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Vulnerability of the Semarang Heritage Area to Climate Change

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ABSTRACT

Semarang is a coastal city with many historical buildings as a relic of past civilisations. Along with the recent worsening of climate change, these historic structures are in danger of damage. If this condition persists, historic buildings will be lost. This study aims to determine the vulnerability of historic buildings in four different landscape conditions to climate change indicators, such as temperature, air quality, object shading, activity level, and vegetation. The analysis process on the sample measurement data is in the form of vulnerability identification based on landscape characteristics via climate parameters, followed by the final assessment process of environmental adaptability and vulnerability level of historic buildings using the Range Analysis Method (RAM). A standardisation approach to the value of each indicator strengthens this. The spatial approach method was carried out on the final results of the vulnerability assessment to produce a Vulnerability Map for the Semarang Heritage Area. The outcomes obtained in the form of community beliefs and habits significantly impact the building maintenance level. Locations with a solid attachment for trade and religious activities are more likely to care for historic buildings. The influence of regulations and the government's commitment to handling the impacts of climate change is also very influential in reducing the value of vulnerability in the Semarang Heritage Area. Locations close to the coast tend to have a low level of vulnerability due to the high focus on environmental management in these locations.

Keywords: Adaptation, climate change, heritage area, vulnerability

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INTRODUCTION

The world is entering the highest phase of extreme climate change, which has various impacts on human life. Issues of environmental damage are always associated with the phenomenon of

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increasing air temperature due to damage to the ozone layer. Since 1880, the Earth's surface temperature has risen by 0.08°C every decade and is predicted to grow (Heshmati, 2020; Lindsey & Dahlman, 2024). The increase in global temperature is expected to increase sharply until 2101 and is very likely to produce severe impacts in various parts of the world (see Figure 1). This occurs because of an imbalance between solar radiation and the ability of the atmosphere to absorb radiation toward the Earth. Global issues regarding the impacts of this phenomenon are widespread. However, many sectors still change the function of green land into buildings without considering the long-term impact on the preservation of the Earth (Ahima, 2020; Hsiang & Kopp, 2018; McMichael & Lindgren, 2011; Wu et al., 2016).

The Earth's surface temperature increase causes various disasters, such as tidal waves in coastal areas that threaten ecosystems (Cook et al., 2016; Lelieveld et al., 2016; Schilling et al., 2020). Coastal areas have the highest vulnerability to climate change impacts on Earth (Harley et al., 2006). He and Silliman (2019) stated that coastal areas with high-density levels are threatened with damage due to climate change. This is because coastal communities depend on marine conditions and the surrounding environment to meet their needs. High tidal waves, coastal abrasion, and tidal flood inundation are getting worse due to uncertain climate change, causing a decrease in catches and damaging residential infrastructure.

Some countries also face difficulties preserving cultural heritage areas, particularly those near the coast, because historic structures are particularly vulnerable to tidal waves and flooding. This is also supported by several previous studies which found that cultural heritage is very vulnerable to climate change phenomena such as extreme weather, sea level rise, flooding, coastal erosion, and others

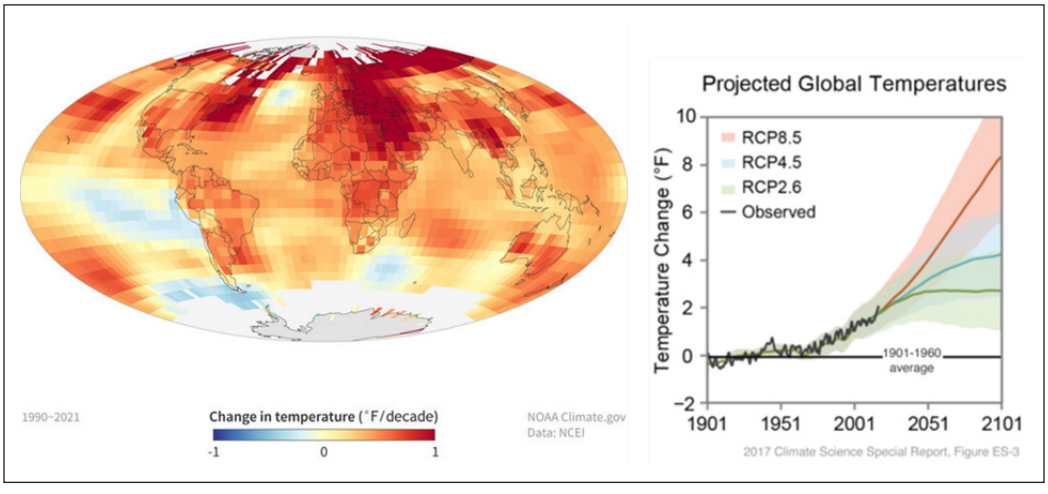

Figure 1. Climate Change: Global Temperature (Source: Lindsey & Dahlman, 2024)

(Gomez-Heras & McCabe, 2015; Leissner et al., 2015; Reeder-Myers, 2015; Ronco et al., 2014). Based on this, comprehensive planning steps are needed to minimise the damage caused by the environmental, economic, and sociocultural aspects.

Indonesia has a relatively high green area and is called one of the "World's Lungs." It is a country with the second-largest forest area in the world (Menlhk, 2016). The extent of forest areas in Indonesia is one of the potential sources of O2 production that can minimise solar radiation due to climate change. Based on data obtained from WorldClim in the Ministry of Environment and Forestry (2020), most regions in Indonesia have an average air temperature of 22°C–26°C, and in the highlands, the temperature reaches 16°C–20°C. For approximately 30 years (1991–2020), various regions in Indonesia have experienced an annual increase in air temperature of 0.01°C–0.06°C.

The rise in global temperatures affects heritage properties and will become even more dangerous in the future (World Heritage Committee, 2006). Climate change threats on 46 Cultural World Heritage sites were reported, and the result shows that almost all cultural sites mentioned were "human-built structures," such as archaeological ruins, churches, mosques, temples, and fortresses. Cultural heritage objects must be protected and saved because they have a high historical value for the development of a region. On the other hand, research on the impact of climate on cultural heritage is still limited for countries in Africa, Asia, and South America because it is still concentrated in the United Kingdom and the United States (Fatorić & Seekamp, 2017).

Based on this, this study aims to determine the vulnerability experienced by Heritage Areas in Semarang City and provide relevant recommendations. The concept of Climate Sensitive Urban Design (CSUD), supported by the theory of vulnerability and resilience of historic heritage sites, is the basis for this research. The urgency to plan resilient historic heritage sites in accordance with United Nations Educational, Scientific and Cultural Organization (UNESCO) directives is the background of the research objectives. The interesting thing found in this study is that each location has unique characteristics in the form of ethnic elements such as European, Chinese, Malay, and Pakistani. Therefore, this study is expected to find the vulnerability characteristics to certain climates in each heritage landscape to prepare recommendations for climate change adaptation.

Vulnerability of Heritage Areas to Climate Change

The results of a systematic review conducted by Fatorić and Seekamp (2017) found that many studies on the influence of climate on cultural heritage began in 2003 and have increased due to several findings about the resulting negative impacts. For example, the results of Sabbioni et al. (2006, 2008) produced a guide to climate change adaptation for cultural heritage in Europe by practising improved monitoring, maintenance, and preparedness against

floods and landslides. Grøntoft (2011) recommends adopting building materials or cultural heritage areas to minimise the impact of solar radiation and increase the area's humidity.

In recent decades, Climate Sensitive Urban Design (CSUD) has been widely used to modify urban landscapes to adapt to climate change. CSUD is a planning concept on a regional scale designed to address the need for environmental adaptation due to the impacts of climate change (Emmanuel, 2005; Kurniati et al., 2021). This approach can be used to assess the potential for adaptation that can be applied to various forms of urban landscapes, such as the landscape of cultural heritage areas. Indicators that can be assessed in CSUD include sunlight (radiation level), wind speed, air temperature, shadow, air quality, wind direction, and land cover (vegetation and material), among others (Hakim, 2013; Kurniati et al., 2020; Lakitan, 2004; Oke, 2006; Shashua-bar & Hoffman, 2003; Yu & Hien, 2009). Certain locations may have different indicator adjustments based on differences in geographical conditions or community characteristics. New research may lead to adjustments in indicators due to the highly dynamic climate cycle.

The components or indicators that exist in the CSUD concept are the basis for this research. Forms of adaptation in accordance with the landscape conditions of the historic area in the CSUD concept proved linearly can improve outdoor thermal comfort as well as a form of physical preservation of heritage areas (Kurniati et al., 2023). This is supported by research conducted by Adger (2006) and Turner et al. (2003), which states that vulnerability theory is important for understanding how historic heritage sites are affected by climate change. In terms of sensitivity, historic heritage sites are particularly sensitive to climate change due to their specific material conditions and historic value. For example, rising sea levels in coastal cities like Semarang City and extreme weather can damage historic buildings. The concept of CSUD, in this case, relates to the resilience theory of historic heritage sites as a measure to create systems to withstand and the ability to recover from climate-induced disturbances (Folke, 2006; Walker et al., 2004). This theory also explains that the adaptive capacity of the community to plan and implement adaptation strategies is also indispensable to enhance resilience. In line with the indicators in the CSUD concept, climate resilience theory encourages using various strategies, including physical engineering solutions, while adhering to the requirements for altering historic heritage sites.

The high vulnerability of historic areas to climatic conditions has led UNESCO to issue a list of recommended areas for protection by future generations (Sesana et al., 2020; UNESCO, 2013). European countries are focusing on the vulnerability of historic areas to climate change. The factors of climate influence on the vulnerability of heritage areas are very diverse. Hence, environmentalists and historians recommend using vulnerability

assessment as a tool to measure the impact that climate change has on historic areas. The Vulnerability Assessment Framework (VAF) can also incorporate participatory planning from various stakeholders and identify the physical conditions of historic areas (Sabbioni et al., 2010).

The vulnerability of historic districts in Indonesia is an increasingly researched issue. Many factors contribute to the loss of historic areas in Indonesia, with environmental conditions being a key factor. As a tropical country, Indonesia experiences high humidity in the outside air, which can threaten historic building materials. The high vulnerability of cultural heritage in Indonesia is attributed to the fact that most sites are in the open air and are directly exposed to water and weather conditions such as temperature, humidity, and wind (Table 1).

The Borobudur Temple Cultural Heritage site is affected by various factors such as climate, water temperature, radiation, evaporation, air pollution, water, disasters, destruction, displacement, and others. Historical records show climate change has threatened the temple for around 1,200 years. Data from the Indonesian Climatology Agency indicates that the surface temperature in the temple area can reach 38°C, leading to weathering and flattening of the temple stones (Megarani, 2022). This vulnerability is also a concern for many other historic sites in Indonesia, potentially leading to the loss of these sites in the future.

METHODOLOGY

Semarang Heritage Area

The research was conducted in four areas of the Cultural Heritage of Semarang City, Indonesia. Semarang is known for its rich ethnic diversity, reflecting the lives of Europeans, Chinese, Malays, and Pakistanis in its cultural heritage buildings. The research areas represent the amalgamation of these

Table 1
Indicators of climate change adaptation in cultural heritage areas

Num	Indicators	Sources	Parameter
1	Temperature (°C)	Koch-Nielsen (2002), Koerniawan (2015)	The daily outdoor air temperature in a location
2	Air Quality (Aqi)	Kurniati et al. (2021)	Air quality is measured using the Air Quality Index (Aqi) on a particular scale.
3	Shadow (m)	Yeang (2006)	Measure the daily average shadow length from morning to evening on buildings and vegetation.
4	Activity Density	Kurniati et al. (2021)	The density of area activities and types of activities owned.
5	Vegetation	Hakim (2013), Lakitan (2004), Yu & Hien (2009)	Distribution of vegetation around the landscape by looking at the type and ability to produce shade (shade) and vegetation density.

ethnicities and their historical significance: Old Town (Europe), Chinatown (Chinese), Kampong Melayu, and Kampong Pekojan, each with distinct landscape characteristics. Located near the coastal zone of Semarang City, these areas are characterised by high activity density. Each location has a unique historical narrative, depicting Semarang as a significant trade centre and seaport in the past. Due to their historical and cultural significance, these locations are popular tourist destinations in Semarang.

Kampong Melayu is situated in the northern part of Semarang District and is characterised by buildings used primarily as residential areas (Febbiyana & Suwandono, 2016). Due to the Malay people's affinity for sailing, this location is close to the Semarang River (see Figure 2). On the other hand, the Old City area is known for its colonial buildings, symbolising European influence. This area is a popular historical tourist destination in Semarang City and has been designated as a World Cultural Heritage site by UNESCO (Prabowo & Harsritanto, 2018).

Kampong Pekojan is a symbol of the life of the Pakistani community in Semarang City. It proudly maintains its traditions and culture through various community

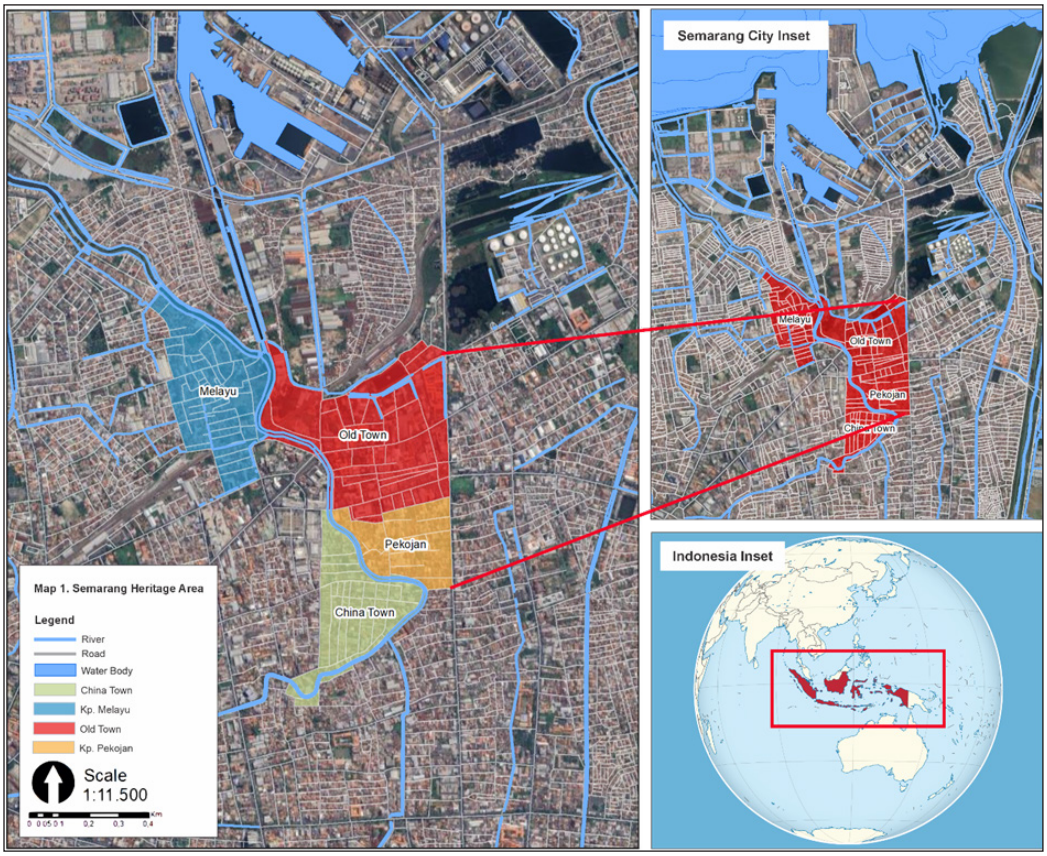

Figure 2. Study location: Heritage area of Semarang

activities. This location consists of a row of shops and residential neighbourhoods, predominantly engaged in trading activities, which is a major attraction (Kurniasari & Nurini, 2016). What makes this community unique is its blend of several ethnic groups, including indigenous Indonesians, the Koja ethnic group (Pakistani Tribe), and Chinese residents (Wahjoerini & Handayani, 2020). On the other hand, Semarang's Chinatown is a Chinese settlement characterised by a row of shops serving as a commercial centre. The area is still home to a thriving ethnic Chinese community, earning it the nickname "Land of a Thousand Temples" due to its large number of operational temple buildings.

The four Cultural Heritage Areas were selected as research sites due to their unique characteristics as symbols of diversity and high tolerance in Semarang. These areas also exhibit diverse environmental factors and physical building arrangements, which could lead to varied responses in the context of climate change.

Data and Methods

Data was collected in 2022 at four locations in Semarang: Kampong Melayu, Kampong Pekojan, Chinatown, and Old Town. The collected data primarily focused on measuring indicators to assess climate conditions. These indicators included temperature, air quality, object shadowing, activity density, and the presence of vegetation. The assessment of these indicators was carried out at three sample points. Additionally, field observations were conducted to identify the vulnerability or damage experienced by historic buildings in Semarang. The collected data went through several synthesis processes before being used as the basis for analysis.

This study utilised a qualitative approach to conduct a detailed analysis of the data collected. The analysis involved describing vulnerable conditions based on field observations and evaluating climate change indicators using the Range Analysis method to categorise the characteristics of climatic conditions in different historical landscapes. Table 2 outlines the process of determining the analytical scale or parameters, taking into account various factors, such as assessing the temperature component based on the humidity index limit in coastal areas, which ranges from 21°C to 27°C (Laurie, 1990; Stathopoulos et al., 2004).

The International Air Quality Index measures air quality. It is calculated using a formula that considers the highest and lowest values, shadow length, and activity density. Additionally, the vegetation indicator describes the landscape's condition based on vegetation type and density. The overall indicators are grouped into Good (score 2) and Poor (score 1). Finally, the average level of vulnerability in four Semarang Heritage Area locations is visualised on a map.

The research data was collected over three five-days periods: 10:00 AM, 12:00 PM, and 4:00 PM. The initial data collection process lasted about 12 hours, from 8:00 AM to 6:00 PM. The results were obtained by categorising climate conditions based on three general characteristics at each data

collection station in the Semarang Heritage Area. The chosen times were representative of the overall conditions. The sample data collection stations were selected based on important locations in the study area. The data used for the research analysis can be found in Table 3.

Table 2
Climate condition assessment model in Semarang Heritage Area

Num.	Indicators	Description	Study Scale	Value*
1	Temperature (°C)	Based on the Humidity Index level, the comfortable temperature limit for activities with air temperature is less than 27°C (Laurie, 1990; Stathopoulos et al., 2004).	Poor: >27°C	1
			Good: ≤ 27°C	2
2	Air Quality (Aqi)	Based on the World Air Quality Index, the air quality scale is as follows: 0-5 = Healthy 5-100 = Medium 101-150 = Unhealthy for Sensitive Groups 151-200 = Unhealthy 201-300 = Very Unhealthy (Alqausar, 2019).	Poor: >100	1
			Good: ≤ 100	2
3	Shadow (m)	Shadow measurement is based on the accumulation of the highest value and the lowest value (value interval) during field data collection.	Poor: < 5.10 m	1
			Good: ≥ 5.10 m	2
4	Activity Density	Based on the characteristics and density scale of field data collection results.	Poor: High Density	1
			Good: Low Density	2
5	Vegetation	Used for a complementary description of the components of climate adaptation. The location with the most shade vegetation is the best.	Poor: High Density	1
			Good: Low Density	2

Note. The meaning of value is getting closer to 1 (Poor) and 2 (Good). *level of vulnerability

Table 3
Research data of Semarang Heritage Area towards climate change

No.	Sample Point	Time	Temp (°C)	Air Quality (Aqi)	Shadow Length (m)	Activity Density	Activity Type	Vegetation
A. Old Town Semarang								
1	Marba Building	10:00 AM	34.1	96	2	Low	Office	Decorative
		12:00 PM	41.0	105	0.7	Low	Office	Decorative
		04:00 PM	38.9	154	9	Medium	Office	Decorative

Table 3 *(continue)*

No.	Sample Point	Time	Temp (°C)	Air Quality (Aqi)	Shadow Length (m)	Activity Density	Activity Type	Vegetation
2	Koperasi Giri Makmur	10:00 AM	31.3	87	3.3	Low	Empty Building	Shade
		12:00 PM	40.6	105	2.25	Low	Empty Building	Shade
		04:00 PM	37.6	154	7.7	Low	Empty Building	Shade
3	Soesman Kantoor	10:00 AM	31.7	85	1.3	Low	Trade and Services	Decorative
		12:00 PM	38.8	111	0.4	Low	Trade and Services	Decorative
		04:00 PM	37.3	153	10	Medium	Trade and Services	Decorative
B. Kampong Melayu								
4	Layur Mosque	10:00 AM	34.6	87	3	Low	Worship Place	Shade
		12:00 PM	38.8	106	1.4	Medium	Worship Place	Shade
		04:00 PM	35.5	134	3.6	Low	Worship Place	Shade
5	Gerak Cepat Photo Studio	10:00 AM	33.5	83	2.2	Low	Tourism	Shade
		12:00 PM	37.6	98	2	Medium	Tourism	Shade
		04:00 PM	34.2	129	2.2	Medium	Tourism	Shade
6	Rumah Panggung	10:00 AM	33.8	87	2.75	Low	Worship Place	Shade
		12:00 PM	38.3	106	1.7	Low	Worship Place	Shade
		04:00 PM	34.6	134	3.25	Low	Worship Place	Shade
C. Kampong Pekojan								
7	Jami Mosque	10:00 AM	35.2	103	2.2	Low	Worshipping	Shade
		12:00 PM	39.2	115	2.7	High	Worshipping	Shade
		04:00 PM	37.6	144	4.3	Low	Worshipping	Shade
8	Jaya APoori Iron Shop	10:00 AM	33.4	98	1.2	Low	Trade and Service	None
		12:00 PM	35.4	105	0.3	Medium	Trade and Service	None
		04:00 PM	34.2	134	1.9	Medium	Trade and Service	None
9	Boma Shop	10:00 AM	33.2	98	1.1	Low	Trade and Service	None
		12:00 PM	34.2	134	1.9	Medium	Trade and Service	None
		04:00 PM	34.1	134	1.8	Medium	Trade and Service	None

Table 3 *(continue)*

No.	Sample Point	Time	Temp (°C)	Air Quality (Aqi)	Shadow Length (m)	Activity Density	Activity Type	Vegetation
D. China Town Semarang								
10	Tong Pek Bio Temple	10:00 AM	36.8	98	3	Low	Worshipping	Decorative
		12:00 PM	40.8	105	1	Low	Worshipping	Decorative
		04:00 PM	36.8	134	4.5	Low	Worshipping	Decorative
11	PD Sumber Makmur	10:00 AM	33.9	84	5.5	Low	Trade and Service	None
		12:00 PM	37.6	96	4	Medium	Trade and Service	None
		04:00 PM	33.9	132	6	Medium	Trade and Service	None
12	Rented House	10:00 AM	35.2	84	4	Low	Housing	None
		12:00 PM	38.9	96	1.5	Low	Housing	None
		04:00 PM	35.2	132	5	Low	Housing	None

Note. Data samples were taken over five days in 2022

RESULT AND DISCUSSION

Climate Change Vulnerability by Landscape Characteristics

Semarang City is located on the coast and is highly vulnerable to the effects of climate change. Since 1985, a recorded sea level rise of 40 cm to 80 cm has occurred. Over the last 100 years, the potential flooding area has increased by 1.7 km and 3 km (Mulyana et al., 2013). The large number of cultural heritage sites in Semarang makes the city and its components even more susceptible to the impact of climate change. Most of Semarang's historical areas are in coastal regions, particularly the northern areas near the Java Sea, where sea level rise and land subsidence are ongoing issues.

The data collection results reveal various characteristics of the climatic conditions in four cultural heritage areas in Semarang City. These areas were assessed based on temperature, air quality, shading, activity density, and vegetation indicators. The assessment considered the landscape conditions of the historic areas and their activities, resulting in the average climate indicators for each historical area in Semarang City.

Based on Table 5, all historic villages in Old Town have temperatures exceeding the comfort limit (27°C), with the highest air temperature reaching 40.13°C at noon when the sun is perpendicular to the buildings. Buildings exposed to sunlight with high radiation levels decay or get damaged faster, depending on the material. Radiation significantly impacts the surrounding environment, especially in materials that reflect light, leading to uncomfortable air temperatures for outdoor activities. This is one of the main reasons why people in Semarang have a low desire to walk. Old

Town and Chinatown have the highest average air temperatures compared to the other two locations, influenced by the many activities in the area from morning to evening.

Air quality pertains to the level of pollution created by activities in a particular area and correlates with the rise in the average daily temperature within the cultural heritage area. The results of the air quality index in each Heritage Area are displayed in Table 4. According to the AQI standard, air quality values exceeding 100 are classified as unhealthy. Old Town, a heritage area, exhibits the highest air pollution level, with an AQI value of 153.67 at 04:00 PM. This condition is attributed to the increased activity of tourist visitors, who gather in the area from afternoon to evening. An interview with various tourists in 2021 revealed that they avoid visiting Old Town during the day due to high air temperatures and a lack of shaded vegetation, making them uncomfortable.

The amount of shading in the heritage area heavily depends on the buildings' physical structure. The sun's position also affects the length of the shadows cast. From 10:00 AM to 12:00 PM, the heritage area experiences minimal shadows due to the sun being perpendicular to the buildings. The lack of vegetation and shading objects exacerbates humans' exposure to solar radiation. In Kampong Pekojan, the shortest building casts a shadow of 1.10 meters, with an average height of 8 meters.

Conversely, the longest shadows occur around 4:00 PM in the Old Town area, reaching 8.90 meters. The colonial buildings, with their high roof foundations and canopies, contribute to the formation of shadows. The average building height in Old Town ranges from 10 to 12 meters, resulting in up to 80% of the area being covered in shadows in the afternoon starting at 3:00 PM. Areas like Kampong Melayu and Kampong Pekojan, dominated by shophouses and low-rise residential buildings, tend to have minimal shadow coverage (see Figure 3).

The distribution of vegetation varies significantly in different areas. In the Old Town, decorative vegetation, like potted plants and hanging plants on streetlamps, is typical. Sri Gunting Park, which features large shade trees with a 15-meter diameter, is the main green area and public space for visitors. In Kampong Melayu, Kampong Pekojan, and Kampong Chinatown, there is a greater need for more vegetation to help mitigate the impact of climate change, as these areas are dominated mainly by decorative vegetation like potted plants. Due to high building density, there is a pressing need for more green and public space to provide the community with adequate greenery.

At 10:00 AM, all heritage areas had poor overall climatic indicators, including air temperature, air quality, shading, and activity levels. At noon, the object shadow indicator and air temperature condition were uniformly poor in every location. Old Town had the highest activity density indicator value at this time. However, due to the low tourist and community activities, Chinatown had the best air quality indicator at 12:00

Table 4
Climate condition in Semarang Heritage Area

Num	Indicators	Time	Semarang Heritage Area							
			Old Town (N=3)	**Value**	**Kp. Melayu (N=3)**	**Value**	**Kp. Pekojan (N=3)**	**Value**	**China Town (N=3)**	**Value**
1	Temperature (°C)	10:00 AM	32.37	1	33.97	2	33.93	1	35.30	2
		12:00 PM	40.13	1	38.23	1	36.60	1	39.10	1
		16:00 PM	37.93	1	34.77	1	35.30	1	35.30	1
2	Air Quality (Aqi)	10:00 AM	89.33	2	85.67	2	99.67	2	88.67	2
		12:00 PM	107.00	1	103.33	1	108.33	1	99.00	2
		16:00 PM	153.67	1	132.33	1	137.33	1	132.67	1
3	Shadow (m)	10:00 AM	2.20	1	2.65	1	1.50	1	4.17	1
		12:00 PM	1.12	1	1.70	1	1.10	1	2.17	1
		16:00 PM	8.90	2	3.02	1	2.67	1	5.17	2
4	Activity Density	10:00 AM	Low	2	Low	2	Low	2	Low	2
		12:00 PM	Medium	1.5	Medium	1.5	Medium	1.5	High	1
		16:00 PM	High	1	Low	2	Medium	1.5	Medium	1.5
	Activity Type **dominant condition in a cultural heritage landscape*		Tourism, Office, Trade and Service	1	Tourism, Settlement, Trade and Service	1	Trade and Service, Settlement	1.5	Trade and Service, Settlement	1.5
5	Vegetation **dominant condition in a cultural heritage landscape*		Decorative, Shade, Low Density	1	Shade, Low Density	1	Shade, None, Low Density	1	None, Decorative, Low Density	1

Note. Getting closer to 1 (Poor, high level of vulnerability); getting closer to 2 (Good, low level of vulnerability)

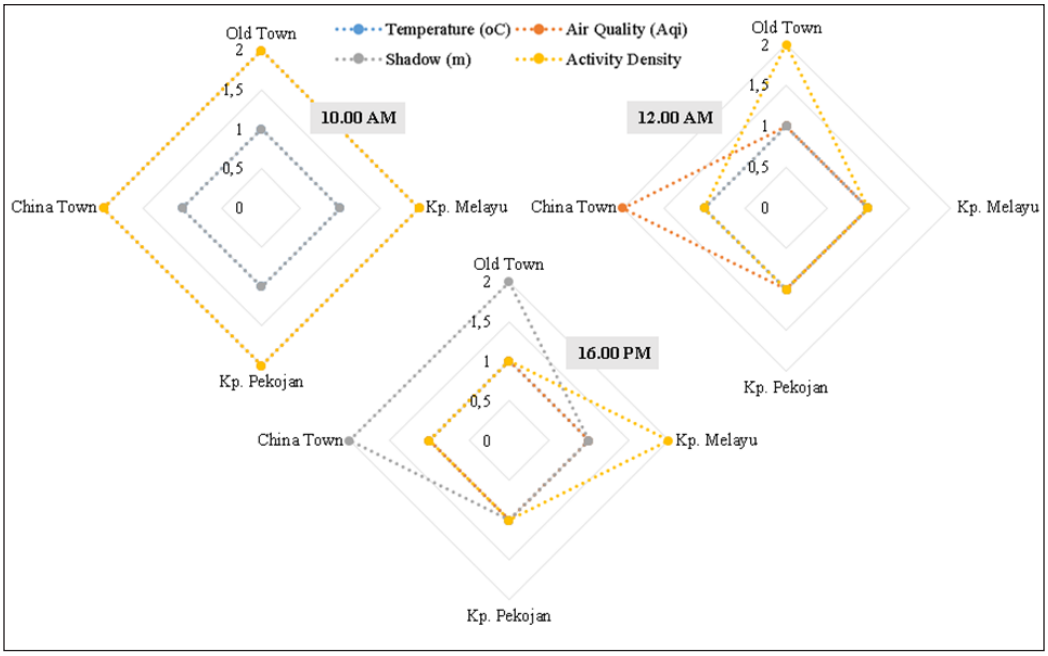

Figure 3. Climate condition in Semarang Heritage Area per time

PM. This was because shopping activities tend to be quiet during the day, and workers prefer to rest before resuming activities at 1:00 PM.

At 4:00 PM in the Semarang Cultural Heritage Area, there is a high variation in climate conditions based on various indicators. The Old Town experiences poor activity conditions, temperature, and air quality due to increasing tourist density. However, the shadow indicator shows good conditions as the length of the shadow reaches its maximum compared to other times. In contrast, Kampong Pekojan still has poor scores on every indicator. On the other hand, Kampong Melayu has a good activity density at 4:00 PM due to the cessation of some shopping activities at night. Similarly, Chinatown also has good shading conditions compared to other indicators. At 4:00 PM, the alignment of the shophouses and the road grid helps optimise the length of the shadow produced, as it is influenced by the height of the building and the width of the road (H/W).

Data was collected from 12 sample locations to assess climate change indicators. Each location was chosen for its unique characteristics in different heritage areas (see Figure 4). After processing the data, the crucial temperature values, which are the most essential climate change indicators, were obtained. The air temperature and the damage conditions of each historic building were compared to determine the effect. Typical Chinese historical buildings, including numerous temples and trading centres such as shophouses, characterise Semarang's Chinatown.

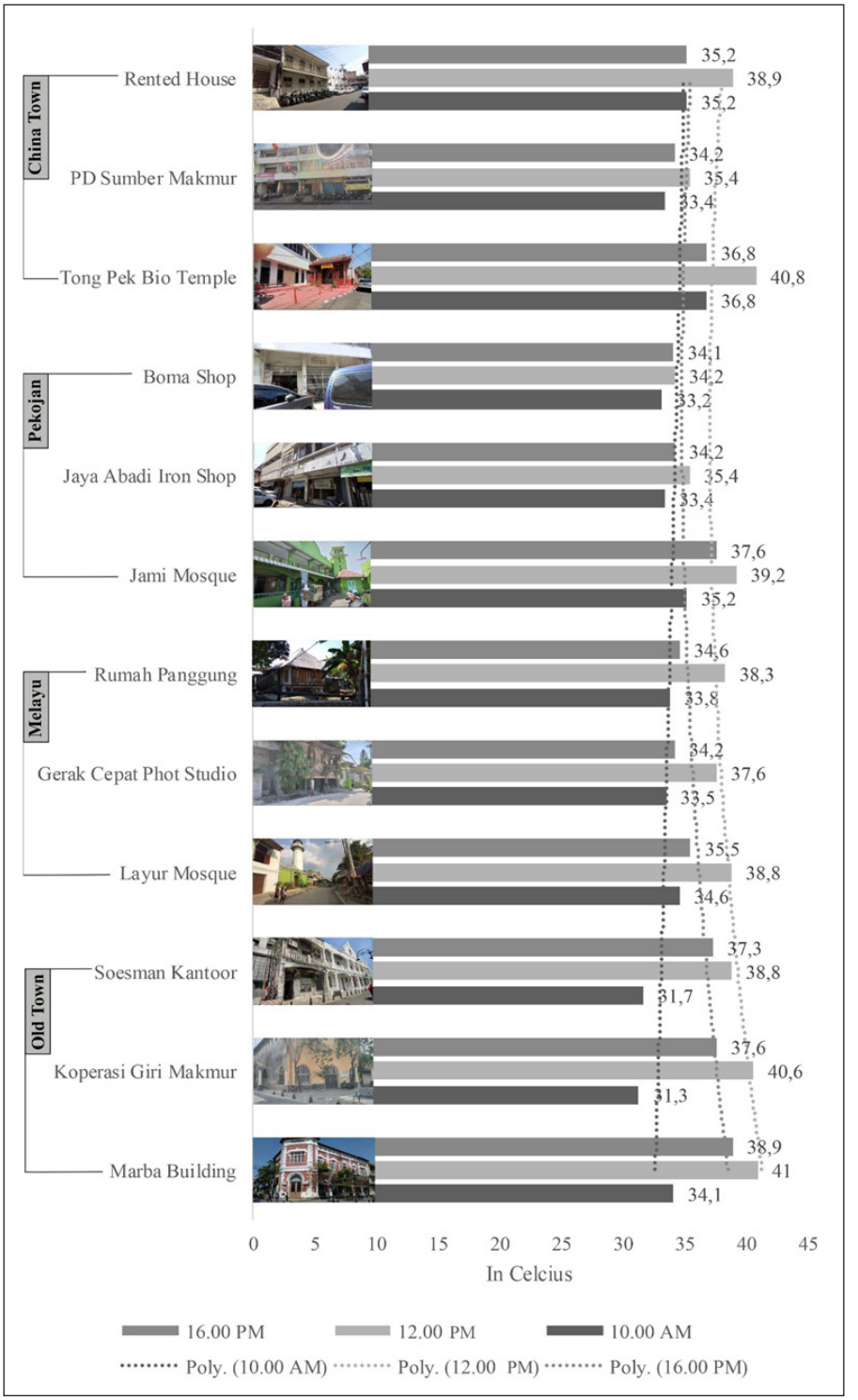

Figure 4. Heritage building condition towards climate change (temperature)

Most of the buildings in Chinatown have been well maintained due to infrastructure improvements carried out by the Semarang City Government in 2021. The local community still upholds the belief and tradition that the temple, as a place of worship, is one of the holy places that must be protected from damage. Similarly, their housing, as a source of daily livelihood, has been well maintained until now. However, the air temperature at three locations, namely a rented house, Tong Pek Bio Temple, and PD Sumber Makmur was relatively high, with low humidity levels (>27^{o}C).

Meanwhile, Kampong Pekojan has characteristics almost similar to Chinatown because of the many shophouses throughout the area. Jami Mosque, one of the historical buildings of Islamic civilisation in Semarang, creates a sense of architectural mixing in this area. As residences and places of worship are considered components of life for the community, most of the buildings in this location are still well-maintained, and there are no visible signs of significant building damage due to high temperatures that can reach a height of 39.2°C. In conclusion, Chinatown and Kampong Melayu show a high level of maintenance based on the scale of the buildings' importance for the core community's life as an economic and religious resource.

Kampong Melayu differs slightly from the two previous locations. The buildings in this area still showcase the characteristics of Arabic and Malay architecture, primarily using a combination of wood and concrete materials. Historic buildings in this location were damaged, including the Rapid Motion Studio Building, which suffered material damage and was overgrown with moss. Some homes were also severely damaged, and the level of weathering caused by the elements was extremely high. Kampong Melayu is the area closest to the sea compared to the other three locations.

Additionally, persistent climate change leads to problems such as tidal flooding and land subsidence every year. As a result, most buildings are vulnerable to damage from environmental conditions such as water and air temperature. The wood material, highly susceptible to weathering, significantly affects the air temperature conditions of the area. It was found that the average air temperature in this location can reach 38.8°C (not suitable for outdoor activities). Following the Decree of the Mayor of Semarang Number 050/801 of 2014, Kampong Melayu and its surroundings are still designated as slum areas with severe damage to residential infrastructure.

Old Town Semarang underwent significant revitalisation and repairs in 2018, led by the Semarang City Government. The improvements focused on environmental infrastructure, such as roads and drainage, to protect buildings from the adverse effects of climate change, particularly the high average temperature of up to 40.6°C daily. The colonial buildings have solid foundations, and some are made of natural stone, which helps absorb heat. The area is highly vulnerable to damage due to high tourism activities, but most structures, including cafes and restaurants, are in good

condition thanks to special preservation rules. Unlike the other areas, Old Town has fewer residential communities in its heritage area, minimising the impact of residential activities on the quality of historic buildings.

The condition of historic buildings in various locations is significantly influenced by the patterns of community activities and habits related to the building's function regarding climate change. For instance, activities like worship and trade necessitate high community effort to maintain the structure in good condition. However, buildings constructed with materials that are not weather-resistant, such as wood and concrete, are more susceptible to damage from high temperatures and water elements, particularly in coastal areas prone to rain and tidal flooding.

Assessment of Vulnerability and Adaptation Towards Climate Change

The assessment results of the heritage area's vulnerability to climate indicators are then reprocessed to determine the level of damage, vulnerability value, and adaptation level. Then, the final value of the heritage area condition is found to determine relevant recommendations. Table 5 shows that Old Town has the highest final value of vulnerability and adaptation compared to other locations. This is due to the improvement of environmental infrastructure carried out by the Semarang City Government to maintain the quality of the environment.

Due to the humid air condition, some damage was still discovered in a small portion of the building materials in the narrow alleys, and the buildings remained abandoned. On the other hand, tourists' high daily activity is an indicator that needs to be investigated further in Old Town because it will have a long-term impact, particularly on motorised vehicle activity, which can damage the structure of historic buildings. The landscape around the Old Town is very supportive as a source of water absorption because there are several green and blue areas in the form of rivers and polders. This causes a low level of damage to historic buildings due to floods. With a suitable handling system and adequate regulations, the level of vulnerability in the Semarang Old Town area can be reduced, as shown by the resulting value of 1.63 with a low level of vulnerability.

Kampong Melayu still has a relatively high level of vulnerability to building damage due to climate change. However, the level of adaptation due to the impact of the changes is still quite good when viewed from the structure of the building. One of them is the form of a historic building in the form of a house on stilts, which can minimise the impact of floods that often occur in this location. However, building materials made of wood and concrete still need extra protection from adverse environmental influences such as high air temperatures and pollution. Some buildings, such as the Quick Motion studio, were damaged due to neglect, and the materials were not resistant to weather changes. In addition, many buildings with positions that are not conducive to sun exposure and at peak lighting will be fully illuminated, thus increasing the level of vulnerability.

Table 5
Vulnerability assessment and level of adaptation of Semarang Heritage Area

No.	Landscape Conditions	Damage	Vulnerability (V)	Adaptation (A)	Value = Avr V.A
1	 Old Town		Value from the average of Climate Change Indicators: 1.25 (High)	The value of the amount of damage and the Building Structure: 2.00 (Good)	1.63
2	 Kampong Melayu		Value from the average of Climate Change Indicators: 1.32 (High)	The value of the amount of damage and the Building Structure: 2.00 (Good)	1.66
3	 Kampong Pekojan		Value from the average of Climate Change Indicators: 1.27 (High)	The value of the amount of damage and the Building Structure: 1.00 (Poor)	1.13
4	 China Town		Value from the average of Climate Change Indicators: 1.43 (High)	The value of the amount of damage and the Building Structure: 1.00 (Poor)	1.22

Note. Getting closer to 1 (Poor, high level of vulnerability); getting closer to 2 (Good, low level of vulnerability)

The vulnerability value obtained at this location is 1.66, which is the lowest level of vulnerability compared to other locations.

Kampong Pekojan has the lowest vulnerability and adaptation assessment results compared to other locations, which

is only 1.13 (high level of vulnerability). This is because Kampong Pekojan does not have a systematic environmental care and improvement system compared to other heritage areas. Its location in the city's centre, which has a high density of buildings, increasingly threatens the physical quality of its historic buildings. Some old-style shophouse buildings also appear unkempt and have some material damage, such as moss. Motorised vehicles pass by this location every day, increasing the level of pollution and shocks received. In contrast to Chinatown, people in Kampong Pekojan pay little attention to cultural heritage buildings because this location has no strong customs and beliefs.

Chinatown's vulnerability and adaptation value is 1.22 (high level of vulnerability) and is the lowest value after Kampong Pekojan. This is because the level of adaptation possessed by Chinatowns in maintaining historical building structures is still low. The building still utilises the old conditions without adjusting to the current environmental conditions (adaptive). However, the improvement of tourism-supporting infrastructure has improved the condition of this area from year to year. Trading activity is very high from morning to evening; it turns into tourist activity at night. The high activity in the area at any time threatens the quality of the cultural heritage buildings in this location.

The average grouping of vulnerability conditions in the Semarang Heritage Area can be seen spatially in Figure 5. This figure shows that Cultural Heritage Areas located close to the coast (Java Sea) tend to have a lower level of vulnerability compared to locations closer to the city centre. This can happen because the focus on disaster management around the coastal areas of Semarang City has been going quite well and has priority on locations near the sea (with high levels of degradation). In recent years, the City of Semarang has made massive improvements in regulations and development in heritage areas, especially those with a high potential for coastal disasters. One example is what happened in the Old Town area, which underwent regular restructuring in 2018.

Due to the results of Yanuardi (2009) and Sadirin (2008) on the causes of damage to the Borobudur Temple Cultural Heritage, historic buildings have damage problems caused by extreme weather, causing weathering of building materials. This study recommends careful maintenance measures for cultural heritage buildings with building materials susceptible to weather. Among them can be first aid, cleaning, repair, consolidation, preservation, and protection. There are particular techniques for cleaning moss attached to historical buildings, such as using the steam cleaning method, namely using pressurised hot water and a brush and clean water. Restrictions on motorised vehicle activity must also be done to minimise the resulting air pollution. Building materials easily damaged by extreme weather changes can be replaced with waterproof coatings through smear or water-repellent spray methods. In addition, it is necessary to improve drainage quality

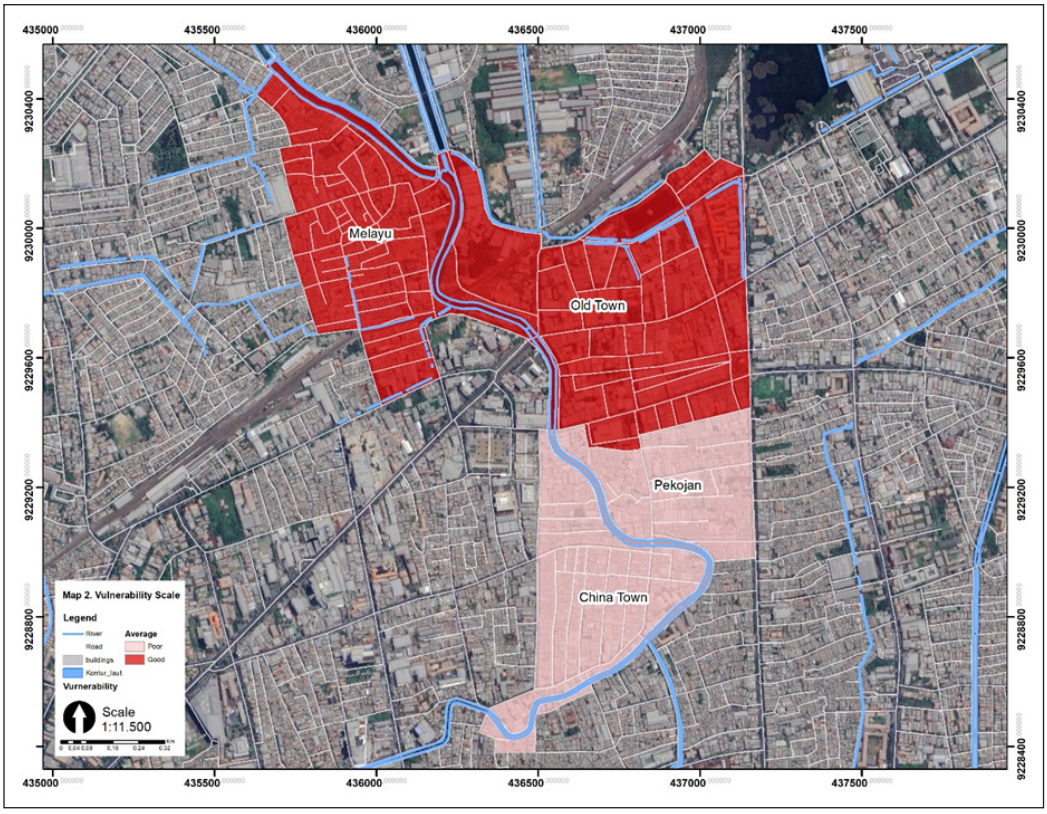

Figure 5. Average scale of vulnerability in Semarang Heritage Area

by using river flows that connect the four research sites as water catchment areas. In addition, technical engineering, such as that carried out by Kampong Melayu, can be carried out on certain buildings by changing the structure of the building into a house on stilts.

In general, the study location (Semarang Heritage Area) is a historical tourist area with a level of tourist visits predicted to continue to increase after the COVID-19 pandemic. This becomes a challenge in handling historical heritage vulnerabilities if they are not managed better. The dualism between the economic needs of tourism and the preservation of historical heritage is an exciting issue experienced by various historical areas. Based on research findings by Leh et al. (2021), the rapidly growing tourism industry could increase the risk of environmental damage. Increasing the resilience of communities around the area is highly recommended as an essential step in preventing worse impacts. In Malaysia, using non-alternative energy is one of the main problems that triggers the high impact of climate change in tourist areas. Therefore, support for advances in low-carbon technology can be an alternative to minimising the effects of climate change in the future, one of which is in vulnerable locations such as historical areas.

CONCLUSION

The results of the analysis found a significant influence between climatic conditions and the quality of historic buildings with different landscape forms. Most locations experience high solar radiation levels, so the air temperature is always high. In addition, high activity levels in some areas cause potential damage to building structures due to the intensity of movement. The similarity of the condition of the heritage area in this study is that essential activities such as trade and engagement and certain beliefs can increase public awareness in protecting historic buildings.

The adaptive capacity of the people around the historic area primarily determines the level of vulnerability. The mixture of tourism and local community activities can threaten the preservation of cultural heritage sites because regulations for communities outside the area usually tend to be complicated. Implementing reasonable regulations has so far been one of the keys to success in dealing with environmental damage in historic areas, such as what happened in Old Town Semarang. Optimally structuring tourist areas can reduce the impact of environmental degradation from sea level rise and land subsidence while increasing tourist visits. However, a particular management system is needed for historical area zones close to the city centre because the analysis results found that historical areas in these locations have a higher level of vulnerability. This can be influenced by the high building density level and human activity approaching the city centre.

Implication of Theory and Practice

Climate-adaptive historical heritage sites are formed from indicators in the Climate Sensitive Urban Design (CSUD) concept, vulnerability theory, and climate change resilience theory (Adger, 2006; Folke, 2006; Kurniati et al., 2023; Turner et al., 2003; Walker et al., 2004). Based on the research on the existing condition of the historic area in Semarang City, the vulnerability scheme of Semarang Heritage Area to climate change is summarised in Figure 6.

The sensitivity component can be realised in practice using several indicators and sub-indicators. Based on this component, historical heritage sites can apply planning and structuring to the scope of the area, in this case, historical kampong, by making arrangements to improve thermal comfort. In the historical building component, the arrangement is recommended to comply with the preservation requirements of historical buildings in accordance with international and local regulations. This component can be applied by conducting technical engineering to revitalise historic buildings damaged by climate change. On the other hand, the existing Semarang Heritage Area is mostly used as a tourism trade and service area that always has a high level of activity. The high level of activity in the area can damage the structure of historic buildings due to the resulting shocks. Therefore, it is necessary to regulate activity zones through zoning regulations, starting from within the area and moving to the surrounding area.

The adaptive capacity component is necessary to increase the chances of success

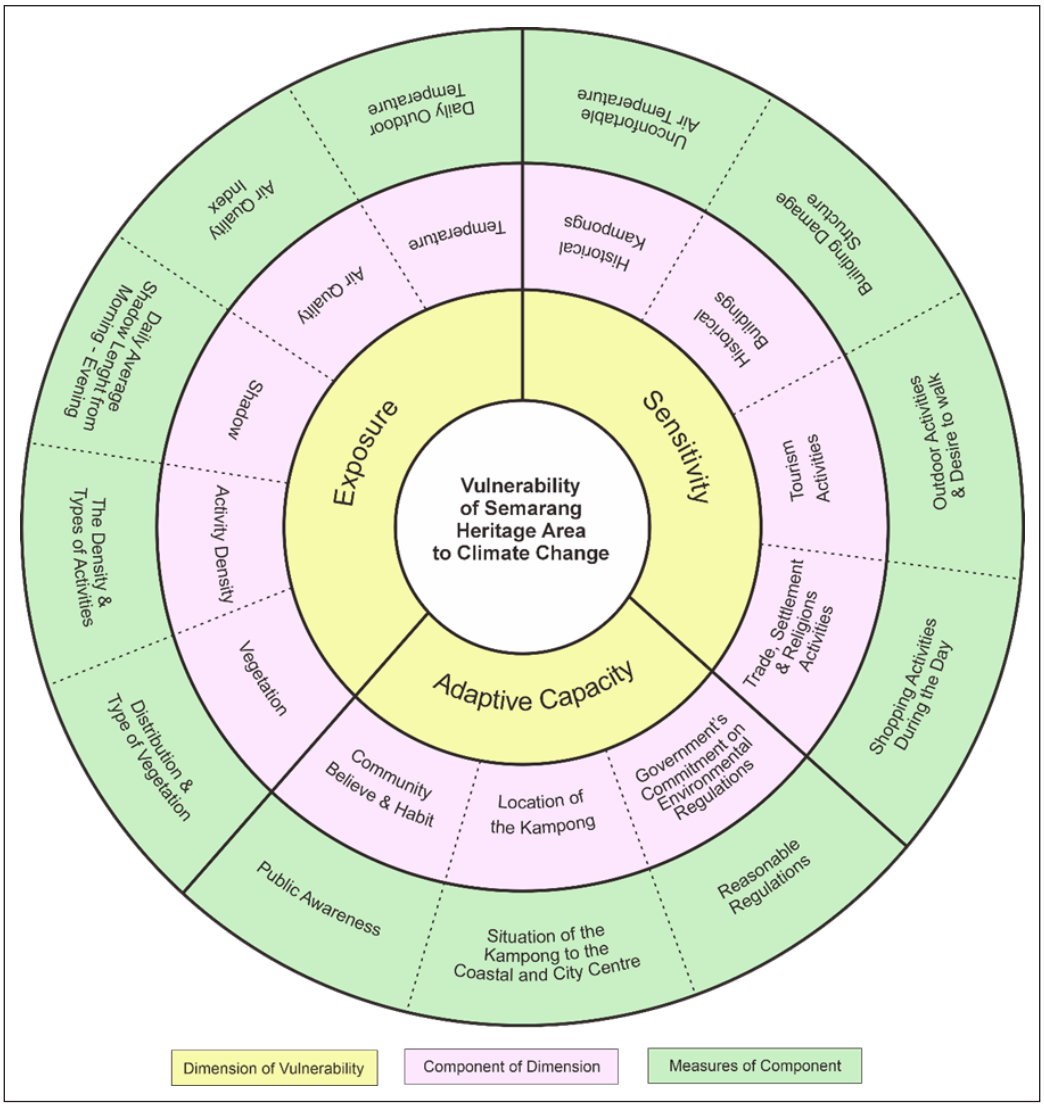

Figure 6. Vulnerability scoping diagram of Semarang Heritage Area to climate change

in vulnerability theory and resilience theory (Adger, 2006; Folke, 2006; Turner et al., 2003; Walker et al., 2004). The role of the community and government is needed to carry out adaptive actions to climate change, such as by forming climate-resilient communities and preparing relevant regulatory documents. In addition, the location of the historic area near the coastal area requires a water management-based structuring system. The Semarang City Government has implemented this through various programmes, one of which is the construction of an integrated drainage system.

The exposure component describes the application of the CSUD concept, which emphasises climate adaptive indicators,

such as temperature, air quality, shadow, activity density, and vegetation. Based on previous research conducted by Kurniati et al. (2020, 2023)Fog, it was found that shadow and vegetation indicators are the most likely indicators to be applied in the Semarang Heritage Area. This study also found that increasing shadow production in historic buildings by applying canopies and increasing the presence of shading vegetation can improve the thermal comfort of historic areas.

Limitations and Recommendations for Future Studies

This study still has limitations in quantitative data testing, especially to determine how much influence each adaptation indicator has on the level of vulnerability in the Semarang Heritage Area. This research has also not conducted an in-depth analysis of all indicators, especially for the CSUD concept, which requires detailed samples at several location points in each of the Heritage Kampongs as study locations. This is very important because each Heritage Kampong has very different landscape characteristics and activities.

Future research also needs to consider the characteristics of the morphological formation of historic areas in each study location. Semarang City, as one of the cities with a long history, has a strong connection with its historic kampongs. Therefore, future research is suggested to develop the concept of the historical development of Semarang City towards a climate change adaptation approach in each Historical Kampong. Other relevant studies have also overlooked these approaches.

The researchers recommend that several additional regulations be applied to the historic building maintenance system in the heritage area of Semarang City, including maintaining building materials with materials that are resistant to extreme weather due to climate change, as was done in the Borobudur Temple area. In addition, changes in building structures that are adaptive to climate change can also be carried out on certain buildings, such as turning the building into a house on stilts to avoid the impact of flood disasters. This study is also still open to further research, especially on assessing the level of influence of each climate change indicator on the damage to historic buildings.

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