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A fuzzy hybrid decision-making framework for increasing the hospital disaster preparedness: The colombian case

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ABSTRACT

The recent increase in the number of disasters over the world has once again brought to the agenda the question of preparedness of the hospitals, which are the most necessary units of healthcare pillar to resist these disasters. The COVID-19 epidemic disease, which has affected the whole world, has caused a large number of people to die in some countries simply because of the inadequate and incomplete planning and lack of readiness of hospitals. For this reason, determining the disaster preparedness level of hospitals is an important issue that needs to be studied and it is important in terms of disaster damage reduction. In this study, a fuzzy hybrid decision-making framework is proposed to assess hospital disaster preparedness. The framework covers three important decision-making methods. For the first phase, Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) is used to assign relative weights for several disaster preparedness criteria considering uncertainty. Secondly, Intuitionistic Fuzzy Decision Making Trial and Evaluation Laboratory (IF-DEMATEL) is applied to identify interrelations among these criteria and feedback. Finally, via the VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method, priorities of hospitals regarding disaster readiness are obtained. A case study involving the participation of 10 Colombian tertiary hospitals is carried out to show the applicability of this fuzzy hybrid approach.

1. Introduction

Disasters adversely affect human life and the environment, as their destructiveness is high, and disrupt socioeconomic stability with their effects [1]. The amount and severity of disasters are increasing over the world and as a result, many deaths, diseases, and economic losses are experienced. The most vivid and up-to-date example of these devastating disasters is COVID-19, the viral epidemic that has recently affected the whole world. It is stated that this infectious disease first appeared on December 30, 2019 in a seafood market in Wuhan, China [2]. In a very short period, the infection spread first to certain countries of the world and then to all countries. The world health system, unfortunately, confronted infected patients who applied to hospitals and health facilities irregularly and suddenly, and interventions were interrupted from time to time. This virus has caused approximately 119 million cases and 2.6 deaths

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worldwide as of March 14, 2021 [3]. The symptoms of COVID-19 are not specific and may be encountered with symptoms that may vary from patient to patient, or no symptoms at all. The report WHO-China Joint Mission regarding COVID-19 states typical signs and symptoms include such as fever, sore throat and headache, fatigue, cough, and shortness of breath [4]. Like other countries in the world, COVID-19 has a strong impact on Colombian society and economy. It is evidenced through different epidemiological indicators. Up to the date of August 13, 2020, for instance, 422,519 cases are detected and 239,785 are recovered while 13,837 deaths are counted regarding this virus in Colombia. Besides, Colombia is now experiencing an accelerated spread of the virus which entails that the infection peak has already been reached. Considering the devastating negative effect of this virus or any other disasters, it is required to take into account the Colombian hospital care systems' dynamics and performance measures in times of disasters as well as evaluating the effectiveness of hospitals for improving their surge capacity.

Historically, Colombia has faced many devastating disasters. On average, it faces 8 disasters a year. These resulted in an average of 1043 deaths and 2937 injuries per year, according to figures in the Emergency Situations Database [5]. It is possible to read the disaster statistics of Colombia in detail from Fig. 1a–(d). According to these statistics, Colombia has faced 151 disasters in the last 21 years. It is noted that the recent COVID-19 figures are not included in these statistics. Flood and transport accidents accounted for more than 60% of the total number of disasters (n = 94/62%). The highest number of deaths occurred in 2010, with a total of 755. When an evaluation is made in terms of the number of injured people in these disasters, it can be easily seen that an epidemic experienced in 2019 caused the highest number of injured people (n = 79644). These disasters negatively affected the financial balance. Colombia, as a developing country, with a specific political and geographical context, is frequently hammered by outbreaks. Solid and applicable frameworks and decision support systems are needed to combat such disasters and to prepare hospitals, which are first response units in disasters, for these disasters.

The evaluation of hospitals preparedness is a relevant topic considering the disasters which Colombia has faced. According to Krein et al. [6]; it is important to point out, that highly contagious diseases such as SARS or Ebola in which the rate of transmission is very high, especially among healthcare workers, personnel need to be protected with necessary precautions and pre-determined treatment algorithms need to be applied. In this sense, there must be changes in policies, personnel behavior, training, and education of ambulance crew members and emergency department (ED) personnel. This situation has a strong impact on ambulance and ED services costs and system performance considering that the new policies may include the complete disinfection of ambulances, beds, rooms, and personnel for example. This situation affects the preparedness of both ambulances and ED, and consequently the capacity and costs of the hospital system [7]. On the other hand, the impact of disasters like epidemic outbreaks can be contradictory considering that the number of cases related to the disaster itself increases day after day in the hospitals (or at hospital EDs) [96]. This patient influx situation can be observed in the case of any disasters such as earthquakes, pandemics, terrorist and biological attacks. In

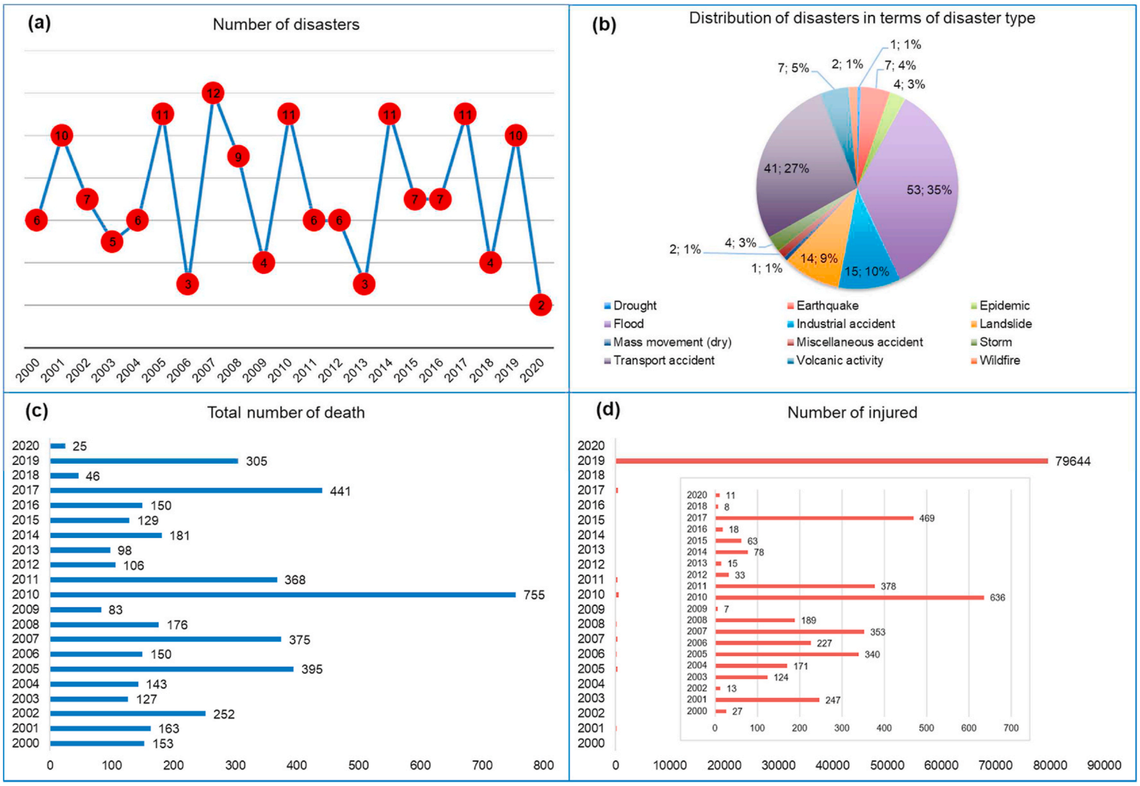


Fig. 1. Disasters in Colombia between the years 2000–2020 (EM-DAT database, 2020) (a) number of disasters, (b) distribution in terms of disaster type, (c) the total number of death, (d) number of injured.

these cases, medical institutions should be available for infrastructure and resource planning [8–10]. As can be understood from the studies in which the most important criteria in the disaster preparedness of hospitals are discussed in the literature, disasters directly affect the activities of hospitals [11–14]; and [15–17]. Therefore, adapting the hospital resource planning to disaster situations and increasing the preparedness of the hospitals for disasters will prevent loss of life, as well as facilitate the access of the society to health services.

Therefore, in this study, a fuzzy hybrid decision-making framework is proposed to assess hospital disaster preparedness. The framework includes Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP) [18,19], Intuitionistic Fuzzy Decision Making Trial and Evaluation Laboratory (IF-DEMATEL) [20], and VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [21,22] incorporation for two ultimate aims. The first is to weigh decision criteria based on interdependence and the second is to rank hospitals.

AHP, which is the most frequently applied multi-criteria decision-making (MCDM) method in determining criteria weights in a traditional decision-making problem, is considered under intuitionistic fuzzy sets. The intuitionistic fuzzy set concept is initially suggested by Atanassov [23]. It is a generalization of the classical fuzzy set theory of Zadeh [24]. The fuzzy set reflects vagueness and uncertainty well in computational analysis. While Zadeh's fuzzy set suggests merely one membership function, Atanassov's intuitionistic fuzzy set also provides a non-membership function. Therefore, we have merged it with AHP to assign weights to hospital disaster assessment criteria by linear dependency. Linear dependency is related to the hierarchical structure in AHP. The hierarchy shows the relationship between the elements of a level and the level elements immediately below. This relationship percolates down to the lowest levels of the hierarchy and how every element is connected to every other one, at least indirectly [25]. When comparing elements at each level, a decision-maker must compare only according to the contribution of lower-level elements to higher-level elements [26]. Besides, IF-AHP, we have also injected IF-DEMATEL into our proposed approach to identify interrelations among these criteria and feedback. DEMATEL is first developed as a network analysis approach based on graph theory [27,28]. It is structured by a causal relationship in a network and classifies the criteria under two groups of "cause" and "effect". To reflect the uncertainties encountered in reaching judgments in the DEMATEL method, an integrated approach with an intuitionistic fuzzy set has been adopted in this study. IF-DEMATEL has been applied to some crucial healthcare problems such as Ocampo and Yamagishi [29]. When the current knowledge is scanned, it is easily observed that merging AHP-DEMATEL under the intuitionistic fuzzy concept is indeed novel. Considering the importance of the topic of hospital disaster preparedness, the application of this novel approach in emergency aid and disaster management is scant. For the final stage of the proposed approach, a multi-criteria optimization and compromise solution method is used. This is named VIKOR. It is initially proposed by Opricovic [21] and applied to various healthcare problems such as evaluation of influenza intervention strategies [30], evaluation of hospital-based post-acute care [31], health risk assessment [33,95], selection of most appropriate classifier for people with dementia [10], hospital service quality evaluation [34], medical supplier selection [35] and so on. It ranks alternatives and generates the compromise solution which is the nearest to the "ideal solution" [97]. In our approach, we used VIKOR to rank hospitals considering their preparedness for the disasters. To do this, data for some key performance indicators for the assessed criteria has been gathered via direct interviews with the directors from the hospitals in Colombia. With the VIKOR method, we can calculate a consensus ranking for each hospital within the weights of the disaster preparedness criteria of the hospitals. First, this method determines a ranking for each hospital with a multi-criteria ranking index, taking into account the distances to the ideal solution. Secondly, its ability to provide highly accurate results based on three different indexes (S, R, and Q) including utility and regret measures and the simplicity of its algorithms in implementation make this method popular among other methods in the MCDM pool [36,37].

With this current study, we ultimately aim to provide some profound contributions to the literature. We develop our model for a general disaster event. From this aspect, it can be used as a generic framework and adapted to hospitals in other disaster events. We benefit from two main concepts: MCDM modeling and intuitionistic fuzzy set. The model we propose is about disaster preparedness assessment and ranking of hospitals. Our study differs from similar studies in the literature with the following points:

1. Our approach uses a comprehensive list of components (6) and sub-components (35) for disaster readiness assessment. Such elements will be extracted from the current research from the literature and reports of global institutions like WHO (for example, WHO's report on hospital preparedness against COVID-19 and other previous disasters) [38]. Also, in the ranking stage of the approach, some indicators of hospitals (time metrics such as waiting time, length of stay, overcrowding level, and patient flow time; metrics regarding the capability of equipment, staff, and hospital building, etc.) are gathered from the selected hospitals in Colombia. Our model can be founded on a solid background, and it is adaptable for all countries and disaster events.
2. We developed an intuitionistic fuzzy MCDM approach including AHP, DEMATEL, and VIKOR. In particular, IF-AHP is used for determining the relative importance of evaluation components/sub-components related to hospital disaster preparedness by linear dependency. Then, IF-DEMATEL is used to identify interrelations by causal and effect graphs. Finally, VIKOR is applied to the hospital ranking phase. Our approach can systematically and analytically handle the problem given the characteristics of MCDM methods and intuitionistic fuzzy modeling, either individually or integrated.

Our approach has been applied in Colombia's tertiary healthcare system (hospitals). Ten tertiary hospitals from Colombia were determined for this implementation. Analysis can guide hospital administrators and national policy-makers as to what aspects hospitals need to develop to improve their response against disaster events.

The remainder of this paper is organized as follows: Section 2 presents a literature review on the assessment of hospital disaster preparedness whereas Section 3 describes the proposed methodology. Section 4 outlines the results and analyses their major implications. Ultimately, Section 5 delineates the main conclusions and future research lines.

Table 1
Literature analysis of previous hospital disaster preparedness assessment studies.

Study	Disaster type	Country of case study	Study type	Methods used	Fuzziness in criteria weighting?	Interdependence evaluation between criteria?	No. of main criteria	Main criteria	No. of sub-criteria
Ortiz-Barrios et al. [47]	General	Turkey	MCDM-based	FAHP, FDEMATEL, TOPSIS	Yes	Yes	6	Hospital building, Equipment, Communication, Transportation, Personnel, Flexibility	36
Ortiz-Barrios et al. [48]	General	Colombia	MCDM-based	AHP, DEMATEL, TOPSIS	No	Yes	7	Environment, Quality, Caregivers, Materials, Technology, Patient safety, References	23
Hosseini et al. [9]	Earthquake	Iran	MCDM-based	TOPSIS	No	No	4	Structure, Non-structure, Functional, Human resources	21
Marzaleh et al. [49]	Radiation & nuclear incidents	Iran	MCDM-based, Cross-sectional questionnaire-based	AHP, Delphi	No	No	3	Staff, Stuff, Structure (system)	31
Tabatabaei and Abbasi [59]	All disaster types	Iran	Cross-sectional questionnaire-based	Hospital Safety Index Standard Questionnaire	No	No	3	Structure, Non-structure, Functional	145
Gul and Guneri [11]	Earthquake	Turkey	Conceptual	One to one interviews	No	No	3	Geological, Medical, Management	NA
Top et al. [60]	General	Turkey	Cross-sectional questionnaire-based	Questionnaire	No	No	1	Hospital disaster plan	32
Naser et al. [61]	General	Yemen	Cross-sectional questionnaire-based	WHO standards checklist 2011	No	No	9	Post-disaster recovery, Command & control, Communication, Safety & security, Logistics, and supply management, Triage, Surge capacity, Continuity of essential services, Human resources.	NA
Samsuddin et al. [62]	General	Malaysia	Cross-sectional questionnaire-based	Questionnaire	No	No	4	Structure, Non-structure, Functional, Resilience	243
Shabanikiya et al. [63]	General	Iran	Cross-sectional questionnaire-based	Delphi	No	No	5	Management of operations and spaces in disasters, Medication/equipment, Manpower, Administrative functions, Training/exercise/drills	13
Alruwaili et al. [23]	All disaster types	NA	Review (19 papers included)	PRISMA	No	No	NA	NA	NA
Omidi et al. [64]	General	Iran	Cross-sectional questionnaire-based	Checklist	No	No	10	Emergency, Admission, Discharge and Transfer, Traffic, Communications, Security, Training, Support, Manpower, Management	NA
Rezaei and Mohebbi-Dehnavi [65]	General	Iran	Cross-sectional questionnaire-based	Checklist	No	No	10	Emergency, Admission, Human resources, Transmission, Traffic, Security, Communication, Support, Management, Education	NA
Saeid et al. [1]	General	Iran	Cross-sectional questionnaire-based	Questionnaire	No	No	9	Post-disaster recovery, Command & control, Communication, Safety & security, Logistics, and supply management, Triage, Surge capacity, Continuity of essential services, Human resources.	NA

2. Review of the literature

Evaluation of hospitals (regardless of the concept of disaster preparedness) is a subject that has been extensively addressed and studied in the literature [39,40]. In this context, it is seen that researchers frequently use MCDM methods and especially Data Envelopment Analysis (DEA) [41–43]. In most of these studies, an evaluation was made according to the criteria that directly affect the quality of health services or the determined input/output variables. Here, in most studies, the resilience of hospitals in case of disaster times has been ignored. Studies developed for these situations were also discussed with the motivation of "evaluation of disaster preparedness of hospitals". The topic of disaster preparedness assessment of hospitals is not yet an area in which there are many studies in the literature [9,44–49]. While some of the studies conducted are conceptual or cross-sectional questionnaire-based studies by researchers from medical branches, others are MCDM-based studies where researchers from the field of computer science generally work. In conceptual-based studies, the readiness of hospitals against disasters is evaluated without any numerical tool. That is to say, multiple criteria and sub-criteria are determined and their relationship with disaster preparedness is established logically. Afterwards, a framework is revealed as a hierarchical or networked structure. In these studies, researchers evaluate the criteria in terms of structurality, human origin, or not in terms of functionality.

On a different note, in MCDM-based studies, researchers first put forward parameters such as "goal, criterion-sub criterion, alternative, decision-makers, criterion-sub criterion weights, performance values of alternatives according to each criterion" that a classic decision-making problem has. MCDM is the process of developing methods and procedures in which multiple and often conflicting criteria can be included in the planning and decision-making process. It has developed over the years as an essential field of Operations Research. It can be easily applied to the basic and sub-activities of decision-making, for example, disaster management. MCDM methods are used when selecting the most suitable one among several alternatives is necessary, or even ranking or prioritizing them according to different evaluation criteria. It provides a unique convenience to decision-makers and policy-makers to make the most appropriate decision with appropriate solutions. This feature makes MCDM attractive in addressing the different problems of healthcare and disaster management decisions. According to the Yalcin et al. [50]'s taxonomy, they are categorized under five classes as follows: (1) Pair-wise comparison-based methods [51–53], (2) outranking-based methods [54,55], (3) distance-based methods [53,56], (4) interaction-based methods [57], (5) utility-based methods [58].

In this problem, alternatives refer to hospitals, decision criteria, and sub-criteria refer to the decision measures that hospitals resort to in disaster preparedness. Then, depending on whether the data can be expressed with crisp numbers or not, methods based on the fuzzy logic concept using linguistic variables can also be used. Finally, all these are brought together and a decision-making matrix is formed. By employing this decision matrix, a final decision can be made applying various MCDM methods, including Order of Preference by Similarity to Ideal Solution (TOPSIS), VIKOR, Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), complex proportional assessment (COPRAS), and so on [36,37].

In this section, the studies regarding hospital disaster preparedness assessment are analyzed and classified as in Table 1. When Table 1 is examined in detail, it is easily inferred that cross-sectional questionnaire-based studies are mostly used in the hospital disaster preparedness assessment domain [1,59–65]. On a different tack, the type of MCDM-based studies which is within the scope of this study has not been adequately addressed in this domain [9,47–49]. As one of the results for this brief literature review and analysis, MCDM methods along with various versions of fuzzy sets can be successfully applied to this problem since they have not sufficiently been taken into account yet. Therefore, in this paper, intuitionistic fuzzy sets have been merged with AHP, DEMATEL, and VIKOR MCDM methods. A general type of Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method was followed in collecting the articles presented and compiled in this table (Table 1). We first identified the research directory ('Multi--Criteria Decision Making' OR ′Multi-Criteria Decision Analysis' OR 'MCDM' OR 'MCDA' AND ′Hospital disaster preparedness'). Afterwards, we systematically searched for English-language articles in Web of Science, Scopus, and Google Academic databases. However, we have not included the old date articles (published before 2010). Research and review articles are included in the literature review. The review also consists of the stages of scanning the literature, examining the title and abstract, and reading the full text. Studies thought to be irrelevant to the subject were excluded from this review. Full text reading was carried out at the end of the

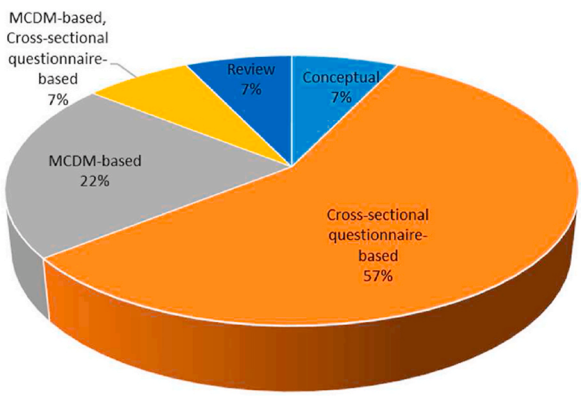


Fig. 2. Distribution of papers in terms of study type.

evaluation on these articles as indicated in Table 1. Table 1 categorizes the articles in terms of many features. These features are as follows: *Published year, Paper type, published outlet, Disaster type, Country of case study, Study type, Methods used, Fuzziness in criteria weighting, Interdependence evaluation between criteria, Number of main criteria, Main criteria,* and *Number of sub-criteria.* As a result of this review, some graphical analysis has been made regarding these features, and several inferences have been obtained. Graphical analysis for the study type is provided in Fig. 2.

Moreover, an analysis is also performed in terms of methods used in the study as shown in Fig. 3. When Fig. 3 is examined, it is seen that the studies generally used the methods of a checklist, questionnaire, AHP, and TOPSIS.

Regarding the usage of MCDM in hospital disaster preparedness assessment, it is known that integration of fuzzy set extensions with MCDM provides the ability in such modeling problems with more flexible results reflecting uncertainty of the problem [47]. For this reason, we proposed an extended fuzzy MCDM model (IF-AHP + IF-DEMATEL + VIKOR).

3. Methodology

A seven-phase methodology is suggested to assess the hospital disaster preparedness, pinpoint their major weaknesses, and create improvement interventions upgrading their response in presence of outbreaks such as the COVID-19 (Fig. 4). A detailed description of the suggested framework is as follows:

Phase 1. Selection of an expert decision-making team: A group of experts is chosen based on a set of inclusion criteria to support the creation of the disaster preparedness assessment model, the calculation of criteria and sub-criteria weights, and the evaluation of cause-and-effect interrelations among these decision elements.

Phase 2. Design of the disaster preparedness assessment model: The decision-making network is then constructed by incorporating criteria and sub-criteria derived from the experts' opinion, the pertinent healthcare regulations, and the related scientific literature.

Phase 3. Calculation of criteria and sub-criteria relative weights under uncertainty: IF-AHP method is then implemented to estimate the relative priorities of criteria and sub-criteria considering the suspicion that experts may have when performing the pairwise comparisons. IF-AHP outcomes will serve as a groundwork for the development of short-term intervention plans regarding hospital disaster preparedness.

Phase 4. Assessment of interrelations among criteria and sub-criteria considering uncertainty: IF-DEMATEL is implemented to evaluate the presence and strength of intertwined relationships among criteria and sub-criteria, considering the inherent uncertainty of eliciting comparisons in a network model.

Phase 5. Estimation of the hospital disaster preparedness index and hospital ranking elaboration: In this step, VIKOR is used for calculating a disaster preparedness index for each hospital. After this, the institutions are ranked in a decreasing order to easily identify those with high performance ($Q_j \leq 0.25$) as well as those with an immediate need of intervention ($Q_j > 0.25$) (see sub-section 3.1.3).

Phase 6. Identification of weaknesses: The next phase involves pinpointing the sub-criteria most contributing to the difference between the current disaster preparedness and the desired performance in each hospital using the $w_i(f_i^* - f_{ij})/(f_i^* - f_i^-)$ values resulting from the VIKOR method (see sub-section 3.1.3).

Phase 7. Design of focused improvement interventions targeting increased hospital disaster preparedness: Finally, potential causes related to each weakness are discussed to then devise intervention plans increasing the disaster preparedness of each hospital.

As previously evidenced, a fuzzy hybrid decision-making framework has been proposed to operationalize the hospital disaster preparedness model based on IF-AHP, IF-DEMATEL, and VIKOR methods. In addition to being the first study using this combination in the aforementioned context, the selection of these methods responds to the decision-making scenario inherent to hospital readiness in presence of human-made and/or disasters. The description of this scenario is outlined as follows:

i) *Weight elicitation under uncertainty*: Different qualitative and quantitative criteria from distinct areas of expertise have been pointed out as influencing the readiness of hospitals when facing sudden outbreaks. Such criteria are often conflicting and it is hence of paramount importance to define which priorities to use and how to obtain them taking into account the need for reaching a non-dominated result represented by a disaster preparedness index. We also aim to denote the preferences of various

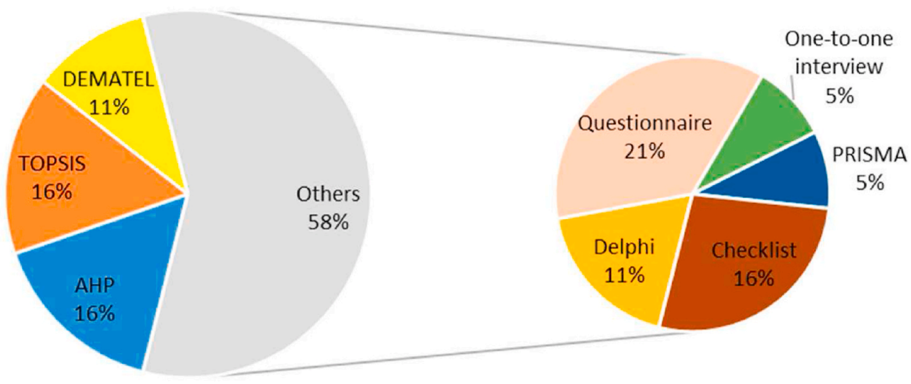


Fig. 3. Distribution of papers in terms of methods used.

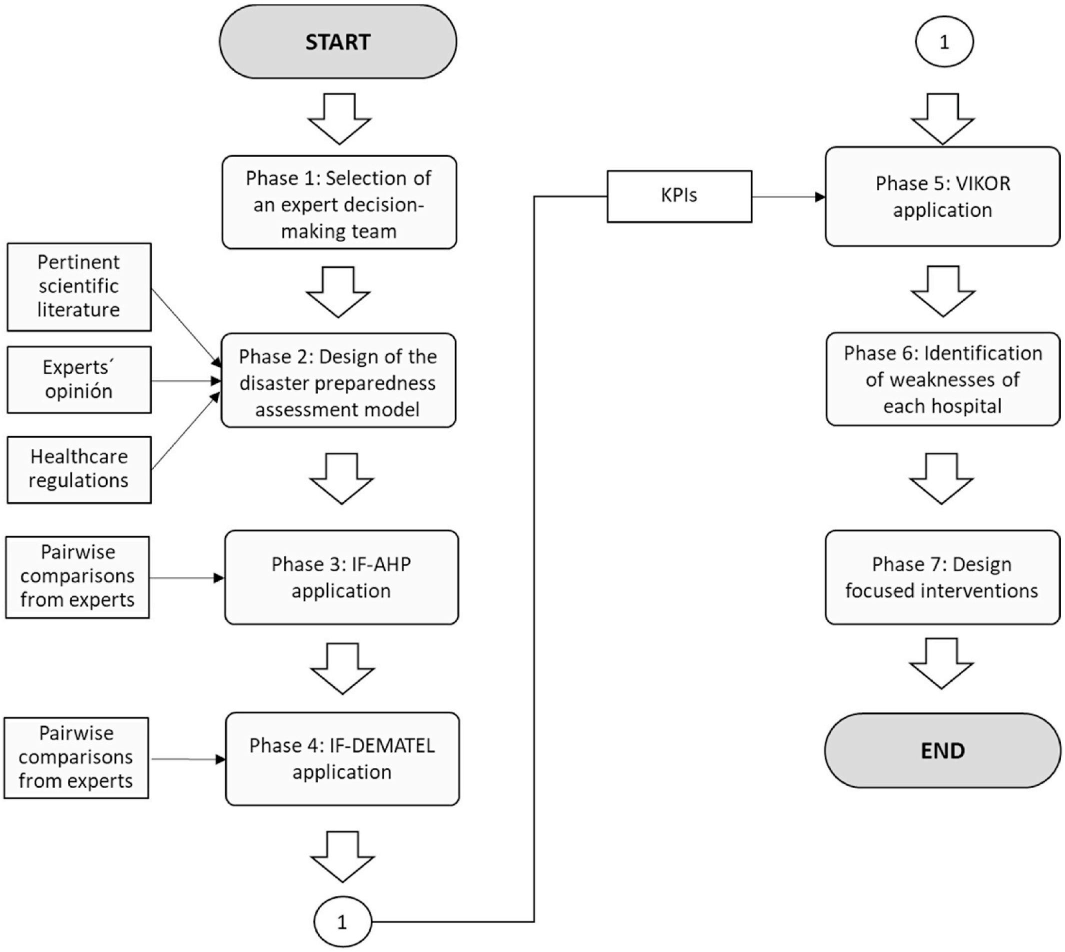


Fig. 4. The proposed methodology for increasing the disaster preparedness of hospitals.

hospital administrators, policymakers, and medical staff concerning the relative weights of these criteria. Additionally, there is a certain degree of imprecision in the knowledge about hospital preparedness in different disaster scenarios which requires the use of methods providing a more realistic representation of the decision-making context. The conventional AHP is suitable for weighting qualitative and quantitative factors [25,66,67] possibly affecting the overall goal of hospital preparedness. However, AHP is not capable of dealing with the uncertainty expected in this scenario which can be certainly addressed through its intuitionistic fuzzy version "IF-AHP" [68,69]. IF-AHP is suitable for responding to the above-mentioned considerations as: i) it allows eliciting the global and local relative weights of criteria and sub-criteria ii) it represents the uncertainty of experts' judgments by incorporating precise membership (degree of belongingness) and precise non-membership (degree of non-belongingness) [32]; in this case, an indeterministic part remains, iii) it takes into account the preferences emerging from experts who are part of the decision-making scenario [69], iv) it is straightforward to apply in the wild if appropriate data-collection tools are used, v) it allows comparing criteria or sub-criteria in a paired way rather than contrasting all of them concurrently, and vi) it considers crisp consistency based on Saaty's approach, which enables to evaluate the quality degree of the decision-making process [70]. Despite these advantages, IF-AHP holds some technical limitations. For instance, it does not consider the assumption of interdependence among criteria, a pattern often observed in the hospital performance context [71, 72]. Another shortcoming is that IF-AHP requires too many comparisons in presence of a significant number of alternatives (hospitals), thereby restricting its applicability for outranking purposes in practical scenarios. Based on the previous considerations, it is necessary to integrate other methods tackling the IF-AHP weaknesses as will be further explained in the next points.

ii) *Assessment of intertwined relationships among decision criteria:* Healthcare processes are scenarios where multiple care options, several patient pathways, and diverse treatment alternatives often converge. To support this, it is necessary to effectively administer the interactions among different performance criteria that accordingly affect the hospital response in the face of disasters. This requires elucidating cause-and-effect interrelations whose direction and strength underpin the creation of long-term intervention plans targeting increased disaster preparedness of hospitals. Expert decision-making teams can provide an overview of these interrelations given their wide experience and knowledge on both healthcare systems and disaster preparedness regulations. The realistic nature of this approach will also depend on the possibility of representing the vagueness and uncertainty inherent to human judgments. IF-DEMATEL can deal with these aspects because: i) it employs the graph theory for understanding complex network decision-making models as those exemplified in hospital disaster readiness [73], ii) it identifies dispatchers and receivers so that we can know where to focus the improvement strategies and how these will affect several disaster preparedness domains, iii) it considers the membership and non-membership functions as well as a hesitancy degree which jointly illustrate opposition, support, and neutrality that may appear when defining the influence of each criterion and sub-criterion [29], and iv) it takes into account the experts' opinion on how each criterion and sub-criterion affects the others.

iii) *Estimation of disaster preparedness index and identification of improvement points*: Hospitals need to know how far they are compared to the ideal disaster preparedness. In this regard, it is important to count on a general disaster preparedness index encompassing all the contributing criteria and sub-criteria. Such an index will allow decision-makers, policymakers, healthcare authorities, and other stakeholders to rank the hospital alternatives and undertake comparative studies among medical institutions with a similar legal framework and healthcare context. On a different note, it is of paramount relevance to look into the main causes leading to poor potential performance so that sectorial improvement interventions can be deployed for increasing the disaster preparedness of the entire healthcare system. VIKOR can efficaciously fulfill the methodological requirements behind these considerations since: i) it calculates the Q index, which can represent the multidimensional nature of hospital disaster preparedness, ii) it allows ranking the hospitals based on the Q index, and iii) it pinpoints the weaknesses of each hospital by considering the contribution of each $w_i(f_i^* - f_{ij})/(f_i^* - f_i^-)$ to S_j [74,75].

3.1. Intuitionistic Fuzzy Analytic Hierarchy Process (IF-AHP)

In this section, before explaining the IF-AHP and IF-DEMATEL, some preliminaries are provided regarding intuitionistic fuzzy sets. Then, the algorithms of IF-AHP and IF-DEMATEL are presented in detail. Intuitionistic fuzzy (IF) sets are firstly proposed by Atanassov [76] and have been applied by many scholars to various areas to handle uncertainty. In this case, IF logic is preferred over type-1 fuzzy sets since it is more capable to capture the imprecision inherent to complex decision-making problems through the introduction of a non-membership element added to the degree of membership proposed in normal fuzzy sets [69,77,78]. Unlike the type-1 fuzzy sets, IF logic also deals with the inaccuracy of judgments due to lack of knowledge (hesitancy degree), an aspect that may be expected in real-life applications given the high degree of uncertainty that disasters and hospital systems entail. In the following, some definitions of intuitionistic fuzzy sets which are required to set up the algorithms of IF-AHP and IF-DEMATEL are provided.

Definition 1. Let X be a set in a universe of discourse. An intuitionistic fuzzy set I has the form in the following [29,76,79]:

$$I = \{\langle x, \quad I(\mu_I(x), v_I(x))\rangle | x \in X\} \tag{1}$$

where $\mu_I(x) : X \mapsto [0,1]$ refers to the degree of membership and $v_I(x) : X \mapsto [0,1]$ refers to the degree of non-membership, and, for each $x \in X$, it takes:

$$0 \leq \mu_I(x) + v_I(x) \leq 1 \tag{2}$$

Also, the degree of lack of knowledge is as in Eq. (3).

$$\pi_I(x) = 1 - \mu_I(x) - v_I(x), \quad x \in X \tag{3}$$

Definition 2. As stated by Anzilli and Facchinetti [20] and Ocampo and Yamagishi [29]; the defuzzification process in intuitionistic fuzzy sets is defined as in Eqs. (4) and (5). Let C_φ be a defuzzification operator. This process is defined in two different steps as follows: (1) transformation of intuitionistic fuzzy set into a classical fuzzy set, and (2) assessment of classical fuzzy set via a defuzzification method. The operator of C_φ is depicted as in Eq. (4).

$$C_\varphi(I) = \{x, \mu_I(x) + \varphi\pi_I(x), v_I(x) + (1-\varphi)\pi_I(x), x\varepsilon X\} \text{ with } \varphi\varepsilon[0,1] \tag{4}$$

It can be noted that $C_\varphi(I)$ is a classical fuzzy subset with a membership function as given in Eq. (5) below:

$$\mu_\varphi(x) = \mu_I(x) + \varphi\pi_I(x). \tag{5}$$

Particularly, $\varphi = 0.5$ is a solution to the minimization problem $\min_{\varphi\varepsilon[0,1]} d(C_\varphi(I), I\Big)$. Here, d refers to the Euclidian distance. With $\varphi = 0.5$, the fuzzy set $C_{0.5}(I)$ is characterized by a membership function $\mu(x) = \frac{1}{2}(1 + \mu_I(x) - v_I(x)\Big)$. The part so far has been regarding the transformation of an intuitionistic fuzzy set into a classical fuzzy set. For the second step, which is the assessment of classical fuzzy set, any valid defuzzification method can be used such as the center of area.

Before setting up the steps of the IF-AHP algorithm, it is important to mention that a new triangular intuitionistic fuzzy numbers-based preference scale is used in this study. The measurement and computational steps of this new scale can be found in Karacan et al. [80]. In this new scale, triangular intuitionistic fuzzy numbers and their reciprocal values are calculated. Also, conversion of consistency expressions to membership grades is identified in certain interval values. For more details, one can refer to Abdullah and Najib

[19]'s study. The IF-AHP steps are then explained as follows:

Step 1: Definition of the evaluation criteria/sub-criteria (dimension/sub-dimension) regarding hospital disaster preparedness.

Step 2: Determination of the scale which can be used in pairwise comparison evaluation of criteria. The scale used in this study is the following [80] (Table 2):

Step 3: Determination of importance weights of experts who will evaluate the criteria/sub-criteria (dimension/sub-dimension) regarding hospital disaster preparedness. To assess experts and assign them a weight, a triangular intuitionistic fuzzy scale which is suggested by Boran et al. [77] is used. According to this scale, five linguistic terms as Very important, Important, Medium, Unimportance, and Very unimportance and their corresponding triangular intuitionistic fuzzy numbers as (0.90, 0.05, 0.05), (0.75, 0.20, 0.05), (0.50, 0.40, 0.10), (0.25, 0.60, 0.15), and (0.10, 0.80, 0.10) are used. To assign a weight to any of the experts, the following formulation is applied.

Let $D_k = (\mu_k, \nu_k, \pi_k)$ is an intuitionistic fuzzy number for assessing of the kth expert. The ω_k refers to the weight of kth expert.

$$\omega_k = \frac{(\mu_k + \pi_k(\mu_k/(\mu_k + \nu_k)))}{\sum_{k=1}^{t}(\mu_k + \pi_k(\mu_k/(\mu_k + \nu_k)))} \tag{6}$$

Step 4: Building the aggregated intuitionistic fuzzy decision matrix based on experts' pairwise comparison evaluations.

Let $R^{(k)} = (r_{ij}^{(k)})_{mxn}$ is an intuitionistic fuzzy decision matrix of the kth expert. An operator called "intuitionistic fuzzy weighted averaging (IFWA) aggregation operator" is used to aggregate all the experts' pairwise comparison evaluations on the criteria/sub-criteria (dimension/sub-dimension) regarding hospital disaster preparedness.

$$r_{ij} = IFWA_{\omega} = \left(r_{ij}^{(1)}, r_{ij}^{(2)}, \ldots., r_{ij}^{(t)}\right) = \omega_1 r_{ij}^{(1)} \oplus \omega_2 r_{ij}^{(2)} \oplus \ldots \oplus \omega_t r_{ij}^{(t)} \tag{7}$$

$$IFWA_{\omega} = \left(1 - \prod_{k=1}^{t}\left(1 - \mu_{ij}^{(k)}\right)^{\omega_k}, \prod_{k=1}^{t}\left(\nu_{ij}^{(k)}\right)^{\omega_k}, \prod_{k=1}^{t}\left(1 - \mu_{ij}^{(k)}\right)^{\omega_k} - \prod_{k=1}^{t}\left(\nu_{ij}^{(k)}\right)^{\omega_k}\right) \tag{8}$$

Here, $r_{ij} = (\mu_{ij}, \nu_{ij}, \pi_{ij})$.

Step 5: Calculation of the consistency ratio (CR) for the aggregated intuitionistic fuzzy decision matrix. Here, the CR is calculated considering the hesitancy degree $\pi(x)$ of the aggregated fuzzy decision matrix. The classical CR calculation is as in Eq. (9) which is proposed by Saaty [81]. The use of crisp consistency of Saaty' method is recommended for all types of fuzzy sets [32].

$$CR = \frac{((\lambda_{max} - n)/(n-1))}{RI} \tag{9}$$

Here n is the number of the criteria/sub-criteria (dimension/sub-dimension) regarding hospital disaster preparedness. A value of lower than 0.10 is satisfying for a CR [81]. If the CR is greater than 0.10, the pairwise comparison of the expert must be reassessed. The changing value of RI in times of a change in the size of matrices can be found in Abdullah and Najib [19].

Step 6: Computation of the intuitionistic fuzzy weights of the aggregated intuitionistic fuzzy decision matrix.

$$\overline{\overline{w_i}} = -\frac{1}{n ln2}(\mu_i ln\mu_i + \nu_i ln\nu_i - (1-\pi_i)\ln(1-\pi_i) - \pi_i ln2) \tag{10}$$

$$w_i = \frac{1 - \overline{\overline{w_i}}}{n - \sum_{i=1}^{n}\overline{\overline{w_i}}} \tag{11}$$

Step 7: If the weights are not normalized, it must be normalized in order to ensure $\sum w_i = 1$.

3.2. Intuitionistic Fuzzy Decision Making Trial and Evaluation Laboratory (IF-DEMATEL)

After giving the details regarding the intuitionistic fuzzy set in Section 3.1.1, the algorithm of IF-DEMATEL includes the following steps.

Step 1: Determination of the evaluation criteria/sub-criteria (dimension/sub-dimension) regarding hospital disaster preparedness.

Step 2: Construction of direct relation matrix. Here the evaluations of the expert group on consensus are in intuitionistic fuzzy sets. The expert group determines the $\mu_I(x)$ and $\nu_I(x)$ values. The $\pi_I(x)$ values are computed as in Eq. (3). Each element of expert' assessment is demonstrated as a 2-tuple intuitionistic style. The judgment scale is as follows: Null influence $<0.1, 0.9>$, Low influence $<0.35, 0.6>$, Medium influence $<0.5, 0.45>$, High influence $<0.75, 0.2>$, and Very high influence $<0.9, 0.1>$.

Table 2
Linguistic terms and fuzzy numbers in IF-AHP.

Definition	Intuitionistic fuzzy number
Much more important	(0.33, 0.27, 0.40)
More important	(0.13, 0.27, 0.60)
Equally important	(0.02, 0.18, 0.80)
Less important	(0.27, 0.13, 0.60)
Much less important	(0.27, 0.33, 0.40)

Step 3: Computation of the corresponding membership degree of the equivalent fuzzy subset. Here, in this step, in order to proceed, it is required to defuzzify the experts' assessment which is in intuitionistic style. We follow the procedure of Anzilli and Facchinetti [20] as discussed in Definition (2). In the first step, the intuitionistic fuzzy set is converted into a corresponding standard fuzzy subset via $\mu(x) = \frac{1}{2}(1 + \mu_I(x) - \nu_I(x)\Big)$. Thus, the initial-direct relation matrix in standard fuzzy subsets is constructed.

Step 4: Defuzzify the standard fuzzy subset values. To proceed in this step, the membership functions determined at the end of Step 3 are assigned to a triangular fuzzy number. The membership function of this triangular fuzzy number is computed, as usual. The obtained values make up the initial-direct relation matrix values in crisp numbers.

Step 5: Construct the normalized direct-relation matrix. The normalized direct-relation matrix (G) is calculated using the standard crisp DEMATEL steps as in Eqs. 12–14.

$$G = g^{-1}X. \tag{12}$$

$$g = max\left(\max_{1\le i\le n}\sum_{j=1}^{n}x_{ij}, \max_{1\le j\le n}\sum_{i=1}^{n}x_{ij}\right) \tag{13}$$

$$X = \left(x_{ij}\right)_{nxn} = \left(\frac{\sum_{K=1}^{h}w_k x_{ij}^{k}}{\sum_{K=1}^{h}w_k}\right)_{nxn} \tag{14}$$

Here, w_k refers to the importance weight of kth expert. The X describes the aggregate direct-relation matrix.

Step 6: Obtain the total relation matrix (T). This matrix is achieved using Eq. (15) as follows:

$$T = G(I - G)^{-1} \tag{15}$$

Here, I refer to the identity matrix. Net cause and net effects are identified. The following equations (Eqs. (16) and (17)) are used to calculate the prominence vector $(D + R^T)$ and relation vector $(D - R^T)$.

$$D = \left(\sum_{j=1}^{n}t_{ij}\right)_{nx1} = (t_i)_{nx1} \tag{16}$$

$$R = \left(\sum_{i=1}^{n}t_{ij}\right)_{1xn} = (t_j)_{1xn} \tag{17}$$

Step 7: Draw the prominence-relation map digraph.

3.3. VIKOR

The VIKOR method was developed [21] as an MCDM method. It presents a compromised solution for rank and selection problems taking into account conflicting criteria. The compromise solution is a feasible solution that is the closest to the ideal solution like TOPSIS [22]. The algorithm of the VIKOR method includes the following steps [21,22,82]:

Step 1: Let us have n hospitals that are denoted as $H_1, H_2, ..., H_n$. For alternative H_j, the related rating of the ith criterion is denoted by $f_{ij}(i = 1, 2, ..., m; j = 1, 2, ..., n)$. Determine the best f_i^* and the worst f_i^- values of all criterion functions, $i = 1, 2, ..., m$. If the ith function represents a benefit or cost then:

$$f_i^* = \max_j f_{ij},\ \ f_i^- = \min_j f_{ij},\ \text{ if the } i\text{th function represents a benefit,}$$

$$f_i^* = \min_j f_{ij},\ \ f_i^- = \max_j f_{ij},\ \text{ if the } i\text{th function represents a cost}$$

Step 2: Compute the values S_j andR_j using Eqs. 18 and 19.

$$S_j = \sum_{i=1}^{n} w_i\left(f_i^* - f_{ij}\right) / \left(f_i^* - f_i^-\right) \tag{18}$$

$$R_j = \max\left[w_i\left(f_i^* - f_{ij}\right) / \left(f_i^* - f_i^-\right)\right] \tag{19}$$

Step 3: Calculate Q_j values by Eq. (20).

$$Q_j = v\frac{(S_j - S^*)}{(S^- - S^*)} + (1 - v)\frac{(R_j - R^*)}{(R^* - R^*)} \tag{20}$$

Here, $S^* = \min_j S_j,\ \ S^- = \max_j S_j,\ \ R^* = \min_j R_j,\ \ R^- = \max_j R_j$, $v \in [0, 1]$ is refers to the maximum group utility.

Step 4: Rank the hospitals, according to the S R, and Q values (in decreasing order).

Step 5: Propose a compromise solution to the alternative A_1 , which is ranked as the best by the measure Q (minimum) if two conditions of VIKOR are satisfied [21,22,82].

4. Results

4.1. The expert team

In this decision-making context, an expert team is of paramount importance i) to identify the criteria and sub-criteria potentially affecting the disaster preparedness of hospitals (see subsection 4.2 **The disaster preparedness assessment model)**, ii) to determine the relative priorities of these decision elements in the disaster preparedness index of each institution (the IF-AHP application), and iii) to evaluate interdependence and feedback among disaster preparedness factors and sub-factors (IF-DEMATEL application). Particularly, we had the support of five highly qualified experts who were previously selected based on the following inclusion criteria (Table 3): i) experience in disaster management (9 years as a minimum), ii) wide knowledge and education (both undergraduate and post-graduate) in healthcare or management-related areas, iii) current position related to healthcare management, and iv) involvement in disaster management roles. They usually act as a decision-making unit called "external commission" which provides recommendations and guidelines to the healthcare authorities in the management of disasters and healthcare affairs. The sample size of experts (n = 5) was based on CL = 95%, p = 50%, and e = 5% which reinforces the appropriateness of conclusions derived from this study. These experts (E1, E2, E3, E4, and E5) previously gave formal consent on their participation in the here described intervention. Apart from these participants, 3 researchers with PhD. in Industrial Engineering (2) and PhD. in Industrial Production and Operations in addition to wide knowledge in MCDM and healthcare improvement, acted as the leaders of this implementation in the hospital sector. Specifically, they designed the disaster preparedness assessment model with the aid of the experts, explained to decision-makers how to perform the pairwise comparisons in both IF-AHP and IF-DEMATEL methods, and identified a suitable set of metrics for underpinning the VIKOR implementation.

4.2. The decision model

A hospital disaster preparedness model was designed considering different criteria and sub-criteria involved in the disaster preparedness assessment of hospitals. The hierarchy is integrated by 6 criteria and 35 sub-criteria supporting the evaluation of 10 hospitals (H1, H2, H3, …, H10). These criteria and sub-criteria were defined considering the related Colombian legal framework from the Ministry of Health and Social Protection (Resolution 3100–2019, Resolution 4445–1996, Decree 780–2016, Decree 582–2017, Decree 583–2017), the experts' opinion, and the related scientific literature. Afterwards, the final model was socialized with the expert team to assure its clear and consistent understanding before the implementation of the IF-AHP and IF-DEMATEL methods. A brief description of each criterion is outlined in Table 4.

Below is a definition of each sub-criterion integrating the decision-making model. Particularly, *"Physical infrastructure (SC01)"* evaluates the physical condition of core hospital wards and their supporting services. *"Localization (SC02)"* considers the distance between the hospital and the target community. On the other hand, *"Number of storeys (SC03)"* refers to the number of plants that the medical institution has arranged for serving patients affected by a disaster. *"Installed capacity (SC04)"* estimates the number of nurses, doctors, and medical support staff available for healthcare provision during outbreaks. Another relevant sub-criterion in this hierarchy is the *"Disaster meeting point (SC05),"* which verifies if there are disaster meeting zones established by the hospitals for effectively managing patient flows in a chaotic scenario. *"Isolation (SC06)"* denotes how well the hospital has implemented and maintained isolated practices for avoiding the spread of potential airborne infections within their rooms. The last criterion in *"Hospital Buildings"* cluster is *"Ventilation (SC07)"* which determines whether the hospital has adopted appropriate ventilation systems within their wards so that high-quality indoor air can be kept while lowering nosocomial infections.

In the *"Equipment and supplies"* group, *"Medicaments (SC08)"* denotes the average service level or fill rate established by the hospital about the medicines provided in response to the services demand resulting from the disaster situations. Regarding *"Safety supply management (SC09)"*, our model verifies whether the hospital has adopted Material Safety Data Sheets (MSDS) standards along their supply chains. On a different tack, *"Medical equipment for Emergency care services (SC10)"* established the proportion of medical equipment that is available for supporting healthcare in the course of an outbreak. Another sub-criterion included in this cluster is *"Electric generator (SC11)"* which checks if the hospital has installed an independent electrical generator underpinning hospital operations in case of a power blackout or other failures in the power supply. Meanwhile, *"Potable Water Supply (SC12)"* assesses the availability and accessibility to water with <1 coliform bacterium/100 ml within the medical institution. Besides, *"Tent availability*

Table 3
Description of experts' profile.

Expert	Profession	Years of working experience	Current position
E1	Nurse with MSc. in Healthcare Management and specialization degree in Health Services Audit	12	National Healthcare Risk Manager in a health insurance company
E2	Nurse with MSc. in Epidemiology and Public Health. She also holds a specialization degree in Quality Management and Health Services Audit	9	National Healthcare Project Manager in a hospital
E3	Bacteriologist with MSc. in Epidemiology	10	Professor in a Health Sciences department
E4	Dentist with MSc. in Healthcare Management	30	Healthcare Manager/Secretary of Health
E5	Medical surgeon with MSc. in Healthcare Management	36	Healthcare Manager

Table 4
Description of criteria.

Criterion	Sub-criterion	Criterion Description
Hospital Buildings (C1)	Physical infrastructure (SC01) Localization (SC02) Number of storeys (SC03) Installed capacity (SC04) Disaster meeting point (SC05) Isolation (SC06) Ventilation (SC07)	This criterion evaluates how ready the hospital infrastructure is in terms of availability and quality for effectively facing potential outbreaks. Significant differences concerning the required performance may result in poor response to the healthcare demands caused by a disaster [83].
Equipment and Supplies (C2)	Medicaments (SC08) Safety supply management (SC09) Medical equipment for Emergency care services (SC10) Electric generator (SC11) Potable Water Supply (SC12) Tent availability (SC13) Food services (SC14) Hospital beds (SC15) Triage label (SC16) Financial resources (SC17) Supply Source (SC18)	This domain evaluates the availability of areas, services (electricity and water), financial resources, supplies, and equipment that are necessary for effectively addressing a disastrous situation [84].
Networks and Communications (C3)	Emergency service network (SC19) Communications channels/ equipment (SC20) Information Quality (SC21)	It assesses the hospitals' ability to manage the collaboration flows with the nodes integrating the emergency service networks. In addition, it reveals how each hospital use different communication channels for optimizing the information flows during outbreaks [74].
Transport (C4)	Number of ambulances (SC22) Heliport area (SC23) Safety (SC24) Road accessibility (SC25)	It verifies how ready the transportation infrastructure and fleet of a particular hospital are for facing the logistical demands, especially the patient transfers, emanating from the disaster scenario [85].
Human Resources (C5)	Education and training (SC26) Disaster drill (SC27) Emergency response team (SC28) Integration and coordination (SC29) Number of emergency staff (SC30) Working time (SC31)	This criterion encompasses the availability, education, skills, coordination, and management of human resources involved in the disaster response teams set by the hospitals [86].
Adaptability (C6)	Flexibility in the use of facilities (SC32) Contingency staff (SC33) Blood bank (SC34) Flexible supply of medicines and medical materials (SC35)	This criterion measures the hospitals' capacity to provide their services to the largest possible number of patients under disaster situations considering standards of flexibility in the use of facilities, medicine, medical materials, and contingency staff [87].

(SC13)" corroborates whether the hospital has set at least one tent area for disaster attention while *"Food services (SC14)"* verifies whether the hospital has created a food service department for supporting the nutritional needs of patients derived from the disaster. On the other side, *"Hospital beds (SC15)"* denotes the number of hospital beds that are available for those injured after a disastrous event. *"Triage label (SC16)"* verifies if the medical center has adopted triage labels for identifying and monitoring patients. The next sub-criterion, *"Financial resources (SC17)"* measures the budget availability for supporting operations in the aftermath of disaster events, whereas *"Supply Source (SC18)"* checks the availability of equipment supplying sources in the hospital during an outbreak.

In the *"Networks and communications"* domain, *"Emergency service network (SC19)"* determines whether the hospital is part of an integrated Emergency Service Network so that patient transfers can be fully supported, targeting faster and more effective healthcare. The second decision element is *"Communications channels/equipment (SC20)"* which evaluates the availability of a communication platform underpinning the collaboration flows with other hospitals integrating the network. The last sub-criterion in this category is *"Information Quality (SC21)"* which determines how well the healthcare information can be disseminated both outside and inside the hospital during an outbreak.

Also, four sub-categories were considered in the *Transport* criterion. First, *"Number of ambulances (SC22)"* denotes the number of ambulances that the medical institution can use for responding to a disaster event. In turn, *"Heliport area (SC23)"* determines if the medical institution counts on heliports close to their diagnosis and treatment areas so that patients resulting from a disaster can be safe and efficiently cared for. The next element is *"Safety (SC24)"* which estimates the number of security guards the hospital has for monitoring and controlling the behavior of patients and their families which may become unstable throughout the disaster. Another aspect to be considered in this domain is the *"Road accessibility (SC25)"* which specifies how well the physical road conditions between the disaster epicenter and hospitals are considering if they are paved and passible.

Concerning *"Human Resources"* area, six sub-criteria were considered. *"Education and training (SC26)"* establishes the number of disaster management training courses created by the medical institution for reducing potential adverse events generated by the medical staff in the course of a disaster. Secondly, *"Disaster drill (SC27)"* measures the number of disaster drills performed by the medical center to reduce non-adherence to healthcare protocols in case of a disaster. Another sub-criterion of relevance in this category is *"Emergency response team (SC28)"* which evaluates the potential emergency response degree of all medical staff when using the disaster preparedness procedures established by the hospital and healthcare authorities. *"Integration and coordination (SC29)"* estimates the co-working level between the medical and administrative staff of the hospital considering the disaster drill results. It is also of paramount importance to consider *"Number of emergency staff (SC30)"* to create training plans for those hospital workers non-skilled in disaster management. The last element in this category is *"Working time (SC31)"* which calculates the average time devoted by the hospital trained staff to disaster management activities.

Another criterion integrating the backbone of this model is *Adaptability* which takes four decision elements into account. First, *"Flexibility in the use of facilities (SC32)"* determines the number of administrative zones that can be rearranged for healthcare, especially in disastrous events. *"Contingency staff (SC33)"* denotes the availability of additional support personnel or allies trained in disaster management for helping frontline workers to face the excess demand on healthcare services. The next sub-criterion in this cluster is *"Blood bank (SC34)"* which verifies if the blood availability presented in the hospital is sufficient to effectively address the demand resulting from the outbreak. Ultimately, *"Flexible supply of medicines and medical materials (SC35)"* has been included in the model to stipulate the number of allied companies supplying medication and consumables to the hospital and having an extra production capacity that may be assigned to the medical center in case of demand peaks.

4.3. Fuzzy linear dependency: the IF-AHP implementation

IF-AHP was employed to obtain the final relative weights of criteria and sub-criteria in the hospital disaster preparedness model. An easy-to-use survey was designed by the facilitators to gather the paired comparisons required in IF-AHP. The expert team performed the judgments by employing the scale depicted in subsection 3.1 (Table 2). Then, the importance weights of experts (refer to Table 5) who evaluated the criteria/sub-criteria regarding hospital disaster preparedness were calculated according to Boran et al. [57] and Karacan et al. [80] by using Eq. (6). The weights of experts were defined by the researchers leading this implementation (see Section 4.1) by analyzing their profile in terms of experience and relevance to the topic of hospital disaster preparedness. In this case, the expert with the highest relative weight was E1 (0.278), given their wide knowledge and experience in the disaster preparedness field.

The pairwise comparisons expressed by the experts enrolled in the decision-making unit were then aggregated using the IFWA operator (Eq. (7)) [88,89]. An example of this step (Aggregated fuzzy matrix of criteria) is found in Table 6. Afterwards, the final relative weights of criteria and sub-criteria are calculated by using Eqs. (9) and (10). An illustration of this procedure is outlined in Table 7 (matrix of criteria).

The resulting ranking of criteria is shown in Fig. 5. Also, the overall weights of criteria/sub-criteria (OW) and local priorities, were enlisted in Table 8. The CR assessment was undertaken for each aggregated intuitionistic fuzzy matrix by implementing the crisp consistency of Saaty' method (Eq. (9)). The resulting CR values for the matrixes are the following: Criteria (5.35%), Hospital buildings (4.83%), Equipment and Supplies (8.84%), Networks and Communications (1.21%), Transport (2.78%), Human resources (7.42%), and Adaptability (1.51%).

4.4. Fuzzy interrelations and feedback: the IF-DEMATEL implementation

The decision-making team was also asked to express their judgments regarding the interdependence and feedback among the criteria and sub-criteria integrating the disaster prepared model. The experts employed the comparison scale depicted in Section 3.1.2 (Step 2), which contains a set of 2-tuple numbers $< \mu_I(x),\ \nu_I(x) >$ denoting the opposition, support, and neutrality that may appear when establishing the influences between the compared elements. Close follow-up was implemented by the leading researchers to avoid whimsical judgments during the decision-making process. Table 9 presents the direct-relation matrix (in intuitionistic fuzzy sets) derived from the expert 1 concerning the *Networks and Communications* sub-criteria. The subsequent step was to defuzzify the standard intuitionistic fuzzy set (IFS) values through a two-step algorithm. First, we transformed the IFS into their respective standard fuzzy subsets by using the formula $\mu(x) = \frac{1}{2}(1 + \mu_I(x) - \nu_I(x)\Big)$ presented in Step 3 (Sub-section 3.1.2) as exemplified in Table 10. The following step in the defuzzification process was to use a defuzzification function converting the fuzzy subset into a crisp value (Step 4 – Sub-section 3.1.2). To address this, the values in Table 10 are allocated to the triangular fuzzy number <0, 4, 4> The resulting crisp direct-relation matrix for *Networks and Communications* sub-criteria (Expert 1) is outlined in Table 11. Afterwards, we aggregated the crisp values of experts by using the arithmetic mean (Table 12). Then, the normalized direct-relation matrix (G) presented in Table 13 is calculated via applying Eq. (12)–(14). Subsequently, the total relation matrix (Table 14) is achieved by employing Eq. (15). The prominence $D + R^T$ (Eq. (16)) and relation $D - R^T$ (Eq. (17)) values resulting from the total-relation matrixes have been enlisted in Table 15.

Interrelations among the criteria/sub-criteria of each cluster were further studied by drawing prominence-relation map digraphs. The orange arrows represent feedback relationships whilst the blue ones denote one-direction dependencies. Some examples are presented in Fig. 6 Fig. 7. For instance, the influential-relation map for criteria is shown in Fig. 6a. Specifically, the adopted threshold in this cluster was set as $p = \frac{25.376}{6^2} = 0.705$. Similarly, the existing interdependence among *Networks and communications* sub-criteria

Table 5
Relative weights of experts.

Expert	E1	E2	E3	E4	E5
IFN	(0.90, 0.05, 0.05)	(0.75, 0.20, 0.05)	(0.5, 0.4, 0.1)	(0.5, 0.4, 0.1)	(0.5, 0.4, 0.1)
Weight	0.278	0.232	0.163	0.163	0.163

Table 6
Aggregated intuitionistic fuzzy matrices for criteria.

	C1	C2	C3	C4	C5	C6
C1	(0.020, 0.180, 0.800)	(0.083, 0.226, 0.691)	(0.133, 0.237, 0.630)	(0.135, 0.216, 0.649)	(0.114, 0.176, 0.710)	(0.149, 0.237, 0.614)
C2	(0.168, 0.150, 0.681)	(0.02, 0.180, 0.800)	(0.126, 0.230, 0.644)	(0.088, 0.230, 0.682)	(0.191, 0.216, 0.593)	(0.150, 0.253, 0.597)
C3	(0.196, 0.169, 0.635)	(0.180, 0.172, 0.648)	(0.020, 0.180, 0.800)	(0.171, 0.216, 0.613)	(0.039, 0.193, 0.769)	(0.065, 0.212, 0.723)
C4	(0.139, 0.202, 0.658)	(0.180, 0.148, 0.672)	(0.139, 0.236, 0.625)	(0.020, 0.180, 0.800)	(0.114, 0.176, 0.710)	(0.083, 0.226, 0.691)
C5	(0.096, 0.191, 0.712)	(0.176, 0.238, 0.586)	(0.066, 0.171, 0.763)	(0.096, 0.191, 0.712)	(0.020, 0.180, 0.800)	(0.209, 0.253, 0.538)
C6	(0.196, 0.180, 0.624)	(0.234, 0.160, 0.606)	(0.128, 0.159, 0.714)	(0.168, 0.150, 0.681)	(0.234, 0.207, 0.559)	(0.020, 0.180, 0.800)

Table 7
Final relative weights for criteria.

Criterion	Intuitionistic fuzzy weight	Non-fuzzy weight	Overall weight
C1	(0.106, 0.212, 0.682)	0.333	0.146
C2	(0.124, 0.210, 0.666)	0.371	0.163
C3	(0.112, 0.190, 0.698)	0.370	0.163
C4	(0.113, 0.195, 0.693)	0.366	0.161
C5	(0.111, 0.204, 0.685)	0.351	0.154
C6	(0.163, 0.173, 0.664)	0.486	0.213
Total		2.278	1.000

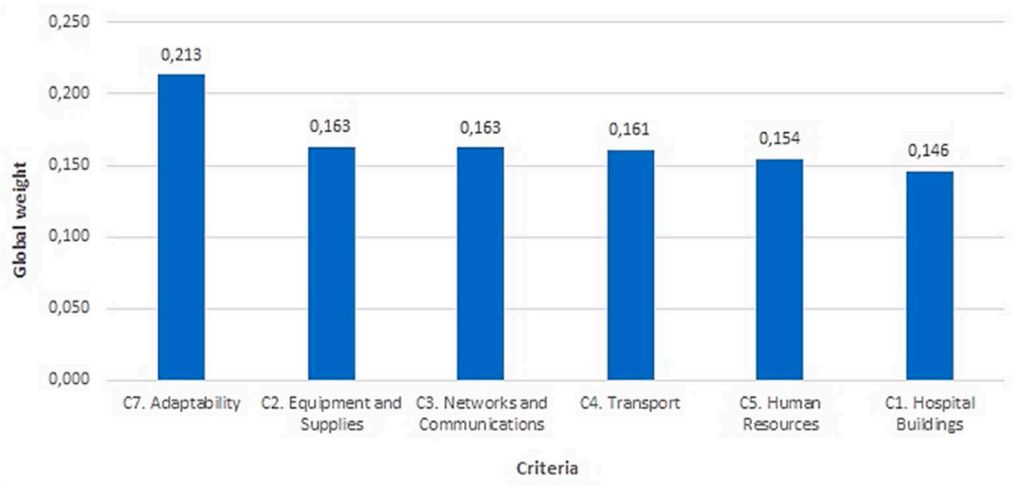


Fig. 5. Multicriteria decision-making model for assessing the disaster preparedness of hospitals.

was elucidated in Fig. 6b considering $p = \frac{33.325}{3^2} = 3.703$. Also, the prominence-relation set was graphed for appraising the interrelations among the *Flexibility* sub-components (Fig. 7a). The reference value set for this group of sub-criteria was $p = \frac{42.558}{4^2} = 2.660$. Finally, existing interdependencies among sub-elements of the *Adaptability* cluster were reported in Fig. 7b ($p = \frac{47.4567}{6^2} = 1.3182$).

4.5. Ranking of hospitals: the VIKOR application

This section shows the detailed implementation of the VIKOR method whose primary aim is three-fold: i) to calculate the disaster preparedness index of 10 Colombian hospitals (H1, H2, H3, H4, H5, H6, H7, H8, H9, and H10), ii) to identify those aspects in which each hospital should improve to increase its response against future disastrous events, and iii) to design interventions focused on the main shortcomings identified through VIKOR. Specifically, H1 provides a wide variety of healthcare services (including surgery and maternal care) while offering 118 available beds to the target community. H2 is specialized in neuroscience, neurosurgery, internal medicine, and cardiology. On the other hand, H3 is characterized by supplying low-, medium-, and high-complexity healthcare attention and has 400 beds for supporting its comprehensive and specialized care of patients. H4 is a leading hospital specialized in kidney, liver, and pancreas transplantation with an installed capacity of more than 100 beds. Meanwhile, H5 supplies surgery, hospitalization, intensive care, gynaecology, and obstetrics services to a large community in the region. H6 primarily provides a wide range of services including imaging, hospitalization, clinical lab, and intensive care. This hospital is the current COVID-19 medical centre in this region and has installed bedding of 87 units. Another hospital placing a wide range of services at disposal is H7 whose attention is mainly directed towards oncology, cardiology, and physiotherapy. The second biggest hospital concerning installed

Table 8
Local and overall weights of criteria and sub-criteria via implementing IF-AHP.

	Local weight	Overall weight
Criteria		
Hospital Buildings (C1)		0.146
Physical infrastructure (SC01)	0.131	0.019
Localization (SC02)	0.131	0.019
Number of storeys (SC03)	0.155	0.023
Installed capacity (SC04)	0.158	0.023
Disaster meeting point (SC05)	0.155	0.023
Isolation (SC06)	0.149	0.022
Ventilation (SC07)	0.120	0.018
Equipment and Supplies (C2)		0.163
Medicaments (SC08)	0.102	0.017
Safety supply management (SC09)	0.073	0.012
Medical equipment for Emergency care services (SC10)	0.084	0.014
Electric generator (SC11)	0.088	0.014
Potable Water Supply (SC12)	0.093	0.015
Tent availability (SC13)	0.092	0.015
Food services (SC14)	0.092	0.015
Hospital beds (SC15)	0.083	0.014
Triage label (SC16)	0.096	0.016
Financial resources (SC17)	0.099	0.016
Supply Source (SC18)	0.097	0.016
Networks and Communications (C3)		0.163
Emergency service network (SC19)	0.297	0.048
Communications channels/equipment (SC20)	0.295	0.048
Information Quality (SC21)	0.408	0.066
Transport (C4)		0.161
Number of ambulances (SC22)	0.203	0.033
Heliport area (SC23)	0.238	0.038
Safety (SC24)	0.248	0.040
Road accessibility (SC25)	0.311	0.050
Human Resources (C5)		0.154
Education and training (SC26)	0.183	0.028
Disaster drill (SC27)	0.129	0.020
Emergency response team (SC28)	0.182	0.028
Integration and coordination (SC29)	0.169	0.026
Number of emergency staff (SC30)	0.175	0.027
Working time (SC31)	0.163	0.025
Adaptability (C6)		0.213
Flexibility in the use of facilities (SC32)	0.266	0.057
Contingency staff (SC33)	0.258	0.055
Blood bank (SC34)	0.243	0.052
Flexible supply of medicines and medical materials (SC35)	0.233	0.050

Table 9
Direct-relation matrix in Intuitionistic Fuzzy Sets – Expert 1 (Networks and Communications sub-criteria).

	SC19		SC20		SC21	
SC19	0	0	0,75	0,20	0,75	0,20
SC20	0,75	0,20	0	0	0,75	0,20
SC21	0,75	0,20	0,90	0,10	0	0

Table 10
Direct-relation matrix in standard fuzzy subsets – Expert 1 (Networks and Communications sub-criteria).

	SC19	SC20	SC21
SC19	0	0.775	0.775
SC20	0.775	0	0.775
SC21	0.775	0.9	0

capacity is H8 with 300 beds. The major specialty of this institution is oncology medicine which is provided at different complexity levels. H9 is recognized as a modern medical center with high-tech equipment and a sterilization plant capable of effectively underpinning the day-to-day hospital operation. Finally, H10, as a 3-level institution, offers 29 healthcare specialties including hospitalization, outpatient care, surgery, and neonatal intensive care.

The first step of the VIKOR method involves defining a Key Performance Index (KPI) for each sub-criterion as evidenced in Table 16.

Table 11
Crisp direct-relation matrix – Expert 1 (Networks and Communications sub-criteria).

	SC19	SC20	SC21
SC19	0	3.1	3.1
SC20	3.1	0	3.1
SC21	3.1	3.6	0

Table 12
Aggregated crisp direct-relation matrix.

	SC19	SC20	SC21
SC19	0	3.4	2.8
SC20	3	0	2.8
SC21	2.8	3.1	0

Table 13
Normalized direct-relation matrix.

	SC19	SC20	SC21
SC19	0	0.523	0.431
SC20	0.462	0	0.431
SC21	0.431	0.477	0

Table 14
Total relation matrix.

	SC19	SC20	SC21	D
SC19	3.522	4.147	3.734	11.403
SC20	3.683	3.636	3.583	10.902
SC21	3.705	3.997	3.318	11.020
R	10.910	11.779	10.636	

The mathematical formula of each indicator is also presented in this table, thus allowing a general evaluation and comparison among hospitals in terms of disaster preparedness. The metrics were established considering the pertinent regulations set by the government and associated healthcare authorities. Following this, an initial VIKOR matrix containing the KPI values of each hospital, the overall weights (OW) emanating from the IF-AHP method, and the best f_i^*/worst f_i^- scenarios of each sub-criterion was arranged (Table 17).

The values of S_j, and R_j were computed using Equations (18) and (19) correspondingly (Table 18). In this case, S*, S^-, R*, and R^- were found to be 0.070, 0.386, 0.021, and 0.057 respectively. After this, Q_j ($\nu = 0.5$), considered as the disaster preparation index, was computed for each hospital. Accordingly, all the participating hospitals (H1, H2, H3, H4, H5, H6, H7, H8, H9, and H10) were ranked based on these measures as also appreciated in Table 18. Based on the ranking, H1 ($Q_1 = 0.000$) was found to be the readiest hospital when addressing disaster crisis. To confirm the compromise solution, two conditions were validated (Table 19). On one hand, it was found that $Q(P^{(2)}) - Q(P^{(1)}) > DQ$ with $DQ = \frac{1}{10-1} = 0.111$ which satisfies the acceptable advantage condition. On the other hand, as H1 was ranked first concerning S_j (0.070) and R_j (0021), there is then acceptable stability in the decision-making process.

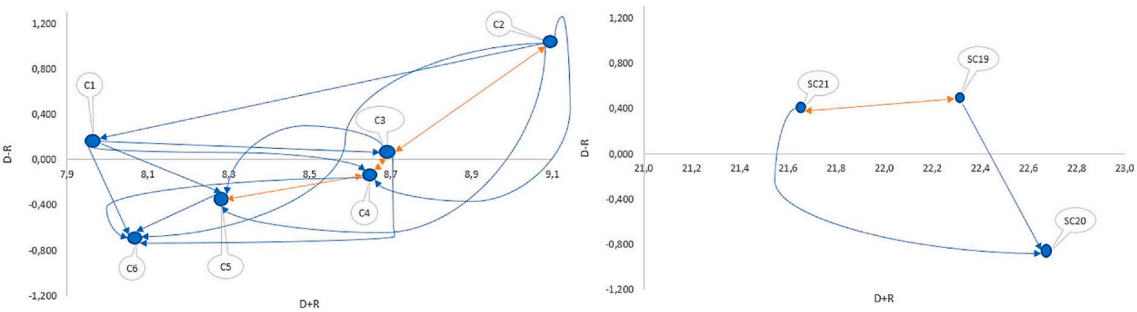
4.6. Validation study: comparing VIKOR results with TOPSIS and SAW

Although we propose a solid holistic approach combining three different MCDM methods and intuitionistic fuzzy sets, there is always a need to test its accuracy. In this direction, we compared the outranking method (VIKOR) used in the last stage with two different MCDM methods (TOPSIS and SAW). The ranking results obtained are presented in Fig. 8. According to this graph, there is no change in the disaster preparedness rankings of hospitals “H1, H5, H7, H9 and H10” three methods. There are some expected changes in the rankings of the remaining hospitals, although not very contradictory. As emphasized in the literature, no change has been observed in ranking the readiest and least-ready hospitals. Other intermediate rankings may contain slight changes within the framework of the internal procedures of each method. Thus, it has been demonstrated that the applicability of the proposed method in this field produces accurate and good results. In addition, Pearson and Spearman correlation analysis has been performed for both the final scores of the methods (this is the Q value in VIKOR, the closeness coefficient-CC value in TOPSIS, and the final score value in SAW) and the final rankings, respectively, to strengthen the validation.

According to the Pearson correlation analysis presented in Fig. 9, it is seen that the final scores yielded by the methods for hospitals are correlated with each other over 90%. It should be noted here that the correlation coefficient between VIKOR and other methods is negative because the low Q value (closer to zero) in the VIKOR method indicates that the relevant hospital is more prepared for the disaster. In Spearman rank correlation analysis, as shown in Fig. 10, coefficients over 84% were obtained.

Table 15
Prominence and relation vectors in the hospital disaster preparedness model.

CRITERION (C)/SUB-CRITERION(SC)	D + R	D-R	DISPATCHER	RECEIVER
Hospital Buildings (C1)	7.966	0.153	x	
Physical infrastructure (SC01)	39.052	−1.440		X
Localization (SC02)	38.214	1.784	x	
Number of storeys (SC03)	37.515	0.269	x	
Installed capacity (SC04)	37.740	1.047	x	
Disaster meeting point (SC05)	38.224	−1.009		X
Isolation (SC06)	38.072	−0.544		X
Ventilation (SC07)	39.176	−0.109		X
Equipment and Supplies (C2)	9.088	1.040	x	
Medicaments (SC08)	8.713	0.830	x	
Safety supply management (SC09)	8.474	1.157	x	
Medical equipment for Emergency care services (SC10)	8.597	0.782	x	
Electric generator (SC11)	6.949	1.668	x	
Potable Water Supply (SC12)	8.067	1.373	x	
Tent availability (SC13)	7.146	−1.415		X
Food services (SC14)	7.440	−1.095		X
Hospital beds (SC15)	6.885	−1.678		X
Triage label (SC16)	7.677	−0.884		X
Financial resources (SC17)	8.632	−0.049		X
Supply Source (SC18)	8.164	−0.689		X
Networks and Communications (C3)	8.692	0.049	x	
Emergency service network (SC19)	22.314	0.493	x	
Communications channels/equipment (SC20)	22.682	−0.877		X
Information Quality (SC21)	21.655	0.384	x	
Transport (C4)	8.649	−0.160		X
Number of ambulances (SC22)	20.641	2.147	x	
Heliport area (SC23)	20.603	−1.035		x
Safety (SC24)	21.937	−0.459		x
Road accessibility (SC25)	21.934	−0.652		x
Human Resources (C5)	8.282	−0.362		x
Education and training (SC26)	15.270	1.824	X	
Disaster drill (SC27)	15.077	−0.253		x
Emergency response team (SC28)	15.742	−1.753		x
Integration and coordination (SC29)	16.677	−0.216		x
Number of emergency staff (SC30)	15.993	0.278	X	
Working time (SC31)	16.154	0.120	X	
Adaptability (C6)	8.074	−0.720		x
Flexibility in the use of facilities (SC32)	28.598	0.870	X	
Contingency staff (SC33)	29.191	1.020	X	
Blood bank (SC34)	27.727	−1.984		x
Flexible supply of medicines and medical materials (SC35)	29.699	0.094	X	



(a) (b)

Fig. 6. Influential-relation map for (a) Criteria and (b) Networks and communications (C3).

5. Discussion

The application of the proposed methodology has derived in a set of findings entailing important practical and managerial implications that will serve as a decision-making platform for policy makers, disaster administrators, hospital directors, and health authorities. First, the IF-AHP results revealed that the most important criterion in disaster preparedness of hospitals is "Adaptability"

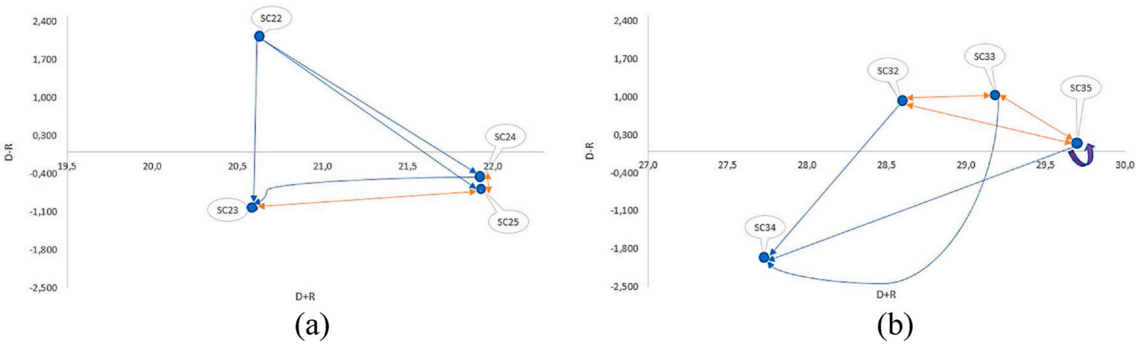


Fig. 7. Influential-relation map for (a) Transport (C4) and (b) Adaptability (C6).

(C6) with 0.213. Accordingly, these institutions need to upgrade their resilience by deploying a wide range of flexible plans propelling a rapid adaption of healthcare services to sudden outbreaks so that expected demand peaks can be balanced with the necessary hospital capacity. This can be done by implementing forecasting models focused on predicting the potential number of Mass Casualty Events (MCE) that may occur under different disaster scenarios while ensuring a solid group of allies with extra capacity and short lead times.

Following this line of argument, the second most relevant criteria are “Equipment and supplies” (C2) and “Networks and communications” (C3) with 0.163. On the one hand, hospitals are advised to establish agreements with the industry groups involved in the supply of critical medical equipment and the healthcare authorities to create a sectorial stockpile acting as a buffer when the instant provision of these materials may not be possible. On the other hand, significant efforts should be directed towards the continuous improvement of communication flows to optimize the healthcare provided to patients resulting from a disaster. Specifically, effective communication may reduce the wastes of time and adverse events often experienced in outbreaks. In the interim, hospitals are suggested to integrate an emergency care network functioning as a “big hospital” so that assistance can be provided in a more timely way. This, from an operational perspective, entails the creation of governance protocols regulating patient transfers and communication procedures. The fourth most important criterion is “Transport” (C4) with 0.161. In these unprecedented times, the strengthening of hospital transport systems has been vital for increasing the timeliness of diagnosis and treatment processes in COVID-19 patients [90]. Appropriate administration of the hospital fleet can minimize the patient waiting times while lowering the mortality and risk of developing more severe complications during disasters. Ambulance scheduling models considering staff requirements, multiple objectives, and route restrictions have become in decision support systems dealing with the above-mentioned scenario and are therefore recommended for implementation in the wild. The remaining gap, however, is the lack of spatial-temporal forecasting approaches suitably mapping the demand behavior expected in chaotic situations. Meaningful attention should be also paid to the “Human resources” (C5) criterion (OW = 0.154). Medical and administrative staff also play a pivotal role in the response of hospitals against disastrous situations. In this respect, it is advised to invest in disaster management training for gaining an understanding of the situations that may appear during these outbreaks and how they could be effectively addressed in the practical context. The society witnessing these events should support these actions to reduce the intricate knock-on effects and facilitate the deployment of contingency plans as those implemented in the current COVID-19 outbreak. Failures in the response of the internal workforce and the affected community may result in a major hit on patients trying to pull through and an increased number of casualties. Targeted efforts should be also concentrated on the “Hospital buildings” (C5) factor (OW = 0.146), which has been demonstrated as a cornerstone in hospital disaster performance [91]. The number of people accessing the healthcare system increases dramatically in the course of an outbreak and infrastructure, therefore needs to be ready, both quality and quantity. Likewise, involved policymakers are recommended to devise plans for constructing disaster-resilient facilities and rapidly restoring the physical hospital plants in the aftermath of a catastrophe. Another main challenge to be considered in the disaster preparedness strategy is how the hospitals can operate when essential services (water supply and electricity) are disrupted due to the crisis. This is added to the need for ensuring an infrastructure facilitating the rapid evacuation of patients, especially those with high-complex diseases and impairments.

Second, the IF-AHP outcomes also help decision-makers and hospital managers to elucidate specific sub-criteria to be intervened considering their global relative weight to the overall disaster preparedness index (>5%). Considering the results here presented, the most contributing sub-component is *Information Quality* (SC21) with overall weight of 0.066. This evidences the need for ensuring an efficient administration of communication platforms and procedures so that ad hoc decision-making can be fully supported and accelerated during a catastrophe. As disaster management involves continuous collaboration among the different stakeholders, suitable Information and Communication Technologies (ICT) should be embraced to remove information flow hindrances and accordingly optimize efforts in the aftermath of a disaster. In this regard, it is also suggested to incorporate data quality filters to avoid logistics and medical errors; as well as design appropriate information interaction protocols underpinning the creation of joint solutions diminishing or lessening the knock-on effects of future disasters. On a different note, *Flexibility in the use of facilities* (SC32) (OW = 0.057) has been pinpointed as the second most important sub-criterion in hospital disaster preparedness and is indeed a measure of surge capacity. In this regard, Roud [92] emphasizes the relevance of planning to improvise by arguing that disaster managers often adopt approaches that discourage creativity and impeding flexibility when outbreaks occur. Additionally, an aspect to be considered in this context is the infrastructural damage that hospitals may suffer as a result of a catastrophe. To effectively cope with the problem,

Table 16
Key performance indicators for sub-criteria.

Sub-criterion	Performance Metric	Formula
Physical infrastructure (SC01)	% of rooms in good infrastructure condition	$\frac{NRGIC}{TNR}*100$ $NRGIC$: *Number of rooms in good infrastructure condition* TNR : *Total number of rooms*
Localization (SC02)	Average distance from target community	$\frac{\sum_{i=1}^{c} d_i}{c}$ d_i : *Distance from hospital to target community i* c : *Number of target communities*
Number of storeys (SC03)	Number of storeys	*Number of storeys that the hospital has*
Installed capacity (SC04)	Total medical staff	$N + D + MSS$ N : *Total number of nurses* D : *Total number of doctors* MSS : *Number of medical support staff*
Disaster meeting point (SC05)	Availability of disaster meeting point	*If available* (2), *otherwise* (1)
Isolation (SC06)	% of correctly isolated ED rooms	$\frac{NCIEDR}{TNR-ED}*100$ $NCIEDR$: *Number of correctly isolated ED rooms* $TNR-ED$: *Total number of rooms in ED*
Ventilation (SC07)	% of rooms with appropriate ventilation	$\frac{NRAV}{TNR}*100$ $NRAV$: *Number of rooms with appropiate ventilation* TNR : *Total number of rooms*
Medicaments (SC08)	Average fill rate of medicaments	$\frac{\sum_{k=1}^{m} FR_k}{m}$ FR_k : *Fill rate of medicament k* m : *Number of medicaments*
Safety supply management (SC09)	Implementation of MSDS standards	*If implemented* (2), *otherwise* (1)
Medical equipment for Emergency care services (SC10)	Availability of Medical Equipment for ECS	$\frac{NAMD}{TNMD}*100$ $NAMD$: *Number of available medical services* $TNMD$: *Total number of medical devices*
Electric generator (SC11)	Availability of Electric Generator	*If available* (2), *otherwise* (1)
Potable Water Supply (SC12)	Availability of Potable Water Supply	*If available* (2), *otherwise* (1)
Tent availability (SC13)	Availability of tent area	*If available* (2), *otherwise* (1)
Food services (SC14)	Availability of Food Services Department	*If available* (2), *otherwise* (1)
Hospital beds (SC15)	Bed capacity in ED	*Number of available beds in ED*
Triage label (SC16)	Usage of triage labels	*If used* (2), *otherwise* (1)
Financial resources (SC17)	Availability of budget for disaster events	*If available* (2), *otherwise* (1)
Supply Source (SC18)	Availability of equipment supplying sources	*If available* (2), *otherwise* (1)
Emergency service network (SC19)	Connection with Emergency Service Network (ESN)	*If connected* (2), *otherwise* (1)
Communications channels/ equipment (SC20)	Availability of ESN communication platform	*If available* (2), *otherwise* (1)
Information Quality (SC21)	Information quality level	*Linguistic term* (1 − *Very Low*, 2 − *Low*, 3 − *Medium*, 4 − *High*, 5 − *Very High*
Number of ambulances (SC22)	Total number of ambulances	*Total number of ambulances that the hospital has*
Heliport area (SC23)	Availability of heliport area	*If available* (2), *otherwise* (1)
Safety (SC24)	Total number of security guards	*Number of security guards that the hospital usually employs*
Road accessibility (SC25)	Road accessibility	*Linguistic term* (1 − *Very Low*, 2 − *Low*, 3 − *Medium*, 4 − *High*, 5 − *Very High*
Education and training (SC26)	Disaster management training	*Number of disaster management programs organized by the hospital*
Disaster drill (SC27)	Number of disaster drills	*Number of disaster drill that the hospital has performed*
Emergency response team (SC28)	Emergency response degree	*Linguistic term* (1 − *Very Low*, 2 − *Low*, 3 − *Medium*, 4 − *High*, 5 − *Very High*
Integration and coordination (SC29)	Integration and coordination level	*Linguistic term* (1 − *Very Low*, 2 − *Low*, 3 − *Medium*, 4 − *High*, 5 − *Very High*
Number of emergency staff (SC30)	Disaster training	*Percentage of staff trained in disaster management*
Working time (SC31)	Disaster management experience	$\sum_{n=1}^{z} WH_n/z$ WH_n : *Number of working hours of employee n in disaster situations* z : *Total number of staff trained in disaster management*
Flexibility in the use of facilities (SC32)	Extra capacity	*Number of administrative areas that can be adapted for emergency care*
Contingency staff (SC33)	Availability of contingency staff	*If available* (2), *otherwise* (1)
Blood bank (SC34)	Availability of blood bank	*If available* (2), *otherwise* (1)
Flexible supply of medicines and medical materials (SC35)	Supply chain size	*Number of allied suppliers providing medicines and medical materials*

non-medical facilities can be adapted to care for patients with minor injuries and low-complex diseases. On the other hand, nearby 1-level hospitals can be adjusted to perform ambulatory surgeries and admit non-disaster patients [87]. This is highly correlated to the availability of *Contingency staff* (SC33) (OW = 0.055) previously trained in disaster management and who can provide support to save lives during a major incident. Educational initiatives fostered by healthcare authorities are of paramount relevance to augment the

Table 17
Initial VIKOR matrix for evaluating the hospital disaster preparedness.

Sub-criterion	OW	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	Best value	Worst value
SC01	0.019	99.7	94	94	94	98	96	90	75	85	90	100	0
SC02	0.019	10	6	6	15	4	4	4	4	4	4	4	15
SC03	0.023	8	4	8	4	6	5	3	8	2	8	8	2
SC04	0.023	600	300	450	445	400	250	200	300	200	700	700	200
SC05	0.023	2	2	2	2	2	2	2	2	1	2	2	1
SC06	0.022	98.5	92	92	93	95	92	89	80	75	75	100	0
SC07	0.018	95	90	90	95	95	90	85	80	80	90	100	0
SC08	0.017	99	96	90	98	98	95	95	94	90	98	100	0
SC09	0.012	2	2	2	2	2	2	2	2	2	2	2	1
SC10	0.014	99.5	97	93	98	99	96	94	94	90	97	100	0
SC11	0.014	2	2	2	2	2	2	2	2	2	2	2	1
SC12	0.015	2	2	2	2	2	2	2	2	2	2	2	1
SC13	0.015	2	2	2	2	2	2	2	2	2	2	2	1
SC14	0.015	2	2	2	2	2	2	2	2	2	2	2	1
SC15	0.014	75	65	65	55	72	66	30	75	65	120	120	30
SC16	0.016	2	2	2	2	2	2	2	2	2	2	2	1
SC17	0.016	2	2	2	2	2	2	2	2	2	2	2	1
SC18	0.016	2	2	2	2	2	2	2	2	2	2	2	1
SC19	0.048	2	2	2	2	2	2	2	2	2	2	2	1
SC20	0.048	2	2	2	2	2	2	2	2	2	2	2	1
SC21	0.066	5	4	4	4	5	4	3	3	3	4	5	1
SC22	0.033	4	2	3	3	3	2	1	3	1	6	6	1
SC23	0.038	2	1	1	1	2	1	1	2	1	2	2	1
SC24	0.040	24	16	14	10	12	16	16	24	18	12	24	10
SC25	0.050	4	5	5	4	4	5	4	4	4	4	5	1
SC26	0.028	1	2	2	2	4	4	4	3	3	3	4	0
SC27	0.020	4	4	4	4	4	4	4	4	4	4	4	0
SC28	0.028	5	4	4	5	5	5	4	4	4	4	5	1
SC29	0.026	5	5	4	4	4	5	4	4	4	4	5	1
SC30	0.027	95	90	90	90	80	90	85	80	80	80	95	80
SC31	0.025	40	30	30	30	30	30	30	40	30	35	40	0
SC32	0.057	4	2	2	2	2	2	2	2	2	2	4	2
SC33	0.055	2	2	2	2	2	2	2	2	2	2	2	1
SC34	0.052	2	2	2	2	2	2	2	2	2	2	2	1
SC35	0.050	20	10	11	12	11	8	7	6	4	15	20	4

Table 18
S_i, R_i and Q_i ranking for hospitals in accordance with their level of disaster preparedness.

Alternatives	S_j	Rank	R_j	Rank	Q_j (v = 0.5)	Rank
H1	0.070	1	0.021	1	0.000	1
H10	0.196	2	0.057	10	0.700	2
H5	0.222	3	0.057	10	0.741	3
H8	0.253	4	0.057	10	0.790	4
H6	0.259	5	0.057	10	0.799	5
H3	0.261	6	0.057	10	0.803	6
H2	0.279	7	0.057	10	0.831	7
H4	0.304	8	0.057	10	0.871	8
H7	0.338	9	0.057	10	0.925	9
H9	0.386	10	0.057	10	1.000	10

Table 19
Assessment of conditions for the compromise solution.

Condition	Conclusion
C1: Acceptable advantage (0.700 ≥ 0.111)	Satisfied
C2: Acceptable stability in decision making (1st place in the ranking for both S_i and R_i)	Satisfied

number of staff, both medical and non-medical, wisely responding to a particular disaster. In parallel, hospital administrators are advised to create interdisciplinary teams facing the multifaceted needs arising from outbreaks while devising plans for reducing future flaws and casualties. Another primary cornerstone in the disaster performance of hospitals is the accessibility to *Blood bank* (SC34) (OW = 0.052) services. Blood transfusions often ramp up in the presence of MCEs and therefore call for balancing donor attendance with blood supply. Replenishment models considering different types of disaster risk, blood type statistics in the target community, and demand forecasts under several outbreak scenarios are particularly welcomed to offer robust and realistic solutions addressing this

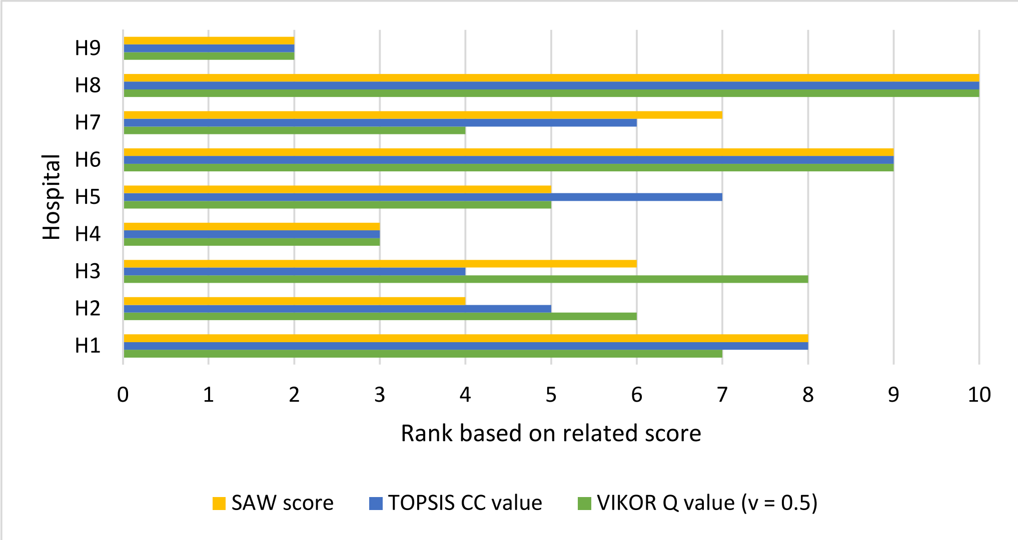


Fig. 8. Ranking results of hospitals according to the three MCDM methods.

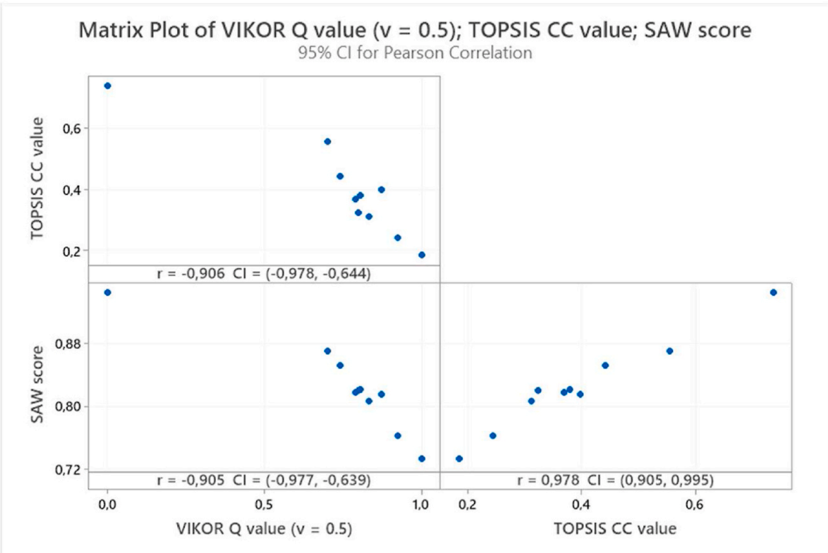


Fig. 9. Results of Pearson correlation analysis.

problem. Moreover, as road accessibility is significantly reduced during a disaster, satellite blood collection groups are recommended to access voluntary and non-voluntary donors' homes. Thereby, high service levels can be granted for wisely responding to different disasters, especially during a pandemic situation (i.e., COVID-19) where various infection swells are expected in conjunction with their associated blood requirements. An operational perspective of the hospital disaster preparedness should also consider a *Flexible supply of medicines and medical material* (SC35) (OW = 0.050) in charge of stable and robust supply chain structures capable of managing the disruptions emanating from a particular catastrophe as those currently experienced with COVID-19 pandemic. In particular, the suppliers should work considering the worst-case scenario specified by the healthcare authorities and hospital managers where medication and supply needs for a full-capacity occupation must be provided at shorter lead times. Also, an optimal stock including the most critical elements required in the disaster should be granted in case of excess demand for healthcare. In this regard, it is first necessary to undertake a needs evaluation based on stakeholders' feedback, proper inventory data, and demand volumes to define the type and quantity of medications and supplies needed for the treatment of disaster patients [93]. Following this, the purchasing departments are recommended to establish direct contact with wholesalers, manufacturers, and local vendors to obtain the aforementioned resources under different commercial agreements. Significant attempts should be also directed towards the improvement of geographical *Road accessibility* (SC25) (OW = 0.050) to and from hospitals so that post-disaster travel delays during the patient

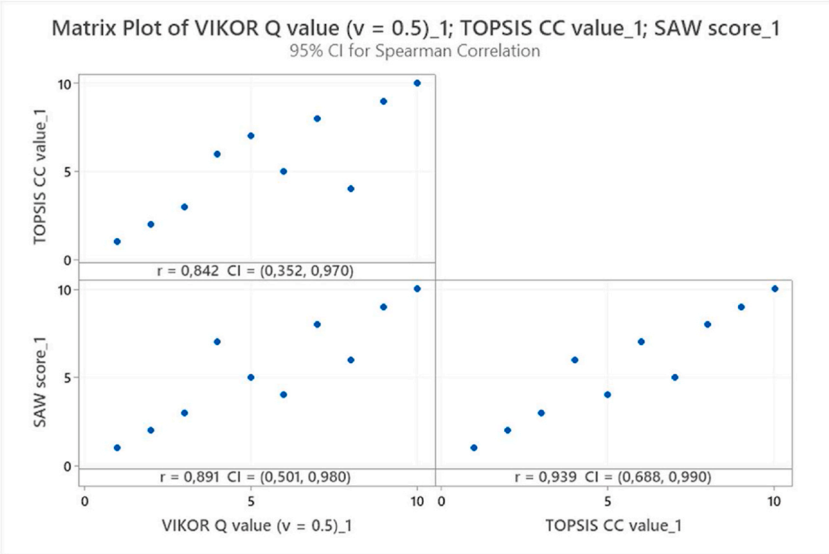


Fig. 10. Results of Spearman rank correlation analysis.

transfers from the disaster epicenter to the hospitals can be substantially lowered. Having roads encroached upon residues and material restricting the free movement of ambulances directly impacts the rapid diagnosis and treatment of disaster patients. A practical solution is the implementation of mobile outreach units accessing those places with a high number of affected people whereas road and healthcare authorities establish concerted plans for swiftly enabling the damaged roads via satellite rapid-response reparation groups.

Third, it can be concluded that all matrixes are consistent, considering that CRs are lower than 10%. Indeed, large-size matrixes, often characterized by inconsistency were found to satisfy this assumption: C2 (CR = 8.84%; 11 elements), C1 (CR = 4.83%; 7 elements), C5 (CR = 7.42%; 6 elements), and Criteria (CR = 5.25%; 6 elements). In view of the above, we can conclude that selecting suitable experts, teach unskilled decision-makers how to perform the paired judgments, and employing a short evaluation scale are advantageous for lessening inconsistencies during the decision-making process. Therefore, these practices can be recommended for future IF-AHP and IF-DEMATEL applications in disaster management contexts considering decision-makers who are non-expert in MCDM or complex mathematics as often expected in healthcare scenarios.

A complementary perspective to the IF-AHP results is provided by the IF-DEMATEL method. According to the $D - R^T$ values, *Hospital buildings (C1)*, *Equipment and supplies (C2)*, and *Networks and Communications (C3)* were categorized as key dispatchers whereas *Transport (C4)*, *Human resources (C5)*, and *Flexibility (C6)* were classified as receivers. It is also evident that *Equipment and supplies (C2)* has the greatest positive prominence score (9.088) and can be then considered as the principal influence generator in the disaster preparedness of hospitals. Accordingly, this criterion should be highly targeted by policymakers, health authorities, and hospital administrators to increase hospital disaster preparedness. Such an outcome was also highlighted by Fallah-Aliabad et al. [83] in their review where it is concluded that diagnostic tools prepared by hospitals in regards to disaster management often evaluate the availability of supplies and some medical equipment features. Furthermore, this study states the need for intervening in this aspect in conjunction with government officials to lessen the vulnerability and poor response of hospitals against disasters. To cope with this arduous task, it is advised to establish resilience plans involving the suppliers of critical resources to build a buffer responding to the demand peaks expected under different disaster scenarios so that delays due to resource shortage can be significantly tackled.

The IF-DEMATEL results also uncovered a significant feedback between "Equipment and supplies" (C2) and "Network and communications" (C3) since the availability and quality of medical supplies and equipment greatly influences the effectiveness of operations within the emergency care networks. Indeed, if proper medical devices, medication, and consumables are not disposed of in the destination node; it will not be then possible to efficaciously underpin the patient transfers that may occur in an emergency care network. In the interim, the legal framework and service protocols established in an emergency care network shapes the procurement and maintenance plans of hospitals focused on providing timely care based on a high service level of the drug supply, the accomplishment of minimum operational standards, and a suitable administration of medical equipment inventory. In this respect, facility and inventory managers are called for developing demand forecasting models focused on disaster contexts whose results allow them to update the reorder points and embrace new sourcing policies increasing the resilience of emergency care networks during outbreaks. Likewise, there is a bi-directional cause-and-effect relation between "Transport" (C4) and "Human resources" which evidences the need for upgrading the coordination between the hospital transportation system and the rapid reaction teams so that potential adverse events, delays, and other process inefficiencies can be further reduced. In this framework, disaster drills implemented by healthcare authorities should implement full-scale tabletop exercises in training rooms where involving roles can interact to showcase how the hospital will handle the disaster. The results of these drills must be overseen and documented by external consultants to identify improvement points regarding the i) location of ambulances, ii) communication among transporters and candidate destination hospitals to verify the bed availability, iii) patient safety during transportation, and iv) timeliness of medical staff to receive the patients arriving at the ED.

Another interesting finding from the above-cited is that *Emergency service network (SC19)* and *Information quality (SC21)* are the main dispatchers while *Communication channels/equipment (SC20)* is of receiving nature. The governance protocols and configuration (size and type) of emergency service networks define the required communication channels/equipment that will operationalize the collaboration flows among the hospital nodes integrating this system [10]. The communication platforms adopted for supporting healthcare functioning depend upon the amount and type of data that need to be processed and analyzed by decision-makers. On a different note, two key aspects arise from the feedback observed between SC19 and SC21. The primary consideration lies in the necessity for defining and characterizing the critical key performance indicators to be constantly appraised by a particular hospital during a disaster. Following this, the policymakers should identify the technology that best supports this activity while ensuring the most proficient performance in terms of computational time, visualization, and statistical analysis. A secondary aspect considers establishing an appropriate procedure for administering the communication flows within the emergency care network and underpin decision-making. In a similar vein, capturing high-quality information will guide disaster managers towards outlining the specific domains to be intervened for increasing the hospital resilience.

It was also confirmed that *Heliport area (SC23), Safety (SC24),* and *Road accessibility (SC25)* are receivers while *Number of ambulances (SC22)* belongs to the dispatching group. The ambulance fleet of hospitals is considered when defining the size of the helicopter landing zone serving hospitals during a disaster. Typically, ambulance transport ground is required when there is a significant distance between the heliport zone and the destination hospital. On the other hand, accessibility to hospitals should be designed considering the number of ambulances accessing to and departing from the hospital in the course of an outbreak. Likewise, the number of required security guards may be influenced by the flow of ambulances picking up and transporting injured people to the hospital especially when seeking to keep the safety of medical staff and patients inside and outside the premises. Results obtained from the IF-DEMATEL application then reveals the need for developing a simulation-optimization tool for ambulance location and deployment that can empower disaster managers to reach real-time solutions based on data entries from the incident.

Likewise, *Flexibility in the use of facilities (SC32), Contingency staff (SC33),* and *Flexible supply of medicines and medical materials (SC35)* were concluded to be dispatchers whereas *Blood bank (SC34)* was found to be of receiving nature. Accordingly, special focus should be directed towards SC32, SC33, and SC35 not only for being within the cause group but evidencing feedback relations among them. This is an important finding towards upgrading the resilience of hospitals when facing disastrous situations and involves a careful planning process focused upon these interactions. In particular, healthcare authorities are advised to elaborate concerted contingency procedures where facility managers, industry representatives, and universities can converge and define: i) how many contingency staff universities need to train for assisting hospitals in different disaster scenarios, ii) how these contingency staff can convert the hospital administrative areas into healthcare points, iii) what is the buffer size and inventory service level required by hospitals in each critical medicine and consumable for ensuring a continuous healthcare of patients resulting from disasters iv) how contingency staff can support inventory replenishment during a particular outbreak, and v) how the contingency plans can be rapidly implemented to avoid delays, adverse events, and other major deficiencies declining the disaster resilience of hospitals.

It has become evident from the IF-AHP and IF-DEMATEL how hospital disaster preparedness may be increased as a result of cojoint efforts in both short and long terms. However, it was also necessary to apply VIKOR not only for ranking the hospitals but designing specific interventions for each participating hospital. The outcomes revealed that there is much room for improvement in each of the participant hospitals regarding disaster preparedness. For example, H8 (75%; Contribution to $S_8 = 0.0048$) and H9 (85%; Contribution to $S_9 = 0.00288$) presented the lowest percentage of rooms in good infrastructure condition and thereby limiting the use of their installed capacity in case of outbreaks. This is very alarming considering that demands on healthcare services usually increase dramatically when disasters occur. It is therefore necessary to establish in-time maintenance plans focused on: i) ensuring a high standard and patient-friendly spaces with good light, ii) increasing the degree of cleanliness in wards and common spaces, iii) artificial intelligence models predicting the reparation need of specific infrastructure features based on the frequency of use. On a different tack, it was identified that H1 (10 km; Contribution to $S_1 = 0.1046$) and H4 (15 km; Contribution to $S_4 = 0.1918$) are the hospitals with the greatest distance from the target community. Such a condition hinders the rapid response of healthcare services when addressing disastrous events. To face this problem, it is recommended to install satellite sites of the hospital close to the outbreak epicentre so that faster diagnosis and treatment can be provided to the victims. For effective deployment in the wild, this activity should be simulated during the disaster drills scheduled by the hospital and thereby determining potential fails that may take place in the practical scenario. Another aspect of concern was that H2 (4 storeys; Contribution to $S_2 = 0.01508$), H4 (4 storeys; Contribution to $S_1 = 0.01508$), H7 (3 storeys; Contribution to $S_7 = 0.01884$), and H9 (2 storeys; Contribution to $S_9 = 0.02261$) were found to have a low number of available storeys which highly restricts their response when experiencing demand peaks as those expected in outbreaks. Overcrowding, long waiting times, extended patient flow time, and prolonged length of stay are some of the consequences that an insufficient capacity (number of storeys) may bring about [8]. In this regard, it is important to develop investment plans considering the demand variations and the probabilities of a significant catastrophe. While allocating resources for an increased number of plants may be highly costly and of a slow return on investment, some alliances may be set with other healthcare institutions taking into account patient transfers and equitable distribution of utilities. On the other hand, H6 (250 medical staff; Contribution to $S_6 = 0.02084$), H7 (200 medical staff; Contribution to $S_7 = 0.02315$), and H9 (200 medical staff; Contribution to $S_9 = 0.02315$) were pointed out as the hospitals with the fewest number of doctors, nurses, and support staff. As this aspect greatly influences the correct and fast provision of healthcare services, it is thus suggested to settle partnership agreements with 2-level hospitals for treating patients with low risk of developing more severe complications [94]. Apart from these findings, H9 (1; Contribution to $S_9 = 0.0226$) was concluded to be the only hospital without disaster meeting points. These zones facilitate people flow management during a disaster whereas safely deploying the emergency evacuation plans within the medical centers. In this respect, hospitals are advised to decide whether to evacuate safely and implement shelter-in-place procedures so that potential affectations on hospital staff can be further avoided. For optimal placement of disaster meeting points, it is necessary to calculate the disaster probability of candidate locations and then select the ones with minimum hazard risk. Another significant finding is the low percentage of correctly isolated ED rooms detected in H9 (75%; Contribution to $S_9 = 0.0055$) and H10 (75%; Contribution to $S_{10} = 0.0055$). Inefficacious isolation may endanger patients' health, especially in biological disasters as currently experienced with the COVID-19 pandemic. In this regard, it is urged to: i) separate patient beds by installing droplet curtains, ii) build isolation facilities for patients with infectious diseases diagnosis, and iii) ensure minimum distancing between beds ($\leq$3 feet). An aspect of similar importance is that related to the low percentage of rooms with appropriate ventilation found in H8 (80%; Contribution to $S_8 = 0.0035$) and H9 (80%; Contribution to $S_9 = 0.0035$). Poor ventilation is associated with an increased concentration of germens and viruses within the hospital wards which threats patient safety and augments the possibility of health complications during the stay. For this reason, it is advisable to equip ED rooms with air filtering systems with a minimum of 12 air changes per hour in addition to constantly measuring the level of infectious agents within the hospital. Another weakness identified in H7 was the limited number of available beds in the emergency room (30 beds; Contribution to $S_7 = 0.01358$). The crisis-level bed shortage lowers the resilience capacity of EDs when facing the overload caused by a disaster. This is even more sharpener when considering that EDs will be slammed with patients overflowing during an outbreak. To tackle this disadvantage, it is widely suggested to repurpose beds from low-requested specialties to care for disaster victims. Moreover, it is necessary to target an expansion of these supplies supported by government resources and manufacturers considering demand forecasts so that patients can be better served during the crisis.

Another interesting result provided by VIKOR is the medium performance evidenced in H7 (3; Contribution to $S_7 = 0.03317$), H8 (3; Contribution to $S_8 = 0.01358$), and H9 (3; Contribution to $S_9 = 0.03317$) regarding information quality. Inefficient information flows within healthcare services may lead to wrong medical decision-making and thereby worsening the response of hospitals when addressing overtopping disasters. In this respect, it is important to establish coaching programs refining teamwork among medical staff complemented with the adoption of decision support and communication sensor-based technologies mapping the patient pathway along with the hospital. Another finding revealed by the VIKOR application is that H2 (2 ambulances; Contribution to $S_2 = 0.02614$), H6 (2 ambulances; Contribution to $S_6 = 0.02614$), H7 (1 ambulance; Contribution to $S_7 = 0.03268$), and H9 (1 ambulance; Contribution to $S_9 = 0.03268$) are the hospitals with the fewest number of ambulances. Such a constraint highly limits the patient transfers from the disaster point to these medical institutions and thereby delaying the diagnosis and treatment processes. This is even more concerning, taking into account that disaster zones are usually teemed with injured people needing immediate care. For this reason, policymakers are asked to develop optimization models establishing the minimum number of ambulances required to address the demand resulting from disaster surges along with reduction of overcrowding and waiting times in EDs. A more critical situation is observed regarding the heliport availability. Indeed, 60% of hospitals (H2, H3, H4, H6, H7, and H9; Contribution to S_2, S_3, S_4, S_6, S_7, and $S_9 = 0.03825$) have not considered building this area. As the consequences of some disasters (i.e. earthquake and flood) may restrict road access to victims, helicopter transportation emerges as an alternative to rapidly pick up affected people with urgent need of care; in this sense, the shortage of helicopter infrastructures is a significant disadvantage and then diminishes the flexibility of disaster attention provided by these hospitals. In reply, it is advised to construct these facilities following the recommendations specified by the Federal Aviation Administration (FAA) regarding safety, location, and cost so that patient flow from the disaster epicentre to the hospitals can be further accelerated and optimized. Although off-site helipads can be also proposed to deal with this problem, risks associated with patient transfers and the above-mentioned shortage of ambulances may represent a new operational problem reaching desperate levels in the wild. It is additionally relevant to devise plans for augmenting the number of security guards to control aggressive patients who may barge into the hospital wards seeking immediate care or information about their relatives' health specifically in H4 (10 guards; Contribution to $S_4 = 0.03992$), H5 (12 guards; Contribution to $S_5 = 0.03422$), and H10 (12 guards; Contribution to $S_{10} = 0.03422$). For instance, decision-makers may opt to set alliances with security companies so that additional staff can be assigned to these hospitals in case of outbreaks.

Moreover, an uptick in the number of implemented disaster programs is greatly suggested in H1 (1 disaster program; Contribution to $S_1 = 0.0221$). The adoption of these practices ramps up the hospital preparedness and entails a lot of staff training for underpinning their application in the real scenario. It is notably a daunting task leading hospitals to remove barriers, identify non-adherence problems, and incorporate supporting technologies, finally influencing the hospital disaster response. This is also related to the proportion of staff trained in disaster management which were found insufficient in H5 (80%; Contribution to $S_5 = 0.02695$), H8 (80%; Contribution to $S_8 = 0.02695$), H9 (80%; Contribution to $S_9 = 0.02695$), and H10 (80%; Contribution to $S_5 = 0.02695$). Effective disaster preparedness will allow medical staff to perform relevant roles during these outbreaks so that creative and tailored responses can be provided under pressure. It is thus important to stimulate investments in disaster management training supported by local universities specialized in this knowledge area. The effectiveness of this training should be validated through disaster drills revealing the adherence degree to the pre-established protocols.

A compelling weakness observed in 90% of the hospitals (H2, H3, H4, H5, H6, H7, H8, H9, and H10) was the small number of administrative zones that can be assigned for healthcare in case of a disaster (2 administrative areas; Contribution to S_2, S_3, S_4, S_5, S_6, S_7, S_8, S_9, $S_{10} = 0.05674$). During outbreaks, the number of people needing urgent care usually climbs at desperate levels and hospital administrators therefore require to free up the overburdened wards for treatment and diagnosis. In this regard, the construction of double-purpose spaces is highly suggested to increase the hospital flexibility when addressing chaotic situations. This task entails the incorporation of flexible furniture into these areas so that setup times can be further lowered. Ultimately, a disturbing drawback is the low number of allied suppliers presented in H6 (8 suppliers; Contribution to $S_6 = 0.03729$), H7 (7 suppliers; Contribution to $S_7 = 0.04039$), H8 (6 suppliers; Contribution to $S_5 = 0.04350$), and H9 (4 suppliers; Contribution to $S_5 = 0.04972$). When the healthcare system is battered by different disastrous situations, there could be a shortage of medicines and supplies. This notably affects the timely provision of treatment to patients, decreases the survival odds, and increases overcrowding in emergency rooms. To face this problem, it is advised to strike trade deals with new high-productive flexible providers considering the outputs of supplier selection models. In the long term, new business configurations can be created via incorporating a drug manufacturing process directly administered by the hospitals and thereby effectively responding to healthcare demand variations evidenced during an outbreak.

6. Conclusions

Disasters, which all countries of the world have experienced as a painful experience in recent years, once again highlighted the necessity of countries' health systems to be ready. The decision mechanisms developed in this context are beneficial in seeing the level of resistance of hospitals against disasters and designing remedial processes. In this study, a fuzzy hybrid decision-making model is proposed to evaluate hospitals' preparedness for disasters. The model deals with three important multi-criteria decision-making methods in an integrated manner. For the first stage, the IF-AHP is used to assign weights to a set of disaster preparedness criteria with linear dependence. Second, the IF-DEMATEL is applied to determine the relationships between these criteria and feedback. Finally, by the VIKOR method, disaster preparedness levels of hospitals are determined. A case study was conducted for 10 Colombian hospitals to test this integrated and fuzzy logic-based approach's applicability.

Numerical results from both IF-AHP and IF-DEMATEL show that the most important criterion in disaster preparedness of hospitals is "Adaptability" (C6) with 0.213 while the most influential component is *Equipment and supplies (C2)* has the greatest positive prominence score (9.088) and can be then considered as the principal influence generator in the disaster preparedness of hospitals. Despite that "Adaptability" is the most relevant aspect in this context, multi-criteria interventions are widely recommended in the short term considering that there are no significant differences between this criterion and the others. On a different tack, based on the ranking, H1 ($Q_1 = 0.000$) was found to be the readiest hospital when addressing disaster crisis. Additionally, it was concluded that there is much room for improvement in this set of hospitals especially in adaptability-related sub-criteria such as flexibility in the use of facilities and flexible supply of medicines and medical materials.

This paper's contributions are summarized as follows: (1) The study includes an approach that integrates the intuitionistic fuzzy set theory and the MCDM concept. The benefit of this lies in the combination of each method along with its advantages. While determining the criteria' importance levels by considering linear dependence with IF-AHP, relationships between the criteria are determined with cause-effect graphs of IF-DEMATEL. Finally, rankings of hospitals in terms of disaster readiness were determined with the VIKOR compromise solution method. (2) A secondary ranking regarding each main criteria heading has been demonstrated to observe which hospital is ready or not ready under these main headings. (3) The proposed approach can be used as a decision support tool for assessing hospitals for disaster events to provide a reliable decision strategy in emergency aid and disaster management. From the application point of view, the study results have revealed the need to determine the disaster preparedness levels of Colombian hospitals and propose a general network model that would cover all hospitals nationally.

Although this work has many merits in the decision-making of hospital disaster preparedness evaluation, it still has drawbacks. The most significant one is, in the disaster preparedness criteria weight modeling, due to the usage of AHP, a full factorial version of pairwise comparisons has been fulfilled. Alternatively, for future studies, to reduce the number of pairwise comparisons, the Best and Worst Method (BWM) can be preferred. This work can be refreshed considering both pairwise comparison and consistency-related issues by attaching BWM instead of AHP. Another one is to set up various criteria hierarchies based on the disaster event type in future attempts so that researchers can carry out their preparedness model for disaster events. Besides evaluating a limited number of hospitals in the model, all hospitals in the country can be used. This makes it easier for policymakers to see the big picture and a more comprehensive response plan against disasters can be prepared.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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