


Research

Adapting to climate change and multi-risk governance: toward sustainable adaptation and enhancing urban resilience—Indonesia

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Abstract

Climate change has contributed to an increase in natural catastrophes over the past five years in Indonesia, causing various forms of damage in urban areas and posing a severe danger to multi-risk governance for municipal governments in Indonesia. This study explores how multi-risk governance strategies encourage sustainable adaptation to climate change and increase urban resilience in Bandung and Makassar City, Indonesia. This study method uses a qualitative-exploratory approach with a case study in two (2) climate-vulnerable cities in Indonesia. Data analysis uses qualitative-interactive analysis. The results of this study show that the impact of climate change in Bandung and Makassar City, Indonesia has caused an increase in the potential for erosion, reduced wetlands along the coast, an increase in the rate of seawater intrusion, a decrease in food production, damage to infrastructure, a reduction in clean water sources, an increase in disease. respiratory, floods, droughts, and other hydrological disasters. This has resulted in many climate approaches and actions being taken to respond to the impact of climate change in Indonesia (Bandung and Makassar City), the results of which are still not optimal to date. This study suggests a sustainable adaptation approach to climate action in Bandung and Makassar City which prioritizes social justice and environmental integrity so that it has a real impact on community vulnerability and environmental damage due to the impacts of climate change. The contribution of this study provides sufficient insight into the institutional approaches and adaptive sustainability measures needed to promote resilience in Indonesia. At the same time, this study will be a useful reference in future research on multi-risk governance and sustainable adaptation strategy for climate action and enhancing urban governance.

Article Highlights

- Threats and challenges of climate change in Indonesia include increased flooding, hot temperatures, sea level rise, and extreme weather events, which significantly impact communities and infrastructure.
- There is a need to move away from traditional mitigation approaches to more adaptive governance models that can effectively respond to the dynamic nature of climate risks in Indonesia.
- Multi-risk governance advocates for integrated strategies that take into account a range of environmental, social, and economic factors.

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- Policy recommendations to improve climate governance in Indonesia include improving coordination across government agencies, investing in infrastructure resilience, and fostering collaboration between local and national governments.

Keywords Climate change · Sustainable adaptation · Multi-risk governance · Resilience governance · Indonesia

1 Introduction

Sustainable adaptation has similarities to sustainable-development SDGs [1]. Sustainable adaptation, until now there is still much debate about the best way to respond to the negative impacts (climate change), especially in poor and developing-countries in the world [1]. Sustainable adaptation emphasizes that interventions in sustainable development must simultaneously address the problems of climate change, poverty, and development disparities [1–3]. So far, although there is no agreed definition of sustainable adaptation [2] sustainable adaptation is adaptation actions that also contribute to the agenda of resilience, social justice, and environmental integrity, which are the pillars of sustainable development. Two key areas between the concepts of sustainable adaptation and sustainable development are social fairness and sustainable environmental integration [2, 3]. Stated differently, these two processes work together to help us comprehend sustained adaptation.

Sustainable adaptation [2] in various previous literature shows ambiguity, tension, and contradiction in the idea/concept, as well as its application/implementation. Sustainable adaptation which is often equated with sustainable development shows that this concept has gaps that need to be addressed. Even according to Eriksen and Brown [2] and Eriksen and O'brien [3] that many of the adaptation strategies used now are not long-term/sustainable; This may put long-term resilience in jeopardy and perhaps cause “maladaptation.” Furthermore, it's very harder to uncover synergistic measures than is commonly believed because the relationship between poverty reduction and climate change adaptation is not well understood. Additionally, sustainable adaptation ultimately forces us to confront the underlying causes of poverty and environmental change, which may call for a reevaluation of conventional wisdom and methods of development [1–3]. These issues pose obstacles to efforts to promote and adopt sustainable adaptation and hinder the success of achieving its goals of encouraging sustainable development. According to Mignan et al. [5], multi-risk governance is a multi-level approach that can help manage the impacts of disasters due to climate change in an integrated and coordinated manner for obstacles and problems in sustainable adaptation. This is in line with research from Scolobig et al. [6, 7] who also briefly explained that multi-risk governance is an effort to adapt to the impacts of climate change in integrated and coordinated government-level activities in supporting environmental sustainability and resilience.

The effects of global warming are clearly obvious: Climate change is already causing food poverty and clean water crises that affect millions of people, and efforts to adapt to its effects have been inconsistent, dispersed, and insufficient to stop its catastrophic effects [8–12]. One of the challenges in addressing these impacts is the lack of funding for resilience, as available funding is only around 10% of needs and does not reach those on the front lines of climate change, such as small farmers, whose livelihoods depend entirely on food security. Where these conditions depend on favorable climatic conditions [8, 9, 12].

Two significant reports were released by the IPCC in 2022 as a component of its sixth assessment cycle. The globe is still not on track to create a future that is climate-secure, according to a report published in February on the effects, adaptation, and vulnerability of climate change [12, 13]. Billions of people and ecosystems are already suffering greatly as a result of climate change, and efforts to mitigate its effects are still falling short of what is required to stop the worst effects [8–11]. The decade from 2010 to 2019 saw the largest increase in greenhouse gas emissions in human history, according to the April Climate Change Mitigation Report. Even though there is still time to limit warming to 1.5 °C, there are strategies that can be implemented in every sector to reduce emissions [12, 14, 15].

In Indonesia, the impact of climate change has resulted in an increase in the potential for erosion, reduced wetlands along the coast, an increase in the rate of seawater intrusion, a decrease in food production, damage to infrastructure, a reduction in clean water sources, an increase in respiratory diseases, floods, droughts, and other hydrological disasters [10–12, 16, 17]. Based on the report of BNPB Indonesia (2024) during the last 5 years Indonesia has experienced various natural disasters that have caused multiple problems and damage in various cities in Indonesia, the number of natural disasters recorded in the last 5 years was 3,814 natural disasters, which caused 478 people to die, 111 people missing, 3,421 people injured, 5,693,171 people suffered during the disaster that occurred, there were 436,234 people displaced,

there were 73,723 people lost/damaged homes, there were 1,123 educational facilities damaged, and there were 213 health facilities damaged, there were 688 places of worship damaged and there were 450 public facilities damaged.

In Makassar City, climate change has resulted in flooding, increasing vulnerability for coastal communities and hampering urban mobility, especially coastal cities which are geographically surrounded by sea waters and are vulnerable to the impact of the rainy season which can result in urban roads being submerged, as happened in Makassar City in mid-February 2023 [10, 18]. In 2022, Makassar City will experience the highest climate shift in Indonesia, reaching 279 days of shift. This figure puts Makassar in the top 15 in the world and 4th on the Asian continent as the city with the highest weather shifts [10]. This makes Makassar City one of the cities that has a high level of vulnerability to climate change in Indonesia. Apart from being not far from Bandung City, one of the largest cities in West Java, Indonesia is experiencing the impact of climate change such as increasing air temperatures which can cause various problems, such as decreasing air quality, forest and land fires, landslides, and lack of clean water [19–21]. Bandung City and Makassar City are two urban areas in Indonesia that exhibit significant vulnerability to climate change due to a combination of geographical, socio-economic, and infrastructural factors. Understanding these vulnerabilities is crucial for developing effective adaptation strategies.

Several studies have shown this condition, such as in Bandung, rapid urbanization has led to significant land conversion, which has severely impacted the city's natural water management systems. The increase in built-up areas has resulted in approximately 95% of rainwater being unable to infiltrate the ground, leading to increased risks of flooding and water shortages during dry seasons [21]. This urban expansion is exacerbated by land subsidence, which occurs at an alarming rate due to excessive groundwater extraction and inadequate drainage systems [19, 21]. Furthermore, the city's governance challenges in managing water, waste, and climate change contribute to its vulnerability, as the existing infrastructure struggles to cope with the increasing frequency and intensity of climate-related events [21]. Makassar City, on the other hand, faces vulnerabilities primarily due to its coastal location and rapid population growth. The city is experiencing significant changes in climate variables, including increased rainfall intensity and rising temperatures, which are closely linked to alterations in land use patterns [10]. The coastal ecosystems, which are critical for the livelihoods of many residents, are under threat from climate change impacts such as sea-level rise and extreme weather events [4, 15, 16]. Moreover, the lack of institutional commitment and adaptive governance strategies further exacerbates the city's vulnerability, as local authorities often struggle to implement effective climate change responses [4, 15, 16].

The idea of sustainable adaptation can be understood as part of a solution in dealing with climate change and vulnerability in the case of encouraging city-resilience and sustainability towards risk reduction and poverty alleviation as a multi-risk governance strategy [2, 3]. In line with this, the latest research by Xiao and Seekamp [4] states that the implementation of a sustainable adaptation approach to optimize various goals in a resilient and sustainable development path requires various systematic strategies. Eriksen and Brown [2] define sustainable adaptation which combines aspects of sustainability and adaptation in its concept. The concept of sustainable adaptation also includes steps and strategies that reduce vulnerability and increase long-term resilience to the impacts of climate change. According to Eriksen and O'Brien [3], sustainable adaptation is also defined as a set of actions that establish connections and exchanges between initiatives aimed at reducing environmental damage and promoting social health on the one hand, and reducing poverty and promoting environmental sustainability on the other. The relationship between poverty and vulnerability to climate change is meant to focus on: (1) reducing risks using existing methods to ensure prosperity, (2) strengthening adaptive efforts by increasing the capacity of poor communities and (3) addressing the causes of community vulnerability. Sustainable adaptation efforts can be focused on any of these relationships, as long as they do not harm the other two [2, 3]. According to these criteria, the conventional adaptation approach gains two new dimensions, or two new elements or requirements, from sustainable adaptation. Initially, adaptation needs to take proactive steps to decrease poverty and/or vulnerability. Secondly, adaptation needs to make sure that the activities implemented are long-term. These two aspects of sustainable adaptation reflect sustainable development's intra- and intergenerational dimensions [2, 3].

In line with the idea of sustainable adaptation, multi-risk governance involves the comprehensive management of multiple hazards and risks associated with cascading disasters through the engagement of various stakeholders. This necessitates a comprehensive and integrated strategy that covers every stage of risk management, from disaster preparedness to prevention, and highlights the need of include a variety of stakeholders in the continuous evaluation process [7, 22]. This strategy underscores the necessity for multi-stakeholder participation, multi-scalar coordination, and the integration of various measures to enhance the resilience of socio-ecological systems against complex risks [23, 24]. Effective multi-risk governance acknowledges the interconnections between different hazards, the potential cascading impacts of these risks, and the need for collaboration among authorities responsible for managing these interconnected threats [25]. By embracing a multi-risk perspective, governance can develop a more comprehensive

understanding of how risks interact and influence each other, offering a holistic view supporting decision-making and policy development [26].

2 Objective

This study explores how multi-risk governance strategies encourage sustainable adaptation to climate change and increase urban resilience in Bandung and Makassar City, Indonesia which are some of the most vulnerable and affected areas. In 2022, Makassar City will experience the highest climate shift in Indonesia, reaching 279 days of shift. This figure puts Makassar in the top 15 in the world and 4th on the Asian continent as the city with the highest weather shifts [10]. This makes Makassar City one of Indonesia's cities with a high level of vulnerability to climate change. Apart from being not far from Bandung City, one of the largest cities in West Java, Indonesia is experiencing the impact of climate change such as increasing air temperatures which can cause various problems, such as decreasing air quality, forest and land fires, landslides, and lack of clean water [19–21].

What is the research summary question:

- a. What are the challenges and responses to climate change governance in Bandung City and Makassar City?
- b. How is the synergy in sustainable adaptation through multi-risk governance due to climate change in Bandung City and Makassar City?
- c. How is the sustainable adaptation policy strategy in building urban resilience in Indonesia (especially in Bandung City and Makassar City)?

In the initial part of this study, it explores and identifies the challenges and threats of climate change that occur in Indonesia. Then, in the second part, this study presents a model and context analysis on the issue of resilience to more adaptive climate change governance, while also criticizing the mitigation approaches that are more often used in Indonesia. Then in the third part, we present existing mitigation policies in Indonesia and we also present shortcomings and recommendations for encouraging resilient climate governance in Indonesia.

3 Methods

3.1 Research design

This study uses a qualitative-exploratory method where the researcher is the key instrument in collecting and analyzing data [27]. Data sources are primary data and secondary data, primary data comes from researchers/authors as key instruments in this study which were obtained through studies, observations and various simple discussion forums regarding the impact of the polycrisis in Indonesia and globally. Secondary data in this study was obtained through document studies (15 documents of the Indonesian government, UN and UNICEF report), literature reviews (12 important studies on climate change governance in Indonesia), and online media (9 online media articles from various sources) that publish climate change and natural disaster issues in Indonesia (The database center of the Indonesian National Disaster Management Agency (*Badan Nasional Penanggulangan Bencana*, BNPB: Link—<https://bnpb.go.id/>). The urgency of qualitative research methods in case studies related to climate change adaptation is increasingly recognized as essential for understanding the complex social dynamics and local contexts that influence adaptation strategies [27]. Qualitative methods, particularly case studies, offer nuanced insights into how communities perceive and respond to climate change, which is crucial for developing effective adaptation policies [27]. The conceptual approach used in this study is a sustainable adaptation as a multi-risk governance strategy, namely a concept that studies the threats and challenges of climate change in global crises, crisis management patterns, and resilience strategy models that are tried to be implemented to the maximum level in alleviating poverty and vulnerability [2, 3]. The reason this approach is used in this study is to refine various conceptual approaches that have existed previously, such as disaster management and climate action which only emphasize actions to reduce exposure to disasters, the climate change governance and urban governance approach which tends to emphasize the governance scheme carried out, and the multi-level governance approach which tends to emphasize coordination at each level. The sustainable adaptation as a multi-risk governance strategy approach is an approach that is

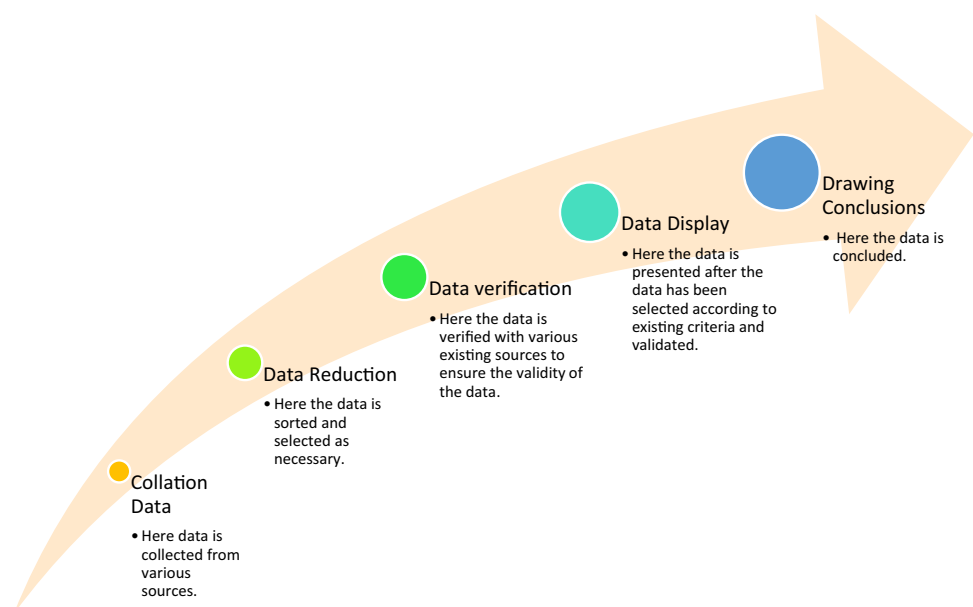
contextual to the conditions of Indonesia which has a high multi-risk variation and a high level of vulnerability due to exposure to natural disasters.

Data sources were obtained from the field observation (All author's field notes), the database center of the Indonesian National Disaster Management Agency (*Badan Nasional Penanggulangan Bencana*, BNPB: Link—<https://bnpb.go.id/>), books (15 documents of the Indonesian government, UN and UNICEF report), journal articles (12 important studies on climate change governance in Indonesia), media online survey (9 online media articles from various sources), and laws & policy on climate change governance in Indonesia ((a) The Paris Agreement on the United Nations Framework Convention on Climate Change, as ratified by the Republic of Indonesia Law Number 16 of 2016 Concerning Ratification of the Paris Agreement; (a) The 2015–2019 National Medium-Term Development Plan (*Rencana Jangka Panjang Menengah Nasional*, RPJMN); (c) medium-term development plan of Makassar City 2024; (d) Medium-Term Regional Development Plan (RPJMD) of Bandung City 2018–2023; (e) Regional Regulation (*Peraturan Daerah*, Perda) Number 4 of 2015 concerning Makassar City Regional Spatial Planning (*Rencana Tata Ruang Wilayah*, RTRW) 2015–2035; (f) Bandung City Regional Regulation Number 5 of 2022 concerning Bandung City Regional Spatial Planning (RTRW) for 2022–2042), all data obtained in the lesson and reconfirmed using data triangulation (method, time and place) to ensure the validity of the data.

After all the data was obtained, we carried out data analysis using in-depth interactive analysis [28] by collecting data, reducing data, verifying data, presenting data, and drawing conclusions to get the best findings, these steps are shown in Fig. 1.

The rare steps in the Interactive Qualitative Analysis (IQA) in this study are (in Fig. 1): The first step in Interactive Qualitative Analysis (IQA) is the identification of the research phenomenon/case study, which involves defining the specific issue or experience that the study aims to explore. Following this, the second step is data collation through field observation, document study, literature study, policy survey and digital media exploration. and then to reduce data as the selection process is essential for gathering rich, contextually relevant data. The third step is the coding of the data, where researchers and participants collaboratively identify key themes and categories that emerge from the discussions. The fourth step is the construction of a systems diagram or mind-map, which visually represents the relationships between the identified themes and categories. This diagram serves as a synthesis of the participants' collective understanding of the phenomenon and is a critical output of the IQA process. The final step involves the interpretation of the findings, where researchers and participants reflect on the implications of the results and how they relate to existing literature and theories.

Fig. 1 Data collection and analysis techniques of in-depth interactive analysis. Source: processed from Miles et al. [28], 2024



4 Research site

The locations for this study are in Bandung City, West Java, and Makassar City, South Sulawesi Indonesia (See Fig. 2). The capital of Indonesia's West Java Province is Bandung City, which is located in the West Java area. Bandung City is situated between 107° 36' East Longitude and 6° 55' South Latitude, according to astronomy. Bandung City's borders are as follows: Bandung Regency and West Bandung Regency to the north; Bandung Regency to the south; Cimahi City to the west; and Bandung Regency to the east. The elevation of Bandung City is 700 m above sea level (ASL). Ledeng Village in Cidadap District has the highest point at 892 m above sea level, while Rancanumpang Village in Gedebage District has the lowest point at 666 m above sea level. In 2022, rain will occur relatively throughout the year with varying intensity each month. The highest rainfall occurred in October, namely 366.7 mm. Meanwhile, the lowest rainfall was in August

Fig. 2 Research location on Mult-risk governance strategies in Indonesia. Source: Processed from Google Earth, 2024



where rainfall only reached 29.9 mm. During 2022, the average temperature of Bandung City is 25.35 °C. The highest temperature in Bandung City in 2022 will reach 32.2 °C in September and the minimum temperature is 16.8 °C in July 2022 [29]. These geographical conditions cause the city of Bandung to become one of the cities in Indonesia that is vulnerable to climate change, especially impacts such as floods and landslides. Makassar City Astronomically, Makassar City is located between 119° 24' 17" 38" East Longitude and 5° 08' 06" 19" South Latitude which is in the coastal area. Makassar City's borders are as follows: east—Maros Regency; west—Makassar Strait; south—Gowa Regency. These boundaries are based on the city's geographic location. One month's cumulative rainfall is the amount of rainfall accumulated over 28 or 29 days for February and 30 or 31 days for other months [30]. These conditions make Makassar City a city that is vulnerable to climate change, especially impacts such as increasing air temperatures, rising sea levels in coastal areas, and flooding.

5 Results and discussion

5.1 The challenges and responses of sustainable adaptation for climate change governance in Indonesia

Indonesia is one of the countries experiencing threats from climate change. Natural disasters such as Floods, long droughts, landslides, forest fires, extreme weather, decreasing land surface in coastal areas due to rising sea levels, and increasing air temperatures that occur in Indonesia are related to climate change in the world [17, 31]. Climate change that occurs in Indonesia revolves around massive deforestation, forest fires, destruction of swamp land and loss of carbon dioxide absorption. Strategies that can be implemented to deal with climate change are developing and improving irrigation networks, integrated natural disaster management, building infrastructure, and protecting beaches from potential damage due to abrasion and rising sea levels and public campaigns [10, 16, 17]. This climate change poses challenges to sustainable development in the social and economic environment as well as to achieving Indonesia's development goals, this is seen in: The Medium-Term Regional Development Plan (Rencana Pembangunan Jangka Menengah Daerah, RPJMD) of Bandung City 2018–2023; (b) the Medium-Term Development Plan of Makassar City 2024; and (c) the Indonesia National Medium-Term Development Plan (Rencana Pembangunan Jangka Panjang Nasional, RPJMN) 2015–2019; (d) the BPS Bandung and Makassar City report [10, 16, 17]. The mitigation and adaptation of climate change must be quickly incorporated into Indonesia's social development planning system in order to overcome this. The issues and solutions to climate change that Bandung and Makassar City, Indonesia, are facing are listed below (see to Table 1).

In Bandung City, rising air temperatures, increasing rainfall, and urban population growth, as well as urbanization which increases CO₂ due to vehicles, are challenges for the Bandung City government in responding to the impacts of climate change occurring in Bandung City. Data from the Disaster Management Agency states that 95% of disaster events in Indonesia are climate-related, with floods being the most frequent disaster in Bandung City [29]. Rainfall in 2022 will be distributed throughout the year, with monthly variations in severity. October saw the most rainfall, totaling 366.7 mm. Meanwhile, the lowest rainfall was in August where rainfall only reached 29.9 mm. During 2022, the average temperature

Table 1 Challenges and Responses (Climate Change) that occur—Bandung & Makassar Cities, Indonesia

Cities	Challenges due to climate change	Response to climate change
Bandung City	Air pollution caused by human activities has an impact on increasing temperatures by 98%. Clearing land by cutting down trees also increases global temperatures. Gas pollutants resulting from vehicle activities cause an increase in global temperatures [29] Increased Rainfall, which causes floods and landslides [29, 32]	Controlling temperature increases due to human and vehicle activities with road network systems and design, drainage system management, flood control, and the implementation of public roads in Bandung City [32]
Makassar City	The challenges faced by Makassar City due to climate change are increasing air temperatures which can cause various problems, such as decreasing air quality, forest and land fires, landslides, and lack of clean water [30]	Accelerate decarbonization and strengthen climate resilience. Encouraging the application of local wisdom values in responding to the impacts of climate change occurring in Makassar City. Encouraging city management based on the principle of inclusivity towards all [30, 33]

Source: Processed from various sources, 2024

for Bandung City is 25.35 °C. The highest temperature for Bandung City in 2022 will reach 32.2 °C in September and the minimum temperature will be 16.8 °C in July 2022 [29]. Due to its geographic location, Bandung City is among the Indonesian cities most at risk from climate change. The response to the challenges caused by climate change-Bandung City is to try to control the increase in temperature due to human and vehicular activities with road network systems and design, drainage system management, flood control, and the implementation of public roads in Bandung City [29, 32].

Makassar City with increasing hot weather, flooding due to increased rainfall, rising sea levels which have a sinking impact on coastal land, increasing CO₂ due to human and vehicle activities, and difficulty of going to sea for coastal communities due to high sea waves is a challenge for the government of Makassar City due to the impact-climate change. Makassar City is located between 119° 24' 17" 38" East Longitude and 5° 08' 06" 19" South Latitude which is in the coastal area. With the height of rainwater falling on a flat place, the assumption is that it does not evaporate, does not seep, and does not flow. 1 mm of rainfall is 1 mm of rainwater that falls (is collected) on a flat area of 1 m² assuming that nothing evaporates, flows, or seeps. One month's cumulative rainfall is the amount of rainfall accumulated over 28 or 29 days for February and 30 or 31 days for other months [30]. These geographical conditions make Makassar City vulnerable to global climate change [20, 33].

The Indonesian government is making pro-environmental policies as a response to the challenges of climate change that are occurring [11, 17, 34–36]. However, policies so far tend to prioritize investments that exploit natural resources and ignore environmental sustainability. Accelerating development at the local level means that the Bandung and Makassar City Governments will not only accelerate normally (business as usual) in carrying out government in all aspects. Bandung and Makassar City as public service cities and smart cities of world standards that are safe, comfortable, and highly competitive with connectivity and contribution to the international network (global chain) towards being resistant to the threat of climate change impacts [32, 33]. Realized by the quality of noble cultural values with technological developments in various public service programs for the community, Makassar City is friendly, polite, and friendly, supporting the use of information and communication technology (ICT) in services and community empowerment and development. The public service program at Sombere in Makassar City & Integrated Population Administration Service Information System (*Sistem Informasi Pelayanan Administrasi Kewilayahan Terpadu*, SIPAKU) in Bandung City is related to hardware or heart devices while smart city is related to hardware and software or hardware and software [37, 38]. It is hoped that Sombere and SPAKU will make Bandung and Makassar City into smart cities that are technology-based and have local cultural characteristics, environmental sustainability, and climate resilience.

The realization of Bandung and Makassar City as resilient cities that can prepare themselves to face and recover when facing future disasters/shocks (economic, environmental, social, and health) to encourage sustainable development and be resilient to the possibility/threat of disasters, including the impact of change climate and the growing number of people living in urban areas [39, 40]. In realizing this, Bandung and Makassar City are pushing for a more transformative and inclusive city that can be enjoyed and felt by all levels of society without discrimination based on age, gender, social status, including disabled groups, as well as reducing social disparities, accelerating innovation and increasing economic growth so that creating equality and inclusiveness [11, 16, 17, 41].

5.2 Synergy of sustainable development in adaptation sustainable through multi-risk governance to climate change in Indonesia

Indonesia boasts a vast landmass and a variety of climates. There are three climatic zones in Indonesia: equatorial, monsoon, and local. The kind of rainfall that happens in the region determines the division. The monsoon type experiences one peak of rainfall in December, January, and February; a dry season occurs in June, July, and August; the remaining six months are a transitional period. The majority of the islands that experience this weather pattern are Java (with six regionals), along with a few locations on Sumatra (with ten regionals) and Kalimantan (with five regionals). The two rainfall peaks of the equatorial type fall in March and October or around the equinox. This area encompasses parts of Papua, northern Kalimantan, and western Sumatra Island. In the meantime, the equatorial and monsoon forms of rain have a different pattern from the local variety that occurs in portions of Papua, the Maluku Islands, and Sulawesi [36, 42, 43].

The breakdown of Indonesia's average air temperature difference between 2020 and 2019 shows a fairly balanced value between rising (red) and falling (blue) temperatures. The southern regions of Java, Sumatra, and Kalimantan as well as Nusa Tenggara Island, the Maluku Islands, and West Papua experienced an increase in temperature. Certain areas of Java, Sumatra, and Sulawesi, which are in the northern hemisphere, experienced a drop in temperature. The Moez Kilangan–Mimika Meteorological Station recorded the most temperature drop (−0.4 °C) and the West Seram Climatology Station recorded the largest temperature increase (1.3 °C). As shown in Fig. 3, the global warming phenomena, Indonesia

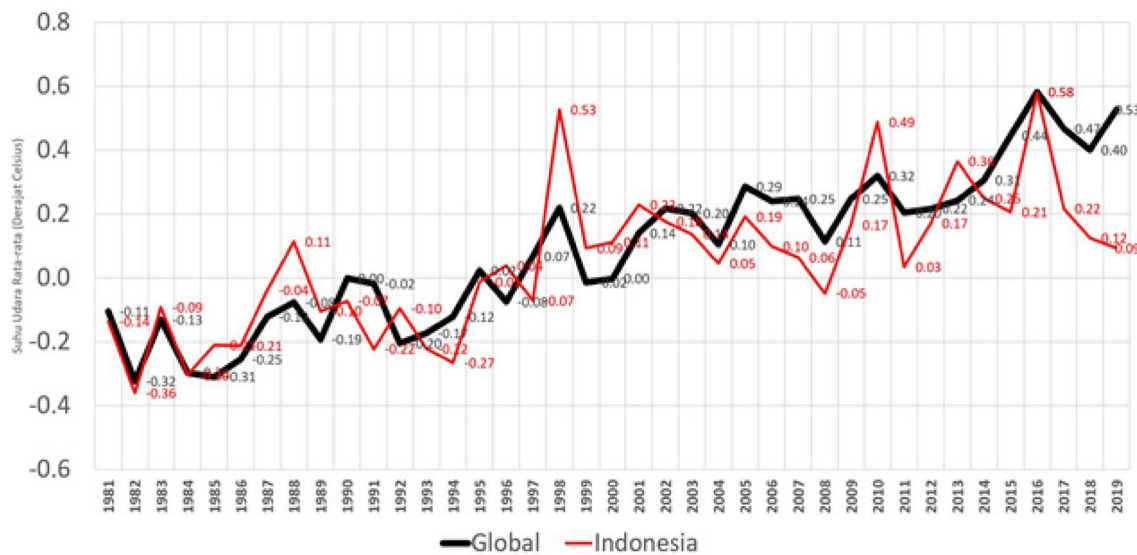


Fig. 3 The upward trend of global and Indonesian temperatures between 1981 and 2020. Source: Taken from Unicef (2023), 2024

is also experiencing an increase in air temperature. When the average temperature for the world and Indonesia is compared to the average temperature for the years 1981–2020, the two tend to be higher [36]. This is in line with the trend of conditions in Bandung and Makassar City which are experiencing an increase in temperature.

Based on Fig. 4 above, it shows annual temperature changes from 2010 to 2022. Temperature data is presented with two parameters, namely surface temperature and temperature at 2 m, both of which show the same pattern. From the results of temperature analysis in Bandung and Makassar City, in general, the temperature change pattern is the same every year. For the city of Bandung, the average temperature is 22 °C and Makassar City is 28 °C. From the picture above, a fairly clear increase in temperature can be seen from 2014 to 2016.

Based on Fig. 5 above, explains the pattern of changes in rainfall in the two cities of Bandung and Makassar. In the city of Bandung, there is a fluctuating pattern of changes in rainfall. Low rainfall occurred from 2009 to 2015. Meanwhile, for

Fig. 4 The trend of increasing Bandung and Makassar temperatures (2010–2022). Source: Taken from NASA-Power Data (2023), 2024

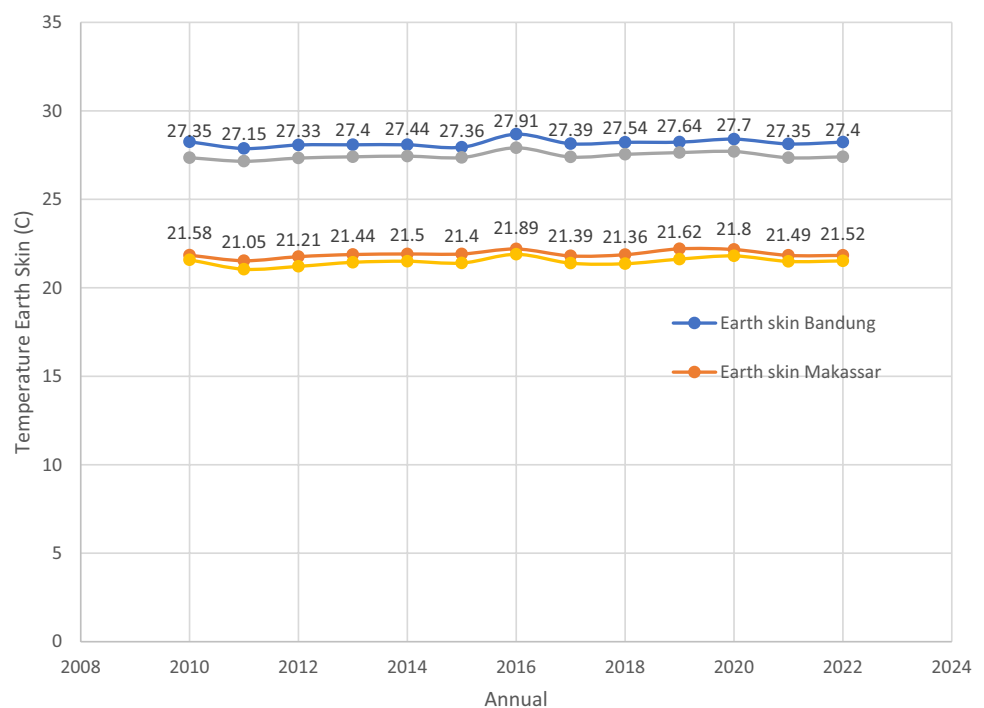
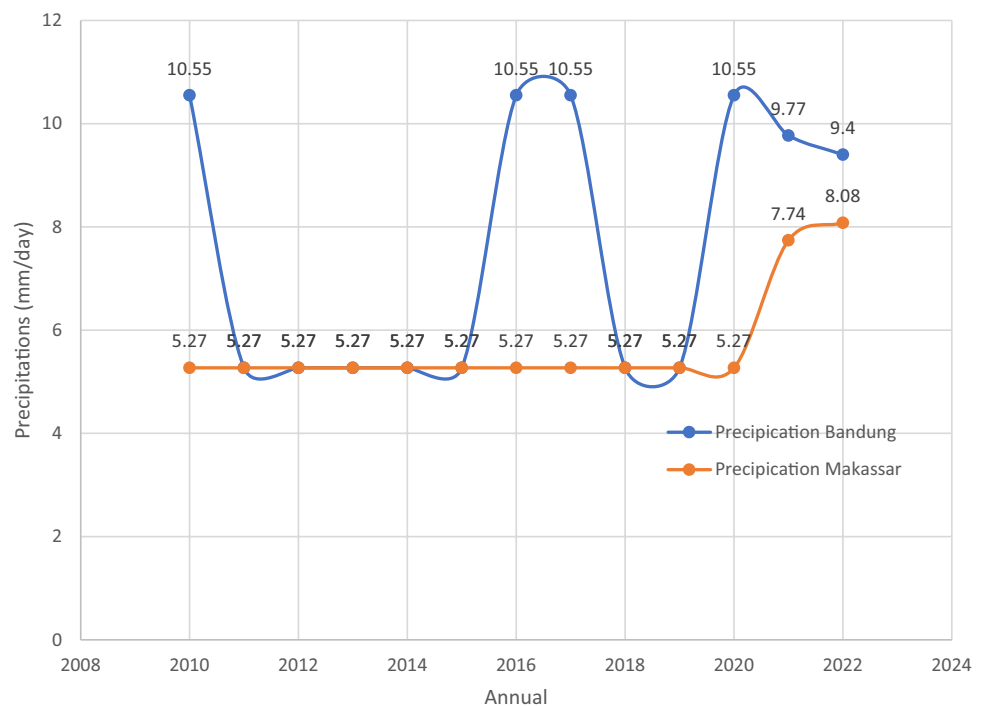


Fig. 5 The trend of increasing Bandung and Makassar precipitation (2010–2022). Source: Taken from NASA-Power Data (2023), 2024



the city of Makassar, rainfall is relatively the same every year and will only increase in 2021. If aligned with sustainable adaptation actions, these conditions can refer to research from van Noordwijk et al. [44] stated that the climate changes occurring in Africa and Asia (Indonesia), are closely related because of the existing forestry-agriculture dichotomy and create space for a continuum of landscape land use in their management it is necessary to emphasize the multifunctionality of land and water management for all SDGs goals, also further knowledge of man-made and natural disasters, encouragement of group efforts, and active involvement in the value chain. Research from Abbass et al. [45] stated that To better understand the problem of the impacts of climate change, it is very important to study various climate change mitigation and adaptation approaches throughout the world in important sectors by various stakeholders. The results of this study also demonstrate that government engagement is required for long-term growth by holding previous legislation and resources strictly accountable to create state-of-the-art climate policies. Consequently, the top priority must be to mitigate and address the negative effects of climate change. The global threat posed by these effects calls for cooperation at all levels, including the individual, local, state, regional, and global, to overcome these effects and ensure wider survival. According to research by Chowdhury et al. [46], discovering and launching current adaption solutions and putting them into practice in the appropriate settings will be key to solving the climate change challenge. This is done in order to prepare for worst-case scenarios and get beyond barriers when addressing the effects of climate change in different nations. As a result of rising exposure levels and the frequency of natural disasters, a large number of people are compelled to relocate from one location to another. This occurs because barriers to sustainable adaptation as well as human activity itself are major contributors to environmental degradation in many circumstances. From January 1-February 15, 2024, there were 292 natural disasters in Indonesia due to the impact of climate change that occurred in Indonesia. This resulted in 20 fatalities, 40 people injured, 1,099,485 suffering and 87,592 displaced, 10,994 houses damaged, 9 educational facilities damaged, and 16 health facilities damaged [47]. The implementation of sustainable adaptation measures, a lack of awareness of vulnerability, and disregard for the needs of local communities are further barriers to climate change adaptation. Other issues include inadequate program and policy integration, climate change adaptation and mitigation, and disaster risk management.

A methodology for understanding how ecosystems and socioeconomic sectors mediate these linkages is proposed by Fuldauer et al. [48], providing a more comprehensive understanding of how climate change affects 169 SDG targets. The framework's global application demonstrates that to ensure that the SDG target of 68% of short-term climate risks being met by 2030 is achieved, an adaptation-wetlands, rivers, agricultural land, construction, water, energy, and housing in the most vulnerable nations is required. Research from Yang et al. [49] states that adaptation is becoming increasingly urgent in the ever-changing face of climate change, particularly in developing nations is expected to bear

the most severe impacts due to climate change. Based on a concise overview of the literature on adaptability and the effects-climate change, this study proposes that Industrial Ecology (IE) can be crucial in the following two areas. First, by emphasizing a systems approach, IE can assist us in figuring out how our socioeconomic systems interact with climate change and how those interactions might intensify (or lessen) its direct effects, or whether they might shift the burden to other environmental concerns. Second, we may achieve sustainable adaptation by measuring the direct and indirect-environmental impacts-adaptation actions and identifying chances for mitigation with the use of the Industrial Ecology (IE) technique. Research from Gruda et al. [50] suggests modifications for winter production, including more natural and artificial light, sufficient cooling, and both. Along with structural options like passively ventilated greenhouses and screen houses, technical and conceptual improvements like semi-enclosed greenhouses based on mechanical cooling and dehumidification are considered. To deal with anomalous climate changes and harsh weather conditions linked to climate change, the study also suggests modifications in terms of cultivar selection, greenhouse type, covering materials, cultural practices, and production methods. According to research by Taylor [51], political ecology insights offer a crucial means of advancing the discussion on climate change adaptation and human security. Although the present perspectives on human security are useful in placing efforts to adapt to climate change within social justice concerns, they are inadequate in offering suitable analytical tools for understanding the connections between power, inequality, and vulnerability.

Insights from political ecology and climate change adaptation frameworks are applied to identify the relational dynamics of vulnerability, or the ways marginalized communities are inserted into political, social, and economic relationships that generate vulnerability, to address gaps in climate action in Bandung and Makassar City, Indonesia. They also give others a sense of relative security at the same time. Several inadequacies and opportunities for improvement in sustainable adaptation to the impacts of climate change in Indonesia were discovered after the identification and analysis of numerous documents for managing the effects of climate change in Indonesia, numerous scientific publications, and numerous policies, especially in Makassar and Bandung Cities, as shown in Table 2.

Several studies that focus on Sustainable Mitigation of Climate Change in Indonesia, in the last 5 years, mention several challenges and shortcomings in climate change governance in Indonesia. Among them, The government of Jokowi Widodo and the government of former president Susilo Bambang Yudhoyono in Indonesia used different approaches, according to Alisjahbana and Busch [59]. They also question whether Indonesia's resources, actions, and budgeted results to date are commensurate with its commitment to mitigating climate change in Indonesia. According to research by Bohensky et al. [60], creating policies for climate adaptation in Indonesia requires a strong personal commitment to the issue of climate change. According to research by Djalante et al. [52], Indonesia's physical, socioeconomic, and geographic characteristics make it one of the nations most susceptible to climate change. Research conducted by Tickamyer and Kusujarti [61] also states that Indonesia is vulnerable to natural disasters due to climate change and offers a public participation approach to gender in climate change planning and action. Research conducted by Abdillah et al. [17] stated that cities in Indonesia face the threat of vulnerability due to climate change and advised the Indonesian government to encourage sustainable adaptation in climate change actions in Indonesia. In line with research from Prianto and Abdillah [16] states that managing vulnerability due to climate change in Indonesia needs to be encouraged in sustainable adaptation to climate change actions that increase community resilience.

The findings of the impact-climate change in Bandung and Makassar City, Indonesia have increased air temperature, and increased flood disasters due to increased rainfall in the last 4 years in these two cities. This is due to several obstacles such as limited access and the availability of sufficient data in urban mitigation and adaptation, reporting and recording systems that are weak and not yet standardized regarding the impacts-climate change in Bandung and Makassar City, Indonesia, and various impacts resulting from impact management policies. Climate change in Indonesia is not widely interpreted properly in various cities in Indonesia, especially in Bandung and Makassar City.

Multi-risk governance in supporting urban resilience and sustainable adaptation in Indonesia still needs to involve a comprehensive approach that integrates various elements to enhance the ability of cities to withstand and recover from multiple risks. This method incorporates multi-risk governance, which is crucial to comprehending how governance and institutional frameworks, personal assessments, and the dissemination of risk assessment outcomes impact decision-making procedures [53, 58, 62, 63]. By uniting formal and informal institutions and individuals across various scales to envision collaborative sustainable and resilient environmental outcomes, multi-risk governance for sustainable adaptation for enhancing urban resilience in Bandung and Makassar City plays a crucial role in facilitating strategies for building urban resilience and sustainability at the local level [57].

Bandung and Makassar City can improve urban resilience by implementing strategies like risk assessments, integrating resilience into urban planning, allocating resources for resilient infrastructure, fostering social cohesion, encouraging

Table 2 Disadvantages and Synergies in Sustainability Adaptation through Multi-risk Governance to the Impact of Climate Change in Indonesia

No	Lack of climate change action in Indonesia	Synergy in sustainable adaptation through multi-risk governance to climate change in Indonesia
1	Approaches to climate change action are different in each power regime in Indonesia [16, 52]	It is necessary to encourage a climate change action framework that is aligned with the SDGs and balances the social, economic and ecological sectors [14, 17]
2	Climate change action is not a joint movement for every element in Indonesia [16, 20]	The involvement of various elements and actors in climate change action (such as Industrial Ecology) can help in strengthening systems and methodologies for sustainable adaptation to the impacts of climate change occurring in Indonesia [54–56]
3	Climate change action tends to be a mitigation approach, not a sustainable adaptation movement [53]	Encourage sustainable adaptation, including steps that reduce social vulnerability and increase long-term resilience in the climate crisis in Indonesia [49, 52, 57]
4	There is still a great need for resource and policy support in climate change action in Indonesia [11]	Encouraging understanding of ecological politics in developing a change action framework as a suitable analytical tool climate for conceptualizing the relationship between power, inequality, and vulnerability [58]

Source: Processed from various sources, 2024

economic diversification, utilizing technology and innovation, and fortifying governance structures and collaborations [53, 63, 64]. Governance for urban resilience involves grappling with implementing a complex adaptive systems view—the world within real-world institutional and ecological-environments, emphasizing the importance of multi-scale governance for successful urban resilience governance [55, 65]. Promoting urban resilience requires effective governance frameworks, which include participatory governance and transparent decision-making procedures [66]. Incorporating urban risk and resilience also has to prioritize government funding, expert renovation aid, and traditional authority [67].

5.3 Policy integration in climate resilience governance in adapting to build urban resilience In Indonesia

Concerns about the effects of climate change have grown among governments and the international community, including Indonesia. Indonesia, an archipelagic nation with abundant natural resources and high biodiversity, has a great deal of potential to be negatively impacted by climate change, but it also has a great deal of potential to help mitigate and adapt to those effects [41, 52, 56]. Many people are aware that climate change is a natural occurrence that has scientific explanations and is regarded as such [41, 52]. The Intergovernmental Panel on Climate Change (IPCC) report [68] indicates that the impacts of climate change are becoming more widely felt by humanity in different parts of the world and that the process of climate change is progressing more quickly. This is what has caused the issue of climate change to come to light and become a topic of discussion for many people in the last few decades, specifically after the era of industrialization.

Indonesia has been paying attention to climate change for quite some time, marked by ratifying the UNFCCC in 1994. Now, Indonesia's climate change mitigation policies are outlined in the 2020–2024 RPJMN (National Medium Term Development Plan) Indonesia, especially in National Priority 6, namely developing the living environment, improving disaster resilience and climate change [34, 35]. Apart from that, Table 3 shows the strengths and weaknesses of the Indonesian government's supporting policies in climate governance which have negative impacts on various cities in Indonesia, including Bandung and Makassar City.

Geographically, Indonesia is situated in a region that is highly susceptible to the effects of climate change [41, 52]. According to estimates, Indonesia's average temperature will rise by 0.5–3.92 degrees Celsius by 2100 compared to 1981–2010 conditions [42]. In the meantime, there has been a change in the number of rainy and dry months according to observational data [42]. The northern regions of Sumatra and Kalimantan experience higher rainfall intensity and shorter rain durations, whereas the southern regions of Java and Bali experience lower rainfall and longer rain durations [42]. According to projections, sea level rise from climate change will reach 35–40 cm by 2050 compared to 2000 values [42].

Indonesia's 13th national goal (the Sustainable Development Goals) calls for immediate action to combat climate change. In order to meet the 2030 national goal for addressing climate change, five targets have been established, with eight indicators serving as a gauge [34, 35]. These goals include mitigating and adapting to climate change, decreasing the number of people killed in disasters, and disaster risk reduction (DRR). The policies, programs, and initiatives that the government and non-government organizations will implement detail the efforts undertaken to accomplish these goals [34, 35]. To realize goal 13 of handling climate change, the Bandung City Regional Government and the Makassar City Government are based on the strategy: (1) Management of environmental pollution and damage (2) Disaster risk reduction, with policy directions: (1) Management of environmental pollution and damage (2) Comprehensive disaster risk reduction. The Regional Government of Bandung City in the 2017–2022 RPJMD Document and the Makassar City Government in the 2021–2024 RPJMD Document, set targets (indicators) and strategies for adapting climate change governance according to Indonesia's national goals, namely: (1) Increasing the capacity of government human resources; (2) increasing human resource capacity; (3) increasing cross-sector coordination regarding climate change control programs; (4) enforcement of rules or regulations; and (5) updating data and information about climate change conditions [39, 40]. Based on policy directions that are in line with achieving Goal 13 of the TPB, programs related to strengthening capacity and institutions related to risk reduction due to climate change and natural disasters will be implemented by the Regional Government of Bandung City and the Regional Government of Makassar City which includes (1) Prevention and Preparedness Program Disaster; (2) Emergency Management and Disaster Logistics Program; (3) Post-Disaster Rehabilitation and Reconstruction Program [34, 35]. We underline that, from the various initiatives and strategies in Indonesia's future national development policies and plans, multi-risk governance strategies in supporting urban resilience and sustainable adaptation still require a holistic approach that includes adaptive governance, risk assessment, resilient infrastructure, social cohesion, technology utilization, and strong governance structures to enhance cities' ability to withstand and recover from various risks (See Fig. 6).

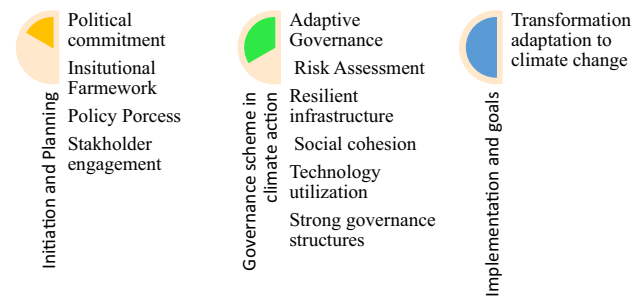
Based on Fig. 6, a complete strategy has to incorporate multiple components to enhance the city's resilience to diverse dangers. Therefore, one approach to sustainable adaptation in Makassar City and Bandung City, Indonesia, to mitigate

Table 3 Climate Governance Policies From Indonesia climate policy

No	Climate change regulations in Indonesia	Advantages (Content of the policy)	Disadvantages (Content of the policy)
1	The Paris Agreement on the United Nations Framework Convention on Climate Change (Paris Agreement on the United Nations Framework Convention on Climate Change) was ratified by the Republic of Indonesia Law Number 16 of 2016	<ul style="list-style-type: none"> • This policy aligns Indonesia's national goals with the UN's SDGs agenda in facing the global climate crisis • As a commitment and effort to face the risks of climate change and increase regional protection against the impacts of climate change in Indonesia 	<ul style="list-style-type: none"> • Lack of a climate change action framework in sustainable adaptation in protecting areas affected by climate change such as in Bandung and Makassar City • Financial and policy support is still needed for climate change action in various regions such as Bandung City and Makassar City • There is still a need for understanding and awareness of the threat of climate change and support for public participation in climate change action in Indonesia
2	Regarding Bandung City Regional Spatial Planning (RTRW) for 2022–2042, see Bandung City Regional Regulation Number 5 of 2022	Area management based on regional needs	<ul style="list-style-type: none"> • There are still weak strategies and frameworks for dealing with the impacts of climate change occurring in Bandung City
3	Makassar City Regional Spatial Planning (RTRW) 2015–2035 is governed by Regional Regulation (Perda) Number 4 of 2015	Area management based on regional needs	<ul style="list-style-type: none"> • There are still weak strategies and frameworks for dealing with the impacts of climate change occurring in Makassar City

Source: Processed from various sources, 2024

Fig. 6 Model Multi-Risk Governance strategies as a sustainable adaptation in Indonesia



the adverse effects of climate change involves a range of climate actions, including multi-risk governance, about which it is crucial to comprehend the ways in which individual assessments, institutional and governance structures, and the communication of risk assessment results impact the decisionmaking process. This multi-risk governance aims to increase urban resilience in Bandung and Makassar City by bringing together formal and informal institutions, individuals, and groups at different scales to collaboratively realize resilient and sustainable environmental outcomes. This plays a significant role in facilitating strategies to build urban resilience and sustainability at the local level. In order to successfully manage urban resilience and achieve sustainable adaptation to the adverse effects of climate change for Indonesia in the future, multi-risk governance highlights the significance of multi-scale governance. This entails applying a complex adaptive systems view of the world to actual institutional and ecological environments.

In summary, while climate change governance strategies and adaptation sustainability through multi-risk governance in Indonesia have the potential to address environmental and social inequalities through inclusive and targeted approaches, there are significant challenges that can perpetuate these inequalities. Policymakers must be aware of these dynamics and strive to create governance frameworks that genuinely promote equity and resilience for all communities, particularly the most vulnerable. We also believe that the current exploration between stakeholders in the sustainable conservation process in Indonesia requires a multi-faceted approach that includes collaboration, capacity building, and inclusive decision-making. With strong relationships between local communities, government, NGOs, and civil society, Indonesia can increase its resilience to climate change and ensure effective, equitable, and sustainable adaptation strategies.

The key ways that can be implemented in policy practice by policymakers in Indonesia:

- **Integration of Multi-Risk Governance:** Policymakers are encouraged to adopt a multi-risk governance approach that integrates various sectors and stakeholders. This involves enhancing cross-sector coordination and collaboration among government agencies, local communities, and private sectors to address the multifaceted challenges posed by climate change.
- **Capacity Building:** There is a strong emphasis on increasing the capacity of human resources within government agencies. This includes training and development programs aimed at equipping officials with the necessary skills to manage climate-related issues effectively. Policymakers are urged to allocate budgets for capacity-building initiatives to ensure that staff can handle the complexities of climate governance.
- **Public Participation and Awareness:** The research underscores the importance of public participation in climate adaptation strategies. Policymakers are encouraged to engage communities in decisionmaking processes and raise awareness about climate change-impacts and adaptation measures. This can be achieved through workshops, public forums, and educational campaigns.
- **Data and Information Systems:** Implementing robust data collection and management systems is crucial for effective climate governance. Policymakers are advised to establish standardized reporting and recording systems to monitor climate impacts and adaptation efforts. This data-driven approach helps in making informed decisions and formulating effective policies.
- **Policy Frameworks and Regulations:** The research suggests that existing climate governance policies need to be reviewed and strengthened. Policymakers are encouraged to develop comprehensive frameworks that outline clear actions for climate adaptation and resilience building. This includes updating regulations to reflect current challenges and integrating climate considerations into urban planning and development.
- **Goals for Sustainable Development (SDGs) Alignment:** It is recommended that local climate policies be in line with the Sustainable Development Goals (SDGs) of the United Nations. This alignment promotes a comprehensive approach to sustainability by ensuring that efforts related to the climate also contribute to more general development goals.

6 Conclusion and future research directions

Climate change in Indonesia currently poses challenges to sustainable development in the social and economic environment as well as to achieving Indonesia's development goals. To overcome this, the Indonesian government needs to immediately integrate climate change mitigation and adaptation into a social development planning system that is more adaptive and climate-resilient. Disaster trends due to the impact of climate change are currently frequently occurring in Bandung and Makassar City, such as rising air temperatures, increasing rainfall and urban population growth, to urbanization which increases CO₂ due to vehicles, which are challenges faced in Bandung and Makassar City.

The results of this study show that the impact of climate change in Bandung and Makassar City, Indonesia has caused an increase in the potential for erosion, reduced wetlands along the coast, an increase in the rate of seawater intrusion, a decrease in food production, damage to infrastructure, a reduction in clean water sources, an increase in respiratory diseases, floods, droughts, and other hydrological disasters. This has resulted in many climate approaches and actions being taken to respond to the impact of climate change in Indonesia, the results of which are still not optimal. This study suggests a sustainable adaptation approach to climate action in Bandung and Makassar City which prioritizes social justice and environmental integrity so that it has a real impact on community vulnerability and environmental damage due to the impacts of climate change. In addition, the multi-risk governance strategy to improve urban resilience to the impacts of climate change is a proactive and participatory approach that integrates multiple stakeholders, recognizes the interconnected nature of risks, and operates at multiple scales to increase resilience and improve decision-making in the face of complex and cascading disasters.

According to research, there are some challenges when putting adaptation plans into action and reducing the effects of climate change. This includes a lack of funding, sectoral egoism, poor public engagement and knowledge, and inadequate human resource capacity in government agencies to address Bandung's and Makassar City's climate issues, Indonesia's geographical location on the equator and flanked by two oceans, the Pacific and Indian make Indonesia vulnerable to climate change, and climate change adaptation policies in the implemented are still half-hearted. The most significant strategies that have been put into practice in Indonesia include strengthening government human resource capacity, strengthening human resource capacity, enhancing cross-sector coordination related to climate change control programs, enforcing rules or regulations, and updating data and information about climate change conditions in Bandung and Makassar City. The Indonesian government can better equip itself to deal with future hazards resulting from the effects of global climate change by implementing the multi-risk governance strategies approach as a sustainable adaptation.

The limitation of this study is that it only investigates two cities in Indonesia, namely Bandung and Makassar City. Several cities have different situations in facing the impact of climate change that is occurring in the world. So this study suggests that future researchers conduct research in various other cities in Indonesia to complement this study in dealing with climate change and vulnerability in the context of encouraging urban resilience and sustainability.

In the context of the digital transformation era, future research directions on sustainable adaptation through multi-risk governance are increasingly vital. The integration of digital technologies into governance frameworks can enhance the capacity to manage multiple risks associated with climate change and other environmental challenges. This integration necessitates a shift towards more participatory and networked governance structures that leverage digital tools for stakeholder engagement and data sharing. One promising avenue for research is the application of network analysis to assess and improve multi-risk governance frameworks. Which emphasizes the importance of an integrated, holistic approach to risk management that encompasses all phases from prevention to emergency response, highlighting the need for participation from a diverse range of stakeholders.

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Declarations

Competing interests The authors declare no competing interests.

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