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International Journal of Building Pathology and Adap

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Journal:	*International Journal of Building Pathology and Adaptation*
Manuscript ID	IJBPA-10-2019-0094.R2
Manuscript Type:	Original Article
Keywords:	Flood Resilience Measurement, Fuzzy-AHP, Flood Resilient Attributes, Flood Resilient Sub-attributes, Index

A Fuzzy-Analytic Hierarchy Process Approach for Measuring Flood Resilience at the Individual Property Level

Purpose	Recent changes in climate, rainfall patterns, snow melt and rising sea levels coupled with an increase in urban development have increased the threat of flooding. To curb these threats and mitigate these damages, property level approaches to improving resilience are now being encouraged as part of an integrated approach to flood risk management. This raises questions such as, what are the flood resilient attributes within individual properties, what is their importance, and how can these be quantified. This research sought to develop a quantitative approach for the measurement of property level flood resilience.
Design/Methodology/Approach	A synthesis of literature was undertaken to establish the main resilient attributes and their relevant sub-attributes. This process led to the development of a new method, named the Composite Flood Resilient Index (CFRI) to weigh the attributes and sub-attributes of flood resilience based on their importance. The approach adopts the use of the fuzzy-analytic hierarchy process approach (F-AHP) to quantify flood resilience.
Findings	The implications of the proposed methodology in determining the flood resilience of individual property, including the potential use in retrofitting activities, and the benefits to a range of stakeholders are considered.
Social Implication	The methodology offers the potential to support the measurement of flood resilience of individual properties, allowing the identification and prioritisation of specific interventions to improve the resilience of a property.
Originality/Value	Whereas previous attempts to quantify flood resilience have adopted qualitative approaches with some level of subjectivity, this proposed methodology represents an important advancement in developing a scientific and quantitative approach.

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1.0 INTRODUCTION

Many parts of the world have experienced an increase in flooding frequency, magnitude and damages in recent times (De Bruijn 2004; Jalayer *et al.,* 2015; Herslund *et al*., 2016; Huang *et al*., 2018). This has led to the loss of many properties worth billions of dollars, caused many fatalities (McAneney *et al*., 2017; Teng *et al*., 2017) and thereby making flooding one of the most hazardous natural occurrences to the built environment and humanity (van den Honert & McAneney, 2011; QFCI, 2012). While awareness of flood risk and its impacts have increased, the hazard still remains a threat to humans and the physical environment. This is as a result of the upsurge in many flood influencing factors, such as, rising sea levels, ice melt and increasing and excess rainfall (Meusburger & Alewell 2008; Schaller *et al*., 2016; Hall *et al*., 2018). Other contributing factors such as climate change, global warming and anthropogenic activities in flood-prone areas have significantly increased the risk (IPCC, 2012; Poussin *et al*., 2015; Kwak *et al*., 2015; Su, 2016). Yet, there are predictions of probable worse situations to come in some areas (IPCC, 2012; UNISDR, 2010). Considering some of these challenges and their impacts on the environment and humanity, attention has been drawn towards finding methods to ease these challenges. This has been a point of discourse in many conferences, parliaments and gatherings of world leaders. Responses to these effects have led to different policies at both national and international levels. For instance, the Flood Directive 2007/60/EC (EC, 2007; ABI, 2008; EFRA, 2010; ABI, 2010). However, further efforts are still demanded.

Early efforts directed towards the management of flooding have seen considerable investment committed to the development of structural measures. Structural measures involve the use of various hard engineering interventions, such as dykes, river conveyances, defences and dams (Dawson *et al*., 2011; Wesselink *et al*., 2015). However, they have proved to be insufficient in dealing with flood hazards. An instance was the occurrence in December 2013 and early 2014 flooding in the United Kingdom where the magnitude of water overtopped defences that were meant to prevent flooding (Nquot & Kulatunga, 2014). Such experiences have brought the researchers and experts into a consensus that flooding cannot be totally prevented but their risks and the impacts on the built environment can only be greatly reduced (Bharwani *et al.,* 2008; Joseph *et al*., 2014). To this end, considerable work is now organized towards improved methods of flood risk management. These include the improvement and placement of integrated flood risk management over the traditional approaches. This represents a paradigm shift from large scale hard engineering structures and other flood defences to integrated approaches which include soft engineering (EC, 2007; Schelfaut *et al*., 2011). These approaches include land practices, early warning systems, beach nourishment and vegetation management (Dawson *et al*., 2011). This integrated flood risk management thinking allows for various methods that enhance human capacity and the environment against flooding. This monumental shift is majorly from the mindset of flood prevention to flood risk mitigation (Schelfaut *et al*., 2011; Batica *et al*., 2013). The concept of resilience is central to this thinking and has now become a focus of flood risk management with its usefulness being extended to the planning of the environment and decision making (Hammond *et al*., 2015; Oladokun & Montz, 2019).

In line with this new paradigm, this study aimed at proposing a methodology for the measurement of flood resilience at the individual property level. In this concept, buildings are treated as a single entity whose level of exposition to flood hazard are to be revealed. To achieve this measure of flood resilience, the proposed concept adapted the fuzzy analytical hierarchical approach in measuring the relative importance of the notable resilient attributes and sub-attributes in an individual property.

1.1 Resilience

Resilience at its basic is a concept that describes the ability of a system or component to return to its initial state, position or functions after being perturbed (Gallopin, 2006; UNISDR, 2010; Adebimpe, *et al*., 2018). Different perspectives to the definitions of resilience have been established (see for example Adger *et al*., 2005; NRC, 2012; ADB, 2013; DFID, 2011; IPCC, 2012; Twigg, 2009). However, Walker *et al*. (2004) definition of resilience as *"the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks"* seems to be all-encompassing. The resilience concept is widely known and has been applied in many fields of science, engineering, environmental management, ecological systems theory and economics (Keating *et al*., 2017). For instance, Masten and Reed (2002); Masten and Obradovic (2008) considered the resilience of human development while Walsh (2015) considered family resilience in the face of uncertainties. Lamine (2015) applied resilience in agrifood, Lengnick-Hall and Beck (2016) in organization resilience in a dynamic environment, Wang *et al.* (2017) on built environment resilience to earthquakes while Jesse *et al*. (2019) adapted the concept to energy systems.

These demonstrated the versatility of the concept across many fields of study. However, a much recent development in the application of resilience is in its application to flood risk management. Flood resilience is an approach developed to reduce the significance of flooding with coping and recovery mechanisms (Vis *et al*., 2003; de Bruijn, 2004; Proverbs *et al*., 2018; Bertillson *et al*., 2019). Resilience to flooding at the level of the individual property is characterised in different ways based on the methods for flood water management. According to Rose *et al*. (2016), it was reported that water exclusion and water entry strategies are two basic methods to manage flood water. The water entry strategy incorporates resilience measures such as permeable materials with water-resistant materials, resilient wall plasters, the use of plastic units in kitchens and bathrooms, raised electrical sockets, represent some examples (Owusu *et al*., 2015). While, the elevation of structure above flood level, dry flood proofing and flood barriers were referred to as the water exclusion resilience measures (Maqsood *et al*., 2016). These two basic approaches demonstrate in simple terms the meaning of flood resilience at the individual property level. Some of the propositions of Adebimpe *et al*. (2018) towards the development of flood resilient buildings in Nigeria can also be categorised under these two basic methods. These include tiled floors, tiled walls, raised foundations and building entrances, etc. Therefore, the need to hasten the process of flood resilience in buildings becomes imperative (Kotzee & Reyers, 2016). However, there remain many challenges that slow down the adoption of this concept.

Some of the challenges include low awareness, reluctance in flood resilience investment, operationalising flood resilience, economic justification, the ambiguity of the impact of resilience during flood events and its quantification (Schelfaut *et al*., 2011; Nguyen & James, 2013). According to Keating *et al*. (2017) measuring resilience to disasters is not a straightforward issue. Presently there is "no one size" that fits all in the measurement of resilience while even some schools of thought agreed that there should not be (Levine, 2014; Schipper & Langston, 2015; Keating *et al*., 2017). These statements could mean that there is yet to be strong empirical evidence that validates the measurement of resilience, thus making research on flood resilience measurement open to further deliberation. However, some positive developments have been made towards the actualisation of the objective. A majority of research works that have attempted to develop methods for the quantification of flood resilience have been more theoretical in nature with little attention or adoption of quantitative aspects, see for example IFRC (2012) and Adedeji *et al*. (2019).

However, few studies have started making progress from the qualitative thinking of flood resilience to the quantitative measurements but still, the field is yet to be dealt with exhaustively. For instance, Cutter *et al*. (2010) established a baseline for monitoring resilience in disaster resilience benchmarking while Qasim *et al*. (2016) used a subjective weighting system in measuring community resilience in Pakistan. Kotzee and Reyers (2016) selected some flood resilience indicators and integrated them into a composite index using principal component analysis for the transformation of the variables. Oladokun *et al*. (2017) considered the approach of fuzzy logic for measuring the flood resilience in buildings. Bottazi *et al*. (2018) evaluated empirically what was regarded as "live with water" in Dakar, Senegal using a subjective resilience indicator and a before-and-after-control-intervention concept. Moghadas *et al*. (2019) evaluated the flood resilience of Tehran using a hybrid multi-criteria decision-making approach. While this gave an insight into the application of multi-criteria decision making (MCDM) in flood resilience measurement in urban areas, their approach adopted a ranking methodology in the resilient measurement using a comparative analysis. Thus, the study ranked the resilience of urban areas and did not include the measurement of resilience of individual property as an entity. Analysing flood resilience in the context of the urban environment is clearly different from the individual property considering the specificity of the elements. Thereby, making the approach of Moghadas *et al*. (2019) to be appropriate in resilience of a predetermined population. This is different from the case of individual property in which each entity has to be treated and measured independently of the other within the same location. Thus, applying a ranking methodology for the purpose of flood resilience estimation may be vague and may lack sufficient evidence regarding the status of each individual property. Therefore, this research work has considered the development of a methodology that can measure resilience at individual property levels.

1.2 Justification

Developing a methodology for flood resilience measurement in individual property involves the identification and the ability to quantify the resilience of the key components of the property (Kotzee & Reyers, 2016). It is also suggested that the measurement of the resilience of the property will aid the understanding and determination of the vulnerability of the property in the case of flood hazards. Understanding this will help to upscale the resilient features of the buildings to cope, recover faster and better during and after flooding. This in a way will impact the environment through the enhancement of flood resilient cities (Golz *et al*., 2015). Knowing full well that properties are not in isolation but rather they are major elements that dominate cities. Thus, the resilience of the set of properties is indirectly indicative of the resilience of the city.

However, information regarding the quantification of the resilience attributes and the overall measurement of their impact remains open for further discussion. These aspects of flood risk management are yet to be dealt with systematically. Implementation of the resilient measures, full adoption of resilience in developing cities and policy making hinges on the effective measurement of resilience. Even though the concept exists, the level of implementation does not reflect awareness. This was observed by Joseph *et al*. (2014) among UK properties owners in flood-prone areas. Therefore, an appropriate quantification methodology is a prerequisite to achieve a step-change in individual property resilience and to tender a business case for investments in resilient retrofits (Cutter, 2016). This has been demonstrated in academic literature and government communications as a viable option of flood risk management. That is why there is a monumental increase in flood resilience as a way to manage flood risk.

Achieving this requires the support of an easy to use a methodology that measures the resilience of properties to flooding. Therefore, this model can form a basis for judging the level of individual properties as an entity and to justify the investment of property /home owners in flood resilience attributes.

1.3 Overview of Fuzzy Analytic Hierarchy Process

The Fuzzy Analytic Hierarchy Process Approach (FAHP) is an operational research tool which is referred to as a multi-criteria decision-making method or approach (MCDM/MCDA). MCDM concept allows for a compromise among conflicting criteria or attributes for objective decision making. TOPSIS, VIKOR, PROMETHEE, ELECTREE are other examples of MCDM with some basis being taken from AHP. Analytic Hierarchy Process (AHP) involves the use of experts' opinions for objective decision making (Adebimpe & Odedairo, 2017). However, FAHP is an extension of AHP which was earlier developed by Saaty in 1977. Thus, FAHP combined the existing concept of analytic hierarchy process with the fuzzy theory to determine preference for a range of variables. This is achieved by modelling the experts' response in the fuzzy environment to remove vagueness or imprecision of the qualitative response (Kahraman, 2018). The transformation of the response of the experts into fuzzy numbers helps to mimic human reasoning and the comparison of attributes and sub-attributes to arrive at a quantitative score.

FAHP has been found to be applicable across many fields of engineering, management and environmental related issues. In Haq and Kannan (2006), the fuzzy analytic hierarchy process was applied to the evaluation and selection of vendors in a supply chain model. Darko *et al.* (2019) discussed the application of the analytic hierarchy process in construction management while Abadi *et al*. (2018) applied it to notebook selection. Fuzzy analytic hierarchy process has been applied in urban mobility systems. Kramar and Topolsek (2018), Tang and Hsu (2018) used FAHP to evaluate the critical element of marketing strategic alliance development in the mobile telecommunication industry. Also, it was used to model the risk analysis and assessment of construction sites in Greece (Koulinas *et al*., 2019). A closed example application of FAHP in environmental management is in Choubin *et al*. (2019) where it was applied in the analysis of gully erosion susceptibility. Thus, the various applications of FAHP have demonstrated its versatility across many fields. However, a basic requirement in the application of FAHP in any field is the ability to abstract and model the response of the experts in the fuzzy environment and to apply the fuzzy theory in the evaluation. This is preceded by the identification of the relevant attributes and/ sub-attributes appropriate for the intended purpose.

2.0 METHODOLOGY

The activities involved in the process of developing the methodology for flood resilience measurement includes; the conceptualization of the flood resilience system; followed by identification and the characterisation of the resilient attributes and sub-attributes under each attribute; the sub-attributes and the attributes are further characterised into hierarchical levels; followed by the adaptation of fuzzy analytic hierarchy process for the weighting of the attributes' and sub-attributes' importance and contributions to the overall resilience. Then, a method to measure the specific values of each sub-attribute was proposed. The Composite Flood Resilience Index (CFRI) concept for flood resilience measurement was derived based on the aggregation of the weight of the resilient attributes, sub-attributes and the measured value of each of the sub-attributes. This concept perceived and treated resilient attributes, sub-attributes and the state of each of the sub-attributes as factors that have a combined effect on the resilience measure based on their hierarchical level. Thereafter, a mathematical model was developed for the composite flood resilience index.

2.1 Research Questions

For the purpose of this study, these research questions have been considered during the process of developing a methodology for flood resilient measurement;

1. What are the attributes and sub-attributes of flood resilience in a building and how they influence the resilience of an individual property?

2. How can the sub-attributes be grouped into basic functional attributes that best describe the resilience?

3. Of what specific importance and contribution are each of the sub-attributes and the attributes to the overall resilience of the property?

2.2 Resilience Attributes and Sub-Attributes and Basic Functional Classification

A review and characterisation of literature described some factors that influence the resilience of a building to flooding. These are various features of buildings that aids in coping, recovery as well as the response of buildings to flooding. Kreibich *et al*. (2005) and Diakakis *et al*. (2017) identified some of these relevant resilient features upon which Oladokun *et al*. (2017) synthesised to arrive at three main subthemes. The three sub-themes are Inherent Resilience, Supportive Facilities and Resident Capacity. They explained inherent resilience (IR) as inbuilt features of the building. These include some structural components that enhance the ability of the building to cope during flood events. Meanwhile, the supportive facilities (SF) are the added facilities that can be deployed during flood events for resistance, coping and recovery measures. The supportive facilities are slightly different in functions and peculiarities from inherent resilience because they are basically some kind of add-ins. These may not be part of a building at the onset but as a result of preparing towards future flooding. Of course, the human capability in achieving flood resilience cannot be overemphasised and consequently was described as resident capacity (RC). The capacity of the potential flood victim was viewed under resident capacity. In a broad sense, the resident is considered one of the principal elements. Therefore, considerations on the ability of the residents to resist and cope during such situations that could be traumatic are considered important for resilience measurement.

These three dimensions were considered as a representation of some variables set in properties resilience measurement. Such variable sets are referred to in this study as flood resilient sub-attributes in an individual property. However, for the purpose of this study, we adopted the established knowledge of Oladokun *et al*. (2017) for flood resilient measurement as relevant dimensions for the resilience classification in the developed methodology. Also, we combined Adedeji *et al*. (2018) suggestions in the developed framework for resilience measurement.

Adedeji *et al*. (2018) discussed the measurement of flood resilience at an individual property level based on two themes which are engineering and psychological resilience. The engineering resilience describes the features added to the building for the purpose of flood risk management while the latter describes the human coping capability. Under these were listed some various variables, such as material type, point of water entry, material type etc. and gender, health status, past experience etc. exhibited by the building and human respectively. Further analysis of some of the highlighted resilient features and their classifications showed that Resident Capacity established by Oladokun *et al.* (2017) can be further broken down. Therefore, this study reconsidered the resident capacity (RC) and simplified it to human resilience (HR) which is similar to the expression in Adedeji *et al.* (2018) and socio-economic resilience. These formed the basic structure for the measurement at an individual property level. Therefore, the four proposed attributes in this research are; Inherent Resilient Attributes (IRA), Supportive Resilient Attributes (SRA), Human Resilient Attributes (HRA) and Socio-Economic Resilient Attributes (S-ERA) of the property owners/occupants. These are summarised as follows:

1. Inherent Resilient Attributes (IRA): are inbuilt physical attributes of a building that makes it not to be exposed to flood water and/or reduces the effect of the flood on the building. These are parts of the building design. They are part of the construction and not alterable unless there is a major alteration on the whole building.

2. Supportive Resilient Attributes (SRA): these are majorly added facilities, back-up systems that defend the building, properties and the occupants from being affected by flooding. These are only deployed when needed for flood control measures.

3. Human Resilient Attributes (HRA): this refers to adaptive and coping of residents of the building. Factors such as occupants' demography, level of flood awareness, flood experience, education and health status are covered within this attribute.

4. Socio-Economic Resilient Attributes (S-ERA): this covers both the social and the economic attributes of the occupants. This further describes the social relations and networks of the residents beyond the immediate environment. These include factors such as income level, socio-capital status, insurance etc. of the resident which can aid quick recovery during flood events.

2.3 Flood Resilient Measurement

The proposed flood resilience measurement methodology is based on an input-output concept. The output is a quantitative measurement in the form of an index which is a function of the aggregates of the input factors. An index is an indication of an element or system. According to

Sullivan and Meigh (2005), an index is referred to as an obtainable quantitative score from the combination of certain variables using some set of rules. In this case, the variables are the input factors. The input factors are; the resilient attributes, sub-attributes and the measured value of the sub-attributes based on their state in the building. These input factors are at different hierarchy and contribute differently to the outputs based on the interactions and interdependence within the system. Thus, the resultant effects of all these input factors on the final measurement of flood resilience are regarded as the Composite Flood Resilience Index (CFRI). This is an index which is to be used for flood resilient measurements in buildings.

2.3.1 Theoretical Structure of the Composite Flood Resilience Index (CFRI)

Figure 1 describes the theoretical structure for the CFRI. This depicts the basis upon which the proposed concept and equation were formulated. In the structure (see figure 1), there are three hierarchical levels, with the CFRI being the third and the utmost level on the hierarchy. The first level depicts the resilient sub-attributes. These are the notable features of resilience in the building. At this level, each of the sub-attributes is a subset of an attribute and by implication, it interacts with such attributes. Also, each sub-attribute has its own specific contribution to flood resilience. This contribution is unique and specifies its importance differently within the attribute classification. Aside from the weighting of the importance of the sub-attribute, there is a specific measurement of the value of the sub-attributes. This specific measurement is demonstrated in figure 1 with an iconic symbol of a gauge. The proposition is that even though the weight is known, the specific value of the sub-attribute is a critical factor. This value is a variable at the individual property level.

The second level represents the resilient attributes which stand for the basic categorisation of the referred themes of flood resilience. This is the intermediate level that garners the resilient sub-attributes. At this level, the contribution in terms of the importance of each of the sub-attributes to the final resilience measurement (CFRI) is defined and measured quantitatively. This is the penultimate level to the flood resilience score of the property. Thereafter, the final score of the measurement which is at the apex of figure 1 represents the final index on the hierarchical structure. This is the combined effect of the other two levels and the specific measurement of the gauge.

Figure 1: Theoretical Structure for the Composite Flood Resilience Index (Here)

2.3.2 Composite Flood Resilient Index (CFRI) Model

The CFRI model is therefore, a function of the resilience attributes and sub-attributes in the building. It is the product of the individual indicators of the sub-attributes (i.e. the status of each of the sub-attributes in the building considered), the weights which depict the importance of the attributes and the sub-attributes in terms of flood resilience of a building. This is mathematically represented in equation 1- 3 with their notations and meanings. In the equation 2 and 3, A_i and S_{ij} are the model parameters while v_j is a variable.

$$CFRI = f(Resilient\ Attributes, Sub\ Attributes, measure\ of\ the\ sub\ attributes\ ) \qquad 1$$

$$CFRI = f(A_i, S_{ij}, v_j) \qquad 2$$

$$CFRI = \sum_{i=1, j=1}^{n,\ m_i} A_i * S_{ij} * v_j \qquad 3$$

Where;

i *is the level of the attributes and sub attributes from* 1 *to* n
j *is the position of resilient sub attributes from* 1 *to* m_i

A_i *is the weight of flood resilient attribute*

S_{ij} *is the weight of the flood resilient sub attributes* i *at position* j

v_j *is the score of the status of ith sub attributes of flood resilient in jth position*

2.3.3 Parameter: Weighting the Resilient Sub-Attributes and Attributes

The weights of the flood resilient attributes and sub-attributes in a building are the parameters of equation 2. To estimate those parameters, this methodology considered the adaptation of the Fuzzy Analytic Hierarchy Process to assign weights to the attributes and sub-attributes of flood resilience based on their importance. The weightier an attribute and sub-attribute, the more important it is and the more it contributes to the flood resilience index. The process of assigning weights involves the careful selection of the experts which includes academic, government officials, agencies and policy makers in flood risk management. These experts are asked to make a decision on the importance of a set of resilient attributes and sub-attributes over one another based on their expertise and experience. To achieve this, a comparison of the resilient attributes and sub-attributes would be used by forming the set of variables under consideration into a pairwise comparison matrix. This will use a prepared set of the linguistic variables to describe the degree of importance of one attribute/sub-attribute over another as stated in table 1. The quantitative terms of the linguistic variables ratings are described with corresponding triangular fuzzy numbers (TFNs).

2.3.3.1 Pairwise Comparison for Flood Resilient Attributes and Sub-Attributes

Pairwise comparison is the approach used in the fuzzy analytic hierarchy procedure to retrieve the relative importance of a set of variables. The pairwise comparison is a square matrix of the variables in consideration. In this case, flood resilient attributes and sub-attributes are the variables which are being filled across the first row and first column to retrieve response from experts (see tables 2-6). During the comparison, the attributes/sub-attributes being compared to another is judged using the linguistic variables which has a corresponding triangular fuzzy number (TFN) (see table 1). The comparison for the resilient attributes and sub-attributes are described in tables 2 and 3-6 respectively. Each cell in tables 2-6 demonstrates two attributes/sub-attributes being compared with the options of five linguistic variables (see table 1) except for the cells along the principal diagonal of the matrix. From these five options, one option that best describes the relative importance based on the experts' knowledge is to be picked. However, elements in the principal diagonal of the pairwise comparison matrix automatically have Equal Importance as their response because each cell involved is a coordinate between the same attributes/sub-attributes.

Table 1 Linguistic Variables with Corresponding Triangular Fuzzy Number (Here)

Table 2: Pairwise Comparison Matrix for Flood Resilient Attributes in Individual Property (Here)

Table 3: Pairwise Comparison Matrix for Sub-Attributes of Inherent Resilient Attributes (IRA) in Individual Property (Here)

Table 4: Pairwise Comparison Matrix for Sub-Attributes of Supportive Resilient Attributes (SRA) in Individual Property (Here)

Table 5: Pairwise Comparison Matrix for Sub-Attributes of Human Resilient Attributes (HRA) in Individual Property (Here)

Table 6: Pairwise Comparison Matrix for Sub-Attributes of Socio-Economic Resilient Attributes (S-ERA) in Individual Property (Here)

2.3.3.2 Modelling of the Attributes and Sub-Attributes

The fuzzy analytic hierarchy process was adapted for modelling the response of the experts in assigning weights for the importance of the resilient attributes and sub-attributes. The corresponding triangular fuzzy numbers (TFNs) (see figure 2 and table 1) are substituted for the linguistic variables from the response of the experts.

$$A = \{a_{ij}\} \in R^{nxn} \qquad 4$$

$$\text{Where; } a_{ji} = \frac{1}{a_{ij}} \; and \; a_{ij} > 0 \; \forall \; j = 1, 2, \ldots m \; and \; i = 1, 2, \ldots n \qquad 5$$

Figure 2: Fuzzy Triangular Function Representation (Here)

Thereafter, the quantitative measurement of the importance of the attributes and sub-attributes are to be determined using extent analysis method of Chang (1992) and Chang (1996) as described in the following steps;

Step 1: From the experts' response, the preference of the attributes/sub-attributes is compared as described in matrix $\tilde{C} = \{\tilde{c_{ij}}\}$ with the TFN transformed responses from all the experts. The number of matrices for the attributes and sub-attributes would be corresponding to the number of respondents.

$$\tilde{C} = \begin{bmatrix} 1 & \tilde{c}_{12} & \tilde{c}_{1n} \\ \tilde{c}_{21} & 1 & \tilde{c}_{2n} \\ \tilde{c}_{n1} & \tilde{c}_{n2} & 1 \end{bmatrix} \forall\, k = 1, 2, \ldots h \tag*{6}$$

Step 2: Aggregate the TFN transformed response using the geometric mean method (see equation 7). These scale the matrices down to a single matrixe_{ij}.

$$l_i = \left(\prod_{k=1}^{h} \tilde{l}_k\right)^{1/h}, m_i = \left(\prod_{k=1}^{h} \tilde{m}_k\right)^{1/h}, u_i = \left(\prod_{k=1}^{h} \tilde{u}_k\right)^{1/h} \tag*{7}$$

Step 3: Determine the row sum and column sum of the new matrixe_{ij}

Step 4: Compute the fuzzy synthetic extent value s_i with respect to the i^{th}attribute/sub-attribute as given in equation 8.

$$s_i = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \otimes \left(\sum_{i=1}^{n}\sum_{j=1}^{m} l_{ij}, \sum_{i=1}^{n}\sum_{j=1}^{m} m_{ij}, \sum_{i=1}^{n}\sum_{j=1}^{m} u_{ij}\right)^{-1} \tag*{8}$$

Step 5: Approximate fuzzy priorities for the criteria from the fuzzy synthetic extent values. The non-fuzzy values that represent the weight of one attribute/sub-attribute in relation to another are derived. Figure 3 described the intersection and degree of possibility between two attributes/sub-attributes and equation 9-13 for the determination of the relative weight of one attribute/sub-attribute to another for all attributes/sub-attributes.

Figure 3: Graphical representation showing the intersection between $s_{i+1}$and s_i (Here)

$$V(s_1 \geq s_2) = 1 \; iff \; m_1 \geq m_2 \;\; \text{and} \tag*{9}$$

$$V(s_1 \geq s_2) = hgt(s_1 \cap s_2) = \mu_{s_1}(d) \tag*{10}$$

$$V(s_2 \geq s_1) = \begin{cases} 1 & if \;\; m_2 \geq m_1 \\ 0 & if \;\; l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \tag*{11}$$

$$V(s_i \geq s_1, s_2, \ldots, s_z) = \min V(s_i \geq s_z) = w'(S_i) \quad \forall\, z = 1,2,\ldots\ldots n \tag*{12}$$

where, n is the number of attributes/sub-attributes criteria, $z \neq i$ and $w'(S_i)$ value represents the relative preference or weight of one attributes/sub-attributes over another and is a non-fuzzy number. We have;

$$w'(s_1), w'(s_2), w'(s_3), \ldots\ldots, w'(s_n) \tag*{13}$$

Step 6: The weight of the criteria (see equation 13) are normalised, normalised weight vectors are checked to and must be approximately 1 as described in equation 14;

$$\sum_{i=1}^{n} w_i = 1 \tag*{14}$$

The responses are checked for consistency. The experts' responses are expected to be near uniform based on their knowledge and level of expertise. The reliability of their judgement is tested using the consistency index model and consistency ratio. Saaty (1977) specified consistency index (CI) and consistency ratio (CR) model as described in equation 15 and 16.

$$CI = \frac{\lambda_{max} - n}{n - 1} \qquad 15$$

$$CI = \frac{CI}{RI} \qquad 16$$

2.3.4 Variables: Scoring the Sub-attributes of Flood Resilient in Property

Table 7 describes some of the sub-attributes under their functional attributes and specifies their meaning in relation to their functions during flood events. Aside from the parameter measurement (i.e. weight), the values of each of these sub-attributes are to be measured. This has a kind of variation from one building to another. For this to be measured, a standardised scoring system is to be adopted with inputs from the experts' to classify the status of the sub-attributes on a Likert scale of 1 to 10.

Table 7: Some Sub-attributes and their Description in Individual Property (Here)

3.0 IMPLICATIONS

In this section, expositions on the general impact of the methodology towards measuring flood resilience at the individual property level are considered. According to Adedeji *et al.* (2019), a tool that captures all the necessary features and quantifies flood resilience of a building would be of great value to a range of stakeholders (i.e. homeowners, property experts and surveyors, insurers and government). In this regard, this procedure has many potential applications for professional stakeholders involved in maintaining the built environment. Therefore, the different ways in which the methodology would benefit those responsible for managing flood risk are now put forward.

3.1 Flood Resilience Status of Property

Measuring the flood resilience of a property is imperative in flood risk management (Oladokun *et al*., 2017). In this regard, the methodology would provide accurate and reliable information regarding the current resilience status and consequently the level of exposure of the property to flooding. The methodology identifies and quantifies flood resilience attributes and sub-attributes in the individual property. It has the capability to present in an index form the coping and recovery capacity of properties during flood perturbation.

For instance, it would reveal the extent to which a property is protected from flooding. Also, the methodology would inform and improve the knowledge of home owners on flood resilience attributes and sub-attributes. With this, home owners can identify elements of their properties that need improvement. The model can assist in creating boundary (i.e. upper and lower) limits for flood resilience measurement and also, to quantify what needs to be done in order to improve the flood resilience of a property. The output from the methodology would present to home owners the resilience status in an index format which can easily be interpreted. For example, less than 10% could refer to low and above 80% high flood resilience. The lower the index the more exposed the property to flood risk while the higher the index the more the capacity of the property to recover and cope in a time of flood. This would assist home owners in understanding the true position of their properties in the time of flooding and also highlight relevant safety concerns.

Property experts and surveyors would also benefit much from this methodology as it will clearly distinguish vulnerable and flood resilient properties. Also, the attributes and sub-attributes promulgated by this methodology would increase the knowledge of property experts and surveyors. It would further guide in their various functions and decision-making. Such as property costing, price bargaining, mortgaging and renting. Since, flood risk influences the value of homes (Lamond *et al*., 2010; Kropp, 2012; Wilkinson, 2018), this index could provide a logical basis for valuing and/or bargaining a property with consideration for flood risk. Interaction with the methodology would provide an evident-based tool which uses levels of flood exposition of properties as a basis for setting properties cost/price range. Such that, low, average and high flood resilient-properties would have a corresponding cost or rental fee. Of course, this together with the knowledge of the flood resilient attributes and sub-attributes can as well be used by property experts/surveyors in offering professional advice to clients.

A fair palliative measure from the government to assist property owners can be achieved using this methodology. The responsibility of the government partly covers the protection of individuals and properties from flood damage (World Meteorological Organisation, 2013; Henstra *et al*., 2019). That is why many times the government respond by bringing relief to flood victims. To ensure an effective relief process, aids that commensurate to the flood resilience status of the properties are required. Therefore, applying this methodology to determine the flood resilience status of properties would assist in determining a corresponding palliative measure. Of course, this would also help agencies who are in charge of risks and emergency management to identify properties that are under flood threat and the degree of threat. Such as, buildings that can lead to catastrophic situations during flash floods and/or high floods. Thus, a response plan that supports in flood emergencies is required (Nquot & Kulatunga, 2014). To this end, the weights generated from the methodology would help to identify and prioritise critical properties and, to logically guide the deployment of needed facilities among the critical properties during flood emergencies. Furthermore, the methodology could offer guidance to necessary agencies on relevant steps to avert or lessen flood risk, informing future flood resilience education. Guidance on flood resilience attributes and sub-attributes and the best means to achieve this would help permeate flood resilience knowledge and increase flood awareness of society.

3.2 Aiding Retrofitting

Retrofitting is a way of achieving flood resilience in existing properties and built-up areas (Minnery, 2011). To achieve retrofitting, considerations of the specific elements to be retrofitted and the elements to be prioritised are vital (Minnery, 2013). However, these basics require more clarity in order to implement the anticipated retrofit actions that improve the flood resilience of properties (Delgrange & Adeyeye, 2018).

In this regard, the proposed methodology has the capability to identify specific property elements that require retrofit action and to prioritise them based on their level of flood risk. The methodology achieved this by quantitatively determining the status and importance of the elements in a property. The importance is measured by determining the weight of various property elements and their contributions in the coping and recovering of property from flooding. The clarification would inform home owners on necessary retrofit actions to make their properties more flood-resilient. Also, the method can appropriately guide home owners in prioritising their funds to achieve the best retrofit result. That is, the methodology can assist in the determination and selection of the best retrofit combination that improves the flood resilience of properties.

The methodology would be of help to property experts and surveyors to determine the flood risk of property, the flood risk of property elements and the needed retrofits. This is necessary especially for properties located in flood-prone areas. The proposed methodology would assist property experts and surveyors to determine the flood exposure of the property, the state of their elements and the impacts of each element on the property. Knowing the state of each specific element of the property would reveal the magnitude of retrofit action required in each element. Of course, prioritisation of the flood risk of the property elements can help focus on the important elements so that retrofit is achieved within the budget. Thus encouraging retrofit actions alongside the renovation of a property. That is, identifying the vulnerable property elements can lead to a replacement of such an element with a new and equally flood resilient ones. For example, if doors and/or windows are identified as being vulnerable, then they can be replaced with flood resilient types during normal household improvements. Also, the information regarding the required retrofit of different properties can guide the investment decision-making of property experts/surveyors.

The information from the methodology would benefit insurers in developing robust premium charges to capture various levels of retrofits. Quantifying the benefits of resilience measures can be difficult (May *et al*., 2015), especially when a property is newly retrofitted. For instance, to measure whether a retrofitting has increased the flood resilience of a property can be subjective. However, the methodology is a quantitative measure which can help to quantify the respective premium charge of properties after they have been retrofitted. Such that, existing buildings can seamlessly change to premium charge that commensurate with their retrofit efforts and improvement in flood resilience. Also, this can further assist insurers in payment of indemnity in case of flood loss and to incentivize property insurance.

4.0 CONCLUSIONS

Measuring the resilience of properties is a very important component of the flood risk management concept and towards the implementation of resilience. That is, as much as we think of resilience in flood risk management, its quantification is necessary and therefore, a quantitative measurement model becomes imperative. A theoretical concept has been proposed which would help aggregate and evaluate the necessary attributes and sub-attributes of resilience in properties in such a way that reveals their impact on the flood resilience status of individual property. The research presented the application of the fuzzy analytic hierarchy process approach in measuring the flood resilience of properties. The concept of fuzzy analytic hierarchy process approach was adopted in the theoretical thinking of flood resilience measurement and was used in the development of the methodology regarded as the Composite Flood Resilient Index (CFRI) which is an Input-Output model. The CFRI model will take input parameters and variables from the building under consideration to give an output flood resilience measurement in an index form.

The proposed methodology represents advancement over the previous approaches in the sense that, it is an evidence-based way of measuring flood resilience in individual property. Also, the methodology is a quantitative measurement which is based on an advanced tool that provides greater clarity and removes vagueness from the process of flood resilience measurement. Its capability to accommodate experts' inputs has made it a robust method for resilience measurement. The methodology will contribute by highlighting basic functional attributes and sub-attributes of flood resilience within the individual property and will demonstrate their importance using a scientific weighting method. The assigned weights represent the importance of each of the functional attributes and each sub-attribute in flood resilience measurement at the level of an individual property. These weights aid in ranking the flood resilient attributes and sub-attributes and in identifying their significance and contribution to the overall property resilience. This will be useful to a range of stakeholders in understanding which flood resilient attributes and sub-attributes to prioritise. Furthermore, the weight of the flood resilient attributes and sub-attributes form a vital part to derive the Composite Flood Resilience Index of the property. This represents a method which will actively engage the knowledge of experts on flood resilience in the quantitative assessment of resilience. The potency of this methodology makes it robust and further demonstrates its extensibility beyond individual properties. Thus, further recommendations could be in its application towards different types of properties (i.e. commercial, industrial, public buildings) and at different spatial scales (i.e. community and city level resilience measurement).

It is acknowledged that the proposed tool is based on a purely theoretical approach and that this will require further work to rigorously test and refine the method before it can be reliably applied in practice. Future research work will involve testing and validating the methodology commencing initially with a survey of experts on property level flood resilience to establish the value of the key parameters. Subsequently, a selection of real life case studies, namely buildings in flood affected areas and/or flood prone areas, will then be analysed to determine the specific score of the sub-attributes. These would then be fed into the model together with the measured level of importance of resilient attributes and sub-attributes to arrive at a CFRI score for each of the case studies. Interviews with the property owners will then be used to help refine the model outcomes.

The ultimate testing of the accuracy of the CFRI model would be to consider real cases of flooded properties, measure the actual level of damage caused and compare it with the predicted resilience of the properties. This could be achieved through a retrospective study of properties equipped with resilient measures and that were subjected to flooding. By this, the reliability of the CFRI tool can be determined to ascertain its performance in the expected function of resilient measurement.

Acknowledgement: The authors acknowledge the support of the Federal Government of Nigeria through the University of Ibadan Revitalisation Fund.

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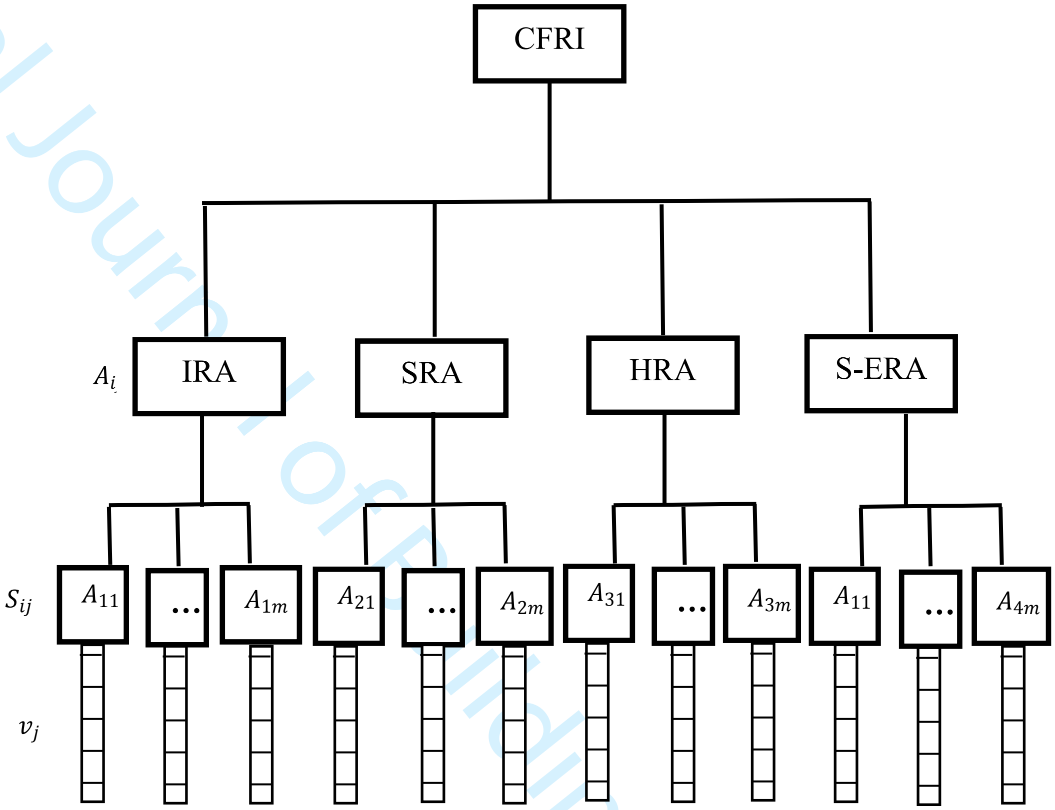

Figure 1: Theoretical Structure for the Composite Flood Resilience Index

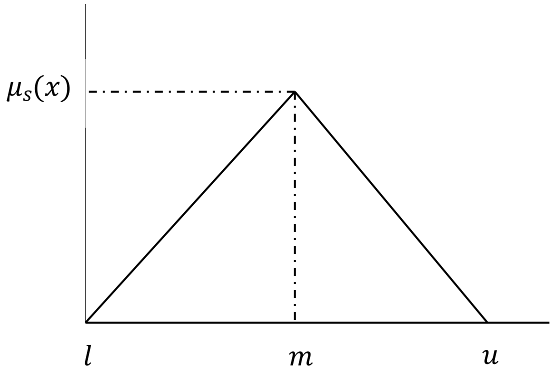

Figure 2: Fuzzy Triangular Function Representation

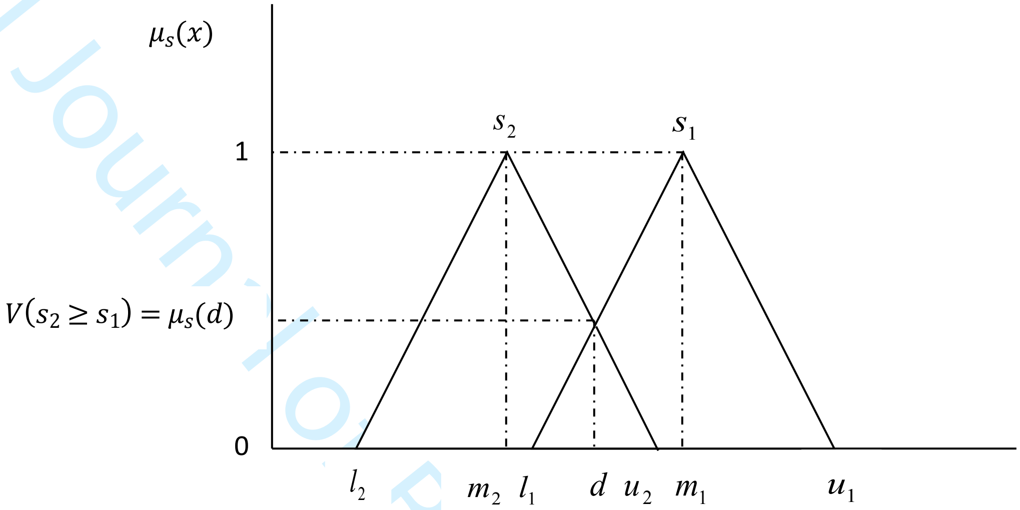

Figure 3: Graphical representation showing the intersection between $s_{i+1}$and s_i

Table 1: Linguistic Variables with Corresponding Triangular Fuzzy Number

Ratings	**Linguistic Term**	**Triangular Fuzzy Number** *(l, m, u)*	**Reciprocal**
1	Equally Important (EI)	1,1, 1	1,1, 1
3	Moderately Important (MI)	${}^{2}/_{3}, 1, {}^{3}/_{2}$	${}^{2}/_{3}, 1, {}^{3}/_{2}$
5	Strongly Important (SI)	${}^{3}/_{2}, 2, {}^{5}/_{2}$	${}^{2}/_{5}, {}^{1}/_{2}, {}^{2}/_{3}$
7	Very Strongly Important (VSI)	${}^{5}/_{2}, 3, {}^{7}/_{2}$	${}^{2}/_{7}, {}^{1}/_{3}, {}^{2}/_{5}$
9	Extremely Strongly Important (ESI)	${}^{7}/_{2}, 4, {}^{9}/_{2}$	${}^{2}/_{9}, {}^{1}/_{4}, {}^{2}/_{7}$

Table 2: Pairwise Comparison Matrix for Flood Resilient Attributes in Individual Property.

A_i	**(IRA)**	**(SRA)**	**(HRA)**	**(S-ERA)**
Inherent Resilient Attributes (IRA)	**EI**	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI
Supportive Resilient Attributes (SRA)	EI, MI, SI, VSI, ESI	**EI**	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI
Human Resilient Attributes (HRA)	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	**EI**	EI, MI, SI, VSI, ESI
Socio-Economic Resilient Attributes (S-ERA)	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	**EI**

Table 3: Pairwise Comparison Matrix for Sub-attributes of Inherent Resilient Attributes (IRA) in Individual Property.

S_{1j}		S_{11}	S_{12}	S_{13}	S_{14}
Inherent Resilient Attributes (IRA)	S_{11}	**EI**	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI
	S_{12}	EI, MI, SI, VSI, ESI	**EI**	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI
	S_{13}	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	**EI**	EI, MI, SI, VSI, ESI
	S_{14}	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	**EI**

Table 4: Pairwise Comparison Matrix for Sub-attributes of Supportive Resilient Attributes (SRA) in Individual Property.

S_{2j}		S_{21}	S_{22}	S_{23}	S_{24}
Supportive Resilient Attributes (SRA)	S_{21}	**EI**	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI
	S_{22}	EI, MI, SI, VSI, ESI	**EI**	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI
	S_{23}	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	**EI**	EI, MI, SI, VSI, ESI
	S_{24}	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	**EI**

Table 5: Pairwise Comparison Matrix for Sub-attributes of Human Resilient Attributes (HRA) in Individual Property.

S_{3j}		S_{31}	S_{32}	S_{33}	S_{34}
Human Resilient Attributes (HRA)	S_{31}	**EI**	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI
	S_{32}	EI, MI, SI, VSI, ESI	**EI**	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI
	S_{33}	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	**EI**	EI, MI, SI, VSI, ESI
	S_{34}	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	**EI**

Table 6: Pairwise Comparison Matrix for Sub-attributes of Socio-Economic Resilient Attributes (S-ERA) in Individual Property.

S_{4j}		S_{41}	S_{42}	S_{43}	S_{44}
Socio-Economic Resilient Attributes (S-ERA)	S_{41}	**EI**	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI
	S_{42}	EI, MI, SI, VSI, ESI	**EI**	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI
	S_{43}	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	**EI**	EI, MI, SI, VSI, ESI
	S_{44}	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	EI, MI, SI, VSI, ESI	**EI**

Table 7: Some Sub-attributes and their Description in Individual Property.

Attributes	Sub-attributes Notation	Sub-attributes	Description
Inherent Resilient Attribute	S_{11}	Building Type	It describes the type of building. i.e. Single storey building or multi-storey building.
	S_{12}	Wall Type	It describes the resistance of the material of the wall to flood water.
	S_{13}	Wall Finishing	This describes the finishing type of the wall and its resistance to flood water.
	S_{14}	Floor Type	This describes the resistance to water of materials from which the floor is made.
	S_{15}	Floor Finishing	This describes the finishing type of the floor and its resistance to flood water.
	S_{16}	Electrical Installation	It describes the type of electrical installation of the building. e.g. Conduit or surface.
Supportive Resilient Attributes	S_{21}	Back up Storage Space	It describes a prepared location within the building where valuables can be kept away from water.
	S_{22}	Back-Up Power and Energy Source	It describes order safe energy system that cannot lead to electrocution should there be a need to off the main energy source from the grid.
	S_{23}	Evacuation Transport System	It describes the availability of means of moving to a safety zone away from the flood.
	S_{24}	Flood Water Removing Systems	It describes the availability of means to evacuate flood water from building towards recovery.
Human Resilient Attributes	S_{31}	Demography	This refers to the age range of residents.
	S_{32}	Health Status	This refers to the health challenges and/or disability of the residents which can further put them into disadvantage during a flood event.
	S_{33}	Flood Education and Awareness	It refers to the level of awareness of the residents and their experience of the flood.
	S_{34}	Technical Capacity	This refers to the ability of the residents to quickly fix and to render some kind of service without necessarily being an expert in the area. i.e. DIY “Do It Yourself”

Socio-Economic Resilient Attributes	S_{41}	Insurance	This refers to resident insurance policy whether insured against flood and the details of the benefits involved.
	S_{42}	Personal Income	This refers to the financial standings of the residents based on their income.
	S_{43}	Socio-Capital	It refers to the network and relationships of the residents with people who are willing and can come to their aid during the period of flood distress.
	S_{44}	Investment	It refers to other sources of income of the residents which brings additional fund beyond the regular income. This can put an individual at an advantage during recovery.