



Direction of infrastructure concept based on resilient city in urban area

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ABSTRACT

Background: Natural disasters such as earthquakes, tsunamis, and floods frequently affect Indonesia, worsened by its location on the Ring of Fire and climate change. Bulukumba Regency is historically vulnerable to such hazards. To address this, the “Resilient City” concept focuses on a city’s ability to cope with disaster risks while maintaining social, economic, and environmental stability. Resilient infrastructure is a key component, ensuring long-term functionality and durability. **Methods:** This study applied a mixed quantitative, qualitative, and spatial approach. Data were collected through observation, interviews, and documentation, then analyzed using scoring, GIS mapping, and the qualitative 4R framework (Robustness, Redundancy, Resourcefulness, Rapidity) to assess urban resilience. **Findings:** The study found that the urban area exhibits a low level of resilience. The infrastructure concept for improvement emphasizes resilient design with durable materials, strong structural standards, periodic inspections, and strict construction quality. Backup systems, alternative infrastructure, and additional evacuation routes are planned to maintain functionality during disasters. Community capacity is strengthened through disaster management knowledge, skill development, cooperation networks, and technology utilization to improve response efficiency. Advanced early warning systems, comprehensive evacuation plans, and accessible emergency response infrastructure and documents are also recommended to accelerate response and recovery. **Conclusion:** Implementing the 4R approach is expected to enhance infrastructure resilience and increase overall urban resilience to multiple disaster types. **Novelty/Originality of this article:** This study introduces a resilient city-based infrastructure framework grounded in the 4R approach, integrating the latest methods and in-depth analysis to guide disaster-resilient urban planning.

KEYWORDS: Bulukumba Regency urban area; city resilience; disaster; infrastructure; resilient infrastructure.

1. Introduction

Disasters result from a combination of disaster threats, vulnerabilities, and capacities triggered by a particular event. Under Law No. 24 (2007), disaster refers to an event or series of events that threaten and disrupt people’s lives and livelihoods. Disasters can be caused by natural factors, non-natural factors, or the interaction between the two, as well as human impacts, resulting in casualties, environmental damage, material losses, and psychological impacts. Of the several types of disasters, one of the most common disasters is natural disasters.

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Data from the *Badan Perencanaan Pembangunan Nasional*/National Development Planning Agency (Bappenas, 2014) show that around 62% of districts/cities in Indonesia face a high risk of natural disasters. The main factor is Indonesia's geographical location, which is on the Ring of Fire and is dominated by seawater, covering more than 65%. This increases the potential for disasters related to natural phenomena such as storms, hurricanes, floods, and sea level rise. Climate change and global warming exacerbate Indonesia's disaster-prone natural conditions.

One region in Indonesia with a high level of natural disaster potential is Bulukumba Regency, located at the southern tip of Sulawesi Island, with strong potential for earthquakes and tsunamis (Massinai et al., 2017). Bulukumba Regency in its history has had a fairly large tsunami, this event occurred on December 29, 1820, triggered by a magnitude 7.5 earthquake in the Flores Sea and eliminated hundreds of lives, this tsunami hit several areas along the southern coast of Sulawesi, including Bulukumba Regency (Pertiwi et al., 2018). The potential for earthquakes in Bulukumba Regency is strengthened by the existence of the Welanae Fault which crosses from Bontobahari to the north of the Regency Bulukumba and the Flores Thrust Fault, which runs along the Flores Sea. This disaster threat is a serious concern for the local government and the people of Bulukumba, including the Urban Area of Bulukumba Regency, which has a complex urban system and is therefore more vulnerable to disasters.

One solution to deal with this situation is to apply the concept of a Resilient City. This concept focuses on a city's ability to overcome disaster risks and impacts while maintaining social, economic, and environmental balance (Abdurrohman et al., 2021). The concept of a resilient city includes improving the city's ability to overcome disasters, reduce disaster risk, and build community involvement in the urban planning and development process (Godschalk, 2003).

The concept of a resilient city that effectively creates urban resilience is resilient infrastructure (Resilient Infrastructure). This concept strongly influences a city's sustainability. It not only helps maintain the city's physical survival but also supports the continuation of its economic, social, and cultural functions over the long term (Renald, 2016). Based on this reality, the research focused on the Urban Area of Bulukumba Regency. This study aims to analyze the resilience level of the Urban Area of Bulukumba Regency and, through the 4R approach, formulate the direction of the Resilient City-based infrastructure concept in the region.

2. Methods

2.1 Types of research

The research uses quantitative, qualitative, and spatial approaches. The quantitative method estimates the value of factors that determine the resilience level of the Bulukumba Regency Urban Area, and the spatial approach describes spatial changes (based on administration), supported by qualitative methods that describe the concept of resilience related to the infrastructure system. This research is located in South Sulawesi Province, covering Bulukumba Regency, with a focus on the Urban Area of Bulukumba Regency. Geographically, the Urban Area of Bulukumba Regency is located at 5°32'13"S - 120°13'25"E and 5°34'56"S - 120°8'27"E, with an area of 2,012.62 Ha.

Population is the entire object of research or the object to be researched. The population is a group in an area that meets certain conditions related to the object of study (Dzwigol, 2022). The population in this study is people in the Urban Area of Bulukumba Regency, as well as stakeholders and related government officials

The sample represents the population being studied (Dzwigol, 2022). This study uses purposive sampling. Purposive sampling is a data collection technique that uses specific criteria to select participants (Sugiyono, 2011). This study drew its sample from the population using purposive sampling. This technique selects respondents with relevant information and knowledge. Respondents who are the target of the research have the

criteria of Village Head/*Kelurahan*, Community Leaders, Exposed Communities, Regional Disaster Management Agency/*Badan Penanggulangan Bencana Daerah*(BPBD), Public Works and Spatial Planning/*Pekerjaan Umum dan Tata Ruang*(PUTR), and Regional Development Planning Agency/*Badan Perencanaan Pembangunan Daerah*(BAPPEDA).

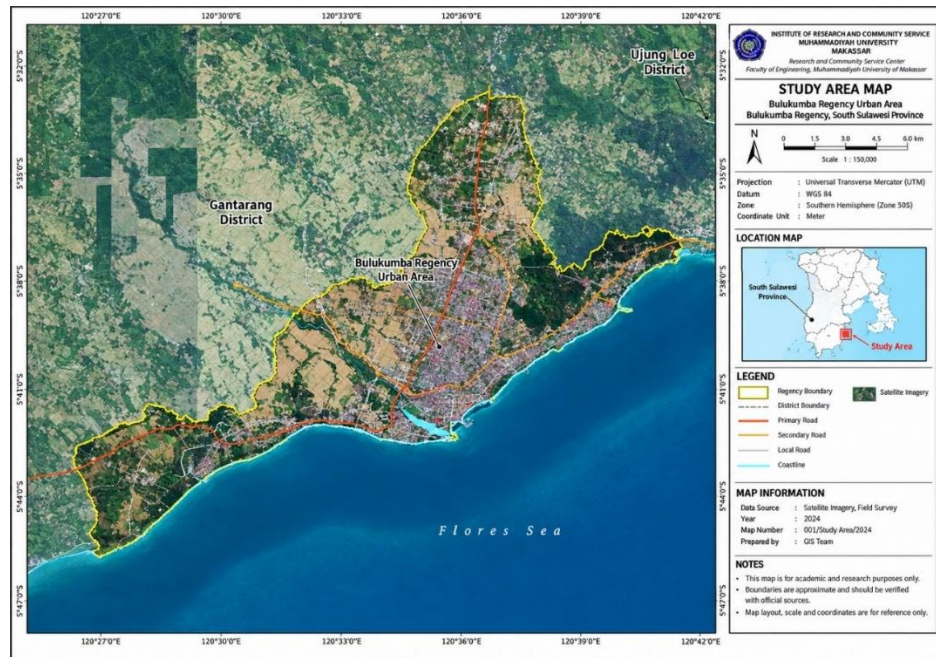


Fig. 1. Research location

This study includes spatial variables such as disaster risk assessments, mapping of disaster-prone areas, and disaster mitigation strategies. Community and institutional variables include the presence of disaster-aware community groups, strong relationships and cooperation with surrounding areas in disaster mitigation efforts, and community knowledge related to Disaster Risk. Infrastructure variables include the availability and range of early warning systems and emergency response support infrastructure. The economic assistance variable includes the availability of emergency funds and procedural plans for distributing donations and financial assistance. The Reconstruction and Rehabilitation Variable includes post-disaster recovery plans, infrastructure revitalization or maintenance, improved mental health services, and adaptation of Social Harmonization. The research variables include the use of geographic information system technology for disaster information, the timeliness of disaster-related data, and the application of resilient infrastructure concepts.

2.2 Data collection techniques

This study uses observation, interviews, and documentation to collect data. Observation involves directly observing the research location to gather data on existing conditions, land-use changes, and conditions for constructing facilities in the Urban Area of Bulukumba Regency. Interviews are a systematic, directed data collection technique in which researchers gather information through questions and answers with respondents about the availability of Resilient City devices in their area. In this study, the researcher conducted interviews with residents of the urban area of Bulukumba Regency and relevant government officials. Documentation is a data collection technique that uses relevant literature or policies and creates visualizations through images, carried out directly at the research site. The collected data were analyzed descriptively to identify the existing conditions and challenges related to the implementation of the Resilient City concept in the Urban Area of Bulukumba Regency. The findings from observations, interviews, and documentation were then integrated to provide a comprehensive understanding of the

availability of supporting facilities, relevant policies, and measures needed to strengthen urban resilience.

2.3 Analysis methods

The analysis employed a scoring method to assess the resilience of the Bulukumba Regency Urban Area across six dimensions: spatial planning; society and institutions; infrastructure; economic assistance; reconstruction and rehabilitation; and research and information. Each dimension includes several assessment indicators, each assigned a score from 1 to 5 based on predefined criteria. A score of 1 represents the lowest performance level, whereas a score of 5 represents the highest performance level for the corresponding indicator. Appendix A provides the complete list of assessment indicators, scoring criteria, and score descriptions.

The total resilience score was calculated by summing the individual scores assigned to all assessment indicators. With 16 indicators assessed on a five-point scale, the possible total scores range from 16 to 80. The resulting total score was then used to determine the study area's resilience category. We established five categories, very low, low, moderate, high, and very high, as presented in Table 1. These categories represent the overall resilience level based on the accumulated indicator scores rather than the score assigned to any individual indicator.

Table 1. Classification of urban area resilience levels

Class	Score
Very Low	16 – 29
Low	30 – 43
Currently	44 – 57
Tall	58 – 71
Very High	>72

The assessment results were then processed using a Geographic Information System (GIS) to visualize the spatial distribution of urban resilience across Bulukumba Regency's administrative areas. The spatial mapping identified differences in resilience levels among the assessed areas based on their total scores and classifications. Individual indicator scores range from 1 to 5, while total resilience scores sum all 16 indicator scores. The resilience category indicates the classification assigned to the resulting total score. This distinction ensures consistency in the presentation and interpretation of the assessment results. The scoring framework was developed with reference to the United Nations Office for Disaster Risk Reduction (2017), Bruneau et al. (2003), and the Ministry of Agrarian Affairs and Spatial Planning (2016).

In addition to the score analysis, a qualitative descriptive analysis is applied using the 4R approach, consisting of robustness, redundancy, resourcefulness, and rapidity. Robustness refers to the ability of infrastructure to withstand disruptions and continue to function properly. In the context of a resilient city, robustness can be realized through robust infrastructure design, where buildings and other infrastructure must be designed to withstand a variety of disturbances such as earthquakes, floods, and high winds, achieved by using robust building materials, applying appropriate design techniques, and considering risk factors in the design process; proper maintenance, ensuring infrastructure is in optimal condition through regular inspections, timely repairs, and replacement of worn-out components; and resource availability, in which cities must have access to sufficient resources such as food, water, and energy to meet people's needs during times of crisis.

Redundancy refers to the existence of multiple components or systems that can perform the same function. In the context of a resilient city, redundancy can be realized through built-in redundancy systems for critical systems such as electricity and water networks so that if one part of the system fails, the other parts can still function—for

example, building a double-track power grid, providing backup water sources, and having redundant systems for communications and transportation; multiple evacuation routes designed taking into account factors such as accessibility, population density, and potential hazards; backup resources such as food, water, and shelter stored in a safe and easily accessible location; and economic diversification, since cities with diversified economies are more resilient to disruptions than cities that rely on a single economic sector, achieved by encouraging the development of a wide variety of industries and businesses.

Resourcefulness refers to the ability to find creative solutions to problems. In the context of a resilient city, resourcefulness can be manifested through responsive communities encouraged to solve their own problems through education and training on disaster preparedness and crisis management; adaptive governance, in which governments build flexible and responsive governance structures and involve citizens in the decision-making process; use of technology to improve the efficiency and effectiveness of disaster response, such as drones to map disaster-affected areas, smartphone apps to provide information to the public, and AI technology to predict and respond to disruptions; and collaboration between government, private sector, non-profit organizations, and civil society in fields such as planning, funding, and implementation of resilient programs.

Rapidity refers to the ability to respond quickly and effectively to disruptions. In the context of a resilient city, rapidity can be realized through an accurate, reliable, and easy-to-understand early warning system; a clear, structured, and easily implemented emergency response plan; effective communication between the government, the public, and other organizations during times of crisis through channels such as social media, mobile applications, and public address systems; resource mobilization built on a strong logistics system and collaboration with various parties; and rapid post-disaster recovery achieved by building disaster-resilient infrastructure, providing financial assistance to affected communities, and promoting economic recovery.

3. Results and Discussion

3.1 Level of resilience of urban areas in Bulukumba Regency

3.1.1 Spatial planning

Based on the literature review, the selected spatial variables were used as assessment variables for the resilience level of the Bulukumba Regency urban area, with three indicators. The scoring for each indicator is shown in the following table. The table shows that the scoring results for the spatial planning variable are consistent across all 14 administrative areas within the Bulukumba Regency Urban Area.

Each area receives a score of 4 for the disaster risk assessment indicator, 3 for the mapping of disaster-prone areas indicator, and 3 for the disaster mitigation strategy indicator, resulting in an identical total score of 10 for each administrative area. This uniform scoring pattern indicates that the spatial planning component related to disaster management is assessed at the same level across the study area, with disaster risk assessment contributing the highest individual score among the three indicators. The consistency of the scores suggests that the implementation or availability of spatial planning measures related to disaster risk assessment, hazard mapping, and mitigation strategies does not vary substantially among the assessed villages and sub-districts. Therefore, the spatial planning variable demonstrates a relatively homogeneous condition across the Bulukumba Regency Urban Area, as reflected by the identical total score obtained by all administrative areas. These findings provide a baseline for evaluating the spatial planning dimension of urban resilience across the study area. However, the identical scores indicate that further improvements in disaster-prone area mapping and mitigation strategies are needed to achieve higher resilience levels. These results also highlight the importance of examining other assessment dimensions to identify variations in overall urban resilience among the 14 administrative areas.

Table 2. Scoring of spatial planning variable indicators

Sub-district/Village	Indicator			Total
	Disaster risk assessment	Mapping disaster-prone areas	Disaster mitigation strategy	
Paenre Lompoe Village	4	3	3	10
Polewali Village	4	3	3	10
Taccorong Village	4	3	3	10
Matekko Village	4	3	3	10
Jalanjang Subdistrict	4	3	3	10
Bintarore Subdistrict	4	3	3	10
Kasimpureng Subdistrict	4	3	3	10
Bentenge Subdistrict	4	3	3	10
Caile Village	4	3	3	10
Ela-ela Village	4	3	3	10
Kalumeme Village	4	3	3	10
Loka Village	4	3	3	10
Tanah Kongkong Subdistrict	4	3	3	10
Terang-terang Village	4	3	3	10

3.1.2 Institutions and society

Based on the literature review results, the institutional and community variables were selected to assess the level of resilience of the Bulukumba Regency Urban Area using three indicators. The scoring for each indicator is shown in the following table. These indicators were selected to capture key institutional capacities and community characteristics that contribute to urban resilience. The scoring process provides a systematic basis for evaluating each indicator's relative performance and identifying areas that require improvement.

Table 3. Scoring of indicators for institutional and social variables

Sub-district/Village	Indicator			Total
	The existence of disaster-aware community groups	There is good relations and cooperation with surrounding areas in disaster mitigation efforts.	Community knowledge regarding disaster risks	
Paenre Lompoe Village	1	2	2	5
Polewali Village	1	2	1	4
Taccorong Village	1	2	1	4
Matekko Village	1	2	2	5
Jalanjang Subdistrict	1	2	1	4
Bintarore Subdistrict	1	2	3	6
Kasimpureng Subdistrict	1	2	3	6
Bentenge Subdistrict	1	2	2	5
Caile Village	1	2	2	5
Ela-ela Village	1	2	2	5
Kalumeme Village	1	2	2	5
Loka Village	1	2	2	5
Tanah Kongkong Subdistrict	1	2	3	6
Terang-terang Village	1	2	2	5

The table presents the scoring results for community capacity and social preparedness in disaster mitigation across the administrative areas of the Bulukumba Regency Urban Area. The assessment covers three indicators: the existence of disaster-aware community groups, the quality of relations and cooperation with surrounding areas in disaster mitigation efforts, and community knowledge of disaster risks. The results show that the

first indicator receives a uniform score of 1 across all administrative areas, while the second indicator consistently receives a score of 2, indicating a relatively similar level of community organization and inter-area cooperation throughout the study area. In contrast, the third indicator shows greater variation, with scores ranging from 1 to 3. Polewali Village, Taccorong Village, and Jalanjang Subdistrict have the lowest community knowledge score of 1, resulting in a total score of 4. Paenre Lompoe Village, Matekko Village, Bentenge Subdistrict, Caile Village, Ela-ela Village, Kalumeme Village, Loka Village, and Terang-terang Village each obtain a total score of 5, reflecting a moderate level of community knowledge regarding disaster risks. Meanwhile, Bintarore Subdistrict, Kasimpureng Subdistrict, and Tanah Kongkong Subdistrict achieve the highest total score of 6, driven by a score of 3 for community knowledge. Overall, total scores range from 4 to 6, indicating that community capacity for disaster preparedness is not uniform across the study area, particularly in community knowledge and awareness of disaster risks.

3.1.3 Institutions and society

Based on the literature review and the study area's characteristics, the Institutional and Community variables were identified as key components for assessing the resilience of the Bulukumba Regency Urban Area to disaster risks. These variables reflect how institutional capacity, community organization, inter-area cooperation, and public understanding contribute to disaster preparedness and resilience. To provide a more comprehensive assessment, the Institutional and Community variables are measured using three indicators: the existence of disaster-aware community groups, the quality of relations and cooperation with surrounding areas in disaster mitigation efforts, and community knowledge regarding disaster risks. The scoring of these indicators is applied to each village and sub-district within the Bulukumba regency urban area, with the results presented in Table 4.

Table 4. Scoring of indicators for institutional and social variables

Sub-district/Village	Indicator			Total
	The existence of disaster-aware community groups	There are good relations and cooperation with surrounding areas in disaster mitigation efforts.	Community knowledge regarding disaster risks	
Paenre Lompoe Village	1	2	2	5
Polewali Village	1	2	1	4
Taccorong Village	1	2	1	4
Matekko Village	1	2	2	5
Jalanjang Subdistrict	1	2	1	4
Bintarore Subdistrict	1	2	3	6
Kasimpureng Subdistrict	1	2	3	6
Bentenge Subdistrict	1	2	2	5
Caile Village	1	2	2	5
Ela-ela Village	1	2	2	5
Kalumeme Village	1	2	2	5
Loka Village	1	2	2	5
Tanah Kongkong Subdistrict	1	2	3	6
Terang-terang Village	1	2	2	5

Based on the indicator score values for institutional and community variables, the results show the level of community sensitivity and knowledge of disaster potential in their respective sub-districts. These results provide an overview of community awareness and institutional capacity in responding to potential disasters across the study area. The findings also highlight the importance of strengthening community participation and interregional cooperation to improve disaster preparedness and urban resilience.

3.1.4 Infrastructure

Based on the literature review, the selected infrastructure variable assesses the level of resilience of the Bulukumba regency urban area using three indicators. The scoring for each indicator is shown in the following table.

Table 5. Scoring of infrastructure indicators

Sub-district /Village	Indicator			Total
	Availability of Early Warning System	Range Early Warning System	Availability of Emergency Response Support Infrastructure	
Paenre Village Lompoe	1	1	1	3
Polewali Village	1	1	1	3
Taccorong Village	1	1	1	3
Ward Matekko	1	1	1	3
Ward Long Road	1	1	1	3
Ward Bintaro	1	1	1	3
Ward The Kasimpureng	1	1	1	3
Ward Fortress	1	1	1	3
Caile Village	1	1	1	3
Ela- ela Village	1	1	1	3
Ward Kalumeme	1	1	1	3
Loka Village	1	1	1	3
Tanah Kongkong Subdistrict	1	1	1	3
Ward Out in the Open	1	1	1	3

Based on the table above, the Infrastructure variable's indicator score reflects the availability of early warning system infrastructure at each location and its reach.

3.1.5 Economic assistance

Based on the literature review results, the economic assistance variable was selected to assess the resilience level of the Bulukumba Regency Urban Area using two indicators. The scoring for each indicator is shown in the following table.

Table 6. Scoring of economic assistance variable indicators

Sub-district/Village	Indicator		Total
	Emergency Fund Availability	Availability of procedural plans for distribution of donations and financial assistance	
Paenre Lompoe Village	3	3	6
Polewali Village	3	3	6
Taccorong Village	3	3	6
Matekko Village	3	3	6
Jalanjang Subdistrict	3	3	6
Bintarore Subdistrict	3	3	6
Kasimpureng Subdistrict	3	3	6
Bentenge Subdistrict	3	3	6
Caile Village	3	3	6
Ela-ela Village	3	3	6
Kalumeme Village	3	3	6
Loka Village	3	3	6
Tanah Kongkong Subdistrict	3	3	6
Terang-terang Village	3	3	6

Based on the table above, the indicator score for the economic assistance variable reflects the availability of emergency funds and procedures for distributing aid funds during a disaster.

3.1.6 Reconstruction and rehabilitation

Based on the literature review results, the reconstruction and rehabilitation variables were selected as assessment variables for the resilience level of the Bulukumba regency urban area, with two indicators. The scoring for each indicator is shown in the following table.

Table 7. Scoring of reconstruction and rehabilitation variable indicators

Sub-district/Village	Indicator			Total
	Post-Disaster Recovery Plan	Infrastructure Maintenance	Improving mental health services and adapting Social Harmonization	
Paenre Lompoe Village	2	3	1	6
Polewali Village	2	2	1	5
Taccorong Village	2	2	1	5
Matekko Village	2	5	1	8
Jalanjang Subdistrict	2	3	1	6
Bintarore Subdistrict	2	5	1	8
Kasimpureng Subdistrict	2	5	1	8
Bentenge Subdistrict	2	5	1	8
Caile Village	2	5	5	12
Ela-ela Village	2	5	1	8
Kalumeme Village	2	5	1	8
Loka Village	2	5	1	8
Tanah Kongkong Subdistrict	2	5	1	8
Terang-terang Village	2	5	1	8

Based on the table above, the indicator score values for the reconstruction and rehabilitation variables show the level of community sensitivity and knowledge of disaster potential in their respective sub-districts.

3.1.7 Research

Based on the results of the literature review, the research variable was selected as the variable for assessing the level of resilience of the Bulukumba regency urban area with two indicators. The scoring for each indicator is shown in the following table.

Table 8. Scoring of research indicators

Sub-district/Village	Indicator		Total
	The application of geographic information system technology for disaster information	Disaster-related data up-to-date	
Paenre Lompoe Village	1	4	5
Polewali Village	1	4	5
Taccorong Village	1	4	5
Matekko Village	1	4	5
Jalanjang Subdistrict	1	4	5
Bintarore Subdistrict	1	4	5
Kasimpureng Subdistrict	1	4	5
Bentenge Subdistrict	1	4	5
Caile Village	1	4	5
Ela-ela Village	1	4	5

Sub-district/Village	Indicator		Total
	The application of geographic information system technology for disaster information	Disaster-related data up-to-date	
Kalumeme Village	1	4	5
Loka Village	1	4	5
Tanah Kongkong Subdistrict	1	4	5
Bright-bright sub-district	1	4	5

Based on Table 8, all 14 observed sub-districts and villages scored 5, with 1 for the application of geographic information system (GIS) technology for disaster information and 4 for the availability of up-to-date disaster-related data. These results indicate consistent scoring across the study area, although GIS application received a lower score than data availability. The cumulative scores of these indicators will be used to classify the level of urban resilience in the Bulukumba regency urban area based on the established assessment criteria. This classification will help identify institutional capacities and areas requiring improvement in disaster information management.

3.1.8 Classification of city resilience levels

The classification results, based on the total score of each indicator, will be used to determine the resilience level of the Bulukumba regency urban area. The resilience level classification for the urban area is shown in the following table.

Table 9. Classification of resilience levels

Class	Score
Very Low	16 – 29
Low	30 – 43
Currently	44 – 57
Tall	58 – 71
Very High	>72

Based on the results of the accumulation of the scoring above, the results of the analysis that has been carried out revealed that the urban area in Bulukumba Regency has a relatively low level of resilience. This is evidenced by the scores, which range from 30-42. These scores show that the urban area in Bulukumba Regency still has many weaknesses and vulnerabilities in dealing with or anticipating various disturbances and disasters. This condition is worrying, given that the urban area is the center of important economic, social, and cultural activities.

Therefore, serious action is needed to increase the urban area's resilience in Bulukumba Regency. Efforts made must be integrated and sustainable by involving all stakeholders, including the government, community, private sector, and non-governmental institutions. Thus, it is hoped that the urban area in Bulukumba Regency can become more resilient and better able to face various disturbances and disasters. Based on the first problem formulation, the following table shows the priority handling directions based on variable data. Auffrey (2017) and Renald (2016) stated that the elements of a resilient city that must be prioritized are the resilience and development of city infrastructure and its supporting elements to survive and function during and after a disturbance. Therefore, the resilient city concept focuses on resilient infrastructure.

The findings also indicate that improving urban resilience requires a comprehensive assessment of the factors contributing to vulnerability across the study area. Particular attention should be given to strengthening disaster management systems, improving infrastructure preparedness, and enhancing coordination among relevant stakeholders. Furthermore, the prioritization of resilience measures should consider the specific needs and capacities of each administrative area to ensure that interventions are effective and

contextually appropriate. These efforts are expected to reduce potential disaster impacts and support the continuity of essential urban functions during and after a disaster.

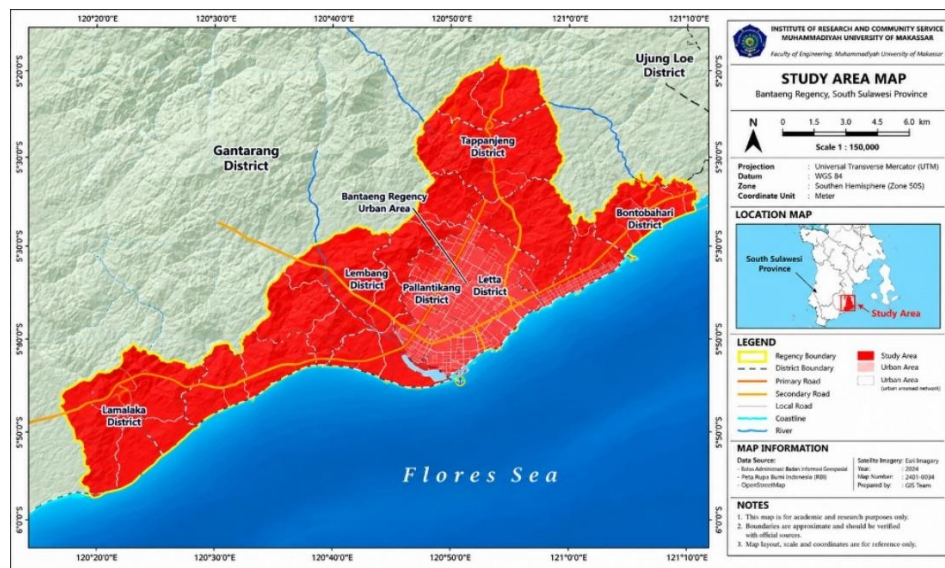


Fig. 2. Level of resilience

3.2 Directions for the resilient city-based infrastructure concept in the urban area of Bulukumba Regency

3.2.1 Robustness

Looking at the characteristics and history of disasters in Bulukumba regency, the implementation of infrastructure that must be implemented has durability/resilience in facing excessive pressure, the concept of Robustness is not only the application of physical form but also the application of policies or standards that must be applied in one development (Mehvar et al, 2020), the direction of the Robustness concept applied based on the priority direction table in the first problem formulation can be seen in the following graphic.

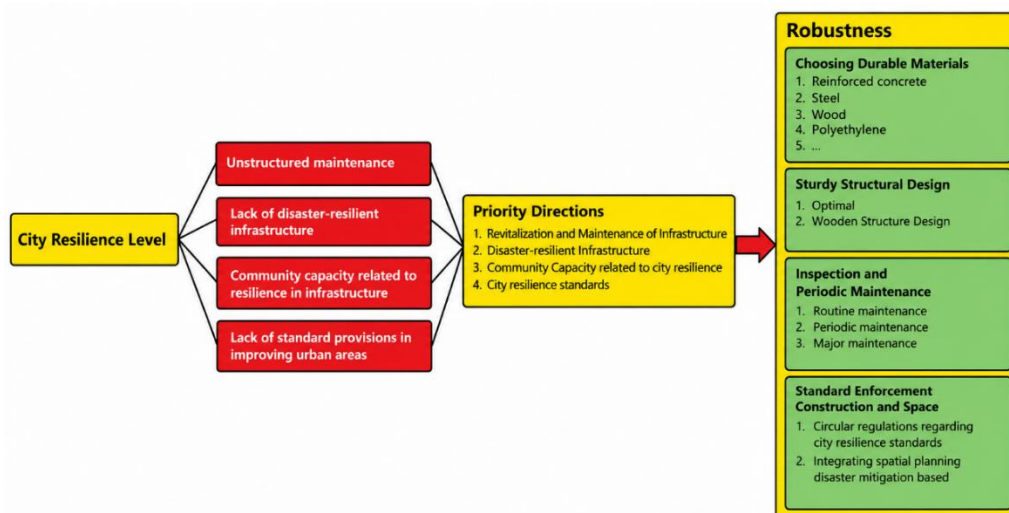


Fig. 3. Robustness concept direction

Robustness concept in increasing the resilience of the Bulukumba Regency Urban Area can be seen as follows. Choosing Durable Materials, the selection of construction materials for infrastructure in coastal areas , such as the Bulukumba Regency Urban Area, needs to

consider several fundamental aspects. The strength and durability of the material are the main priorities, with a focus on water and corrosion resistance (Strain et al., 2022; Karim & Rafiq, 2025). This is crucial for infrastructure such as pipes, electrical cables, and basic building structure materials that are susceptible to degradation due to seawater intrusion. The following are some materials that are suitable for creating Robustness in the Bulukumba Regency Urban Area.

Reinforced concrete is a composite material made of concrete and steel. Concrete is resistant to compression, while steel is resistant to tension. Combining these two materials produces a strong, durable material that provides resilience throughout the Urban Area of Bulukumba Regency. Steel is strong and durable, with high tensile strength. Steel can be used for various applications, such as building structures, bridges, and pipes in the Bulukumba Regency Urban Area. Wood is a strong, durable natural material with high compression strength; in addition, it has a very low application cost. Wood can be used for various applications, such as earthquake-proof building structures. Polyethylene (PE) is one of the most commonly used plastics in the construction industry because it is waterproof, durable, flexible, and easy to install. This material is commonly used in electrical infrastructure, water networks, and roofs.

Sturdy Structural Design: This concept plays an important role in increasing urban areas' resilience to earthquakes; therefore, building structure design in the urban area of Bulukumba Regency must adopt a design concept that is more flexible to various shocks and has a lower application cost. Dactylophone found that reinforced concrete structures with sufficient reinforcement and proper detailing can absorb earthquake energy through plastic deformation (curving); this concept is called the Ductile concept (Hassan, 2025; Asadimanesh & Jalilifard, 2025). This frame concept is considered effective in creating a sturdy structure and has a lower cost.

Wooden Structure Design, as described by the American Society of Civil Engineers (2017), presents a resilient concept for timber building structures. This concept has the potential to be applied efficiently in the urban area of Bulukumba Regency. This is because the area's settlement characteristics reflect traditional building practices that may be more adaptable to wood use. In addition to offering structural resilience when properly designed, timber construction can also be relatively cost-effective. Furthermore, using locally available timber could support the development of context-sensitive housing solutions, provided sustainability and material durability are considered. However, its implementation should comply with applicable building standards and account for local hazards, particularly fire, moisture, and seismic risks.

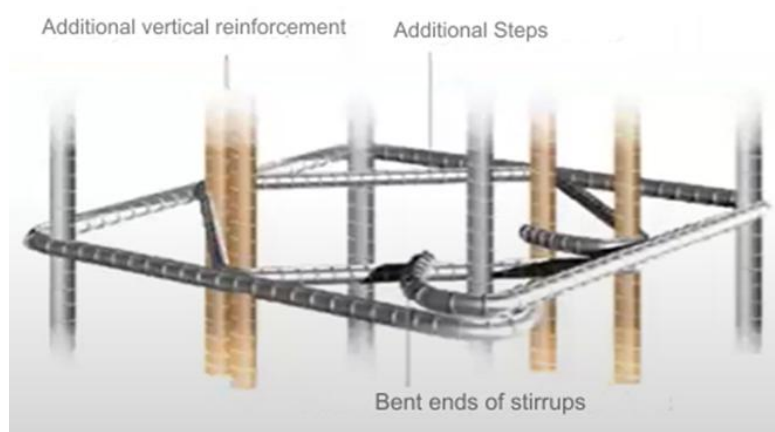


Fig. 4. Ductile structure concept

Regular inspection and maintenance of infrastructure in urban areas can make them safer, more resilient, and better able to withstand various disasters. This can help protect lives and property and improve quality of life. The maintenance cycle that can be adapted to the Bulukumba regency urban area can adopt the three types of maintenance that are

proposed (Chock, 2016), namely: routine maintenance, carried out periodically, usually every month, week, or even every day. For example, cleaning water channels, pruning trees along the road, and painting signs. Periodic maintenance is carried out periodically, usually every year or every two years. For example, repairing potholes, repainting bridges, and replacing street lights are major maintenance activities, carried out periodically, usually every 5 or 10 years. For example, road rehabilitation, building renovation, and rebuilding irrigation networks.

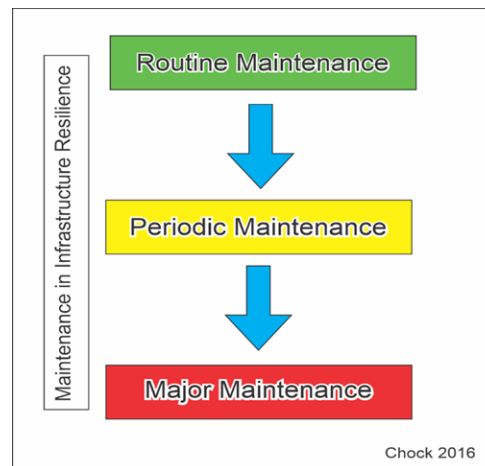


Fig. 5. Maintenance concept

Construction and spatial standards for resilience in infrastructure is not only limited to improving the physical quality of infrastructure, but must also be supported by improving standards and regulations that must be applied to every development, such as creating regulations regarding development standards, such as those carried out by the American Society of Civil Engineers (ASCE), which created internationally recognized construction standards for disaster-resistant structural design, especially earthquakes, as well as procedures for implementing audits or inspections of construction projects to ensure compliance with established standards. These standards can be adapted to the Bulukumba Regency Urban Area to create more targeted and sustainable enforcement of construction regulations.

In addition to improving construction standards, improving the resilience of the Bulukumba Regency urban area in terms of space is one of the variables in creating city resilience (Ministry of Agrarian Affairs and Spatial Planning, 2016). Bulukumba Regency's spatial planning has not integrated disaster mitigation, so improving disaster mitigation-based spatial planning is a solution to strengthening the resilience of the Bulukumba Regency urban area. (*Rencana Tata Ruang Wilayah/RTRW* Bulukumba Regency 2012-2032) emphasizes that disaster mitigation-based spatial planning emphasizes several important aspects, namely: a) Protected area designation: Protected areas are areas protected from development activities to maintain environmental sustainability and prevent natural disasters. In Bulukumba Regency, protected areas include forest areas, coastal areas, and mountain slopes. b) Zoning arrangement: Zoning divides an area into several zones with different functions, such as residential zones, commercial zones, industrial zones, and green zones. Proper zoning can reduce the risk of natural disasters and increase urban resilience. c) Disaster-responsive infrastructure development: Infrastructure such as roads, bridges, and drainage systems needs to be designed and built with potential natural disasters in mind. Using durable materials and sturdy construction is also important to ensure infrastructure can withstand disaster conditions. d) Increased public education and awareness: The public needs to be educated about the potential for natural disasters and ways to deal with them. High public awareness can help reduce the risk of loss of life and property during a disaster.

3.2.2 Redundancy

The redundancy concept in the 4R Resilient City framework is an important strategy for minimizing disaster impacts by providing backup systems and alternative infrastructure ready for use when a disruption occurs. The directions for the redundancy concept, based on the priority direction table in the first problem formulation, are shown in the following graphic.

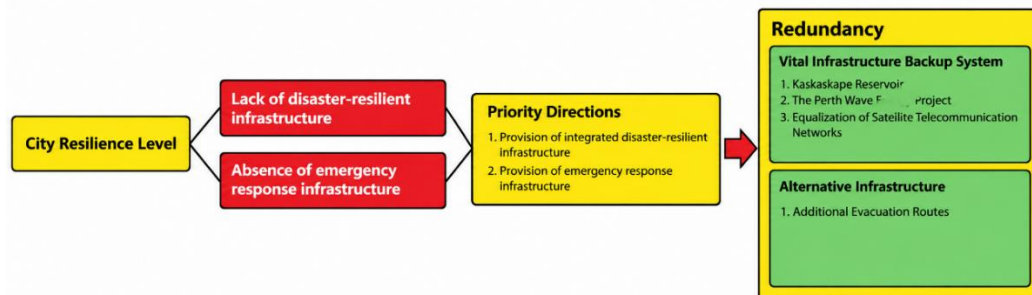


Fig. 6. Concept direction

The concept of redundancy that can be applied to the urban area of Bulukumba Regency can be seen as follows. Vital Infrastructure Backup System (Vital Infrastructure Backup System). This system allows the replacement of vital infrastructure when the main vital infrastructure system is disrupted (Mehvar et al, 2020), this can be done by applying the handling concept of countries that have applied the concept in developing city resilience such as providing backup power plants, additional water reservoirs, and satellite communication networks, by implementing a Backup System like this allows the availability of vital community needs such as electricity, water and telecommunications networks to be uninterrupted when a disaster occurs .

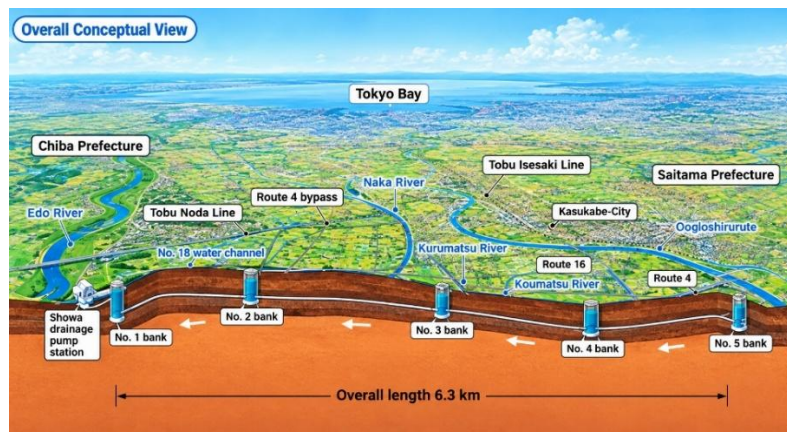


Fig. 7. Kasukabe reservoir concept

Kasukabe Reservoir is a flood and tsunami control infrastructure in Japan, this development project is also equipped with filtration equipment to purify water, in addition to aiming as a flood control system, this infrastructure also aims as a reservoir backup infrastructure during a water crisis or during a disaster. This concept can be applied to the Bulukumba Regency Urban Area by adapting the concept and considering the appropriate development costs.

The Perth Wave Energy Project is a backup infrastructure developed by the Australian Renewable Energy Agency (ARENA). This project is here to create renewable energy that can be used as a backup energy source if the vital electricity system experiences problems/disasters, seeing the characteristics of the Bulukumba Regency Urban Area,

which is adjacent to the Flores Sea, this concept can be adapted as a backup electricity infrastructure when the main electricity system is disrupted.

Equality Satellite Telecommunication Network VSAT (Very Small Aperture Terminal) is a satellite-based internet service that can serve data communication needs ranging from 2.4 Kbps to 2 Mbps and is guaranteed to remain on even if there is damage to vital infrastructure, but its application in Indonesia is still uneven, increasing the reach of satellite telecommunications services is directed as one of the adaptations to improve the Backup system in telecommunications.

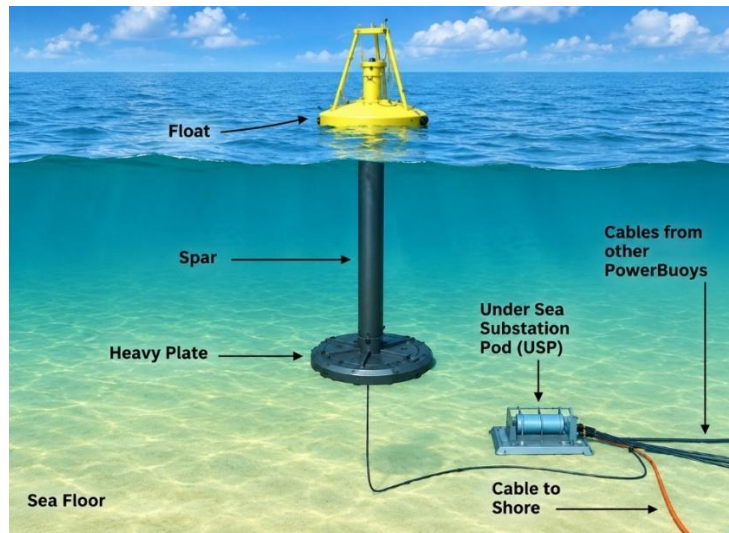


Fig. 8. Concept of wave power station

Alternative infrastructure Mehvar (2020) Building alternative infrastructure is an important step in increasing disaster resilience. This infrastructure serves as a backup when a disaster damages the main infrastructure, so the community still has access to essential services and safe evacuation routes. Adaptation of alternative infrastructure in the Bulukumba Regency Urban Area is directed at adapting the concept of alternative infrastructure to build additional evacuation routes, emergency bridges, and temporary shelters. Evacuation routes must be designed with geographical conditions and potential congestion during a disaster in mind. (Yamamoto, 2017) developed the concept of a double evacuation route, which is divided into several Clusters according to the level of difficulty of the route to the evacuation site.

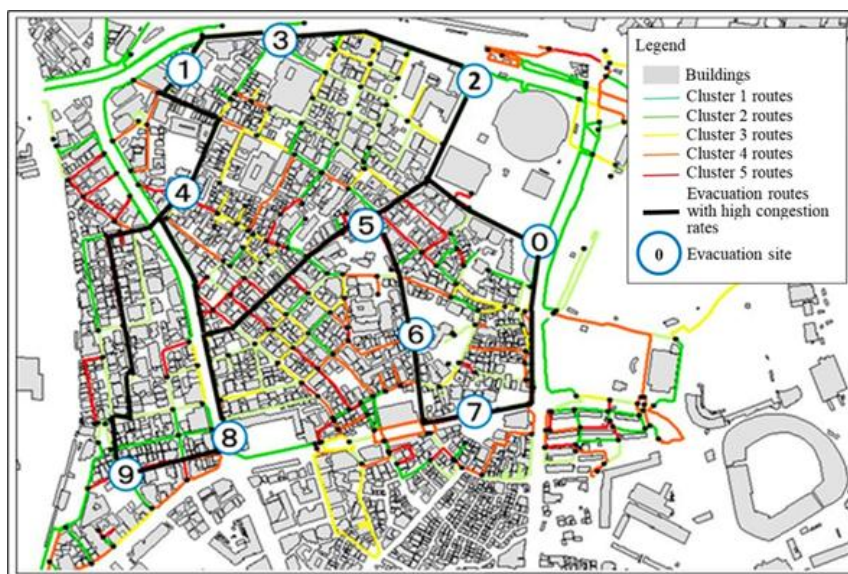


Fig. 9. Double evacuation route concept

3.2.3 Resourcefulness (Resource Mobilization Capacity)

The ability to mobilize resources and services needed in an emergency; the Resourcefulness concept directions applied based on the priority direction table in the first problem formulation can be seen in the following graphic.

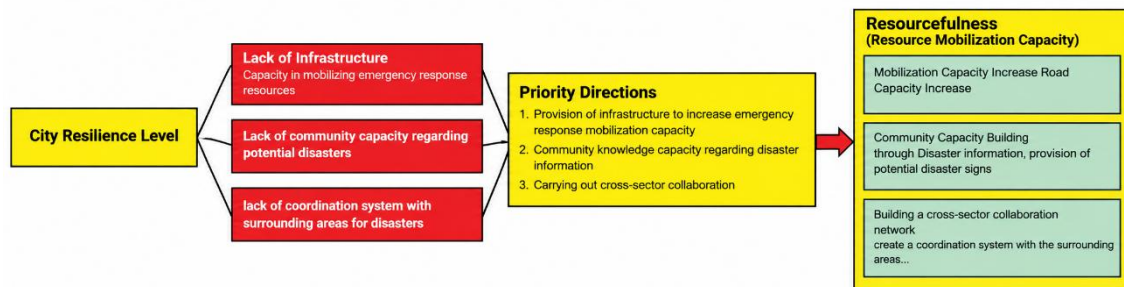


Fig. 10. Concept direction

Mehvar (2020) Argues That Resource mobilization capacity is achieved by developing a resilient logistics system in urban areas to ensure rapid, efficient distribution of aid and resources by increasing road capacity, training and equipping communities with disaster management knowledge and skills, and building collaborative networks between institutions and communities to strengthen disaster response capacity. Resource mobilization is also supported by faster road infrastructure and is highly efficient during a disaster; therefore, to enable rapid mobilization during a disaster, the Resourcefulness direction focuses on increasing road infrastructure capacity in the Bulukumba Regency Urban Area.

Improving community capacity through disaster information is a crucial step in building a resilient city (United Nations Office for Disaster Risk Reduction, 2017). This can be achieved through various efforts, including installing potential disaster signs; these signs serve as educational media and early warnings about potential disaster hazards in the community. Building a cross-sectoral cooperation network is a strategic step to increase resource-mobilization capacity and build a resilient city. This involves collaboration and coordination between various parties, including the government, non-governmental organizations, the private sector, academics, and civil society that are interconnected through an integrated system, such as the provision of a telecommunications system that is interconnected with the surrounding areas.

3.2.4 Rapidity (response acceleration)

According to the United Nations Office for Disaster Risk Reduction (2017), an area's ability to respond to and overcome disturbances quickly is the foundation of urban resilience. The conceptual direction for creating a resilient Bulukumba regency urban area, based on the priority table for creating a rapidity concept, is shown in the following graphic.

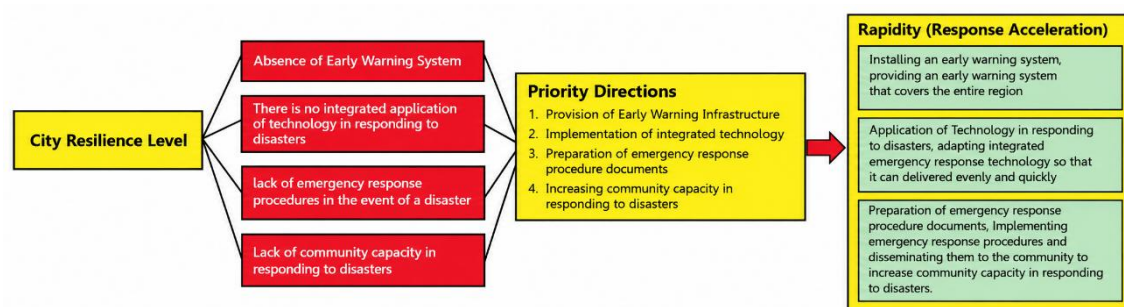


Fig. 11. Concept direction

Provision of early warning systems. The development of resilient infrastructure in the Bulukumba regency urban area can be supported by installing early warning systems focused on earthquakes and tsunamis. These systems should be designed to reach all areas and respond to various types of hazards in the urban area. Their effectiveness depends on adequate infrastructure, reliable communication networks, and regular maintenance. Public awareness and preparedness are also essential to ensure that warnings lead to timely protective actions. Therefore, the integration of early warning systems with local disaster management mechanisms should be prioritized.

Integrated technology application in disaster response. Integrated technology in disaster response can improve the efficiency, effectiveness, and accountability of emergency operations. In the Bulukumba regency urban area, this approach can be implemented by integrating early warning systems with community communication networks to ensure rapid and equitable dissemination of emergency information. Places of worship can also serve as communication channels within early warning system coverage areas. Local authorities, emergency response teams, and community representatives must coordinate to ensure consistent information delivery. Communication systems should remain accessible to vulnerable groups and function during power or network disruptions. These measures can strengthen community preparedness and support a more coordinated disaster response.

Preparation of emergency response procedure documents. Developing comprehensive emergency response procedure documents is a crucial step toward establishing effective community disaster preparedness. These documents guide the management of various emergencies, including hazard identification, emergency response team formation, standard operating procedures, and training and simulation activities. Clear, structured procedures enable communities to coordinate actions, protect lives and property, and speed post-disaster recovery. The procedures should be tailored to the specific hazards and conditions of each area within the Bulukumba regency urban area. Regular drills and periodic reviews are needed to ensure that the procedures remain practical and relevant. Community participation in developing these procedures can further improve local understanding, acceptance, and readiness to respond to disasters.

4. Conclusions

The resilience level of the Bulukumba Regency Urban Area is classified as low, indicating limited preparedness to face various types of disasters. This condition reflects existing weaknesses and vulnerabilities that may exacerbate disaster impacts. To address these challenges, this study proposes a resilient infrastructure development framework based on the 4R approach: robustness, redundancy, resourcefulness, and rapidity. Robustness involves selecting durable construction materials, implementing strong structural designs, conducting regular inspections and maintenance, and enforcing appropriate building standards to ensure infrastructure can withstand disaster hazards. Redundancy focuses on establishing backup systems for critical infrastructure, providing alternative facilities, and developing additional evacuation routes to maintain essential functions when primary infrastructure is disrupted or damaged.

Resourcefulness emphasizes developing resilient logistics systems, equipping communities with disaster management knowledge and skills, strengthening collaboration among institutions and communities, and utilizing technology to improve disaster response. These measures aim to mobilize resources effectively and strengthen community preparedness. Rapidity refers to the capacity to respond quickly to disasters and restore essential services through effective earthquake and tsunami early warning systems, comprehensive evacuation plans, accessible emergency response infrastructure, and clear emergency response procedures. Implementing the 4R approach can provide a strategic framework for strengthening infrastructure resilience in the Bulukumba Regency Urban Area. However, its effectiveness depends on coordinated institutional action, adequate

funding, community participation, and consistent implementation tailored to local disaster risks.

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Author Contribution

Conceptualization of the research framework, M.F., A.I.A.; Methodology, A.I.A.; Spatial Analysis, M.F., A.I.A.; Field Survey, M.F.; Draft Preparation, M.F.

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Data Availability Statement

The data supporting the findings of this study are publicly available at <https://bit.ly/4zKvYoq>.

Conflicts of Interest

The authors declare no conflict of interest.

Declaration of Generative AI Use

During preparation of this work, the authors did not use any generative artificial intelligence tools to assist with writing, translating, editing, or analyzing the manuscript content. All content was produced by the authors, who take full responsibility for the content of the publication.

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