy Process (AHP) technique have been applied to compare responses for the individual Medical Doctors. The individual matrices were aggregated using Arithmetic mean to produce a single matrix to represent the group. Hence group ranking of scores was employed in determining group weighting of the alternatives and the criteria. The result of the study will aid Health planning officers and other concern decision-makers. Computations carried out using the Business Performance Measurement Singapore (BPMSG) online AHP software to rank the alternatives. The study revealed that a treated mosquito net has the highest priority. If the priority orders are to adhere, our result should be given much attention to the control of malaria. It has recommended that similar studies be carried out by incorporating other health personnel in addition to Medical Doctors in order to obtain enriched opinions, thus extending the work to the heterogeneous population.**

Keywords: **Analytic Hierarchy Process, Alternative Strategy, Malaria Control, Multi-Criteria Decision Analysis, Priority.**

I. INTRODUCTION

According to Alexander (2012), the complex decision-making problem is inherent when many factors, especially when the element to be weight are many against challenging priorities. According to Simon et al. (2019), to accomplish a sound and viable decision, creativity, wisdom and intelligence are required for humans to satisfy the innate desires or at worst to survive a leaving. The evaluation of any decision process requires one to consider the benefits or otherwise resulting from making the acceptable decision, the cost and risks associated if the wrong decision has been made. “Multi-criteria decision analysis” (MCDA) is used in the field of decision theory to support decision-maker(s) who faced with evaluating available alternatives, with multiple and most often conflictive goals. (Thokala, 2011). MCDA used many terminologies, such as “multi-criteria decision making” (MCDM) and “multi-attribute

decision analysis" (MADA) among others. MCDA initially applied in the field of decision science popularly known as operations research with varying techniques and algorithms. (Adunlin, Diaby, Montero and Xiao, 2014)

According to Adunlin *et al.* (2014), MCDA has classified broadly into three in the field of operations research. These are "outranking models; value measurement models; and goal, aspiration or reference level models". Choosing the best MCDA method depends on the nature, source, and information about the environment give the decision-makers' abilities to use a particular model. Some useful techniques are goal programming, "multi-attribute utility theory" (MAUT) and AHP. Over many years, there has been considerable interest in MCDA application in the field of healthcare. (Diaby, Campbell and Goeree, 2013).

In the study conducted by Tu, Fang, Huang and Tan, (2014), risk in an emerging disease which is infectious was assessed using AHP techniques in Shaoxing City of Southern China. This implied that AHP is a social science technique used in an attempt to analyse a complex system based on subjective judgments, such as experience.

AHP was used successfully for evaluating bovine spongiform encephalopathy surveillance, raw milk-associated foodborne infections, the risk of airborne infectious diseases in aircraft cabins, and an index system of the risk of infectious diseases at ports. AHP conducted an infectious disease risk assessment during the Shanghai Expo, and a prime infectious disease was identified, thus providing scientific materials for health management policy establishment. The central potency of AHP is that it is sound methodologically and user-friendly. It has been applied by many researchers, including Alimi et al. (2016), Maino et al. (2012), Schmidt et al. (2015), according to them, over two hundred studies discovered to have been carried out in healthcare using AHP. Implementation for alternative strategies for malaria control can be planned, managed and control in a multi-criteria dimension. Strategies to control malaria include but not limited to vector control that reduces the mosquito disease vector transmission from the humans to the insects and then back to the humans, which can be minimized by the use of insecticide-treated nets or indoor residual spraying; "chemoprevention which prevents the blood-stage infections in humans; case management which includes diagnosis and treatment of infections". (world malaria report, 2015); by DDT spray (Carrington, 2001); preventive treatment intermittently; other personal measures of prevention such as wearing long pants, long-sleeved shirts, and a hat, the use of repellents on exposed skin and clothes, and staying indoors behind screened entries, among others.

The suitability of the technique to malaria control is evident from the MCDA applications in

healthcare systems. According to Diaby *et al.* (2014), specific problems can be evaluated quantitatively; while qualitative aspect is complex to extend that it is difficult to evaluate numerically and that some healthcare providers, when confronted with such problems often rely solely on clinical practice ethics, results from clinical trials or approaches that heuristic to be able to simplify the complexity of the lingering problem. Despite the years put with intervention programmes in controlling and preventing malaria, it seems to have followed the slow lane. Evidence-based-decisions using "surveillance, appropriate responses and building community awareness"; focused investigations for developing medicines, vaccines and insecticides, and enhancing epidemiological and entomological operations research findings; strengthening existing health services by well-coordinated actions, policies and providing technical support and harmonised ideas to generate a global solution through partnership.

II. METHODOLOGY

A questionnaire has been designed with the help of three Experts (medical doctors in primary healthcare units of the state specialist hospital Yola), it was administered to obtain the relative importance for each criterion and alternatives over others. World Health Organization (WHO) reports and journals on malaria control are used. Interviews conducted to identify the control strategies practised in the study area with the view of identifying the primary alternatives and criteria. We decomposed the problem into three segments viz: objective, alternatives and criteria and adopted the AHP model developed by Saaty (1980), and construct the analytical hierarchy as shown in Figure 1. The goal is to control malaria in Yola North and denoted by **G**, while alternatives are Insecticide-Treated Net (ITN) or Long-Lasting Insecticidal-Net (LLIN) (**A1**), Indoor Residual Spraying (IRS) (**A2**), Larval Source Management (LSM) (**A3**), Intermittent Preventive Treatment of pregnant women, Infants (IPTp/IPTi) and children under five years (**A4**), testing of all suspected malaria cases, before treatment (**A5**), and providing qualitative treatment to all patients (**A6**). The criteria to malaria control in the study area are Accessibility (**C1**); Affordability (**C2**); Availability (**C3**); Acceptability (**C4**); Convenient (**C5**); and Practicality (**C6**). We constructed Matrices from the questionnaire responses, and weight obtained. Table 1 is an importance intensity provided as a guide to the experts.

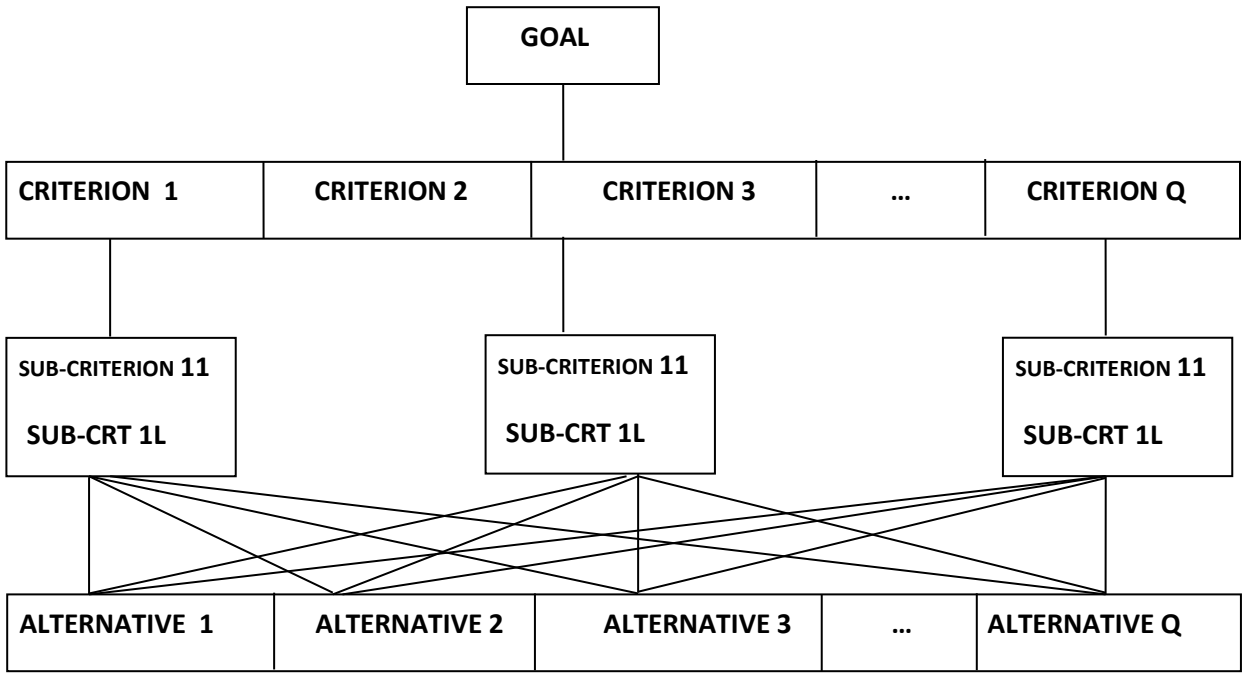

FIGURE 1: Analytic Hierarchy Structure. Source: Bhurshan et al., 2004

Table 1: The Fundamental Scale of Absolute Numbers

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, Very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

Source: Saaty (2012)

The table of pairwise comparison for each criterion was constructed, and each alternative compared against the other given a particular criterion at a time. A relative weight for each criterion obtained

for the goal. A "Business Performance Management Singapore" (BPMSG AHP ONLINE) package and an online matrix calculator (**matrix.reshish**), were employed to the analysis of all the matrices (Goepel, 2018). According to Saaty (1990), the Eigenvector solution is the best approach for ranking of priorities from a pairwise matrix. Coyle (2004) stated that the AHP is sometimes sadly misused and the analysis stops with the calculation of the eigenvector from the pairwise comparison matrix of relative importance sometimes without computing the confidence ratio (CR). In this study, the software computed both the eigenvector solution and the CR; hence the matrices were adequately validated. Weights were obtained and ranked for each Expert comparison matrix; from the final ranking of each Expert, the aggregate ranking of the individual final weights was computed, and then the criteria and the control strategies ranked, all the consistency index were found to be less than 10%.

III. RESULTS AND DISCUSSIONS

There was consensus on alternative A1, A4 and A5 by all the Experts with the aggregated weights ranks, as alternatives A1, A4 and A5 were ranked as number one, two and six respectively. The first Expert ranking and the aggregated weights ranking are the same. The aggregated weights ranks and that of the second and third Experts vary in A2 and A3. Expert-2 ranked A2 and A3 as number four and number five respectively, Expert-3 ranked A2 and A3 as number four and three respectively while the aggregated weights ranked A2 and A3 as number five and four respectively.

*3.1 **Decision** Matrices, Resulting Priorities and Rankings for Expert-1*

The following matrices (Figure 1-7) were obtained based on expert-1 verbal judgements of the criteria and alternatives. Table 2-8 shows the resulting analysis for each matrix (Figure).

Figure 1: Criteria given Goal G

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	1	2	0.5	0.17	4	0.33
C_2	0.5	1	0.5	0.25	3	0.2
C_3	2	2	1	0.25	5	0.25
C_4	6	4	4	1	5	2
C_5	0.25	0.33	0.2	0.2	1	0.33
C_6	3	5	4	0.5	3	1

Figure 2: Alternatives given Criterion C1

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	4	1	5	1	3
A_2	0.25	1	0.5	3	1	1
A_3	1	2	1	3	1	4
A_4	0.2	0.33	0.33	1	0.33	0.5
A_5	1	1	1	3	1	2
A_6	0.33	1	0.25	2	0.5	1

Figure 3: Alternatives given Criterion C2

Figure 4: Alternatives given Criterion C3

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	7	3	0.5	7	3
A_2	0.14	1	0.5	0.33	3	3
A_3	0.33	2	1	0.33	3	2
A_4	2	3	3	1	4	3
A_5	0.14	0.33	0.33	0.25	1	0.5
A_6	0.33	0.33	0.5	0.33	2	1

Figure 5: Alternatives given Criterion C4

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	8	3	2	4	3
A_2	0.12	1	0.5	0.33	3	0.33
A_3	0.33	2	1	0.33	4	3
A_4	0.5	3	3	1	3	2
A_5	0.25	0.33	0.25	0.33	1	1
A_6	0.33	3	0.33	0.5	1	1

Figure 6: Alternatives given Criterion C5

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	3	3	3	6	3
A_2	0.33	1	0.5	0.33	4	0.5
A_3	0.33	2	1	0.5	3	0.33
A_4	0.33	3	2	1	3	3
A_5	0.17	0.25	0.33	0.33	1	0.33
A_6	0.33	2	3	0.33	3	1

Figure 7: Alternatives given Criterion C6

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	5	3	4	6	0.5
A_2	0.2	1	0.33	0.33	0.5	0.33
A_3	0.33	3	1	3	3	1
A_4	0.25	3	0.33	1	2	0.5
A_5	0.17	2	0.33	0.5	1	0.5
A_6	2	3	1	2	2	1

Table 2: Priorities and Ranking for Figure 1

Criterion	Priority	Rank
C1	0.097	4
C2	0.071	5
C3	0.13	3
C4	0.388	1
C5	0.044	6
C6	0.27	2

Table 3: Priorities and Ranking for Figure 2

Alternatives	Priority	Rank
A1	0.287	1
A2	0.125	4
A3	0.244	2
A4	0.056	6
A5	0.194	3
A6	0.094	5

Table 4: Priorities and Ranking for Figure 3

Alternative	Priority	Rank
A1	0.329	1
A2	0.104	4
A3	0.129	3
A4	0.32	2
A5	0.044	6
A6	0.074	5

Table 5: Priorities and Rankings for Figure 4

Alternative	Priority	Rank
A1	0.373	1
A2	0.075	5
A3	0.161	3
A4	0.229	2
A5	0.06	6
A6	0.103	4

Table 6: Priorities and Rankings for Figure 5

Alternative	Priority	Rank
A1	0.37	1
A2	0.094	5
A3	0.111	4
A4	0.224	2
A5	0.045	6
A6	0.156	3

Table 7: Priorities and Ranking for Figure 6

Alternative	Priority	Rank
A1	0.331	1
A2	0.052	6
A3	0.191	3
A4	0.104	4
A5	0.073	5
A6	0.249	2

Table 8: Priorities and Ranking for Figure 7

Alternative	Priority	Rank
A1	0.288	2
A2	0.144	3

A3	0.053	6
A4	0.324	1
A5	0.088	5
A6	0.103	4

3.2 Decision Matrices, Resulting Priorities and Rankings for Expert-2

The following matrices (Figure 8-14) were obtained based on Expert-2 verbal judgements of the criteria and alternatives. Table 9-15 shows the resulting analysis for each matrice (Figure).

Figure 8: Criteria given the Goal

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	0.14	0.14	0.12	1	0.11
A_2	7	1	2	0.5	8	0.33
A_3	7	0.5	1	0.12	8	0.14
A_4	8	2	8	1	9	1
A_5	1	0.12	0.12	0.11	1	0.12
A_6	9	3	7	1	8	1

Figure 9: Alternative given Criterion C1

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	2	2	3	5	3
A_2	0.5	1	2	0.5	3	3
A_3	0.5	0.5	1	0.33	5	2
A_4	0.33	2	3	1	5	5
A_5	0.2	0.33	0.2	0.2	1	0.5
A_6	0.33	0.33	0.5	0.2	2	1

Figure 10: Alternative given Criterion C2

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	5	5	2	6	3
A_2	0.2	1	0.33	0.25	1	1
A_3	0.2	3	1	2	3	3
A_4	0.5	4	0.5	1	3	3
A_5	0.17	1	0.33	0.33	1	0.5
A_6	0.33	1	0.33	0.33	2	1

Figure 11: Alternative given Criterion C3

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	5	2	2	4	3
A_2	0.2	1	2	0.25	6	1
A_3	0.5	0.5	1	0.2	3	1
A_4	0.5	4	5	1	5	2
A_5	0.25	0.17	0.33	0.2	1	0.5
A_6	0.33	1	1	0.5	2	1

Figure 12: Alternative given Criterion C4

Figure 13: Alternative given Criterion C5

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	2	3	2	4	0.5
A_2	0.5	1	2	0.5	3	0.25
A_3	0.33	0.5	1	0.25	2	0.17
A_4	0.5	2	4	1	6	0.33
A_5	0.25	0.33	0.5	0.17	1	0.14
A_6	2	4	6	3	7	1

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	5	4	2	6	3
A_2	0.2	1	1	1	4	1
A_3	0.25	1	1	0.33	4	1
A_4	0.5	1	3	1	2	2
A_5	0.17	0.25	0.25	0.5	1	0.5
A_6	0.33	1	1	0.5	2	1

Figure 14: Alternative given Criterion C6

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	3	4	2	5	4
A_2	0.33	1	1	0.33	4	1
A_3	0.25	1	1	0.25	3	1
A_4	0.5	3	4	1	2	2
A_5	0.2	0.25	0.33	0.5	1	0.5
A_6	0.25	1	1	0.5	2	1

Table 9: Priorities and Ranking for Figure 8

Criterion	Priority	Rank
C1	0.026	5
C2	0.157	3
C3	0.10	4
C4	0.342	2
C5	0.025	6
C6	0.351	1

Table 10: Priorities and Ranking for Figure 9

Alternatives	Priority	Rank
A1	0.334	1
A2	0.166	3
A3	0.129	4
A4	0.259	2
A5	0.044	6
A6	0.069	5

Table 11:Priorities and Ranking for Figure 10

Alternative	Priority	Rank
A1	0.42	1

A2	0.062	5
A3	0.197	2
A4	0.182	3
A5	0.056	6
A6	0.083	4

Table 12: Priorities and Rankings for Figure 11

Alternative	Priority	Rank
A1	0.342	1
A2	0.127	3
A3	0.096	5
A4	0.287	2
A5	0.045	6
A6	0.103	4

Table 13: Priorities and Rankings for Figure 12

Alternative	Priority	Rank
A1	0.216	2
A2	0.105	4
A3	0.061	5
A4	0.181	3
A5	0.040	6
A6	0.396	1

Table 14: Priorities and Ranking for Figure 13

Alternative	Priority	Rank
A1	0.403	1
A2	0.132	3
A3	0.115	4
A4	0.189	2
A5	0.052	6
A6	0.109	5

Table 15: Priorities and Ranking for Figure 14

Alternative	Priority	Rank
A1	0.37	1
A2	0.121	3
A3	0.104	5
A4	0.242	2
A5	0.059	6
A6	0.104	4

3.3 Decision Matrices, Resulting Priorities and Rankings for Expert-3

The following matrices (Figure 15-21) were obtained based on Expert-3 verbal judgements of the criteria and alternatives. Table 16-22 shows the resulting analysis for each matrice (Figure).

Figure 15: Criteria given Goal

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	0.14	0.14	0.12	1	0.11
A_2	7	1	2	0.33	8	0,33
A_3	7	0.5	1	0.12	4	0.14
A_4	8	3	8	1	9	1
A_5	1	0.12	0.25	0.11	1	0.12
A_6	9	3	7	1	8	1

Figure 16: Alternative given Criterion C1

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	9	9	2	9	9
A_2	0.11	1	3	0.14	1	1
A_3	0.11	0.33	1	0.14	0.33	1
A_4	0.5	7	7	1	7	7
A_5	0.11	1	3	0.14	1	2
A_6	0.11	1	1	0.14	0.5	1

Figure 17: Alternative given Criterion C2

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	9	3	9	9	9
A_2	0.11	1	0.11	1	1	3
A_3	0.33	9	1	7	5	7
A_4	0.11	1	0.14	1	2	2
A_5	0.11	1	0.2	0.5	1	1
A_6	0.11	0.33	0.14	0.5	1	1

Figure 18: Alternative given Criterion C3

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	2	9	3	7	7
A_2	0.5	1	7	2	7	7
A_3	0.11	0.14	1	0.25	0.5	0.33
A_4	0.33	0.5	4	1	7	3
A_5	0.14	0.14	2	0.14	1	0.33
A_6	0.14	0.14	3	0.33	3	1

Figure 19: Alternative given Criterion C4

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	9	9	3	9	4
A_2	0.11	1	2	0.12	0.5	0.14
A_3	0.11	0.5	1	0.14	0.33	0.14
A_4	0.33	8	7	1	7	3
A_5	0.11	2	3	0.14	1	0.5
A_6	0.25	7	7	0.33	2	1

Figure 20: Alternative given Criterion C5

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	9	9	3	9	4
A_2	0.11	1	1	0.12	0.5	0.14
A_3	0.11	1	1	0.14	0.5	0.14
A_4	0.33	8	7	1	7	3
A_5	0.11	2	2	0.14	1	0.5
A_6	0.25	7	7	0.33	2	1

Figure 21: Alternative given Criterion C6

	A_1	A_2	A_3	A_4	A_5	A_6
A_1	1	4	3	9	9	9
A_2	0.25	1	1	7	9	9
A_3	0.33	1	1	4	7	9
A_4	0.11	0.14	0.25	1	1	1
A_5	0.11	0.11	0.14	1	1	1
A_6	0.11	0.11	0.11	1	1	1

Table 16: Priorities and Ranking for Figure 15

Criterion	Priority	Rank
C1	0.027	6
C2	0.151	3
C3	0.086	4
C4	0.361	1
C5	0.028	5
C6	0.347	2

Table 17: Priorities and Ranking for Figure 16

Alternatives	Priority	Rank
A1	0.475	1
A2	0.060	4
A3	0.035	6
A4	0.320	2
A5	0.067	3
A6	0.043	5

Table 18: Priorities and Ranking for Figure17

Alternative	Priority	Rank
A1	0.504	1
A2	0.057	4
A3	0.298	2
A4	0.060	3
A5	0.045	5
A6	0.036	6

Table 19: Priorities and Rankings for Figure 18

Alternative	Priority	Rank
A1	0.402	1
A2	0.288	2
A3	0.032	6

A4	0.168	3
A5	0.040	5
A6	0.070	4

Table 20: Priorities and Rankings for Figure 19

Alternative	Priority	Rank
A1	0.463	1
A2	0.035	5
A3	0.028	6
A4	0.273	2
A5	0.059	4
A6	0.142	3

Table 21: Priorities and Ranking for Figure 20

Alternative	Priority	Rank
A1	0.465	1
A2	0.031	6
A3	0.032	5
A4	0.273	2
A5	0.055	4
A6	0.144	3

Table 22: Priorities and Ranking for Figure 21

Alternative	Priority	Rank
A1	0.467	1
A2	0.226	2
A3	0.203	3
A4	0.038	4
A5	0.034	5
A6	0.033	6

On the whole, there is no much difference between the three Experts ranking of the alternatives and their aggregate weights ranking. The second method of aggregating the Expert's opinions was also handled. Use of treated bed net is ranked first both in the individual final rankings of the alternatives and in the aggregate methods, intermittent preventive treatment of pregnant women, infants and children were ranked second by all the Experts. The overall ranking of the alternatives shows some reasonable level of consistency in the Experts' opinions in that the variation between opinions are not much. The study revealed that if the priority orders are followed as identified, malaria transmission would be reduced significantly in Yola North. The study

shows that treated mosquito net play a vital role in preventing and controlling the spread of malaria in Yola North, hence be given high priority.

IV. CONCLUSION

There is a need for proper knowledge of the strategy with a high priority by the people concern in order to pay more attention to it. It has been discovered that the treated mosquito net has been converted to a fishing net, used for fencing gardens, malaria drugs are sold in the markets like any other commodity. Therefore, alternative strategies are required to prioritise and identify the ones with the highest priority so that more efforts and resources will be channelled in that direction. In this research, a systematic study to prioritise alternative strategies for malaria control has been carried out; a mathematical tool for easy planning was provided to guide policy or decision-makers in implementing intervention programmes. Also, the study will bring to limelight the need to channel resources in the right direction and help to acquaint the government with the knowledge of using a mathematical model in some of its multi-criteria decision makings. Finally, it serves as a push for proper implementation of the alternative strategies in Yola North local government area.

V. RECOMMENDATION

We can make the following recommendations based on the results of this study and the model applied.

i. More enlightenment should be made on the use of treated bed net since the result ranked it as the first control strategy.

ii. The aggregate ranking of the alternatives and the individual ranking by the three Experts did not show much difference. Hence we recommended that the aggregate method be adopted as a measure to reach consensus among decision-makers.

iii. Further studies can incorporate other health personnel other than Medical Doctors, thus extending the work to the heterogeneous population.

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