

Evaluating Resilience of Coastal Communities Upon Integrating PRISMA Protocol, Composite Resilience Index and Analytical Hierarchy Processing

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Abstract

This research intends to investigate resilience of coastal communities to natural hazards upon adopting: (i) Analytical Hierarchy Process to generate a weight for each indicator and major components of resilience; and (ii) indexing method to calculate the extent of resilience for each community. The results highlight that 25.81% of communities in the study area are registered in the very low to low resilience class, whereas 58.07% are classified as very high to high. Additionally, the research identifies 11 critical action areas for building resilience in Khulna City, which is crucial for major stakeholders in setting up development strategies and plans for disaster risk reduction and sustainability.

Keywords: Climate change; disaster; community resilience; indexing method; AHP; GIS.

1. Introduction

The world has recently been observing the most rapid urbanization in history, with more than half of the world's population today living in cities [1–3]. The United Nations (UN) has projected that by 2050, 66 percent of the global population will be living in urban areas worldwide [1–4]. Cities are confronting a range of acute shocks resulting from natural catastrophes, as well as long-term strains such as the consequences of climate change due to their huge urban growth [1,5]. Moreover, massive rural to urban migration due to disaster and climate-induced stress has

facilitated a significant increase of population in the coastal cities [6,7]. Unfortunately, the coastal cities are highly vulnerable to the potential impacts of climate change and the increasing number of natural hazards, such as cyclones, storm surges, tornados, floods, tsunamis, earthquakes, drought, river erosion, and salinity intrusion [8–10]. In such conditions, communities in coastal cities must enact policies to strengthen resilience and enhance preparation to deal with acute and long-term stressors [1,11]. Thus, it is critical to introduce and implement an advanced integrated approach for assessing and mapping the resilience of coastal cities and communities to complement better management frameworks, policy planning, and decision-making processes. Therefore, the central focus of this research is to use an integrated indexing, Analytical Hierarchy Process (AHP), and GIS-based technique to analyze the geographical extents and degrees of the community resilience of a coastal city and understand the dynamics in the case of Khulna City, Bangladesh.

In recent decades, resilience has seen meteoric growth in academic, policy, and planning circles [12,13]. The idea has been utilized in many different fields, such as climate change, disaster studies, coastal studies, ecosystem conservation, and management, built environment, and urban planning [12–14]. Therefore, resilience is conceptualized in various ways by scholars of different disciplines, and a series of approaches are outlined to analyze and evaluate the systems associated. Usamah et al. (2014) have defined resilience as the ability of a system to resist or adapt to a hazardous event with having the capacity to recover quickly [15]. Pasteur (2011) has stated that resilience is the ability of a community to resist, absorb, cope with and recover from hazardous events, including efficient long-term adaptation [16]. Similarly, Tompkins et al. (2005) have defined resilience as the ability to self-organize and buffer disturbance, including the learning capacity and adaptation that enable the social system to bounce back after a shock (e.g., cyclone, coastal inundation, flood, etc.) [17]. Moreover, city resilience explains the ability of cities to function properly no matter what stresses or shocks is experienced in the face of disaster or climate change [1,18,19]. After carefully considering all these definitions, this study outlines resilience as a multi-dimensional (i.e., physical, social, economic, institutional, and environmental) form of ability of a community to cope with anticipated or unanticipated hazards and eventually return back to the previous stage in the shortest possible time.

Over the years, a growing body of literature has built a robust theoretical foundation of resilience [8–10] and provided critical methodological approaches for measuring and evaluating it, including the UN-Habitat City Resilience Action Plan (CityRAP) tool [20] and the Rockefeller City Resilience Index [18]. Additionally, in understanding and quantifying resilience, several theories describe the significance of asset-based approaches [21,22], while others propose quantitative strategies based on various complicated parameters [23–25]. Interestingly, some theories also have emphasized the significance of ecology or ecosystem-based adaptation to improve resilience [26,27]. Yet, there is a lack of literature that connects spatial features and quantitative data, as well as physical, social, economic, institutional, and environmental concerns or drivers that influence the resilience of a community. On this basis, this study focuses on a cerebral discussion on community resilience using a pragmatic approach of Khulna City in Bangladesh to better understand the nexus. Note that, Khulna is one of the vulnerable coastal districts of Bangladesh that has experienced several natural disasters (e.g., cyclones, floods, water surges, etc.) in the last three decades with significant human and economic losses.

Several methods and strategies are available in the contemporary literature to analyze, assess and visualize the resilience of cities and communities at various spatial scales. Orenco and Fujii (2013) have assessed the resilience of five coastal communities in the northeastern Philippines based on a composite index and AHP-based approach [28]. Ha-Mim et al. (2020) have analyzed the resilience and vulnerability nexus of coastal households using an equal weight-based indexing method [24]. Asmamaw, Mereta, and Ambelu (2019) have integrated Principal Component Analysis (PCA) based weighted approach and indexing method to measure the resilience of households to climate change in the northcentral highlands of Ethiopia [29]. The Rockefeller Foundations has suggested a city resilience framework consisting of twelve key indicators to provide a lens to understand the resilience of a city [18]. It is worth noting that these mentioned methodological frameworks have considered interesting schemas to document resilience in diverse geographic settings. Moreover, gaps in indicator selection, weighting, and spatial integration also motivate this study to develop a comprehensive and standardized resilience assessment approach. Therefore, in this study, we have used indexing, AHP, and Geographic Information System (GIS) based multi-criteria technique to assess and map the degree of resilience

for the communities of Khulna City to enhance accuracy, comparability, and spatial understanding of resilience. The combination of these three tools as a medium of multi-criteria decision-making provides a solid basis for the methodology and optimum results for resilience assessment [28,30–35].

This study on the resilience of coastal cities, focusing on Khulna City in Bangladesh, aims to address several research gaps identified in the existing literature. Firstly, all the resilience measurement methods in the literature are based on random indicator selection process [24,29,30,36]. However, this research has used a Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) based novel approach for the selection of the resilience indicators, which will enhance the reliability of the resilience assessment methods. Secondly, the literature emphasizes the lack of integrated approaches in resilience assessment [24]. Many existing methodologies focus on specific aspects or indicators of resilience without considering the multi-dimensional nature of resilience [21,24]. This study seeks to fill this gap by adopting an integrated approach that incorporates various dimensions of resilience, including physical, social, economic, institutional, and environmental factors. Thirdly, there is a limited consideration of spatial analysis in resilience studies [37,38]. Spatial features and geographical information play a crucial role in understanding the dynamics of resilience within a city [37,38]. However, many studies neglect to incorporate spatial analysis, resulting in a lack of understanding of the spatial patterns and interactions that shape resilience [37]. This research aims to bridge this gap by utilizing Geographic Information System (GIS) techniques to analyze the spatial extent and distribution of resilience in Khulna City. By integrating spatial data with resilience indicators, the study can provide valuable insights into the spatial dynamics of resilience and inform targeted interventions in specific areas. Fourthly, the literature highlights the importance of considering the local context and specific challenges faced by coastal cities [10,39,40]. Each coastal city has unique characteristics, vulnerabilities, and resilience capacities influenced by local environmental, social, and economic factors [10,40]. However, many studies on resilience often provide generalized frameworks that do not account for the specific context of individual cities. This study aims to address this gap by focusing on Khulna City, a vulnerable coastal district in Bangladesh that has experienced various natural disasters. By examining the resilience dynamics within this specific context, the study

can provide context-specific insights and recommendations for resilience-building efforts in Khulna City.

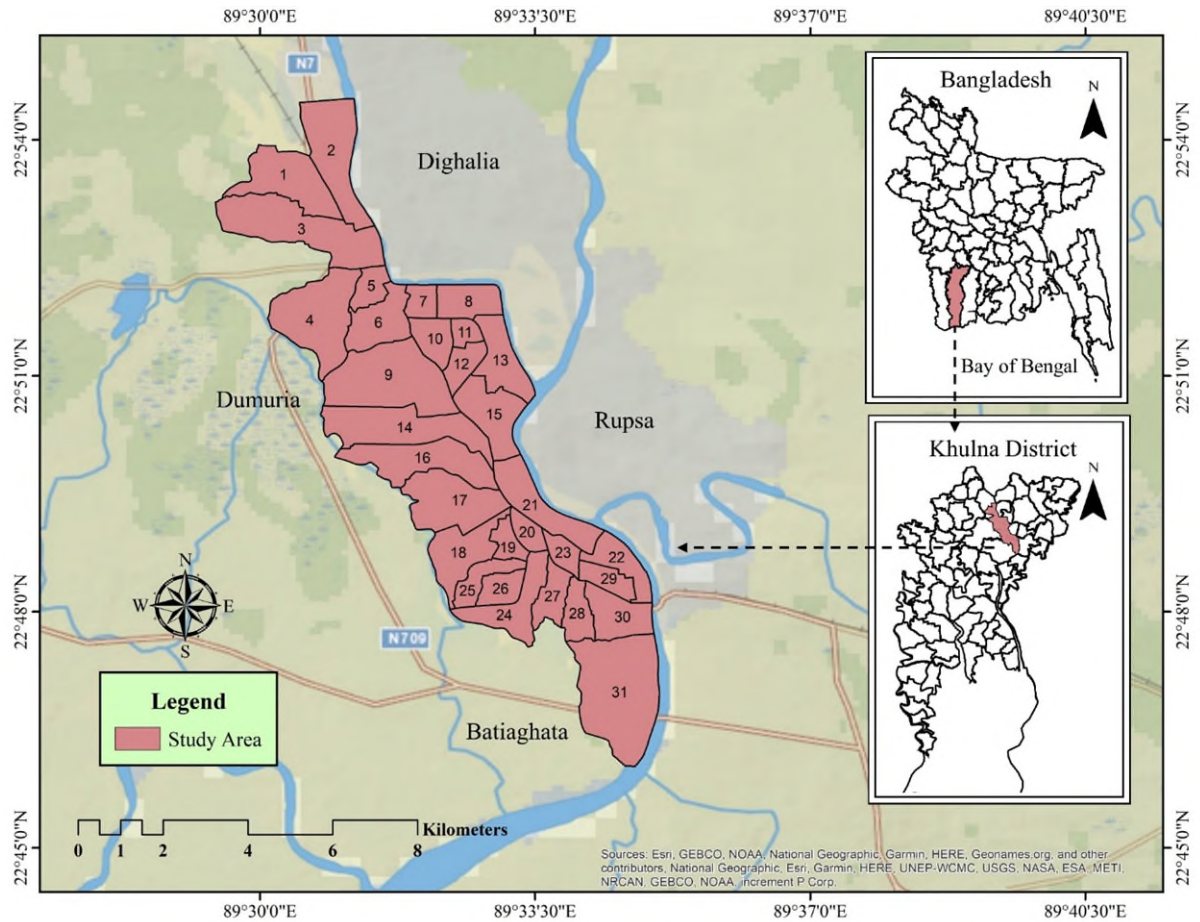
Furthermore, the literature emphasizes the need for practical and accessible resilience frameworks [21,24]. Existing frameworks and tools for resilience assessment are often complex and challenging to implement in practice [24]. There is a need for user-friendly and accessible frameworks that can be utilized by decision-makers, urban planners, and communities [21,33]. This study aims to develop a comprehensive resilience framework that is measurable, evidence-based, and complements existing urban planning practices. The findings will provide practical insights and potential development strategies for climate change adaptation and mitigation in Khulna City. It will be helpful for decision-makers at different levels to formulate potential development strategies for climate change adaptation and mitigation. Also, the study will be instrumental for administrators, urban planners, communities, and Non-Government Organizations (NGOs) to promote resilience building and vulnerability reduction activities. Consequently, this research will lead to open opportunities for engaging major stakeholders like civil society, local and international donors, governments of different levels, and private sectors on what makes the community resilient and which contributes to sustainable city development strategy.

2. Research Methodology

2.1 Study Area

Khulna is the third-largest city in Bangladesh, with an inhabitant of 1.5 million and a population density of 32,873 per sq. km [41]. The city is located between 22°46' and 22°55' north latitudes and between 89°29' and 89°35' east longitudes (Figure 1). It is surrounded by the Rupsha River, Dumuria Upazila, Khan Jahan Ali Thana, and Batiaghata Upazila on the east, west, north, and south, respectively. The city contributes a significant role to the economy of the country with its locational importance, unique geography, and ample opportunities for businesses. Khulna is situated in the closest proximity to the world's largest mangrove forest, the Sundarbans, and 2nd largest seaport in the country (i.e., Mongla Seaport). This region is prominent for its fisheries production, shrimp processing industries, and substantial commercial base related to natural resources extractions and production of agricultural goods (e.g., rice, vegetables, honey, etc.). However, being a coastal city,

Khulna is highly susceptible to climate-induced hazards such as extreme cyclones, tidal surges, severe floods, excessive rainfall, and high salinity intrusion [33,42]. The distinct geographic location of this city is considered to be more vulnerable to climate change and less resilient to extreme weather events. Additionally, the city has been receiving an influx of climate migrants after experiencing severe climatic events in the recent past at a frequent interval [42]. As a result, Khulna suffers the pressure on the



sustainability indices to ensure the well-being of the city dwellers in the face of climate change.

Figure 1. Map demonstrates the location of the study area, generated by the authors using the data provided freely by the GIS unit of the Local Government and Engineering Department (LGED) of the Government of Bangladesh (2021).

2.2 Indicator Selection Using PRISMA Method

We have used the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to review the most relevant literature for selecting appropriate resilience indicators. Therefore, five electronic databases were searched on 20 October 2021, which were updated on 11 November 2021 (see [Figure 2](#)) to identify suitable research articles for meta-analysis. Any restrictions regarding location, the scale of the study, data collection, and publication date are not imposed to increase the probability of obtaining the most relevant studies. Identification, screening, eligibility, and inclusion are the four steps used in the PRISMA methodology [43], and for this study, these four steps are explained below:

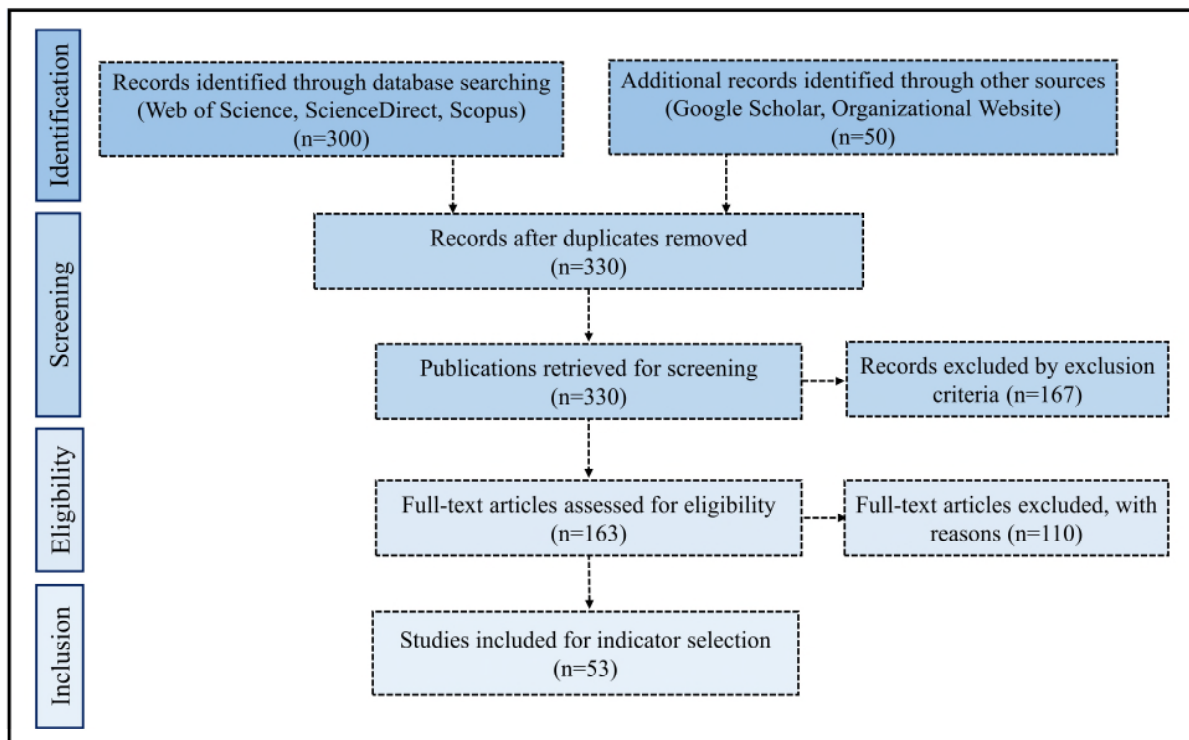


Figure 2. PRISMA flow diagram for choosing research articles for indicator selection.

Step 01- Identification Stage: To identify the potential articles for indicator selection, the key search strategy included the terms "Resilience" or "Resilience Assessment" or "Index" and "Natural Hazards" or "Disaster" or "Climate Change" in the title, abstract, and keywords. A total of 350 full-text articles are selected at the identification stage.

Step 02- Screening Stage: In this stage, duplications are removed from initially selected articles by screening the title and abstracts, which are further narrowed down through the inclusion and exclusion criteria represented in [Table 1](#). After excluding

167 articles according to the requirements, 163 papers are finally selected for the eligibility test.

Step 03- Eligibility Stage: All of the 163 articles are further checked based-on additional exclusion and inclusion criteria (see [Table 1](#)) to be included in the review analysis. Consequently, 53 articles have passed the eligibility criteria.

Step 04- Inclusion Stage: In this stage, the full texts of all the 53 articles are reviewed for selecting resilience indicators.

Table 1. Inclusion and exclusion criteria for screening and eligibility checking of research articles in the PRISMA method.

Steps of PRISMA	Inclusion	Exclusion
Screening	<ul style="list-style-type: none"> ✓ English research articles. ✓ Studies focused on resilience assessment to natural hazards/disasters/climate change. ✓ Studies focusing on adaptation, resilience, or vulnerability discourses. 	<ul style="list-style-type: none"> ✓ Research articles published in languages other than English. ✓ Studies focused on other disciplines except for climate change, disaster, and social science. ✓ Studies concentrate on other issues rather than adaptation, resilience, or vulnerability.
Eligibility Check	<ul style="list-style-type: none"> ✓ Studies using dimensions/indicators to analyze resilience. ✓ Studies explaining the link/nexus between more than one of the following: <ul style="list-style-type: none"> • Resilience • Disaster • Climate change 	<ul style="list-style-type: none"> ✓ Studies without any discussion revolving around resilience dimensions or indicators. ✓ Studies explaining the discrete understanding of resilience, disaster, and climate change.

The review has identified a total of 36 major components and 164 indicators for resilience assessment. However, major components and indicators are filtered based on their citation frequency to make them manageable. Finally, highly cited five major components and 48 indicators are selected to construct the resilience index for this study (see [Appendix A](#)).

2.3 Data Collection

This research is framed to unpack the resilience dynamics at the community level, which requires data that provide a critical lens to analyze the relationship between the concepts. Therefore, several steps are considered to collect appropriate data from the target audience.

2.3.1 Structured Questionnaire Survey

Content analysis of the selected literatures are performed for the selection of the resilience indicators. After that, a structured questionnaire survey is conducted to collect the data for those indicators from each community to assess their resilience. The questionnaire includes both close and open-ended questions to collect primary data from 31 communities/Wards in Khulna City. Then the questionnaire is tested in the field, and necessary corrections and modifications are made to make it more accurate. Later, the required number of samples is allocated, and a final survey is conducted in all the communities considered for this study.

2.3.2 Sample Size and Sampling Technique

Taro Yamane's sampling formula is used in this research to determine the sample size. According to the formula [44]:

$$n = \frac{N}{1 + N \cdot e^2}$$

Where 'n' is the sample size, 'N' is the total number of households in Khulna City, e is the error margin of 0.035 (3.5%), and '1' is the occurrence probability of the event. Finally, the formula provided a total sample size of 815. However, some of the inferential statistics require at least a sample size of 30 to be performed. Therefore, this research has collected 930 samples for an equal distribution of 30 samples in 31 communities to draw inter-community inferences from the collected data. The samples are collected following the random sampling techniques in each community. The locations of the sample data collection are shown in [Figure 3](#).

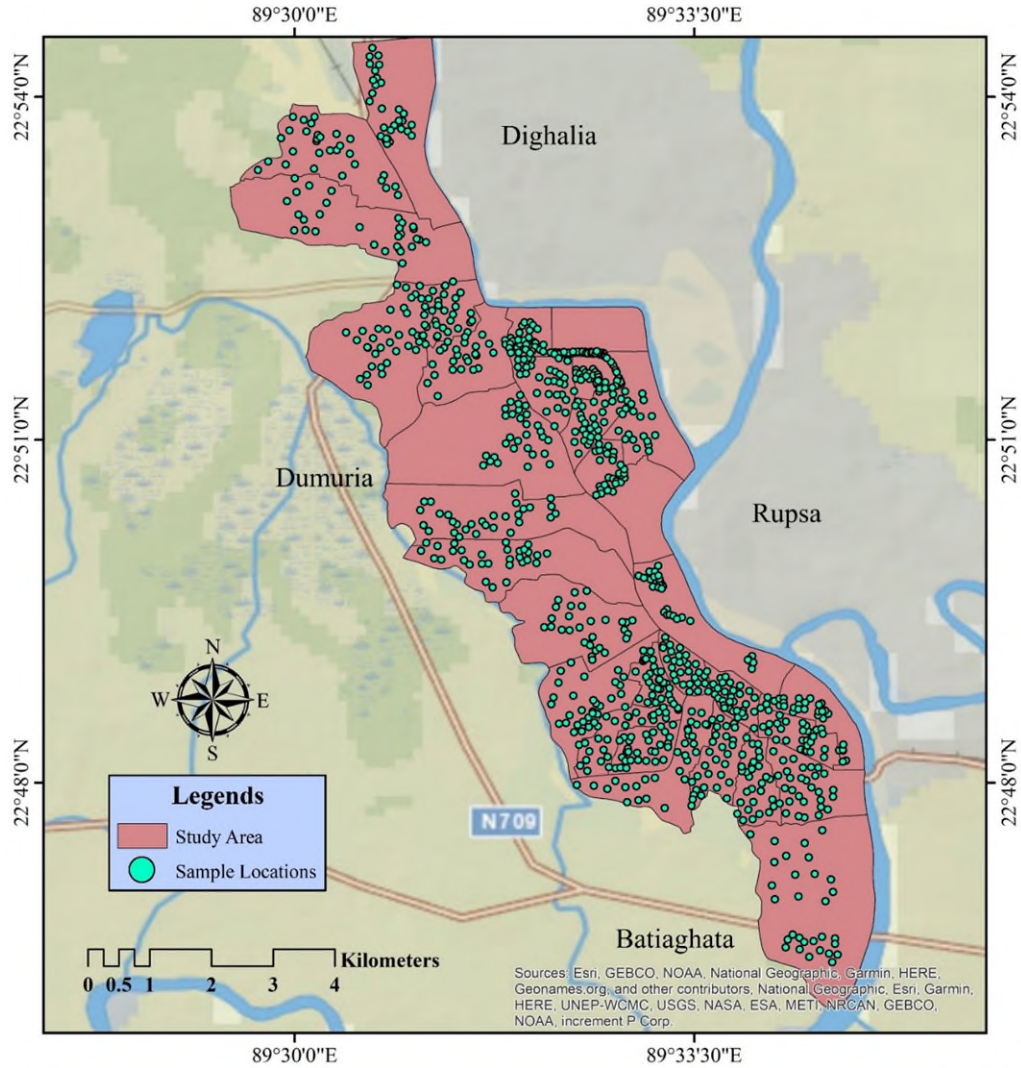


Figure 3. Locations of the samples considered in this study for primary data collection.

2.3.3 Secondary Data Collection

We have gathered secondary data from varied reputable sources (i.e., Bangladesh Bureau of Statistics (BBS), Khulna Development Authority (KDA), Khulna City Corporation (KCC)). Several published documents are only accessible in Bengali and required to be translated into the English language. For instance, local government materials outlining adaptation plans and essential procedures are published as pamphlets, flyers, and brief essays. These papers are only accessible to readers who speak the native language (i.e., Bengali). In addition, information is also gathered from census data, worldwide peer-reviewed journal articles, newspapers, and published university theses.

2.3.4 Spatial Data Collection

We have collected necessary spatial data from the United States Geological Survey (USGS), Khulna Development Authority (KDA), Local Government Engineering Department (LGED), and published scientific articles to gather required information and prepared essential maps. Also, we have altered some maps to meet our needs and projected them into the WGS84 system so that they accurately reflect the study area. Moreover, we double-checked the authenticity of the GIS data sets from several sources (e.g., Google Earth, Open Street Map, SafeGraph) to ensure reliability.

2.4 Data Analysis

The data analysis technique incorporates quantitative and spatial analysis to generate results. The preferred methods used for data analysis in this research are described below.

2.4.1 Overview of the Analytical Approach

The analytical approach ([Figure 4](#)) provides an overview of the activities performed to assess and map each component of community resilience. Firstly, based on the literature review, 48 indicators (see [Appendix A](#) for details) are selected under five major components to evaluate the resilience of the communities. Secondly, the AHP method has generated weight for each indicator and major component using the expert's opinion. After that, the generated weights are integrated with the indexing method to construct the value of community resilience. Later, the value of the resilience of each community is joined with their corresponding spatial data layer to create necessary maps. The created maps are classified into five classes, namely very low, low, moderate, high, and very high using the equal interval classification method of ArcGIS 10.4 to generate important spatial statistics. Equal interval is a popular method used by many scholars to classify the spatial data [45–49].

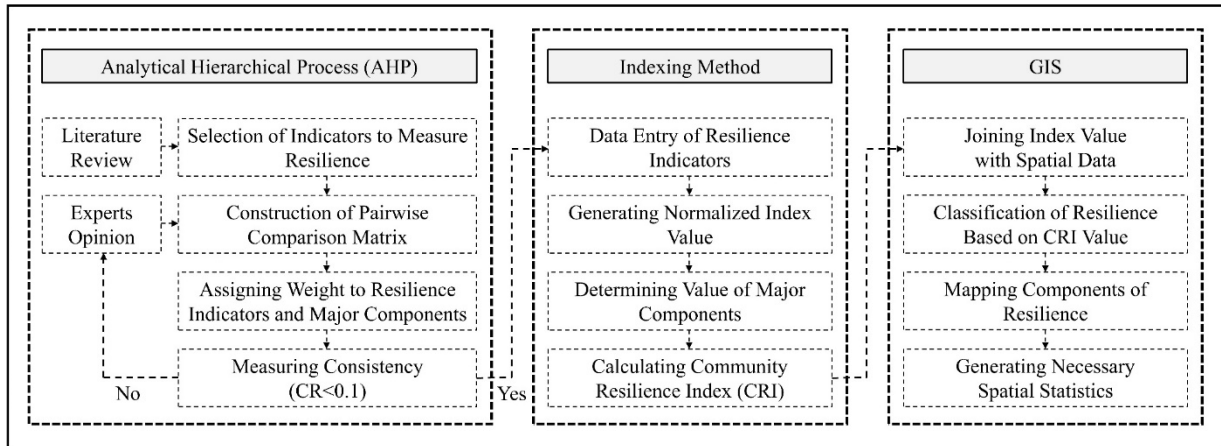


Figure 4. Analytical approach followed in this study to assess community resilience.

2.4.2 Analytical Hierarchical Process

Saaty (1980) created Analytical Hierarchical Process (AHP) as a strong technique for making decisions among various indicators using pair-wise comparisons of measurements based on expert opinion [50]. This research included local resilience specialists as an expert for the AHP, which incorporates resilience specialists from Khulna Development Authority (KDA), Khulna City Corporation (KCC), Khulna University (KU), Khulna University of Engineering and Technology (KUET), and Bangladesh Rural Advancement Committee (BRAC). AHP considers both qualitative and quantitative components of choice and assign weight¹ to each indicator.

To provide the weight, AHP follows three basic steps. The first step is to create a comparison matrix based on expert opinion on a scale of 1 to 9. One signifies two parameters are equally essential, whereas nine indicates that one parameter is highly important than the other. Table 2 shows the scale of importance defined by Saaty (1980) [50].

¹AHP assign the weight of each indicator based on expert opinions. For example, there are two resilience indicators, A and B. Now, a questionnaire is prepared and sent to the local resilience experts to give importance on a scale of 1 to 9 to these criteria. For instance, based on average value of the importance provided by the experts, criteria A is 3 times more important for community resilience than criteria B. So, in such case, criteria A will get 3 times more weight (75%) than criteria B (25%). This is a generic example of AHP, and it gets complicated when the number of criteria is increased.

Table 2. The magnitude of importance for pair-wise comparison.

Intensity of Importance	Definition
1	Equal importance
2	Weak or slight
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong or demonstrated importance
8	Very, very strong
9	Extreme importance
Reciprocals	If criteria x is assigned with any of the above values compared to y , then y has the reciprocal value of x .

In step two, all the values of each column of the pair-wise comparison matrix are summed, and then each value of a column is divided by their respective column sum to generate a normalized matrix.

In the third step, the consistency of the judgments is analyzed using [equations 1 and 2](#). A consistency ratio (CR) higher than 0.1 indicates the unreliability of the results. Therefore, reiterating the pair-wise comparison is required.

$$\text{Consistency Index, } CI = \frac{L - n}{n - 1} \quad \dots\dots\dots (1)$$

$$\text{Consistency Ratio, } CR = \frac{CI}{RI} \quad \dots\dots\dots (2)$$

Where L represents the largest eigenvalue of the matrix, n is the dimension of the matrix, and RI denotes the random index. The value of RI depends on the number of indicators considered in the AHP model (see [Table 3](#)).

Table 3. Random index values for the corresponding number of indicators (Golden and Wang, 1989).

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.52	1.54	1.56	1.57	1.59

The AHP-derived weights of the resilience major components and indicators are presented in [Appendix A](#). Moreover, all the AHP models show sufficient consistency by fulfilling the requirement of a CR value less than 0.1.

2.4.3 Community Resilience Index

The indexing method is based on 48 indicators under five major components for developing the 'Community Resilience Index (CRI)'. The method has used AHP-derived weights. At the initial indexing stage, all the indicators are normalized to make them comparable, as indicators are in different units or scales. There are two possible types of functional relationships to normalize the data. If the resilience increases with the indicator's value, there is a positive functional relationship. Alternatively, a negative functional relationship is established if resilience decreases with an increase of the indicator's value. The third equation (see Equation 3) is used for normalizing the indicators with a positive functional relationship, and the fourth equation (see Equation 4) is used for normalizing the indicators with a negative functional relationship. It ensures that the higher index value means high resilience and vice versa.

$$Index_{N_s} = \frac{X_s - X_{min}}{X_{max} - X_{min}} \dots \dots \dots (3)$$

$$Index_{N_s} = \frac{X_{max} - X_s}{X_{max} - X_{min}} \dots \dots \dots (4)$$

Where $Index_{N_s}$ is the normalized index value, X_s is the original value of the indicator for a Ward (i.e., local level administrative unit) S , X_{max} and X_{min} are the maximum and minimum values of the indicator at the Ward level. After normalization, equation 5 is used to obtain the value of the major components for each individual Ward.

$$M_s = \sum_{i=1}^n Index_{N_s^i} \times W_{N_s^i} \dots \dots \dots (5)$$

In the above equation, M_s is the value of one of the major components for Ward S , n is the number of indicators under the major component, $Index_{N_s^i}$ is the normalized value of the i th indicator for Ward S , and $W_{N_s^i}$ is the weight of the i th indicator determined from the AHP.

Once values for each of the major components of all the Wards are calculated, equation 6 is used to obtain the CRI value for each Ward.

$$CRI_s = \sum_{i=1}^m M_{S^i} \times W_{M^i} \dots \dots \dots (6)$$

In the above equation, CRI_s is the Community Resilience Index (CRI) for Ward S , m is the number of major components, and M_{si} is the value of the i th major component for Ward S . Then, W_{Mi} is the weight of the i th major component, which is determined by the AHP model.

2.4.4 Categorization of the Index Value

To categorize the index value of the major components and CRI, two major steps are followed: (1) the outliers are removed (2) index values are normalized using [equation 7](#) to bring them on the scale from 0 to 1.

$$N = \frac{X - \min}{\max - \min} \dots \dots \dots (7)$$

Where N is the normalized score of a community; $\min$ and $\max$ is the minimum and maximum index value among the communities, and X is the actual index value of the community. Afterward, the index value is classified into five classes (i.e., very-low, low, moderate, high, and very high) using the equal interval method.

3. Results

The results of this research are summarized in three main parts. Firstly, it provides an in-depth assessment of community resilience in Khulna City. Secondly, it analyzes the dynamic nature of resilience at the community level; and finally, it identifies the major shortcomings of community resilience in Khulna City.

3.1 Community Resilience Index: In-depth Assessment

3.1.1 Physical resilience

The generated physical resilience index demonstrates that 38.71% of communities (see [Table 4](#)) in the study area are registered in the high to a very high physical resilience class. These communities include Ward No. 5, 10, 11, 12, 16, 19, 20, 22, 23, 27, 28, and 29 (see [Figure 7a](#)). The main contributing factors of high to a very high physical resilience in these communities are high access to water, electricity, sanitation, drainage, housing, health care, waste management, and communication facilities. The moderate physical resilience class registers 38.71% of the communities and includes Ward No. 2, 6, 7, 8, 9, 13, 14, 15, 17, 24, 25, and 30. The high index value of some indicators like access to water, electricity, sanitation, and healthcare are major reasons

for the communities to register in the moderate physical resilience class, whereas the values for other indicators are very low. Moreover, the very low to low physical resilience class includes Ward No. 1, 3, 4, 18, 21, 26, 31, and accounts for 22.59% of the communities. These communities (i.e., low and very low) have reported very low physical resilience value for all the indicators except sanitation facility.

3.1.2 Social resilience

Social resilience among the communities in the study area is analyzed based on thirteen indicators. The index value of social resilience shows that 32.26% of communities (see [Table 4](#)) in the study area are registered in the low to very low social resilience class. The primary reason for lower social resilience in these communities are poor performance in most indicators, i.e., literacy, social safety nets, gender equity, vulnerable population, population density, disaster risk reduction (DRR) training, and place attachment. The communities registered in the low to very low social resilience class are Ward No. 6, 7, 12, 18, 19, 20, 21, 26, 27, and 31 (see [Figure 7b](#)). Moreover, the moderate social resilience class covers 38.71% of communities in the study area, whereas the high to very high social resilience class accounts for 29.04%. The moderate social resilience class includes Ward No. 1, 2, 5, 10, 11, 13, 17, 22, 23, 24, 28, 30, and the high to very high social resilience class includes Ward No. 3, 4, 8, 9, 14, 15, 16, 25, and 29. The major contributing factors for the moderate social resilience class are, i.e., low population density, higher access to social safety nets, previous disaster experience, small household size, disaster awareness, high literacy level, DRR training, and NGO participation. Furthermore, the high to very high social resilience communities have performed very well in all indicators except disaster training and household size.

3.1.3 Environmental resilience

The results of the environmental resilience index reveal that 12.9% of communities in the study area are registered in the very high environmental resilience class, while 22.58% registered in the high environmental resilience class (see [Table 4](#)). The intersection of high-performing indicators (i.e., natural drainage, rooftop gardening, open space, ecological awareness, low flood risk, and low cyclone exposure) contributes to higher resilience in these communities. Moreover, the very high

environmental resilience communities include Ward No. 3, 4, 9, 14, and high environmental resilience communities include Ward No. 1, 2, 6, 7, 8, 11, and 16 (see [Figure 7c](#)). The moderate environmental resilience class registers 19.36% of the communities and comprises Ward No. 5, 10, 12, 15, 23, and 27. The moderate environmental resilience class of communities is mainly due to the high index value of some indicators like ecological awareness, rooftop gardening, low flood risk, and low cyclone exposure, which have counterbalanced the lower values of other indicators. Furthermore, the low to very low environmental resilience class performs poorly in all indicators, including fourteen Wards and 45.17% of the communities.

3.1.4 Institutional resilience

The developed institutional resilience index indicates that 51.61% of the communities (see [Table 4](#)) in the research region are classified as having a high to a very high level of institutional resilience. These communities include sixteen wards. The higher index values of all the indicators are the major contributor to these communities' high to very high levels of institutional resilience. The moderate institutional resilience class covers Wards 6, 8, 9, 10, 12, 15, 31 (see [Figure 7d](#)) and accounts for 22.58 percent of all communities. Some variables, such as trust in public officials, rapid circulation of disaster information, effective leaders, and high election participation, have contributed significantly to the communities' inclusion in the moderate institutional resilience class. In addition, the very low to low institutional resilience class is comprised of Wards 7, 11, 18, 19, 21, 24, 26, and 30, which represent 25.8% of the communities and shows poor institutional resilience score in all indicators.

3.1.5 Economic resilience

Ten indicators are used to assess economic resilience among the communities in the study area. According to the generated index, 41.93 percent of communities (see [Table 4](#)) fall into the low to very low economic resilience category. Poor performance in most metrics, such as savings, amount of assets, livelihood diversity, homeownership, risky occupation, and seasonality effect, are the key foundations for reduced economic resilience in these areas. A total of thirteen Wards are registered in this low to very low economic resilience category. Moreover, the moderate economic resilience class encompasses 25.81 percent of the communities, while the high to very high economic

resilience class comprises 32.26 percent. The moderate economic resilience class includes Ward No. 2, 10, 11, 16, 25, 26, 28, 29, and the high to very high economic resilience class includes Ward No. 1, 3, 4, 9, 15, 17, 23, 27, 30, and 31 (see [Figure 7e](#)). In the moderate economic resilience class, higher scores of livelihood diversity, access to credit, service and industry employment, economic assistance, and low seasonality effect counterbalance the lower value of other indicators. Furthermore, the high to very high economic resilience communities have performed very well in all indicators except access to credit and economic assistance.

3.1.6 Community Resilience Index (CRI)

The CRI map ([Figure 7f](#)) portrays that relatively high resilience is evident in the northwestern, middle, and upper northern parts of the study area. The area mainly includes Ward No. 1, 2, 3, 4, 5, 8, 9, 10, 11, 12, 14, 15, 16, and 17. The index value indicates that high to very high resilience covers 58.07% of communities (see [Table 4](#)) in the area. The high level of resilience in these areas is due to the convergence of the high value of the major components (see [Figures 5](#), and [6](#)). In addition, 16.13% of the communities are registered in the moderate resilience class, followed by 25.81% as a very low to low resilience class. These three categories cover most of the southern part of the area. Specifically, the moderate resilience class includes Ward No. 13, 20, 22, 28, 30, and the low to very low resilience class includes Ward No. 6, 7, 18, 19, 21, 24, 26, and 31. The main reason for low resilience in these areas is comparatively low index value, especially in economic, social, and environmental components.

Table 4. Percentage of Wards registered into different resilience classes based on major components and CRI value.

Class	Physical Resilience	Social Resilience	Environmental Resilience	Institutional Resilience	Economic Resilience	CRI
Very low	19.36%	6.45%	19.36%	12.9%	12.9%	19.36%
Low	3.23%	25.81%	25.81%	12.9%	29.03%	6.45%
Moderate	38.71%	38.71%	19.36%	22.58%	25.81%	16.13%
High	25.81%	19.36%	22.58%	35.48%	19.36%	25.81%
Very high	12.9%	9.68%	12.9%	16.13%	12.9%	32.26%

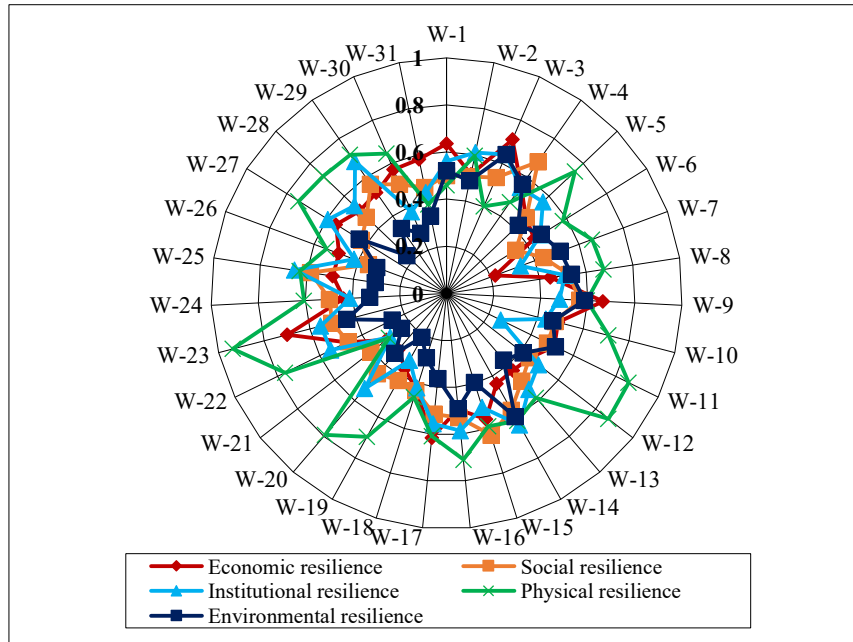


Figure 5. Spider diagram of major component's value of communities in Khulna City.

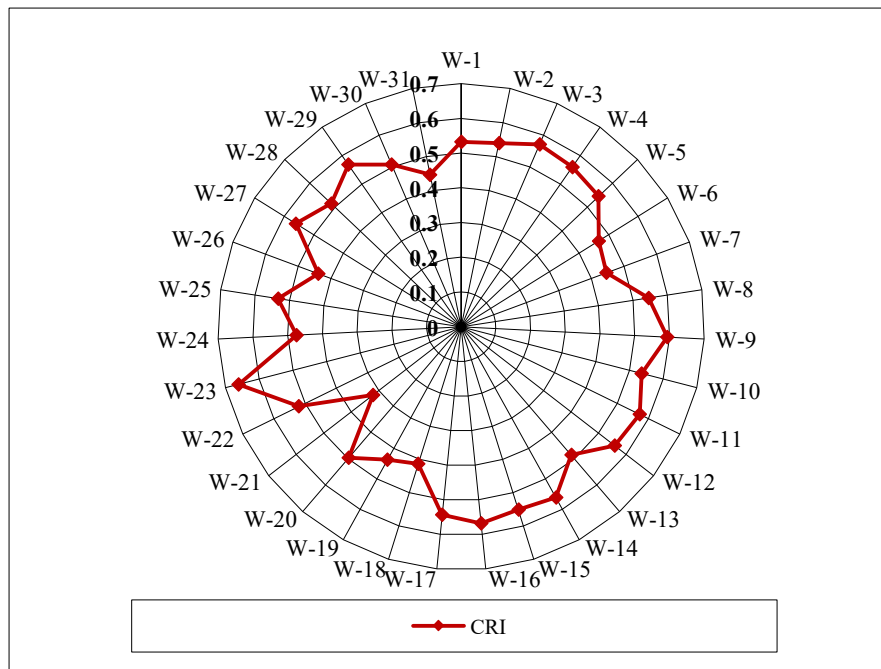


Figure 6. Spider diagram of CRI values obtained for communities in Khulna City

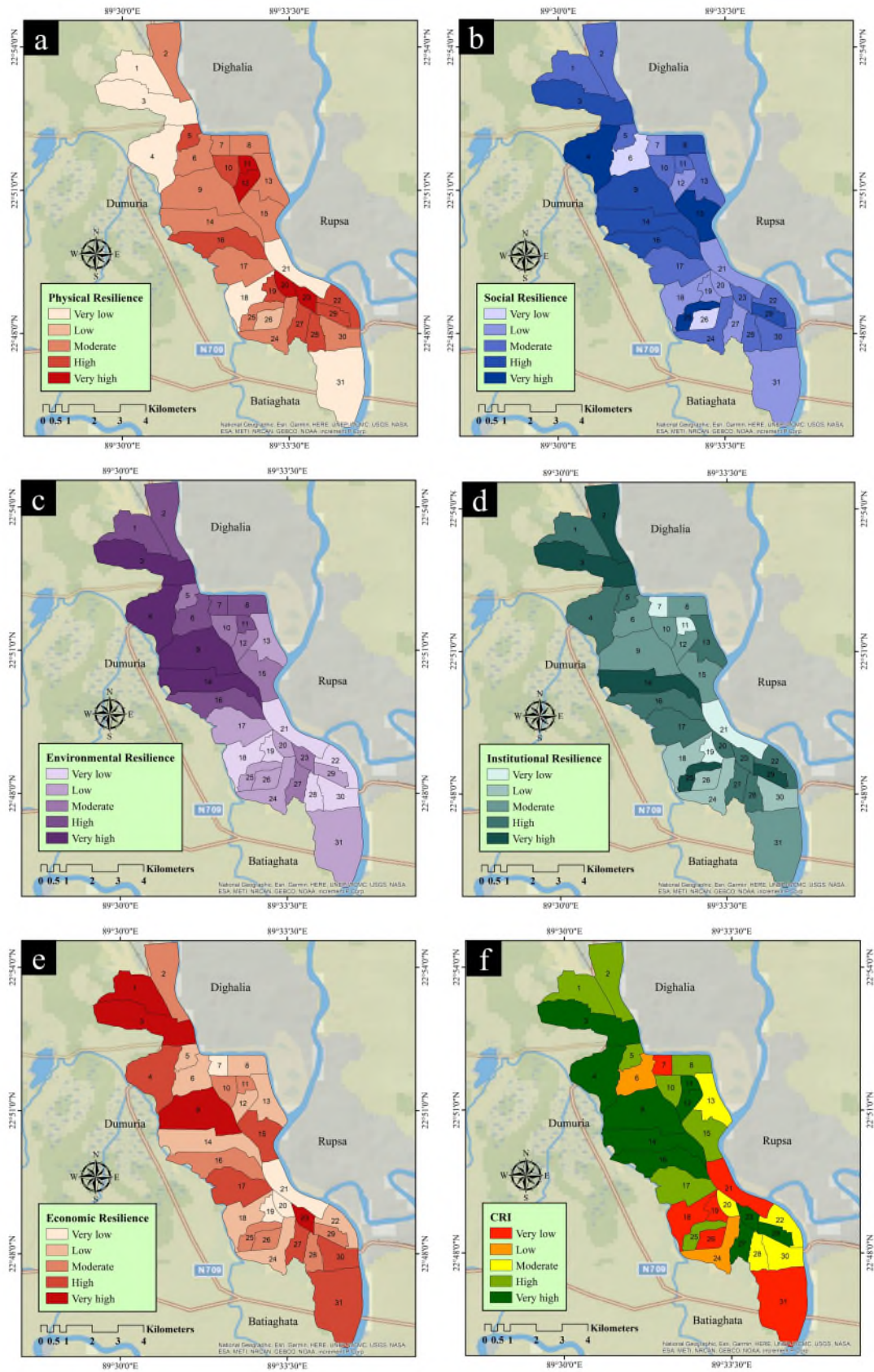


Figure 7. Major components specific resilience and composite resilience maps: (a) physical resilience; (b) social resilience; (c) environmental resilience; (d) institutional resilience; (e) economic resilience; and (f) community resilience index (CRI).

3.2 Dynamic Nature of Community Resilience

The contribution of different major components is not evenly distributed among the communities. According to [Figure 8](#), major components like physical resilience and institutional resilience substantially contribute to most communities' resilience in Khulna City. In contrast, economic and social resilience have a moderate; and environmental resilience has a low contribution to the resilience at the community level. However, the major contributing factors of resilience also vary from community to community. The major components that have a greater contribution to a community's resilience can also have less contribution to the resilience of another community. For example, in Ward No. 1, all the major components have contributed almost equally to the resilience of the community, whereas in Ward No. 7, major components like physical resilience, social resilience, and environmental resilience have a higher contribution than others. This is a common dynamic that is found in almost all communities in Khulna City. Furthermore, the contribution of major components varies significantly among different resilience classes ([Table 5](#)). Similarly, the dynamics are also real at the indicator level of the major components, where the contribution of indicators also varies among the communities. Therefore, authorities need to focus on building resilience by increasing the share of lowly contributing factors. They also need to consider these heterogeneous resilience characteristics among communities and resilience groups to produce the optimum result.

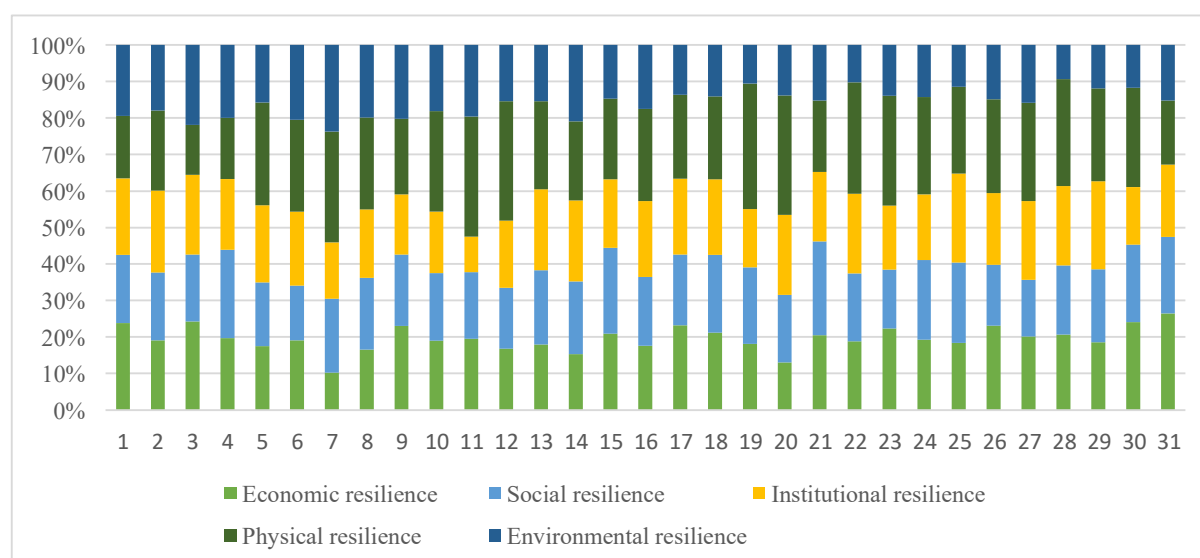
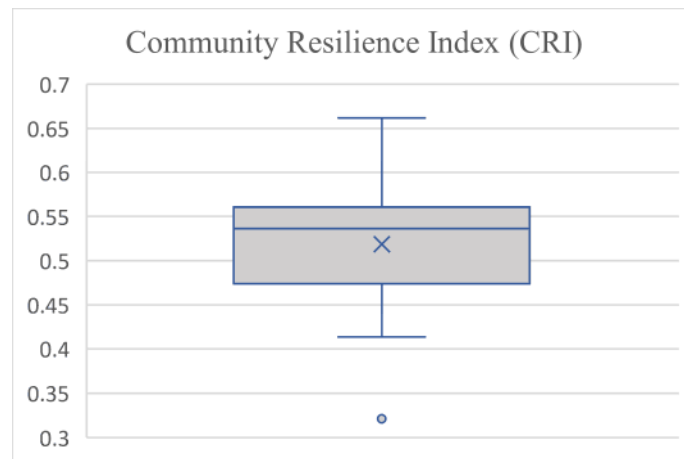


Figure 8. Contribution of major components to the composite resilience of 31 Wards of Khulna City.

Table 5. Mean value of major components among different resilience classes.

Major Components	CRI Class					F-Statistics	P-Value
	Very High	High	Moderate	Low	Very Low		
Economic	0.559	0.527	0.46	0.438	0.401	F (4, 26) = 3.11	0.032*
Social	0.529	0.526	0.475	0.422	0.419	F (4, 26) = 4.83	0.005**
Institutional	0.547	0.549	0.507	0.44	0.372	F (4, 26) = 4.71	0.005**
Physical	0.692	0.628	0.701	0.593	0.509	F (4, 26) = 2.12	0.107
Environmental	0.502	0.437	0.295	0.4	0.318	F (4, 26) = 6.41	0.001***

Moreover, the box plot (Figure 9) illustrates the distribution of the Community Resilience Index in Khulna City, with quartile values of 0.474 (Q1), 0.536 (Q2), 0.560 (Q3), and an outlier at 0.321. The median resilience index (Q2) is 0.536, representing the central tendency, while the interquartile range (IQR) spans from 0.474 to 0.560, encapsulating the middle 50% of the data. An outlier is observed at 0.321, deviating significantly from the bulk of the data. This outlier suggests a community (Ward no 21) with an unusually low resilience index, due to very poor performance in most of the resilience measuring indicators. Ward no 21 is a community with highest level of seasonality effects, high involvement in risky occupation, low amount of savings, limited access to water, low ecological awareness, limited access to insurance, lack of literacy, and having limited skills, which make them very low resilience to the effect of climate change. However, none of the community is found outliers in terms of high resilience score.

**Figure 9.** Box plot of community resilience index (CRI) in Khulna City.

3.3 Major Limitations of Resilience in Khulna City

The major low-performing indicators of resilience in Khulna City are presented in [Figure 10](#). On a normalized scale of 0 to 1, indicators with a value of less than 0.5 are registered in this category. It shows that Khulna City performs very poorly in 23 indicators such as vegetation coverage, natural drainage area, DRR training, open space, vulnerable population, asset value, accessibility during heavy rain, household size, female employment, drainage facilities, affordable insurance, etc. It includes indicators from all types of major components of resilience. These 23 indicators can be noted as the first priority action area for Khulna City. Moreover, in [Figure 9](#), the lower the value of an indicator, the higher the priority for action.

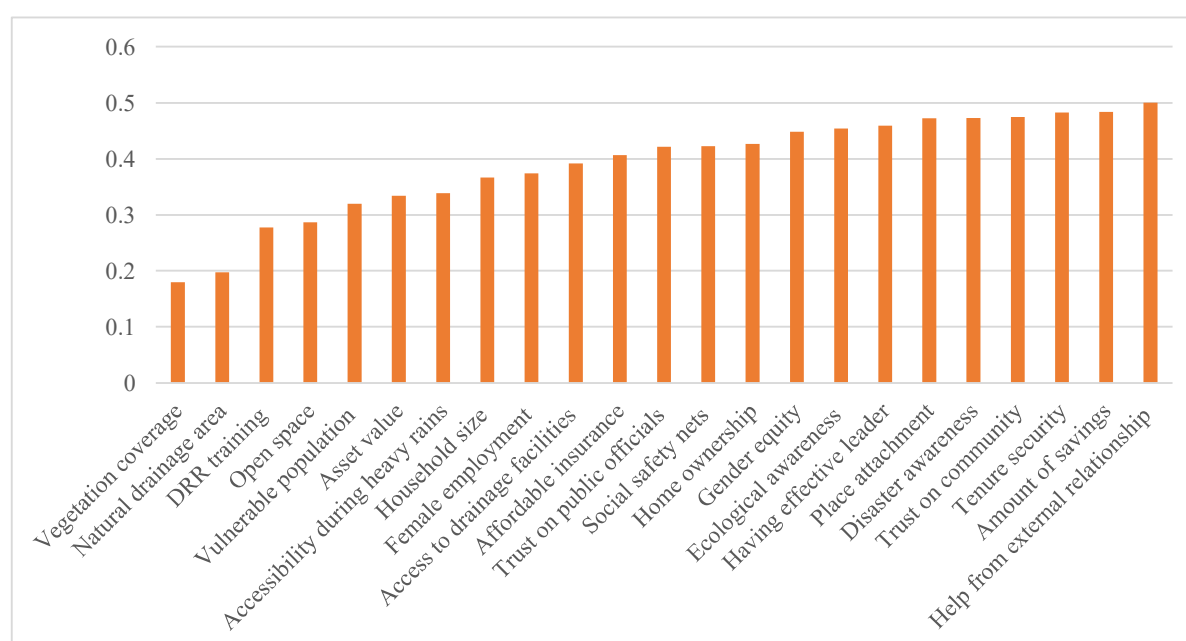


Figure 10. Major low-performing indicators of resilience in Khulna City.

4. Discussion

Building city resilience has evolved as a valid strategy to handle crises and shift risk management from a siloed approach to a holistic approach for securing cities' long-term sustainability. Thus, several techniques and theoretical frameworks based on indicators and metrics have been suggested throughout the last decade. However, decision-makers have urged more practical tools that may enhance the process of creating resilience into practice rather than a theoretical accomplishment. In doing so,

this research has operationalized an indexing and AHP-based pragmatic approach to assess and map the resilience and considered the Khulna City of Bangladesh as the case study. The results highlight that 25.81% Wards of the study area are registered in the very low to low resilience class. Besides, the moderate resilience class covers 16.13% Wards of the study area, whereas the high to very high resilience class accounts for 58.07%. Moreover, the higher resilience in the study area is mainly led by the intersection of the indicators with a high index value and vice versa.

Additionally, this research has explored the complex interplay between resilience factors among the communities of Khulna in Bangladesh. It has demonstrated that the dynamics are real, and each community has its unique resilience properties. For example, some communities are highly resilient in terms of their physical, social and environmental components; however, they are inadequately resilient or vulnerable to the economic and institutional components and vice versa. The dynamics are also evident at the indicator level of each major component. The contribution of each indicator to the overall resilience of a major component varies among the communities. The indicator that has a stronger contribution to a community's resilience can also have a lower contribution to other communities. So, vulnerability and resilience can co-exist and communities experiencing similar exposure to a climatic extreme can have differential level of vulnerability and resilience over time. The theoretical importance of this finding lies in recognizing that resilience is a multidimensional concept and cannot be understood or improved upon with a one-size-fits-all approach. Understanding the specific resilience characteristics of each community allows authorities to tailor interventions and policies to address the unique needs and challenges faced by each community.

Therefore, any type of strategic action or policy implication requires considering these unique characteristics at the community level. Consequently, this study indicates a "Pareto-optimal" condition, which refers to a solution that may provide maximum production for all resilience-building initiatives. Due to the fact that indicators and major components have varying degrees of influence in different localities, community-specific planning will allow us to work with the appropriate influential factors to produce optimal resilience strategies. Also, it will assist us in reaching a state of "Pareto-optimal" response to disaster and climate change. For this, to aid the decision-making process, this research has listed the priority-based action areas of all

the communities (see [Appendix B](#)). Moreover, the findings highlight some major resilience-building action areas for Khulna City, which are as follows:

- (1) Increase vegetation coverage, open space, and natural drainage area.
- (2) Building capacities for resilience strategies among the vulnerable populations.
- (3) Increase financial intelligence for asset building at the household level.
- (4) Improve drainage facilities and accessibility during intense rainfall.
- (5) Guide the population growth with increased access of women in employment.
- (6) Enhance access to insurance and social safety nets.
- (7) Ensure accountability of public officials and elected leaders.
- (8) Increase community awareness programs about the environment, disasters, and climate change.
- (9) Ensure gender equity, tenure security, and homeownership.
- (10) Intensify horizontal and vertical linkage among the communities.
- (11) Increase savings and rapport building with neighbors and relatives.

Furthermore, in resilience assessment and mapping, multiple challenges are encountered in collecting up-to-date and high-quality datasets. For example, this research has used remote sensing data like satellite images from Landsat 8, which may have a moderate spatial and temporal resolution. Also, land use, drainage, healthcare facilities, and road network data are collected from the Khulna Development Authority (KDA), which is not updated at a regular interval. Thus, there is a chance of missing any new installation (i.e., residence buildings, infrastructure, commercial establishments, etc.), which may influence the overall results of this study. Additionally, the data for some indicators are collected from the current population and housing census of 2011. Note that, the next census data of 2021 may be available by the end of 2023, and thus, we have had to rely on the 2011 dataset. Despite having some limitations, this research is helpful in formulating resilience enhancement plan, master plan, detailed area plan, livelihood sustainability plan, and climate adaptation and mitigation plan in Khulna City, Bangladesh. Furthermore, we are highly encouraging researchers and practitioners to look for reliable sources of similar datasets before employing the method in their own geographic jurisdiction.

5. Concluding Remarks

The central goal of this study was to assess and map the resilience of communities in Khulna City, Bangladesh, based on a comprehensive and scientific methodological approach. In doing so, three major steps are performed: (i) selection of the major components and indicators based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-analyses) method; (ii) assimilation of state of the art in resilience assessment approaches and methods to develop a robust resilience assessment model; and (iii) integration of five key components of resilience (i.e., social, economic, physical, institutional, and environmental) in our generated model to examine resilience using geospatial, Indexing, and AHP techniques. The generated resilience map shows that higher resilience is evident in the northwestern, middle, and upper northern parts of the study area, whereas comparatively lower resilience is apparent in the southern part. Moreover, in Khulna City, there is no existence of individual resilience scales for the communities to identify the required actions when necessary. The findings of this research would be instrumental in providing the information readily to disaster managers, planners, and administrators. It would also be crucial for policymakers to complement disaster risk reduction strategies by perceiving the level and extent of resilience among the communities. It might also contribute to formulate a holistic resilience framework by considering appropriate adaptive measures in the zones with a lower level of resilience.

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Data Availability Statement: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Indicators to measure community resilience in Khulna City and their AHP-derived weights.

Major Components	Indicators	Unit of Measurement	FR ²	Major Components Weight	Indicators Weight
Economic Resilience (10)	Livelihood diversity	Count	+	0.248	0.203
	Homeownership	Percent	+		0.197
	Asset value	Taka	+		0.165
	Amount of savings	Taka	+		0.118
	Service and industry employment	Percent	+		0.081
	Female employment	Percent	+		0.065
	Economic assistance (i.e., pensions, remittances)	Percent	+		0.061
	Access to credit	Percent	+		0.053
	Effects of seasonality	Percent	-		0.035
	Engagement in hazardous and risky activities	Percent	-		0.022
Social Resilience (13)	Literacy rate	Percent	+	0.217	0.205
	Population density	Person/sq.km	-		0.176
	Access to social safety nets	Percent	+		0.129
	Vulnerable population (i.e., children, old, disabled)	Percent	-		0.108
	Trust on community	Likert Scale	+		0.092
	Gender equity	Likert Scale	+		0.069
	Participating with NGOs	Percent	+		0.055
	Previous disaster experience	Percent	+		0.046
	Disaster awareness	Likert Scale	+		0.04
	Help from the external relationship (neighbors, friends, and relatives)	Likert Scale	+		0.027
	Place attachment	Percent	+		0.022
	Attend climate change and DRR training programs	Percent	+		0.018

² FR refers to the functional relationship (positive/negative) of indicators with community resilience.

	Household size	Person/HH	-		0.013
Institutional Resilience (07)	Maintaining building codes and standards	Likert Scale	+	0.1	0.235
	Tenure security	Percent	+		0.219
	Trust on public officials	Likert Scale	+		0.158
	Having effective leader	Likert Scale	+		0.184
	Access to affordable insurance	Percent	+		0.103
	Circulation of disaster information	Likert Scale	+		0.059
	Election participation	Percent	+		0.042
Physical Resilience (11)	Katcha housing structure	Percent	-	0.268	0.227
	Distance from healthcare facilities	Kilometer	-		0.179
	Access to piped water	Percent	+		0.125
	Access to electricity	Percent	+		0.124
	Using non-sanitary toilet	Percent	-		0.087
	Access to drainage facilities	Length/Sq.km	+		0.058
	Access to solid waste management	Likert Scale	+		0.079
	Distance from fire stations	Kilometer	-		0.043
	Access road to evacuate during an emergency	Length/Sq.km	+		0.027
	Accessibility during heavy rains	Likert Scale	+		0.033
	Access to internet	Percent	+		0.018
Environmental Resilience (07)	Exposure to cyclone	Index value	-	0.167	0.227
	Exposure to flood	Index value	-		0.201
	Ecological awareness	Likert Scale	+		0.181
	Natural drainage area	Sq.km	+		0.156
	Vegetation coverage	Sq.km	+		0.121
	Open space	Sq.km	+		0.071
	Rooftop gardening	Percent	+		0.043

Appendix B

Table A2. Priority-based action areas according to major components.

Ward No.	Physical	Social	Economic	Environmental	Institutional
Ward -01	1	2	5	3	4
Ward -02	4	2	3	1	5
Ward -03	1	2	4	3	3
Ward -04	1	5	3	4	2
Ward -05	4	2	2	1	3
Ward -06	5	1	2	4	3
Ward -07	5	3	1	4	2
Ward -08	5	3	1	4	2
Ward -09	4	2	5	3	1
Ward -10	5	3	4	2	1
Ward -11	4	2	3	3	1
Ward -12	4	2	2	1	3
Ward -13	5	3	2	1	4
Ward -14	4	2	1	3	5
Ward -15	4	5	3	1	2
Ward -16	4	2	1	1	3
Ward -17	4	2	5	1	3
Ward -18	4	3	2	1	2
Ward -19	5	4	3	1	2
Ward -20	5	3	1	2	4
Ward -21	2	4	3	1	2
Ward -22	5	2	3	1	4
Ward -23	5	2	4	1	3
Ward -24	5	4	3	1	2
Ward -25	4	3	2	1	5
Ward -26	5	2	4	1	3
Ward -27	5	1	3	2	4
Ward -28	5	2	3	1	4
Ward -29	5	3	2	1	4
Ward -30	5	3	4	1	2
Ward -31	2	4	5	1	3

Note: Here, 1, 2, 3, 4, and 5 refer to the first, second, third, fourth, and fifth priority, respectively.

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AHP Questionnaire

(To mark an importance, just highlight the score e.g., 8)

Table 1: Please provide necessary weight for the major components of resilience.

Factor	Factor Weighting Score																	Factor
	More Importance Than								Equal	Less Importance Than								
Economic resilience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Social resilience
Economic resilience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Institutional resilience
Economic resilience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical resilience
Economic resilience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental resilience
Social resilience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Institutional resilience
Social resilience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical resilience
Social resilience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental resilience
Institutional resilience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Physical resilience
Institutional resilience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental resilience
Physical resilience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environmental resilience

Table 2: Please provide necessary weight for environmental resilience.

Factor	Factor Weighting Score																Factor	
	More Importance Than								Equal	Less Importance Than								
Exposure to cyclone	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Exposure to flood
Exposure to cyclone	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ecological awareness
Exposure to cyclone	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Natural drainage area
Exposure to cyclone	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Vegetation coverage
Exposure to cyclone	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Open space
Exposure to cyclone	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Rooftop gardening
Exposure to flood	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Ecological awareness
Exposure to flood	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Natural drainage area
Exposure to flood	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Vegetation coverage
Exposure to flood	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Open space
Exposure to flood	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Rooftop gardening
Ecological awareness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Natural drainage area
Ecological awareness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Vegetation coverage
Ecological awareness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Open space
Ecological awareness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Rooftop gardening
Natural drainage area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Vegetation coverage
Natural drainage area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Open space
Natural drainage area	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Rooftop gardening
Vegetation coverage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Open space
Vegetation coverage	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Rooftop gardening
Open space	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Rooftop gardening

Table 3: Please provide necessary weight for institutional resilience.

Factor	Factor Weighting Score																Factor	
	More Importance Than								Equal	Less Importance Than								
Maintaining building code & standard	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Tenure security
Maintaining building code & standard	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Trust on public officials
Maintaining building code & standard	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Having effective leader
Maintaining building code & standard	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to affordable insurance
Maintaining building code & standard	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circulation of disaster information
Maintaining building code & standard	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Election participation
Tenure security	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Trust on public officials
Tenure security	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Having effective leader
Tenure security	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to affordable insurance
Tenure security	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circulation of disaster information
Tenure security	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Election participation
Trust on public officials	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Having effective leader
Trust on public officials	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to affordable insurance
Trust on public officials	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circulation of disaster information
Trust on public officials	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Election participation
Having effective leader	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to affordable insurance
Having effective leader	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circulation of disaster information
Having effective leader	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Election participation
Access to affordable insurance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Circulation of disaster information
Access to affordable insurance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Election participation
Circulation of disaster information	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Election participation

Table 4: Please provide necessary weight for economic resilience.

Factor	Factor Weighting Score																Factor	
	More Importance Than								Equal	Less Importance Than								
Livelihood diversity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Homeownership
Livelihood diversity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Asset value
Livelihood diversity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Amount of savings
Livelihood diversity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Service and industry employment
Livelihood diversity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Female employment
Livelihood diversity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic assistance
Livelihood diversity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to credit
Livelihood diversity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Effects of seasonality
Livelihood diversity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Engagement in risky activities
Homeownership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Asset value
Homeownership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Amount of savings
Homeownership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Service and industry employment
Homeownership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Female employment
Homeownership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic assistance
Homeownership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to credit
Homeownership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Effects of seasonality
Homeownership	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Engagement in risky activities
Asset value	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Amount of savings
Asset value	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Service and industry employment
Asset value	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Female employment
Asset value	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic assistance
Asset value	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to credit
Asset value	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Effects of seasonality
Asset value	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Engagement in risky activities
Amount of savings	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Service and industry employment
Amount of savings	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Female employment
Amount of savings	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic assistance
Amount of savings	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to credit

Factor	Factor Weighting Score																	Factor
	More Importance Than								Equal	Less Importance Than								
Amount of savings	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Effects of seasonality
Amount of savings	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Engagement in risky activities
Service and industry employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Female employment
Service and industry employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic assistance
Service and industry employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to credit
Service and industry employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Effects of seasonality
Service and industry employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Engagement in risky activities
Female employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic assistance
Female employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to credit
Female employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Effects of seasonality
Female employment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Engagement in risky activities
Economic assistance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to credit
Economic assistance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Effects of seasonality
Economic assistance	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Engagement in risky activities
Access to credit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Effects of seasonality
Access to credit	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Engagement in risky activities
Effects of seasonality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Engagement in risky activities

Table 5: Please provide necessary weight for physical resilience.

Factor	Factor Weighting Score																Factor	
	More Importance Than								Equal	Less Importance Than								
Katcha housing structure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from healthcare facilities
Katcha housing structure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to piped water
Katcha housing structure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to electricity
Katcha housing structure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Using non-sanitary toilet
Katcha housing structure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to drainage facilities
Katcha housing structure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to solid waste management
Katcha housing structure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from fire stations
Katcha housing structure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access road to evacuate
Katcha housing structure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Accessibility during heavy rains
Katcha housing structure	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to internet
Distance from healthcare facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to piped water
Distance from healthcare facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to electricity
Distance from healthcare facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Using non-sanitary toilet
Distance from healthcare facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to drainage facilities
Distance from healthcare facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to solid waste management
Distance from healthcare facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from fire stations
Distance from healthcare facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access road to evacuate
Distance from healthcare facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Accessibility during heavy rains
Distance from healthcare facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to internet
Access to piped water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to electricity
Access to piped water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Using non-sanitary toilet
Access to piped water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to drainage facilities
Access to piped water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to solid waste management
Access to piped water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from fire stations
Access to piped water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access road to evacuate
Access to piped water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Accessibility during heavy rains
Access to piped water	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to internet
Access to electricity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Using non-sanitary toilet

Factor	Factor Weighting Score																	Factor
	More Importance Than							Equal	Less Importance Than									
Access to electricity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to drainage facilities
Access to electricity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to solid waste management
Access to electricity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from fire stations
Access to electricity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access road to evacuate
Access to electricity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Accessibility during heavy rains
Access to electricity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to internet
Using non-sanitary toilet	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to drainage facilities
Using non-sanitary toilet	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to solid waste management
Using non-sanitary toilet	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from fire stations
Using non-sanitary toilet	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access road to evacuate
Using non-sanitary toilet	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Accessibility during heavy rains
Using non-sanitary toilet	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to internet
Access to drainage facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to solid waste management
Access to drainage facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from fire stations
Access to drainage facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access road to evacuate
Access to drainage facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Accessibility during heavy rains
Access to drainage facilities	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to internet
Access to solid waste management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Distance from fire stations
Access to solid waste management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access road to evacuate
Access to solid waste management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Accessibility during heavy rains
Access to solid waste management	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to internet
Distance from fire stations	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access road to evacuate
Distance from fire stations	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Accessibility during heavy rains
Distance from fire stations	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to internet
Access road to evacuate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Accessibility during heavy rains
Access road to evacuate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to internet
Accessibility during heavy rains	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to internet

Table 6: Please provide necessary weight for social resilience.

Factor	Factor Weighting Score																Factor	
	More Importance Than								Equal	Less Importance Than								
Literacy rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Population density
Literacy rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to social safety nets
Literacy rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Vulnerable population
Literacy rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Trust on community
Literacy rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Gender equity
Literacy rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Participating with NGOs
Literacy rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Previous disaster experience
Literacy rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Disaster awareness
Literacy rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Help from the external relationship
Literacy rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Place attachment
Literacy rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Attend DRR training programs
Literacy rate	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Household size
Population density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Access to social safety nets
Population density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Vulnerable population
Population density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Trust on community
Population density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Gender equity
Population density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Participating with NGOs
Population density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Previous disaster experience
Population density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Disaster awareness
Population density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Help from the external relationship
Population density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Place attachment
Population density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Attend DRR training programs
Population density	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Household size
Access to social safety nets	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Vulnerable population
Access to social safety nets	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Trust on community
Access to social safety nets	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Gender equity
Access to social safety nets	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Participating with NGOs
Access to social safety nets	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Previous disaster experience

Factor	Factor Weighting Score																Factor	
	More Importance Than								Equal	Less Importance Than								
Access to social safety nets	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Disaster awareness
Access to social safety nets	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Help from the external relationship
Access to social safety nets	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Place attachment
Access to social safety nets	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Attend DRR training programs
Access to social safety nets	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Household size
Vulnerable population	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Trust on community
Vulnerable population	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Gender equity
Vulnerable population	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Participating with NGOs
Vulnerable population	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Previous disaster experience
Vulnerable population	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Disaster awareness
Vulnerable population	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Help from the external relationship
Vulnerable population	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Place attachment
Vulnerable population	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Attend DRR training programs
Vulnerable population	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Household size
Trust on community	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Gender equity
Trust on community	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Participating with NGOs
Trust on community	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Previous disaster experience
Trust on community	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Disaster awareness
Trust on community	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Help from the external relationship
Trust on community	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Place attachment
Trust on community	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Attend DRR training programs
Trust on community	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Household size
Gender equity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Participating with NGOs
Gender equity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Previous disaster experience
Gender equity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Disaster awareness
Gender equity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Help from the external relationship
Gender equity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Place attachment
Gender equity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Attend DRR training programs
Gender equity	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Household size
Participating with NGOs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Previous disaster experience

Factor	Factor Weighting Score																Factor	
	More Importance Than								Equal	Less Importance Than								
Participating with NGOs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Disaster awareness
Participating with NGOs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Help from the external relationship
Participating with NGOs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Place attachment
Participating with NGOs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Attend DRR training programs
Participating with NGOs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Household size
Previous disaster experience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Disaster awareness
Previous disaster experience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Help from the external relationship
Previous disaster experience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Place attachment
Previous disaster experience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Attend DRR training programs
Previous disaster experience	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Household size
Disaster awareness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Help from the external relationship
Disaster awareness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Place attachment
Disaster awareness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Attend DRR training programs
Disaster awareness	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Household size
Help from the external relationship	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Place attachment
Help from the external relationship	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Attend DRR training programs
Help from the external relationship	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Household size
Place attachment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Attend DRR training programs
Place attachment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Household size
Attend DRR training programs	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Household size



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Evaluating resilience of coastal communities upon integrating PRISMA protocol, composite resilience index and analytical hierarchy process

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