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An Intelligent Decision Support System to Prevent and Control of Dengue

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Abstract

Demographic shifts, social behavior modification, and climate change enhance the risk of dengue outbreaks globally. The Government of India has developed prevention and control strategies for dengue fever. We propose an intelligent decision support system based on multi-criteria decision analysis to improve strategic decision making among various alternatives, such as vaccination, disease surveillance, vector control, improved sanitation and access to safe drinking water, strengthening public health activities, awareness creation, and improving nutrition for women and children. The proposed alternatives are selected based on people, space and time criteria, such as low temperature and heavy rain, high temperature and high humidity, rainfall and water accumulation, resources and facilities, sociocultural and sociodemographic variables. The selection of alternatives based on multiple criteria is a complex decision-making problem. Policy and decision makers use linguistic terms to give their opinions and perspectives. We used the fuzzy logic based VIKOR (VIsekriterijumska optimizacija i KOMpromisno Resenje) method to analyze the linguistic terms collected from policy and decision makers to rank the optimal alternatives based on multiple criteria.

Keywords: Fuzzy logic, VIKOR, dengue, multi-criteria decision analysis, infectious disease prevention and control

1. Introduction

Government and healthcare professionals manage dengue outbreaks using multiple prevention and control strategies (Manogaran et al. 2017a; Manogaran et al. 2017b; Manogaran et al. 2017c). Complex procedures and challenges are involved in the dengue control strategies (Manogaran et al. 2017d; Thota et al. 2018), and the selection of the optimal dengue prevention and control strategy depends on people, space and time. Medical providers and health care administrators endeavor to reduce the operational and maintenance costs for prevention and control of dengue fever (Varatharajan et al. 2017a; Varatharajan et al. 2017b; Varatharajan et al. 2017c). The expenditure and demand for healthcare are also increasing rapidly. Professionals and administrators from the healthcare and other industries

are jointly conducting various healthcare delivery procedures with the aim to enable efficient disease control strategies using the limited resources (Manogaran et al. 2017e; D. Lopez et al. 2016). These considerations are used to develop a decision-making model based on multiple criteria and alternatives (Cromwell et al. 2015). The goal of Multi Criteria Decision Making (MCDM) models is to make an effective decision at various stages of healthcare planning, such as strategic, tactical and operational. In every complex decision-making problem, there could be an optimal solution though it is a challenging task to identify such a solution. In general, strategic decisions are determined by the administrators or top-level management to develop and sustain the organization. In addition, there are ambiguities in strategic decisions, potential synergies among various alternatives, and uncertainties in the overall outcome (Manogaran et al. 2016; Manogaran et al. 2017f). Once the strategic decisions are made, then the organization determines tactical and operational planning decisions. Strategic, tactical and operational planning are grouped as a taxonomy in healthcare planning (Figure 1) (Manogaran et al. 2018; Kumar et al. 2017; Lopez et al. 2017a). Disease prevention and control strategies comprise of various managerial functions such as facility planning, arrangement and decision making (Manogaran et al. 2017g; Lopez et al. 2016; Varatharajan et al. 2017d). The above-mentioned criteria are used in the decision-making model to make the decisions for improving the organization. Thus, multi criteria decision analysis (MCDA) is employed in various environments (Tromp et al. 2012; Ghandour et al. 2015; Dehe et al. 2015).

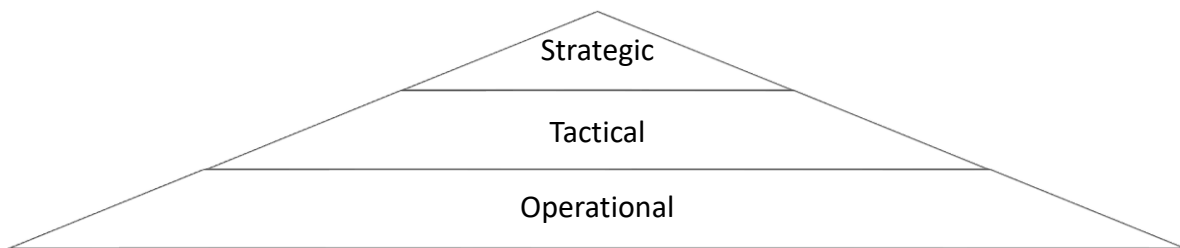


Figure 1. Taxonomy in healthcare planning.

1.1 Strategic Planning in Healthcare

Strategic planning is a long-term plan to achieve the overall goals and objectives of the organization (Frishammar 2003). In general, strategic planning consists of various administrative and organizational procedures to get the desired output (Varkey et al. 2010). Strategic planning in healthcare includes various factors such as designing an overall plan, identifying the goals, and getting approvals from the manager. For example, identifying the overall resource needs (hospitals, medical providers, drugs, and vehicles) and dimensioning the required resources (variety and specification of various resources) are some of the strategic plans in healthcare (Hulshof et al. 2012; Bradshaw et al. 2015).

1.2 Tactical Planning in Healthcare

Tactical planning refers to the overall steps that need to be followed to achieve the desired goals. The following questions are some of the examples of tactical planning in any

organization i.e. where, what, which, how, who and when (Manogaran et al. 2017h). Tactical planning in healthcare is followed in two steps – Step 1: Identifying and classifying the individuals based on the disease and its severity and defining various required resources; Step 2: Collecting and installing the resources (hospitals, medical providers, drugs, and vehicles) that are identified in the strategic planning, and scheduling the workload, assigning tasks to all workers and scheduling them over time. Tactical planning in the healthcare industry includes staff shift scheduling and overtime scheduling in the surgical block (Gunduz et al. 2015). Tactical planning is also named as a blueprint of operational planning.

1.3 Operational Planning in Healthcare

Operational planning refers to the short-term goal of the organization. The primary purpose of the operational plan is to make a decision for desired healthcare delivery. Operational planning is also used to execute the steps that are identified in the tactical planning. In other words, blueprints are implemented at each resource level and individual patient level in the operational planning to get the desired output (Hulshof et al. 2012). In this paper, operational plan is done with the help of Fuzzy VIKOR Multi Criteria Decision Making (FMCDM). The proposed system provides various alternatives to prevent and control dengue fever. The proposed alternatives are selected based on people, space and time criteria, such as low temperature and heavy rain, high temperature and high humidity, rainfall and water accumulation, resources and facilities, sociocultural and sociodemographic variables. The above-mentioned criteria are used to identify the optimal alternative from the list of alternatives, such as vaccination, disease surveillance, vector control, improved sanitation and access to safe drinking water, strengthening public health activities, awareness creation, and improving nutrition for women and children.

1.4 Dengue Surveillance

Dengue fever is caused by *Aedes aegypti* and *Aedes albopictus* mosquitoes. *Aedes aegypti* mosquitoes breed in manmade products such as water tanks, tyres, pitchers, discarded containers, cement tanks, desert coolers and junk materials. Water stagnates in these places for several days, which enhances the breeding of these mosquitoes. *Aedes aegypti* is a day biting mosquito and breeds in dark areas such as inside the houses and storerooms (Manogaran et al. 2017i; Lopez et al. 2017b; Gandhi et al. 2018). *Aedes albopictus* mosquitoes breed in natural habitats such as gardens, inside grass, tree gaps and agricultural estates. Dengue disease burden is greater than before due to improper water storage methods, lack of awareness and rapid urbanization, and these root causes lead to increase in the mosquito breeding sites. Dengue cases are not uniformly distributed during the year, and they generally peak after the monsoon period. However, in the southern states of India, dengue burden is constant for all months, and in Gujarat the transmission is permanent. The major symptoms of dengue include fever, headache, rash, joint pains, muscle, nausea and vomiting (Rawal et al. 2017).

Table 1. Midterm plan for dengue surveillance (National Vector Borne Disease Control Programme).

Components	Description
Surveillance	Surveillance activities collect, analyze and generate reports from large volumes of data from various sources. The results, guidelines and prevention strategies generated from the surveillance system are used for prevention and control of diseases.
Case management	Case management is used to provide quality of care, laboratory diagnosis, desired healthcare delivery, resource management and clinical management. Case management is also used to enable efficient patient care services through various functions. They include scheduling and planning, service monitoring, awareness creation, patient education service and patient monitoring.
Vector management	<i>Aedes aegypti</i> and <i>Aedes albopictus</i> mosquitoes are the main vectors of chikungunya and dengue fever in India. In order to control <i>Aedes aegypti</i> and <i>Aedes albopictus</i> mosquitoes, effective vector control schemes are to be developed based on the knowledge of the vector and its biology. Vector management is performed through environmental source management, water storage management and drainage maintenance, personal protection by protective clothing, chemical control and waste disposal management.
Outbreak response	Rapid emergency actions are needed to control and prevent dengue and chikungunya. Outbreak responses are two types – the first one is an early diagnosis of diseases and provide control strategies based on disease severity to prevent severe cases and deaths. The second one is to provide emergency vector control guidelines to control transmission of diseases. In addition, the following steps are also followed in outbreak response – creating guidelines and sharing using media, verification of outbreak with current and previous records, and perform lab tests such as blood sample collection, entomological surveys and specimen analysis.
Capacity building	In order to share and implement the guidelines for prevention and control from dengue requires trained professionals. It is required to conduct workshops, seminars and regional meetings to strengthen the skills of individuals who are involving in the disease prevention and control groups. Hands-on training sessions and simulation exercises should be given to the medical force and skilled workers that would help to provide appropriate services to the patients. Operational research should be performed at each region – it includes analyzing space and time dynamics of dengue transmission, disease burden, and mapping various vectors that are involved in space and time for dengue transmission.
Behavior change communication	Social mobilization and awareness creation are the major functions in controlling the dengue outbreak. Social mobilization is used to involve individuals from not only the local communities but also political leaders, VIPs and government officers.
Inter-sectoral coordination	In order to share the prevention and control strategies to the people, there is a need to collaborate every health and non-health sector individuals. This collaboration is used to enable resource sharing and policy adjustments between various individuals who are working in the health and non-health sectors.
Monitoring and supervision	In order to control the outbreak of dengue, there is need to provide a robust surveillance and monitoring system through entomological surveys and the resources to sustain the surveillance system. Supervision is another task to control the dengue fever. Reports generated from various locations, feedback collection, location visits, and review analysis with current and previous disease cases are the major functions of supervision.

Dengue mortality rates can be minimized by surveillance and early detection of symptomatic infections. Government of India has developed various guidelines and prevention and control strategies that are circulated to every state in India. In addition, Indian Committee of Secretaries (CoS) have generated the midterm plan in May 2011 for prevention and control of dengue that are shared among the various states in India. The midterm plan consists of various guidelines and is also named as ‘Octalogue’, since it includes eight major components as depicted in Table 1 (NVBDPCP 2018).

1.5 Dengue Epidemiology

Figure 2 illustrates the global burden of dengue in 2013, with 15.95 DALYs per 100,000 population (95% UI: 10.15-27.61) (Institute for Health Metrics and Evaluation 2016). Like the confidence interval, the 95% uncertainty interval (UI) corresponds to the estimation related modeling uncertainties in the Global Burden of Disease (GBD) study (Murray et al. 2015), which includes uncertainties in data and estimates from other sources. DALYs combine the morbidity metric of Years of Life lost due to Disability (YLD) and mortality metric of Years of Life Lost due to premature mortality (YLL); that is, $DALY = YLD + YLL$. Figure 3 illustrates the burden of dengue in India from 1990 to 2013, with 11.1 DALYs per 100,000 population (95% UI: 7.54-18.96) in 1990 increasing to 20.73 DALYs per 100,000 population [95% UI: 11.28-40.24] in 2013.

1.6. Dengue in India

In general, malaria and typhoid fevers were considered as emerging diseases in India. Chickungunya, dengue and leptospiral infections are also now considered in the re-emerging diseases group. The emerging and re-emerging diseases have a large health impact in India and cause major public health concerns. This paper analyses the health impact of dengue in India and proposes a framework for prevention and control of dengue. Dengue fever is caused by genus Flavivirus and Aedes. Aegypti mosquitoes transmit the genus Flavivirus to the individuals (Martina et al. 2009; Carey et al. 1966; Sarkar et al. 1964). People infected by dengue have the following symptoms at the severe stage such as circulatory failure, shock, coma and death (Bhattacharjee et al. 1993; Padbidri et al. 1996). The incidence of dengue was reported first in Chennai during 1780, thereafter it emerged all over India. Since the past few decades, there is a massive increase in dengue cases, and outbreaks have been reported from different states of India (Parida et al. 2002; Broor et al. 1997). World Health Organization (WHO) estimates the annual incidence of dengue infection to be around 50 million (Dar et al. 1999; WHO 2016b; Gupta et al. 2005).

Indian health officials report that in 2015, 84,391 dengue cases have been reported, while there were 40,571 and 4,117 cases in 2014 and 2013 respectively. The following states and union territories have experienced a large number of dengue cases compared to other states of India. It includes Delhi (15,531 cases), Punjab (12,628 cases) and Haryana (8,021 cases) (Herriman 2016). In Delhi, 158 cases reported were reported in 2014, while in 2015 the number of cases has increased to above 15,000 cases; this is the highest number of

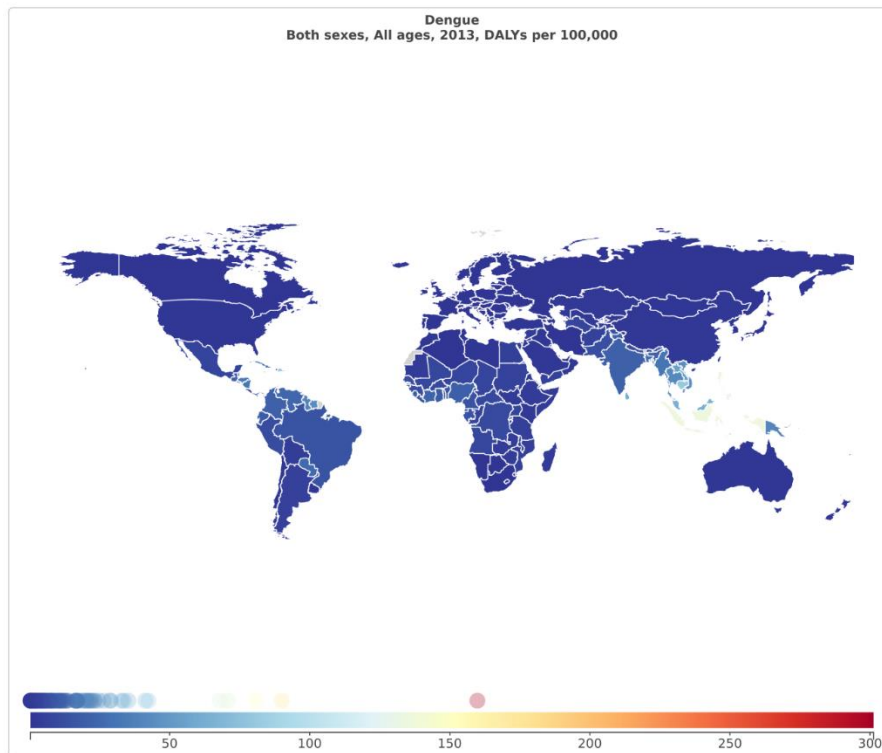


Figure 2. Global burden of dengue in 2013. Global burden of dengue in 2013 was 15.95 DALYs per 100,000 population [95% UI: 10.15-27.61]. (Source: IHME)

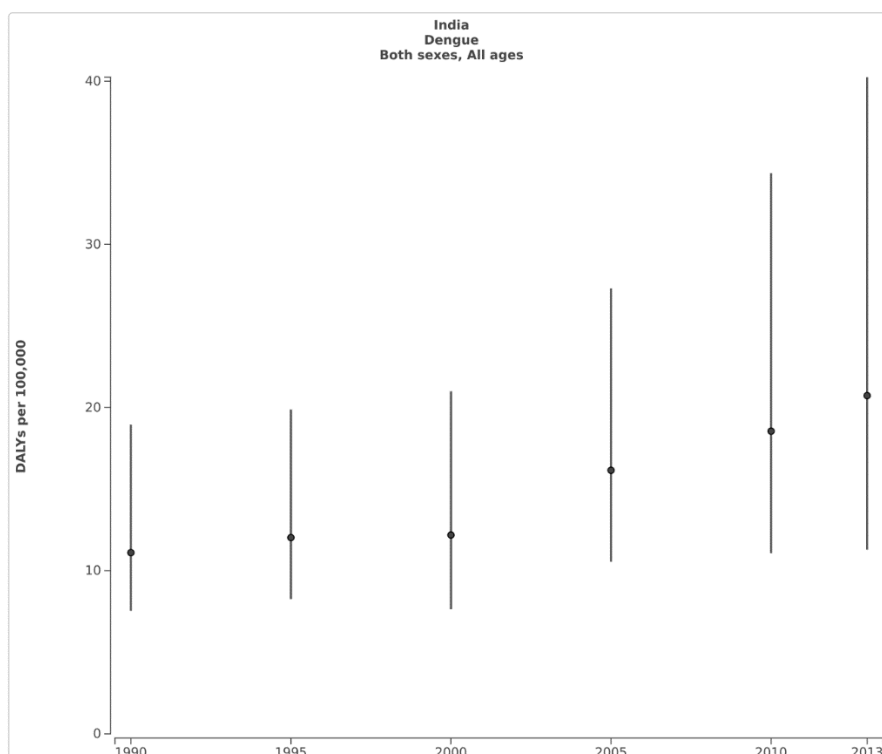


Figure 3. Burden of dengue in India from 1990 to 2013. Burden of dengue in India from 1990 to 2013, with 11.1 DALYs per 100,000 population [95% UI: 7.54-18.96] in 1990 increasing to 20.73 DALYs per 100,000 population [95% UI: 11.28-40.24] in 2013. (Source: IHME)

dengue cases ever in Delhi since 1996 (Nath 2015). In September 2015 alone, dengue disease burden crossed 6,775 cases, and this is the highest number of reported cases since 2010 (India 2016). In the recent decade, 2010 was considered the deadliest year, with 4,375 cases. The worst dengue outbreak in Delhi was in 1996 with 10,252 cases and 423 deaths. In 2015, Punjab was affected by dengue with 13,731 cases and 18 deaths reported, while West Bengal and Haryana had 6,822 and 8,066 cases reported respectively. Tamil Nadu was affected by dengue with 128 cases and five deaths reported in 1998, while in 2003, 2005 and 2015, it increased to 1,600 cases and 12 deaths, 1,150 cases and 8 deaths, and 3,841 cases and 6 deaths respectively (Victor et al. 2007). In 2012, Tamil Nadu had a high number of 12,826 cases and 66 deaths (NVBDPC 2016),

The main reasons for dengue outbreaks include climate change and global warming, large population and population density, air and water pollution, land use change and rapid urbanization, and low awareness among the people. In order to control the dengue outbreaks, the Government of India has provided strategies to the public for prevention and control of dengue. In addition to that, this paper provides seven preventive strategies – vaccination, disease surveillance, vector control, improved sanitation and access to safe drinking water, strengthening public health activities, awareness creation, and improving nutrition for women and children. The proposed alternatives are selected based on people, space and time criteria, such as low temperature and heavy rain, high temperature and high humidity, rainfall and water accumulation, resources and facilities, and sociocultural and sociodemographic variables. In order to resolve uncertainties in the decision-making process and select the best alternative for prevention and control of dengue, this paper uses fuzzy logic based VIKOR method.

1.7 Prevention and Control of Dengue

The increasing burden of dengue in India necessitates improvement in prevention and control programs. Dengvaxia is a dengue vaccine that is licensed for use in 3 countries, including Mexico, Philippines and Brazil, it is not currently licensed for use in India (WHO 2016b). The prevention and control programs for dengue in India are awareness creation; improved nutrition for women and children; improved water, sanitation and hygiene; strengthening public health activities; surveillance; (potential) vaccination; and vector control. The different interventions have variances in epidemiological effectiveness, access and cost, and expert opinion of decision makers provide one viable option for public health decision making under uncertainty. Since there will be variances in the prioritization of interventions among the experts, we propose a fuzzy logic based VIKOR method to make objective decisions based on subjective opinions of the decision makers.

1.7 Public Health Significance

This study addresses the significant public health problem of making an objective decision based on subjective expert opinion of decision makers on dengue prevention and control in India.

2. Multi-Criteria Decision Making

Multi-criteria decision making (MCDM) solves decision-making problems by using qualitative and quantitative evaluation criteria to select the optimal solution in complex environments (Bellman et al. 1970; Phuong et al. 2001). In the public health domain, MCDM models have been used to prevent and control emerging and reemerging diseases (De et al. 2001; Massad et al. 1999).

The following MCDM models have been used, including the Grey System Theory (GST), Goal Programming (GP), Analytic Network Process (ANP), Multi-Attribute Value Theory (MAVT), Analytic Hierarchy Process (AHP) and Data Envelopment Analysis (DEA). Saaty has developed AHP model to solve composite decision-making problems and are used to formulate a decision in contractor prequalification (Al-Harbi et al. 2001). Analytic Network Process (ANP) is similar to Analytic Hierarchy Process (AHP), but AHP forms a hierarchy with an end whereas ANP forms a network (Lu et al. 2007). Data Envelopment Analysis (DEA) is used to monitor various functions of an organization. For example, DEA is used to schedule and monitor the bridge maintenance services (Ozbek et al. 2010). Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is used to make a better decision based on the geometric distance between the events (Şimşek et al. 2013). Grey System Theory (GST) is developed based on differential equations to evaluate decisions. Hybrid decision making model is based on the above mentioned MCDM models (Jato-Espino et al. 2014).

Opricovic had developed VIKOR (VIsekriterijumska optimizacija iKOmpromisno Resenje) MCDM method to identify the optimal solution based on different criteria (Opricovic et al. 2007) by considering the variances in the preference values of different individuals involved in the decision-making process (Wang et al. 2009). Clinical diagnosis and epidemiological analysis have a high level of uncertainty and ambiguity (Broekhuizen et al. 2015, Lopez et al. 2015; Lopez et al. 2014), and decision-making models need to process and resolve this uncertainty. Fuzzy logic based VIKOR method is used in this paper to resolve uncertainties in decision making, with a focus on dengue prevention and control strategies.

3. Fuzzy Logic

3.1. Fuzzy Set Theory

3.1.1. Fuzzy sets

A fuzzy set is a set of objects and membership function valued between 0 and 1. Zadeh (1965) has introduced fuzzy set theory to assess real time fuzzy phenomenon problems that are vague, imprecise and unspecific (Zadeh et al. 1965). Fuzzy set theory is used to process subjective and imprecise judgments. Assume that X be the universe of discourse, $X_i (i = 1, 2, \dots, n)$, a fuzzy set $\tilde{A}(x)$ is denoted by a membership function $\mu_{\tilde{A}}(x)$ (Zadeh et al. 1975).

3.1.2. Fuzzy numbers

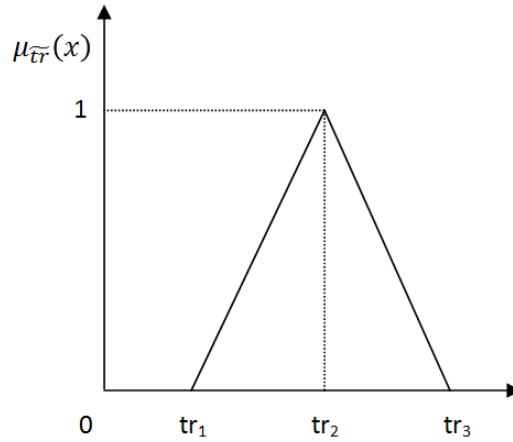


Figure 4. Triangular fuzzy number.

Fuzzy numbers are used to represent the linguistic variables, let a triangular fuzzy number \tilde{r} be denoted as

$$\tilde{r} = (tr_1, tr_2, tr_3) \quad (1)$$

and its membership function $\mu_{\tilde{r}}(x)$ (as shown in Figure 4) can be defined as (Liu et al. 2014):

$$\mu_{\tilde{r}}(x) = \begin{cases} 0, & x < tr_1, \\ \frac{x - tr_1}{tr_2 - tr_1}, & tr_1 \leq x \leq tr_2, \\ \frac{tr_3 - x}{tr_3 - tr_2}, & tr_2 \leq x \leq tr_3, \\ 0, & x > tr_3, \end{cases} \quad (2)$$

This paper focuses on alternatives for prevention and control of dengue based on various criteria. The decisions for each alternative are collected based on the following fuzzy linguistic variables. Triangular fuzzy number of x is $\mu_{\tilde{r}}(x)$, where, $tr_1 \leq tr_2 \leq tr_3$

tr_1 = Least possible rate

tr_2 = More promising rate

tr_3 = Highest possible rate

Let x_i and y_i be two positive triangular fuzzy numbers x_i ($i = 1,2,3$), y_i ($i = 1,2,3$) and a positive real number p , the arithmetical operations can be defined as follows:

$$\tilde{x} \oplus \tilde{y} = [x_1 + y_1, x_2 + y_2, x_3 + y_3], \quad (3)$$

$$\tilde{x} \ominus \tilde{y} = [x_1 - y_3, x_2 - y_2, x_3 - y_1], \quad (4)$$

$$\tilde{x} \otimes \tilde{y} = [x_1 y_1, x_2 y_2, x_3 y_3], \quad (5)$$

The operations of \vee (max) and \wedge (min) are defined as follows:

$$\tilde{x} \vee \tilde{y} = [x_1 \vee y_1, x_2 \vee y_2, x_3 \vee y_3], \quad (6)$$

$$\tilde{x} \wedge \tilde{y} = [x_1 \wedge y_1, x_2 \wedge y_2, x_3 \wedge y_3], \quad (7)$$

Scalar operations are defined as follows:

$$r \oplus \tilde{x} = [r + x_1, r + x_2, r + x_3] \quad (8)$$

$$r \ominus \tilde{x} = [r - x_1, r - x_2, r - x_3], \quad (9)$$

$$r \otimes \tilde{x} = [rx_1, rx_2, rx_3], \quad (10)$$

The Euclidean distance between two triangular fuzzy numbers x_i ($i = 1,2,3$), y_i ($i = 1,2,3$) is defined as follows (Chen et al. 2008):

$$D(X_i, Y_i) = \sqrt{\frac{1}{6}[(x_1 - y_1)^2 + 4(x_2 - y_2)^2 + (x_3 - y_3)^2]} \quad (11)$$

The distance between the two triangular fuzzy numbers x_i ($i = 1,2,3$), y_i ($i = 1,2,3$) by vertex method is defined as follows (Chen et al. 2000):

$$D(X_i, Y_i) = \sqrt{\frac{1}{3}[(x_1 - y_1)^2 + (x_2 - y_2)^2 + (x_3 - y_3)^2]} \quad (12)$$

3.1.3. Linguistic variables

Linguistic terms such as low, medium and high are used to represent the linguistic variables. In general, linguistic variables are used to describe the imprecise or complex expressions. This paper uses fuzzy linguistic terms to rate criteria and rank the various dengue prevention and control strategies.

4. Fuzzy VIKOR Multi-Criteria Decision Making

VIKOR MCDM method is combined with fuzzy logic to solve various complex and ambiguous decision-making problems. In general, VIKOR method identifies two solutions – best and compromise solutions to rate the alternatives in MCDM process.

Fuzzy logic based VIKOR method consists of the following steps to rank the alternatives (Figure 5):

Step 1: Identify the objective of the multi criteria decision making system.

Step 2: List the p alternative methods called $A = \{A_1, A_2, \dots, A_p\}$.

Step 3: List the q selection criteria called $C = \{C_1, C_2, \dots, C_q\}$.

Step 4: List the r decision-makers called $DM = \{DM_1, DM_2, \dots, DM_r\}$ involved in the decision-making process to identify the optimal alternative from p alternatives with respect to each q criteria.

Step 5: Define the appropriate linguistic terms, fuzzy membership function $\mu_{\tilde{t}}(x)$ and triangular fuzzy number $\tilde{t} = (t_1, t_2, t_3)$:

$$\mu_{\tilde{t}}(x) = \begin{cases} 0, & x < t_1, \\ \frac{x-t_1}{t_2-t_1}, & t_1 \leq x \leq t_2, \\ \frac{t_3-x}{t_3-t_2}, & t_2 \leq x \leq t_3, \\ 0, & x > t_3, \end{cases} \quad (13)$$

Step 6: Define the fuzzy criteria weights and collect the ratings for each alternative with respect to each criterion.

Step 7: Calculate the fuzzy decision matrix based on aggregated ratings of fuzzy alternatives and aggregated fuzzy weights of each criteria, let a set of fuzzy ratings of alternatives $A_i (i = 1, 2, \dots, p)$ and criteria $C_j (j = 1, 2, \dots, q)$, called $X = \{x_{ij}, i = 1, 2, \dots, p, j = 1, 2, \dots, q\}$.

Compute the normalized decision makers' fuzzy assessment of alternatives $\tilde{x}_{ij}^k = (\tilde{x}_{ij1}^k, \tilde{x}_{ij2}^k, \tilde{x}_{ij3}^k)$ and aggregated fuzzy weights of criteria $\tilde{w}_{ij}^k = (\tilde{x}_{ij1}^k, \tilde{x}_{ij2}^k, \tilde{x}_{ij3}^k)$:

$$\tilde{x}_{ij} = \sum_{l=1}^q \vartheta_l \tilde{x}_{ijl} \quad (14)$$

$$\tilde{w}_j = \sum_{l=1}^q \vartheta_l \tilde{w}_{jl} \quad (15)$$

Where $\vartheta_l \in [0,1]$ represents the weights given to the l^{th} decision-maker, and $\sum_{l=1}^q \vartheta_l = 1$.

The decision matrix \tilde{D} for dengue prevention and control programs is defined as:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1q} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2q} \\ \vdots & \vdots & \dots & \vdots \\ \tilde{x}_{p1} & \tilde{x}_{p2} & \dots & \tilde{x}_{pq} \end{bmatrix}, \tilde{w} = (\tilde{w}_1, \tilde{w}_2, \dots, \tilde{w}_q)^T \quad (16)$$

Step 8: Calculate the fuzzy best \tilde{f}_j^* ($i = 1, 2, \dots, p$) and fuzzy worst \tilde{f}_j^- ($j = 1, 2, \dots, q$) values from the aggregated fuzzy decision matrix $\tilde{x}_{ij}^k = (\tilde{x}_{ij1}^k, \tilde{x}_{ij2}^k, \tilde{x}_{ij3}^k)$:

$$\tilde{f}_j^* = \begin{cases} \max_i \tilde{x}_{ij}, & \text{for benefit criteria} \\ \min_i \tilde{x}_{ij}, & \text{for cost criteria} \end{cases} \quad (17)$$

$$\tilde{f}_j^- = \begin{cases} \min_i \tilde{x}_{ij}, & \text{for benefit criteria} \\ \max_i \tilde{x}_{ij}, & \text{for cost criteria} \end{cases} \quad (18)$$

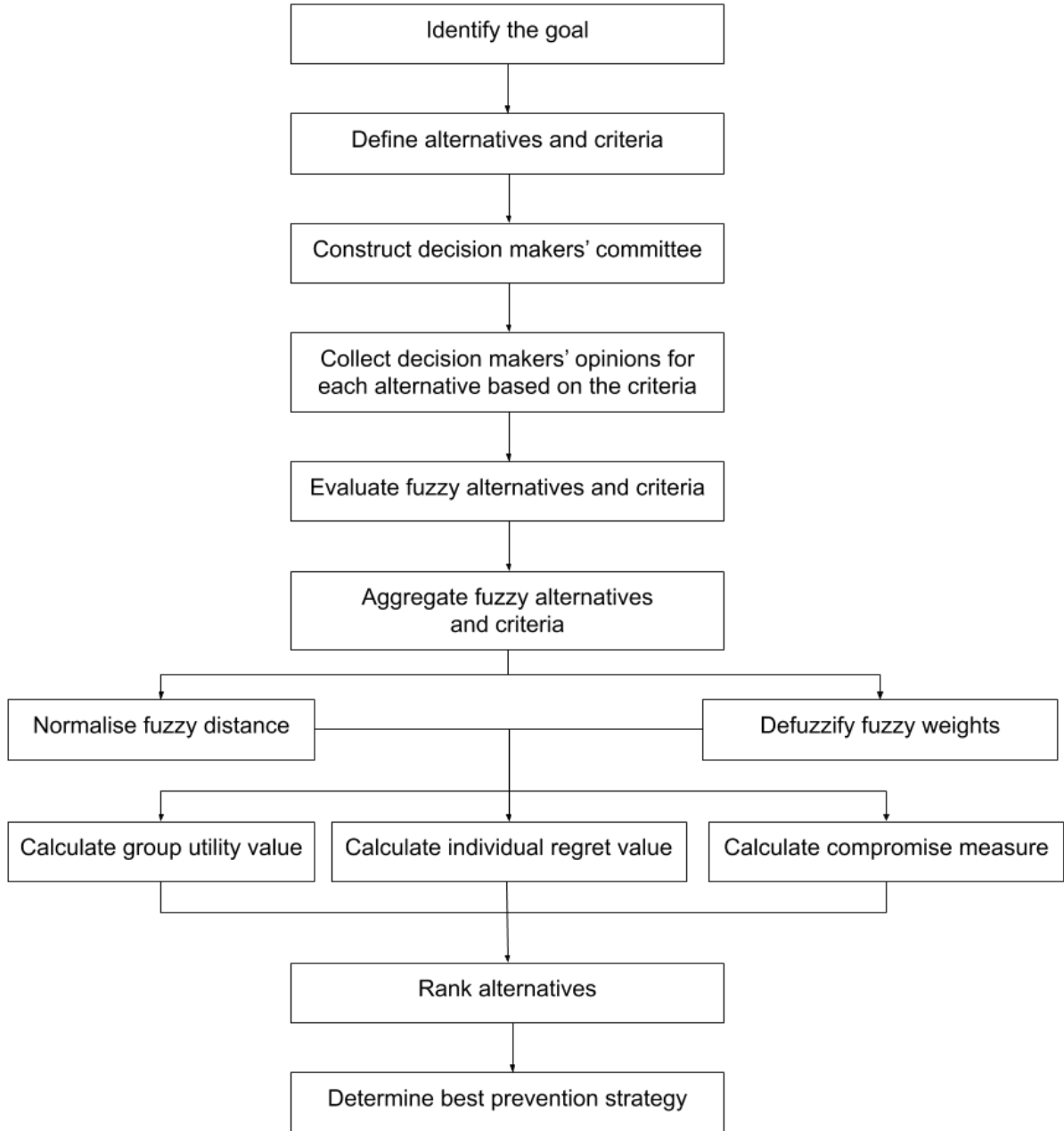


Figure 5. Representation of Fuzzy VIKOR Multi-Criteria Decision Making.

Step 9: Compute the average fuzzy distance values $\tilde{d}_{ij}, (i = 1, 2, \dots, p, j = 1, 2, \dots, q)$ from the aggregated fuzzy decision matrix $\tilde{x}_{ij}^k = (\tilde{x}_{ij1}^k, \tilde{x}_{ij2}^k, \tilde{x}_{ij3}^k)$:

$$\bar{d}_{ij} = \frac{d(\tilde{f}_j^*, \tilde{x}_{ij})}{d(\tilde{f}_j^*, \tilde{f}_j^-)} \quad (19)$$

The Euclidean distance $D(X_i, Y_i)$ between any triangular fuzzy membership functions $A_i = (X_1, X_2, X_3)$ and $Y_i = (Y_1, Y_2, Y_3)$ is calculated as follows:

$$D(X_i, Y_i) = \sqrt{\frac{1}{6} [(x_1 - y_1)^2 + 4(x_2 - y_2)^2 + (x_3 - y_3)^2]} \quad (20)$$

Step 10: Fuzzy weights are defuzzified as \bar{w}_j based on graded mean integration-based method:

$$\bar{w}_j = \frac{\bar{w}_j + 4 \times \bar{w}_j + \bar{w}_j}{6}, j = 1, 2, \dots, q \quad (21)$$

Step 11: Identify the group utility values S_i and individual regret values R_i , $i = 1, 2, \dots, p$, by the following equation:

$$S_i = \sum_{j=1}^n \frac{\bar{w}_j \cdot \bar{d}_{ij}}{\sum_{j=1}^n \bar{w}_j} \quad (22)$$

$$R_i = \max_j \left(\frac{\bar{w}_j \cdot \bar{d}_{ij}}{\sum_{j=1}^n \bar{w}_j} \right) \quad (23)$$

Step 12: The compromise measure Q_i , $i = 1, 2, \dots, p$, can be defined as:

$$Q_i = \vartheta \frac{S_i - S^*}{S^- - S^*} + (1 - \vartheta) \frac{R_i - R^*}{R^- - R^*} \quad (24)$$

Where $S^* = \min_i S_i$, $R^* = \min_i R_i$, $S^- = \max_i S_i$, $R^- = \max_i R_i$,

Let ϑ and $(1 - \vartheta)$ be the weights for S_i ($i = 1, 2, \dots, p$) and R_i ($i = 1, 2, \dots, p$) respectively.

Let $\vartheta = 0.5$ and $(1 - \vartheta) = 0.5$.

Step 13: List the various dengue prevention and control alternatives A_i ($i = 1, 2, \dots, p$) by sorting S_i ($i = 1, 2, \dots, p$), R_i ($i = 1, 2, \dots, p$) and Q_i ($i = 1, 2, \dots, p$) in the decreasing order.

Step 14: Calculate the compromise measure if and only if the following two conditions are satisfied, otherwise go to Step 15.

Condition 1:

$$Q(A^{(2)}) - Q(A^{(1)}) \geq \frac{1}{p-1} \quad (25)$$

Condition 2:

$(A^{(1)})$ Must be the first rank by S_i and R_i .

Step 15: If Condition 1 is not satisfied, then the compromise measure can be calculated as follows:

$$Q(A^{(N)}) - Q(A^{(1)}) < \frac{1}{p-1} \quad (26)$$

Else if Condition 2 is not satisfied, then the compromise measures are alternatives $(A^{(1)})$ and $(A^{(2)})$.

5. Case Study: Assessment of Dengue Prevention Alternatives Selection Process

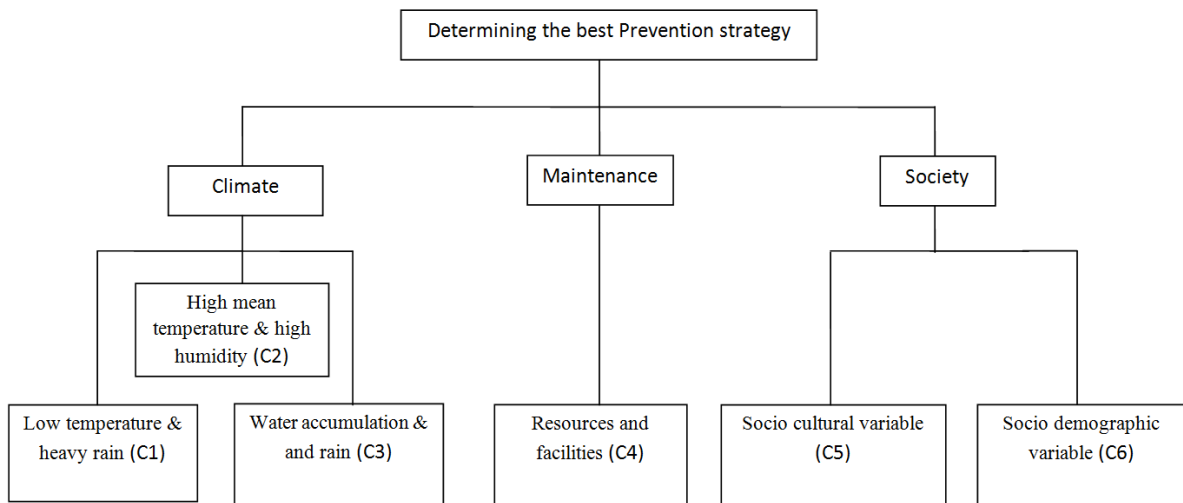


Figure 6. Hierarchical structure of the decision-making problem.

Step 1: The goal of this study is to select the best alternative for dengue prevention and control based on various criteria.

Step 2: Table 2 depicts the various alternatives for dengue prevention and control.

Table 2. Dengue prevention alternatives.

Notation	Alternatives	Description
A ₁	Vaccination	<ul style="list-style-type: none"> Vaccination should be given to the age group of 1.5 years to 15 years. Dengue vaccination should be given in a 3-dose series in the month of January, June and December (Dengue Fever Vaccine Program 2016).
A ₂	Disease surveillance	<ul style="list-style-type: none"> Early detection of various diseases using active and passive surveillance. Strengthening the medical services and improve the response time. Collect, analyze and generate reports from clinical records (National Programmes under NRHM 2016).
A ₃	Vector control	<ul style="list-style-type: none"> Water storage management and drainage maintenance. Encourage to use protective clothes and Long-Lasting Insecticidal Nets (LLINs). Encourage to use Indoor Residual Spraying (IRS) in hot spot regions. Environmental source reduction, identifying various techniques for waste management.
A ₄	Proper sanitation and increased access to safe drinking water	<ul style="list-style-type: none"> Provide proper sanitation facilities. Provide clean drinking water. Proper maintenance of tube well. Clean the water tank and water storage blocks regularly.
A ₅	Strengthening public health activities	<ul style="list-style-type: none"> Having safe food and water, as well as air quality. Encourage to do physical exercise and yoga.
A ₆	Awareness creation	<ul style="list-style-type: none"> Establish more public activities to know more about dengue outbreak.

		<ul style="list-style-type: none"> • Use of electronic media and social networks such as Twitter, Facebook and YouTube to create awareness of dengue.
A ₇	Improving nutrition for women and children	<ul style="list-style-type: none"> • Providing nutritional food for children and women. • Improving food safety, especially for child nutrition products, to international standards. • Implementing new food safety law, and creating awareness of food safety issues through schools, colleges, women's groups and the social media.

Step 3: Six criteria (Table 3) are considered to select an efficient alternative for dengue prevention and control.

Table 3. Multiple criteria for decision making.

Notation	Criteria	Description
C ₁	Low temperature & heavy rain	<ul style="list-style-type: none"> • Most states with low temperature and heavy rain are negatively correlated with the number of dengue cases (Yang et al. 2009; Fouque et al. 2006; Tran et al. 2004).
C ₂	High temperature & high humidity	<ul style="list-style-type: none"> • High mean temperature and high humidity are positively correlated with the number of dengue cases (Ehelepolo 2015).
C ₃	Rainfall & water accumulation	<ul style="list-style-type: none"> • Maintenance process involved in lakes and rivers. • Maintenance process involved in water tank during winter season.
C ₄	Resources & facilities	<ul style="list-style-type: none"> • Infrastructure: Lab, hospitals and in-patient beds. • Transport: Ambulance and other vehicles. • Skilled personnel: Doctors and nurses. • Unskilled personnel: Compounders and wipers. • Working cost: Cost for the building, medical equipment, drugs, staff commitment and other costs for various purposes. • Communication and maintenance cost: Survey collection about individuals' health history, lifestyle, vaccination history, social behaviors, and preparing schedule for vaccination and medical tests.
C ₅	Sociocultural variables	<ul style="list-style-type: none"> • Considering dress habits and lifestyle, for example, improper clothing may increase probability of getting dengue infection. • Considering daily travel plan, persons travelling more are more likely to get dengue infection.
C ₆	Sociodemographic variables	<ul style="list-style-type: none"> • Considering social habits and lifestyle, for example, people who are working in the drainage cleaning block are more likely to get dengue infection (Neiderud 2015). • People who are working in urban places where the hygienic levels are low are more likely to get dengue infection.

Step 4: Different decision makers are identified to select the best prevention alternative from seven alternatives based on the above six criteria. In this study, five decision makers were selected as shown in Table 4, to select the best prevention strategy (Figure 6).

Table 4. Decision makers.

Decision Makers	Profession
DM ₁	Medical Officer from Women & Child Development
DM ₂	Regional Officer from Health & Family Welfare
DM ₃	Head Officer from Housing and Urban Poverty Alleviation
DM ₄	Director from Ministry of Health & Family Welfare
DM ₅	Chief Officer from Ministry of Social Justice & Empowerment

Step 5: Appropriate linguistic variables for each alternative (as shown in Figure 7) and criteria weights (as shown in Figure 8) are identified. The linguistic variables are depicted in Table 5 and Table 6 respectively.

Table 5. Fuzzy linguistic variables for rating the criteria weights.

Linguistic Variables	Fuzzy Membership Function
Very Low (VL)	(0,0,0.25)
Low (L)	(0,0.25,0.5)
Medium (M)	(0.25,0.5,0.75)
High (H)	(0.5,0.75,1)
Very High (VH)	(0.75,1,1)

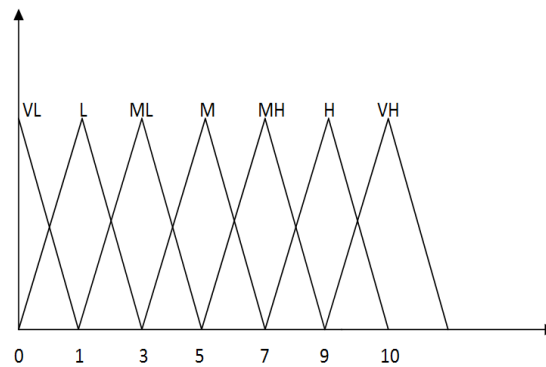


Figure 7. Fuzzy sets for alternative.

Table 6. Fuzzy linguistic variables for rating the alternatives.

Linguistic Variable	Fuzzy Numbers
Very Low (VL)	(0,0,1)
Low (L)	(0,1,3)
Medium Low (ML)	(1,3,5)
Medium (M)	(3,5,7)
Medium High (MH)	(5,7,9)
High (H)	(7,9,10)
Very High (VH)	(9,10,10)

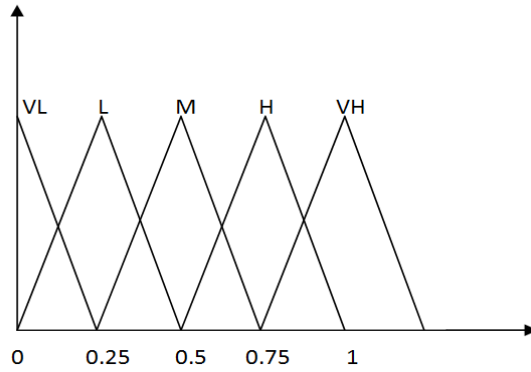


Figure 8. Fuzzy sets for criteria weights.

Step 6: Get the fuzzy logic-based values for all the alternatives with each criterion (Table 7) and linguistic weights for each criterion (Table 8).

Table 7. Decision makers' opinion in linguistic forms.

Decision Makers	Alternatives	Criteria					
		C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
DM ₁	A ₁	MH	H	H	VH	MH	MH
	A ₂	H	MH	MH	H	H	MH
	A ₃	VH	VH	VH	M	MH	H
	A ₄	H	MH	M	H	MH	H
	A ₅	VL	VL	ML	M	M	ML
	A ₆	VL	VL	L	L	ML	VL
	A ₇	M	ML	M	ML	MH	L
DM ₂	A ₁	M	MH	MH	H	H	H
	A ₂	M	MH	M	H	MH	MH
	A ₃	H	VH	H	MH	H	VH
	A ₄	MH	M	H	MH	M	MH
	A ₅	VL	L	VL	ML	ML	VL
	A ₆	VL	VL	L	L	VL	VL
	A ₇	ML	ML	M	MH	M	L
DM ₃	A ₁	ML	H	VH	VH	MH	VH
	A ₂	MH	MH	MH	H	MH	M
	A ₃	H	VH	VH	MH	VH	VH
	A ₄	MH	ML	MH	M	M	MH
	A ₅	ML	VL	ML	L	VL	ML
	A ₆	L	ML	ML	L	VL	VL
	A ₇	ML	M	ML	MH	MH	M
DM ₄	A ₁	H	VH	H	VH	H	H
	A ₂	MH	MH	M	H	MH	M
	A ₃	VH	VH	MH	H	MH	VH
	A ₄	MH	H	M	M	MH	ML
	A ₅	VL	VL	L	ML	VL	L

	A ₆	VL	L	VL	L	VL	VL
	A ₇	ML	ML	M	ML	M	M
DM ₅	A ₁	MH	VH	H	H	MH	MH
	A ₂	M	H	H	MH	M	M
	A ₃	VH	MH	VH	VH	MH	MH
	A ₄	MH	M	M	MH	MH	M
	A ₅	VL	L	ML	ML	L	VL
	A ₆	L	VL	VL	L	VL	VL
	A ₇	ML	M	ML	ML	ML	ML

Table 8. Fuzzy rating of criteria weights.

Decision Makers	Criteria					
	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
DM ₁	H	M	VH	M	L	H
DM ₂	VH	H	M	M	M	M
DM ₃	VH	H	M	L	L	H
DM ₄	H	H	H	M	M	L
DM ₅	H	M	H	H	M	M

Step 7: Aggregated fuzzy logic-based alternatives \tilde{x}_{ij} are calculated, and the results are shown in Table 9. Also, aggregated fuzzy logic-based weights \tilde{w}_j are calculated, and the results are depicted in Table 9. The following equations are used to calculate the values \tilde{x}_{ij} and \tilde{w}_j respectively.

$$\tilde{x}_{ij} = \sum_{l=1}^q \vartheta_1 \tilde{x}_{ijl} \quad (27)$$

$$\tilde{w}_j = \sum_{l=1}^q \vartheta_1 \tilde{w}_{jl} \quad (28)$$

Table 9. Aggregated fuzzy logic-based alternatives and fuzzy ratings of criteria weights.

Alternatives	Criteria					
	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
A ₁	(4.2,6.2,8)	(7.8,8,9.8)	(7.8,8,9.8)	(7.8,9.2,9.8)	(5.8,7.8,9.4)	(6.6,8.4,9.6)
A ₂	(4.6,6.6,8.4)	(5.4,7.4,9.2)	(4.6,6.6,8.4)	(6.6,8.6,9.8)	(5,7,8.8)	(3.8,5.8,7.8)
A ₃	(8.2,9.6,10)	(8.2,9.4,9.8)	(7.8,9.2,9.8)	(5.8,7.6,9)	(6.2,8,9.4)	(7.8,9.2,9.8)
A ₄	(5.4,7.4,9.2)	(3.8,5.8,7.6)	(4.2,6.2,8)	(4.6,6.6,8.4)	(4.2,6.2,8.2)	(4.2,6.2,8)
A ₅	(0.2,0.6,1.8)	(0.0,4,1.8)	(0.6,2,3.8)	(1.2,3,5)	(0.8,1.8,3.4)	(0.4,1.4,3)
A ₆	(0,0,4,1.8)	(0.2,0.8,2.2)	(0.2,1,2.6)	(0,1,3)	(0.2,0.6,1.8)	(0,0,1)
A ₇	(1.4,3,4,5.4)	(1.8,3.8,5.8)	(2.2,4.2,6.2)	(2.2,4.6,6.8)	(3.4,5.4,7.4)	(1.4,3,5)
W	(0.6,0.85,1)	(0.4,0.65,0.9)	(0.45,0.8,0.9)	(0.25,0.5,0.75)	(0.15,0.4,0.65)	(0.3,0.55,0.8)

Step 8: Fuzzy best \tilde{f}_j^* ($j = 1, 2, \dots, q$) and fuzzy worst \tilde{f}_j^- ($j = 1, 2, \dots, q$) values are calculated based on the following equations \tilde{f}_j^* and \tilde{f}_j^- respectively.

$$\tilde{f}_j^* = \begin{cases} \max_i \tilde{x}_{ij}, & \text{for benefit criteria} \\ \min_i \tilde{x}_{ij}, & \text{for cost criteria} \end{cases}$$

$$\tilde{f}_j^- = \begin{cases} \min_i \tilde{x}_{ij}, & \text{for benefit criteria} \\ \max_i \tilde{x}_{ij}, & \text{for cost criteria} \end{cases}$$

$$\tilde{f}_1^* = (0,0.4,1.8), \tilde{f}_2^* = (0,0.4,1.8), \tilde{f}_3^* = (0.2,1,2.6), \tilde{f}_4^* = (0,1,3), \tilde{f}_5^* = (0.2,0.6,1.8), \tilde{f}_6^* = (0,0,1)$$

$$\tilde{f}_1^- = (8.2,9.6,10), \tilde{f}_2^- = (8.2,9.4,9.8), \tilde{f}_3^- = (7.8,9.2,9.8), \tilde{f}_4^- = (7.8,9.2,9.8), \tilde{f}_5^- = (6.2,8,9.4), \tilde{f}_6^- = (27.8,9.2,9.8)$$

Step 9: Aggregated fuzzy logic-based alternatives \tilde{x}_{ij} are converted to normalized fuzzy logic-based distances \tilde{d}_{ij} ($i = 1,2, \dots, p; j = 1,2, \dots, q$) based on the following equations and the results are depicted in Table 10.

$$\tilde{d}_{ij} = \frac{d(\tilde{f}_j^*, \tilde{x}_{ij})}{d(\tilde{f}_j^*, \tilde{f}_j^-)} \quad (29)$$

The Euclidean distance $D(X_i, Y_i)$ between any triangular fuzzy membership functions $A_i = (X_1, X_2, X_3)$ and $Y_i = (Y_1, Y_2, Y_3)$ are calculated based on the following equation:

$$D(X_i, Y_i) = \sqrt{\frac{1}{6}[(x_1 - y_1)^2 + 4(x_2 - y_2)^2 + (x_3 - y_3)^2]} \quad (30)$$

Step 10: Defuzzification of fuzzy weights \bar{w}_j are calculated with help of graded mean integration method. The defuzzified crisp values \bar{w}_j for each fuzzy weight are computed based on the following equation and the results are shown in the last row of Table 10.

$$\bar{w}_j = \frac{\bar{w}_j + 4 \times \bar{w}_j + \bar{w}_j}{6}, j = 1,2, \dots, q \quad (31)$$

Table 10. Normalized fuzzy logic-based distances. Normalized fuzzy logic-based distances \tilde{d}_{ij} for all alternatives $A = \{A_1, A_2, \dots, A_p\}$ for each criteria $C = \{C_1, C_2, \dots, C_q\}$ and crisp values of fuzzy weights \bar{w}_j .

Alternatives	Criteria					
	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
A ₁	0.6348	0.9318	0.9497	1	0.9735	0.8232
A ₂	0.6796	0.7841	0.6865	0.9236	0.8683	0.6398
A ₃	1	1	1	0.8053	1	1
A ₄	0.7692	0.6015	0.4769	0.3661	0.7636	0.6798
A ₅	0.1825	0	0.1216	0.2387	0.1665	0.1586
A ₆	0	0.0386	0	0	0	0
A ₇	0.3287	0.3792	0.3911	0.4407	0.6539	0.3363
W	0.8333	0.6666	0.7583	0.5	0.4	0.55

Step 11: Group utility values S_i ($i = 1, 2, \dots, p$) are computed based on the following equation:

$$S_i = \frac{\sum_{j=1}^n \bar{w}_j \cdot \bar{d}_{ij}}{\sum_{j=1}^n \bar{w}_j} \quad (32)$$

Individual regret values R_i ($i = 1, 2, \dots, p$) are computed based on the following equation:

$$R_i = \max_j \left(\frac{\bar{w}_j \cdot \bar{d}_{ij}}{\sum_{j=1}^n \bar{w}_j} \right) \quad (33)$$

The results S_i ($i = 1, 2, \dots, p$) and R_i ($i = 1, 2, \dots, p$) are shown in Table 11.

Step 12: Compromise measure Q_i ($i = 1, 2, \dots, p$) values are calculated based on the following equation and the results are shown in last row of Table 11.

$$Q_i = \vartheta \frac{S_i - S^*}{S^- - S^*} + (1 - \vartheta) \frac{R_i - R^*}{R^- - R^*} \quad (34)$$

Where $S^* = \min_i S_i$, $S^- = \max_i S_i$, $R^* = \min_i R_i$, $R^- = \max_i R_i$,

Let ϑ and $(1 - \vartheta)$ be the weights for S_i ($i = 1, 2, \dots, p$) and R_i ($i = 1, 2, \dots, p$) respectively. Let $\vartheta = 0.5$ as threshold value and $(1 - \vartheta) = 0.5$

Table 11. Group Utility (S), Individual Regret (R) and Composite Measures (Q) for all alternatives.

Criteria	Alternatives						
	A ₁	A ₂	A ₃	A ₄	A ₅	A ₆	A ₇
S	0.8663	0.7470	0.9737	0.6109	0.1395	0.0141	0.3972
R	0.1941	0.1527	0.2247	0.1728	0.0409	0.0141	0.0799
Q	0.8713	0.7108	1	0.6876	0.1289	0	0.3558

Step 13: Group utility value S_i ($i = 1, 2, \dots, p$), individual regret value R_i ($i = 1, 2, \dots, p$) and compromise measure Q_i ($i = 1, 2, \dots, p$) are sorted in the decreasing order for all alternatives $A = \{A_1, A_2, \dots, A_p\}$, and the results are shown in Table 12.

Table 12. Group Utility (S), Individual Regret (R) and Composite Measures (Q) for all alternatives (ordered).

Criteria	Alternatives						
	A ₁	A ₂	A ₃	A ₄	A ₅	A ₆	A ₇
S	2	3	1	4	6	7	5
R	2	4	1	3	6	7	5
Q	2	3	1	4	6	7	5

Step 14: Condition 1 and Condition 2 are satisfied; hence the compromise measure results Q_i ($i = 1, 2, \dots, p$) shows that vector control alternative (A₃) is the best alternative for dengue prevention and control.

Condition 1:

$$Q(A^{(2)}) - Q(A^{(1)}) \geq \frac{1}{p-1} \quad (35)$$

where,

$(A^{(1)})$ = Ranked 1st by the compromise measure $Q_i(\text{maximum})$ ($i = 1, 2, \dots, p$), which is Q_5

$(A^{(2)})$ = Ranked 2nd by the compromise measure $Q_i(\text{maximum})$ ($i = 1, 2, \dots, p$), which is Q_7

$$0.8713 - 1 \geq \frac{1}{7-1}$$

$0.1287 \geq 0.1666$, Hence condition C_1 is not satisfied.

Condition 2:

Alternative $(A^{(1)})$ must be ranked first by S_i and R_i .

$$S^{(A_3)} > S^{(A_1)} > S^{(A_2)} > S^{(A_4)} > S^{(A_7)} > S^{(A_5)} > S^{(A_6)}$$

$$R^{(A_3)} > R^{(A_1)} > R^{(A_4)} > R^{(A_2)} > R^{(A_7)} > R^{(A_5)} > R^{(A_6)}$$

Hence condition C_2 is satisfied.

The sorted order of dengue prevention and control alternatives are depicted in Table 13.

Thus, the **vector control** strategy is the best method for dengue prevention and control.

Table 13. Ranking of alternatives for dengue prevention and control.

Rank	Notation	Alternatives
1	A ₃	Vector control
2	A ₁	Vaccination
3	A ₂	Disease surveillance
4	A ₄	Proper sanitation and increased access to safe drinking water
5	A ₇	Improving nutrition for women and children
6	A ₅	Strengthening public health activities
7	A ₆	Awareness creation

6. Discussion

6.1 Public health implications

This study illustrates the use of the fuzzy logic based VIKOR method for making an objective decision based on subjective decisions of experts and decision makers on prevention and control of dengue in India.

6.2 Public health decision making under uncertainty

We have presented a solution for public health decision making under certainty, by using the fuzzy logic based VIKOR method for prioritization of interventions based on experts' opinion for dengue prevention and control. Dynamic modeling of dengue transmission dynamics provides another option for estimating the effectiveness and cost-effectiveness of different interventions, as done in the Disease Control Priorities (DCP-3) project to estimate efficacy and effectiveness of interventions for leading causes of global disease burden (DCP 2016).

6.3 Limitations

The limitation of this study is that the proposed model identifies the best alternative based on the input of five decision makers in a single setting. Future work can extend the decision-making framework for identification of best alternatives based on the inputs of different groups of decision-makers in varied settings.

6.4 Conclusions

Professionals and administrators from the healthcare and other industries are jointly designing healthcare strategies with the aim to enable efficient disease control programs using the available resources. To consider the individual preferences of various stakeholders, we have presented a multi-criteria decision-making framework. In the context of dengue, the prevention and control programs are vaccination, disease surveillance, vector control, improved sanitation and access to safe drinking water, strengthening public health activities, awareness creation, and improving nutrition for women and children. The proposed alternatives are selected based on people, space and time criteria, such as low temperature and heavy rain, high temperature and high humidity, rainfall and water accumulation, resources and facilities, sociocultural and sociodemographic variables. We used fuzzy logic based VIKOR method to analyze the linguistic terms collected from decision makers and ranked the best alternatives based on multiple criteria for selecting the optimal dengue prevention and control programs.

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