

## Research Article

# A Decision-Making Approach for Ranking Tertiary Institutions' Service Quality Using Fuzzy MCDM and Extended HiEdQUAL Model

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Received 3 May 2021; Revised 13 October 2021; Accepted 27 October 2021; Published 29 November 2021

Academic Editor: Sebastian Ventura

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The attainment of excellence in institutions is maintained through the institutions' adherence to its core values and efficient service delivery. These factors are very important in facilitating global development of a country and determining the world ranking of an institution. To this effect, this study presents an effective approach for evaluating and ranking quality of services in a higher institution, taking four higher institutions in Nigeria as case studies. Service quality consists of different attributes and many of them are intangible and difficult to measure, which means that using the previously known measurement approach will be insufficient. Therefore, a fuzzy method was proposed to resolve the ambiguity of the concepts and intra-uncertainty, which are associated with human judgments in decision-making. This study adopted a contextualized service quality model for educational domain called HiEdQUAL with some extended criteria in order to evaluate the perception of service quality by respondents from the selected higher institutions: two private universities and two public universities from the south-west region of Nigeria. Four Multi-Criteria Decision-Making (MCDM) methods: TOPSIS, Yager's min-max, Compensatory AND, and Ordered Weighted Averaging are applied to comparatively evaluate the quality of services in the four higher institutions. The MCDM methods are engaged independently to validate the reliability of the ranking results. The importance weight of each performance criterion is found with Fuzzy Analytical Hierarchy Process (FAHP) algorithm. This study has been able to practically establish Ext-HiEdQUAL as a new service quality model for higher education with six concepts and 33 criteria. The output of the Fuzzy MCDM ranking recommends institution B as the best institution to students based on the Ext-HiEdQUAL measures. Also, findings from the sensitivity analysis showed that Yager's min-max outperform the other investigated methods in this study by being consistent and exceptionally tolerant in most instances when there is significant deviation in criteria weights.

## 1. Introduction

Tertiary institutions are pivotal in driving the economic growth and sustainability of a nation. Generally, most governments in developing countries disburse funds to public higher institutions so that tuition fees for students are subsidized, unlike what happens in private institutions where the cost of tuition is higher. This mode of government's financial support is geared towards improving the quality of service being rendered by these institutions to their primary customers (students), which in turn leads to an

increase in student subscription, creation of more values, and higher excellence [1]. It has been observed that students, being the primary customers of every higher institution across all degree levels, prefer to choose a university that has evidence of quality service delivery and a global reputation [2]. In Ref. [3], service quality was defined as the capacity of an organization to equal or surpass the customers' expectations. It is usually quite tasking when the students have to do an evaluation in order to select the best institutions from a set of alternatives. In such cases, ranking the alternative institutions based on their merits in order to make a good

decision becomes imperative. Hence, the Multi-Criteria Decision-Making (MCDM) methods become useful in evaluating and ranking institutions.

MCDM refers to making decisions in the presence of multiple, incommensurable, and conflicting criteria [4, 5]. MCDM can be broadly classified into 2 categories which are the Multi-Attribute Decision-Making (MADM) and Multi-Objective Decision-Making (MODM) [6–10]. MADM belongs to a class of methods that solve decision-making problems that are discrete in nature, i.e., have finite number of alternatives to be evaluated, while the MODM approach, on the other hand, encompasses methods that deal with decision-making problems that are nondeterministic in nature, whereby the decision space is continuous and alternatives are infinite [11–13]. Hence, evaluation of quality of service (QoS) in higher institutions is considered a MADM problem due to its finite number of alternatives. In Ref. [14], a hybrid MCDM method for performance evaluation of private universities in Taiwan was presented using AHP to weigh the performance evaluation indices and the VIKOR method in ranking the private universities. The work was structured to be geographically context-specific to universities in Taiwan. Ref. [15] proposed a fuzzy AHP for ranking the performances of five UK universities with respect to 4 criteria. In Ref. [16], a study was presented that utilized the AHP and TOPSIS in the evaluation of performance of schools. Parents were used as the determinants of the performance of each criterion as the ranking was not based on higher institutions but was on high schools. The work in Ref. [17] developed a web-based support system using the MCDM method—ELECTREIII—in the personalized ranking of British Universities. In Ref. [18], VIKOR was employed as the MCDM method in the ranking of universities in Turkey based on academic performance only. The authors in Ref. [19] presented the use of TOPSIS with Fuzzy type-2 for managing the choice of a university. However, these studies have not considered the comparative evaluation of different methods to ascertain the reliability of the ranked results, thereby, resulting in bias as a result of the selection of a single method for ranking.

Over the years, researchers have proposed a number of state-of-the-art service quality models as evaluation index for assessing performance in Higher Education [3, 20–22]. SERVQUAL model proposed by Ref. [3] with five-dimensional constructs consisting of tangible, reliability, responsiveness, assurance, and empathy has been widely utilized in the industry and educational sectors. This is based on the customers' expectations minus the customers' perceptions. According to Ref. [22], SERVQUAL was reported to answer strongly to the marketing sector but to a lesser extent to the higher education learning sector. The connotation from research is that students who are the primary customers for higher education do not have a well-constructed body of knowledge (imprecision) about expectations of a university [23]. In Ref. [20], another variant of the SERVQUAL model, called the SERVPERF, was proposed. SERVPERF was found to be more psychometrically sound compared to the SERVQUAL. However, its diagnostic power is questionable because it does not provide in-depth insight to the manager

about the shortfalls in the quality of service rendered [24]. In response to this, other researchers have proposed contextualized service quality models for education using service characteristic and features in higher education [21, 25–28]. HedPERF (Higher Education PERFORMANCE-only) was proposed with six dimensional constructs that consist of nonacademic aspects, academic aspects, reputation, access, program issues, and understanding [21]. However, it uses a SERVPERF paradigm, which is adjudged to have less diagnostic power [24]. Furthermore, SQM-HEI was developed as an instrument for measuring service quality in a tertiary institution [22]. SQM-HEI established three dimensions, which are best faculty, excellent physical resources, and wide range of disciplines and placement. However, this is not robust because it scarcely considers nonacademic aspects of services rendered in higher institutions. In Ref. [27], HiEdQUAL was proposed with five dimensions consisting of teaching and course content, administrative services, academic facilities, campus infrastructure, and support services within the higher education sector. In Ref. [28], six dimensional constructs were used, which consist of lecturers (teaching and learning), curriculum, administration, facilities, library, and Islamic environment. However, the HiEdQUAL was limited in its practicability since some of the criteria were not contextualized to universities in sub-Saharan Africa. Therefore, it did not meet the aspirations of the students in sub-Saharan universities.

In summary, evidence from the literature reveals that first, service quality dimensions vary depending on the research objectives, author's perspective, institutional environment, and target customers [28]. Secondly, so far, the service quality models that have been proposed for the educational context did not consider the hierarchical order of importance of criteria dimensions used for evaluation of service quality in tertiary institutions, which limits their practical relevance [16–19]. Thirdly, the models were utilized to measure service quality by selecting a single ranking MCDM method, without considering how to handle the issue of human subjectivity and the reliability of ranked results when evaluating competing alternatives, which is also a limiting factor that can result in bias [29].

Therefore, these shortcomings are addressed when evaluating service quality in higher institutions in this study. Hence, a fuzzy MCDM approach is proposed to evaluate and rank quality of service in four Nigerian higher institutions based on Ext-HiEdQUAL. The following commonly used four MCDM methods, *TOPSIS*, *Yager's min-max*, *Compensatory AND*, and *Ordered Weighted Averaging*, were proposed to comparatively evaluate and rank service quality in four Nigerian higher institutions. Fuzzy MCDM will (1) enable handling of subjectivity in the evaluation of competing alternatives; (2) cater to the hierarchical order of importance of criteria dimensions that makeup the service quality model used for evaluation; and (3) demonstrate the reliability of the ranked results by comparing results from four MCDM methods and show the stability of each of the MCDM methods by employing sensitivity analysis.

The extended HiEdQUAL (Ext-HiEdQUAL) model incorporates the *Internationalisation* dimension in order to

derive a more robust model to evaluate service quality in higher education. The extended model consists of six dimensions that are contextualized for education, namely, *teaching and course content*, *administrative services*, *academic facilities*, *campus infrastructure*, *support services*, and *Internationalisation*. The extension was necessary because: (1) the ranking criteria attributes for the global ranking of higher intuitions by Times Higher Education (<https://www.timeshighereducation.com/world-university-rankings/world-university-rankings-2020-methodology>) includes two service delivery factors, which are *Teaching Content* and *internationalisation*; (2) according to Refs. [1, 30], lack of adequate internationalisation is a major drawback of institutions in many developing countries, particularly Nigerian institutions, which constitute the study context for this research.

The main contributions are:

- (1) Extending an existing HiEdQUAL service quality model with Internalization dimension to meet the need for globalization in Higher institution ranking.
- (2) A comparative evaluation of four fuzzy MCDM methods to validate reliability of the ranked results using a contextualized extended HiEdQUAL model for measuring quality of service in higher institutions. These MCDM methods combine fuzzy set theory to handle subjectivity from decision-makers in the evaluation of alternatives.
- (3) A sensitivity analysis of the proposed four fuzzy MCDM methods to ascertain its impact on the ranking of the alternatives and the stability of each MCDM method.
- (4) It also outlines the importance of each service quality factor in the context of the four Nigerian universities by revealing each institution's weak and strong points quantitatively, and ranking the institutions accordingly, based on multiple service quality performance criteria.

The remaining part of this paper is as follows. In Section 2, an extensive literature review was carried out. In Section 3, the methodology was explicitly described while in Section 4, we present the result and discussion. Section 5 presents a report of sensitivity analysis that compares results of the four MCDM methods with established finding from the literature. The paper is concluded in Section 6 with a summary and overview of future work.

## 2. Literature Review

In Ref. [3], service quality was defined as the capacity of an organization to equal or surpass the customers' expectations. It is usually quite tasking when the students as customers have to do an evaluation in order to select the best institutions from a set of alternatives (institutions). In such cases, it is important to sort, describe, or do a ranking of the alternatives in order to make a good decision or recommendation. In this situation, the Multi-Criteria Decision-Making (MCDM) methods become useful. MADM-based

MCDM methods are sectioned into two categories, which follow human aggregation processes in evaluation of an alternative. This is either by compensatory means, which considers all criteria performance values in choosing an optimal alternative which is termed "*Multi-Attribute Utility Theory*" (MAUT), or noncompensatory means which is termed "*Outranking Approach*." The *Outranking Approach* allows compromise between criteria values and can have an element of unforeseen bias in its recommendations [31]. Hence, the MAUT methods of the MCDM classification are integrated in this work because it aggregates and takes into consideration all the criteria performance values in estimating an overall performance value for each alternative.

MCDM techniques have the capacity for alternatives to be measured explicitly through objective and subjective judgments of a decision-maker. Each method is only unique in how it combines its data and can therefore give different ranking results [32, 33]. MCDM has the capability to accommodate both quantitative and qualitative measurement of criteria. This has made it suitable for evaluating service quality in different sectors, including educational sector, especially when the performance evaluation problem is qualitative in nature. In evaluating alternatives using numerical analysis, the MCDM method follows three important steps: (i) determine the criteria and alternatives; (ii) determine the weights for each criterion to show order of importance and the scores of each criterion with respect to the alternative; and (iii) process the numerical values to aid in ranking of the alternatives [32].

However, in the real world, opinions differ and consist of uncertainties when measurement is made under human consideration. This is not any different in the evaluation of service quality. Therefore, in order to handle the subjectivity and uncertainty in the opinions of decision-makers, Fuzzy Set theory becomes essential for the MCDM process for modeling the decision-makers' opinions [34]. The incorporation of Fuzzy Set theory allows the use of linguistic variables like *Fair*, *Strong*, and *Very Strong* and the like, and membership values in measuring the satisfaction level anticipated for each criterion with respect to the alternative concerned, Hence, in considering the subjectivity and uncertainty in the opinions of decision-makers for evaluating the service quality of higher institutions in Nigeria, a Fuzzy Multi-Criteria Decision-Making (Fuzzy MCDM) approach is appropriate.

Researchers have contributed immensely in the area of using different MCDM methods for the evaluation of alternatives [35–44]. Fuzzy MCDM models have been reported as widely used approaches in decision-making processes [45]. In Ref. [14], a hybrid MCDM method for performance evaluation of private universities in Taiwan was presented using AHP to weigh the performance evaluation indices and the VIKOR method in ranking the private universities. However, the work was structured to be geographically context-specific to universities in Taiwan. In Ref. [16], a study was presented that utilized the AHP and TOPSIS in the evaluation of performance of schools. Parents were used as the determinants of the performance of each criterion as the ranking was not based on higher institutions but was on high schools. The

work in Ref. [17] developed a web-based support system using the MCDM method— ELECTREIII—in the personalized ranking of British Universities. In Ref. [18], VIKOR was employed as the MCDM method in the ranking of universities in Turkey based on academic performance only. The authors in Ref. [19] presented the use of TOPSIS with Fuzzy type-2 for managing the choice of a university. The service quality was based on SERVQUAL model, which is too general to handle the variations in the educational sector while ranking Higher Institutions [32, 33]. Ref. [15] proposed a fuzzy AHP for ranking the performances of 5 UK universities with respect to 4 criteria. In Ref. [46], an AHP method was employed to determine the weight of each criterion and the PROMETHEE method was used in ranking the institutions using a web crawled data.

To the best of our knowledge, different MCDM methods have not been considered comparatively to show different rankings of alternatives to the decision-makers. Hence, this work reduces bias by using results from four fuzzy MCDM methods to ascertain the reliability of ranked alternatives in measuring service quality in higher institutions. Since MCDM methods combine their input data differently, they can therefore give an overall distinctive performance value for each alternative which can result in different rankings. This can be used as a benchmark for determining the reliability of the evaluation and ranking result [32]. In view of this, the ranking order and evaluation in this study was based on four Multi-Attribute Utility Theory (MAUT) methods: TOPSIS, Yager's Min-Max, Compensatory, and Ordered Weighted Averaging (OWA). FAHP algorithm using the iterative power method was proposed to obtain criteria weights that were defined in the extended multi-dimensional HiEdQUAL model. The fuzzy AHP alongside the four fuzzy MCDM methods were implemented with Java programming Language. This study was able to present the general importance of each service quality factor, reveal each institution's shortfalls and strong points quantitatively, and rank the institutions accordingly based on multiple criteria.

### 3. Methodology

In this work, the evaluation process is distinctly covered in four steps as shown in Figure 1, which are (i) definition and establishment of criteria to evaluate the higher institutions based on their quality of service; (ii) the determination of each criterion weight; (iii) determination of criteria performance for each alternative; and (iv) evaluation and ranking of alternatives. The alternatives considered for evaluation are 2 private universities and 2 public universities from the south-west region of Nigeria.

**3.1. Criteria Definition Based on Ext-HiEdQUAL Service Model.** In this study, HiEdQUAL service quality model, which is specific with respect to measurement of service quality in higher institutions, was adopted with few additional criteria. The regular HiEdQUAL model is based

on five dimensional concepts, which are *Teaching and Course content (TC)*, *Administrative Services (AS)*, *Academic Facilities (AF)*, *Campus Infrastructure (CI)*, and *Support Service (SS)*. Each dimensional concept has its attributes embedded such that they are weighted individually. To fully come to terms with expectations of the students in relation to QoS and the global relevance of Nigerian universities, another factor *INTERNALISATION (IN)* was introduced. This additional concept underlines the importance of improving excellence in higher institutions and attaining global relevance. The additional attributes/criteria, which make up IN that were considered include: (i) *University provides international exchange programmes/collaboration*; (ii) *University has a number of international lecturers/faculty*; (iii) *University has standard collaborations for recruitment of international staff and students*; and (iv) *University has international students*. These attributes can provide the focal point for rapid development of institution's products and values, acceleration of its goals, and global relevance among its contemporaries. However, these attributes were not sufficiently embedded in the regular HiEdQUAL model. Therefore, the Ext-HiEdQUAL service quality model proposed in this work produced six concepts and 33 criteria. Each of the criteria is rated based on the Fuzzy linguistic values (*very dissatisfied*, *dissatisfied*, *fair*, *satisfied*, and *very satisfied*). The Ext-HiEdQUAL QoS criteria model and its notations are shown in Table 1.

**3.2. Fuzzy Set Theory.** In order to handle the subjectivity in the assessment, three Fuzzy processes were incorporated into the MCDM methods for appropriate recommendations. These are: (i) Fuzzification process; (ii) Fuzzy Aggregation process; and (iii) Defuzzification.

**3.2.1. The Fuzzification Process.** This models the uncertainties and imprecision of the decision-makers involved in the evaluation process. The students are the decision-makers, being the primary stakeholders of tertiary institutions. In order to elicit criteria importance and institution's performance with respect to the criteria, two linguistic variables are defined and fuzzified: the "Perceived Importance" and "Perceived Performance." These linguistic variables represent the judgments of the decision-makers for eliciting the perceived importance of one criterion over another and perceived performance of each alternative in relation to the Ext-HiEdQUAL QoS model.

In order to fuzzify the linguistic values of both linguistic variables, "perceived importance" and "perceived performance," a triangular membership function model is used because it is easy computationally, and suitable for the process. The linguistic variables and their corresponding triangular membership value for each linguistic value are shown in Tables 2 and 3. The membership function  $\mu_A(x)$  of a Triangular Fuzzy Number (TFN) is defined in (1) and (2):

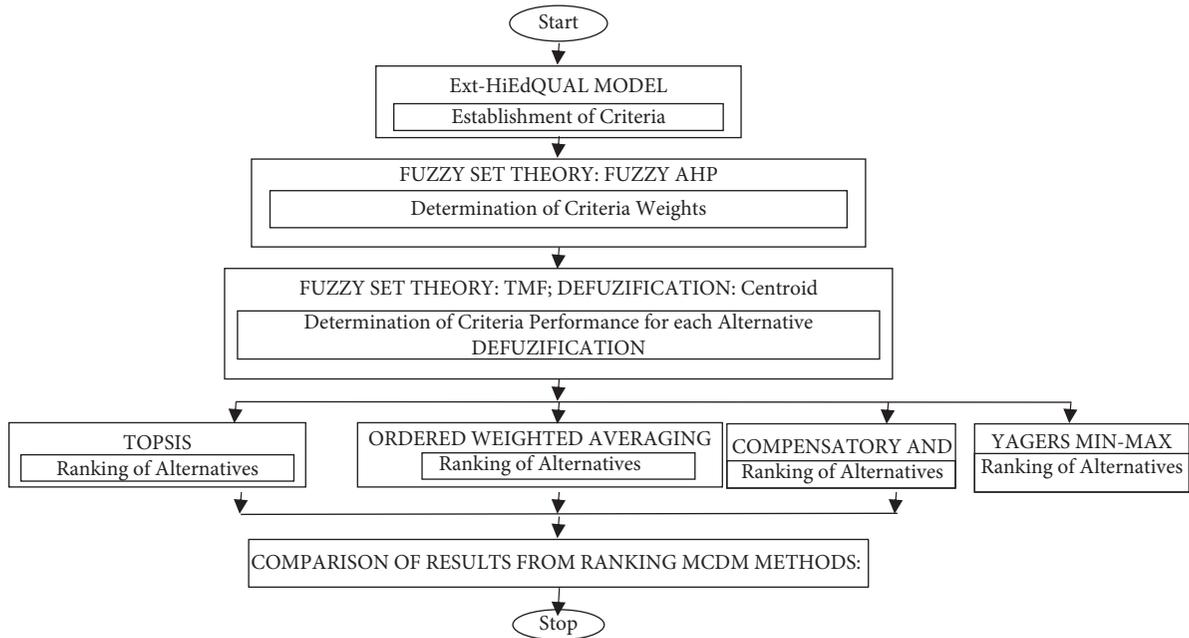


FIGURE 1: The tertiary institution service quality assessment workflow.

TABLE 1: The Ext-HiEdQUAL criteria model with corresponding weights.

S/no	Criteria code	Selected criteria	Weights
1.	TC1	Teachers are responsive and accessible	0.0256
2.	TC2	Teachers follow curriculum strictly	0.0250
3.	TC3	Teachers follow good teaching practices	0.0282
4.	TC4	Relevance between programme and syllabus	0.0347
5.	TC5	Course content develops students' knowledge	0.0427
6.	TC6	Department informs schedules, exams, results on time	0.0388
7.	TC7	Teachers complete syllabus on time	0.0284
8.	TC8	Department has sufficient academic staff	0.0273
9.	TC9	University has more adjunct lecturers than in-house lecturers	0.0306
10	TC10	Departments reflect current trends in the curriculum	0.0292
11.	AS1	Administrative staff provide service without delay	0.0182
12.	AS2	Administrative staff are courteous and willing to help	0.0262
13.	AS3	Administrative staff provide error-free work	0.0270
14.	AS4	Administration maintains accurate storage and retrieval of records	0.0312
15.	AS5	Administrative staff are accessible during office hours	0.0350
16.	AS6	University has safety and security measures	0.0159
17.	AF1	Departments have adequate teaching facilities	0.0166
18.	AF2	Classrooms are equipped with teaching aids	0.0278
19.	AF3	Department has sufficient class rooms	0.0298
20.	AF4	University has adequate auditoriums, conference halls, etc.	0.0312
21.	AF5	Library has adequate academic resources	0.0361
22.	AF6	Computer labs have adequate equipment and internet facilities	0.0161
23.	CI1	University has adequate hostel facilities	0.0217
24.	CI2	University has adequate medical facilities (health centres)	0.0438
25.	CI3	University has adequate social amenities (canteen, shopping centre, bank, ATM, post office, etc.)	0.0518
26.	CI4	Campus infrastructure is well maintained.	0.0206
27.	SS1	University has sufficient sports and recreation facilities.	0.0314
28.	SS2	University/department provides placement services.	0.0387
29.	SS3	University provides counselling services.	0.0326
30.	IN1	University provides international exchange programmes /collaboration	0.0341
31.	IN2	University has a number of international lecturers/faculty.	0.0311
32.	IN3	University has standard collaborations for recruitment of international staff and students.	0.0394
33.	IN4	University has international students.	0.0334

TABLE 2: Linguistic values for pairwise comparison of criteria importance (weights) for fuzzy AHP and their corresponding and reciprocal triangular fuzzy numbers.

Linguistic values	Corresponding triangular fuzzy numbers	Reciprocal fuzzy number
Equally important (EI)	(0, 0.1, 0.3)	
Moderately important (M)	(0.1, 0.3, 0.5)	(1/0.5, 1/0.3, 1/0.1)
Strongly important (S)	(0.3, 0.5, 0.7)	(1/0.7, 1/0.5, 1/0.3)
Very strongly important (VS)	(0.5, 0.7, 0.9)	(1/0.9, 1/0.7, 1/0.5)
Extremely important (EX)	(0.7, 0.9, 1.0)	(1, 1/9, 1/0.7)

TABLE 3: Linguistic values for the qualitative measurement of perceived performance of alternatives and their corresponding triangular fuzzy numbers.

Linguistic values	Corresponding triangular fuzzy numbers	Classification
Very dissatisfied (VDS)	(0, 1, 3)	1
Dissatisfied (DS)	(1, 3, 5)	2
Fair (F)	(3, 5, 7)	3
Satisfied (S)	(5, 7, 9)	4
Very satisfied (VS)	(7, 9, 10)	5

$$(\mu_x)\text{Triangle} = \left\{ \begin{array}{l} 0 \text{ if } x \leq k \text{ or } x > m \\ \frac{x-k}{l-k} \text{ if } k < x \leq l \\ \frac{m-x}{m-l} \text{ if } l < x \leq m \end{array} \right\}, \quad (1)$$

where  $k$  is lower boundary;  $l$  is median point, and  $m$  is upper boundary,  $m \neq l$ ,  $u \neq m$ , as depicted in Figure 2 such that  $\mu_A(x): X \rightarrow \{0, 1\}$ , where

$$\begin{aligned} \mu_A(x) &= 1, & \text{if } x \text{ is totally in } A; \\ \mu_A(x) &= 0, & \text{if } x \text{ is not in } A; \\ 0 < \mu_A(x) < 1, & \text{if } x \text{ is partially in } A. \end{aligned} \quad (2)$$

The linguistic values for the linguistic variable ‘‘Perceived Importance’’ for eliciting each criterion importance from decision-makers are identified as

Perceived Importance {*equally important (EI)*, *moderately important (MI)*, *strongly important (SI)*, *very strongly important (VSI)*, and *extremely important (EXI)*}

Each Fuzzy set is represented by the fuzzy graph in Figure 3. Also, the linguistic values for the linguistic variable ‘‘Perceived Performance’’ for eliciting the performance of each institution with respect to the QoS criteria is defined as:

Perceived Performance {*very dissatisfied (VDS)*, *dissatisfied (DS)*, *fair (F)*, *satisfied (S)*, and *very satisfied (VS)*}

Each fuzzy set is represented by the fuzzy graph in Figure 4.

**3.2.2. The Fuzzy Aggregation Process.** Based on the inherent subjectivity in the evaluation process, the perceptions of the decision-makers are aggregated using the arithmetic operations of Fuzzy set defined in (3). Fifty students in each of the four institutions were polled using a survey in relation to the Ext-HiEdQUAL model to determine the performance of the institutions, respectively. These perceptions are in two parts:

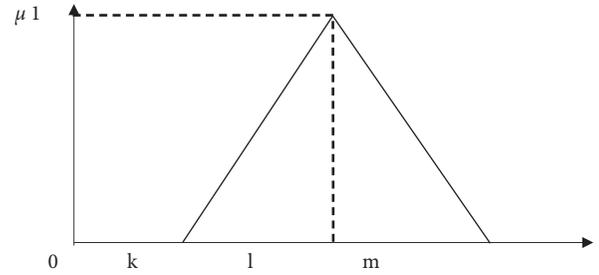


FIGURE 2: Triangular fuzzy number.

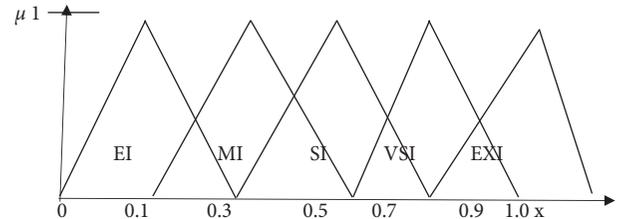


FIGURE 3: Fuzzy sets of the linguistic values for perceived importance.

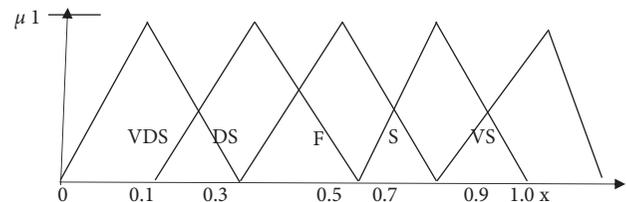


FIGURE 4: Fuzzy sets of the linguistic values for perceived performance.

first, the perceptions based on criteria importance (Perceived Importance) and second, on alternative performance with respect to the Ext-HiEdQUAL criteria Model (Perceived Performance). Consequently, these perceptions

modelled as fuzzy variables are averaged using the following formula in (4), which is expounded in Refs. [47, 48]:

$$A_{ave} = \frac{1}{n} \left( \sum_{i=1}^n k_i \sum_{i=1}^n l_i \sum_{i=1}^n m_i \right). \quad (3)$$

Its average triangular fuzzy number will now be:

$$A_{ave} = (k_a, l_a, m_a) = \left( \frac{1}{n} \sum_{i=1}^n k_i, \frac{1}{n} \sum_{i=1}^n l_i, \frac{1}{n} \sum_{i=1}^n m_i \right). \quad (4)$$

Equation (4) gives us an average fuzzy quantitative performance value for each criterion with respect to the decision-makers' assessment. The Fuzzy performance for each Higher Institution (HI) with respect to the criteria is shown in Table 4.

3.2.3. *Defuzzification.* According to Ref. [49], excessive fuzzification does not infer better modeling of reality, and this could end up being counterproductive. There is a need to transform the fuzzy nature of both the average performance values of each criterion and the criteria importance values into best nonfuzzy value since final judgments are best when crisp in nature. Therefore, in order to transform it into its best nonfuzzy performance (BNF) value, the centroid defuzzification method was employed in this study because it is monotonous, consistent, and its deterministic response curve is characterized by a smooth and continuous behavior [50]. The defuzzified value of a fuzzy number can be attained with equation (5). The best nonfuzzy performance values using centroid defuzzification with respect to selected criteria are shown in Table 5 and graphically represented in Figures 5–8.

$$BNP = \frac{(m - k) + (l - k)}{3} + k. \quad (5)$$

3.3. *Fuzzy Analytical Hierarchy Process (AHP).* AHP was proposed by Saaty [51], and is one of the most commonly utilized weighting MCDM methods [35]. The fusion of Fuzzy set concept addresses the weakness of the AHP by capturing the uncertainties of the decision-makers before making recommendations on criteria importance. Fuzzy AHP was adopted as a weighting model for determining each criterion weight. The experts considered in this study

for the rating of each criterion as relevant to higher institution are people in the University Quality Assurance Unit, Academic Planning Unit, and Heads of Departments from the universities that were considered due to their deeper knowledge about their university's quality of service. The experts are considered for the rating of the criteria importance based on the fuzzy linguistic values {*Equally important, moderately more important, strongly more important, very strongly more important, and extremely more important*}. For the determination of weights/priorities, various methods of AHP have been adopted [52]. Eigenvector method, using the iterative Power method [52], was employed in this study and implemented in Java Programming language. The Fuzzy AHP algorithm is stated as:

Step 1: Construct a fuzzy pairwise comparison matrix for each decision-maker (DM) with the aid of the linguistic scale in Table 2. Each element,  $(\tilde{a}_{ij})$  in the pairwise comparison matrix,  $\tilde{A}$  is a fuzzy number corresponding to its linguistic value selected by the decision-maker (DM) in Table 2.

Consequently, the relative importance of one criterion over another can be subjectively expressed by a DM in constructing the pairwise comparison matrix using the following steps:

- (i) If two criteria have equal importance in pairwise comparison, enter corresponding fuzzy number in Table 2 for both criteria;
- (ii) If one of them is moderately more important than the other, enter the corresponding fuzzy number and for the other enter reciprocal fuzzy number in Table 2;
- (iii) If one of them is strongly more important than the other, enter the corresponding fuzzy number and for the other enter reciprocal fuzzy number in Table 2;
- (iv) If one of them is very strongly more important than the other, enter the corresponding fuzzy number and for the other enter reciprocal fuzzy number in Table 2;
- (v) If one of them is extremely important than the other, enter the corresponding fuzzy number, and for the other enter reciprocal fuzzy number in Table 2;

Then, we have:

$$\tilde{A} = \begin{pmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{pmatrix} \text{ re-written as } \begin{pmatrix} 1 & (a_{12k}, a_{12l}, a_{12m}) & \cdots & (a_{1nk}, a_{1nl}, a_{1nm}) \\ (a_{21k}, a_{21l}, a_{21m}) & 1 & \cdots & (a_{2nk}, a_{2nl}, a_{2nm}) \\ \vdots & \vdots & \ddots & \vdots \\ (a_{n1k}, a_{n1l}, a_{n1m}) & (a_{n2k}, a_{n2l}, a_{n2m}) & \cdots & 1 \end{pmatrix}, \quad (6)$$

where  $(a_{12k}, a_{12l}, a_{12m})$  is represented as a triangular fuzzy number for comparison criterion  $i$  and  $j$ ;  $(a_{21k},$

$a_{21l}, a_{21m})$  represents the reciprocal fuzzy number for the comparison between criterion  $j$  and  $i$ .

TABLE 4: Fuzzy performance for each higher institution (HI) with respect to the criteria. A, B, C, D represent the four universities under consideration.

Criteria	Fuzzy criteria performance of the higher institutions (HI) (fuzzification)			
	HI A	HI B	HI C	HI D
TC1	(3.600, 5.480, 7.400)	(5.040, 7.040, 8.680)	(4.580, 6.560, 8.380)	(4.600, 6.600, 8.480)
TC2	(4.120, 6.120, 8.020)	(5.240, 7.240, 8.900)	(4.660, 6.640, 8.480)	(4.200, 6.200, 8.140)
TC3	(3.640, 5.560, 7.460)	(4.740, 6.720, 8.500)	(3.920, 5.920, 7.860)	(4.040, 6.040, 7.980)
TC4	(3.800, 5.720, 7.640)	(4.580, 6.520, 8.360)	(3.740, 5.720, 7.620)	(4.560, 6.560, 8.420)
TC5	(3.820, 5.720, 7.580)	(5.040, 7.000, 8.760)	(4.460, 6.440, 8.280)	(4.680, 6.680, 8.540)
TC6	(4.240, 6.160, 7.980)	(5.240, 7.240, 8.800)	(3.540, 5.480, 7.380)	(3.760, 5.760, 7.720)
TC7	(3.800, 5.800, 7.740)	(4.620, 6.600, 8.320)	(2.820, 4.720, 6.700)	(3.360, 5.360, 7.340)
TC8	(3.600, 5.520, 7.460)	(4.780, 6.720, 8.420)	(3.460, 5.400, 7.300)	(4.440, 6.440, 8.360)
TC9	(3.240, 5.160, 7.120)	(3.540, 5.440, 7.320)	(3.140, 5.080, 7.000)	(2.780, 4.760, 6.720)
TC10	(3.140, 5.040, 7.040)	(4.560, 6.520, 8.280)	(3.420, 5.360, 7.320)	(3.800, 5.800, 7.780)
AS1	(2.880, 4.760, 6.720)	(3.900, 5.840, 7.800)	(2.720, 4.640, 6.580)	(2.940, 4.880, 6.840)
AS2	(3.600, 5.520, 7.460)	(4.240, 6.200, 8.040)	(3.040, 5.000, 6.940)	(3.340, 5.240, 7.220)
AS3	(3.240, 5.120, 7.060)	(3.600, 5.560, 7.420)	(3.040, 5.040, 7.020)	(3.280, 5.240, 7.200)
AS4	(3.820, 5.720, 7.600)	(3.920, 5.880, 7.780)	(3.900, 5.840, 7.780)	(3.600, 5.600, 7.560)
AS5	(3.840, 5.760, 7.600)	(4.240, 6.200, 8.060)	(4.040, 6.040, 7.940)	(4.400, 6.400, 8.300)
AS6	(3.340, 5.160, 7.100)	(5.060, 7.040, 8.660)	(4.240, 6.240, 8.060)	(3.620, 5.600, 7.560)
AF1	(2.620, 4.400, 6.340)	(4.040, 6.000, 7.840)	(2.620, 4.480, 6.400)	(3.360, 5.280, 7.220)
AF2	(2.340, 4.120, 6.100)	(4.760, 6.760, 8.500)	(2.540, 4.440, 6.360)	(3.600, 5.560, 7.500)
AF3	(3.420, 5.360, 7.340)	(4.160, 6.080, 7.860)	(2.880, 4.720, 6.680)	(4.360, 6.320, 8.200)
AF4	(3.040, 4.920, 6.840)	(4.860, 6.840, 8.520)	(3.480, 5.400, 7.280)	(4.020, 5.960, 7.860)
AF5	(4.120, 6.120, 7.940)	(5.640, 7.640, 9.160)	(3.820, 5.800, 7.600)	(3.940, 5.920, 7.800)
AF6	(2.640, 4.440, 6.400)	(4.820, 6.760, 8.420)	(3.020, 4.840, 6.740)	(2.780, 4.680, 6.640)
C11	(2.140, 3.880, 5.860)	(4.600, 6.560, 8.300)	(2.760, 4.640, 6.620)	(1.140, 2.600, 4.580)
C12	(2.540, 4.320, 6.300)	(4.680, 6.640, 8.360)	(3.100, 5.040, 6.940)	(3.080, 5.040, 7.000)
C13	(2.920, 4.760, 6.720)	(4.580, 6.520, 8.240)	(2.660, 4.560, 6.500)	(4.320, 6.320, 8.240)
C14	(2.380, 4.120, 6.100)	(4.080, 6.040, 7.920)	(3.620, 5.560, 7.440)	(2.760, 4.720, 6.680)
SS1	(3.000, 4.840, 6.780)	(4.060, 6.000, 7.820)	(3.340, 5.280, 7.200)	(3.740, 5.720, 7.620)
SS2	(2.640, 4.440, 6.420)	(3.200, 5.120, 7.000)	(3.040, 4.920, 6.860)	(2.800, 4.720, 6.700)
SS3	(2.240, 4.000, 6.000)	(4.340, 6.280, 8.060)	(3.780, 5.720, 7.540)	(3.580, 5.520, 7.480)
IN1	(2.180, 3.880, 5.880)	(4.400, 6.360, 8.200)	(3.040, 4.960, 6.920)	(2.580, 4.440, 6.420)
IN2	(1.285, 2.836, 4.836)	(3.560, 5.520, 7.380)	(2.220, 4.000, 5.980)	(2.100, 3.920, 5.900)
IN3	(1.775, 3.571, 5.571)	(3.880, 5.800, 7.680)	(2.380, 4.160, 6.140)	(2.320, 4.240, 6.220)
IN4	(1.632, 3.285, 5.285)	(3.600, 5.520, 7.340)	(2.260, 4.080, 6.040)	(2.280, 4.160, 6.100)

Step 2: Add the fuzzy numbers selected by each DM for each pairwise comparison of  $i$ th and  $j$ th criterion using equation (3) if there is more than one DM, and collapse into an aggregated one using equation (4).

Step 3: Due to the condition required of linear additive models like AHP as certainty is prerequisite before final results, defuzzify averaged fuzzy numbers from step (2) for each  $(a_{1nk}, a_{1nl}, a_{1nm})$  in  $\tilde{A}$  using the centroid defuzzification formula in equation (5).

Step 4: Square the averaged pairwise comparison matrix:  $A_{n+1} = A_n * A_n$ .

Step 5: Perform the row sums that are calculated and normalized using equations (7) and (8), respectively:

$$ri = \sum_i aij, \quad (7)$$

where  $ri$  is the summation of the row values and

$$pi = \frac{ri}{\sum_i ri}, \quad (8)$$

where  $pi$  is the normalization of the sums.

This produces the first eigenvector.

Step 6: Repeat steps 4 and 5 using the new matrix  $A_{n+2}$  derived from squaring the  $A_n$

Step 7: Stop when there is a difference between the current and last eigenvector solution in two consecutive priorities calculations derived from steps 5 and 6.

The determined weight for each criterion is shown in Table 1 and is graphically represented in Figure 9.

**3.4. Ranking of Alternatives Using MCDM Methods.** For the ranking of the tertiary institutions of learning under consideration, four MCDM compensatory (MAUT) methods were applied for the evaluation to rank the tertiary institutions. These are: TOPSIS, Yager's min-max, Compensatory AND, and OWA.

**3.4.1. TOPSIS.** TOPSIS, proposed by Hwang and Yoon [53], was developed based on the ideal that the best alternative should have the shortest distance to the positive ideal situation and the

TABLE 5: Best non-fuzzy performance for each higher institution (HI) with respect to the criteria.

Criteria	Selected criteria	Best non-fuzzy performance of the higher institutions (HI) (centroid defuzzification)			
		HI A	HI B	HI C	HI D
TC1	Teachers are responsive and accessible	5.4933	4.7867	6.5067	6.5600
TC2	Teachers follow curriculum strictly	6.0867	5.5267	6.5933	6.1800
TC3	Teachers follow good teaching practices	5.5533	5.1400	5.9000	6.0200
TC4	Relevance between programme and syllabus	5.7200	5.7133	5.6933	6.5133
TC5	Course content develops students' knowledge	5.7067	5.7333	6.3933	6.6333
TC6	Department informs schedules, exams, results on time	6.1267	5.2000	5.4667	5.7467
TC7	Teachers complete syllabus on time	5.7800	4.4533	4.7467	5.3533
TC8	Department has sufficient academic staff	5.5267	4.1867	5.3867	6.4133
TC9	University has more adjunct lecturers than in-house lecturers	5.1733	5.3733	5.0733	4.7533
TC10	Departments reflect current trends in the curriculum	5.0733	4.9333	5.3667	5.7933
AS1	Administrative staff provide service without delay	4.7867	6.0600	4.6467	4.8867
AS2	Administrative staff are courteous and willing to help	5.5267	4.4933	4.9933	5.2667
AS3	Administrative staff provide error-free work	5.1400	3.9600	5.0333	5.2400
AS4	Administration maintains accurate storage and retrieval of records	5.7133	4.3867	5.8400	5.5867
AS5	Administrative staff are accessible during office hours	5.7333	4.8000	6.0067	6.3667
AS6	University has safety and security measures	5.2000	4.2000	6.1800	5.5933
AF1	Departments have adequate teaching facilities	4.4533	4.8733	4.5000	5.2867
AF2	Classrooms are equipped with teaching aids	4.1867	4.5000	4.4467	5.5533
AF3	Department has sufficient classrooms	5.3733	4.0800	4.7600	6.2933
AF4	University has adequate auditoriums, conference halls, etc.	4.9333	3.9800	5.3867	5.9467
AF5	Library has adequate academic resources	6.0600	2.9533	5.7400	5.8867
AF6	Computer labs have adequate equipment and internet facilities	4.4933	3.5933	4.8667	4.7000
C11	University has adequate hostel facilities	3.9600	3.3600	4.6733	2.7733
C12	University has adequate medical facilities (Health centres)	4.3867	4.7867	5.0267	5.0400
C13	University has adequate social amenities (Canteen, Shopping centre, Bank, ATM, Post office, etc.)	4.8000	5.5267	4.5733	6.2933
C14	Campus infrastructure is well maintained.	4.2000	5.1400	5.5400	4.7200
SS1	University has sufficient sports and recreation facilities.	4.8733	5.7133	5.2733	5.6933
SS2	University/Department provides placement services.	4.5000	5.7333	4.9400	4.7400
SS3	University provides counselling services	4.0800	5.2000	5.6800	5.5267
IN1	University provides international exchange programmes/collaboration	3.9800	4.4533	4.9733	4.4800
IN2	University has a number of international lecturers/faculty.	2.9533	4.1867	4.0667	3.9733
IN3	University has standard collaborations for recruitment of international staff and students.	3.5933	5.3733	4.2267	4.2600
IN4	University has international students.	3.3600	4.9333	4.1267	4.1800

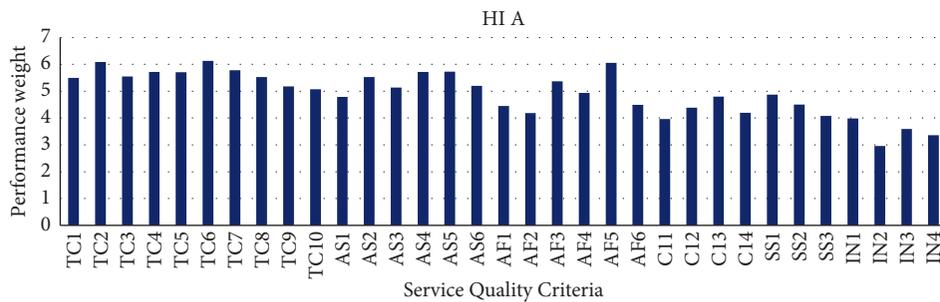


FIGURE 5: Higher institution "A" performance against each criterion.

farthest to the negative ideal situation. The best alternative to the least is selected by using the following steps, which was implemented in Java programming language:

Step 1: Calculation of the normalized performance matrix

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^m a_{ij}^2}}, \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n, \quad (9)$$

where  $a_{ij}$  is the performance matrix,  $i$  is the alternative number, and  $j$  is the criterion number

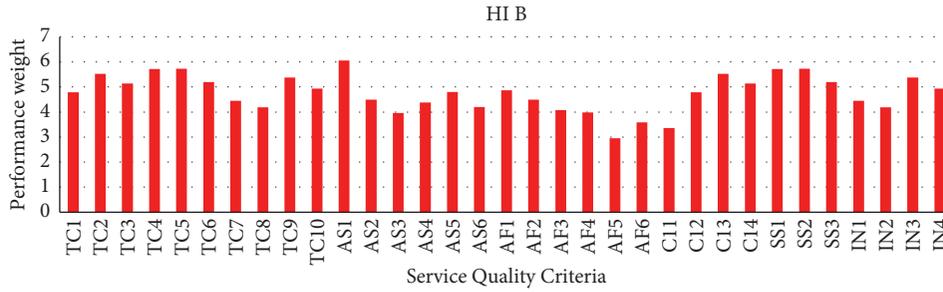


FIGURE 6: Higher institution “B” performance against each criterion.

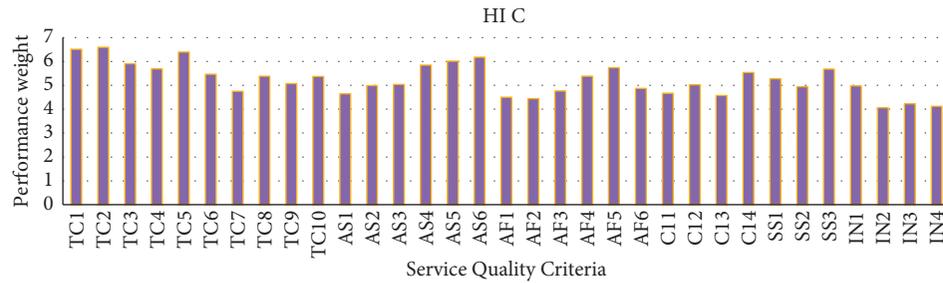


FIGURE 7: Higher institution “C” performance against each criterion.



FIGURE 8: Higher institution “D” performance against each criterion.

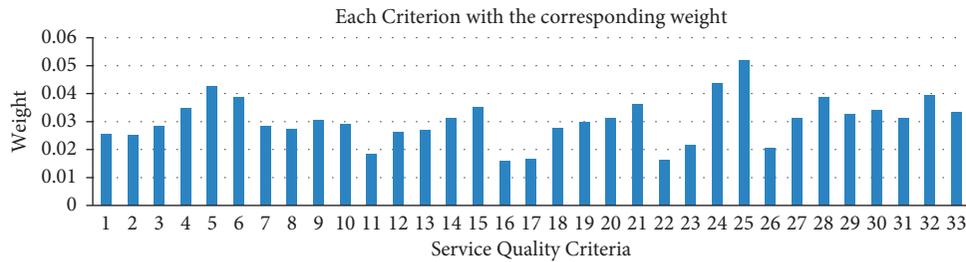


FIGURE 9: Graphical representation of the fuzzy AHP derived weights of Ext- HiEDQUAL QoS criteria.

Step 2: Calculation of weighted and normalized performance matrix

$$v_{ij} = w_j \times r_{ij}, \quad i = 1, 2, \dots, m \quad j = 1, 2, \dots, n, \quad (10)$$

where  $w_j$  is the weight of criterion  $j$ .

Step 3: Determination of positive ideal solution and negative ideal solution

The weighted and normalized values in matrix  $V_{ij}$  give rise to the positive ideal solution ( $A^+$ ) and negative ideal solution ( $A^-$ )

$$\begin{aligned} A^+ &= (V_1^+, V_2^+, \dots, V_n^+), \\ A^- &= (V_1^-, V_2^-, \dots, V_n^-), \end{aligned} \quad (11)$$

where  $V_j^+$  is the best alternative value in criterion  $j$  from the  $V_{ij}$  matrix,  $V_j^-$  is the worst alternative value in criterion  $j$  from the  $V_{ij}$  matrix.

Step 4: Calculation of distance values between alternatives

The distance of alternatives from the positive ideal solution  $S_i^+$  and the distance of alternatives from the negative ideal solution  $S_i^-$  are calculated with (12) and (13), respectively.

$$S_i^+ = \sqrt{\sum_{j=1}^n (V_{ij} - V_j^+)^2}, \quad i = 1, 2, \dots, m, \quad (12)$$

$$S_i^- = \sqrt{\sum_{j=1}^n (V_{ij} - V_j^-)^2}, \quad i = 1, 2, \dots, m. \quad (13)$$

Step 5: Calculation of the closeness to the positive-ideal solution

$$C_i^+ = \frac{S_i^-}{S_i^+ + S_i^-}, \quad i = 1, 2, \dots, m. \quad (14)$$

$C_i^+$  value is in the  $0 \leq C_i^+ \leq 1$  interval. As  $C_i^+$  gets closer to 1, alternative  $i$  gets closer to  $A^+$ , whereas if  $C_i^+$  gets closer to 0, alternative  $i$  gets closer to  $A^-$ . The result is shown in Table 6.

Step 6: Arrangement of alternative choices: Alternatives are arranged according to the decreasing order of  $C_i^+$ .

Normalized Performance matrix and Weighted Normalized Performance matrix for each Higher Institution (HI) with respect to the criteria is shown in Table 6. The final ranking of the institutions performance with TOPSIS is shown in Table 7.

**3.4.2. Compensatory AND Operator.** The compensatory AND operator defined by Ref. [54] sought to emulate human's aggregation procedure in decision-making based on the t-norm and t-conorms on a unit interval. It is defined as:

$$\mu_{A\theta B} = \mu_{A \cap B}^{1-\gamma} \cdot \mu_{A \cup B}^{\gamma} \quad (15)$$

where  $\theta$  is the Compensatory AND operator and  $A$  and  $B$  are the fuzzy sets. The membership of an object in the set  $A\theta B$  equals the product of the weighted membership values for the intersection and the union.

If the intersection and the union are algebraically represented by the product and the algebraic sum, respectively, to represent a closer representation of human aggregation procedures, then (15) becomes:

$$\mu_{\theta} = \left( \prod_{i=1}^m \mu_i \right)^{1-\gamma} * \left( 1 - \prod_{i=1}^m (1 - \mu_i) \right)^{\gamma}, \quad 0 \leq \mu \leq 1; 0 \leq \gamma \leq 1. \quad (16)$$

If it is desired to introduce different weights for the sets in question,  $\mu_i$  and  $1 - \mu_i$  could for instance be replaced by  $\mu_i = (\vartheta_i/n)^{\vartheta_i}$  and  $1 - \mu_i = (1 - (\vartheta_i/n))^{\vartheta_i}$ .

where  $\vartheta_i$  are the (raw) membership values,  $n$  is the highest possible defuzzified value, such that  $n=10$  and  $\delta_i$ , their corresponding weights; and  $\gamma = 0.6$ , which indicates the degree of compensation [54]. The sum of weights  $\delta_i$  should be equal to the number of sets connected. That means  $\sum_i \delta_i = m$  [54].

This procedure was implemented in Java programming language and the final ranking value for each alternative using Compensatory AND is shown in Table 7 and Figure 10.

**3.4.3. Yager's Min-Max.** Yager's min-max has been reported as an efficient group decision-making technique [55]. The best alternative to least is selected by the following:

Let  $X = \{x_1, x_2, \dots, x_n\}$  be the set of Higher Institutions. Criteria are shown with  $G_j$  fuzzy sets  $j=1, \dots, m$ . The criterion importance is expressed by  $w_j$ . The attainment of criterion  $G_j$  by Higher Institution  $x_i$  is expressed by the degree of membership  $G_j(x_i)$ .

In relation to [56], the decision is the intersection of all fuzzy criteria raised to the powers  $w_j$  and is given as follows:

$$\bar{D} = \bar{G}_1^{w_1} \cap \bar{G}_2^{w_2} \cap \dots \cap \bar{G}_m^{w_m}, \quad (17)$$

where  $w_j$  ( $j=1, \dots, m$ ) is the weight attached to the criterion  $G_j$  ( $j=1, \dots, m$ ) depending on its importance. The defuzzified values in Table 5 for each higher institution,  $x_i$ , could represent the criteria values,  $G_j(x_i)$  [26, 35] and the most optimal Higher Institution is one with the highest  $(\mu_{G_j}(x_i))$  in  $\bar{D}$  [55]. The more the weight,  $w_j$  is attached to criterion  $G_j$  exponentially, the more it is included in  $\bar{D}$  as shown in (18).

$$\left( \bar{D} = \left\{ x_i^{\min_j} (\mu_{G_j}(x_i))^{w_j}, \quad |i = 1, \dots, n; j = 1, \dots, m \right\} \right), \quad (18)$$

$w_j$  represents the weight of each criterion computed by the AHP method. For this,  $\sum_j w_j = m$ , where  $m$  is the total number of criteria [56]. The Yager's weighted criteria values,  $\bar{G}_m^{w_m}$  for each higher institution,  $x_i$  is depicted in Table 8 and the final ranking values,  $\bar{D}$  for each alternative is shown in Table 7 and Figure 10.

**3.4.4. Ordered Weighted Averaging (OWA).** Ordered Weighted Averaging (OWA) was proposed by Yager and this is defined as cited in Ref. [4]:

“Definition: A mapping  $F$  from.

- (i)  $I^n \longrightarrow I$  where ( $I = [0, 1]$ ) is called an OWA operator of dimension  $n$  if associated with  $F$ , which has a weighting vector  $W$

$$W = \begin{pmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{pmatrix}. \quad (19)$$

TABLE 6: Normalized performance matrix and weighted normalized performance matrix.

Selected criteria	Normalized matrix performance				Weighted normalized performance matrix				A <sup>+</sup>	A <sup>-</sup>
	HI A	HI B	HI C	HI D	HI A	HI B	HI C	HI D		
TC1	0.4297	0.5413	0.5090	0.5131	0.0110	0.0138	0.0130	0.0131	0.0138	0.0110
TC2	0.4675	0.5474	0.5064	0.4747	0.0117	0.0137	0.0126	0.0119	0.0137	0.0117
TC3	0.4594	0.5503	0.488	0.498	0.0130	0.0155	0.0138	0.0141	0.0155	0.0130
TC4	0.4676	0.5303	0.4654	0.5325	0.0162	0.0184	0.0162	0.0185	0.0185	0.0162
TC5	0.4436	0.5389	0.4969	0.5156	0.0189	0.0230	0.0212	0.0220	0.0230	0.0189
TC6	0.4990	0.5777	0.4452	0.4680	0.0193	0.0224	0.0173	0.0181	0.0224	0.0173
TC7	0.5128	0.5779	0.4212	0.4750	0.0146	0.0164	0.0120	0.0135	0.0120	0.0135
TC8	0.4593	0.5518	0.4477	0.5330	0.0125	0.0151	0.0122	0.0146	0.0151	0.0122
TC9	0.5058	0.5312	0.4960	0.4647	0.0155	0.0162	0.0152	0.0142	0.0162	0.0142
TC10	0.4454	0.5665	0.4711	0.5086	0.0130	0.0165	0.0138	0.0148	0.0165	0.0130
AS1	0.4726	0.5773	0.4588	0.4825	0.0086	0.0105	0.0083	0.0088	0.0105	0.0083
AS2	0.5021	0.5596	0.4536	0.4785	0.0131	0.0146	0.0119	0.0125	0.0146	0.0119
AS3	0.4906	0.5275	0.4804	0.5002	0.0133	0.0143	0.0130	0.0135	0.0143	0.0130
AS4	0.4967	0.5095	0.5077	0.4857	0.0155	0.0159	0.0158	0.0151	0.0159	0.0151
AS5	0.4721	0.5077	0.4946	0.5242	0.0165	0.0178	0.0173	0.0183	0.0183	0.0165
AS6	0.4327	0.5759	0.5143	0.4655	0.0069	0.0091	0.0082	0.0074	0.0091	0.0069
AF1	0.4376	0.5857	0.4422	0.5195	0.0073	0.0097	0.0074	0.0086	0.0097	0.0073
AF2	0.3944	0.6287	0.4189	0.5232	0.0110	0.0175	0.0116	0.0145	0.0175	0.0110
AF3	0.4758	0.5342	0.4215	0.5573	0.0142	0.0159	0.0126	0.0166	0.0166	0.0126
AF4	0.4259	0.5819	0.4651	0.5134	0.0133	0.0181	0.0145	0.0160	0.0181	0.0133
AF5	0.4787	0.5908	0.4534	0.4650	0.0173	0.0213	0.0164	0.0168	0.0213	0.0164
AF6	0.4276	0.6345	0.4632	0.4473	0.0069	0.0102	0.0075	0.0072	0.0102	0.0069
C11	0.4239	0.6943	0.5002	0.2968	0.0092	0.0151	0.0109	0.0064	0.0151	0.0064
C12	0.4128	0.6173	0.473	0.4742	0.0181	0.0270	0.0207	0.0208	0.0270	0.0181
C13	0.4291	0.5763	0.4089	0.5626	0.0222	0.0298	0.0212	0.0291	0.0298	0.0212
C14	0.4065	0.5820	0.5361	0.4568	0.0084	0.0120	0.0110	0.0094	0.0120	0.0084
SS1	0.4458	0.5452	0.4824	0.5208	0.0140	0.0171	0.0152	0.0164	0.0171	0.0140
SS2	0.4661	0.5290	0.5117	0.4910	0.0180	0.0205	0.0198	0.0190	0.0205	0.0180
SS3	0.3752	0.5727	0.5224	0.5083	0.0122	0.0187	0.0170	0.0166	0.0187	0.0122
IN1	0.3968	0.6302	0.4959	0.4467	0.0135	0.0215	0.0169	0.0152	0.0215	0.0135
IN2	0.3501	0.6505	0.4821	0.4710	0.0109	0.0202	0.0150	0.0146	0.0202	0.0109
IN3	0.3958	0.6374	0.4656	0.4693	0.0156	0.0251	0.0183	0.0185	0.0251	0.0156
IN4	0.3857	0.6298	0.4737	0.4798	0.0129	0.0211	0.0158	0.0160	0.0211	0.0129

TABLE 7: Ranking of the four higher institutions by the MCDM methods.

S/ no	Alternatives	TOPSIS	Ranking	Compensatory AND	Ranking	Yager's min-max Values	Ranking	OWA values	Ranking
1.	Higher Institution A	0.1595	4	0.0000720	4	2.2218	3	4.4604	4
2.	Higher Institution B	0.9702	1	0.0021611	1	2.6640	1	5.9875	1
3.	Higher Institution C	0.3416	3	0.0001701	3	2.2832	2	4.8436	3
4.	Higher Institution D	0.4307	2	0.0002781	2	2.0762	4	4.9791	2

Such that

- (1)  $w_i \in (0, 1)$
  - (2)  $\sum_i w_i = 1$
- and where

$$F(a_1, a_2, \dots, a_n) = w_1 b_1 + w_2 b_2, \dots, w_n b_n, \quad (20)$$

where  $b_i$  is the  $i$ th largest element in the sequence  $a_1, a_2, \dots, a_n$ .

The main concern of OWA is to rank the arguments  $(a_1, a_2, \dots, a_n)$  in descending order where  $(a_1, a_2, \dots, a_n)$  represents the performance values of each higher institution depicted in Table 5.

$V_i$  represents the AHP-derived criteria weights where  $V_i \in [0, 1]$ . Therefore, to evaluate the overall satisfaction of the institutions:

- (i) Tertiary institutions are organized distinctly as  $(V_i(A_i) \text{ HI})$  couples.
- (ii)  $A_i(\text{HI})$ s are then lined up in descending order such that  $b_j$  is the biggest  $j$ th value of  $A_i(\text{HI})$ . Consequently,  $U_j$  represents the weight linked with the  $j$ th biggest higher institution satisfaction. Then,  $u_j$  will now be  $V_j$  with respect to  $b_j$ 's which are in descending order [35]. Now we have  $n$   $(u_j, b_j)$  couples.
- (iii) The OWA weights relevant to this aggregation technique is defined as

$$w_j = Q\left(\frac{S_j}{T}\right) - Q\left(\frac{S_{j-1}}{T}\right). \quad (21)$$

Here,

$$S_j = \sum_{k=1}^j U_k, \quad (22)$$

$$T = \sum_{k=1}^n u_k.$$

Linguistic quantifier ‘‘Most’’ which is  $Q(r) = r^2$  is employed in equation (21) to calculate the OWA weight,  $w_j$

- (iv) With the weights calculated, we could find  $D(x)$  evaluation with respect to each alternative as

$$D(x) = \sum_{j=1}^n b_j w_j (H_i). \quad (23)$$

The performance evaluation of Higher institution A, with the OWA, is shown in Table 8. Conclusively, the overall performance value for all four Higher Institutions using the OWA is shown in Table 7 and Figure 10.

#### 4. Discussion

From Table 5, the *best nonfuzzy performance for each higher institution (HI) with respect to the criteria* is determined. This actually revealed the institution’s strong and weak points in terms of quality of service. Figures 5–8 give a graphical picture of alternative institutions’ performance against each criterion, respectively. From Figure 5, Alternative HIA has the strongest weight in TC6 with 6.13 performance weight and the weakest weight in IN2 with 2.95. This shows that HIA has to improve on the number of international lecturers/faculty and maintain its strength in the areas of prompt release of departmental schedules, exams, and results. This discovery further buttresses the importance of internationalisation in evaluating service quality of a higher institution of learning which is omitted in the HiEdQUAL service model [33]. For alternative HIB from Figure 6, the strongest point is AS1 with 6.06 weight, and the weakest point is AF5 with 2.95. This suggests that there is a need for this institution to improve its library academic resources and encourage the administrative staff to provide service without

delay. Also, for alternative HIC from Figure 7, the strongest point is TC2 with 6.593 weight followed by TC5 with 6.39. This shows that greater percentage of this institution’s faculty is following the curriculum and there is a positive impact of this in adding knowledge to its students as indicated by its TC5 performance. Nevertheless, there is a need for more international personnel (faculty) as indicated by its low weight in IN2. In the case of alternative HID as shown in Figure 8, its major strength lies in teaching and course content but no quality hostel facilities as indicated by its lower performance weight of 2.78 (C11).

In Table 1, *Fuzzy AHP was used to derive overall weights for each criterion in Ext- HiEdQUAL service model based on pairwise comparison matrix of the experts’ opinions and the graphical representative of the result is shown in Figure 9 for easy analysis.* Figure 9 shows that Criterion 25 (*University has adequate Amenities— Canteen, Shopping center, Bank, ATM, Post office, etc.*) has the highest overall weight, followed by Criterion 24 (*University has adequate medical facilities (Health centers)*). The lowest weighted criterion was 16 (*University has safety and security measures*). This result indicates that in ranking universities in Nigeria, amenities and facilities are very important as indicated by the experts. For criterion 16, having the lowest weight shows the level of importance attributed to security and safety by the decision-makers. Nevertheless, the institutions that were considered are not doing badly on the issues of safety and security. The security threats and terrorism in Nigeria could have motivated their performances.

Regarding the implementation, Fuzzy AHP was found to be highly cognitively demanding as this was in consonance with findings reported in Ref. [57]. The OWA had the second highest amount of computations and the TOPSIS is third, while the Yager’s min-max was fourth and less demanding. The compensatory AND had the least amount of computation and was least cognitively demanding. In terms of conflicts in the results of the four MCDM methods, two perspectives can be determined. First, note the rate at which the best alternative is the same all through the four methods and second, note the rate at which the ranking of any alternative is different in any of the MCDM methods. The TOPSIS, OWA, the Compensatory AND, and the Yager’s min-max fulfill this perspective by selecting Higher Institution B as the best; this is shown in Table 7. In the second contradiction rate, the ranking result of the Yager’s min-max for the second, third, and fourth placed higher institutions is opposing the other consensus ranking results. This indicates that even when the performance data from the decision-makers are consistent, there can be different ranking results due to the unique aggregation processes involved. Figure 10 gives more insight to the performance of the alternatives; the performance of Alternative HIB is not just ranked first with all the four methods but with outstanding best performance compared with other institutions. For instance, according to TOPSIS, overall evaluation ranking result, shown in Table 7, HIB is evaluated and ranked as the best alternative with the 0.97 coefficient of closeness to the ideal institution, even though there are still distinct rooms for improvement as revealed by Figure 8. This is followed by HID with 0.43

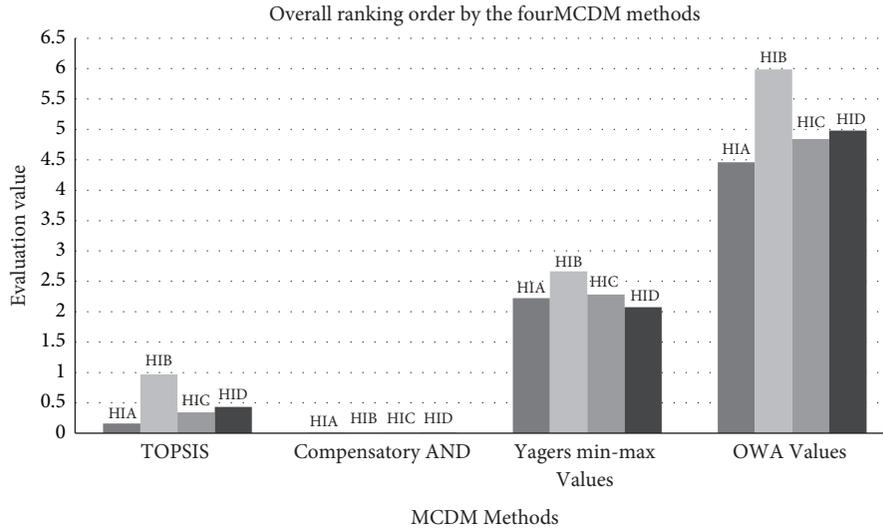


FIGURE 10: Graphical representation of the overall ranking process by the four MCDM methods.

TABLE 8: Yager’s min-max criteria values of the four higher institutions (HI) and OWA generated weights and the overall performance value for higher institution B.

Criteria	Yager’s min-max criteria values of the four higher institutions (HI)				OWA performance evaluation for higher institution A			
	HI A	HI B	HI C	HI D	$V_i$	$b_i$	$w_i$	D (HI A)
TC1	4.2136	5.1205	4.8610	4.8947	0.0387	6.12666666	0.001501	4.4604
TC2	4.431	5.0462	4.7328	4.4869	0.0249	6.08666666	0.002559	
TC3	4.9409	5.8472	5.2277	5.3268	0.0361	6.06	0.005905	
TC4	7.3687	8.5104	7.3294	8.5505	0.0283	5.78	0.006475	
TC5	11.6073	15.2673	13.6204	14.3456	0.0349	5.73333333	0.010198	
TC6	10.1563	12.2491	8.7787	9.3578	0.0347	5.72	0.012533	
TC7	5.1753	5.7882	4.3031	4.8165	0.0311	5.71333333	0.013309	
TC8	4.6690	5.5089	4.5623	5.3391	0.0426	5.70666666	0.021364	
TC9	5.2546	5.5213	5.1521	4.8242	0.0282	5.55333333	0.016144	
TC10	4.7799	6.0267	5.0459	5.4318	0.0261	5.52666666	0.016385	
AS1	2.5590	2.8854	2.5139	2.5910	0.0273	5.52666666	0.018563	
AS2	4.3769	4.8068	4.0097	4.1985	0.0255	5.49333333	0.018741	
AS3	4.3075	4.5954	4.2276	4.3821	0.0298	5.37333333	0.023481	
AS4	6.0050	6.1636	6.1420	5.8681	0.0158	5.2	0.013217	
AS5	7.5125	8.1720	7.9276	8.4788	0.0305	5.17333333	0.026920	
AS6	2.3695	2.7517	2.5936	2.4617	0.0270	5.14	0.025346	
AF1	2.2702	2.6640	2.2832	2.4943	0.0291	5.07333333	0.029012	
AF2	3.7212	5.7082	3.9328	4.8225	0.0311	4.93333333	0.032846	
AF3	5.2258	5.8565	4.6386	6.1046	0.0314	4.87333333	0.035120	
AF4	5.1603	7.1123	5.6484	6.2530	0.0517	4.8	0.062146	
AF5	8.5575	10.9974	8.0218	8.2667	0.0181	4.78666666	0.023094	
AF6	2.2218	2.7400	2.3181	2.2756	0.0387	4.5	0.051355	
C11	2.6795	3.8154	3.0169	2.0762	0.0161	4.49333333	0.022245	
C12	8.4697	15.1497	10.3117	10.3512	0.0166	4.45333333	0.023527	
C13	14.5951	24.1609	13.4371	23.1871	0.0437	4.38666666	0.064580	
C14	2.6474	3.3772	3.1945	2.8655	0.0205	4.2	0.031642	
SS1	5.1735	6.3753	5.6148	6.0795	0.0278	4.18666666	0.044149	
SS2	6.8279	8.0248	7.6918	7.2964	0.0326	4.08	0.053782	
SS3	4.5461	7.1674	6.4921	6.3035	0.0340	3.98	0.058453	
IN1	4.7296	7.9570	6.0768	5.4031	0.0217	3.96	0.038424	
IN2	3.0384	5.7370	4.2190	4.1197	0.0393	3.59333333	0.072078	
IN3	5.2649	9.7752	6.5005	6.5672	0.0334	3.36	0.063663	
IN4	3.8076	6.5404	4.7767	4.8448	0.0310	2.95333333	0.061227	

TABLE 9: Distribution of sensitivity coefficients  $SC_j^*$ .

MCDM method	% change in criterion weight				
	5%		50%		
	0	1	>1	0	>1
TOPSIS	32	1	0	12	7
Compensatory AND	33	0	0	23	1
Yagers min-max	32	1	0	32	0
OWA	32	1	0	21	1

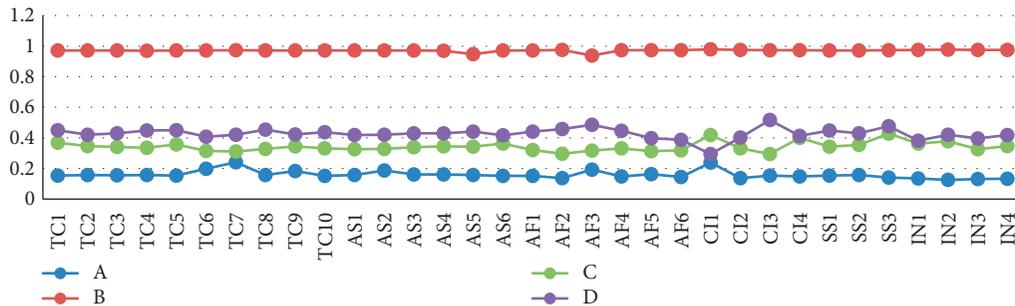


FIGURE 11: Performance sensitivity of the higher institution alternatives when criteria weights are increased by 5% for the TOPSIS method.

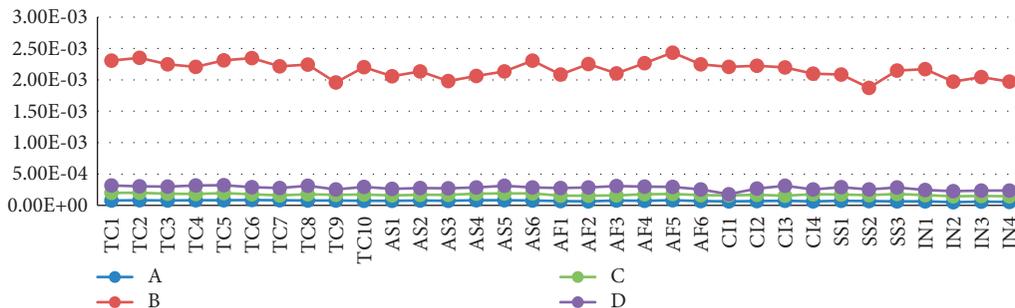


FIGURE 12: Performance sensitivity of the higher institution alternatives when criteria weights are increased by 5% for compensatory AND method.

coefficient of closeness, HIC with 0.34 and HIA are the farthest institutions from the Ideal with 0.16 coefficient of closeness.

### 5. Sensitivity Analysis

The deviation of each criterion weight is investigated to ascertain its impact on the ranking of the alternatives and the stability of each MCDM method. This deviation becomes paramount because the criteria weights are highly subjective, depending on the decision-makers' judgment. It depicts the robustness of the ranked alternatives by showing trends in performances as a consequence of the alteration of the criteria weights. Each criterion weight is separately altered by a certain percentage (0.01–100%) which in turn results in the other criteria weights to be simultaneously changed in order to ensure a total of 100% when all criteria weights are added. Table 9 presents the distribution of sensitivity

coefficients,  $SC_j^*$  for criterion  $j$  for the four MCDM methods. In this work, the specific value of the sensitivity coefficient,  $SC_j^*$  for criterion  $j$ , imply that an increase by 5% or 50% leads to a single, or double or multiple changes in the ranked order of alternatives. Figures 11–18 depicts the sensitivity analysis of each individual criterion when increased by 5% and 50% accordingly for each of four methods: TOPSIS, Compensatory AND, Yager's min-max and OWA respectively.

With 5% increase change in all criteria weight, the sensitivity analysis showed that the Compensatory AND outperformed the other MCDM methods considered in this study. It is more stable in its generated ranking order of alternatives (HIB > HID > HIC > HIA), i.e. no change observed in the ranked order of alternatives after 5% increase in criteria weights which can be seen in Table 7 and Figure 13. In view of this, the Compensatory AND method revealed its tolerance to changes in 5% criteria weight increase as against the others. This shows that Compensatory AND should be

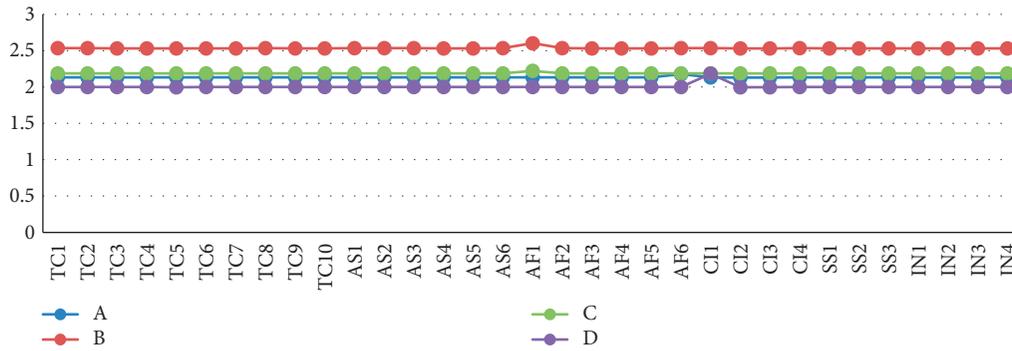


FIGURE 13: Performance sensitivity of the higher institution alternatives when criteria weights are increased by 5% for Yager’s min-max method.

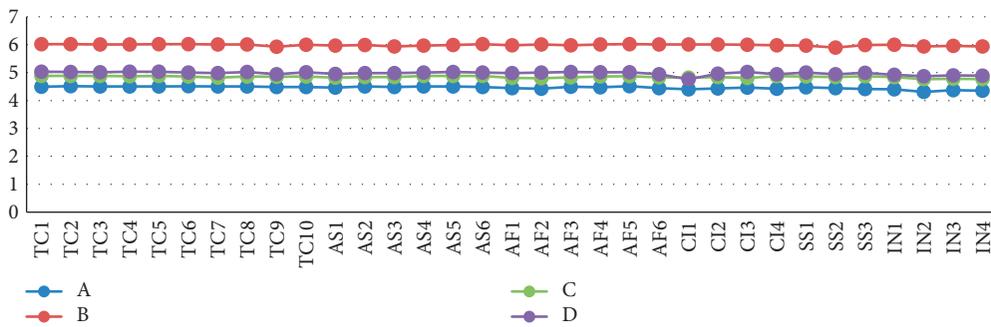


FIGURE 14: Performance sensitivity of the higher institution alternatives when criteria weights are increased by 5% for the OWA method.

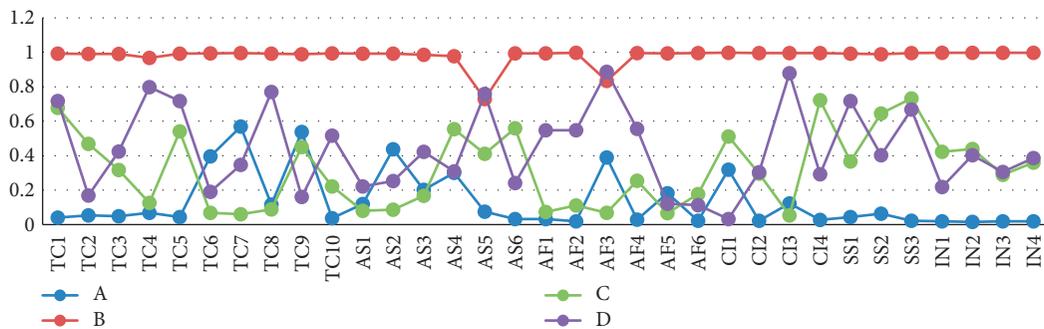


FIGURE 15: Performance sensitivity of the higher institution alternatives when criteria weights are increased by 50% for the TOPSIS method.

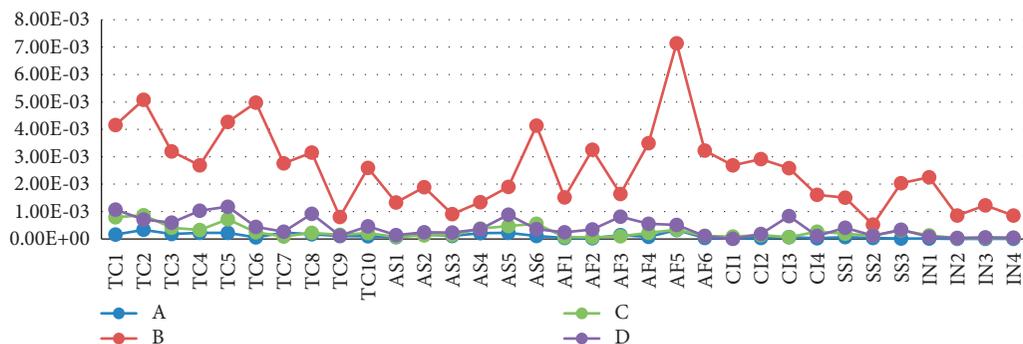


FIGURE 16: Performance sensitivity of the higher institution alternatives when criteria weights are increased by 50% for compensatory AND method.

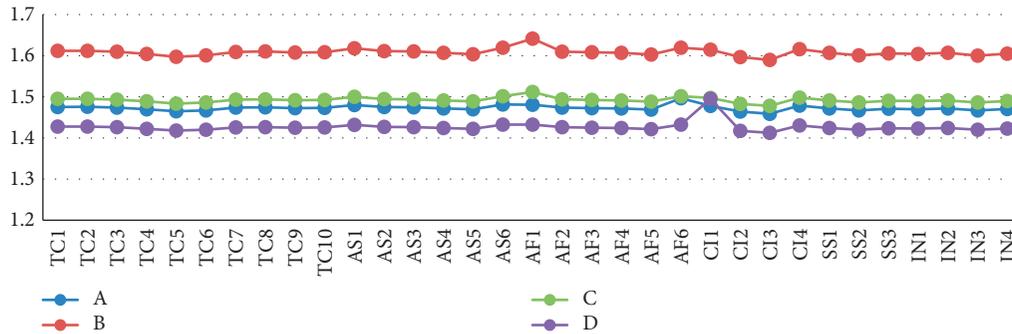


FIGURE 17: Performance sensitivity of the higher institution alternatives when criteria weights are increased by 50% for Yager’s min-max method.

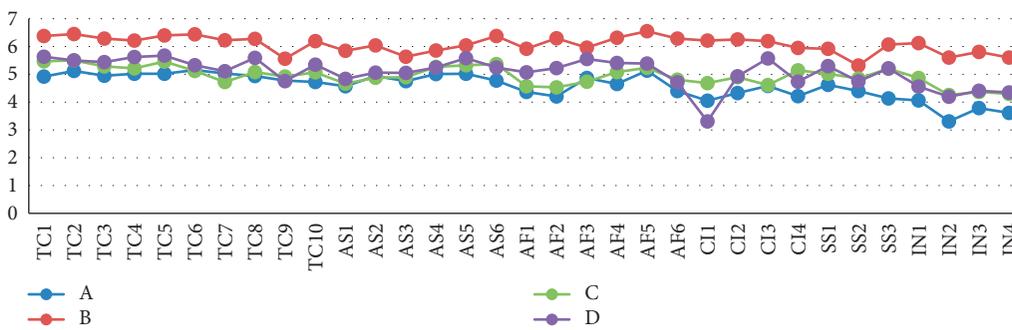


FIGURE 18: Performance sensitivity of the higher institution alternatives when criteria weights are increased by 50% for the OWA method.

considered when a minimal level of increase in criteria weights are needed. For other methods, 5% increase change in criterion CI 1, changed the ranking order. For example, the TOPSIS order of ranking changed from original ranking order of (B > D > C > A) to (HI B (0.9785) > HI C (0.4188) > HI D (0.2947) > HI A (0.2391)). This is shown in Table 7 and Figure 11

Meanwhile, when the increase of each individual criterion was at a higher level of 50%, the sensitivity analysis graphs showed that the Yager’s min-max can be adjudged to outperform the other methods: TOPSIS, Compensatory AND, OWA by being consistent and exceptionally tolerant in most instances than the other methods. For example, when each individual criterion was increased by 50%, the Yager’s min-max experienced only a single change in its ranked order of alternatives which was at CI1 as depicted in Figure 17 as against the original ranking in Table 7. However, the number of criteria with unstable/changed order of alternatives increased considerably with the TOPSIS method which is adjudged the most inconsistent and intolerant as depicted in (Figure 15, Table 9). Also, in second place is the Compensatory AND as depicted in (Figure 16, Table 9) and the thirdly inconsistent is OWA in (Figure 18, Table 9).

In summary, the sensitivity analysis indicated that irrespective of the increase in weights by 5% or 50%, Higher Institution B will always be the best ranked alternative, with the exception of the TOPSIS method in Figure 15 (with 50% increase in AS5 and AF3), which is otherwise confirmed as the most unstable method in the comparative analysis. This

established the robustness of the Higher Institution B as the best service rendering institution.

### 6. Conclusion and Future Work

This work presents a credible way to advance the status and reputation of higher institutions, by providing an approach for measuring quality of service in different institutions in a scientific manner. The approach presented in this study offers a reliable feedback system, which will enable the management of higher institutions to pay attention to their strengths and weak points in order to be properly positioned for improved service delivery and better global rankings among world universities. The investigation of the four MCDM (MAUT) methods, using the survey data, has been characterized through the ranking of the institutions and their respective computational procedure of combining data are explored. The robustness and reliability of the MCDM methods are identified and reinforced through their consistency in the ranking of the alternative institutions apart from the Yager’s min-max, which yielded slightly different results. Also, Ext-HiEDQUAL domain-specific service quality model for evaluating higher institutions was introduced and employed for the evaluation, which gives more consideration to specific quality of service in institutions. In view of this, relevant decision was made on the best institution in the context of day-to-day services that higher institutions are expected to render in line with global and international practices. This study also reveals each

institution's strong practice and weak practice to give room for improvement and good service delivery. Also, incorporating Fuzzy concept into the evaluation model injected a level of objectiveness in the decision-making process by capturing the intra-uncertainties of a decision-maker due to high level of subjectivity of the process. In future work, a higher level of objectiveness can be achieved in the decision-making process by incorporating enhanced interval type-2 Fuzzy concept to MCDM approaches. This will enhance the robustness of the decisions by capturing both inter-uncertainty among different decision-makers and intra-uncertainties of a decision maker.

## Data Availability

The dataset is a survey data from four institutions in Nigeria; it can only be released strictly on a formal request for verification.

## Conflicts of Interest

No conflicts of interest.

## Acknowledgments

The authors are grateful to the Covenant University for providing conducive environment and adequate support for carrying out this research work.

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