Research Article

Dharyll Prince Abellana*

# Modelling the interdependent relationships among epidemic antecedents using fuzzy multiple attribute decision making (F-MADM) approaches

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**Abstract:** With the high incidence of the dengue epidemic in developing countries, it is crucial to understand its dynamics from a holistic perspective. This paper analyzes different types of antecedents from a cybernetics perspective using a structural modelling approach. The novelty of this paper is twofold. First, it analyzes antecedents that may be social, institutional, environmental, or economic in nature. Since this type of study has not been done in the context of the dengue epidemic modelling, this paper offers a fresh perspective on this topic. Second, the paper pioneers the use of fuzzy multiple attribute decision making (F-MADM) approaches for the modelling of epidemic antecedents. As such, the paper has provided an avenue for the cross-fertilization of knowledge between scholars working in soft computing and epidemiological modelling domains.

**Keywords:** antecedents of epidemics; structural modelling; dengue epidemic; fuzzy multiple attribute decision making; soft computing

## 1 Introduction

Epidemics present a growing threat, both locally and on the global scene. They cripple both economic and health statures of countries, especially those belonging to emerging economies. Covid-19 is one of the most recent epidemics that has caused devastation on a global scale. Although Covid-19 is a current issue being tackled, it has received significant attention from scholars in a wide spectrum of domains ranging from epidemiology, medicine, public policymaking, travel and hospitality, mathematical modelling, and applied machine learning, among others. As such, Covid-19 has obtained a much more holistic perspective compared to other epidemics recorded in history. While this indicates that scholars have become more responsive in tackling emerging epidemics, this has also caused a gap in the literature. For one, it has led to a loss of focus in the current literature on other epidemic-causing diseases such as dengue, Chikungunya, Ebola virus disease, and flu. Several outbreaks of such diseases have been recorded during the Covid-19 epidemic. For instance, the World Health Organization (WHO) reported a recent outbreak in the Congo on June 1, 2020 [121]. Likewise, the European Centre for Disease Prevention and Control (ECDC) records cases of Chikungunya reported in the Americas and the Carribean (*e.g.* Brazil, Paraguay, and Peru) and Asia (*e.g.* India, Malaysia, and Thailand) [31]. With these issues, experts such as Dr. Tedros Adhanom Ghebreyesus, WHO Director-General, pointed out that Covid-19 is not the only health threat people are currently facing, and emphasized the need to continually monitor and respond to many other health emergencies despite the Covid-19 pandemic [121].

Aside from the aforementioned outbreaks, dengue cases have been recently reported in tropical countries, particularly the Philippines [32]. To make matters worse, these cases have been detected while the country has still focused its efforts on mitigating the effects of the Covid-19 pandemic. This has therefore affected the country's resilience to other infectious diseases. With dengue being one of the most neglected tropical diseases, increased efforts should be made both in a scholarly and stakeholders' perspective [46]. While there are available studies on dengue in the current literature, most of these focus only on the point of view of epidemiologists and health experts. In order for increased efforts on the stakeholder-side (*e.g.* government, and other policymakers) to intensify, studies that offer lenses in a policy-making perspective would be crucial. However, very few studies have given attention to such a topic. Studies that are directly useful for policy-making usually involve analyzing antecedents, cost-benefit analysis, and forecasting, among others. There have been studies that offer insights

***Corresponding Author: Dharyll Prince Abellana:** Department of Computer Science, University of the Philippines – Cebu, Cebu City, 6000 Cebu, Philippines; Email: dmabellana@up.edu.ph

through forecasting (*e.g.* [11, 118]) and cost-benefit analysis (*e.g.* [83]). However, to the best of the author's knowledge, relatively few efforts have been made to understand the dynamics of epidemics in a system dynamics perspective. That is, understanding how the interactions of different antecedents (*e.g.* social, environmental, and political) affect the occurrence of epidemics in a region. Hence, such deficiency creates a significant gap in the literature.

To address such gaps, this paper offers a cybernetics perspective in analyzing antecedents of epidemics through a structural modelling approach. In particular, a fuzzy decision-making trial and evaluation laboratory (DEMATEL) is adopted to analyze the interrelationships of the antecedents. Structural modelling is the part of soft computing which uses expert decision-making to establish relationships between different antecedents [8, 114]. It has been shown in other domains to be useful in analyzing how the interaction of antecedents influence the occurrence of a certain phenomenon [2, 9, 86, 125]. A case study in the Philippines is performed due to having the highest recorded cases of dengue outbreaks among tropical countries. The contribution of the paper is two-fold. First, it is the first to analyze how the interaction of different antecedents influence the occurrence of dengue in a developing country. Second, it is the first to adopt an expert decision-making approach in analyzing epidemics. Hence, aside from being directly interesting for policymakers, the study provides an avenue for scholars in both epidemiology and soft computing to study epidemics at different but complementary perspectives. While soft computing expands the available techniques used in studying epidemics, the dynamics of epidemics serves as a new problem area for soft computing to be relevant.

To this end, the paper is organized as follows. Section 2 provides a literature review regarding the dengue epidemic, current works in the study of dengue, antecedents of the dengue epidemic, and how antecedents are modelled in current literature. Section 3 presents the methodology. This section discusses how the study is conducted in the Philippines, how the data is analyzed, and the algorithmic and mathematical background of the models used. Section 4 provides a discussion on how the models used are applied in the study, the computational results, and the resulting structural model. Section 5 makes a deeper discussion on the implications of the results both to the literature and stakeholders. Finally, Section 6 presents the conclusions arrived in the study as well as potential future directions.

# 2 Literature Review

## 2.1 Overview of the dengue epidemic

An epidemic is an event described by aspects such as fear and sudden widespread death. Its episodic quality elicits an immediate and widespread response [91]. The deadliest epidemics that affected the population at a global scale include Covid-19, Acquired Immune Deficiency Syndrome (AIDS), Severe Acute Respiratory Syndrome (SARS), Black Death, Small Pox, and Tuberculosis, among others [15, 130]. Likewise, Dengue Fever is among such epidemics that shares similar implications on societal fear of widespread death. Dengue is an acute systemic viral disease that has established itself globally in both endemic and epidemic transmission cycles [14, 68]. It was first described in the 1780s and is said to flourish in less economically productive urban areas, suburbs, and the countryside [119]. In that respect, it also affects affluent neighborhoods especially in tropical and subtropical countries [68, 120]. As reported by the World Health Organization (WHO), dengue is endemic to more than 100 countries in Africa, the Americas, the Eastern Mediterranean, South-East Asia, and the Western Pacific. As a consequence of its potential as a threat to public health, dengue is considered a critical contributor that increases systemic social risks. Scholars estimate dengue infections per year to be at 390 million using cartographic approaches [14]. Moreover, in the Americas alone 2.35 million cases of dengue were reported in 2015, of which 10,200 cases were diagnosed as severe causing 1,181 death cases [120].

In the Philippines, a developing country known to have the highest occurrences of dengue incidents in Southeast Asia, the dengue epidemic is one that significantly affects its stature concerning economic, health, and social performance [24, 26, 116]. A recent report in the period of January 1 – March 11, 2018 indicates that a total of 20,108 dengue cases were detected nationwide. Although such statistics are 25.59% lower compared to the same time period in 2017 (*i.e.* with a trend declining from 2010), the morbidity rate still exhibits an alarming level which has contributed to out-of-pocket spending of the government as well as some political and social concerns that are derived as a result of the country's aim to mitigate the severity of the epidemic [27]. One of the most controversial issues associated with initiatives in mitigating the epidemic is the halting of a dengue immunization campaign of the world's first approved dengue vaccine, Sanofi Pasteurs Dengvaxia, after post-market testing confirmed that it could increase the risk of severe dengue in people who have never been exposed to the virus [29]. To this end, the vaccine has become the center of a significant social and political issue in the Philippines that has still been debated up to the present. Moreover, the issue has affected not only the Philippines but also other nations across the globe after the recommendation of the WHO for additional testing of the vaccine due to safety concerns [74].

## 2.2 Current works in the study of dengue

As a critical factor affecting society at a global scale, it is crucial that the dengue epidemic be addressed in both domain and relevant literature, as well as in practice. Such a problem is widely tackled by several scholars in the extant literature from different perspectives. For instance, [25] generated a panel of human monoclonal antibodies to dengue virus and proposed implications that may be used for future vaccine design. Similarly, [108] reviewed current techniques and future strategies of diagnostic methods for confirming dengue infection and argued that newly established methods must be standardized to maintain high-quality laboratory performance. Moreover, [119] discussed some of the crucial lessons learned in the literature and practice about dengue incidents, as well as its history since 265-420 AD during the Jin dynasty of China up to the incident that occurred in the Philippines in 2015. Also, [70] investigated the potential effects of global climate change on human health, particularly on vector-borne diseases such as dengue fever. With such published scholarly articles, it can be safely inferred that the problem of the dengue epidemic is widely embodied in the literature particularly in the scientific, medical, and health perspectives.

Several scholars in the literature investigated factors that potentially influence the occurrence of dengue incidents. For instance, [28] explored characterization of mosquito breeding in urban hotspot areas and found that larvae density is related to factors such as frequency, intensity, and duration of epidemic variation which pertain to the mosquito habitat's environmental characteristics. Moreover, [64] pointed out the role of socio-economic status as one of the main antecedents of arboviral diseases (*e.g.* dengue). The paper argues that poverty may lead to other antecedents of dengue incidents such as inadequate vector control and prevention programs, sub-optimal health infrastructures, and the creation of environmental conditions that promote mosquito breeding. Furthermore, the paper laid out several other antecedents that may potentially interrelate with other antecedents such as climatic conditions and climate change, and man-related activities, among others. Likewise, [30] and [127] pointed out the role of community involvement and other social antecedents as highly influential to the prevention of dengue outbreaks in a community. A summary of previous works is presented in Table 1.

While works in the literature have explored different factors affecting dengue incidents, they focused on a very contained view of the factors affecting the epidemic. For instance, [127] only considered social antecedents of the dengue epidemic while [57] considered only climate and mosquito density as factors of the disease transmission. As such, no work is given to understanding how the different factors interplay with one another in a more holistic perspective. In other words, very limited attention is given to system dynamics or cybernetics approach in modelling the antecedents of the dengue epidemic. While studying the epidemic in a reductionist approach is important to develop a more fundamental understanding of it, viewing the problem in a holistic perspective is also as important to take into account the complexity of the system when making predictions. [98] pointed out in their review that with the growing interest of the literature in predicting disease dynamics, understanding the interplay of the different factors (*e.g.* climate and socioeconomic antecedents) would be crucial. Several scholars (*e.g.* [6, 64, 98, 126]) collectively agree on the importance of the development of an integrated approach in modelling the dynamics of infectious diseases. Similarly, [73] reiterated the WHO's movement for an Integrated Vector Management (IVM), which implies the development of an integrated approach in tackling the disease by incorporating key elements such as socio-economic, environmental, and other factors. Despite the importance of such an integrated approach, limited attention is given by scholars in the literature to analyzing the interplay between the different antecedents of dengue in a holistic perspective. As it currently stands, the problem remains a significant gap in the literature.

## 2.3 Antecedents of the dengue epidemic

In the literature, factors that influence the occurrence of an event/phenomenon/process are termed as *antecedents*, *drivers*, or *causes*. Throughout the paper, no distinction between the terms is made and they are used interchangeably. Studies on the dengue epidemic have provided results that emphasize the roles of different antecedents in influencing the transmission and spread of dengue in a community [6]. For instance, [57] investigated the role of climate and mosquito density as antecedents of dengue fever incidents in China. [105] studied how socio-demographic factors, socio-cultural factors, knowledge,

**Table 1:** Previous works on the antecedents (also known as factors, drivers, and causes) of dengue spread and transmission in communities. The most relevant papers are selected for brevity.

| No. | Research work | Description of research | Methodology |
|---|---|---|---|
| 1 | [55] | Investigated the role of construction sites as antecedent for sustained dengue transmission. | Statistical analysis of cluster records |
| 2 | [82] | Investigated the role of social behavior and demography as drivers/antecedents of fine-scale dengue transmission in Colombia. | Agent-based modelling |
| 3 | [70] | Studied the effects of global climate change on human health, particularly on vector-borne diseases such as dengue fever | Climate-driven statistical and process-based models. |
| 4 | [28] | Characterized mosquito breeding hotspot area and found that the frequency, intensity, and duration of epidemic variation are related to the environmental characteristics of the mosquitoes' habitat. | Correlation analysis and analysis of variance (ANOVA) |
| 5 | [64] | Studied the effect of socio-economic factors (*e.g.* poverty, resources) to the occurrence of arboviral diseases such as dengue. | Review |
| 6 | [127] | Explored the dengue knowledge and preventive practices among rural residents in the Philippines. | Correlation analysis |
| 7 | [110] | Studied the association of dengue infection and Guillain-Barré syndrome in Malaysia. | Chi-square test, Mann-Whitney U test, and logistic regression |
| 8 | [17] | Reported two cases of Guillain-Barré syndrome complicating dengue infection. | Case report |
| 9 | [109] | Studied how community empowerment in developing dengue vector control. | |
| 10 | [3] | Studied how community mobilization and household level waste management aid in dengue vector control. | Knowledge, Attitude, and Practice (KAP) survey |
| 11 | [12] | Sudied how dengue risk could be driven by human adaptation to climate change. | Distributional models |
| 12 | [20] | Conducted a test about the effectiveness of community empowerment strategy in a routine dengue vector control program. | Generalized estimating equation (GEE) models |
| 13 | [30] | Explored how knowledge, perceptions, and practices of citizens affect the success of dengue prevention programs. | Chi-square test and ANOVA |
| 14 | [47] | Studied how the spatial patterns and socioecological antecedents of dengue affect its transmission. | Bayesian spatial conditional autoregressive (CAR) model |
| 15 | [48] | Explored the role of the urban environment in modelling the potential distribution of the dengue vector. | Review |
| 16 | [98] | Reviewed the climate forcing and infectious disease transmission considering the integration of demographic and socio-economic heterogeneity. | Review |
| 17 | [105] | Determined the risk factors for dengue hemorrhagic fever incidents based on the socio-demographic factors, socio-cultural factors, knowledge, attitudes, practices, environmental factors, and characteristics of caregivers. | Logistic regression |

Table 1: ...continued

| No. | Research work | Description of research | Methodology |
|---|---|---|---|
| 18 | [73] | Provided a review of the epidemiology of dengue and suggested the combination of approaches to incorporate key elements of social mobilization, evidence-based decision-making, among others, to support policy-making and management initiatives in reducing dengue transmission. | Systematic Review |
| 19 | [11] | Developed a predictive model of for dengue occurrences in India based on climate factors. | Time series and regression models |
| 20 | [118] | Analyzed the climatological, virological, and sociological antecedents of current and projected dengue fever outbreak dynamics in Sri Lanka. | Two-strain susceptible-infected-recovered (SIR) model |
| 21 | [49] | Assessed factors associated with the autochthonous transmission of dengue and chikungunya using French surveillance data collected between 2010 and 2018 in areas of Southern France. | Regression analysis |
| 22 | [72] | Analyzed the spatial, temporal, demographic, and vector-related charcateristics of dengue in Sabah state. | Spatial, temporal, and demographic trends analysis. |
| 23 | [126] | Provided a review on the disease burden, epidemic potential, geographical distribution, and population exposed to climatically suitable areas of dengue. | Systematic Review |
| 24 | [50] | Studied the effect of temperature-dependent variation in elevating the risk of vector-borne disease emergence. | Stochastic modelling |
| 25 | [65] | Revealed in a review of the literature that heavy rains, human movements, forest enroachment, and deforestation are identified as antecedents of mosquito-borne diseases in the Democratic Republic of Congo (DRC). | Systematic Review |
| 26 | [104] | Identified ecological factors underlying dengue hemorrhagic fever (DHF) in Jakarta and found environmental patterns and social behavior as its primary antecedents. | Hypothesis testing |
| 27 | [57] | Studied the role of climate and mosquito density as drivers of dengue fever incidence in two high risk areas in China. | Generalized additive model (GAM), random forest, and structural equation modelling (SEM). |
| 28 | [33] | Developed a model for the prediction of dengue importation to China using air travel data. | Regression analysis |
| 29 | [6] | Provided a review of the environmental and population factors impacting the emergence and spread of dengue in Saudi Arabia. The review emphasized the need to understand the interplay between the environmental drivers with other drivers of dengue such as social and population factors. | Systematic Review |
| 30 | [85] | Investigated the effects of socio-economic and environmental factors on the spatial heterogeneity of dengue fever in China and found them to be key drivers of the spread. | GAM |

**Table 2:** Antecedents of dengue epidemic extracted from peer-reviewed sources.

| No. | Antecedent | Source |
|---|---|---|
| 1 | Formation of open stagnant clean water in household proximity. | [3, 30, 71] |
| 2 | Administration's lack of advocacy towards health issues. | [13] |
| 3 | Lack of dengue knowledge and awareness. | [3] |
| 4 | Climatic factors such as rain, temperature and humidity. | [51, 73] |
| 5 | Poverty. | [64, 71] |
| 6 | Lack of sustainable anti-dengue initiatives. | [13] |
| 7 | Inadequate public health resources for vector control. | [47] |
| 8 | Lack of personal household protection such as windows screens and long-sleeved clothes. | [71, 98] |
| 9 | Inadequately planned urbanization. | [20] |
| 10 | Weak enforcement of community participation. | [109] |
| 11 | Lack of local government funding on public health concerns. | [64] |
| 12 | Poor sanitary practice. | [12] |
| 13 | Weak enforcement of health awareness programs. | [71, 99] |
| 14 | Household overcrowding. | [71] |
| 15 | Creation of environmental conditions that promote mosquito breeding. | [64, 71, 99] |
| 16 | High level of proximity to water bodies. | [98] |
| 17 | Disease transmission from increased mobility of people (*e.g.* intercontinental travel). | [49] |
| 18 | Unclear role or responsibility of community members in program implementation and maintenance. | [109] |
| 19 | Lack of partnership between government and community members. | [109] |
| 20 | Homeowners are not convinced that it is in their best interest to control the spread of the disease on their premises and in their community. | [30] |
| 21 | Poor disease surveillance. | [73] |
| 22 | Lack of community involvement in risk prevention initiatives. | [3, 34] |
| 23 | Inadequate attitude towards preventive initiatives. | [3] |
| 24 | Presence of scattered containers (*e.g.* vases, bottles) or reservoirs in the area that serve as larval rearing sites. | [3, 12] |
| 25 | Unprecedented population growth especially in urban areas. | [105] |
| 26 | Lack of effective mosquito management. | [48] |
| 27 | Excessive or widespread installation of water tank storage for drought-proof purposes during climate changes. | [12] |
| 28 | Water supply irregularities. | [12] |
| 29 | Poor house or building characteristics. | [64, 71] |
| 30 | Weak enforcement of hygiene education in local schools. | [3] |
| 31 | Gradual increase in population density. | [95] |
| 32 | Suboptimal health infrastrutures. | |
| 33 | Limited resources. | [64] |
| 34 | Remoteness. | [64] |
| 35 | Great reliance on international trade. | [64] |
| 36 | Fragile environments. | [64] |
| 37 | Small but growing populations. | [64] |
| 38 | Transportation and energy costs. | [64] |
| 39 | Difficulties in creating economies of scale. | [64] |
| 40 | Differences in sovereignty between the various islands and archipelago. | [64] |
| 41 | Difficulty in financing public administration and infrastructure. | [64] |
| 42 | Use of under-developed water distribution systems. | [64] |
| 43 | Use of under-developed waste management systems. | [64] |

attitudes, practices, environmental characteristics, and caregiver characteristics affect the risk factors of dengue hemorrhagic fever incidents. Likewise, [109] investigated how community empowerment influences the success for developing dengue vector control. Moreover, [64] explored the effect of socio-economic factors (*e.g.* poverty, resources) to the occurrence of arboviral diseases such as dengue. Clearly, the antecedents of the dengue epidemic play a crucial role in developing useful models and frameworks. A list of antecedents of the dengue epidemic extracted from peer-reviewed sources is presented in Table 2.

With the existence of numerous dengue epidemic antecedents studied in the literature, an overarching categorization that would span a set of antecedent would be desirable. For example, *poverty* and *limited resources* would be classified as *economic* antecedents. Likewise, *Formation of open stagnant clean water in household proximity*, and *climatic factors* would be classified as *environmental antecedents*. Although no formal consensus has been arrived at in the literature on how these antecedents are categorized, some scholars have termed a classification for some of the antecedents. For instance, [64] classified *poverty*, *inadequate vector control*, *suboptimal healthcare infrastructure*, *differences in sovereignty between the various islands and archipelagos*, *under-developed water distribution system*, and *under-developed waste management system* as *socio-economic antecedents*. Moreover, [49] used the classifications *surveillance factors*, *environmental and socio-economic factors*, and *climatic factors* in grouping the drivers used in analyzing autochthonous transmission in Southern France. Despite the adoption of such classification by some scholars, without an agreed framework on the classification of the antecedent, a gap in the literature remains concerning the characterization of the dengue epidemic antecedents.

## 2.4 Modelling the interdependence of antecedents in a structural modelling framework

Aside from the literature of dengue epidemic, the study involving antecedents has been invaluable in other fields as well. Similar to the field of dengue epidemic, antecedents are considered as concepts that influence the occurrence of a particular phenomenon. For instance, [66] studied the antecedents of secondhand clothing purchasing behavior of millennials in a marketing perspective. [79] studied the antecedents of using green technologies in an innovation point of view. [75] studied the adoption antecedents to Industry 4.0 in a technology management perspective. Moreover, [100] studied antecedents in a sustainable supply chain management application. Clearly, the study of antecedents is a crucial undertaking in many domains.

It has been found in several results in the literature that antecedents exhibit an interdependent structure. In other words, antecedents usually influence one another in causing a phenomenon/process/event to occur. Such results have been observed in many areas such as in green supply chain [62], environmental sustainability [40], green lean practices [103], mobile banking [102], green workforce [69], and technology transfer [86], among others. The interdependence arising from the interplay of the antecedents are modelled using structural modelling techniques such as the interpretative structural model (ISM), decision making trial and evaluation laboratory (DEMATEL), and fuzzy cognitive mapping (FCM), among others. For instance, [66] used ISM in analyzing the hierarchical interdependence of the secondhand clothing buying behavior antecedents. [125] used DEMATEL in finding cause-effect chains between antecedents affecting college students' usage intention of green public welfare activity platforms. [60] used FCM in analyzing the impact of social factors on homelessness.

While ISM, DEMATEL, and FCM can model interdependence between antecedents, the decision concerning which of the structural models to use depends on the insights that decision-makers want to obtain from the model. ISM is suitable for modelling the hierarchical structure of the antecedents [66]. As such, it can be used to determine which of the antecedents are the primary drivers or enablers [2]. With this, [2] used ISM to find the root cause of a quality problem due to its capability to reveal the hierarchical nature of antecedents. On the contrary, DEMATEL is suitable for problems in which decision-makers are interested in characterizing the antecedents into either a cause or an effect [125]. Since antecedents exhibit interdependence, DEMATEL is capable of analyzing the cause and effect chains that exist between them [125]. Furthermore, [10] showed how the DEMATEL is used to characterize barriers to implementing industrial symbiosis networks into a cause group and effect group as well as showing which of the antecedents are the critical factors. Finally, FCM is suitable for modelling problems in which decision-makers are interested in knowing how two antecedents (*i.e.* how strongly one concept causes another concept and if the antecedents are directly or inversely related) [80, 86]. As such, [81] adopted FCM to simulate how a system evolves over time in a terrorism and insurgency context. Therefore, the choice of which structural model technique to use depends on the insights that decision-makers are interested in obtaining.

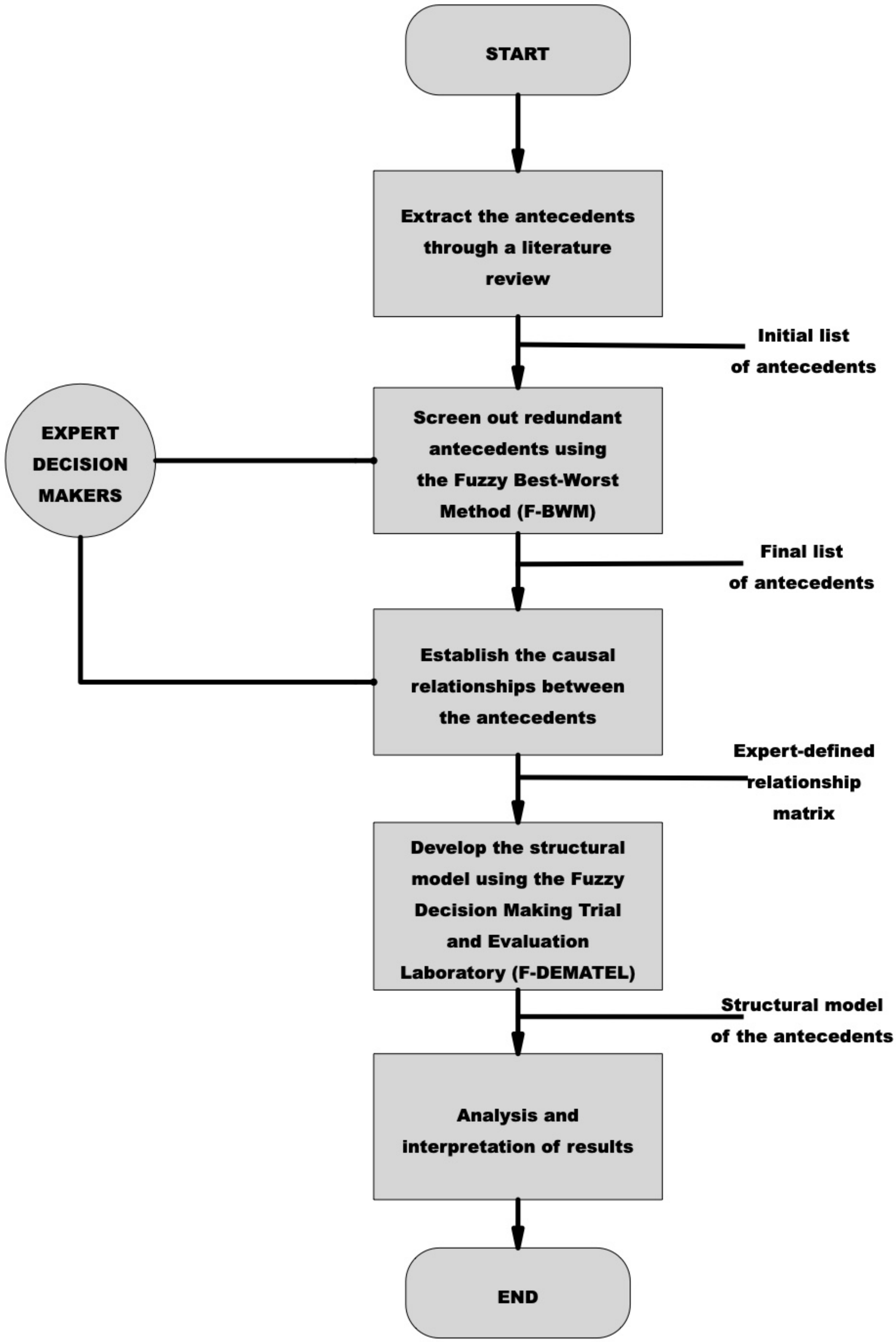


**Figure 1:** Flow of the research process. The rectangular blocks represent a process to be executed. The circular blocks represent actors for a process. The unboxed words on the right represent the outputs produced by the preceding process. Such outputs will be used by their succeeding process.

# 3 Methodology

## 3.1 Case background

In tropical and sub-tropical countries, mosquito breeding is found to be abundant and significant due to favorable environmental characteristics such as temperature, and wind velocity, among others [18, 28]. With this, mosquito-borne diseases such as dengue warrant serious health issues in the global landscape [23]. Dengue incidents are prevalent in many Asian countries, particularly the Philippines [18, 23]. In the Philippines, dengue is one of the more severe health issues, which causes exasperating morbidity and mortality to its population. The country maintains its position of having the highest occurrences of dengue incidents in Southeast Asia [26, 27, 116]. Despite the country's alarming health position, dengue contains to be less studied in the country's epidemiological, environmental, social, and even public health domains, making it one of the country's less understood health issues [18]. [18] maintained that only a few published works tackle the issue in a Philippine context and that most of these works are based on only one community (*i.e.* Manila). Hence, they argued that more studies would have to be conducted in different knowledge domains as well as across different regions of the country. Such approach would enable the development of a holistic perspective both for scientific understanding and policy-making.

Cebu, a province located in the Visayas, is the second largest urban area of the Philippines, next to Manila (*i.e.* the capital and principal city of the Philippines). It is the second most populated area in the country with a population count of 4.633 million as of the year 2015 [84]. Metropolitan Cebu or Metro Cebu, Cebus main urban center, accounts for the 20% of the land area and 61.5% of the population resulting in a high population density of 2700 per square kilometer. Because high population density is related to increasing dengue incidents [18, 23, 28] Metro Cebu may be highly susceptible to the epidemic. The Department of Health in Central Visayas (DOH-7) recorded a total of 6097 dengue cases with 37 deaths from January 1 to March 30 of 2019 [37]. These statistics are enough to manifest the issue of dengue incidents in the area. There are several perspectives upon which such issues can be looked at: (1) epidemiological [18], (2) sociological [107], and (3) ecological and environmental [106], among others. This paper explores the issue with a mix of (2) and (3). The research process used in this study is presented in Figure 1.

To carry out the analysis, a literature review is first conducted to extract antecedents that potentially influence the severity of a dengue epidemic. Scopus is used as the database for searching relevant articles. As a result, 43 antecedents as presented in Table 2 in Section 2.3 and are extracted from 18 research articles to qualify as an initial list of antecedents influencing the severity of the dengue epidemic. To make the analysis more convenient and easy to understand, this paper proposes four classifications for grouping the antecedents – (i) social, (ii) economic, (iii) environmental, and (iv) institutional. Social antecedents pertain to antecedents brought about by human activities (individually or as a group) that influence the occurrence of dengue incidents [90]. Economic antecedents pertain to antecedents measured in terms of economic indices such as employment and monetary gains, among others [41]. Environmental antecedents pertain to environmental conditions influencing dengue incidents such as climate, weather, and temperature, among others [64]. Institutional antecedents pertain to administrative, political, governmental, and regulatory antecedents, among others, which influence the occurrence of dengue incidents.

A total of 15 expert decision-makers with at least 10 years of experience in studying or handling dengue cases are then adopted as respondents of the study. The expert decision-makers consist of 2 biologists, 3 medical technologists, 2 physicians, 3 environmentalists, and 5 public health practitioners. The experts' judgment will be used to: (a) reduce the dimensionality of the initial set of drivers to a more comprehensive size, and (b) to rate the relationship between the antecedents. A supervised survey interview with each respondent is conducted to obtain the required data. To give respondents enough time and convenience in answering the survey, they were given one week before the data was retrieved.

## 3.2 Fuzzy Best-Worst Method (BWM)

In a decision-making environment where several involved criteria impose complexity to the decision-making process, multiple criteria decision-making (MCDM) approaches can be very suitable and useful. Scholars have adopted several MCDM approaches in the literature. The Analytic Hierarchy Process (AHP) developed by [93] can be considered as the most prominent among such approaches [87]. It has been widely applied in different domains. For instance, [52] used AHP in conjunction with a novel index-based methodology for determining flood-prone areas. Likewise, [111] used the AHP in investigating the lean-green implementation practices of Indian small and medium enterprises (SMEs). Moreover, [38] used the AHP in exploring the maintenance policy selection of naval ships. Aside from AHP, several

MCDM methods are widely used in the literature such as the Analytic Network Process (ANP) [94], Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) [114], ELimination Et Choix Traduisant la REalité (ELECTRE) [92], VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) [78], and Preference Ranking Organization METhods for Enrichment Evaluations (PROMETHEE) [61]. The approaches above are primarily based on the pairwise comparison in obtaining relative preferences of actions. On the contrary, such pairwise comparison methods can be susceptible to lack of consistency of the pairwise comparison matrices as observed in practice due to the unstructured way comparisons are executed by pairwise comparison-based methods [45, 87].

To overcome such a concern, a new MCDM approach that uses a different execution of pairwise comparison called the Best-Worst Method (BWM) is developed in the literature [87]. The BWM is a novel MCDM approach developed by [87] for comparing several different alternatives by dividing the pairwise comparisons into two main categories: (1) reference comparisons, and (2) secondary comparisons. As such, it derives the weights based on the pairwise comparison of the best and the worst criteria (alternatives) with the other criteria (alternatives). Several scholars have found essential applications of the BWM. For instance, [89] applied the BWM to a supplier selection life cycle approach that integrates traditional and environmental criteria. Similarly, [43] adopted the BWM in conjunction with fuzzy TOPSIS in the supplier selection among SMEs based on their green innovation ability. Pursuing this further, [42] extended the BWM to the Fuzzy BWM utilizing the fuzzy reference comparisons between the best and worst criteria to generate fuzzy weights to treat the vagueness, ambiguity, and imprecision that frequently arise with the qualitative judgment of decision-makers. Interestingly, [42] found that aside from being able to obtain a reasonable preference ranking for criteria (alternatives) the fuzzy BWM (F-BWM) also exhibits a higher consistency ratio than the non-fuzzy BWM. Despite being relatively new compared to the non-fuzzy BWM, the applications of the F-BWM is growing. For instance, [44] applied the F-BWM for combining individual and group decision-making which enables trade-off between democratic and autocratic decision-making styles. Likewise, [77] adopted a combination of the Fuzzy TOPSIS and F-BWM in finding the optimal combination of power plants alternatives. Comparably, [112] adopted a combination of the F-BWM and other FMCDM methods in developing an approach for performance evaluation.

Several works in BWM and FBWM have been discussed in domain and relevant literatures such as [88], [4], and [124], among others. These works have adopted the use of BWM and FBWM in a group decision-making environment where weights are established into concepts such as factors, antecedents, barriers, and indicators, among others. In this paper, an F-BWM is adopted to screen out relevant factors that qualify as socio-economic and socio-environmental antecedents of dengue incidents in the Philippine context using expert knowledge while treating the inherent ambiguity, imprecision, and vagueness of the human decision-making process. The algorithm used in this paper is adopted from [42] being the most cited work on F-BWM. As such, the steps in performing an F-BWM are as follows:

- **Step 1. Establish the antecedent set to be reduced**. The antecedent set $C$ is the set of antecedents to be analyzed. For $n$ antecedents, we have $C = \{c_1, c_2, .., c_n\}$.
- **Step 2. Determine the best (most important) antecedent and the worst (least important)** antecedent. The decision-makers must select the best and the worst antecedents from the antecedent set $C$. We denote the best antecedent as $c_B$ and the worst antecedent as $c_W$.
- **Step 3. Compare the best antecedent to the other antecedents.** In this step, decision-makers compare the importance of the best antecedent $c_B$ compared to antecedent $c_j$ using the linguistic scale provided in Table 3. By repeating the comparison for each antecedent, we obtain the Best-to-Others vector in Equation (1) as follows.

$$\widetilde{A}_B = \left(\widetilde{a}_{B1}, \widetilde{a}_{B2}, \ldots, \widetilde{a}_{Bn}\right), \tag{1}$$

  where $\widetilde{A}_B$ represents the fuzzy Best-to-Others vector; $\widetilde{a}_{Bj}$ represents the fuzzy preference of the best antecedent $c_B$ over antecedent $c_j$ for $j \in \{1, 2, \ldots, n\}$. We note that the preference of the best antecedent to itself is equally important, hence, $\widetilde{a}_{BB} = (1, 1, 1)$.
- **Step 4. Compare the other antecedents to the worst antecedent.** In this step, each antecedent $c_j$ for $j \in \{1, 2, \ldots, n\}$ is compared to the worst antecedent $c_W$ using the linguistic ratings in Table 3. As a result, we obtain the Others-to-Worst vector in Equation (2)

$$\widetilde{A}_W = \left(\widetilde{a}_{1W}, \widetilde{a}_{2W}, \ldots, \widetilde{a}_{nW}\right), \tag{2}$$

  where $\widetilde{A}_W$ represents the Others-to-Worst vector, $\widetilde{a}_{jW}$ represents the fuzzy preference of antecedent $c_j$ for $j \in \{1, 2, \ldots, n\}$ over the worst antecedent $c_W$. As such, $\widetilde{a}_{WW} = (1, 1, 1)$.
- **Step 5. Determine the optimal fuzzy weights.** In this step, the importance of each antecedent $c_j$ for $j \in \{1, 2, \ldots, n\}$ is calculated. Such importance

**Table 3:** Linguistic scale for Fuzzy Best-Worst Method. The decision makers provide a rating for the importance of each antecedent using the linguistic terms. The linguistic terms are much easier to understand using our natural language. These linguistic terms can then be converted to their fuzzy values under the membership function column.

| Linguistic Terms | Code | Membership Function – Triangular Fuzzy Numbers (TFNs) |
|---|---|---|
| Equally Important | EI | (1,1,1) |
| Weakly Important | WI | (2/3, 1, 3/2) |
| Fairly Important | FI | (3/2,2,5/2) |
| Very Important | VI | (5/2,3,7/2) |
| Absolutely Important | AI | (7/2,4,9/2) |

value is represented using a fuzzy weight $\widetilde{w}$. In order to obtain an optimal weight assignment to each antecedent, a nonlinear optimization model presented in Equation (3), using the vectors $\widetilde{A}_B$ and $\widetilde{A}_W$ as parameters, is formulated. The optimal weights $\widetilde{W}^* = \left(\widetilde{w}_1^*, \widetilde{w}_2^*, \ldots, \widetilde{w}_n^*\right)$ can then be obtained as a result. For a deeper discussion, the reader is referred to [42]. Considering $l^\xi \leq m^\xi \leq u^\xi$, it is supposed that $\widetilde{\xi}^* = \left(k^*, k^*, k^*\right)$ where $k^* \leq l^\xi$. The nonlinearly constrained optimization problem is formulated as follows:

$$
\begin{aligned}
& Min\ \widetilde{\xi}^* \qquad (3)\\
& subject\ to:\\
& \left| \frac{(l_B^w, m_B^w, u_B^w)}{\left(l_j^w, m_j^w, u_j^w\right)} - (l_{Bj}^w, m_{Bj}^w, u_{Bj}^w) \right| \leq \left(k^*, k^*, k^*\right)\\
& \left| \frac{\left(l_j^w, m_j^w, u_j^w\right)}{(l_W^w, m_W^w, u_W^w)} - (l_{jW}^w, m_{jW}^w, u_{jW}^w) \right| \leq \left(k^*, k^*, k^*\right)\\
& \sum_{j=1}^{n} R\left(\widetilde{w}_j\right) = 1\\
& l_j^w \leq m_j^w \leq u_j^w\\
& l_j^w \geq 0\\
& j = 1, 2, \ldots, n
\end{aligned}
$$

The resulting optimal fuzzy weights $\left(\widetilde{w}_1^*, \widetilde{w}_2^*, \ldots, \widetilde{w}_n^*\right)$ with $\widetilde{w}_j^* = \left(l_j^*, m_j^*, u_j^*\right)$ will then be defuzzified to obtain the crisp weights $W^* = \left(w_1^*, w_2^*, \ldots, w_n^*\right)$ of the antecedents [35]. In this paper, the defuzzification approach to be adopted is the graded mean integration representation (GMIR) [42].

## 3.3 Fuzzy decision-making trial and evaluation laboratory (DEMATEL)

The Decision-making Trial and Evaluation Laboratory (DEMATEL) is a structural modeling approach to multiple criteria decision making. It is developed by the Science and Human Affairs Program of the Battelle Memorial Institute of Geneva between 1972 and 1976 to solve and research the complicated, intertwined problem group [115]. The approach is widely adopted in the literature to develop structural models for causally interrelated factors or criteria using expert knowledge [7, 19, 123]. However, due to the vagueness, imprecision, and ambiguity of expert decisions resulting from the subjectivity of the human decision-making process, [123] proposed the Fuzzy DEMATEL approach, which is a fuzzified version of the DEMATEL, achieved through the integration of fuzzy set theory. Fuzzy set theory is a mathematical approach popularized by [129] capable of treating ambiguities, vagueness, and imprecision of the membership of elements in sets. As such, it becomes very suitable in treating the imprecision, ambiguities, and vagueness of the human decision-making process.

Several works have discussed and adopted the use of the Fuzzy DEMATEL approach in relevant domains such as:

- Green supply chains [39]
- Sustainable supply chain [56]
- Sustainable recycling [58]
- Environmental performance evaluation [113]
- Solar power development [59]
- Air transport management [16]
- Human resource management [1]
- Analyzing antecedents of organizational citizenship [76]
- Knowledge transfer evaluation [97]
- Operational hazards evaluation [5]
- Supplier evaluation [53]
- Project outcomes prediction [96]
- Operational risk analysis [101]
- Risk assessment of cargo ships [67]
- Project management [63]
- Sustainable hospitality management [122]

The steps for conducting the Fuzzy DEMATEL is provided as follows:

**Table 4:** Linguistic scale for Fuzzy DEMATEL.

| Linguistic Variables | Code | Membership Function – Triangular Fuzzy Numbers (TFNs) |
|---|---|---|
| **No Influence** | NO | (0.0, 0.1, 0.3) |
| **Very Low Influence** | VLI | (0.2, 0.3, 0.5) |
| **Low Influence** | LI | (0.3, 0.5, 0.7) |
| **High Influence** | HI | (0.5, 0.7, 0.9) |
| **Very High Influence** | VHI | (0.7, 0.9, 1.0) |

– **Step 1. Establish the linguistic relationships between the antecedents.** First, let the decision-makers decide how antecedent $c_i$ influences antecedent $c_j$ for $i, j \in \{1, 2, \ldots, n\}$. For decision-makers to conveniently express their judgment in a natural language, the linguistic scale presented in Table 4 is used to elicit judgment. By performing the pairwise comparison for each antecedent, an expert defined relationship matrix is formed. Since the elements of the matrix are still in linguistic value, they must be transformed to equivalent quantitative values. To do this, Table 4 is used to transform the linguistic values to triangular fuzzy numbers (TFNs). The result will be a fuzzy matrix, also known as the fuzzy direct relation matrix. For $K$ decision-makers a fuzzy direct relation matrix is represented as $\hat{Z}_k = \left(z_{ijk}\right)_{n\times n}$ and $z_{ijk} = \left(l_{ijk}, m_{ijk}, u_{ijk}\right)$ for $i, j \in \{1, 2, \ldots, n\}$. Here, $\hat{z}_{ijk}$ is the equivalent TFN of the $k^{th}$ decision-maker's elicited judgment for the influence of antecedent $c_i$ on antecedent $c_j$.

– **Step 2. Aggregate the individual fuzzy direct relation matrices.** In order to obtain a collective judgment of the $K$ decision-makers, each fuzzy direct relation matrix $\hat{Z}_k$ for $k \in \{1, 2, \ldots, K\}$ can be averaged to form the average direct relation matrix $\hat{Z}$ as shown in Equation (4),

$$\hat{Z} = \left(\hat{z}_{ij}\right)_{nxn} = \left(\frac{\hat{z}_{ij1} \oplus \hat{z}_{ij2} \bigoplus \ldots \bigoplus \hat{z}_{ijK}}{K}\right)_{nxn}. \quad (4)$$

– **Step 3. Normalize the average fuzzy direct relation matrix.** In order to keep all elements in the same dimensions, the average fuzzy direct relation matrix must be normalized. Thus, the normalized fuzzy direct relation matrix $\hat{X}$ can be obtained using Equation (5),

$$\begin{pmatrix} \hat{x}_{11} & \hat{x}_{12} & \cdots & \hat{x}_{1n} \\ \hat{x}_{21} & \hat{x}_{22} & \cdots & \hat{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{x}_{n1} & \hat{x}_{n2} & \cdots & \hat{x}_{nn} \end{pmatrix}, \quad (5)$$

where $\hat{x}_{ij} = \frac{\hat{z}_{ij}}{r} = \left(\frac{\hat{l}_{ij}}{r}, \frac{\hat{m}_{ij}}{r}, \frac{\hat{u}_{ij}}{r}\right); r = max_{1\le i\le n}\left(\sum_{j=1}^{n} \hat{u}_{ij}\right)$.

– **Step 4. Decompose the normalized fuzzy direct relation matrix into $l, m, u$ components.** With $\hat{X} = \left(\hat{x}_{ij}\right)_{n\times n} = \left(\left(l\prime_{ij}, m\prime_{ij}, u\prime_{ij}\right)\right)_{n\times n}$, let $X_l = \left(l'_{ij}\right)_{nxn}$, $X_m = \left(m'_{ij}\right)_{nxn}$, and $X_u = \left(u'_{ij}\right)_{nxn}$ be the decomposed components of the normalized fuzzy direct relation matrix $\hat{X}$. The components are presented in Equation (6) as follows.

$$X_l = \begin{pmatrix} 0 & l'_{12} & \cdots & l'_{1n} \\ l'_{21} & 0 & \cdots & l'_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ l'_{n1} & l'_{n2} & \cdots & 0 \end{pmatrix}, \quad (6)$$

$$X_m = \begin{pmatrix} 0 & m'_{12} & \cdots & m'_{1n} \\ m'_{21} & 0 & \cdots & m'_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ m'_{n1} & m'_{n2} & \cdots & 0 \end{pmatrix},$$

$$X_u = \begin{pmatrix} 0 & u'_{12} & \cdots & u'_{1n} \\ u'_{21} & 0 & \cdots & u'_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ u'_{n1} & u'_{n2} & \cdots & 0 \end{pmatrix}.$$

– **Step 5. Obtain the fuzzy total relation matrix.** Let $Y$ represent any crisp total relation matrix , $D$ represent any crisp direct relation matrix, and $I$ be the identity matrix. By crisp, we mean a non-fuzzy version (or the "usual" numbers). The total relation matrix is then computed as

$$Y = D\left(I - D\right)^{-1}. \quad (7)$$

We apply Equation (7) to $X_l$, $X_m$ and $X_u$ to obtain three total relation matrices from each of the components of the decomposed fuzzy normal direct relation matrix. In similar terms, if we let $\hat{t}_{ij}$ be the elements of the fuzzy total relation matrix $\hat{T}$, then we have

$$\hat{T} = \begin{pmatrix} \hat{t}_{11} & \hat{t}_{12} & \cdots & \hat{t}_{1n} \\ \hat{t}_{21} & \hat{t}_{22} & \cdots & \hat{t}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \hat{t}_{n1} & \hat{t}_{n2} & \cdots & \hat{t}_{nn} \end{pmatrix} \quad (8)$$

where $\hat{t}_{ij} = (l''_{ij}, m''_{ij}, u''_{ij})$ is obtained from $\left(l''_{ij}\right)_{n\times n} = X_l\,(I - X_l)^{-1}$, $\left(m''_{ij}\right)_{n\times n} = X_m\,(I - X_m)^{-1}$, and $\left(u''_{ij}\right)_{n\times n} = X_u\,(I - X_u)^{-1}$.

- **Step 6. Obtain the crisp total relation matrix.** While fuzzy numbers provide a means to handle ambiguities, vagueness, and imprecision, they are difficult to interpret in practice. Hence, it is desirable to obtain a crisp version of the fuzzy total relation matrix. To do this, a defuzzification process is performed. This would transform fuzzy numbers into crisp numbers. Let the resulting crisp total relation matrix be represented as $T = \left(t_{ij}\right)_{n\times n}$, then each $t_{ij}$ is obtained using the defuzzification process in Equation (9),

$$t_{ij} = \frac{\left(l''_{ij} + 4m''_{ij} + u''_{ij}\right)}{6}. \quad (9)$$

The defuzzification method used in Equation (9) is known as the "Center of Gravity" method. There are many more defuzzification methods used in the literature and the interested reader is referred to [117] for a more in-depth discussion.

- **Step 7. Configure a threshold value to filter out insignificant relationships.** A threshold value $\alpha$ is necessary to be established to filter out some negligible causal relationships. If $t_{ij} \geq \alpha$ then antecedent $c_i$ has a significant influence on antecedent $c_j$. In the current literature, the magnitude of the threshold value is determined through interviews with the respondents or judged by the researcher [54]. In this paper, the threshold value is agreed by the researchers to be the arithmetic mean of the elements of the defuzzified total relation matrix $T$. The same reasoning is also made by [22] and [128]. The threshold value can then be used in constructing an adjacency matrix where a value of 1 is assigned to links with significant relationships, and 0 otherwise.
- **Step 8. Develop the structural model or directed graph of the antecedents.** Using the adjacency matrix, a directed graph of the antecedents can be constructed. If the value from $c_i$ to $c_j$ in the adjacency matrix is equal to 1, then a directed link from $c_i$ to $c_j$ must be drawn. Otherwise, no link can exist from $c_i$ to $c_j$. The resulting structural model or directed graph provides a visual representation of the interdependence between the antecedents. Moreover, the graph can be described using the row sum ($D$) and column sum ($R$) of the total relation matrix as described in Equation (10). These measures provide a way to calculate two important structural characteristics for the DEMATEL approach known as: (i) relation ($D - R$), and (ii) prevalence ($D + R$). *Relation* enables the characterization of an antecedent as either a "net cause" or "net effect."A negative relation ($D - R$) value implies that an antecedent is generally influenced by other antecedents, thus being a "net effect." On the other hand, a positive relation ($D - R$) value implies that an antecedent generally influences other antecedents, thus being a "net cause." *Prevalence* depicts an antecedent's degree of importance [76]. The higher the antecedent's prevalence, the more important it is in the system. These structural characteristics can then be used to partition the antecedents into cause and effect groups:

$$D = \left(\sum_{j=1}^{n} t_{ij}\right)_{n\times 1} = (t_i)_{n\times 1}, \quad (10)$$

$$R = \left(\sum_{i=1}^{n} t_{ij}\right)_{1\times n}^{T} = \left(t_j\right)_{n\times 1}.$$

# 4 Results and Discussion

As a result of the literature survey, 43 antecedents were extracted. These antecedents formed the initial list of dengue antecedents. Due to the huge dimensionality of such a list, a dimensionality reduction must be performed to make the structural model more meaningful and easier to understand. The F-BWM serves as the dimensionality reduction technique by assigning priority weights for each antecedent as shown in Table 5. The antecedents are then ranked from greatest to least in accordance with their priority weights. Using an elbow method heuristic, only 18 qualified for the final list of dengue antecedents as presented in Table 6. Afterwards, the F-DEMATEL is performed to develop the structural model of the dengue antecedents. The digraph is shown in Figure 2. Likewise, the total relation matrix, adjacency matrix, and the structural characteristics of the antecedents are presented in Tables 7, 8, and 9, respectively. Such results will be used to draw insights about the dengue epidemic in the Philippine scenario. Understanding the interdependence of the social, institutional, economic, and environmental antecedents of the dengue epidemic would help in understanding its dynamics in a wider context. Since modelling the interdependence of these antecedents has not yet been done in the current literature, the findings of this study offer a fresh perspective on the modelling of the dengue epidemic. Several key results have been found in this study. First, the antecedents of the dengue epidemic are highly interdependent. Since most of the studies on dengue epidemic focused on epidemiological factors, for scholars, this result implies that when studying the dengue epidemic in a more general scope (*i.e.* including social, institution, or economic factors) the inherent interdependence of the considered variables under study must be taken into account. By doing so, more accurate predictive models can be developed. For stakeholders such as policymakers and governments, this result implies that initiatives designed to address some of the antecedents must also consider such interdependence. In other words, addressing some of the antecedents without recognition of their inherent interdependence, may yield solutions that are ineffective. Hence, the finding that these antecedents exhibit a complex interdependence (as can be verified in Figure 2) may help both scholars and stakeholders design more effective solutions in addressing the dengue epidemic.

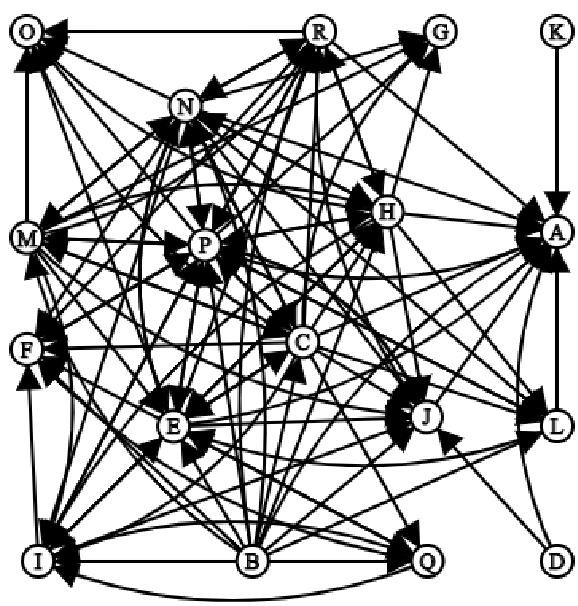


**Figure 2:** Causal graph depicting the interdependence of each concept where the nodes are the antecedents listed in Table 6 and the edges are the relationships between the antecedents presented in Table 8.

Second, by further examining the structural model, this paper finds that although the antecedents exhibit a complex interdependent structure, they can be generally grouped into a cause group and an effect group. This finding is crucial as it enables us to know the causal antecedents. In other words, antecedents that are enablers of other antecedents. This is done by investigating the relation $(D - R)$ values in Table 9. As such, the paper finds ten antecedents that are "net causes." The top 3 "net causes" are *antecedent B (Administration's lack of advocacy towards resolving public health issues)*, *antecedent D (Climatic factors such as rain, temperature, and humidity)*, and *antecedent C (Lack of dengue knowledge and awareness)*. The result for *antecedent D* conforms to several results in the literature. Climatic factors have been found to be highly associated with dengue outbreaks which is why tropical and sub-tropical countries have the highest dengue incidents since the year 1953. Interestingly, the results for *antecedent B* and *antecedent C* are not well pronounced in the literature. Such results emphasize the role of governments and community members in fighting the epidemic. Relating this result to the current situation of Covid-19, it is directly observable that government policies and community members' cooperation increases a community's resilience to the epidemic. A good example would be New Zealand's movement in tackling the Covid-19 epidemic. In the same line of reasoning, the movement towards mitigating the dengue epidemic can be strongly enforced with a combination of well-formed government initiatives and community cooperation. This observation is supported by this paper's results. Although, such findings might be intuitive, it is not well studied in the literature. Thus, the results elucidate on this gap in the current literature.

It is surprising in this paper that institutional actions inflict a strong influence on the occurrence of dengue incidents. This may be one of the reasons why a disparity in the number and severity of the incidents of dengue outbreaks exists between developed and developing countries. Clearly, more developed countries such as the US have formed more robust strategies in handling systemic risk issues such as the dengue epidemic in contrast to less developed countries such as the Philippines. Moreover, in the Philippine context, the interaction of these two major antecedents could have also been a significant contributor in the growing cases of dengue across different localities, *e.g.* Cebu, Bohol, and Negros Oriental, which are provinces that are approaching significant development but have not reached sufficient stability. As such, this may be enforced by two situations: (1) Such localities are rising cities approaching significant development, hence undergoing urban changes that may influence mosquito breeding, and (2) despite being growing localities, their distance from the country's capital city (Manila) may have influenced its instability in developing robust strategies and advocacy towards prioritizing health issues. Moreover, it is also clear that the susceptibility of the Philippines to dengue incidents is not only contributed by its instability across its regions but by its entirety as a nation as well since the Philippines has lagged behind its neighboring countries in terms of economic, health, and environmental sustainability, among others. Hence, these two antecedents may be considered as landmarks in understanding the dynamics of the interrelated antecedents of dengue incidents, particularly in developing countries.

By looking further into the results, this paper finds eight antecedents that are "net effects." The top 3 "net effects" are *antecedent A (Formation of open stagnant clean water in household proximity)*, *antecedent O (Presence of scattered containers (e.g. vases, bottles) or reservoirs in the area that serve as larval rearing sites)*, and*antecedent J (Creation of environmental conditions that promote mosquito breeding)*. Essentially, these antecedents share a common characteristic of being adverse environmental effects that result from the actions of society (*i.e.* human or community activities), administration (*i.e.* government, regulatory, and political activities), and the economy (*i.e.* availability of resources and infrastructures). Drawing a connection to the Philippines' status from a social perspective, it is evident that the Filipino society has weak observance to sanitary initiatives as well as an inadequate attitude to observing environmental wellness, among others. This is strongly supported by [13] stating that the Philippines has lagged behind in terms of environmental sustainability contributed by many Filipino practices including: (1) the use of open dumps for waste disposal which attract disease-carrying organisms, (2) dumping garbage in non-designated garbage collection points (*e.g.* street corners), and (3) non-receptiveness to solid waste management due to the belief that its implementation is solely the responsibility of the government. From an institutional perspective, the progress of the Philippines towards environmental sustainability appears to be lagging. This result is manifested by the weak enforcement of environmental sustainability initiatives which are facilitated by the government and regulators [36]. IFromn an economic standpoint, the position of the Philippines is lagging as manifested by its inadequately low spending on health-related issues, which is negatively disproportionate to its morbidity rate [21]. These findings are crucial as they imply that adverse environmental effects result only from the actions made in the social, institutional, and economic sectors. These results further emphasize the crucial role played by the community and governments in responding to the dengue epidemic.

It can be observed that institutional antecedents provide a major influence on all other types of antecedents. As such, this observation implies that institutional actions such as government interventions serve as a critical success factor in responding to the dengue epidemic. This result provides an avenue for regulators to impose advocacy geared toward providing receptiveness on health-related issues such as dengue incidents. Nevertheless, administrators and related stakeholders should consider placing equal attention towards health-related concerns such as the dengue epidemic. Social antecedents may be induced to shift to the positive side upon the implementation of well-imposed initiatives by the government. Since most of the environmental antecedents follow from society's actions, they may be addressed by shaping a healthier culture in the community. Likewise, economic antecedents are directly influenced by the actions of government and relevant stakeholders, thus, may be addressed by imposing well-formed initiatives. In summary, government and relevant stakeholders are the key players in establishing the country's resilience against the dengue epidemic. These stakeholders can reshape society, address environmental concerns, and enforce economic stability.

These results were obtained due to the capability of the soft computing methodologies used in the paper. First, the F-BWM was able to reduce the dimensionality of the antecedents by removing redundant and less relevant antecedents. This process enables the development of a more meaningful and logical model. Second, the F-DEMATEL paved a way for the construction of a structural model that meaningfully describes the interdependence of the antecedents. The structural model allows scholars and stakeholders to make sense of the intertwined relationships exhibited by a complex system such as the dengue epidemic. The structural model can convert these relationships into an intelligible structural model of the system. This thereby makes the model practical for complicated causal relationships. While soft computing approaches have been shown to be useful in solving decision-making problems in a wide spectrum of domains, they have been given little attention in the context of epidemiological modelling. In particular, the use of fuzzy MCDM methods such as the F-BWM and F-DEMATEL, have not been explored in epidemiological modelling. Thus, this paper offers a fresh perspective on this topic. By showing that these approaches are capable of modelling problems encountered in epidemiology, this paper provides an avenue for the cross-fertilization of knowledge between soft computing and epidemiological modelling.

**Table 5:** Computational results of the Fuzzy Best-Worst Method (F-BWM). The representations of the social, institutional, economic, and environmental antecedents are S,I ,EC, and ENV, respectively. The ratings under columns 3 and 4 are based on Table 3. The optimal weight is the solution of the F-BWM.

| No. | Antecedents | Classification | Best-to-Others | Others-to-Worst | Optimal Weight (W*) |
|---|---|---|---|---|---|
| 1 | Formation of open stagnant clean water in household proximity. | ENV | EI | AI | 0.043571 |
| 2 | Administration's lack of advocacy towards health issues. | I | WI | VI | 0.02569 |
| 3 | Lack of dengue knowledge and awareness. | S | WI | VI | 0.035929 |
| 4 | Climatic factors such as rain, temperature and humidity. | ENV | EI | AI | 0.035213 |
| 5 | Poverty. | EC | VI | FI | 0.033736 |
| 6 | Lack of sustainable anti-dengue initiatives. | S | FI | AI | 0.033736 |
| 7 | Inadequate public health resources for vector control. | EC | WI | FI | 0.033736 |
| 8 | Lack of personal household protection such as windows screens and long-sleeved clothes. | EC | WI | VI | 0.02569 |
| 9 | Inadequately planned urbanization. | I | VI | FI | 0.02569 |
| 10 | Weak enforcement of community participation. | I | VI | FI | 0.02569 |
| 11 | Lack of local government funding on public health concerns. | I | FI | VI | 0.02569 |
| 12 | Poor sanitary practice. | ENV | EI | AI | 0.0508 |
| 13 | Weak enforcement of health awareness programs. | I | WI | VI | 0.02569 |
| 14 | Household overcrowding. | EC | FI | FI | 0.02569 |
| 15 | Creation of environmental conditions that promote mosquito breeding. | ENV | EI | AI | 0.02569 |
| 16 | High level of proximity to water bodies. | ENV | WI | VI | 0.02569 |
| 17 | Disease transmission from increased mobility of people (*e.g.* intercontinental travel). | S | VI | VI | 0.02569 |
| 18 | Unclear role or responsibility of community members in program implementation and maintenance. | I | VI | VI | 0.02569 |
| 19 | Lack of partnership between government and community members. | S | FI | FI | 0.023169 |
| 20 | Homeowners are not convinced that it is in their best interest to control the spread of the disease on their premises and in their community. | S | FI | FI | 0.023169 |
| 21 | Poor disease surveillance. | I | FI | VI | 0.023169 |
| 22 | Lack of community involvement in risk prevention initiatives. | S | WI | VI | 0.021951 |
| 23 | Inadequate attitude towards preventive initiatives. | S | WI | FI | 0.021951 |
| 24 | Presence of scattered containers (*e.g.* vases, bottles) or reservoirs in the area that serve as larval rearing sites. | ENV | EI | AI | 0.021951 |
| 25 | Unprecedented population growth especially in urban areas. | EC | AI | WI | 0.020882 |
| 26 | Lack of effective mosquito management. | S | WI | VI | 0.020796 |

**Table 5:** ...continued

| No. | Antecedents | Classification | Best-to-Others | Others-to-Worst | Optimal Weight (W*) |
|---|---|---|---|---|---|
| 27 | Excessive or widespread installation of water tank storages for drought-proof purposes during climate changes. | ENV | VI | WI | 0.020716 |
| 28 | Water supply irregularities. | ENV | VI | WI | 0.019904 |
| 29 | Poor house or building characteristics. | EC | AI | EI | 0.019904 |
| 30 | Weak enforcement of hygiene education in local schools. | S | FI | WI | 0.019904 |
| 31 | Gradual increase in population density. | EC | AI | WI | 0.018969 |
| 32 | Suboptimal health infrastructures. | I | WI | VI | 0.018927 |
| 33 | Limited resources. | I | FI | WI | 0.018522 |
| 34 | Remoteness. | S | AI | WI | 0.018522 |
| 35 | Overreliance on international trade. | EC | AI | EI | 0.014601 |
| 36 | Fragile environments. | ENV | VI | FI | 0.014601 |
| 37 | Small but growing populations. | EC | VI | WI | 0.013342 |
| 38 | Transportation and energy costs. | EC | VI | WI | 0.013342 |
| 39 | Difficulties in creating economies of scale. | EC | AI | EI | 0.013342 |
| 40 | Differences in sovereignty between the various islands and archipelago. | I | AI | EI | 0.013342 |
| 41 | Difficulty in financing public administration and infrastructure. | EC | VI | EI | 0.012446 |
| 42 | Use of under-developed water distribution systems. | ENV | FI | WI | 0.011686 |
| 43 | Use of under-developed waste management systems. | ENV | WI | FI | 0.010567 |

**Table 6:** The final list of antecedents obtained by removing the irrelevant and redundant antecedents.

| Code | Antecedent | Description | References | Classification |
|---|---|---|---|---|
| A | Formation of open stagnant clean water in household proximity | Stagnant water is also known as standing water from the source of clean water. | [3, 30, 71] | ENV |
| B | Administration’s lack of advocacy towards resolving public health issues | Current administration’s priorities are misaligned with health-related initiatives. | [13] | I |
| C | Lack of dengue knowledge and awareness | Inadequate understanding of Dengue vectors and their inherent risk. | [3] | S |
| D | Climatic factors such as rain, temperature, and humidity | Concerns such as weather and seasons that are not directly controllable by human initiatives. | [51, 73] | ENV |
| E | Lack of sustainable anti-dengue initiatives | Initiatives such as campaigns, seminars, and health programs, among others, geared towards addressing dengue concerns and issues. | [13] | S |

**Table 6:** ...continued

| Code | Antecedent | Description | References | Classification |
|---|---|---|---|---|
| F | Inadequate public health resources for vector control | Lack of government-provided health resources such as vaccines, mosquito control pesticides, and treatment, among others. | [47] | EC |
| G | Lack of personal household protection such as windows screens and long-sleeved clothes | Household equipment and tools provide protection against mosquitoes. The lack thereof may potentially increase the susceptibility to the dengue incident. | [71, 98] | EC |
| H | Poor sanitary practice | The lack of community sanitary practice such as solid waste management, Estero cleaning, and maintaining cleanliness policies, among others. | [12] | ENV |
| I | Weak enforcement of health awareness programs | Lack of facilitation of health awareness initiatives. For instance, seminars may have been provided, but the lack of follow-up initiatives are disregarded. | [71, 99] | I |
| J | Creation of environmental conditions that promote mosquito breeding | Developed environmental conditions (*e.g.* water puddles, stagnant water in open bottles, dirty surroundings) that are preferred by dengue vectors when breeding. | [64, 71, 99] | ENV |
| K | High level of proximity to water bodies | It has been found in the literature that since mosquitoes prefer water bodies, especially stagnant ones, nearness to such areas increases susceptibility to the incidents. | [98] | ENV |
| L | Poor disease surveillance | Infrequent or lack of postings of statistics, and information, to name a few, that raise awareness of community members. | [73] | I |
| M | Lack of community involvement in risk prevention initiatives | Lack of interest of community members to imposed initiatives by government and non-government organizations, among others, in mitigating dengue incident. | [3, 34] | S |
| N | Inadequate attitude towards preventive initiatives | Community members may be interested in participating in anti-dengue initiatives. However, the overall attitude is lacking such as actions taken, and commitment, among others. | [3] | S |
| O | Presence of scattered containers (*e.g.* vases, bottles) or reservoirs in the area that serves as larval rearing sites | Scattered containers in the community may become potential breeding areas of the dengue vectors. | [3, 12] | ENV |
| P | Lack of effective mosquito management | Implemented management initiatives frequently fail. | [48] | S |
| Q | Suboptimal health infrastructures | Use of outdated and inadequate health infrastructures such as hospitals, health centers and facilities, among others, that support community-based health programs. | [64] | I |
| R | Use of under-developed waste management systems | Pre-mature waste management systems that play only a minor or no role at all in improving the sanitary well-being of the community. | [64] | ENV |

**Table 7:** Defuzzified total relation matrix.

| Index | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0.04 | 0.03 | 0.03 | 0.02 | 0.03 | 0.03 | 0.03 | 0.03 | 0.03 | 0.09 | 0.06 | 0.03 | 0.03 | 0.05 | 0.04 | 0.04 | 0.03 | 0.03 |
| B | 0.13 | 0.06 | 0.13 | 0.03 | 0.14 | 0.14 | 0.09 | 0.13 | 0.14 | 0.13 | 0.08 | 0.12 | 0.12 | 0.12 | 0.10 | 0.15 | 0.12 | 0.13 |
| C | 0.13 | 0.10 | 0.08 | 0.03 | 0.14 | 0.12 | 0.11 | 0.13 | 0.13 | 0.12 | 0.07 | 0.13 | 0.12 | 0.12 | 0.11 | 0.14 | 0.11 | 0.12 |
| D | 0.11 | 0.04 | 0.05 | 0.02 | 0.05 | 0.06 | 0.06 | 0.06 | 0.07 | 0.11 | 0.07 | 0.06 | 0.08 | 0.07 | 0.08 | 0.09 | 0.05 | 0.08 |
| E | 0.12 | 0.07 | 0.11 | 0.03 | 0.08 | 0.11 | 0.08 | 0.11 | 0.12 | 0.12 | 0.05 | 0.09 | 0.10 | 0.11 | 0.11 | 0.14 | 0.11 | 0.13 |
| F | 0.07 | 0.05 | 0.08 | 0.02 | 0.10 | 0.05 | 0.04 | 0.05 | 0.10 | 0.06 | 0.03 | 0.05 | 0.07 | 0.07 | 0.05 | 0.11 | 0.10 | 0.05 |
| G | 0.05 | 0.03 | 0.04 | 0.02 | 0.05 | 0.04 | 0.04 | 0.05 | 0.08 | 0.06 | 0.03 | 0.04 | 0.08 | 0.06 | 0.04 | 0.09 | 0.04 | 0.04 |
| H | 0.14 | 0.08 | 0.09 | 0.03 | 0.12 | 0.08 | 0.10 | 0.07 | 0.10 | 0.13 | 0.06 | 0.10 | 0.10 | 0.11 | 0.12 | 0.13 | 0.07 | 0.12 |
| I | 0.07 | 0.04 | 0.10 | 0.03 | 0.11 | 0.11 | 0.05 | 0.06 | 0.07 | 0.10 | 0.04 | 0.10 | 0.10 | 0.09 | 0.06 | 0.11 | 0.10 | 0.06 |
| J | 0.11 | 0.04 | 0.05 | 0.02 | 0.08 | 0.05 | 0.07 | 0.05 | 0.05 | 0.06 | 0.03 | 0.05 | 0.09 | 0.09 | 0.09 | 0.10 | 0.04 | 0.08 |
| K | 0.11 | 0.05 | 0.04 | 0.05 | 0.05 | 0.04 | 0.05 | 0.06 | 0.05 | 0.09 | 0.03 | 0.05 | 0.04 | 0.05 | 0.08 | 0.08 | 0.04 | 0.07 |
| L | 0.10 | 0.07 | 0.09 | 0.02 | 0.10 | 0.08 | 0.06 | 0.08 | 0.10 | 0.09 | 0.04 | 0.05 | 0.06 | 0.07 | 0.07 | 0.11 | 0.05 | 0.06 |
| M | 0.10 | 0.09 | 0.11 | 0.03 | 0.13 | 0.09 | 0.10 | 0.11 | 0.12 | 0.11 | 0.04 | 0.09 | 0.07 | 0.11 | 0.11 | 0.14 | 0.08 | 0.11 |
| N | 0.12 | 0.10 | 0.13 | 0.03 | 0.13 | 0.12 | 0.11 | 0.13 | 0.13 | 0.13 | 0.06 | 0.11 | 0.13 | 0.08 | 0.12 | 0.14 | 0.09 | 0.12 |
| O | 0.09 | 0.03 | 0.03 | 0.02 | 0.04 | 0.04 | 0.03 | 0.04 | 0.04 | 0.04 | 0.03 | 0.03 | 0.04 | 0.04 | 0.04 | 0.08 | 0.03 | 0.09 |
| P | 0.14 | 0.07 | 0.11 | 0.03 | 0.12 | 0.13 | 0.10 | 0.12 | 0.13 | 0.12 | 0.06 | 0.11 | 0.12 | 0.12 | 0.11 | 0.10 | 0.08 | 0.12 |
| Q | 0.06 | 0.04 | 0.08 | 0.02 | 0.10 | 0.11 | 0.06 | 0.07 | 0.11 | 0.06 | 0.03 | 0.09 | 0.08 | 0.08 | 0.07 | 0.10 | 0.05 | 0.07 |
| R | 0.13 | 0.05 | 0.07 | 0.03 | 0.09 | 0.10 | 0.08 | 0.11 | 0.08 | 0.12 | 0.05 | 0.07 | 0.09 | 0.10 | 0.12 | 0.13 | 0.05 | 0.07 |

**Table 8:** Adjacency matrix.

| antecedent | A | B | C | D | E | F | G | H | I | J | K | L | M | N | O | P | Q | R | No. of Impacts Given |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| B | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 15 |
| C | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 15 |
| D | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 3 |
| E | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 13 |
| F | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 4 |
| G | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 3 |
| H | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 13 |
| I | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 9 |
| J | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 5 |
| K | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 4 |

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| L | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 8 |
| M | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 14 |
| N | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 15 |
| O | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 3 |
| P | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 13 |
| Q | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 0 | 0 | 8 |
| R | 1 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 11 |
| No. of impacts received | 13 | 3 | 9 | 0 | 11 | 11 | 7 | 8 | 12 | 13 | 0 | 9 | 11 | 10 | 10 | 16 | 6 | 8 | |

**Table 9:** Structural characteristics of the antecedents. The value $D$ is the row sum of the total relation matrix and $R$ is the column sum of the total relation matrix. The relation $(D - R)$ determines whether an antecedents is a net cause or a net effect. A positive relation value implies that an antecedent is a "net cause", a negative relation implies that it is a "net effect", and a zero relation implies that it is neutral. The prevalence $(D + R)$ determines an antecedent's degree of importance. A higher prevalence implies more importance. See Section 3.3 for more in-depth discussions on these values.

| Dengue Antecedent | D | R | D-R | D+R | Category |
|---|---|---|---|---|---|
| A. Formation of open stagnant clean water in household proximity. | 0.673172 | 1.816318 | −1.14315 | 2.489489 | Net effect |
| B. Administration's lack of advocacy towards resolving public health issues. | 2.063127 | 1.006503 | 1.056624 | 3.06963 | Net cause |
| C. Lack of dengue knowledge and awareness. | 1.992342 | 1.43064 | 0.561702 | 3.422982 | Net cause |
| D. Climatic factors such as rain, temperature, and humidity. | 1.21136 | 0.490898 | 0.720463 | 1.702258 | Net cause |
| E. Lack of sustainable anti-dengue initiatives. | 1.799026 | 1.653181 | 0.145846 | 3.452207 | Net cause |
| F. Inadequate public health resources for vector control. | 1.139925 | 1.511096 | −0.37117 | 2.651021 | Net effect |
| G. Lack of personal household protection such as window screens and long-sleeved clothes. | 0.8706 | 1.27297 | −0.40237 | 2.14357 | Net effect |
| H. Poor sanitary practice. | 1.761834 | 1.466437 | 0.295397 | 3.228271 | Net cause |
| I. Weak enforcement of health awareness programs. | 1.387099 | 1.630097 | −0.243 | 3.017197 | Net effect |
| J. Creation of environmental conditions that promote mosquito breeding. | 1.135952 | 1.738033 | −0.60208 | 2.873985 | Net effect |
| K. High level of proximity to water bodies. | 1.023476 | 0.875094 | 0.148381 | 1.89857 | Net cause |
| L. Poor disease surveillance. | 1.310007 | 1.381211 | −0.0712 | 2.691218 | Net effect |
| M. Lack of community involvement in risk prevention initiatives. | 1.753861 | 1.5134 | 0.240462 | 3.267261 | Net cause |
| N. Inadequate attitude towards preventive initiatives. | 1.973531 | 1.542808 | 0.430722 | 3.516339 | Net cause |
| O. Presence of scattered containers (*e.g.* vases, bottles) or reservoirs in the area that serve as larval rearing sites. | 0.775863 | 1.50916 | −0.7333 | 2.285023 | Net effect |
| P. Lack of effective mosquito management. | 1.893841 | 1.999615 | −0.10577 | 3.893456 | Net effect |
| Q. Sub-optimal health infrastructures. | 1.309881 | 1.241511 | 0.06837 | 2.551392 | Net cause |
| R. Use of under-developed waste management systems. | 1.555964 | 1.551887 | 0.004076 | 3.107851 | Net cause |

## 5 Conclusion

Dengue is a highly feared epidemic worldwide, particularly in tropical countries like the Philippines. Despite the high relevance of such an epidemic in the country, no work has explored the possibility of establishing a framework that characterizes the behavior of such an epidemic from a systemic perspective. Such analysis of the dengue epidemic at a system's level would be crucial in determining how the epidemic propagates within society. Furthermore, a development of such a framework would enable the creation of proactive strategies in its mitigation. To address such gaps, this paper has analyzed the antecedents of the dengue epidemic from a cybernetics perspective. That is, it has used a structural model to describe the interdependence of the dengue antecedents. The contribution of the paper is twofold. First, it analyzed different types dengue epidemic antecedents. In particular, these antecedents were seen to be social, institutional, environmental, or economic in nature. Since analyzing dengue antecedents under these conditions has not been performed in the current literature, this paper offers a fresh perspective on the topic. Second, the paper used a novel application of soft computing approaches for epidemiological modelling. Since these approaches are given less attention in the context of epidemiological modelling, this paper has demonstrated its usefulness in such a domain. Moreover, by introducing such approaches for epidemiological modelling, this paper provides an avenue for the cross-fertilization of knowledge between scholars working in the soft computing and epidemiological modelling domains. This paper, however, is limited in its scope as it incorporated only 15 expert decision-makers that come only from scientific, medical, and health backgrounds. As such, opinions from key stakeholders such as government proponents, among others, may have been omitted. To overcome such limitations, a more extensive pool of experts could be incorporated for future studies.

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