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Climate-sensitive Design in Traditional Residential Architecture: Kars Karakurt Houses

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ABSTRACT

Design based on performance and energy efficiency is important in residential buildings. The design approach, which considers climatic data and energy conservation, was also used in traditional building design. In this context, it is aimed to evaluate the Karakurt houses in Kars, built during the Russian occupation period (1878-1918) in Turkey, within the scope of climate-sensitive design. The inadequacy of studies in the literature on Kars Karakurt houses, which are traditional architectural examples that preserve the original texture of the region as qualified representatives of Baltic architecture, constitutes a research gap. In this study, qualitative and quantitative research methods were used. The architectural plan and facade typologies of the buildings in Karakurt village were obtained by measuring techniques and tools. In the qualitative research part, information about the buildings was obtained from on-site investigations and a situation analysis was made. In the quantitative research part, orientation analyses of buildings and spaces, and window-wall area ratios of facades have been evaluated according to climate-sensitive design approaches. In the research findings, design criteria such as plan, facade, roof and material properties of 10 Karakurt houses, were examined and it was seen that the buildings were standardized within the scope of climate-sensitive design. It is seen that the north direction, where the wind is dominant and the sunlight penetration is the least, is not preferred for the orientation of the buildings and the space, and the window/wall area ratio is kept to a minimum, reducing the energy loss especially due to the openings.

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1. Introduction

Today, buildings represent one of the most energy-consuming economic sectors. In parallel, buildings are also responsible for approximately one-third of global greenhouse gas emissions. At this point, there is a need to reduce energy demand and replace fossil energy sources with renewable energy sources to solve these problems (Bot et al., 2019). In Europe, buildings account for about 40% of the energy consumption, which is an important part of the economy. For this reason, energy efficient buildings that consider energy efficiency criteria have been included in the energy policies of many countries. New standards have been introduced in energy policies that may vary from region to region (Michalak, 2019; Jakubcionis and Carlsson, 2018; Çakıcı and Sorguç, 2009). Traditional buildings are role models today with their energy efficient design approaches (Manurung et al., 2022).

With the need for housing from the past, plans have been made according to solar, wind and other environmental factors (Leng et al., 2019). Necessary comfort conditions are provided in the building by considering the climate factor (Angın et al., 2020).

Providing energy efficient solutions in traditional buildings reduces energy consumption and carbon emissions (Webb, 2017). Traditional building typology differs from other buildings in terms of physical characteristics (Er Akan et al., 2021). In these buildings, where local construction methods and natural materials of the region are used, there are door and window openings and natural ventilation systems (Cantin et al., 2010). The circulation of energy in traditional buildings also contributes to sustainability. For this reason, traditional buildings can continue their functions without being destroyed (Carbonara, 2015). To ensure sustainability, annual energy consumption and carbon emission parameters should be examined, considering into account environmental conditions (Bellia et al., 2015; Ascione et al., 2011). It can be inferred that the buildings that have survived to this day and have been largely preserved, are minimally affected by the harmful effects of the environment and have a high capacity to adapt to the climate of the region in which they are located (Er Akan et al., 2012; Smit and Wandel, 2006; Er Akan and Çakıcı, 2005). The building materials of traditional buildings are also important in transferring the building stock to future generations by affecting the energy efficiency. Considering the local climatic conditions and traditional buildings that provide advantages in natural factors such as heat, lighting and ventilation, it is seen that the use of natural building elements such as porches, skylights, stone and adobe walls is common. It can be said that the building elements, which are supportive of maintaining the natural balance, positively affect the energy performance (Takva et al., 2022; Hegazi et al., 2021, Örmecioğlu et al., 2013).

In the literature, there are studies on energy in buildings built with traditional and local materials. Dehshiri (2022) investigated the usability of hybrid energy systems on traditional buildings due to the dense population and pollution in the city of Isfahan, Iran. Six scenarios for renewable energy systems have been proposed. Evaluations were made with the use of multi-criteria decision-making method and software. Orman et al. (2022) studied the thermal comfort of traditional and smart buildings in Poland. A subjective evaluation of indoor conditions was performed according to occupants' thermal senses and preferences. Survey studies were conducted out together with physical measurements depending on the air temperature and relative humidity. Shadmand and Arslan Selçuk (2022) identified climate-responsive architectural design elements and approaches in the traditional Tabriz houses, located in the cold-arid climatic zone. Közoğlu et al. (2022) calculated the annual energy consumption of traditional Sille houses in Konya using a software program. According to the results, the factors affecting the annual energy consumption were examined. Salom et al. (2021) made an energy assessment of traditional buildings in sustainable positive energy regions. Using a holistic methodology, the keywords of energy and power performance, flexibility, greenhouse gas emissions, indoor environmental quality, cost, sustainability and smartness are emphasized. Obafemi and Kurt (2016) investigated the carbon emission and annual energy consumption of the building using a computer-based simulation method on a traditional adobe building in Northern Cyprus. The energy efficiency of the adobe building material is highlighted. Asadi et al. (2016) investigated Yazd traditional houses and their thermal behavior in Iran. The thermal performance of these houses in summer was examined with an energy software. Oikonomou and Bougiatioti (2011) presented the bioclimatic and environmental aspects of traditional architecture in the town of Florina, located in the northwest region of Greece. The building typology, thermal behavior of the building envelope and thermal comfort conditions of forty buildings that have survived from the 19th and early 20th centuries were examined.

The number of studies on the efficient use of energy in buildings is increasing day by day. Because of changing climatic conditions and economic fluctuations, the efficient use of energy resources has come to the fore. The fact that the houses that make up the living spaces are at the top of energy consumption shows the need for solutions. Climate-sensitive design plays a key role in this respect. Designing the buildings according to the climatic conditions of the region ensures the effective use of energy resources. Traditional houses, where energy is used effectively and efficiently, constitute the scope of the study. In this study, it is aimed to evaluate the climate-sensitive design principles in traditional residential buildings. When the literature studies were examined, the parameters of photovoltaic panel, thermal comfort, indoor environment and annual energy consumption values were analyzed in traditional buildings. In these studies, the lack of space orientation and window/wall area ratio analyses was observed as a research gap. In addition, the limited information about Kars Karakurt traditional houses in the literature shows the importance of this study. Traditional Kars Karakurt houses were selected for analysis by privatizing residential buildings and were examined according to climate-sensitive design criteria. Inferences were made considering the climate of the region.

2. Climate-Sensitive Design

The increase in the demand for energy and the consumption of natural resources affect the climatic conditions and ultimately cause climate change and global warming (Alrashed and Asif, 2015). Because of global warming and climate change, sea-level rise, seasonal irregularities and natural disasters occur. Considering that climate change has a negative impact on humans and natural systems, nations and companies have started to work on this issue (Sánchez et al., 2020). Comprehensive support packages based on gradual and intersectoral actions are prepared in cities by conducting research on this subject to adapt (Aguiar et al., 2018). It is aimed to support sustainable developments with the Paris Agreement, which is a global agreement to deal with energy and environmental problems that have negative effects of climate change. The construction industry is also affected by climate change. At this point, the building stock is one of the main areas in the development of sustainable standards (Khan and Asif, 2017). Due to the synergy between climate conditions, global warming and urban heat island effects, energy performance in buildings significantly changes (Yılmaz et al., 2021).

Developing designs according to climate has cost-effective solutions. Savings and improvements can be made in energy efficiency and renewable energy integration with heating and cooling systems in the thermal environment (López-Ochoa et al., 2019; Congedo et al., 2015). Climate change should also be considered in buildings. By taking strategic measures against climate change, energy efficiency arrangements should be made for existing housing stocks (Soutullo et al., 2018). A balance of indoor air thermal comfort must be achieved within the framework of energy reduction potentials (Wan et al., 2012). Thermal energy storage systems also constitute advanced energy technologies that improve the sustainability of buildings and energy efficiency (Zhu et al., 2009). Strategies such as reducing energy demand, adopting passive systems and optimizing the energy efficiency should be developed to reduce energy usage in buildings and the impact of climate (Mwasha et al., 2011). With the implementation of these strategies, it has been determined that housing costs are balanced compared with a traditional house (Chang et al., 2011). In the literature, studies are conducted on the performance of buildings depending on climate change. In these studies, building simulation approaches are generally adopted to evaluate the impact of climate change on the energy performance of buildings (Ismail et al., 2021).

In the literature, there are many studies in connection with traditional houses using climate-sensitive design approach that constitute the subject of this study. Lin et al. (2022) developed an architectural education program that combines the study of local climate, vernacular buildings, climate-sensitive design strategies, and simulation tools. As a case study, a vernacular building located in a dense area within a hot-humid climate zone in Guangzhou, China was chosen. Features such as climate-sensitive characteristics, sustainable design strategies were tested. Chiou and Elizalde (2019) conducted a study on the indoor thermal performance and climate-sensitive design strategies of three traditional houses in Guanshan town, eastern Taiwan. Keywords such as space usage, thermal insulation and natural ventilation were examined within the framework of design strategies in the hot and humid climate zone. Sim and Sim (2016) analyzed alternative wall solutions with an energy simulation model to improve the energy performance of environmentally friendly South Korean traditional buildings. Five different wall systems were applied to traditional buildings in three different climate zones in South Korea. The system that yields the best solution was given. Nematchoua et al. (2014) conducted a questionnaire-based statistical study of four regions of Cameroon under different climatic conditions. In the study conducted on the inhabitants of the region, questions were asked on thermal comfort and energy consumption. Traditional and modern buildings were compared. Curtis (2010) studied traditional buildings in Historic Scotland due to climate change. It investigated how thermal performance in the traditional building environment can be improved by sensitive intervention. Additionally, inferences were made on passive energy benefits and sustainability. Er Akan and Çakıcı (2005) stated that climatic factors are effective on the design of traditional Turkish houses. The built environment and plan types were analyzed with three case studies selected from different climatic regions of Turkey.

Based on the information obtained from literature studies on traditional buildings, climatic characteristics were considered in the building design. Climatic factors, land use and construction decisions, construction systems and material selection constitute the basic criteria that affect the building design (Çakıcı and Sorguç 2017). Figure 1 shows the parameters affecting the building design. Solar radiation, air temperature, wind speed and humidity are the climate elements that make up the design parameters. Heating indoor environments with solar energy in winter allows for maximize direct solar gains and keep the heat within the thermal mass of the building. Passive solar energy strategies are used on building facades and roofs (Tejero-González et al., 2016). Rapid urbanization and population growth affect land use and construction decisions. The building design should be considered according to the settlement pattern of the location of the building and the flat-slope of the land (Wang et al., 2013). Environmentally friendly and sustainable construction systems and materials that are resistant to harmful gas emissions extend the life of a building. Building elements that offer technological solutions within the scope of climate-sensitive design and that can adapt to the climate zone should be selected (Švajlenka et al., 2018).

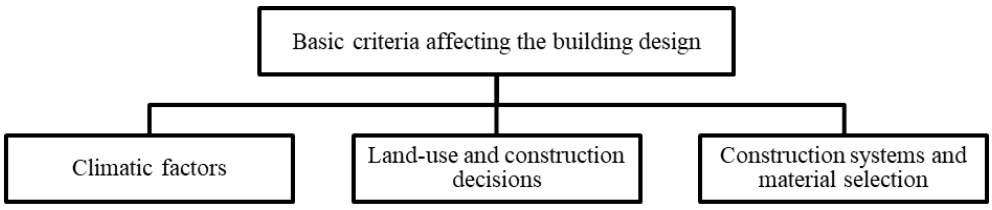


Figure 1 Factors affecting buildings within the scope of climate-sensitive design (by the authors)

3. Methodology

Kars is a city where its traditional and local texture are preserved. In the city, which has been home to different civilizations for centuries, different architectural expressions and variations have emerged along with the cultural diversity. Kars Karakurt, where the traditional and local texture remains alive, was examined in the scope of this study. In this region, where qualified examples of Baltic Architecture are seen, research studies were conducted. In the study, qualitative and quantitative research methods were used (Figure 2). In the qualitative research part, the research methodology was developed by collecting data through observations and documents with the tracking technique. By conducting on-site investigations, information was obtained about the building elements and a situation analysis was conducted. In the quantitative research part, structural scale analyses were

performed considering the data obtained. The plan and facade features of the buildings were examined. Within the scope of energy efficiency and climate-sensitive design, orientation analysis of buildings and spaces was made. Additionally, evaluations were made in the context of climate-sensitive design by investigating the window-wall ratios on the facades and building materials used.

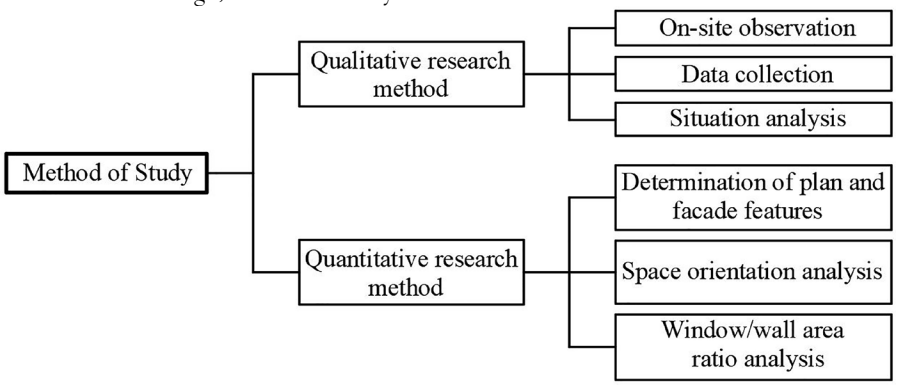


Figure 2 Parameters that make up the method of the study (by the authors)

4. Kars Karakurt Houses

Kars, which has had a dense settlement throughout history due to the suitability of natural conditions and its military and commercial importance, was built on a 1750-meter-high plateau as a military fortress (Kara et al., 2005). Located in northeastern Turkey, Kars has hosted many civilizations for centuries. In the 11th century, the Seljuk Turks conquered the Kars and since then, it has been under the control of different civilizations such as Byzantines, Mongols and Georgians. The Ottoman-Russian War (93 War), which started in 1877, resulted in the defeat of the Ottoman Empire, and Kars, Batumi and Ardahan were left to the Russians (Jukić Buča et al., 2020). With the agreements made with the Russians in Moscow and Kars in 1921, the border between Turkey and Russia was drawn, and Kars and its surroundings joined the territory of the Republic of Turkey. Kars province is located in the northeastern part of the Eastern Anatolia Region, between 42° 10' and 44° 49' east longitudes and 39° 22' and 41° 37' north latitudes and has a surface area of 10,127 km2. (Bilgici Cengiz, 2020). Kars is surrounded by Ardahan from the north, Erzurum from the west, Ağrı from the south and Iğdır from the southeast. Kars province, located on the eastern border of Turkey, forms the border with its eastern neighbor Armenia (Jukić Buča et al., 2020). Figure 3 shows the location of Kars and Sarıkamış on the Turkish map, on the border with Armenia.

Figure 3 The locations of Kars and Sarıkamış on the map of Turkey (URL-1)

When looking at the residential architecture of the Russian occupation period (1878-1918) in Kars, the houses in the new settlement established in the south of the city are mostly single-storey, but there are also a few two-storey houses. The city was under the influence of Baltic architecture during this period. In the city, which has a grid plan, the houses stretching along the streets consist of rectangular or almost square rectangular geometry (Altunsoy, 2005). In the front row facing the street, there are the rooms and hall, while the back row facing the life, there are the workshop spaces. There are coops, warehouses, toilets and tandoori in the life, which are quite large in most of the houses. There were no corridors in the residential buildings. Transitions between spaces are mostly provided from the middle axis. There are no recessed-protruding surfaces on the house facades (Türkan, 2017). An important element that attracts attention in Russian period buildings is the heating elements called 'peç'. They are designed in a way similar to the heating systems in baths. The number of peç varies according to the size of the house. By using the thickness of the wall, the smoke of the wood burned in the peç spreads through the channels opened in the wall and heats all the spaces of the building by circulating. Peç, which are also symbols of ostentatiousness, are made of sheet metal, iron, or brick, and are the furniture of the house with geometric and plant decorations (Arslan, 2015). In Figure 4, buildings belonging to the Russian occupation period are given. During this period, in addition to the center of Kars, it is seen that similar buildings were built in Sarıkamış, Karakurt village.

Figure 4 Russian occupation period buildings (by the authors)

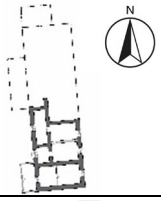
Important buildings of the Russian occupation period are also located in the village of Karakurt in Sarıkamış, Kars. Karakurt village is 80 kilometers avay from Kars city center and 27 kilometers from Sarıkamış district center. Located between the roads to Kars, Erzurum and Iğdır, the village is located in the Aras valley. A continental climate is observed in the region where a village is located. In this study, the residential architecture of the village was examined. The locations of the selected Kars Karakurt residential buildings on the map are shown in Figure 5, depending on the land use and construction decisions at the city scale.

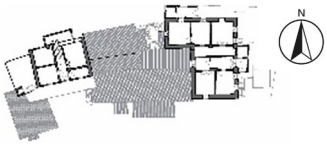
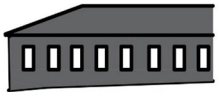
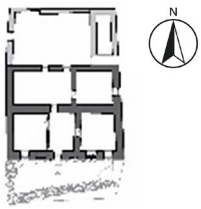
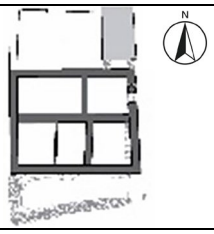
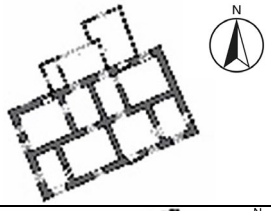
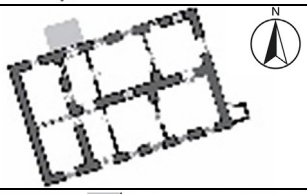
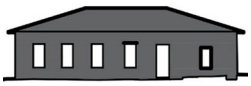
Figure 5 Locations of registered Karakurt residential buildings on the map (by the authors)

5. Findings and Discussions

Ten of the registered buildings that were built during the Russian occupation period and still maintained their originality to a great extent were selected and examined within the scope of this study. When the general characteristics of Karakurt residential buildings are examined at the building scale, it is observed that the plan schemes in rectangular geometry are predominant. While eight of the examined houses are single-storey, two of them are two-storey. Plan schemes and facade configurations of the houses are given in Table 1. When looking at the floor plans and facades of the buildings, it is seen that the buildings usually consist of quadrangular geometry and there is no recess-protrusion on the facade. Window/wall ratio expresses the ratio of the gap ratio (total of door and window areas) to the total of wall areas. As shown in Table 1, the window/wall area ratios of Karakurt houses vary between 5 and 20%.

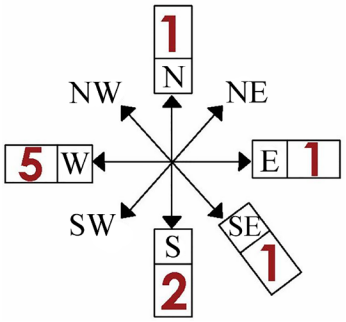
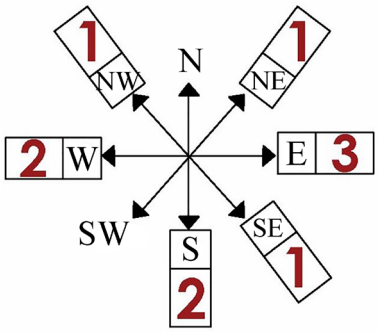
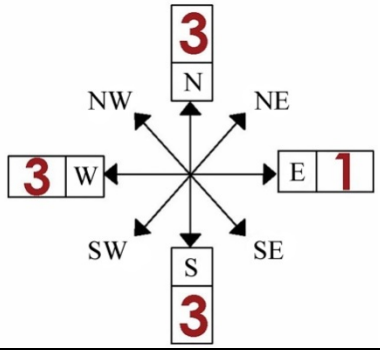
Table 1 Plan and facade features of buildings (by the authors)

Building number	Ground-floor plan	First-floor plan	Building facade	Window/wall area ratio
1		---	 East facade	11%
2		---	 West facade	13%
3		---	 South facade	5%

4			 South facade	11%
5		---	 East facade	16%
6		---	 East facade	18%
7		---	 East facade	20%
8			 East facade	17%
9		---	 Southeast facade	18%
10		---	 Northwest facade	19%
Main building	Added building part(s)			

The orientation of the buildings is also important in the context of climate-sensitive design. When looking at the main entrance orientations of the houses, five buildings face west, two buildings face south, one building faces north, one building faces east, and one building faces southeast (Table 2). When the orientations of the rooms in the house are examined, three buildings are located in the east, two in the west, two in the south, one in the northwest, one in the northeast and one in the southeast. The orientations of the added building parts also vary. Building parts added to three buildings are located to the north, building parts added to three buildings are located to the south, building parts added to three buildings are located to the west, and building parts added to one building are located to the east.

Table 2 Space orientation analysis of Karakurt residential buildings (by the authors)

Main entrance orientation	Orientation of spaces	Orientation of the added building parts
		

W: West, NW: Northwest, N: North, NE: Northeast, E: East, SE: Southeast, S: South, SW: Southwest

There are similarities in terms of building materials in 10 residential buildings in Karakurt village during the Russian occupation period. Metal-sheet coating stands out as a roofing material in all the main buildings and added building parts. It is estimated that the original roofs were covered with tiles, but today it is believed that metal-sheet coating has been switched to enable rapid evacuation according to climatic factors such as snow and rain. It is seen that gable and pitched roofs are preferred as roof forms. The roofs of the added building parts were in the form of porch roofs. Three different stone building materials were used on the facades of the houses with a rectangular plan form. Cut, rubble and chipped stone materials were preferred in the buildings in terms of being suitable for the climate and being ampful in the region. The described properties are given in Table 3. Considering the number of spaces, it is seen that there are seven spaces on average in the buildings. In the buildings where the masonry construction technique was applied, there are kitchens, living rooms and bedrooms. With the increasing needs over time, space additions were made. Among the structures examined, the traditional house with the lowest square meter is 80 square meters. In the added building parts, additions were made up to a maximum of approximately 50 square meters.

Table 3 General characteristics of Karakurt residential buildings (by the authors)

Building number	Main building-roof formation	Added building parts- roof form	Main building-number of spaces	Added building parts-number of spaces	Main building-size (square meters)	Added building parts-size (square meters)	Facade material
1	Pitched roof	Porch roof	7	3	100.56	47.14	Cut and rubble stone
2	Pitched roof	Porch roof	6	1	80.48	11.76	Cut and rubble stone
3	Gable roof	Porch roof	7	2	154.26	9.77	Cut and chipped stone
4	Gable roof	Porch roof	15-15	7	279-231	16.32-25	Rubble stone
5	Pitched roof	Porch roof	9	1	117.38	11.74	Cut and chipped stone
6	Pitched roof	Porch roof	13	4	199.23	14.90	Cut and chipped stone
7	Gable roof	Porch roof	11	5	208.8	25.24	Cut stone
8	Pitched roof	---	7-5	---	103.71-96	---	Cut and rubble stone
9	Pitched roof	Porch roof	8	3	97.19	31.11	Cut and chipped stone
10	Pitched roof	Porch roof	8	2	122.38	6.6	Cut and rubble stone

6. Conclusion

It is seen that the traditional houses in Kars Karakurt village, which has a severe continental climate, are located in a separate order, but close to each other in the street order, do not prevent each other's connection with the sun and do not cause shading. While most of the buildings can be accessed from the west facade, it is seen that the living spaces are located on the east, west and south facades to ensure maximum benefit from the sun's rays. It is seen that the north direction, which has the dominant wind direction and the least sunlight access, is not preferred in the orientation of the buildings and space, and the entrance of the buildings is protected from this direction. At this point, Kars Karakurt houses are designed to be sensitive to climate in the context of the city scale. It is seen that the houses with a compact plan typology have a rectangular plan form and the indentations and protrusions are minimal on their facades, thus minimizing the external facade area that loses energy. It has been determined that metal pitched roofs are used in the houses to prevent rain, snow load and icing, and windbreak areas are created with the added building parts, thus preventing direct heat losses. Additionally, notably energy loss is reduced through openings by keeping the window/wall area ratio at a minimum. These features show that these buildings were constructed sensitively to climate conditions at the building scale. On the exterior, cut stone, which is a local building material and in accordance with the Baltic architecture, is predominantly used. No plaster is used on the exterior, but the thick exterior walls contribute to the thermal performance of the buildings. Additionally, the use of peç systems for heating the buildings in the cold climate zone and where the winter months are harsh due to the continental climate conditions shows the level reached in terms of heating technology. As a result, it was concluded that the traditional Kars Karakurt houses built during the Russian occupation period were designed and built in accordance with the cold climate conditions in the context of climate-sensitive design.

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References

Aguiar, F. C., Bentz, J., Silva, J. M., Fonseca, A. L., Swart, R., Santos, F. D., & Penha-Lopes, G. (2018). Adaptation to climate change at local level in Europe: An overview. *Environmental Science & Policy*, 86: 38-63.

Alrashed, F., & Asif, M. (2015). Climatic classifications of Saudi Arabia for building energy modelling. *Energy Procedia*, 75: 1425-1430.

Altunsoy, A. (2005). *As a Sample of Historical Environment Conservation; Kars*, Master Thesis, Uludağ University, Bursa, Turkey.

Angın, M., Çubukçuoğlu, B., & Gökçekuş, H. (2020). Case Studies on the Impacts of Climate Change on Historical Buildings in Northern Cyprus. *International Journal of Built Environment and Sustainability*, 7(1): 57-65.

Arslan, M. (2015). *Proposed modalities to preserved Kars railway heritage and the conservation project of old powdered milk factory*, Master thesis, İstanbul Technical University, İstanbul, Turkey.

Asadi, S., Fakhari, M., & Sendi, M. (2016). A study on the thermal behavior of traditional residential buildings: Rasoulian house case study. *Journal of Building Engineering*, 7: 334-342.

Ascione, F., De Rossi, F., & Vanoli, G. P. (2011). Energy retrofit of historical buildings: theoretical and experimental investigations for the modelling of reliable performance scenarios. *Energy and buildings*, 43(8): 1925-1936.

Bellia, L., Alfano, F. R. D. A., Giordano, J., Ianniello, E., & Riccio, G. (2015). Energy requalification of a historical building: A case study. *Energy and Buildings*, 95: 184-189.

Bilgici Cengiz, G. (2020). Determination of natural radioactivity in products of animals fed with grass: A case study for Kars Region, Turkey. *Scientific reports*, 10(1): 1-6.

Bot, K., Ramos, N. M., Almeida, R. M., Pereira, P. F., & Monteiro, C. (2019). Energy performance of buildings with on-site energy generation and storage–An integrated assessment using dynamic simulation. *Journal of Building Engineering*, 24: 100769.

Cantin, R., Burgholzer, J., Guarracino, G., Moujalled, B., Tamelikecht, S., & Royet, B. G. (2010). Field assessment of thermal behaviour of historical dwellings in France. *Building and Environment*, 45(2): 473-484.

Carbonara, G. (2015). Energy efficiency as a protection tool. *Energy and Buildings*, 95: 9-12.

Chang, N. B., Rivera, B. J., & Wanielista, M. P. (2011). Optimal design for water conservation and energy savings using green roofs in a green building under mixed uncertainties. *Journal of Cleaner Production*, 19(11): 1180-1188.

Chiou, Y. S., & Elizalde, J. S. (2019). Thermal Performances of Three Old Houses: A Comparative Study of Heterogeneous Vernacular Traditions in Taiwan. *Sustainability*, 11(19): 5538.

Congedo, P. M., Baglivo, C., D'Agostino, D., & Zacà, I. (2015). Cost-optimal design for nearly zero energy office buildings located in warm climates. *Energy*, 91: 967-982.

Curtis, R. (2010). Climate change and traditional buildings: the approach taken by Historic Scotland. *Journal of Architectural Conservation*, 16(3): 7-27.

Çakıcı F.Z. & Sorguç A. (2009). *Not Restrictive Target Directives*. Paper presented at the International Ecological Architecture and Planning Symposium, 22-25 October, Antalya, Turkey, 2: 137-143.

Çakıcı F.Z., & Sorguç A. (2017). A Building Energy Performance Evaluation Program (EnAd) for Architectural Design Process. *International Refereed Journal of Design and Architecture*, 10: 176-201.

Dehshiri, S. S. H. (2022). A new application of multi criteria decision making in energy technology in traditional buildings: A case study of Isfahan. *Energy*, 240: 122814.

Er Akan, A., & Çakıcı, F.Z. (2005). *The influence of climate in the formation of traditional Turkish houses*. Paper presented at the Postgraduate Research Conference on the Built and Human Environment, University of Salford, 14-15 April, 338-347.

Akan, A. E., Dikmen, N., Örmecioğlu, H. T., & Şenol, P. (2012). Sustainability of traditional housing and way of life in Anatolia: A case of Korkuteli-Bozova. *Zeitschrift fur die Welt der Turken. Journal of World of Turks*, 4(3): 175-189.

Akan, A. E., Başok, G. Ç., Er, A., Örmecioğlu, H. T., Koçak, S. Z., Cosgun, T., ... & Sayin, B. (2021). Seismic evaluation of a renovated wooden hypostyle structure: A case study on a mosque designed with the combination of Asian and Byzantine styles in the Seljuk era (14th century AD). *Journal of Building Engineering*, 43: 103112.

Fazelpour, F., Bakhshayesh, A., Alimohammadi, R., & Saraei, A. (2022). An assessment of reducing energy consumption for optimizing building design in various climatic conditions. *International Journal of Energy and Environmental Engineering*, 13(1): 319-329.

Hegazi, Y. S., Shalaby, H. A., & Mohamed, M. A. (2021). Adaptive Reuse Decisions for Historic Buildings in Relation to Energy Efficiency and Thermal Comfort—Cairo Citadel, a Case Study from Egypt. *Sustainability*, 13(19): 10531.

Ismail, F. H., Shahrestani, M., Vahdati, M., Boyd, P., & Donyavi, S. (2021). Climate change and the energy performance of buildings in the future–A case study for prefabricated buildings in the UK. *Journal of Building Engineering*, 39: 102285.

Jakubcionis, M., & Carlsson, J. (2018). Estimation of European Union service sector space cooling potential. *Energy Policy*, 113: 223-231.

Jukić Buča, V., Gwirtzman, K., & Maranci, C. (2020). Armenian Ecclesiastical Sites in the Kars Province (Turkey): Current State, Preservation and Revalorization. *Heritage & Society*, 13(3): 165-197.

Kara, M., Arslan, M. O., & Gicik, Y. (2005). The prevalence of bovine hypodermosis in Kars province, Turkey. *Tropical Animal Health and Production*, 37(8): 617-622.

Khan, H. S., & Asif, M. (2017). Impact of green roof and orientation on the energy performance of buildings: A case study from Saudi Arabia. *Sustainability*, 9(4): 640.

Közoğlu, H. G., Canan, F., & Korumaz, M. (2022). Investigation Of Energy Efficient Architectural Solutions in Traditional Sille Houses. *Süleyman Demirel University Journal of Natural and Applied Sciences*, 26(1): 13-24.

Leng, P. C., Majid, R. A., Rahman, N. A., Ossen, D. R., & Razif, F. M. (2019). Field Investigation of Indoor Thermal Performance in Malaysia Air-Welled Terraced House. *International Journal of Built Environment and Sustainability*, 6(3): 33-41.

Lin, H., Yin, S., Xie, C., & Lin, Y. (2022). Integrated Pedagogy with Climate-Responsive Strategies: Vernacular Building Renovation Design. *Buildings*, 12(9): 1294.

López-Ochoa, L. M., Bobadilla-Martínez, D., Las-Heras-Casas, J., & López-González, L. M. (2019). Towards nearly zero-energy educational buildings with the implementation of the Energy Performance of Buildings Directive via energy rehabilitation in cold Mediterranean zones: The case of Spain. *Energy Reports*, 5: 1488-1508.

Manurung, P., Sastrosasmito, S., & Pramitasari, D. (2022). How to Reveal the Meaning of Space in Vernacular Architecture?. *International Journal of Built Environment and Sustainability*, 9(1): 89-97.

Michalak, P. (2019). A thermal network model for the dynamic simulation of the energy performance of buildings with the time varying ventilation flow. *Energy and Buildings*, 202: 109337.

Mwasha, A., Williams, R. G., & Iwaro, J. (2011). Modeling the performance of residential building envelope: The role of sustainable energy performance indicators. *Energy and buildings*, 43(9): 2108-2117.

Nematchoua, M. K., Tchinda, R., & Orosa, J. A. (2014). Thermal comfort and energy consumption in modern versus traditional buildings in Cameroon: A questionnaire-based statistical study. *Applied Energy*, 114: 687-699.

Obafemi, A. O., & Kurt, S. (2016). Environmental impacts of adobe as a building material: The north cyprus traditional building case. *Case Studies in Construction Materials*, 4: 32-41.

Oikonomou, A., & Bougiatioti, F. (2011). Architectural structure and environmental performance of the traditional buildings in Florina, NW Greece. *Building and Environment*, 46(3): 669-689.

Orman, Ł. J., Majewski, G., Radek, N., & Pietraszek, J. (2022). Analysis of Thermal Comfort in Intelligent and Traditional Buildings. *Energies*, 15(18): 6522.

Örmecioğlu, H.T., Akan, A.E., & Uçar, A. (2013). The Effects of Environmental Factors on Vernacular Construction Systems: The Case of Anatolia. *The Journal of Akdeniz Sanat*, 6(11): 269-279.

Salom, J., Tamm, M., Andresen, I., Cali, D., Magyari, Á., Bukovszki, V., ... & Gaitani, N. (2021). An evaluation framework for sustainable plus energy neighbourhoods: Moving beyond the traditional building energy assessment. *Energies*, 14(14): 4314.

Sánchez, M. N., Soutullo, S., Olmedo, R., Bravo, D., Castaño, S., & Jiménez, M. J. (2020). An experimental methodology to assess the climate impact on the energy performance of buildings: A ten-year evaluation in temperate and cold desert areas. *Applied Energy*, 264: 114730.

Shadmand, A., & Arslan Selçuk, S. (2022). Lessons from traditional architecture in energy efficient building design: the case of traditional Tabriz houses. *International Journal of Environmental Studies*, 79(2): 245-264.

Sim, J., & Sim, J. (2016). The effect of external walls on energy performance of a Korean traditional building. *Sustainable Cities and Society*, 24: 10-19.

Smit, B., & Wandel, J. (2006). Adaptation, adaptive capacity and vulnerability. *Global environmental change*, 16(3): 282-292.

Soutullo, S., Giancola, E., & Heras, M. R. (2018). Dynamic energy assessment to analyze different refurbishment strategies of existing dwellings placed in Madrid. *Energy*, 152: 1011-1023.

Švajlenka, J., Kozlovská, M., & Pošiváková, T. (2018). Analysis of selected building constructions used in industrial construction in terms of sustainability benefits. *Sustainability*, 10(12): 4394.

Takva, Ç., Çalışkan, B. N., & Çakıcı, F. Z. (2022). Net Positive Energy Buildings in Architectural Context. *Journal of Asian Scientific Research*, 12(3): 135-145.

Tejero-González, A., Andrés-Chicote, M., García-Ibáñez, P., Velasco-Gómez, E., & Rey-Martínez, F. J. (2016). Assessing the applicability of passive cooling and heating techniques through climate factors: An overview. *Renewable and Sustainable Energy Reviews*, 65: 727-742.

Türkan, S. (2017). *Analysis of Facade Characteristics of Russian Period Buildings (1878-1918) in Kars*, Master Thesis, Uludağ University, Graduate School of Natural and Applied Sciences, Bursa, Turkey.

URL-1: Location of Kars and Sarıkamış on the map of Turkey, https://www.lafsozluk.com/2009/03/sarikamis-neredir-nereye-baglidir.html, Last Access Date: 8.12.2022.

Wan, K. K., Li, D. H., Pan, W., & Lam, J. C. (2012). Impact of climate change on building energy use in different climate zones and mitigation and adaptation implications. *Applied Energy*, 97: 274-282.

Wang, H., Shen, Q., Tang, B. S., & Skitmore, M. (2013). An integrated approach to supporting land-use decisions in site redevelopment for urban renewal in Hong Kong. *Habitat International*, 38: 70-80.

Webb, A. L. (2017). Energy retrofits in historic and traditional buildings: A review of problems and methods. *Renewable and Sustainable Energy Reviews*, 77: 748-759.

Yılmaz, S., Sezen, I., Irmak, M. A., & Külekçi, E. A. (2021). Analysis of outdoor thermal comfort and air pollution under the ınfluence of urban morphology in cold-climate cities: Erzurum/Turkey. *Environmental Science and Pollution Research*, 28(45): 64068-64083.

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Assessment of Land Surface Temperature Variations and Implications of Land Use/Land Cover Changes: A Case of Malappuram Urban Agglomeration Region, Kerala, India

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ABSTRACT

Urbanization is taking place faster, and urban air temperatures are gradually rising in all cities across the world. Uncontrolled and unplanned urbanization leads to constant environmental threats and can alter local and regional climates. According to the survey published by Economist Intelligence Unit, in India, Kerala's Malappuram district ranks first among the fastest-growing urban areas globally, with a 44.05% growth rate. Hence, the present study aims to identify the hotspot regions of extreme heat within the Malappuram urban agglomeration region and suggest strategies for its improvement. The split-window algorithm retrieved land surface temperature (LST) for 1991, 1998, 2014, and 2020 using Landsat 5 ETM and Landsat 8 satellite imageries. A rising trend in LST has been detected in the last 30 years, and the mean value has increased by 1.70°C within the region. Among the selected hotspots, an LST increase of 1.84°C was observed for those areas with the highest increase in urban density with decreased vegetation. The increasing impact of urbanization and the subsequent change in land use patterns at the cost of greenery have caused a substantial effect on the local climate. Accordingly, planning and policy directions are proposed for the local government that can help provide awareness to the people through the effective implementation of mitigation measures.

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1. Introduction

The impact of climate change has started drastically affecting our cities and settlements. Climate forecasts anticipate severe weather incidents to become more frequent and more intense. Hence, climate change thus becomes "the defining crisis of the time" (United Nations, 2020). Our cities and settlements are thus becoming risky places to live due to the increasing sea levels, harsh weather, and rising temperatures (Appleton, 2021). The condition of heat stress will become more prevalent as a result of the increase in global temperatures brought on by climate change. Globally over 166,000 people died as a result of heatwaves between 1998 and 2017, including over 70,000 during the 2003 heatwave in Europe (World Health Organisation, 2022). On a worldwide basis, intense temperature occurrences are seen to increase in frequency, duration, and size. Between 2000 and 2016, there were over 125

million more persons exposed to heatwaves than there were in 2000 (World Health Organisation, 2022)). The 2022 heatwave across northwest India and southeast Pakistan has led to at least 90 deaths (Business Standard News, 2022). Population dependent on working outside to earn a living (such as street vendors, people working in farm and construction sites, traffic police, etc.) are particularly susceptible to intense heat because they typically lack access to cooling, which restricts their ability to deal with prolonged heat stress.

Land surface temperature (LST) is a fundamental metric for quantifying surface urban heat islands, calculating building energy use, and assessing heat-related concerns (Deng & Wu, 2013; Hu & Brunsell, 2013; Mathew et al., 2016; Weng & Fu, 2014). By modifying the land cover and energy balances, the shift in LST can affect surface air temperature, precipitation, and vegetation cover, which in turn has a significant impact on regional and worldwide environmental conservation (Wilson et al., 2003). Extreme weather events that happen frequently, the ongoing spread of desertification and the deterioration of flora, etc., pose a direct danger to regional ecological sustainability (Chen & Zhang, 2016). Therefore, researchers from all over the world have been interested in the study of LST as a significant quantitative parameter for ecological environment concerns (Feizizadeh et al., 2013; Haghighi et al., 2018; Madanian et al., 2018).

The rate of urbanization around the world is at an unprecedented peak. Planning professionals, environmentalists, and decision-makers all must address urbanization . Urban growth results in significant land use and land cover (LULC) changes (Rimal, 2012). According to Sterling & Duchame (2008), impermeable surfaces have largely replaced the naturally vegetated landscapes that once covered 40% of the Earth's surface with manmade land cover. These changes alter the properties of the land's surface, such as its thermal capacity, surface albedo, and soil moisture. While the temperature in the cities soars, the utilization of air conditioners increases. This in turn causes additional heat to be generated and makes it a vicious cycle. As a result, it will increase energy use, forcing generating stations to emit more harmful gases in order to satisfy the requirement. Increased pollution can result in poor environmental quality, which can cause a public health emergency. Hence rapid urbanization globally has caused a high risk to the quality of physical environmental elements.

As per a report by the United Nations, 55% of the global population resided in urban regions in 2018 compared to 30% in 1950 (United Nations, 2018). According to predictive calculations, the percentage will be around 68% by the year 2050, with developing nations having the greatest rate (United Nations, 2018). A major proportion of this urbanization, which will result in significant social, economic, and environmental changes, is expected to occur in Africa and Asia, according to the United Nations Population Fund (UNFPA). Rapid urban sprawl and land surface extension might be accelerated significantly by unchecked building construction and other economic activity, which would then trigger a serious environmental problem. Like the rest of the world, India is also rapidly urbanizing. A preliminary survey carried out by the Delhi-based Energy and Resource Institute (TERI) revealed that within just 15 years, the temperature in India's megacities, namely Mumbai and Delhi, increased by 2°C to 3°C (Kikon et al., 2016). In Delhi National Capital Region, a study was conducted using data for the years 1998 to 2018 to determine the effect of altering land use patterns on the LST trend. It was found that the built-up area, which made up 21.4% of the total area in 1998, has expanded to 43.23% by 2018. While the vegetated surface declined from 11 percent to 7.40 percent by 2018. The urban sprawl development, rising urban population, deterioration of agricultural land, and vegetation cover have all been linked to a rise in LST and the development of thermal hotspots. Over the years, empirical comparison between LST and LULC has been suggested as a way to quantify the impacts of urbanization on regional climate (P. Singh et al., 2017; Tran et al., 2017; Zullo et al., 2019).

Kerala, a southern state of India, is also not different and has undergone significant demographic and economic profile changes in the past decades, which has resulted in this rapid urbanization (Banerji et al., 2014; Cyriac & Firoz C, 2022; Fathima Zehba et al., 2021; Kallingal & Mohammed Firoz, 2022) ("India is a federal constitutional republic governed under a parliamentary system consisting of 28 states and 8 union territories. All states have elected legislatures and governments. States are organised on a linguistic basis" (Sharma, 2007)). The recent urban growth rate of Kerala has become a challenge for the government and environmentalists (Praveen Lal & Nair, 2017; Sruthi Krishnan & Mohammed Firoz, 2020). Kerala's urban population growth rate exhibits a growing trend when compared to the global and national scenarios, where the rate is displaying a falling tendency (Cyriac & Firoz C, 2022). Compared to the decade before 2001, which had just 25.96% urban composition, the state's rate of urbanization increased to 47.72% in the year 2011 (Banerji et al., 2014; Cyriac & Firoz C, 2022; Kallingal & Joy, 2022; Kallingal & Mohammed Firoz, 2022; Sruthi Krishnan & Mohammed Firoz, 2020). The haphazard rise in urbanization has created significant changes in the state's land use and land cover. In the state, between 1985 and 2005, there was an increase in built-up land by 79%, a 7.65% decrease in forests and a decrease in fallow land by 23% (Browne, 2019). This might be the cause of the state's recurring flooding problems and other environmental risks (T.S. et al., 2022).

The present research focuses on identifying the hotspot regions of extreme heat within one of the upcoming urban agglomerations, namely Malappuram urban agglomeration in Kerala which ranks first among the fastest-growing urban areas globally (2015 – 2020) according to the survey published by the Economist Intelligence Unit. According to the census of 2011, the Malappuram urban agglomeration is the fourth-largest urban agglomeration in the state of Kerala and ranks 25 nationally among urban agglomerations in India. Malappuram is stated to have the highest growth rate of 13.45% among other districts in Kerala (Census of India, 2011). The high rate of urbanization and development in the study area leads to exploitation and overuse of environmental resources and creates an ecological imbalance that can have a negative impact on climate and lead to heat gain. Therefore, it is highly needed that a comprehensive assessment of the microclimate of a region to be done using LST variations to identify the hotspot regions of extreme heat and suggest suitable strategies and planning

recommendations. The planning for strategies is to be attempted as a multi-level, hierarchical process. The research area is selected as the anticipated urban area by 2030 based on the district's (administrative division of an Indian state) trend toward urbanization. Therefore, the study attempts to identify the thermal hotspot regions within the Malappuram urban agglomeration region in order to identify context-specific reasons for LST rise. This becomes the first-level assessment of the larger region which helps in deciding regions in order to perform a detailed assessment at the LSG level (Local Self Government is the third level of the government below the state level that manages the local affairs) in subsequent second and third-level assessments for proposals and policy recommendations. The research also attempts to propose a framework of strategies to be taken up at each planning level. By adopting a multi-level, hierarchical process for planning strategies, organizations can foster coordination, integration, flexibility, and effective decision-making. It ensures that strategies are aligned, resources are optimized, and objectives are integrated across different levels, leading to a more coherent and successful implementation of strategic initiatives.

Accordingly, the present study is organized into six sections, which begin with an introduction. Following this, section two details the literature review on strategies for mitigating heat gain. The third section elaborates on the methodology followed in order to arrive at the research objective. Thermal hotspots are identified in section 4 and spatio-temporal analysis of LST, NDVI and Google Earth images are performed to assess the effects of changing land use and other factors. The fifth section discusses various case-specific and hierarchical planning recommendations to mitigate the effect and the final section concludes the research.

2. Literature Review

Several LST studies have been conducted in India's developed and developing cities. The main causes of the increased temperature, according to most of this research, are due to changes in land-use patterns and increased urban density as mentioned in the introduction section.

As urbanization is seen as a never-ending process, it is increasingly important to take the measures required to achieve a fine balance between the environment and urban expansion. Based on the works already carried out by previous researchers, the mitigation strategies can be classified into 6 heads - vegetation, water bodies and features, materials and shading, urban geometry, transport and energy (Ruefenacht & Acero, 2017). Various tree planting strategies within the urban areas, with local, micro and macro scale forestry and green parks are to be looked into to combat the reduction in vegetation cover as they would help in increasing the rate of evapotranspiration (Norton et al., 2013). Also, green roofs, green pavements, and vertical greenery can be taken up. It results in significant reductions in the amount of energy usage as it reduces the dependency on cooling appliances. Infrastructure greenery on transportation routes can be given, where existing infrastructure, such as tunnels, bridges, motorways, and bus stops, can be enhanced by vegetation to reduce the impact of dark pavements on heat gain.

The coverage of the shaded areas along with the wind condition is influenced by building layout, the placement of urban features, building proportion and orientation. Additionally, sufficient urban planning is essential at a coarser spatial scale to take advantage of the regional environment and airflow, create appropriate wind paths that access the urban area, and eliminate the building up of heat. For example, varying building heights, urban elements that guide wind flow, mixed land use, wider streets, etc can reduce the trapping of heat.

Water bodies and features are beneficial in hot and dry surroundings, but the effects are less in humid areas due to the higher levels of water vapour present in the air, hence it cannot additionally cool the environment. Water's heat capacity allows it to absorb thermal energy from incoming solar radiation. Increasing surface reflectivity is another mitigation approach. As a result, high albedo building materials should be utilized and cool roofs, cool pavements, etc. can be adopted as they will store less heat and maintain a low temperature. Encouragement of the use of public transport and active mobility should be carried out. The use of renewable energy sources and heat recovery systems should be encouraged, and low-carbon fuels should be promoted.

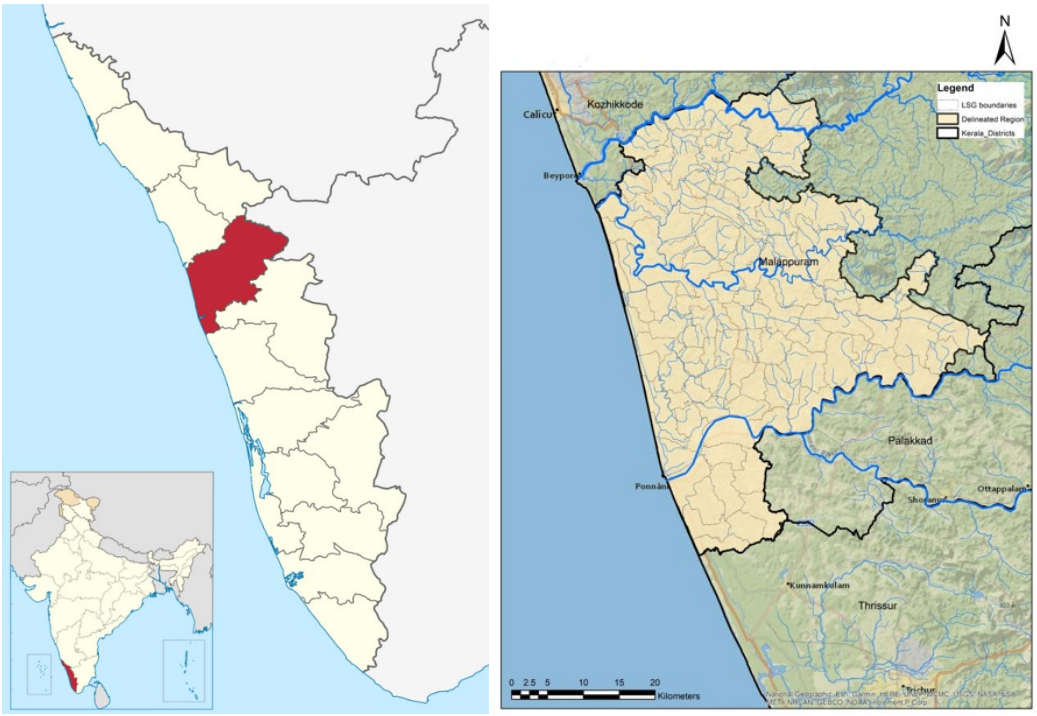
According to a comparative analysis of the two Indian megacities, Mumbai has a greater proportion of heat gain than Delhi (Singh et al., 2014). The research implies that Delhi encountered lower intensity compared to Mumbai because of the city's mixed land use, the presence of green belt throughout the roads, the Delhi Ridge forests, also the Yamuna River, all of that have an impact on and result in a drop in LST (Grover & Singh, 2016). While in the case of Mumbai, the reduced vegetation and diminished carrying capacity of Mumbai's river have contributed to an increase in LST. This causes the heat to become retained in the inhabited areas, creating a significant Urban Heat Island (UHI) effect (Sannigrahi et al., 2017).

3. Materials and Methods

3.1 Study Area

Malappuram, located in Kerala, India, is one of the state's 14 districts and is characterized by its proximity to the Nilgiris Hills in the east and the Arabian Sea in the west. It holds the distinction of being Kerala's most populous district, accommodating roughly 13% of the state's total population (Census of India, 2011). A rapid transformation in the workforce composition from agriculture to non-agriculture has been observed when comparing the census data from 2001 and 2011. According to the survey published by Economist Intelligence Unit, Kerala's Malappuram district ranks first among the fastest-growing urban areas globally (Nijeesh, 2020). The urban population in Malappuram was only 300,000 in 2001, and it increased to 16,00,000 in 2011, an increase of more than five folds in a decade. (Nijeesh, 2020). This exponential growth reflects the rapid pace of urbanization in the district, leading to the selection of the urban agglomeration region as the focus of the study. (Figure 1). The region is delineated considering the present and future urban trends likely to be followed by the region and the anticipated urban area of 2030.

The climate in the study area is generally hot and humid. Relative humidity ranges from 84 to 94 percent during morning hours (Sreenath, 2013). Kerala has been experiencing a scorching summer, with daytime temperatures in several parts of the state reaching above 37°C in 2019. Kerala lost 3 lives in the same year, and 125 people were given medical help due to increasing temperatures (*The Hindu*, 2019). Two places in Malappuram were among the top 8 places within Kerala in maximum temperature observed - Wandoor with 40.30°C and Chugathana with 39.40°C (*Skymet Weather Services*, 2019).



a) b)

Figure 1 Map of a) Kerala, India b) study area (Malappuram urban agglomeration)

3.2 Tools and Techniques

The LST can be measured at different scales using various methods. City level or a larger scale can be measured using thermal remote sensing satellite data as it has got extensive spatial coverage. Temporal coverage and spatial resolution are limited and it is impacted by weather and atmosphere. The neighbourhood scale assessment can be carried out using an aircraft/ thermal scanner which will be having better resolution but higher costs and irregular coverage. Spatial resolution depends on the sensor and aircraft altitude. At the street scale using ground-based techniques, an infrared thermometer can be utilized, which doesn't require any atmospheric corrections. It helps to provide a unique perspective of urban features with high temporal resolution (Voogt & Oke, 2003). According to Cheval & Dumitrescu (2009), satellite temperature data yield more accurate results than interpolated ground station values. The present study is carried out using satellite imagery as it covers a large area and this will help in the broader scale or first level of assessment which can aid in deciding areas that require further studies.

Assessment using satellite imagery includes three popular retrieval methods - single-channel, split-window and multi-angle techniques. The most often used method for retrieving LST from thermal emission in the infrared or microwave range using remote sensing data is the split-window technique because the accuracy of predicted LST using two thermal bands is higher than that of a single band. Only this technique is exempted from accurate atmospheric temperature/water vapour content measurements compared to other LST acquisition techniques. It is vital to keep in mind that inaccuracies in the outcomes will be caused by uncertainties in the atmospheric profile when using the single-channel and multi-angle approaches to retrieve emissivity and LST (Sattari & Hashim, 2014). Hence for the current study, the split window algorithm will be utilized.

3.3 Data sources

Remote sensing data is mainly used in the present study. The data was collected from the United States Geological Survey (USGS) website (United States Geological Survey, 2022). Accordingly, 8 Landsat imageries from 1991 to 2020 were acquired because they best represent the urbanization, change in vegetation and the possible heat gain process. The period is so taken as in Kerala the urbanization pattern was seen to have a normal rate during 1990 to 2000 and it started increasing exponentially after 2011. For 1991 and 1998, Landsat 5 TM (spatial resolution 120m resampled to 30m) are used, while for 2014 and 2020, Landsat 8 (spatial resolution 100m resampled to 30m) imageries are taken. Two

imageries were required for each year as the study area fell into two different tiles. Higher mean maximum temperatures are observed in the months of March and April (34ºC) (Figure 2). Also due to the issues of continuous data availability and cloud coverage, the month of March is chosen, as a closer acquisition date considering the temporal data was better available for that month (Table 1).

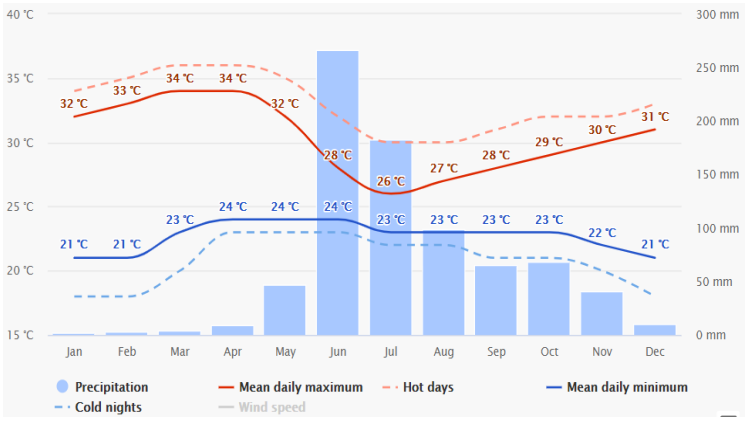


Figure 2 Mean maximum temperature of Malappuram district in 2022 (Source: Meteoblue)

Table 1 Metadata of used satellite imageries (Source: (United States Geological Survey, 2022))

Sensor	Path	Row	Date of acquisition
Landsat 5 (TM)	144	52	12 March 1991
Landsat 5 (TM)	145	52	03 March 1991
Landsat 5 (TM)	144	52	14 March 1998
Landsat 5 (TM)	145	52	10 March 1998
Landsat 8	144	52	11 March 2014
Landsat 8	145	52	02 March 2014
Landsat 8	144	52	12 March 2020
Landsat 8	145	52	19 March 2020

LULC maps were acquired from 'Bhuvan', a geo-platform of the Indian Space Research Organisation (ISRO). The LULC maps were created using multi-temporal satellite data from Resourcsat-2 LISS III (spatial resolution - 30 x 30 m) for the years 2005-06, 2010-11, and 2015-16 as shown in Figure 3. A hybrid technique (Decision Tree - See5, Supervised Maximum Likelihood Classifier) was used to classify the satellite data. (National Remote Sensing Agency, 2007).

3.4 Methodology

The overall methodology followed in the research is given in Figure 4. From the background study conducted, the study area is selected, followed by the acquisition of corresponding satellite imageries. LST and Normalized Difference Vegetative Index (NDVI) retrieval algorithms are reviewed in the coming sections. The study area is mapped and, LST and NDVI estimation and analysis are carried out. Pearson's correlation analysis is used to verify the relations between LST and NDVI. Based on the remote sensing observations, thermal hotspot regions are identified and spatiotemporal variations within the region are analyzed with the help of LST, NDVI and Google Earth images to understand the impact of change in land use. Finally, suitable mitigation strategies are proposed.

3.4.1 Retrieval of LST and NDVI

The split-window algorithm was employed to calculate the surface temperature. Digital Number (DN) values were converted to spectral reflectance and later converted to brightness temperature. For Landsat 8, emissivity correction is also required to accurately calculate the LST. It is carried out using NDVI calculations as shown in Figure 4. Bands 4 and 5 were used to retrieve NDVI, followed by the calculation of the proportion of vegetation which helps in the determination of ground emissivity. The detailed procedure to retrieve LST and NDVI of the study area is explained as follows:

i. Conversion of DN to Top of Atmosphere (TOA) spectral radiance (L_λ)

Conversion of the DN data into spectral radiance was carried out using band 6 from Landsat 5 ETM and band 10 from Landsat 8. It was calculated based on the following equations (Aik et al., 2020; Avdan & Jovanovska, 2016; Sholihah & Shibata, 2019) expressed as Eq. (3.1) and Eq. (3.2):

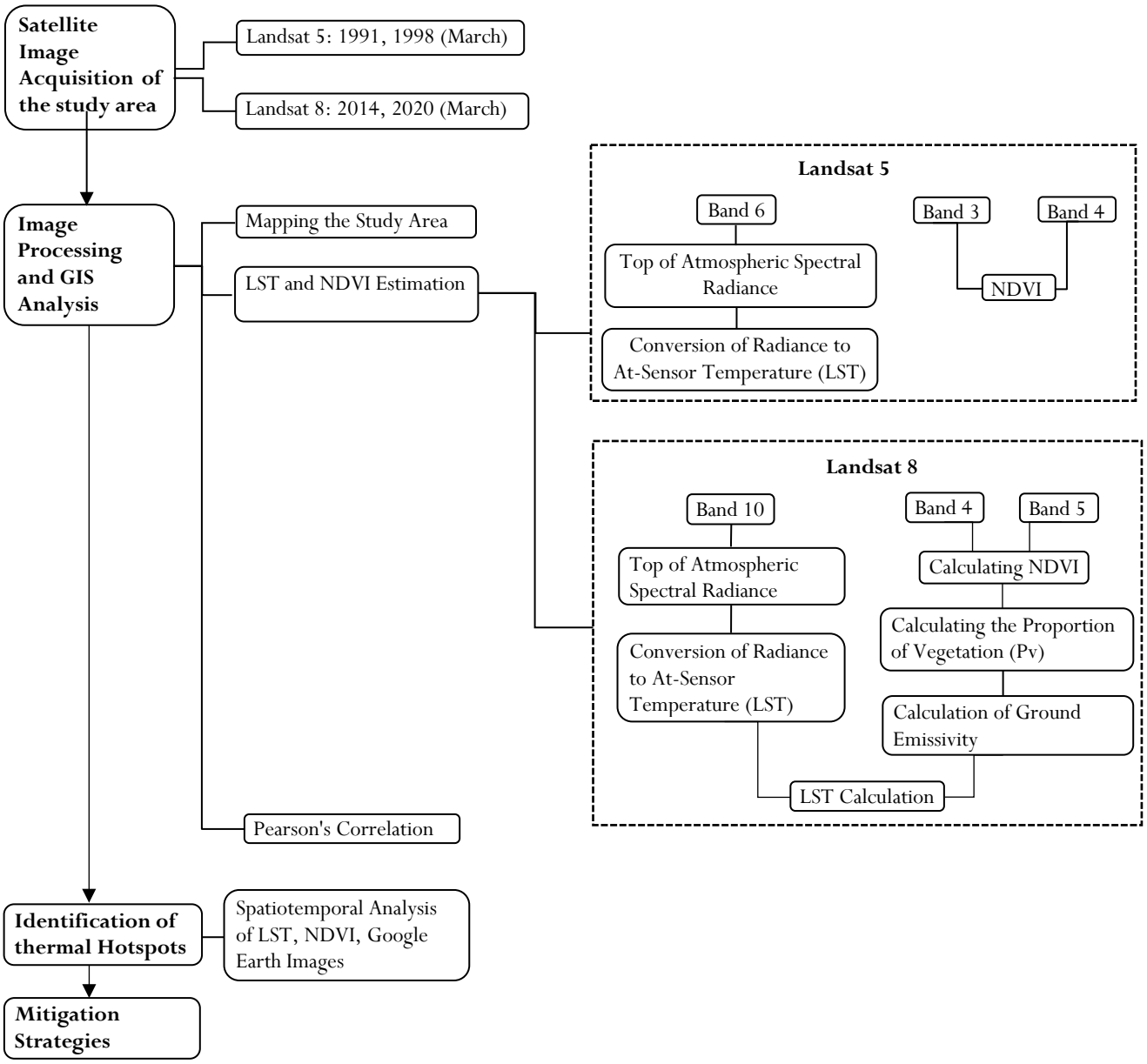


Figure 3 Methodology of the study

a) For Landsat 5 ETM

$$L_\lambda = \frac{L_{MAX} - L_{MIN}}{Q_{CALMAX} - Q_{CALMIN}} \times (Q_{CAL} - Q_{CALMIN}) + L_{MIN} \quad (3.1)$$

Where (Aik et al., 2020),
L_λ = Cell value as radiance
L_{MAX} = Spectral radiance scales to Q_{CALMAX}
L_{MIN} = Spectral radiance scales to Q_{CALMIN}
Q_{CAL} = Digital Number
Q_{CALMAX} = Maximum quantized calibrated pixel value (typically 255)
Q_{CALMIN} = Minimum quantized calibrated pixel value (typically 1)

b) For Landsat 8

$$L_\lambda = M_L Q_{Cal} + A_L \quad (3.2)$$

Where (Sholihah & Shibata, 2019),
M_L = Band-specific multiplicative rescaling factor (for band 10 or 11 = 3.3420E-04)
A_L = Band-specific additive rescaling factor (for band 10 or 11 = 0.10)

Q_{Cal} = Digital Number.
$L\lambda$ = TOA spectral radiance (Watts/ (m2 × srad × μm))
The above-mentioned data is available in the meta-data document of the satellite image data

ii. Conversion of TOA spectral radiance ($L\lambda$) to TOA brightness temperature (Celsius)

$$BT = \frac{K_2}{\ln\left(\frac{K_1}{L_\lambda}\right) + 1} - 273.15 \quad (3.3)$$

Where (Aik et al., 2020),
BT = TOA brightness temperature (°C)
L_λ = TOA spectral radiance
K_1, K_2 = band-specific thermal conversion constants (Table 2)

Table 2 Landsat thermal conversion constant (metadata) (Source: USGS Earth Explorer, 2022)

Sensor	Band	K_1: W/(m².sr.mm)	K_2: Kelvin
Landsat 5	6	607.76	1260.56
Landsat 8	10	774.8853	1321.0789
Landsat 8	11	480.8883	1201.1442

iii. Emissivity Correction using NDVI Method

Emissivity must be included in the calculation of LST, using the near-infrared and visible bands, even though it is feasible to evaluate radiance and temperature data without it (Aik et al., 2020; Avdan & Jovanovska, 2016; Carlson & Ripley, 1997; Estoque & Murayama, 2017; Gazi et al., 2021; Gohain et al., 2021; Kafy et al., 2021; Sekertekin & Bonafoni, 2020; Sobrino et al., 2004; Twumasi et al., 2021).

iv. Calculate the NDVI:

For NDVI calculations (Eq.(3.4)), Landsat visible (Band 4) and near-infrared bands (Band 5) were used (Estoque & Murayama, 2017).

$$NDVI = \frac{Band\ 5 - Band\ 4}{Band\ 5 + Band\ 4} \quad (3.4)$$

v. Calculate the proportion of vegetation P_v (Carlson & Ripley, 1997; Sekertekin & Bonafoni, 2020).

$$P_v = \left(\frac{NDVI - NDVImin}{NDVImax - NDVImin}\right)^2 \quad (3.5)$$

The minimum and maximum values of NDVI calculation performed in the preceding step are designated as $NDVI_{min}$ and $NDVI_{max}$ (Eq. (3.5)).

vi. Calculate Emissivity ε:

The effectiveness of conveying heat energy from the surface into the atmosphere is measured by the land surface emissivity, which is a proportionality factor that scales blackbody radiance (Planck's law) to forecast emitted radiance (Sobrino et al., 2004; Twumasi et al., 2021).

$$\varepsilon = 0.004 * Pv + 0.986 \quad (3.6)$$

vii. Calculate the Land Surface Temperature:

Emissivity-corrected LST is calculated as shown below (Estoque & Murayama, 2017):

$$LST = \frac{BT}{1 + \left(0.00115 * \frac{BT}{1.4388}\right) * Ln(\varepsilon)} \quad (3.7)$$

4. Results and Discussions

The spatial distribution of LST and LULC for the Malappuram district is depicted in Figure 5 and Figure 6. Temperature is seen to increase towards the southwest side, as shown in Figure 5, which is the delineated region. The majority of the study area has a maximum temperature range of 32°C - 34°C. On comparing the LST map with that of the LULC map (Figure 6) of the same year, it can be seen that less amount of vegetation, and the increased built-up area in the study region, could be the reason for the increased temperature when compared to the surrounding regions (Esri, 2020).

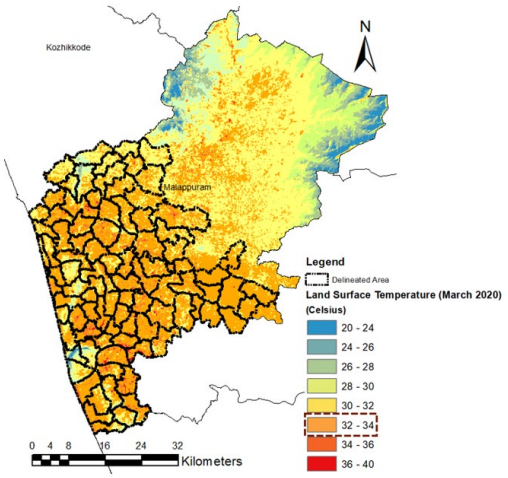


Figure 4 LST Map – March 2020

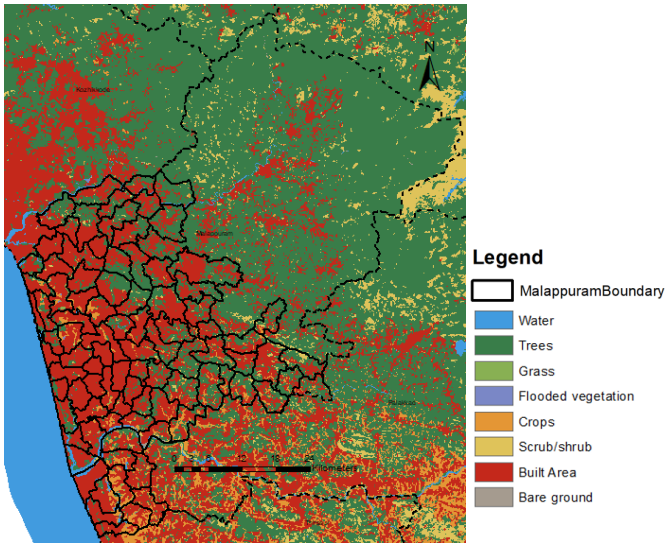


Figure 5 LULC map of 2020 (Source: Esri)

4.1. Spatiotemporal Analysis of Land Surface Temperature

From the spatiotemporal analysis (Figure 7), it is observed that in 1991 the temperature ranged from 30ºC - 32ºC with the mean value being 31.66ºC, while in 1998, the majority region had a temperature range of 31ºC – 32ºC with 31.78ºC as the mean. In 2014, it increased to 31ºC – 33ºC with a mean value of 32.56ºC, and currently, in the case of 2020, the range has increased to 32ºC – 34ºC having a mean of 33.36ºC. Hence, we can infer that around 1.70ºC rise is seen over 30 years time period. Site-specific reasons will be analyzed in the following sections.

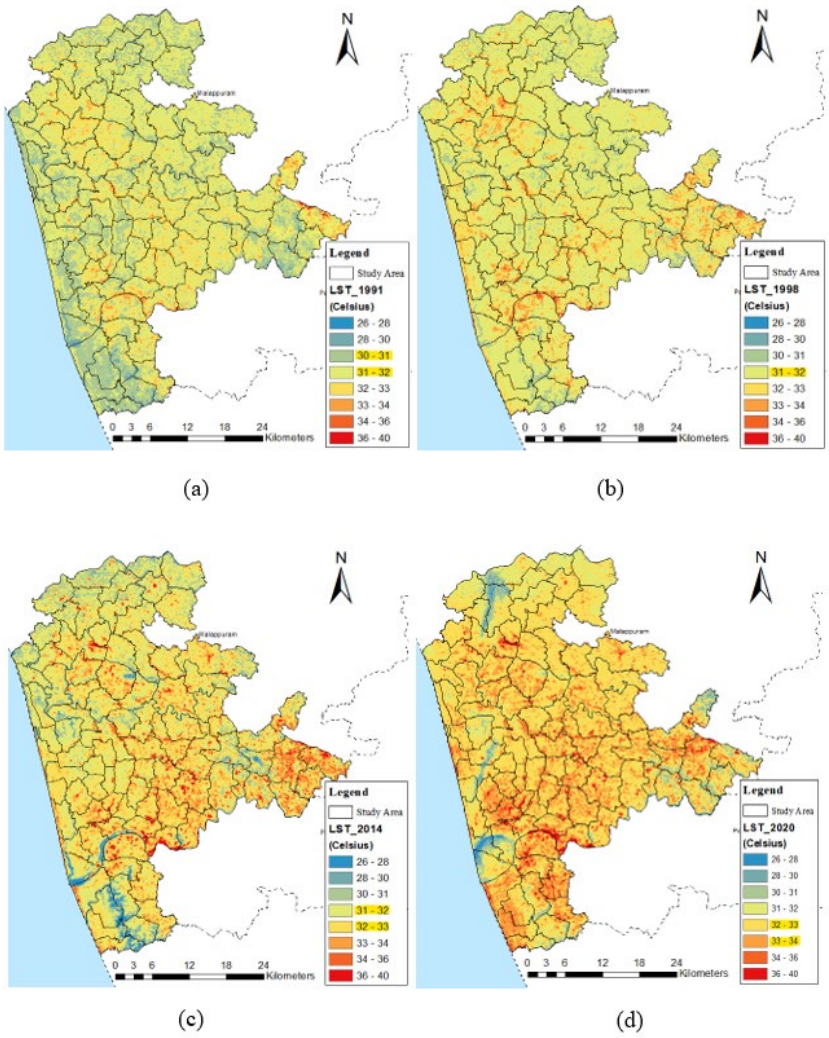


Figure 6 LST map (a) 1991 (b) 1998 (c) 2014 (d) 2020

The temperature rise that has been recorded between 1991 and 2020 is consistent with the prediction by the Intergovernmental Panel on Climate Change (IPCC) in its Fifth Assessment Report (AR5), an organization based in Geneva, Switzerland (*The IPCC Fifth Assessment Report*, 2014). As stated in the report, the rise in global average temperature by the century's end is to be between 2.6 and 4.8 °C. This is mostly due to urbanization and the cities' emission of gases that intensify the greenhouse effect (Kaiser et al., 2022; Revi et al., 2014; Rosenzweig et al., 2018). The contribution of the increasing urbanization rate in the district as mentioned in the Introduction section to the temperature gain is evident in this study.

4.2 Spatiotemporal Analysis of Normalized Difference Vegetative Index

NDVI is used to measure the greenness of vegetation and is useful for determining vegetation density and detecting changes in plant health. Values close to 0, as well as negative values, represent water bodies, 0 to 0.2 represent built-up and barren land, and +1 represents the highest possible vegetation (Guha & Govil, 2020).

From the LULC map shown in Figure 9, a considerable increase in built-up area with decreased vegetation is observed. Hence the impact of decreased vegetation on the LST increase was analyzed. On analysis from 1991 to 2020 (Figure 8), the maximum value decreased from 0.90 to 0.60, which indicates that the vegetation intensity is decreasing. Also, the spatial extent of the green region can be seen to be decreasing over the years, with more areas of lesser intensity vegetation in the case of 2020 and it is quantitatively validated as shown in Table 3. Cross-referencing with Figure 6 shows the spatial correlation between LST and NDVI. It can be interpreted that low LST areas either have the highest NDVI values indicating high vegetative areas or less than 0 NDVI values indicating the water bodies. This is validated through the statistical correlation carried out in the next section. Also, it is observed that over the years, the increase in LST values spatially aligns with the increase in lower NDVI values. The increase in lower NDVI values indicates the change in land use to more of built-up regions. Detailed site-specific interpretations are carried out in Section 4.1.5.

Table 3 NDVI Temporal Variation

NDVI	Area								
	1991		1998		2014		2020		% Change from 1991 to 2020
	Pixel count	%	Pixel count	%	Pixel count	%	Pixel count	%	
VERY LOW	75728	3.97	81090	4.25	41560	2.18	40081	2.10	-1.87
LOW	190404	9.98	204505	10.72	233812	12.26	268297	14.07	4.08
MEDIUM	190224	9.97	227069	11.91	559997	29.36	623023	32.67	22.69
HIGH	363405	19.05	444223	23.29	863830	45.29	780166	40.91	21.85
VERY HIGH	1087475	57.02	950349	49.83	208037	10.91	195669	10.26	-46.76

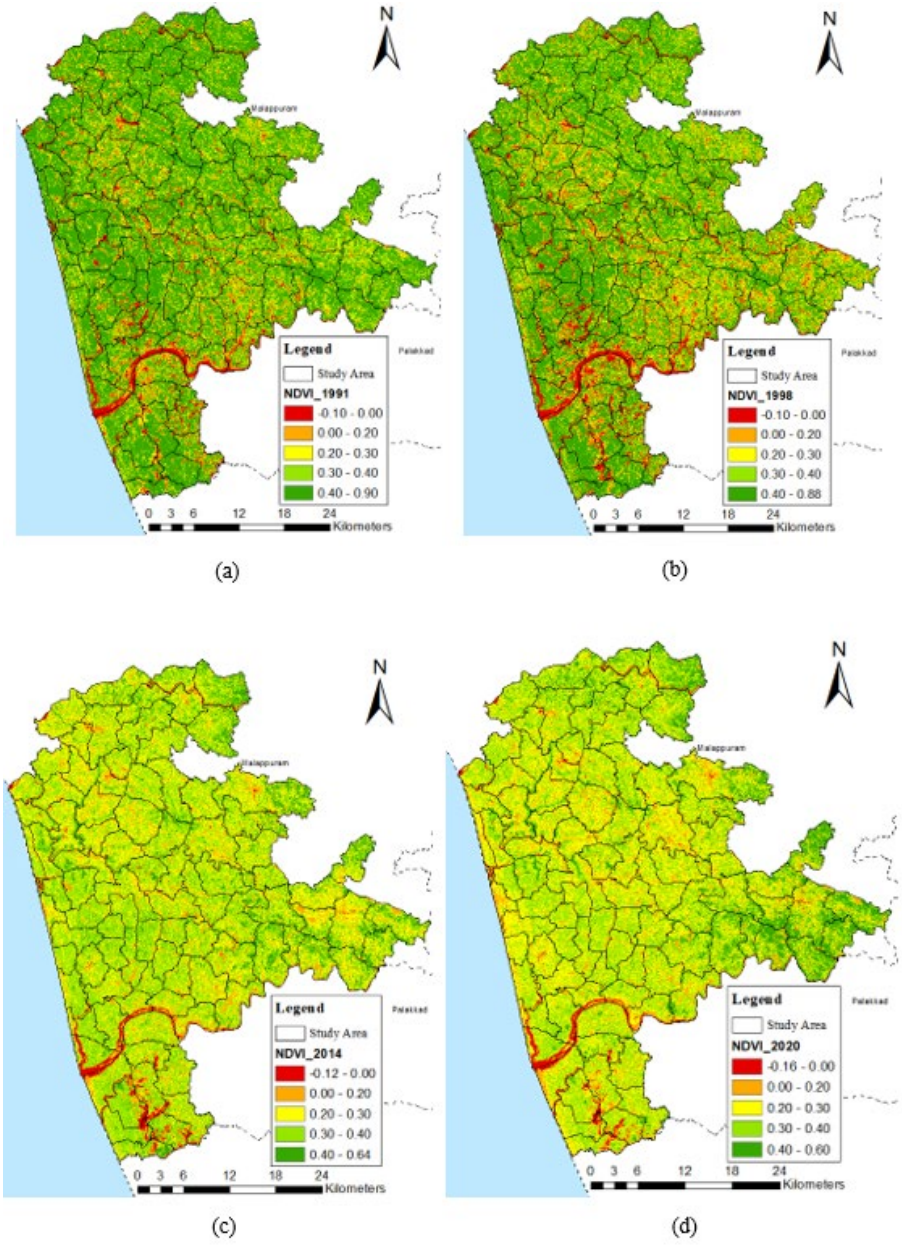


Figure 7 NDVI map (a) 1991 (b) 1998 (c) 2014 (d) 2020

4.3 Statistical Analysis

To validate the relationship between LST and NDVI, statistical analysis was performed using the Pearson correlation coefficient matrix. A sample size of 1048 paired observations was taken and the Pearson Correlation coefficient (r) is obtained to be 0.41. The p-value of this correlation is 1.33E-43, which is less than the significance level (0.05) indicating a statistically significant correlation. Also, the results of the LST-NDVI correlation scatter plot (Figure 8) reveal a negative relationship, with locations with high NDVI values having low temperatures than regions with low NDVI values, which validates the spatial interpretation. The reason can be that plants are excellent absorbers. Flora and moisture-holding soils use a substantial quantity of absorbed radiation during evapotranspiration and produce water vapor, which helps to cool the air in their proximity and therefore reduces the temperature (Kikon et al., 2016). Also, a few values with less than 0 NDVI are seen to have low LST, which is the water bodies having a low-temperature effect.

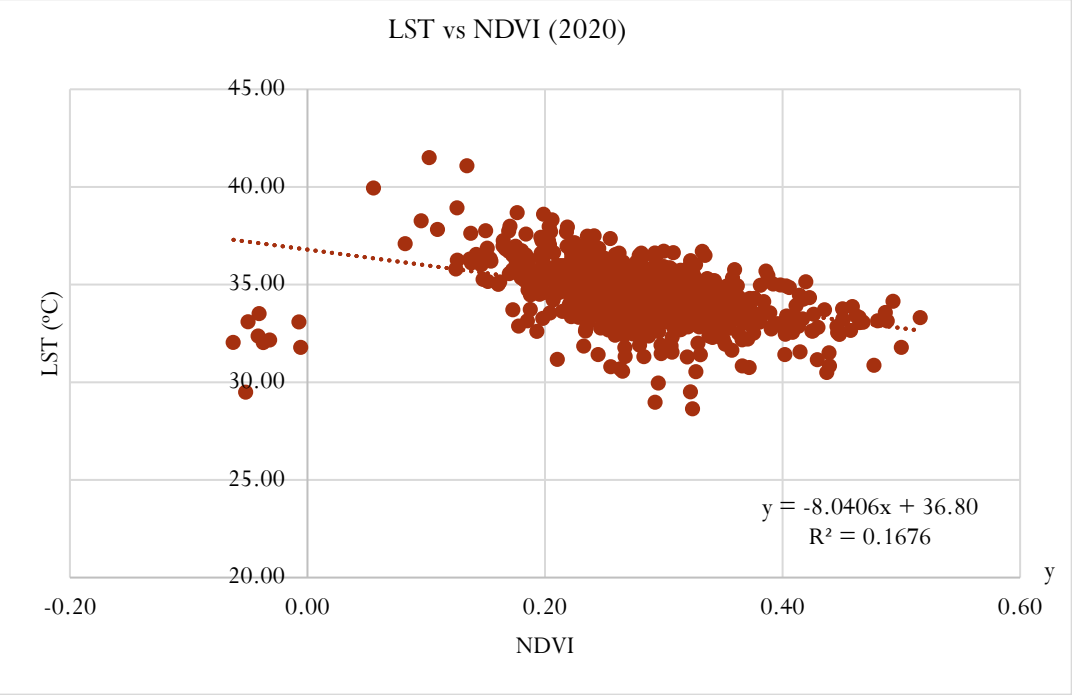


Figure 8 Correlation Analysis - LST vs NDV
I

4.4 Spatiotemporal Analysis of LULC Change

The LULC change analyses of the years 2005–06, 2010–11, and 2015–16 were performed for the categories of built-up, agricultural, forest, wetland/water bodies, and barren/uncultivable land in the 1727 sq. km. of Malappuram urban agglomeration region. While analyzing the percentage difference in the area over the years for different land covers, the built-up area has significantly increased over the years, which can be related mostly to the conversion of cultivable land as shown in Table 4. It is seen that built-up land use has increased by 5.73% inclusive of the urban, rural and industrial land uses (by 98.95 km^2) between 2005-2010 and 4.86% (84.01 km^2) between 2010-2015 leading to an overall increase of 182.96 km^2. Subsequently, the decrease in agricultural land is seen to be about 156.32 km^2 of area. The significant change in built-up land use has been for rural areas due to the transition from agricultural land to rural built-up. It may lead to new town centers and higher urbanization in the future and lead to more rise in LST. The encroachment and degradation of wetlands for agricultural uses have led to a slight drop in water bodies and wetlands in the region of study. These all can be attributed as reasons for the increased temperature and other concerns seen over the years.

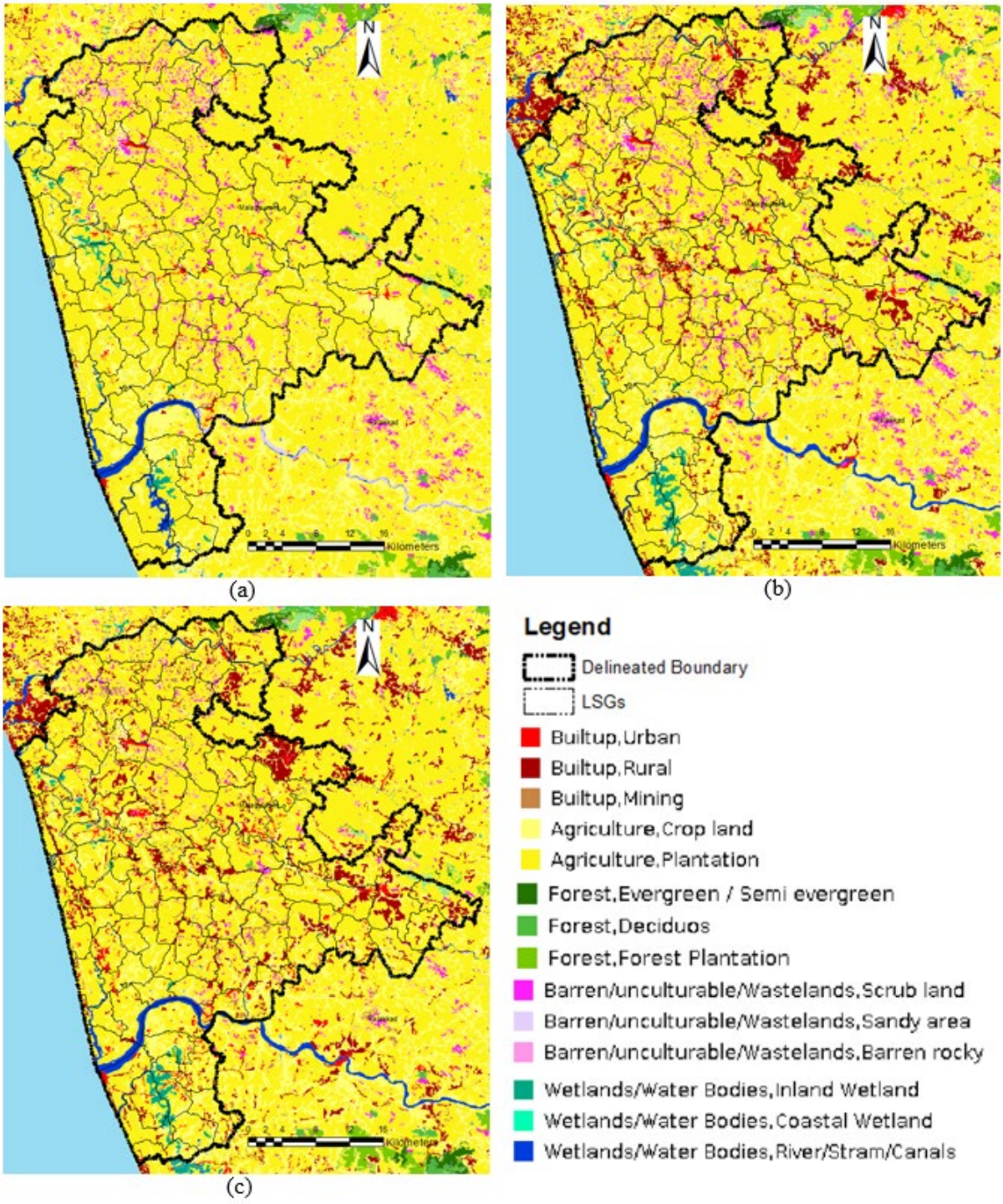


Figure 9 LULC map (a) 2005-06 (b) 2010-11 (c) 2015-16 (Source: Bhuvan WMS overlay)

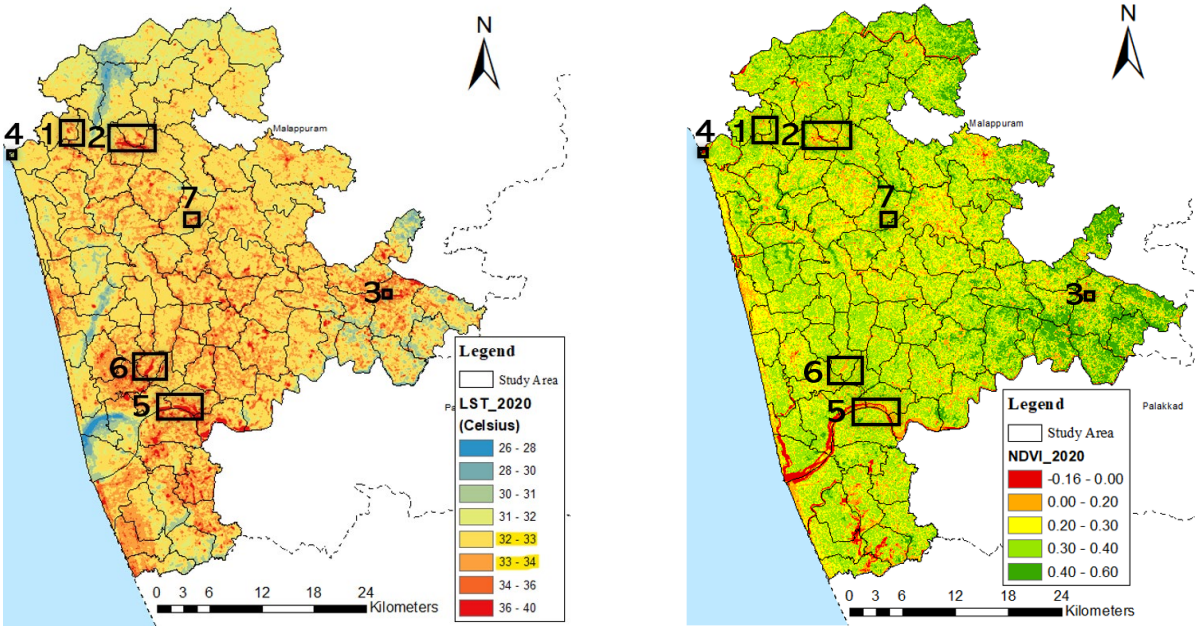
Table 4 LULC Temporal Change (Source: Extracted from (Bhuvan, 2021)

LAND USE			AREA (km^2)			% DIFFERENCE
L1	**L2**		**2005**	**2010**	**2015**	**2005-2015**
Built-Up	Urban	Compact	14.33	14.39	5.99	**+10.60**
		Sparse			32.62	
	Rural		18.19	117.08	172.72	
	Industrial				4.15	
	Total		**32.52**	**131.47**	**215.48**	
	% Area Covered		**1.88**	**7.61**	**12.48**	
Agriculture	Plantation		1314.72	1257.06	1209.30	**-9.06**
	Cropland		220.38	179.26	169.49	
	Total		**1535.10**	**1436.32**	**1378.78**	
	% Area Covered		**88.90**	**83.18**	**79.84**	
Forest	Evergreen Broadleaf		1.39	1.36	1.34	**-0.01**
	Deciduous Needleleaf		0.16	0.16	0.16	
	Mixed Forest		1.04	1.02	0.98	
	Total		**2.59**	**2.54**	**2.48**	
	% Area Covered		**0.15**	**0.15**	**0.14**	
Wetlands/ Waterbodies	Wetlands		24.14	19.43	18.94	**-0.07**
	Waterbodies		55.20	55.07	54.34	
	Total		**79.34**	**74.5**	**73.28**	
	% Area Covered		**4.59**	**4.31**	**4.24**	
Barren/ Uncultivable/ Wastelands	Barren land		3.83	2.22	1.32	**-1.19**
	Scrubland		73.48	68.58	38.44	
	Wastelands				0.22	
	Mining/ Quarrying			11.23	16.87	
	Total		**77.31**	**82.03**	**56.84**	
	% Area Covered		**4.48**	**4.75**	**3.29**	

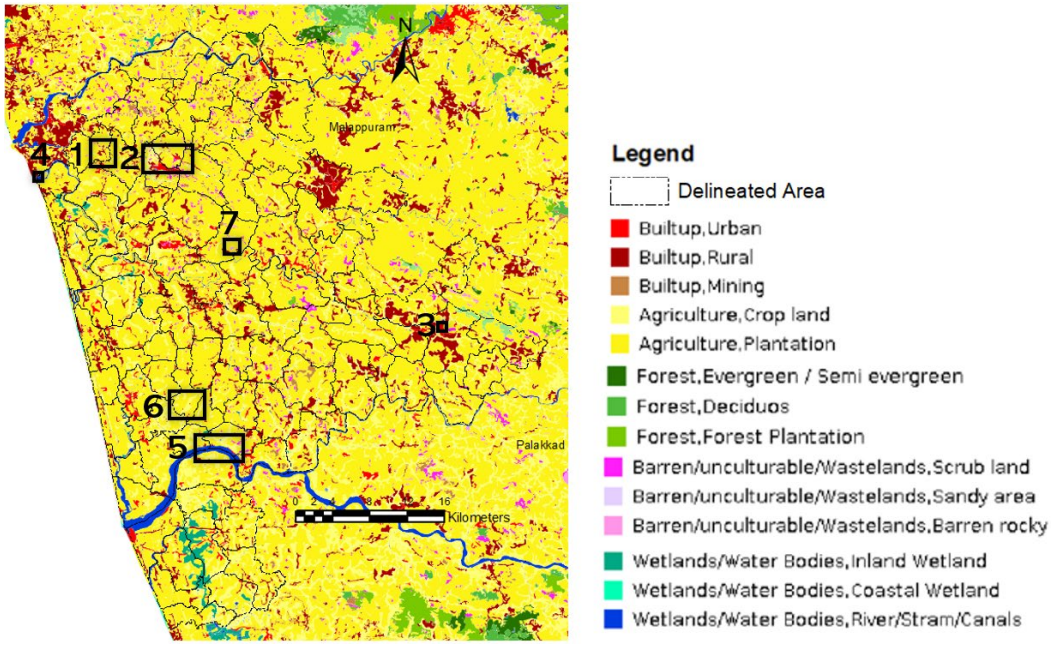
Each land use land cover has got varied reflectance properties and has got a substantial influence on LST. The shift from vegetation cover and water bodies to built-up land can impact LST as they alter the roughness and surface reflectance properties due to the use of anthropogenic substances, multi-story structures, asphalt, and concrete for urban development. The areas of high temperature are depicted in the shades of orange and red and correspond to built-up areas, barren or fallow land, dried river beds, etc. whereas the cooler areas are mapped by the shades of yellow and blue and correspond to the forest, agricultural land, wetlands and water bodies, as shown in Figure 6(d). Location-specific reasons will be examined in the next section. This analysis has shown how LULC modifications can be used as one of the broad factors among others to monitor changes in urban climate.

4.5 Thermal Hotspots

Based on the remote sensing observations, thermal hotspot regions are identified and spatiotemporal variations within the region are analyzed and quantified with the help of LST, NDVI and Google Earth images to understand the impact of change in land use as depicted in Table 5. Hotspot areas are marked from 1 to 7 as shown in Figure 10 namely 1) KINFRA industrial area (Kerala Industrial Infrastructure Development Corporation is a government agency to promote industrialization in the state); 2) Calicut International Airport (located at Karipur, Malappuram district opened on 13 April 1988) and Kondotty region; 3) Perintalmanna built-up area; 4) Kadalundi bird sanctuary area; 5) Bharathapuzha River, 6) fallow land and finally 7) barren land'.



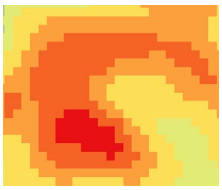
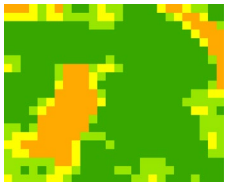
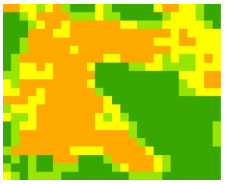
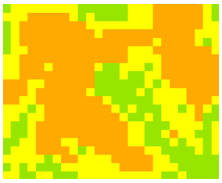
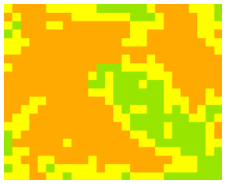
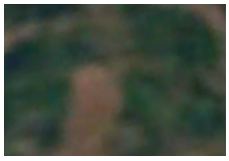
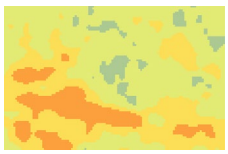
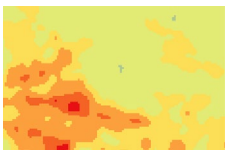
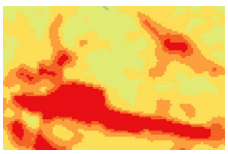
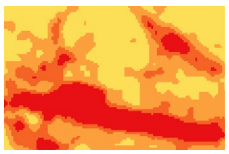
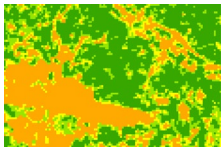
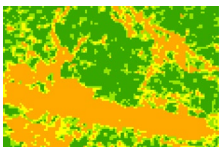
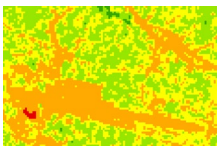
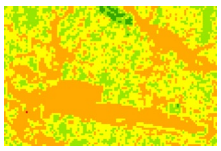
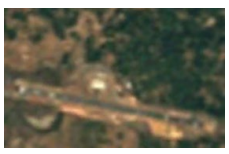
(a) (b)

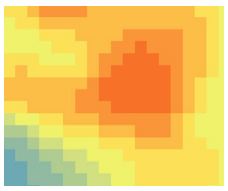
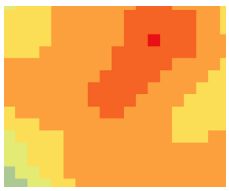
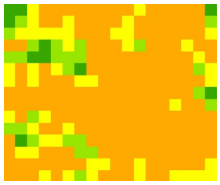
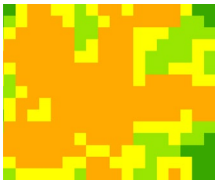
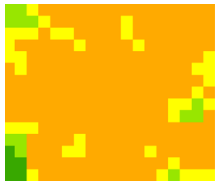
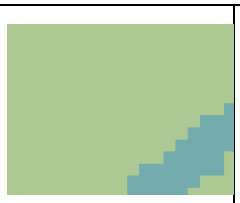
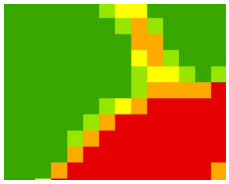
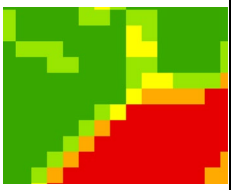
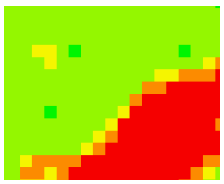
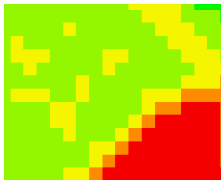
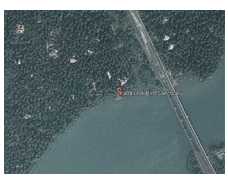


(c)

Figure 10 Hotspot Locations on (a) LST Map (2020) (b) NDVI Map (2020) (c) LULC Map (2015)

Table 5 Spatio-temporal analysis of hotspot regions of 1 to 4

Parameter (Mean Value)	1991	1998	2014	2020	Change from 1991 to 2020
KINFRA INDUSTRIAL AREA					
LST (°C)	 32.92	 33.80	 35.08	 35.46	2.54
NDVI	 0.37	 0.30	 0.24	 0.21	-0.16
Google Earth Image					
CALICUT INTERNATIONAL AIRPORT AND KONDOTTY REGION					
LST (°C)	 31.36	 32.01	 32.79	 33.32	1.96
NDVI	 0.29	 0.27	 0.24	 0.22	-0.07
Google Earth Image					

Parameter (Mean Value)	1991	1998	2014	2020	Change from 1991 to 2020
PERINTALMANNA BUILT-UP AREA					
LST (ºC)	 31.62	 31.98	 33.22	 33.46	1.84
NDVI	 0. 21	 0.20	 0.16	 0.15	-0.06
Google Earth Image					
KADALUNDI BIRD SANCTUARY					
LST (ºC)	 29.88	 29.92	 30.26	 30.50	0.62
NDVI	 0.28	 0.25	 0.12	 0.10	-0.18
Google Earth Image					

(a) Location 1 - KINFRA industrial area

From the spatiotemporal analysis shown in Table 5, it is evident that the land use pattern changed. Initially, it was a vegetation-covered area, and hence it had a low temperature. In 1998 vegetation was replaced by barren land, and the temperature was seen to increase. In 2014 and 2020, the industrial area expanded and hence increased the anthropogenic heat generated from industrial activities, decreased vegetation, and increased built-up leading to the increase in temperature by 2.54ºC.

(b) Location 2 - Calicut International Airport and Kondotty region

In the case of Calicut International Airport and Kondotty region (Table 5) from where the analysis has been derived, the dark paved surface and increased airport activities over time, with increased passenger load, mainly as it became an international airport, can be the reason for the high temperature. The airport is also attracting a considerable proportion of the population, who have occupied the area which was previously thick vegetation. In the case of the Kondotty region, decreased vegetation and increased built-up could be seen as the reasons for the increase in temperature over the years.

(c) Location 3 - Perintalmanna built-up area

In the Perintalmanna region (Table 5), the built-up area and the paved surfaces increased over time with decreased vegetation. It is one of the regions with the highest increase in urban density and subsequently an LST increase of 1.84°C was observed. Increased anthropogenic activities in terms of vehicular emissions can also be a reason.

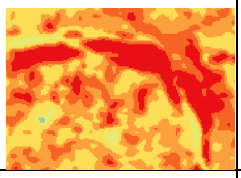
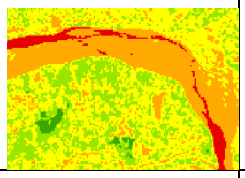
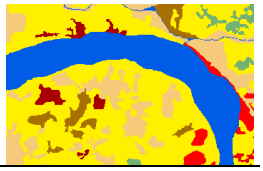
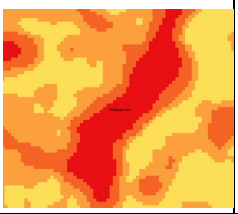
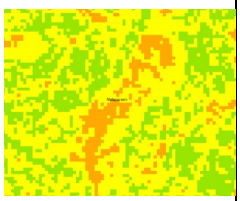
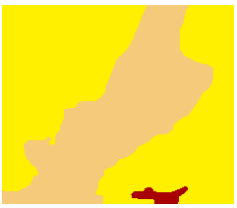
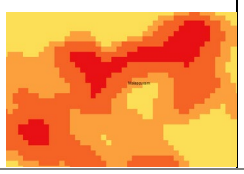
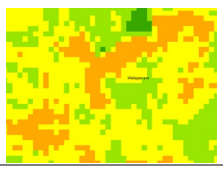
(d) Location 4 - Kadalundi Bird Sanctuary

In this region, in 1991, the temperature mean value is found to be 29.88ºC and it increased to the range of 30.50ºC in 2020, which is a slight increase of 0.62ºC as mentioned in Table 5, hence a gradual increase in temperature over the years is evident which might affect the migratory birds in Kadalundi bird sanctuary. A decrease in vegetation intensity and an increase in built-up are seen in this area to be the reasons.

(e) Location 5, 6, 7 – River sand, Fallow land, Barren land

For the regions shown in Table 6, the sand is having a property of high heat fixation which could be the reason for the high temperature in that area. During the fallow period, the land surface albedo decreases and hence the reflectivity reduces and the temperature rises in the event of continued daylight exposure. As a result, the process of heat irradiation for the environment intensifies, mostly on a local scale (Kaiser et al., 2022).

Table 6 Hotspot locations 5, 6, 7: LST comparison with NDVI, Google Earth and Land Use

Location	LST	NDVI	Google Earth	Land Use
5. River sand (Bharathapuzha)				
6. Fallow land				
7. Barren land				

Through the spatiotemporal analysis of identified thermal hotspots based on remote sensing observations, it is evident that the increasing impact of urbanization and the subsequent change in land use patterns at the expense of greenery; and other anthropogenic factors have a significant effect on the local climate. The rising LST will have detrimental impacts on humans as well as the environment. An overall increase in surface temperature results in more frequent floods and other extreme weather events (Varughese & Purushothaman, 2021) as evident in the case of the 2018 and 2019 Kerala floods, where the Malappuram urban agglomeration region was considerably affected. Hence proper planning and enforcement of context-specific mitigation measures should be strictly performed.

5. Recommendations and Future Implications for UHI Mitigation

Seeing urbanization as a never-ending process, it is increasingly important to take the measures necessary to achieve a fine balance between the environment and urban expansion. As a result, activities should be performed to reduce heat gain. Accordingly, in the current study, two types of planning recommendations are put forward: 1) case-specific recommendations and 2) general planning recommendations.

5.1 Case-specific recommendations

The present section discusses the planning recommendations for the thermal hotspot locations as identified from the research work.

In the industrial region (location 1), where there are various sources of heat rejected from industrial processes, heat recovery can play a significant role, in reducing thermal pollution and decreasing the heat gain effect. For Perintalmanna built-up and Kondotty region (locations 2 and 3) and similar other regions, the use of cool or green roofs with urban farming can be encouraged. Increasing surface reflectivity using cool roofs, cool pavements and other high albedo building materials will help store less heat and maintain a low temperature. To validate this, an analysis using ENVIMET software was carried out (Yeo et al., 2021) and the air temperature difference between different roofing scenarios of identical one-story buildings was found as shown in Figure 11. The highest indoor temperature of 35.88°C was observed in RCC roofing. White-coated RCC roofing registered a temperature of 33.59°C. The lowest indoor air temperature of 31.14°C was observed on green roofs.

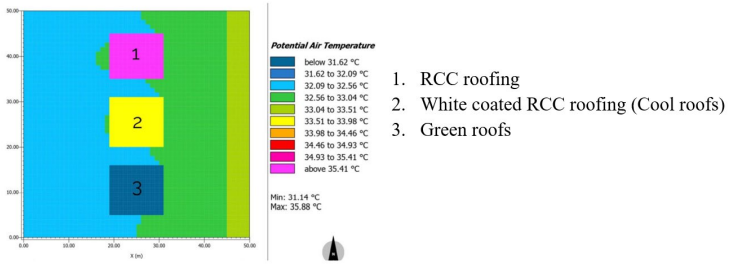


Figure 11 Indoor Air temperature

The sand in fallow land (location 6) has got high heat fixation property, conversion to paddy or green areas can be carried out. Figure 12 maps the fallow land within the study area. The Kerala Conservation of Paddy Land and Wetland Act 2008 shall strictly be implemented. Also, the increased adoption of conservation tillage in agricultural areas can be suggested as it increases the surface albedo over that of the normal tilled cropland, which leads to a decrease in temperature. It reduces the frequency of equipment passages across the field, leading to reduced fuel consumption and the associated carbon emissions. It also increases the productivity of the cropland, improved water and fertilizer penetration and increased moisture levels in the soil. Local authorities need to plan awareness campaigns among the farmers and support systems to help farmers to adopt the conservation tillage practice.

Similar to fallow land, barren land (location 7) has also got high heat fixation properties, so strategies to convert to green zones should be taken up. The area's existing open spaces are devoid of natural elements making them incapable of offering any connections with nature. Urban forestry serves as cooling "islands" in hot urban areas. They can also cool the surrounding landscape as per their scale and wind direction. As they provide cooling to areas downwind, they ought to be placed upwind of hotspot areas (Norton et al., 2013). In Melbourne, urban forestry is placed to the north of priority areas, as extreme heat occurrences are usually accompanied by high-pressure systems. East of Victoria, which bring warm continental air from the North. Royal Park for Melbourne's CBD is an example. Similar strategies may be applied in the case region as well. Since during summer wind flows from southwest to northeast along the study area, suitable vacant land locations are identified upwind of the hotspot regions as shown in Figure 13 where probable urban forestry can be carried out.

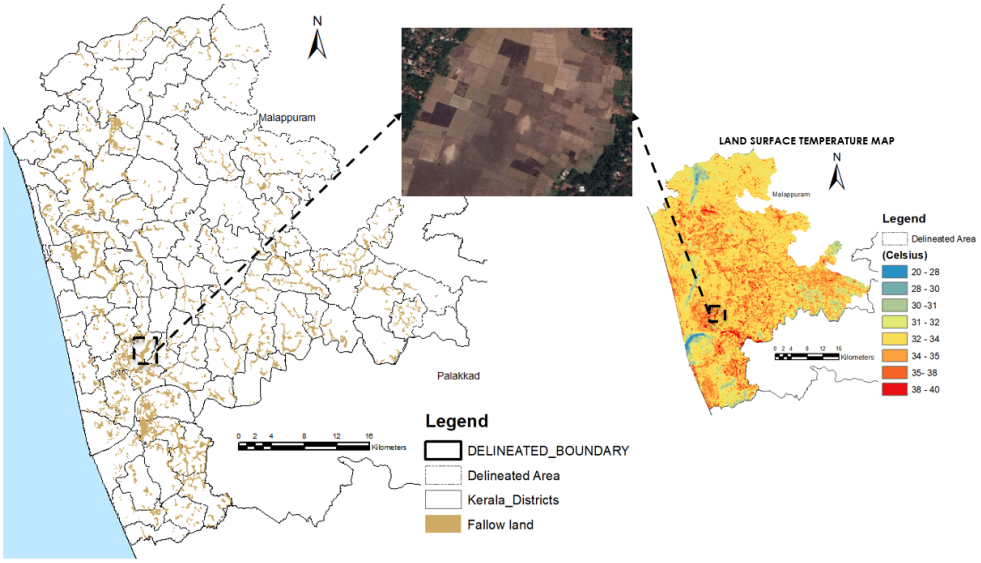


Figure 12 Reclamation of fallow land

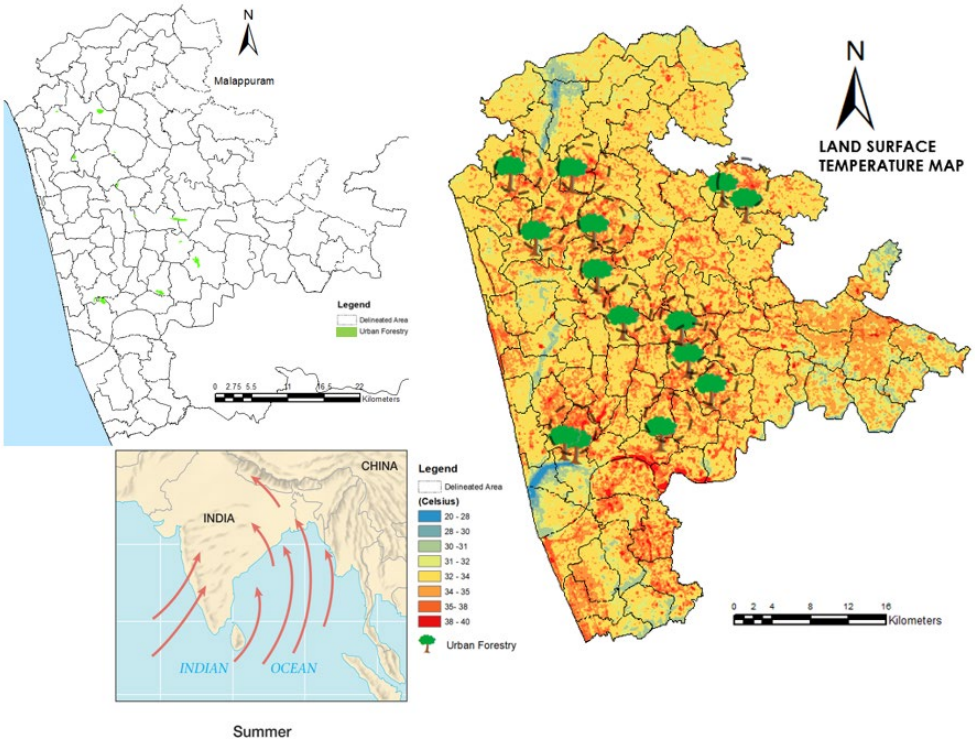


Figure 13 Barren land locations for urban forestry

5.2 General Planning Recommendations

The present section discusses some of the planning recommendations given based on the overall outcome of the research work. They are explained in the subsequent paragraphs.

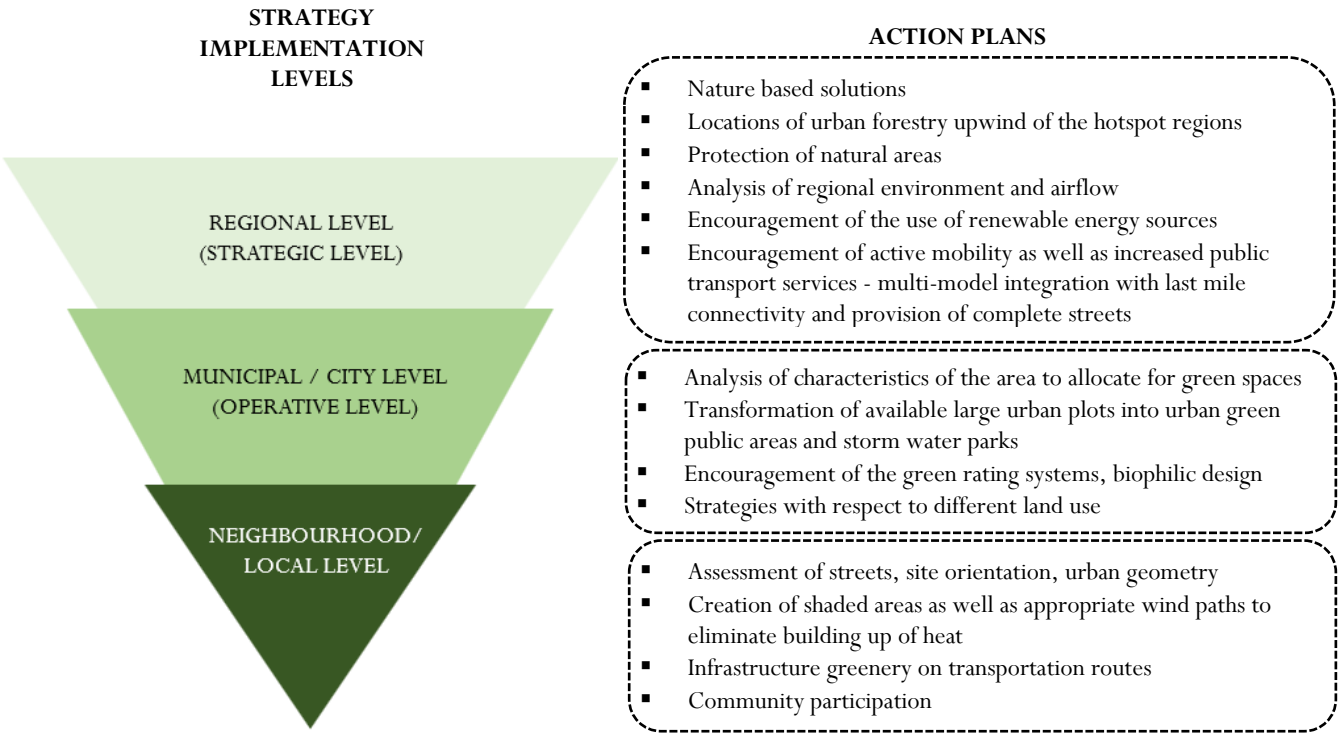


Figure 14 Planning recommendations at various levels

Policies and cooperation at all scales are necessary for effective implementation, which can be improved through integrated solutions that connect mitigation and adaptation with other social goals. It is ideal to think of planning for strategies as a multi-level, hierarchical process (Figure 14). The regional level, which is a strategic level, is the first level. Various nature-based solutions can be incorporated. Suitable locations for urban forestry are to be selected upwind of the hotspot regions identified from this broad assessment. Agroforestry can also be promoted and the ecosystem for it needs to be created at the regional planning level. It is also important to encourage the preservation of vast natural regions, such as river basins contiguous to urban areas. Particularly, it is important to give natural areas like riparian zones and wetlands top priority for preservation so that stream buffers, sites for native plant regeneration, and storm-water parks can be created. Also, the use of renewable energy sources should be encouraged, and low-carbon fuels should be promoted. To reduce anthropogenic heat generation, encouragement of active mobility as well as increased public transport services with more comfort and convenience shall be implemented. Multi-model integration with last-mile connectivity helps in promoting these. Also, the creation of complete streets that provide a uniform carriageway, safe and continuous walkways, separated bike lanes, well-organized on-street parking and secured pedestrian crossings with refuge increases active mobility and should be taken up in the local area planning.

The shift from strategy to action occurs at the next level, which is the municipal or city level. To provide space for green areas, the function and characteristics of the area should be examined. The creation of urban green public spaces like urban parks, urban forests, community gardens, etc. should be done by prioritizing existing large vacant urban plots that are available within the urban fabric. These spaces can be planned to include various environmental and recreational features as well as to boost urban biodiversity. Implementation of these nature-based solutions can be organized by municipalities, NGOs, etc. Encouragement of the green rating systems, where according to the rating certificate, the competent authority shall offer some incentives, for example, in terms of tax relaxation, can be provided to developers constructing housing, schools, resorts, etc. incorporating green infrastructure elements and tools and using sustainable means in creating the outdoor landscape. The incorporation of various green infrastructure components into new building designs may be required by new regulations, which will both serve to improve the environment and the building's internal efficiency. Commercial buildings can plant trees in parking lots and around buildings, green walls and green facades in areas with less ground space. Residential buildings shall have trees around as well as rooftop farming can be carried out. Biophilic design can be incorporated that seeks to connect people with nature and natural elements. Integrating living greenery, use of natural materials and water features, encouraging natural ventilation and incorporating atriums or courtyards with vegetation, use of natural shading devices such as awnings, trellises, pergolas, etc can be used. It results in significant reductions in the amount of energy usage as it reduces the dependency on cooling appliances. Green pavements can also be

adopted. By incorporating these biophilic design elements, spaces become more than just functional structures - they become vibrant and inspiring environments that reconnect people with nature. These design strategies promote well-being, improve air quality, regulate temperature, reduce energy consumption, and enhance the overall human experience within the built environment (Browning et al., 2014).

Next is the neighbourhood/ local level, where the assessment of streets and site orientation, land slopes, vacant sites, community participation, etc. are carried out for creating green spaces. Infrastructure greenery on transportation routes can be given, where existing infrastructure, such as tunnels, bridges, motorways, and bus stops, can be enhanced by vegetation to reduce the impact of dark pavements on heat gain. Urban geometry also plays a role in controlling heat gain. The coverage of the shaded areas along with the wind condition is influenced by building layout, the placement of urban features, building proportion and orientation. Additionally, sufficient urban planning is essential at a coarser spatial scale to take advantage of the regional environment and airflow, create appropriate wind paths that access the urban area, and eliminate the building up of heat. When planning new construction or a building retrofit, the height of the buildings ideally should be in ascending order to the wind direction so that sufficient wind can enter the rear blocks. To improve airflow, staggering building heights and void decks would also be an option. Ventilation into a building and on the streets can be influenced by the building form and composition.
Pilot projects to create awareness regarding the benefits should be carried out. Programs can begin as voluntary initiatives and then expand to building codes as heat gain adaptation measures and norms. It is recommended that local governments use as many effective mitigation measures and technologies as they can for their municipal buildings and facilities, thereby leading as an example for private buildings. To showcase the cost-effectiveness, energy savings, and other advantages of these approaches, cities should document their experiences with them. Local governments should take up the initiative and provide awareness to the people through effective implementation.

6 Conclusions

The present study conducted for Malappuram urban agglomeration area in Kerala, India, revealed that similar to other metropolitan areas in the country, it showed a major rise in the land surface temperature, a 1.70°C rise was seen over 30 years from 1991 to 2020. A significant decrease in the maximum value of NDVI from 0.90 to 0.60 was also observed, which indicates that the vegetation intensity is decreasing. Hence various tree planting strategies within the urban areas, with local, micro and macro scale forestry are to be looked into to combat the reduction in vegetation cover along with the other strategies suggested. Areas with the highest increase in urban density with decreased vegetation observed an LST increase of around 1.84°C. This could be attributed possibly to the minor impacts of climate change as well as the loss of green cover as evident from the LULC and NDVI maps.
The current research focuses only on the broader level of assessment as the study was carried out with the help of remote sensing satellite data since it covered a larger region. Hence, this study can be taken as the first level of assessment by finding the areas to focus on for further analysis which can be carried out using more sophisticated tools like an aircraft thermal scanner, infrared thermometer, etc. which provides better resolution and details. The identified thermal hotspots and similar regions should be further analyzed to give appropriate context-specific mitigation strategies. Model simulations using various software like ENVIMET can be carried out to analyze the microclimate using different planning scenarios and suggest measures through Development Control Regulations. The urban geometry, FAR (Floor Area Ratio), the orientation of buildings, green cover, type of roofing, etc. could be varied in different scenarios and suitable economical and context-specific measures can be implemented to reduce the heat gain (Yeo et al., 2021). Further, the planning recommendations and the mitigation strategies proposed need to be verified or validated by the policymakers or planners.
Proper effective planning is required to subside the effect on the local climate due to the increasing impact of urbanization and the subsequent change in land use patterns at the expense of greenery. Policy recommendations must include consideration of the urban thermal landscape and proper mitigative measures should be taken up; obliviousness of it will have a harmful effect on the environment, meteorology, daily life and health.

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References

Aik, J., Ismail, M. H., & Muharam, F. M. (2020). Land Use / Land Cover Changes and the Relationship. *Land*, *9*(372): 1–23.

Avdan, U., & Jovanovska, G. (2016). Algorithm for Automated Mapping of Land Surface Temperature Using LANDSAT 8 Satellite Data. *Journal of Sensors,* 2016: 8, Article ID 1480307. https://doi.org/10.1155/2016/1480307

Banerji, H., Firoz, M., & Sen, J. (2014). A Methodology to Define the Typology of Rural Urban Continuum Settlements in Kerala. *Journal of Regional Development and Planning,* 3(1), 49.

Bhuvan. (2021). *Thematic Data dissemination*. Bhuvan ISRO/ NRSC. https://bhuvan-app1.nrsc.gov.in/thematic/thematic/index.php Retrieved September 14, 2021

Browne, D. (2019). Leaving no one behind. *Highways*, *88*(5): 3. https://doi.org/10.4324/9781351006941-3

Browning, W., Ryan, C., & Clancy, J. (2014). 14 Patterns of Biophilic Design: Improving Health & Well-Being in the Built Environment. *Terrapin Bright Green,LLC*, 1–60. https://doi.org/10.1016/j.yebeh.2008.04.024

Business Standard News. (2022). *90 people died in 2022 due to heatwave spells in India, Pakistan: Study*. https://www.business-standard.com/article/current-affairs/90-people-died-in-2022-due-to-

heatwave-spells-in-india-pakistan-study-122052400052_1.html (Retrieved October 24, 2022)

Carbon Management Ask the Experts: The IPCC Fifth Assessment Report. (2014). https://doi.org/10.4155/cmt.13.80

Carlson, T. N., & Ripley, D. A. (1997). On the relation between NDVI, fractional vegetation cover, and leaf area index. *Remote Sensing of Environment*, *62*(3): 241–252. https://doi.org/10.1016/S0034-4257(97)00104-1

Chen, J., & Zhang, L. (2016). Joint multi-image saliency analysis for region of interest detection in optical multispectral remote sensing images. *Remote Sensing,* 8(6): 461. https://doi.org/10.3390/rs8060461

Cheval, S., & Dumitrescu, A. (2009). The July urban heat island of Bucharest as derived from modis images. *Theoretical and Applied Climatology*, *96*(1–2): 145–153. https://doi.org/10.1007/S00704-008-0019-3

Cyriac, S., & Firoz C, M. (2022). Dichotomous classification and implications in spatial planning: A case of the Rural-Urban Continuum settlements of Kerala, India. *Land Use Policy*, *114*: 105992. https://doi.org/https://doi.org/10.1016/j.landusepol.2022.105992

Deng, C., & Wu, C. (2013). Examining the impacts of urban biophysical compositions on surface urban heat island: A spectral unmixing and thermal mixing approach. *Remote Sensing of Environment*, *131*: 262–274. https://doi.org/10.1016/J.RSE.2012.12.020

Estoque, R. C., & Murayama, Y. (2017). Monitoring surface urban heat island formation in a tropical mountain city using Landsat data (1987–2015). *ISPRS Journal of Photogrammetry and Remote Sensing*, *133*: 18–29. https://doi.org/10.1016/j.isprsjprs.2017.09.008

Fathima Zehba, M. P., Mohammed Firoz, C., & Babu, N. (2021). Spatial Assessment of Quality of Life Using Composite Index. *Quality of Life*, 181–207. https://doi.org/10.1201/9781003009139-11

Feizizadeh, B., Blaschke, T., Nazmfar, H., Akbari, E., & Kohbanani, H. R. (2013). Monitoring land surface temperature relationship to land use/land cover from satellite imagery in Maraqeh County, Iran. *Http://Dx.Doi.Org/10.1080/09640568.2012.717888*, *56*(9): 1290–1315. https://doi.org/10.1080/09640568.2012.717888

Gazi, M. Y., Rahman, M. Z., Uddin, M. M., & Rahman, F. M. A. (2021). Spatio-temporal dynamic land cover changes and their impacts on the urban thermal environment in the Chittagong metropolitan area, Bangladesh. *GeoJournal*, *86*(5): 2119–2134. https://doi.org/10.1007/s10708-020-10178-4

Gohain, K. J., Mohammad, P., & Goswami, A. (2021). Assessing the impact of land use land cover changes on land surface temperature over Pune city, India. *Quaternary International*, *575–576*: 259–269. https://doi.org/10.1016/j.quaint.2020.04.052

Grover, A., & Singh, R. B. (2015). Analysis of urban heat island (Uhi) in relation to normalized difference vegetation index (ndvi): A comparative study of delhi and mumbai. *Environments - MDPI*, *2*(2): 125–138. https://doi.org/10.3390/environments2020125

Grover, A., & Singh, R. B. (2016). Monitoring Spatial patterns of land surface temperature and urban heat island for sustainable megacity: A case study of Mumbai, India, using landsat TM data. *Environment and Urbanization ASIA*, *7*(1): 38–54. https://doi.org/10.1177/0975425315619722

Guha, S., & Govil, H. (2020). Land surface temperature and normalized difference vegetation index relationship: a seasonal study on a tropical city. *SN Applied Sciences*, *2*(10): 1–14. https://doi.org/10.1007/s42452-020-03458-8

Haghighi, N., Liu, X. C., Zhang, G., & Porter, R. J. (2018). Impact of roadway geometric features on crash severity on rural two-lane highways. *Accident Analysis and Prevention*, *111*(November 2017): 34–42. https://doi.org/10.1016/j.aap.2017.11.014

Hu, L., & Brunsell, N. A. (2013). The impact of temporal aggregation of land surface temperature data for surface urban heat island (SUHI) monitoring. *Remote Sensing of Environment*, *134*: 162–174. https://doi.org/10.1016/j.rse.2013.02.022

Kafy, A. Al, Faisal, A. Al, Shuvo, R. M., Naim, M. N. H., Sikdar, M. S., Chowdhury, R. R., Islam, M. A., Sarker, M. H. S., Khan, M. H. H., & Kona, M. A. (2021). Remote sensing approach to simulate the land use/land cover and seasonal land surface temperature change using machine learning algorithms in a fastest-growing megacity of Bangladesh. *Remote Sensing Applications: Society and Environment*, *21*(December 2020): 100463. https://doi.org/10.1016/j.rsase.2020.100463

Kaiser, E. A., Beatriz, S., Rolim, A., Efrain, A., Grondona, B., Hackmann, C. L., Linn, R. D. M., Käfer, P. S., & Souza, N. (2022). Spatiotemporal Influences of LULC Changes on Land Surface Temperature in Rapid Urbanization Area by Using Landsat-TM and TIRS Images. *Atmosphere,* 13(3):460.

Kallingal, F. R., & Joy, K. P. (2022). Regional Integrated Approach for Smart Master Planning: A Case of Kochi, Kerala, India. *Advances in 21st Century Human Settlements*, 231–247. https://doi.org/10.1007/978-981-19-2386-9_6

Kallingal, F. R., & Mohammed Firoz, C. (2022). Regional disparities in social development: A case of selected districts in Kerala, India. *GeoJournal*, 88: 1–28. https://doi.org/10.1007/s10708-022-10592-w

Kikon, N., Singh, P., Singh, S. K., & Vyas, A. (2016). Assessment of urban heat islands (UHI) of Noida City, India using multi-temporal satellite data. *Sustainable Cities and Society*, *22*: 19–28. https://doi.org/10.1016/j.scs.2016.01.005

Madanian, M., Soffianian, A. R., Soltani Koupai, S., Pourmanafi, S., & Momeni, M. (2018). The study of thermal pattern changes using Landsat-derived land surface temperature in the central part of Isfahan province. *Sustainable Cities and Society*, *39*: 650–661. https://doi.org/10.1016/j.scs.2018.03.018

Mathew, A., Sreekumar, S., Khandelwal, S., Kaul, N., & Kumar, R. (2016). Prediction of surface temperatures for the assessment of urban heat island effect over Ahmedabad city using linear time series model. *Energy and Buildings*, *128*: 605–616. https://doi.org/10.1016/j.enbuild.2016.07.004

Ministry of Housing and Urban Affairs. (2017). *National Capital Region Planning Board*. https://ncrpb.nic.in/rationale.html (Retrieved November 20, 2022)

National Remote Sensing Agency. (2007). *Natural Resources Census National Land Use and Land Cover Mapping Using Multi-Temporal AWiFS Data*. *June*.

Norton, B., Bosomworth, K., Coutts, A., Williams, N., Livesley, S., Trundle, A., Harris, R., & Mcevoy, D. (2013). *Planning for a Cooler Future : Green Infrastructure to Reduce Urban Heat: Climate Adaptation for*

Decision-makers. *October*, 1–29. http://www.vcccar.org.au/sites/default/files/publications/VCCCAR Green Infrastructure Guide Final.pdf

Praveen Lal, C. S., & Nair, S. B. (2017). Urbanization in Kerala—What Does the Census Data Reveal? *Indian Journal of Human Development*, *11*(3): 356–386. https://doi.org/10.1177/0973703018763241

Revi, A., Satterthwaite, D., Aragón-Durand, F., Corfee-Morlot, Robert B R Kiunsi, J., Pelling, M., Roberts, D., Solecki, W., Pahwa, S., & Sverdlik, A. (2014). Towards transformative adaptation in cities: the IPCC's Fifth Assessment. *IIED)*, *26*(1): 11–28. https://doi.org/10.1177/0956247814523539

Rimal, B. (2012). Urbanization and the Decline of Agricultural Land in Pokhara Sub-metropolitan City, Nepal. *Journal of Agricultural Science*, *5*(1): 54–65. https://doi.org/10.5539/jas.v5n1p54

Rosenzweig, C.; Solecki, W.D.; Romero-Lankao, P.; Mehrotra, S.; Dhakal, S.; Ibrahim, S. A. (2018). Climate Change and Cities: Second Assessment Report of the Urban Climate Change Research Network. *Cambridge University Press: Cambridge, UK*. https://doi.org/10.1080/23298758.1994.10685604

Ruefenacht, L. A., & Acero, J. A. (2017). Strategies for Cooling Singapore. *Cooling Singapore (CS)*, *2017*. https://doi.org/10.3929/ethz-b-000258216

Sannigrahi, S., Rahmat, S., Chakraborti, S., Bhatt, S., & Jha, S. (2017). Changing dynamics of urban biophysical composition and its impact on urban heat island intensity and thermal characteristics: the case of Hyderabad City, India. *Modeling Earth Systems and Environment*, *3*(2): 647–667. https://doi.org/10.1007/s40808-017-0324-x

Sattari, F., & Hashim, M. (2014). A Breif Review of Land Surface Temperature Retrieval Methods from Thermal Satellite Sensors. *Middle-East Journal of Scientific Research*, *22*(5): 757–768. https://doi.org/10.5829/idosi.mejsr.2014.22.05.21934.

Sekertekin, A., & Bonafoni, S. (2020). Land surface temperature retrieval from Landsat 5, 7, and 8 over rural areas: Assessment of different retrieval algorithms and emissivity models and toolbox implementation. *Remote Sensing* 12(2): 294.https://doi.org/10.3390/rs12020294

Sholihah, R. I., & Shibata, S. (2019). Retrieving Spatial Variation of Land Surface Temperature Based on Landsat OLI/TIRS: A Case of Southern part of Jember, Java, Indonesia. *IOP Conference Series: Earth and Environmental Science*, *362*(1). https://doi.org/10.1088/1755-1315/362/1/012125

Singh, P., Kikon, N., & Verma, P. (2017). Impact of land use change and urbanization on urban heat island in Lucknow city, Central India. A remote sensing based estimate. *Sustainable Cities and Society*, *32*, 100–114. https://doi.org/10.1016/j.scs.2017.02.018

Singh, R. B., Grover, A., & Zhan, J. (2014). Inter-seasonal variations of surface temperature in the urbanized environment of Delhi using landsat thermal data. *Energies*, *7*(3), 1811–1828. https://doi.org/10.3390/en7031811

Skymet Weather Services. (2016). *Some more days of heatwave in Kerala before brief respite*. https://www.skymetweather.com/content/weather-news-and-analysis/kerala-records-highest-temperature-in-almost-3 decades/ (Retrieved January 08, 2022)

Sobrino, J. A., Jiménez-Muñoz, J. C., & Paolini, L. (2004). Land surface temperature retrieval from LANDSAT TM 5. *Remote Sensing of Environment*, *90*(4): 434–440. https://doi.org/10.1016/j.rse.2004.02.003

Sreenath, G. (2013). *Ground Water Information Booklet of Malappuram District*. *December*, 1–29.

Sruthi Krishnan, V., & Mohammed Firoz, C. (2020). Regional urban environmental quality assessment and spatial analysis. *Journal of Urban Management*, *9*(2): 191–204. https://doi.org/10.1016/j.jum.2020.03.001

Sterling, S., & Duchame, A. (2008). Comprehensive data set of global land cover change for land surface model applications. *Global Biogeochemical Cycles*, 22(3): GB3017. https://doi.org/10.1029/2007GB002959

T.S., S., Mohammed Firoz, C., & Bhagyanathan, A. (2022). The impact of upstream land use land cover change on downstream flooding: A case of Kuttanad and Meenachil River Basin, Kerala, India. *Urban Climate*, *41*(April 2021): 101089. https://doi.org/10.1016/j.uclim.2022.101089

The Hindu. (2019). *Sunstroke claims three lives in Kerala*. https://www.thehindu.com/news/national/kerala/two-more-suspected-sunstroke-deaths/article26627812.ece (Retrieved October 18, 2021)

Tran, D. X., Pla, F., Latorre-Carmona, P., Myint, S. W., Caetano, M., & Kieu, H. V. (2017). Characterizing the relationship between land use land cover change and land surface temperature. *ISPRS Journal of Photogrammetry and Remote Sensing*, *124*: 119–132. https://doi.org/10.1016/j.isprsjprs.2017.01.001

Twumasi, Y. A., Merem, E. C., Namwamba, J. B., Mwakimi, O. S., Ayala-Silva, T., Frimpong, D. B., Ning, Z. H., Asare-Ansah, A. B., Annan, J. B., Oppong, J., Loh, P. M., Owusu, F., Jeruto, V., Petja, B. M., Okwemba, R., McClendon-Peralta, J., Akinrinwoye, C. O., & Mosby, H. J. (2021). Estimation of Land Surface Temperature from Landsat-8 OLI Thermal Infrared Satellite Data. A Comparative Analysis of Two Cities in Ghana. *Advances in Remote Sensing*, *10*(04): 131–149. https://doi.org/10.4236/ars.2021.104009

United Nations. (2019). *The Climate Crisis – A Race We Can Win | United Nations*. https://www.un.org/en/un75/climate-crisis-race-we-can-win (Retrieved December 30, 2021)

United States Geological Survey. (2022). *EarthExplorer*. https://earthexplorer.usgs.gov/ (Retrieved August 10, 2021)

Vancutsem, C., Ceccato, P., Dinku, T., & Connor, S. J. (2010). Evaluation of MODIS land surface temperature data to estimate air temperature in different ecosystems over Africa. *Remote Sensing of Environment*, *114*(2): 449–465. https://doi.org/10.1016/j.rse.2009.10.002

Varughese, A., & Purushothaman, C. (2021). Climate Change and Public Health in India: The 2018 Kerala Floods. World Medical and Health Policy, 13(1), 16–35. https://doi.org/10.1002/wmh3.429. *World Medical and Health Policy*, *13*(1): 16–35. https://doi.org/10.1002/wmh3.429

Voogt, J. A., & Oke, T. R. (2003). Thermal remote sensing of urban climates. *Remote Sensing of Environment*, *86*(3): 370–384. https://doi.org/10.1016/S0034-4257(03)00079-8

Weng, Q., & Fu, P. (2014). Modeling diurnal land temperature cycles over Los Angeles using downscaled GOES imagery. *ISPRS Journal of Photogrammetry and Remote Sensing*, *97*: 78–88. https://doi.org/10.1016/j.isprsjprs.2014.08.009

Wilson, J. S., Clay, M., Martin, E., Stuckey, D., & Vedder-Risch, K. (2003). Evaluating environmental influences of zoning in urban ecosystems with remote sensing. *Remote Sensing of Environment*, *86*(3): 303–321. https://doi.org/10.1016/S0034-4257(03)00084-1

World Health Organisation. (2022). *Heatwaves*. https://www.who.int/health-topics/heatwaves#tab=tab_1

Yeo, L. B., Hoh, G., Ling, T., & Tan, M. L. (2021). Interrelationships between Land Use Land Cover (LULC) and Human Thermal Comfort (HTC): A Comparative Analysis of Different Spatial Settings, *Sustainability*, 13(1): 382. https://doi.org/10.3390/su13010382

Zullo, F., Fazio, G., Romano, B., Marucci, A., & Fiorini, L. (2019). Effects of urban growth spatial pattern (UGSP) on the land surface temperature (LST): A study in the Po Valley (Italy). *Science of The Total Environment*, *650*: 1740–1751. https://doi.org/10.1016/j.scitotenv.2018.09.331

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A Systematic Review of The Recent Geospatial Approach in Addressing Spatially-Related Radicalism And Extremism Issues

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ABSTRACT

This systematic review article focuses on the geospatial issues of radicalism and extremism. The scholar has intensified the application of geospatial in radicalism and extremism study to understand better the causes, patterns, and trends of the radicalism and extremism incidents. The advanced geospatial approach provides more spatio-temporal information on radicalism and extremism incidents'. It improves the conventional study method that only focuses on fundamentals and theory. Unfortunately, some geospatial issues from previous radicalism and extremism studies have been found. Hence, the present study reviewed past studies on geospatial applications in radicalism and extremism. Meanwhile, the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method were used to review the current research. This systematic review utilises two major journal databases, Scopus and Web of Science. Searching works found in a total of 24 articles can be analysed systematically. The selected article was separated into four corresponding geospatial analysis types: distribution pattern analysis, cluster analysis, statistical and prediction analysis, and 3D technology. Finally, several recommendations were offered after this study for future scholars' consideration.

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1. Introduction

The term radicalism and extremism has not yet been well defined but has developed and improved. Some research has defined radicalism and extremism. However, radicalisation most often

centres around two different foci. Firstly on violent radicalisation, where the emphasis is put on the active pursuit or acceptance of violence to attain the stated goal. Secondly, on a broader sense of radicalisation, where the emphasis is placed on the active pursuit or acceptance of far-reaching changes in society, which may or may not constitute a danger to democracy and may or may not involve the threat of or use of violence to attain the stated goals (Veldhuis & Staun, 2009). Extremism is the commitment to extreme forms of resolving social conflicts, so it allows and justifies the need to use violent means, including terrorism and different manifestations (Baisagatova *et al.*, 2016). Besides that, extremists usually do not qualify for another point of view, and they hold their opinion as being quite exclusive when they do not allow for the possibility of differences. The occurrence of terrorism events until 2019 had shown a decreasing trend. The number of deaths has decreased by 52 per cent since 2014, from 33,555 to 15,952. However, it is still a severe and significant issue in many countries. In 2019, 63 countries recorded at least one death from a violent act, while seventeen countries recorded more than 100 deaths from terrorist incidents, this trend has shown that the violent act is still widely spread globally (Peace & World, 2020). Terrorism has transformed the environment and created a severe challenge for many countries in recent years. Scholars are attracted on how GIS can contribute to radicalism and extremism.

Although many studies focus on the GIS approach in radicalism and extremism, there was still a small amount of systematic review of the previous studies. Hence the present article conducted a systematic literature review to address spatial-related issues in radicalism and extremism studies involving the GIS approach.

Doing a systematic review of past studies is crucial. As mentioned by (Neal Robert Haddaway & Macura, 2018), traditional literature may lack transparency, making it impossible to verify how rigorously they were conducted, whether they missed necessary evidence, or may reflect vested interests. Besides, this also might reduce the reliability and usability of a synthesis. Instead, systematic reviews that use rigour to synthesise data from many research may be required. The systematic review is a research synthesis that relies on evidence-based methods to maximise rigour and minimise susceptibility to bias. (Neal R. Haddaway *et al.*, 2020). Systematic reviews involve steps to mitigate biases and limitations. Most importantly, perhaps, they aim to be as transparent as possible by documenting all activities during the reviewing process (Neal Robert Haddaway & Macura, 2018).

1.1 Background of Radicalism and Extremism

Radicalism and extremism are frequently misused concepts. The war that took place has confused in distinguishing between these two terms. The violent action during the incidents gave the community the impression that radicalism and extremism were groups in the same circle. This impression happens when people only assess radicalism and extremist actions from the point of view of violence. Undeniably, most radicalism and extremism events will end up with the destruction and damage to property and possibly even life. There are ten critical distinctions between radicalism and extremism, focusing on the action taken by the perpetrator, the concept practised, and the ideology (Bötticher, 2017). Table 1 lists the ten differences between radicalism and extremism.

Table 1: Difference between radicalism and extremism

Aspect	Radicalism	Extremism
Types of violence	• Tend to use political violence pragmatically and on a selective basis	• Consider violence against their enemies as a legitimate form of political action and tend to embrace extreme forms of mass violence as part of their political ideology
Consent to democratic action	• Radicalism is emancipatory (freedom on social or political freedom and rights) and not anti-democratic. Democracies can live with radicals but not with uncompromising, aggressive extremist militants.	• Extremism is anti-democratic action that aims to eliminate representative government and the rule of law. Extremist movements cannot be integrated into societies due to their intolerance toward ideologies other than their own.
Human rights	• Not opposed to equal human rights; historically, progressive radicals have sought to extend human rights to the underprivileged.	• Extremists openly confront the notion of universal human rights and those institutions that serve to uphold them for all.
Acceptance of an open-minded society	• Radicalism action may differ from the continuation of the status quo, but they do not seek to close open societies and do not destroy diversity in society.	• Extremists want to close/ reject the open marketplace of the idea. Extremism is extreme in both its goals and the choice of means to reach them.
Acceptance of	• Radicalism stands in rebellious opposition	• Against those who do not embrace its

the establishment	against the establishment.	principle in transforming society.
Reaction when in the weak phase	• When numerically weak, radicals can withdraw from mainstream society into intransigent isolationism, co-existing with plural societies and not continuously seeking a direct conflict with society.	• Extremists engage in provocative and aggressive interventions against the established order when numerically weak.
Morality	• It is oriented more towards a universal morality.	• It is characterised by a particular morality valid only for its members.
Concept and ideology	• Radicalism has been more egalitarian and less elitist.	• Extremists are supremacists opposed to the sovereignty of the ordinary people. The concept of extremism is closely linked to authoritarian dictatorships and totalitarianism.

The differences in Table 1 have brought to the varying factors causes of radicalism and extremism incidence, which can be social, political, economic, individual, modernisation, etc.

Many factors can contribute to the occurrence of radicalism and extremism. The factor of radicalism needs attention as it is vital for the future deradicalisation process. Previous cases of radicalism and terrorism have shown that multiple factors can act as catalysts, triggering the outbreak of such incidence. Much research has been done to study the roots of radicalisation and violent acts. It has been found that an enormous scope of factors can be related to radicalisation. For example, demographic and socioeconomic factors such as poverty, inequality, and economic issues contributed to the violent act (Ehrlich & Liu, 2002). Another studied had found a connection between poverty, education, and terrorism, where reducing poverty or increasing education will reduce the number of violent acts (Krueger & Malečková, 2003). Most studies focused on the economic scope in explaining the causes of radicalisation. Poverty can contribute to radicalisation in the context of the economic factor. However, it needs to be realised that not all impoverished individuals are involved in radicalisation. Poverty is not a direct factor but depends on individual and social aspects (Veldhuis & Staun, 2009).

Figure 1 shows the model developed to explain how different factors and levels related to each other and how those factors contributed to radicalisation (Veldhuis & Staun, 2009). There are distinguishing factors layers at the micro and macro levels. The model clearly shows that many factors are related to radicalisation, where individual factors as the central point, as individuals are strongly influenced by their environment. The environment can be classified in terms of the political environment, social environment involving religion, and ethnicity.

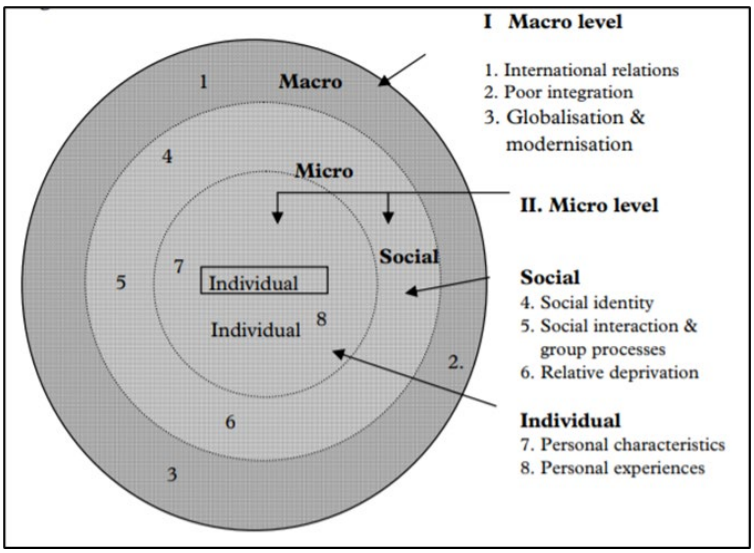

Figure 1: Casual factor of radicalisation

Based on Figure 1, radicalism and violent extremism were separated into macro and micro factors. Macro-level variables influence social structures and include, among other things, demographic changes, political, economic, and cultural shifts, educational attainment, and labour-force involvement. The model's two inner layers represent the micro-level emphasising the individual's importance as an embedded unit. The micro-level is further subdivided into social and individual factors. Social factors, represented by the second or middle layer, define the individual's relationship to relevant others. The model's third and final layer represents causative factors at the personal level. Individual factors, like social factors, are subcategorisation of micro-level variables. Individual variables include psychological traits, personal experiences, and personal ideas and values. The biological differences between men and women, and the consequent behaviour implications of those natural disparities, provide a simple illustration of how individual traits impact human behaviour. Similar to this model, (Allan *et al.*, 2015) also came up with a multi-layer radicalism and extremism factor. Conversely, the authors have devised the idea to group the macro level as the push factor while social and individual factors as the pull factor.

However, the factors for radicalism and extremism can be better understood from a geographic perspective. Where and when the incident happens, and what triggers them to occur, is the big question that needs to be understood to prevent radicalism and extremism. The historical event helped people to understand more about the factor and the causes of such incidence.

Even though the research on radicalism and extremism was still low, the research increased yearly after the 11/9 incident. 11/9 was the starting point that attracted more researchers to study radicalism and extremism to understand the behaviour of radicals and extremists. The systematic study of terrorism began decades ago, assuming that understanding and combating this type of political violence was urgently needed (Bahgat & Medina, 2013). The September 11th, 2001 terrorist attacks dramatically extended this community of terrorism academics and encouraged attempts for new and novel research methodologies from a wide range of disciplines, ushering in what some have dubbed as the second wave of terrorism study (A. U. Khan, 2005).

The latest method of research used for radicalism seems more focused on the use of GIS technology. However, non-geospatial research is still crucial and contributes to geospatial research. It can be seen that geospatial technology has enhanced non-geospatial research. Geospatial help create the relationship between the time, location and situation and give a more understanding to analyse the radicalism incident. However, non-geospatial research is still needed to strengthen further the analysis of studies conducted using geospatial and verification purposes. All studies will usually be related to theory and basic field knowledge.

Radicalism and extremism happen anytime and everywhere around the world at different locations. Every location brings different perspectives. Among the perspective are social, political, economic, and individual. This shows that the occurrence of radicalism and extremism incidents is varied in terms of location, time, and causes. Apart from that, radicalism and extremism have been increasingly subjected to scientific study. It involved the social science area and involved many kinds of other studies area including Geographic Information Systems (GIS). GIS can provide more information on incidence patterns and improve the conventional radicalism and extremism study method. The geospatial approach provided geographical connections that would otherwise go neglected or ignored in traditional terrorism and counter-terrorism research (Henkin *et al.*, 2020).

2. Methodology

2.1 PRISMA

This systematic review was conducted using the reporting guidelines in the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA). PRISMA is a published standard for conducting a systematic literature review. PRISMA's general concepts and topics are relevant to any systematic review (Moher et al., 2009).

2.2 Data Source And Search Term

The data for this systematic review were retrieved mainly from the electronic bibliographic database of Web of Science and Scopus. Besides, the JSTOR database is also used to retrieve the fundamentals of the radicalism and extremism theory. JSTOR encompasses books, other primary sources, and current issues of humanities and social sciences journals. Due to the low number of research, a google scholar database is also included to increase the number of the journal. Even so, minimal studies still focus on both subjects, radicalism and extremism. The time interval was started from early 2000 until 2021. Several steps were taken to identify significant literature for this review.

2.3 Systematic Review Process

2.3.1 Identification

The systematic review process involved three main stages in selecting the relevant articles. The first stage is the identification using the keywords and other related and similar terms. This systematic review searched for the associated keywords and terms with 'radicalism' and 'extremism'. Then, follow with the 'geospatial' words. After that, both queries were combined with the 'AND' operator to identify literature likely to contain studies on both topics. Table 2 shows the search string on the Scopus and WOS database. Current research retrieved 20 articles from both databases, while manual searching contributed to the 17 articles. In total, 37 articles were retrieved in the first stage of the systematic review process.

Table 2: Search string

Database	Search String
WoS	(("radicalism" OR "radical" OR "extremism" OR "extremist" OR "terrorism" OR "terrorist" OR "violence" OR) AND ("geographic information system" OR "geographic" OR "GIS" OR "geospatial" OR "spatio-temporal" OR "spatial analysis"))
Scopus	Article Title-Abstract-Keywords (("radicalism" OR "radical" OR "extremism" OR "extremist" OR "terrorism" OR "terrorist" OR "violence" OR) AND ("geographic information system" OR "geographic" OR "GIS" OR "geospatial" OR "spatio-temporal" OR "spatial analysis"))

2.3.2 Screening

The screening was done mainly to remove the duplicated articles. Three articles were eliminated during the first stage. In the second stage, 37 articles were screened based on the eligibility criteria. The article that was considered eligible for this review were assessed on a) published in English, b) reviewed journal articles, c) radicalism and extremism as the main topic, and d) presented the application of geospatial analyses. Moreover, it is crucial to note that 11 years (2010- 2021) were chosen for the timeline. The 2010- 2021 period is selected because geospatial only became popular among radicalism and extremism after 9/11.

2.3.3 Eligibility Criteria

A total of 34 articles then moved to the third stage, known as eligibility. At this stage, the article's title, abstract, and main contents were examined thoroughly to ensure that they fulfilled the inclusion criteria to achieve the objective of the current research. Consequently, ten articles were excluded because they are not based on the subject area and do not use geospatial as the main method. Finally, a total of 24 are ready to be analysed. Figure 2 shows the flow diagram of the study.

2.3.4 Selection of Studies

All citations retrieved through database searching were imported into Mendeley reference manager software for curating the collective bibliography. Then, the variable of a) publication details, b) the objective of the study, c) the data sources, d) the scope of radicalism studies, e) the application of geospatial analysis, and f) research output and finding from the selected journals article were extracted.

2.3.5 Summary And Characteristics Of Review Articles

These studies retrieved 37 research. After applying the selection process, summarised in Figure 2, 24 studies were included for review. The research paper was categorised into four general groups based on the geospatial analysis applied in the study. The selected article was published in a peer-reviewed journal such as Terrorism and Political Violence, Perspectives on Terrorism, and Behavioral Science of Terrorism and Political Aggression.

In total, 10 out of 24 studies choose Middle East countries (Iraq, Iran, and Afghanistan), Kenya (2), Nigeria (2), Indonesia (2), America (1), and Malaysia (1) as their study area. Several studies involve global-scale analysis. Another study involves Asian countries such as Malaysia, the Philippines, Indonesia, and Thailand. The high number of studies concerning the Middle East can be due to the country's situation, which is undergoing a series of long-term wars.

Esri ArcGIS was the most common platform used in the review research. Besides, some of the studies used open-source platforms like QGIS for the data analysis process. 80% of the studies used the Global Terrorism Database (GTD) as the leading platform for the data source. The GTD is the most extensive terrorist database. The database contains roughly 120 pieces of information, including the targeted location's name and coordinates, assault date and time, attack method (e.g., bombing), offender identity, and other relevant details. Until July 9th 2020, the database had more than 200,000 terrorism incidents recorded from 1970 to 2019. The database is updated once a year. Apart from all review articles, two studies used remote sensing data such as aerial photogrammetry and USGS satellite image as the support data to interpret their finding and 3D analysis.

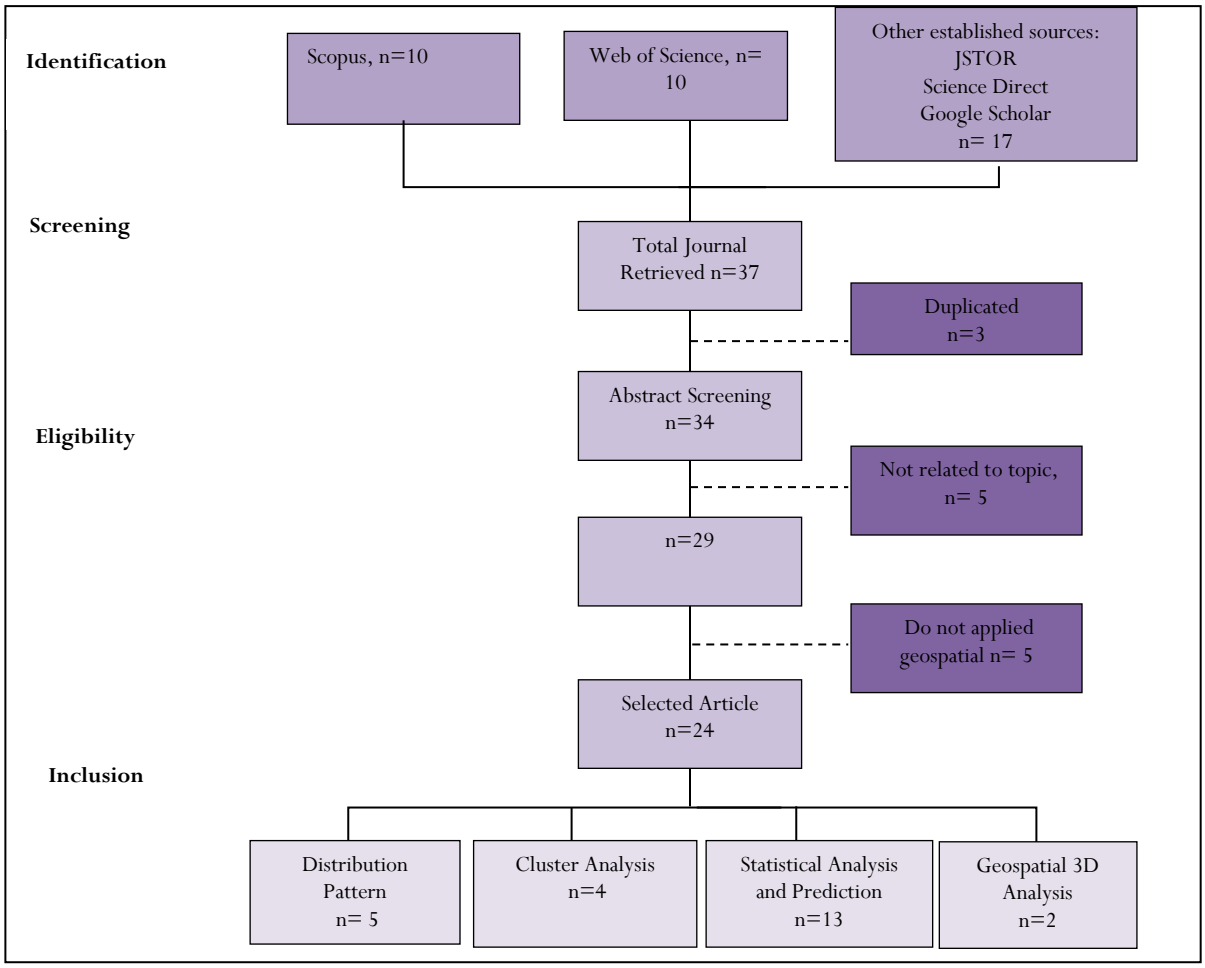

Figure 2: Geospatial applications in radicalism and extremism research literature search and evaluation for inclusion

3. Result and Analysis

Geospatial can provide more information on the geographical patterns of radicalisation and improve the conventional method in radicalism study. The geospatial approach provided geographical connections that would otherwise go neglected or ignored in traditional terrorism and counter-terrorism research(Henkin *et al.*, 2020). This review focused on the different geospatial approaches in radicalism studies. The selected article in this review was separated into four thematic groups based on the geospatial analysis types; attack trend pattern (n=12), Incident distribution (n=8), Predicting future incidents (n=7), and the use of 3D geospatial analysis (n=2).

3.1 *Distribution Pattern of Radicalism and Extremism*

Identifying geographic patterns is essential for understanding how geographic phenomena behave. In radicalism and extremism studies, pattern analysis started to be used after 2000. However, it was widely used after the incident of 9/11 as researchers began to understand more about the behaviour of the radicals and extremists. The increasing data source is also one of the reasons trend pattern analysis developed among radicalism studies (Webb & Cutter, 2009). A substantial number of studies were found to apply spatial-temporal and statistical analysis in analysing distinct aspects of radicalism and extremism. Most of these works were focused on analysing the spatial distribution pattern of radicalism and extremism cases using the previous incident data.

3.1.1 Spatial Distribution Pattern

A study by Chukwudi (Okeniyi *et al.*, 2018) examined terrorism in Africa using Nigeria and Kenya as case studies. From 2010 to 2016, terror incidents were investigated using Armed Conflict Location and Event Data data. Density and hot spot analysis were applied to study the attack pattern in Negeri and Kenya. Using the additional information from the data collected, the researcher examines the mode and target of attack types used by the radicals and extremists. Results showed similarities in the trend of attacks in both countries, peaking in 2012 and declining in 2016. The shooting was the highest mode of attack in Nigeria and grenades in Kenya, with civilians mainly targeted, resulting in deaths and injuries, which climaxed in 2014.

Another study (Chen & Mu, 2021) performed a trend analysis to analyse the number of terrorist attacks in the Belt and Road

regions. This study seems different as the scale does not focus on the region or sub-region, but the area was grid into hexagonal unit cells. Figure 3 shows the gridding result of the study area using the honeycomb model. Honeycomb was claimed to be the best topological structure covering a two-dimensional plane and help reduce distortion caused by the earth's curvature when a large study area is involved. Most people were alert that terrorists, radicalism, and extremism usually occurred in the Middle East. This study discovered that many terrorist attacks occurred, with Iraq having the most attacks.

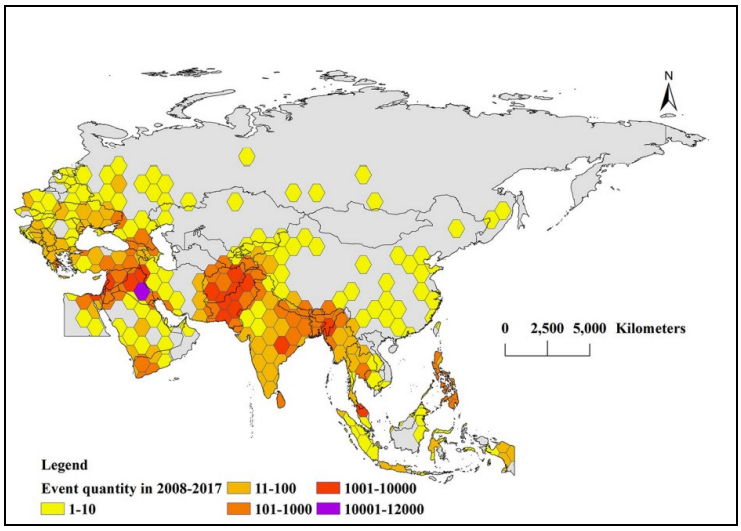

Figure 3 The result of attack distribution using the honeycomb grid

3.1.2 Temporal Distribution Pattern

Violent acts by extremists, radicals, and terrorists do not occur spontaneously, but it is the planning work prepared before the targeted attack. Figure 4 shows the general principle of terrorist attacks and examples of planning activities involved in the planning. From this figure, it can be summarised that the violent act required a specific period to move from one phase to another phase.

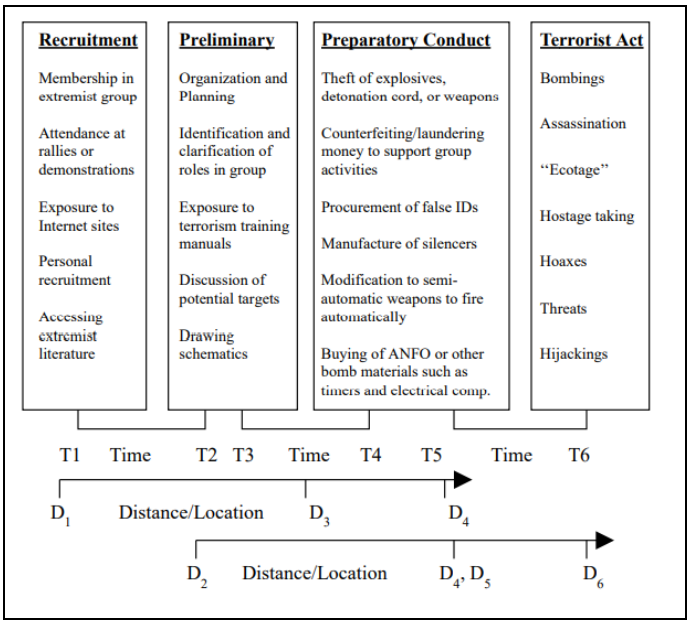

Figure 4 General principles and examples of each type of behaviour

Two studies focus on the temporal pattern to study the time the radical shifts from the recruited phase to the incident day. Using 29 and 30 sample data,(Cothren *et al.*, 2008) and (Smith *et al.*, 2008) measured the time the radical allocated to move from a planning phase to incident day. From the analyses, (Cothren *et al.*, 2008) found that almost 14 days are required from the planning

phases to the attack incident day. However, (Smith *et al.*, 2008) conclude that only 24 hours are needed to start the incident after the last planning preparation. Figure 5 shows the result produced by (Cothren *et al.*, 2008). However, from the result, the patterns shown in the figure reflect "averages" rather than behavioural trends. This can be due to the number of outliers affecting these statistics. Hence, temporal distribution analyses are needed to help the researcher predict the future incident by observing the previous trend. However, a large data sample may be required to understand the movement (Li *et al.*, 2018).

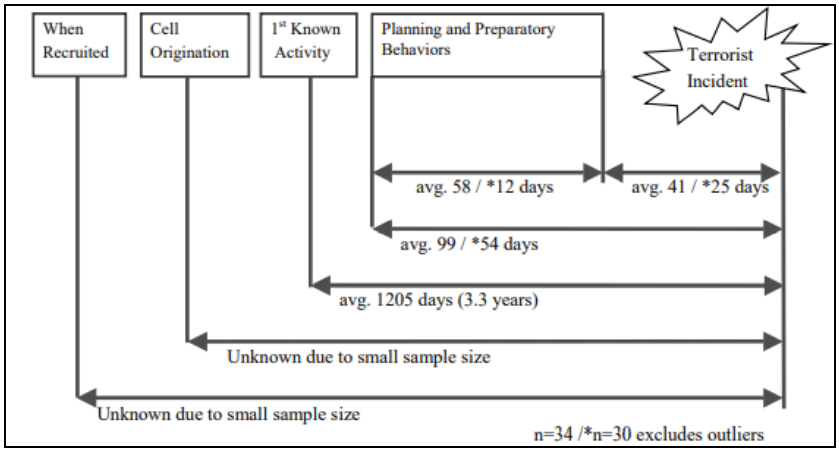

Figure 5: Behavior temporal trend of violence activity planning

Besides mapping the incidents based on the location, another research was done by (Chen & Mu, 2021) and (Li *et al.*, 2018) to analyse the distribution of the terrorist attack temporally. (Li *et al.*, 2018) has used wavelet analysis to determine the distribution law of terrorist attacks in BRI regions for ten years. The wavelet function may uncover hidden change phases in diverse time series and represent a trend at different time scales. Figure 6 shows an example of the result of the study. Dark colours show a higher number of events, and light colours show fewer numbers of events. This study also mentions that most attacks occur on Fridays and during the weekend.

(Chen & Mu, 2021) examined the distribution pattern in two ways: the periodic characteristics of the group and the link between behaviour and the network. However, as operation-oriented terrorist groups have some specific characteristics, only a thorough understanding of the characteristics can effectively predict their behaviour. Both studies also overcome the issue of the previous research, which either considered spatio-temporal characteristics in a limited way or analysed such characteristics without connecting them.

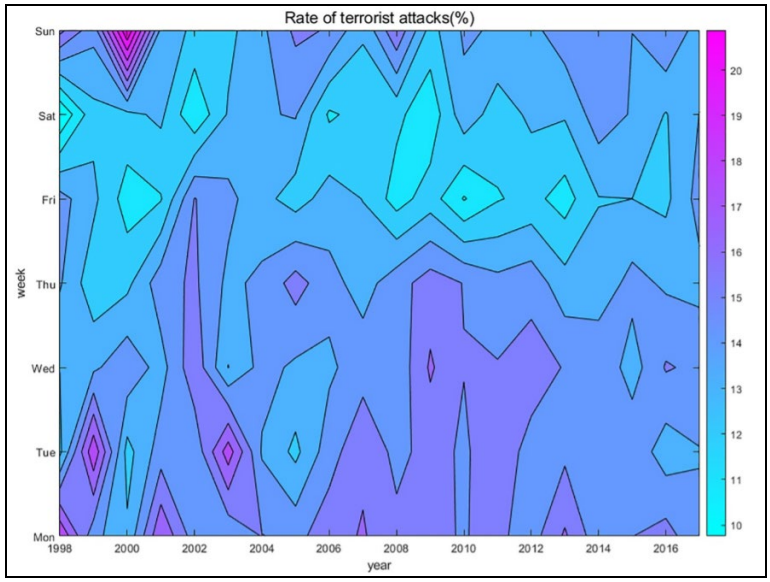

Figure 6 Contour map shows the week-year relationship between the incidence of events. Dark colours show a higher number of events, and light colours show less number of events.

3.2 Cluster Analysis

Cluster analysis was performed to identify statistically significant hot spots, cold spots, spatial outliers, and similar features or zones. Clustered mapping allows visualisation of the cluster locations and extent.

A study done by (Rokhman *et al.*, 2020) applied spatial multi-criteria analysis to study the distribution of radicalism based on the targeted attack; church, residential, police station, business, and government building. The AHP method was used to calculate the vulnerability index and sensitivity analysis to validate the result. Another study by (Zhang *et al.,* 2018) used a machine learning approach (Python Programming) to study the distribution of radical incidents with multi-factor within 11 countries. A result produced with 88% accuracy showed that the Indochina Peninsula and the Philippines are high-risk areas, and medium-risk areas are mainly distributed in the coastal regions. This study looks to improve the previous research as they included other factors of radicalism instead of time, location, type of attack, and type of target, which is commonly used by the earlier study.

Different studies have applied several methods to map the pattern of radicalism incidents. For example, the IDW method (I. Khan *et al., 2020)*, Moran's I analysis (Siebeneck *et al.*, 2009)· and Person R correlations (Okeniyi *et al., 2018)* were used to analyse the distribution of the number of incidents, the number of deaths, types of attack, type of weapon used, and types of target attack within a specific time and location. At the end of the studies, risk assessment was done by compositing all the distribution maps to analyse the high level of risk location. By using the result, future radical incidents were predicted. However, it is good to include the causes of radicalism in the analysis because any risk location for radical incidents has its own related causes of radicalism.

3.3 Statistical Analysis and Prediction

Most of the studies were focused on examining the spatial distribution and relationship between the location of radicalism incidents, number of deaths, types of targets, and types of attacks. Prediction of future incidents of radicalism was one of the studies that were difficult to be found. However, these studies found seven articles related to the prediction of future incidents. The previous researcher had applied many methods to predict the future violent act, including using the spatial regression statistical and machine learning approach.

3.3.1 Geographically Weighted Regression (GWR)

Geographically Weighted Regression (GWR) is a local form of linear regression used to model spatially varying relationships. A GWR approach models the relationships that vary over space by introducing distance-based weights to provide parameter estimates for each variable and geographical location. A study by (Nadir *et al.,* 2010) analysed the effects of terrorism on economic growth across provinces of Turkey from 1987 to 2001 using a geographically weighted regression approach. The empirical result suggests that the GWR model outperforms the classic global model in model fitting, implying that the old global model is misspecified. Furthermore, the GWR model estimates indicate significant differences in parameter estimations, particularly in the case of terrorism.

(Gao *et al.*, 2013) used spatial scan and space-time statistics to predict the radicalism incident at an early stage. (Jha, 2009) and (Brown *et al.*, 2004) use the concept of crime to model the prediction of radical events. (Jha, 2009) used Dynamic Bayesian Network to predict the likelihood of future attacks, which acts as an initial step in predicting terrorist behaviour at critical transport infrastructure facilities. A study by (Caplan *et al.*, 2011) applied risk terrain modelling to predict the crime event and criminal behaviour, including shootings, aggravated assaults, assaults on police officers, and terrorism at the province level. Another study by (Basu *et al.*, 2017) used GIS and machine learning random forest methods to predict radicalism. Various parameters, such as the date and incident information, incident location, attack and weapon information, and target information, were used to develop the model.

3.3.2 Forest-based Classification and Regression

A study by (Hao *et al.*, 2019) predicted the risk of terrorist attacks on the Indochina Peninsula by using (1) social, (2) natural, and (3)geographical elements as the parameter to run the prediction. After applying Kernel Density to analyse the evolution of terrorist attacks from a time and space perspective, the author prepared spatial geographic data and corresponding raster data of the terrorist attack and constructed the RF algorithm to predict terrorist attacks at the spatial scale of the Indochina Peninsula. The author seems to improve the previous studies primarily on the national scale, focusing only on the time and location parameters. Figure 7 demonstrates how to simulate a terrorist attack using the RF model. An RF classifier with various element kinds was applied to estimate future terrorist threats. This study found Thailand is the most hazardous location for terrorist attacks, according to the possible terrorist attack risk zones, notably in southern Thailand, Bangkok, and its surrounding cities. The centre of Cambodia and sections of Myanmar's north and south were categorised as high-risk zones.

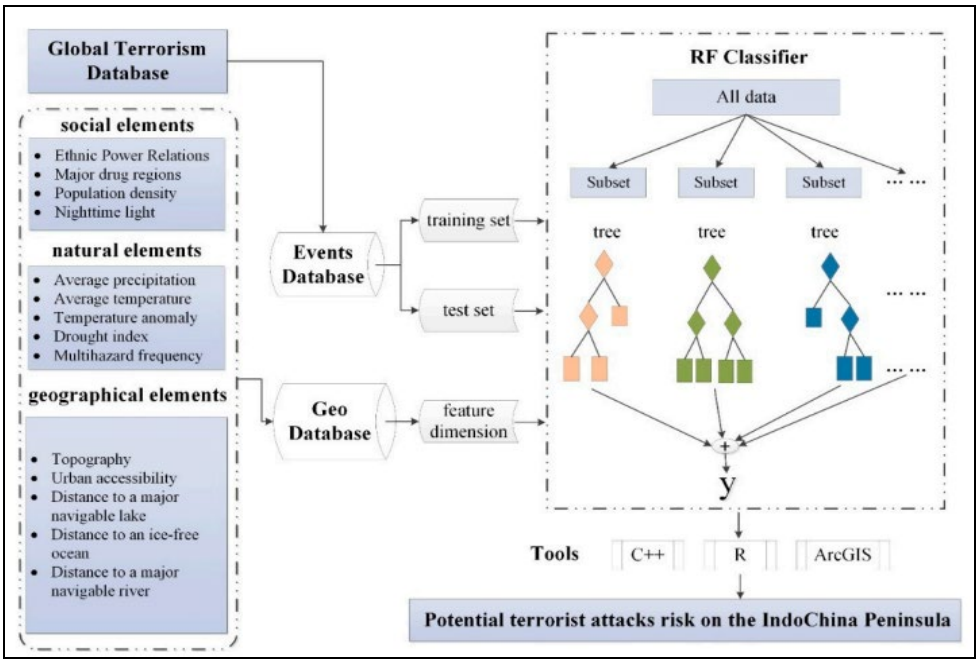

Figure 7 The system architecture that is used for predicting a terrorist attack

A study by (Kanika et al., 2019) concentrated on examining the GTD dataset and making predictions on several aspects that could have harmed terrorism. This study focused on analysing the dataset of GTD and predicting different factors that might have given a blow to terrorism. Various data mining and machine learning algorithms such as SVM, Random Forest, and logistic regression were used. Research by (Kalaiarasi *et al.,* 2019) has developed multiple classifiers for the terrorist group and predicted terrorist activities using the k-NN algorithm and Random Forest techniques. They used the GTD dataset for the detection of terrorism.

A study by (Maniraj *et al.*, 2019) developed a system that examines the growth or decay of terrorist groups by the time, location, type of attack, target motives, weapon type, and availability. They analysed the GTD dataset and used a machine-learning algorithm to predict the probability of attacks in different regions. In 2019, (Freilich *et al.*, 2015) studied the dynamics of unclaimed terrorism events in Pakistan using machine learning algorithms. They predicted terrorist attributes such as an attack, target, weapon type, spatial attack, and lethality. The study attempted to match the unattributed terrorist attack to known terrorist groups.

Another research in 2019 (Ahmad *et al.*, 2019) developed a method for detecting and classifying social media-based extremist affiliations based on sentiment analysis. The focus was to classify tweets into extremist and non-extremist classes. The system uses deep learning-based sentiment analysis to classify the tweets. Other similar studies in 2020 can be found in (Gui *et al.*, 2020) and (Yu *et al.*, 2020).

Apart from the various method used, some improvements have seemed to expand the use of geospatial to predict the future radical event. But still, some improvement needs to be done in choosing the parameter for the model. The study only focuses on the incident's time, location, and frequency as the prediction indicator. This is because each site has a different factor in the occurrence of the radical incident.

3.4 3D Analysis

Geospatial analysis not only concentrated on 2D analysis but also involved 3D modelling. The 3D approach is popular in other fields such as urban planning, construction, medical, and historical building study. However, little research has applied this approach in radicalism and extremism studies. GIS's potential to simulate local spatial interactions to protect individuals from terrorism situations in a 3D model. Research (Kwan & Lee, 2005) has focused on using the 3D approach to prevent and respond to future terrorism incidents. They have conducted a study to examine the possibility of utilising real-time 3D GIS to implement GIS-based intelligent emergency response systems (GIERS) to assist in rapid emergency response to terrorist attacks on multi-level facilities.

Another research (VanHorn & Mosurinjohn, 2010) examines the prevention of terrorism using 3D model analysis to protect populations in urban environments. They found that creating urban viewsheds using DSMs and visualisation can estimate the area where a target would be vulnerable to sniper attack. Apart from this study, there is no other study that has concentrated on GIS's potential to simulate local spatial interactions to protect individuals from terrorist situations in a 3D model.

4. Discussion

The number of studies that applied the geospatial approach in radicalism and extremism studies is still low. However, previous studies have shown that geospatial is directly or indirectly involved in increasing the understanding of radicalism, especially in spatial and temporal scope. Geospatial had improved the temporal pattern analysis. Temporal analysis is used to analyse the pattern of terrorist distribution at a specific location within a particular duration, such as daily, weekly, yearly, and monthly (Millett, 2009). Literally, from all the previous research, some improvements can be made to increase the use of geospatial applications in studying radicalism and extremism.

Firstly, the limitation or the geospatial issues in the previous study can be found in the parameter used for the analysis. Most studies are concentrated on time and location, type of attack, type of target, and type of weapon for the research until some important parameter was neglected. As mentioned before, it is better to include the aspect of the causes of radicalism in the analysis. When the cause of radicalism is included, much other valuable and essential information can be analysed and extracted. For example, if the causes of radicalism at a location are due to religion, the probability of worship being the target is high. In contrast, if radicalism is due to poverty, it is possible for the religious building to be the targeted attack. So, when it comes to analysis, more focus can be directly done by analysing the parameter related to the causes of radicalism.

Large scale study seems to be less valuable compared to a small-scale study. Small scale can be easy to integrate and provide helpful information that various parties, such as the state authority, can use. This information can be used to counterattack the radicals and extremists. However, many data or samples are needed to produce a high accuracy result.

The data collection was the most challenging part of using the geospatial approach in radicalism and extremism studies (Freilich *et al.*, 2015). The methodology used to gather the data is still the issue in applying the geospatial approach to radicalism. As mentioned by (Okeniyi *et al.*, 2018), the researchers were highly dependent on just two methodologies for data collection (1) the analysis of documents (or secondary data analysis) and (2) form interviewing. In 2010, (Freilich *et al.*, 2015) stated concerns over the reliability of research that depends heavily on such open sources. Nowadays, many available databases, such as GTD, seem to be used as the source of data gathering. The question is now how the sincerity of this data source can be trusted without doubt and how to ensure that this data source supplies accurate and unquestionable data.

Undeniable direct inventory (parameter) data such as the incident location, timing of incidents, types of attack, number of death, types of weapons and other related data is essential to map the distributions, trends, patterns and predicting radicalism incidents. However, indirect parameters are also crucial to run the analysis and produce a more accurate result. Historical radicalism incident has proved that many causes lead to radicalism, such as crime, ethnicity, poverty, economic, religious, and political (Veldhuis & Staun, 2009). So, it is essential to consider the causes factor to produce more accurate prediction results for better analysis. For example, in the geospatial prediction model, apart from time and location, the parameter of the incidents (causes incidents to happen) is also essential to be used as a critical consideration in the model. Including other related parameters was needed to ensure the model could predict the incident based on the exact situation.

Finding studies on radicalism or extremism associated with such predictions is pretty tough. If any, the percentage is deficient when compared to the use of other geospatial applications. However, researchers have started developing the geospatial model to predict the radicalism incident. Nevertheless, some improvements can be applied to their study. The previous study built the model by considering that radicalism incident in every location was due to the same factor (I. Khan *et al.*, 2020),(Siebeneck *et al.*, 2009),(Gao *et al.*, 2013),(Jha, 2009), (Donald Brown, Jason Dalton, 2004). Considering each location have the same factor may produce bias because a different factor might influence radicalism in a different location. So, it is better if a model was built according to their parameter (causes of radicalism) to generate the prediction result based on the actual situation and factor.

5. Conclusion

This systematic review evaluated the issues of geospatial in radicalism and extremism context. It explored the scope of geospatial analysis in the current research efforts and future research and practice. In the age of the digital revolution, there is a rising demand for the exchange of technical advances across scientific fields. The geospatial approach and associated technology in radicalism and extremism illustrate such integrations and offer academic insights into how complex societal and global concerns may be comprehended using current tools. However, this also requires reconsidering evidence curation's current strengths and limitations across different contexts. Institutions must enhance their geospatial research and development capacity to counter radicalism and extremism, enabling research groups to collaborate more effectively.

This review article has sparked the idea of enhancing the benefits of geospatial applications in overcoming existing issues and limitations. Current geospatial issues have shown that most research does not emphasise the factors of radicalism and extremism in their investigation. Randomly they assume the events that occur in each place are due to the same factors. Finding the research that came up with the analysis related to radicalism is infrequent. The previous research used the wavelet method to analyse why violent acts are higher on weekends than weekdays. Ideally, it is good to come up with research that relates the distribution of radicalism with the factor of its occurrence. By adding the factor of radicalism as one attribute, geospatial can identify the roots of radicalism and extremism act at any location. Some existing research uses statistical analysis such as Geographically Weighted Regression (GWR) to predict future radicalism acts. The current prediction study seems to produce a biased result. Most researchers do not include the factor of radicalism as one of the parameters for the prediction.

It is crucial to predict any event based on the surrounding circumstances. Building the geospatial predictive model by including the occurrence factor as the parameter or indicator is suggested to overcome this limit.

The efforts in addressing the geospatial issue can maximise the use of GIS technology in tackling the radicalism and extremism act. However, these implications can benefit various parties, such as the agencies that maintain national harmony. The key to maintaining harmony is combating and preventing things that threaten national security. With the support of several data, geospatial manages to identify or predict the situation that can lead to a threatening act and provides information for areas where security control needs to be emphasised. Geospatial acts as the medium to provide information to ensure that early preventive measures can be done and indirectly can inhibit the acts of radicalism and extremism. Besides, geospatial can measure the harmony index of any area. This helps the authority plan the actions that must be taken to maintain national security. For example, the additional police station or security post at the hot spot area (low level of harmony index) was essential as a preparatory measure in the face of threats. Using various GIS tools, geospatial help to identify the host spot area. Next, strong and enough geospatial data can provide information on the roots that triggered the occurrence of violent activity at any location. This may help the authority to manage the radicalism and extremism issue by strengthening the effectiveness of deradicalisation programs. This is because the existing module was flexible, and the rehabilitation process for the detainer is general and does not focus on the causes of one's involvement in radicalisation. Based on the location where the radicalism act occurs, geospatial manages to identify the causes of the radicalism act.

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References

Ahmad, S., Asghar, M. Z., Alotaibi, F. M., & Awan, I. (2019). Detection and classification of social media-based extremist affiliations using sentiment analysis techniques. *Human-Centric Computing and Information Sciences*, *9*(1): 24. https://doi.org/10.1186/s13673-019-0185-6

Allan, H., Glazzard, A., Jesperson, S., Reddy-Tumu, S., & Winterbotham, E. (2015). Drivers of violent extremism: Hypotheses and literature review. *Serial Report*, *October*, 35. https://assets.publishing.service.gov.uk/media/57a0899d40f0b64974000192/Drivers_of_Radicalisation_Literature_Review.pdf

Bahgat, K., & Medina, R. (2013). An Overview of Geographical Perspectives and Approaches in Terrorism Research. *Perspectives on Terrorism*, *7*(1): 38–72.

Baisagatova, D. B., Kemelbekov, S. T., Smagulova, D. A., & Kozhamberdiyeva, A. S. (2016). Correlation of concepts "extremism" and "terrorism" in countering the financing of terrorism and extremism. *International Journal of Environmental and Science Education*, *11*(13): 5903–5915.

Basu, A., Saha, S., Aladi, H., Kurian, A., & Basu, A. (2017). *Future Terrorist Attack Prediction using Machine Learning Techniques*. PESIT South Campus: Bengaluru, India, 2017. https://doi.org/10.13140/RG.2.2.17157.96488

Bötticher, A. (2017). Towards academic consensus definitions of radicalism and extremism. *Perspectives on Terrorism*, *11*(4): 73–77.

Brown, D., Dalton, J., & Hoyle, H. (2004). Spatial forecast methods for terrorist events in urban environments. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *3073*: 426–435. https://doi.org/10.1007/978-3-540-25952-7_33

Caplan, J. M., Kennedy, L. W., & Miller, J. (2011). Risk Terrain Modeling: Brokering Criminological Theory and GIS Methods for Crime Forecasting. *Justice Quarterly*, *28*(2): 360–381. https://doi.org/10.1080/07418825.2010.486037

Chen, L., & Mu, F. (2021). Spatiotemporal characteristics and driving forces of terrorist attacks in Belt and Road regions. *PLoS ONE*, *16*(3 March): 1–24. https://doi.org/10.1371/journal.pone.0248063

Cothren, J., Smith, B. L., Roberts, P., & Damphousse, K. R. (2008). Geospatial and Temporal Patterns of Preparatory Conduct among American Terrorists. *International Journal of Comparative and Applied Criminal Justice*, *32*(1): 23–41. https://doi.org/10.1080/01924036.2008.9678776

Donald Brown, Jason Dalton, H. H. (2004). Spatial Forecast Methods for Terrorist Events in Urban Environments. *Symposium on Intelligence and Security Informatics*, 426–435. https://doi.org/10.1007/978-3-662-19161-3

Ehrlich, P. R., & Liu, J. (2002). Some roots of terrorism. *Population and Environment*, *24*(2): 183–192. https://doi.org/10.1023/A:1020700221602

Freilich, J. D., Chermak, S. M., & Gruenewald, J. (2015). The future of terrorism research: a review essay. *International Journal of Comparative and Applied Criminal Justice*, *39*(4): 353–369. https://doi.org/10.1080/01924036.2014.922321

Gao, P., Guo, D., Liao, K., Webb, J. J., & Cutter, S. L. (2013). Early detection of terrorism outbreaks using prospective space-time scan statistics. *Professional Geographer*, *65*(4): 676–691. https://doi.org/10.1080/00330124.2012.724348

Gui, R., Chen, T., & Nie, H. (2020). Erratum: In-depth analysis of railway and company evolution of Yangtze River Delta with deep learning (Complexity (2020) 2020 (5192861) DOI: 10.1155/2020/5192861). *Complexity*, *2020*. https://doi.org/10.1155/2020/7562682

Haddaway, Neal R., Bethel, A., Dicks, L. V., Koricheva, J., Macura, B., Petrokofsky, G., Pullin, A. S., Savilaakso, S., & Stewart, G. B. (2020). Eight problems with literature reviews and how to fix them. *Nature Ecology and Evolution*, *4*(12): 1582–1589. https://doi.org/10.1038/s41559-020-01295-x

Haddaway, Neal Robert, & Macura, B. (2018). The role of reporting standards in producing robust literature reviews. *Nature Climate Change*, *8*(6): 444–447. https://doi.org/10.1038/s41558-018-0180-3

Hao, M., Jiang, D., Ding, F., Fu, J., & Chen, S. (2019). Simulating spatio-temporal patterns of terrorism incidents on the Indochina peninsula with GIS and the random forest method. *ISPRS International Journal of Geo-Information*, *8*(3): 133. https://doi.org/10.3390/ijgi8030133

Henkin, S., Boyd, M. A., & Martin, A. (2020). Southeast Asia after the Caliphate: Identifying Spatial Trends in Terrorism and Radicalization in Malaysia. *Statistics, Politics and Policy*, *11*(2): 139–165. https://doi.org/10.1515/spp-2020-0001

Jha, M. K. (2009). Dynamic Bayesian Network for Predicting the Likelihood of a Terrorist Attack at Critical Transportation Infrastructure Facilities. *Journal of Infrastructure Systems*, *15*(1): 31–39. https://doi.org/10.1061/(asce)1076-0342(2009)15:1(31)

Kalaiarasi, S., Mehta, A., & Bordia, D. (2019). Using Global Terrorism Database (GTD) and Machine Learning Algorithms to Predict Terrorism and Threat. *International Journal of Engineering and Advanced Technology*, *9*(1): 5995–6000. https://doi.org/10.35940/ijeat.a1768.109119

Kanika, S., Anurag, C., & Parmeet, K. (2019). A Machine Learning Approach for Enhancing Defence Against Global Terrorism. *2019 Twelfth International Conference on Contemporary Computing (IC3)*, 1–5. https://doi.org/10.1109/IC3.2019.8844947

Khan, A. U. (2005). The terrorist threat and the policy response in Pakistan. *SIPRI Policy Paper No. 11*, 2007(11): 56. http://www.sipri.org/contents/publications/Policypaper11.pdf/

Khan, I., Hamza, S., Burke, F., & ul-Hud, S. N. (2020). Application of GIS for evaluation of ethnic fault lines of Karachi. *Malaysian Journal of Society and Space*, *16*(4): 15–29. https://doi.org/10.17576/geo-2020-1604-02

Krueger, A. B., & Malečková, J. (2003). Education, poverty and terrorism: Is there a causal connection? *Journal of Economic Perspectives*, *17*(4): 119–144. https://doi.org/10.1257/089533003772034925

Kwan, M. P., & Lee, J. (2005). Emergency response after 9/11: The potential of real-time 3D GIS for quick emergency response in micro-spatial environments. *Computers, Environment and Urban Systems*, *29*(2): 93–113. https://doi.org/10.1016/j.compenvurbsys.2003.08.002

Li, Z., Sun, D., Li, B., Li, Z., & Li, A. (2018). Terrorist Group Behavior Prediction by Wavelet Transform-Based Pattern Recognition. *Discrete Dynamics in Nature and Society*, *2018*. https://doi.org/10.1155/2018/5676712

Maniraj, S. P., Chaudhary, D., Deep, V. H., & Singh, V. P. (2019). Data Aggregation and Terror Group Prediction using Machine Learning Algorithms. *International Journal of Recent Technology and Engineering*, *8*(4): 1467–1469. https://doi.org/10.35940/ijrte.d7590.118419

Millett, S. M. (2009). Trend Analysis as Pattern Recognition. *World Futures Review*, *1*(4): 5–16. https://doi.org/10.1177/194675670900100403

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *BMJ (Online)*, *339*(7716): 332–336. https://doi.org/10.1136/bmj.b2535

Okeniyi, C. G., Ayara, O. O., & Akoth, N. N. (2018). Terrorism in Africa: Mapping the Nigeria and Kenya situation. *International Journal of Development and Sustainability*, *7*(3): 993–1014. www.isdsnet.com/ijds

Peace, M., & World, I. N. A. C. (2020). *Institute for Economics & Peace. Global Peace Index 2020: Measuring Peace in a Complex World*. http://visionofhumanity.org/reports

Rokhman, M., Chalim, A., Sholahuddin, A., Suharnoko, D., & Usman, F. (2020). *Geo-spatial of Terrorism and Radicalism in Indonesia -A Preventive Efforts-*. *25*(7): 1–9. https://doi.org/10.9790/0837-2507010109

Siebeneck, L. K., Medina, R. M., Yamada, I., & Hepner, G. F. (2009). Spatial and temporal analyses of terrorist incidents in Iraq, 2004-2009. *Studies in Conflict and Terrorism*, *32*(7): 591–610. https://doi.org/10.1080/10576100902961789

Smith, B. L., Cothren, J., & Damphousse, K. R. (2008). *Geospatial Analysis of Terrorist Activities : The Identification of Spatial and Temporal Patterns of Preparatory Behavior of International and Environmental Terrorists*. *May 2014*, 86.

VanHorn, J. E., & Mosurinjohn, N. A. (2010). Urban 3D GIS Modeling of Terrorism Sniper Hazards. *Social Science Computer Review*, *28*(4): 482–496. https://doi.org/10.1177/0894439309360836

Veldhuis, T., & Staun, J. (2009). Islamist radicalisation: a root cause model. In *Clingendael Security Paper* 12(October). http://www.clingendael.nl/cscp/publications/papers/?id=7740&&type=summary

Webb, J. J., & Cutter, S. L. (2009). The geography of U.S. terrorist incidents, 1970-2004. *Terrorism and Political Violence*, *21*(3): 428–449. https://doi.org/10.1080/09546550902950308

Yu, X., Zhe, Z., Lei, W., Wei, P., Hechang, C., Zhezhou, Y., & Bin, L. (2020). Deep Ensemble Learning for Human Action Recognition in Still Images. *Complexity*, *2020*. https://doi.org/10.1155/2020/9428612

Zhang, X., Jin, M., Fu, J., Hao, M., Yu, C., & Xie, X. (2018). On the risk assessment of terrorist attacks coupled with multi-source factors. *International Journal of Geo-Information Article*, *7*(9): 354. https://doi.org/10.3390/ijgi7090354

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Operative Temperature Variance and Life Cycle Assessment Impacts of Wall Construction Materials

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ABSTRACT

The overdependence on concrete in the construction industry in sub-Saharan African countries limits the potential use of sustainable materials in the construction of buildings. Hollow Concrete Block (HCB), the industry's most widely used wall material, contributes to excessive carbon emissions and environmental degradation. Moreso, constructions that employ HCBs, specifically in Nigeria, severely threaten the indoor comfort levels in Naturally Ventilated Spaces NVSs. This study relies on quantitative data to analyse the impact of alternative wall materials in a case building in northern Nigeria. Mud bricks (MB) and Timber/brick (TB) were compared with the existing concrete (CW) case building. The study uses Meteonorm 8 and Climate Consultant 6.0 for EPW file generation. At the same time, dynamic thermal simulation and comparative experiments for thermal comfort and carbon emissions were conducted using DesignBuilder V6 and OneClick Lifecycle assessment tools, respectively. Modelled and simulated under NVS conditions using ASHRAE's PMV model, the result of the study suggests that the MB alternative, although with an intermediate U-value of 0.318 W/m²k, accounts for the best indoor comfort temperature annually. While the CW building accounts for 41.31% of hours above the comfort temperature of 28°C, the TB and MB alternatives account for 29.99% and 27.37% of hours, respectively. Furthermore, the MB alternative is the most environmentally friendly material with 510 $KgCO_2/m^2$ emissions, a value 26% less than the CW building with an embodied carbon benchmark of 690 $KgCO_2/m^2$ during the building's life cycle stages. The author suggests that mud construction's thermal properties and Global Warming Impact (GWI) make it a better alternative to concrete and timber buildings in the tropics.

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1. Introduction

The Intergovernmental Panel on Climate Change, IPCC, warns that global temperature is increasing and has called for sustainable means and practices for mitigating climate change effects. The impact of climate change is felt in all regions across the globe, with the most significant change due to anthropogenic activities (IPCC, 2021). Buildings generally account for the largest share of global greenhouse emissions. These emissions raise serious concerns, especially in developing African countries that are very vulnerable to the catastrophic effects of a changing climate (Czechowski, 2020). Several countries are adopting different

techniques to adapt to the changing climate, such as retrofitting the existing housing stocks (Kristl et al., 2020), improving energy efficiency in buildings (Ramos Ruiz & Olloqui del Olmo, 2022) and improving the "blue-green" landscape (Croce, 2020). In sub-Saharan Africa, extreme temperatures are experienced year-round. As buildings become more efficient in the operational phase, the material, manufacturing, and construction stages (embodied carbon phases) increasingly become the primary carbon hotspot (D'Amico et al., 2021). With a changing climate, the existing construction methods and material fabrics are unlikely to withstand the predicted extreme weather conditions in the next century. Several studies have predicted a high risk of overheating in future buildings in future climate scenarios, as modelled under different representative concentration pathways (Croce, 2020; Dodoo, 2020).

Nigeria is a growing economy with a high rate of urbanisation. The growth rate is expected to be more than double its current figure by 2055, according to (Macrotrends, 2022). This increase in population will amount to more housing needs that will result in a dramatic increase in heat stress and a higher energy demand for cooling in the future (Jenkins et al., 2015; Mahmoud & Ragab, 2021). One of the ways to improve the energy efficiency of both new and existing buildings is by using sustainable building fabrics with low global warming impact. Indoor temperature of naturally ventilated spaces is largely influenced by outdoor conditions. When the building fabric components are not adequately insulated, it results in uncomfortable hours indoors (Alegbe, 2022). One of the challenges with construction in Nigeria, especially in the building envelope, is the need for insulation and excessive use of concrete products known for high greenhouse gas emissions. However, other known sustainable materials like timber, brick, bamboo, and mud are readily available, but their use in the Nigerian construction industry is not fully harnessed. As asserted by (Agboola & Zango, 2014), incorporating indigenous materials into the building systems could enhance the traditional comfort principles of tropical buildings.

Furthermore, Nigeria's annual CO_2 emission in 2020 was 130.18 million tons, about a 39.5 % increase from 78.82 million tons recorded in 2000 (Hannah Ritchie et al., 2020). The 2030 emission targets set by Nigeria's Nationally Determined Contribution (NDC) do not seem to be in tandem with the reality of a geometric increase in Nigeria's carbon emission as it does not yet include lifestyle-based mitigation strategies like reduced material consumption (Salem et al., 2021). Governments of a developing country like Nigeria need to understand the extent of vulnerability to climate change impact. They must employ adaptive measures in the most threatened sectors, especially the built environment industry, which accounts for the largest share of GHG emissions (Huq et al., 2006). Therefore, this study experiments on the GWI and thermal comfort levels of locally sourced materials against the widely used concrete blocks employed in residential building constructions. An existing concrete block building in northern Nigeria was identified for this study. Thermal simulations were conducted on the existing building by replacing the wall fabrics with timber, brick, and mud in distinctive design combinations. The lifecycle assessment of these material alternatives was also calculated for 50 years to evaluate their global warming impacts. The results presented and discussed in section 5 of this research suggest the opportunity to attain thermal comfort and a reduced environmental impact through a conscious choice of construction materials.

2. Literature/Theoretical Underpinning

The primary focus of the construction of buildings is to provide a durable system that can protect all occupants and furniture in the building from the deteriorating effect of weather and other influential factors (Akande & Adebamowo, 2010). The building fabric which forms the building's enclosure plays a vital role in reducing capital and operational costs, improving energy efficiency and reducing carbon emissions when considered first in building design, using an approach called "fabric first" (DesigningBuildings, 2021). In furtherance, the changing trend in the design of buildings globally necessitates the importance of passive and low-carbon design strategies to achieve thermo-environmental balance in a hot-dry climate (Akande, 2010).

As purported by (A.C. Van Der Linden et al., 2002), one of the defining features of a building's performance is its indoor thermal condition. It is expected that this condition should optimally support the activities of the people and provide a good atmosphere for the furniture within the building. Additionally, (Iso, 2005) defined "thermal comfort" as the condition of the mind that feels relaxed with the thermal environment. This condition of the mind is affected by several factors, with temperature acting as the most common indicator or determinant (HSE, 2022). With reference to (Gorse et al., 2020), adaptive comfort temperature focuses on a temperature range within which most of the occupants in a building feel thermally comfortable. While indoor comfort levels depend on various parameters, including one's perception of an environment, its actual measurement, as suggested by (Akande & Adebamowo, 2010; Özdamar Seitablaiev & Umaroğulları, 2018), ideally captures three parameters: air temperature, relative humidity, and air velocity. In Nigeria, a tropical climate with a monthly mean external temperature of around 26^{o}C (MOP, 2016) suggests that 90% of occupants in Nigerian buildings would feel comfortable with temperatures up to 28^{o}C, as defined in the adaptive comfort chat in figure 1. This comfort temperature is tantamount to results presented by other literature, including that of (Siti Handjarinto & Veronica I, 1998), (Ogbonna & Harris, 2008) and (Jegede & Taki, 2021), who agree that most people feel comfortable between 25^{o}C and 28^{o}C.

Greenhouse gas (GHG) emissions from buildings across Africa contribute to 3.8% of global emissions. Although this figure, compared to 23% GHG emissions from China alone and 19% from the US, appears minimal, its effect poses severe threats to the carbon emissions reduction target (UN, 2006). (Dunne, 2020) reported that in 2015, the annual GHG emissions of Nigeria were 506 metric tons of CO_2 equivalent ($MtCO_2e$) with a proposed target of 13% reduction by 2030 (Transparency, 2020). Also, In line with the Carbon Disclosure Project (CDP) Africa report of 2020, Lagos, the largest city in Nigeria and the most populous city in Africa, accounts for the most significant share of city-wide emissions in Africa (Figure 2).

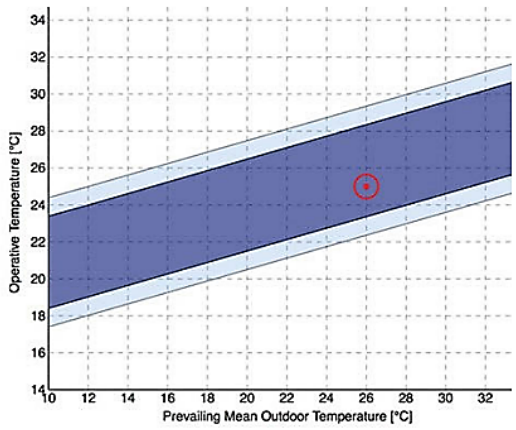


Figure 1 Adaptive Comfort Chart (MOP, 2016)

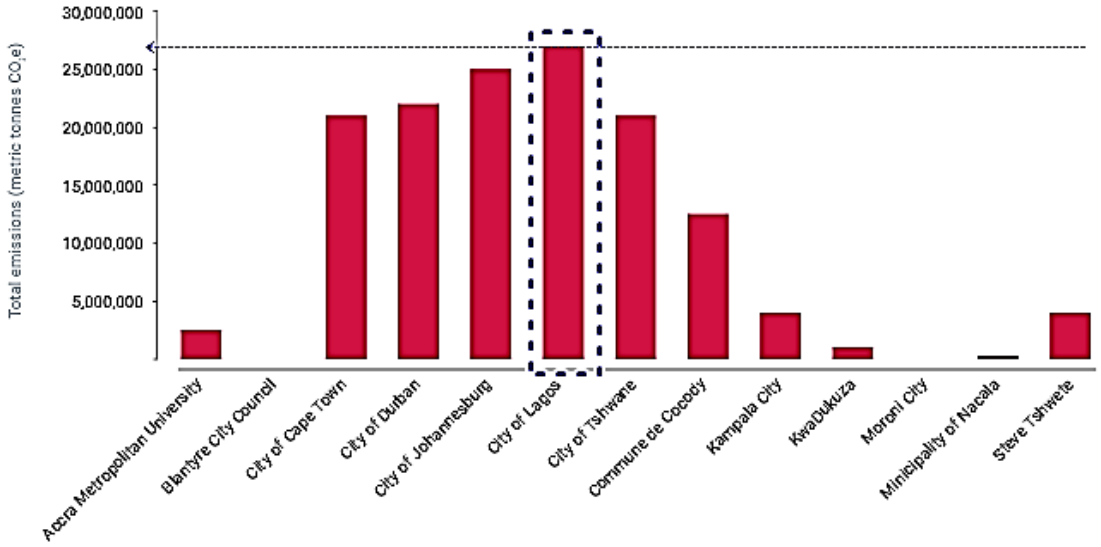


Figure 2 City-wide Emissions in Africa: Lagos Emphasised (Jegede & Taki, 2021)

These emissions from buildings relate to building materials processing and manufacturing, transportation to the site, installation and maintenance, and electricity generation from non-renewable technologies. Specifically, a large amount of these emissions is attributed to cities. According to (Alegbe, 2022; Gurupatham et al., 2021), electricity generation from fossil fuels has the most significant emissions amounting to about 92% of the total global warming impacts. Operational energy in a building's life cycle makes up the majority of energy consumption (Chang et al., 2019). These emissions from electricity can be reduced by considering natural and renewable systems for ventilation, cooling and or heating when needed. Also, mitigation opportunities exist through the efficient use of materials, by using less of the same material and by close substitution with a different but similar material in performance (D'Amico et al., 2021). The estimates provided by the International Energy Agency (IEA) show that cities account for more than 71% of energy-related emissions. This value is expected to escalate to 76% by 2030, making energy-related emissions the largest single source of GHGs (FME, 2021).

Previous research compared the performances of different building materials, using various analytical approaches to optimise indoor thermal comfort and decarbonise buildings. Most of the comparative studies conducted involved building materials like mass concrete, reinforced concrete, steel, clay bricks, compressed stabilised earth bricks (SEBs), HCBs, cross-laminated timber (CLT), and timber frames. The analysis done for embodied carbon emissions and environmental performance involved the life cycle cost and life cycle assessment methods. In addition, while the investigations drawn from this literature cut across tropical, temperate, and polar climates, they presented a similar approach regarding the investigation and computational methods.

To discuss further, (Ahlund, 2020) compared the embodied and operational environmental impact of a building in the temperate region of Sweden with concrete, wooden and cross-laminated

timber frames. A multifamily residential building made of concrete was used as the base case study. His findings show that while the concrete building has the largest share of total embodied emissions, the wooden frame alternative has the least environmental impact, with 30% less embodied emissions. More so, (Broun & Menzies, 2011), using the LCA technique, compared the energy consumed and environmental impact of brick made from clay, hollow blocks from concrete and traditional timber frames as used for partitions in the temperate climate of the Uk. Findings from this work indicate that the timber wall has the least environmental impact of the three partitions, with clay brick having the most.

Also, (Gurupatham et al., 2021) compared and evaluated the environmental benefits of compressed stabilised earth bricks, burnt bricks, and cement sand blocks in Sri Lanka, a tropical climate. His findings, using the life cycle thinking approach, show that CSBs are the most efficient material, primarily when used without plaster, while cement sand blocks have the least eco-efficiency index. Cost comparison also indicates that using CSBs costs less for building projects than other materials. Similarly, the works of (Jayalath et al., 2020; Ryberg et al., 2021; Soust-Verdaguer et al., 2020; Zeitz et al., 2019) all presented similar views in analysing the environmental impacts of the use of timber and wood-based products against the likes of steel as investigated by (Zeitz et al., 2019) in the US, and reinforced concrete as analysed by (Jayalath et al., 2020) in Australia. The results presented by these works, though with different analytical approaches and research focus areas, show the degree to which the use of wood-based products, as against concrete and steel, lowers emission levels and improves the environmental performance of buildings globally.

In the tropical climate of Nigeria, an attempt was made by (Jegede & Taki, 2021) to analyse building performance by optimising the building envelope (roof, wall, and floors) using a combination of indigenous materials. According to the findings from his work, as against the existing concrete building, the optimised model (in DesignBuilder) made primarily with brick and timber resulted in about an 8% reduction in operative temperature. This attempt also increased the "thermal comfort months" (months with a mean operative temperature of 28^{0}C) from 3 to 9 months annually. The optimised model's emission and construction costs presented 32.31% and 41.81% reductions, respectively. Using indigenous material like mud for construction compared to concrete and HCBs proves to be an affordable and suitable alternative in the tropics due to its thermal properties (Olotuah & Taiwo, 2013). A recent study by (Alegbe, 2022) in the tropical climate of south-south Nigeria compared timber, timber/brick and concrete materials as external and internal wall fabrics in different design combinations. His study suggests that concrete walls, although with the least emissions in the maintenance (B2) and end-of-life (C1-C4) life cycle stages, account for the largest GWI. On the other hand, the timber alternative contributed to the most improved indoor comfort hours and reduced global emissions. The study, however, implies that the timber walls as the external fabric are the most expensive construction alternative.

These works of literature show that a study comparing timber and mud bricks, an indigenous material, with the widely used HCBs, especially their combined options or alternatives towards improving indoor thermal comfort and environmental impact, for use in the sub-Saharan African context is limited; hence, the need for this materials study in Nigeria.

2.1 Building Construction in Nigeria

Building construction in Nigeria is dependent on the concept of "total environment", which according to (Laryea, 2012) is "the sum total of the physical and cultural factors that exist in any locality". This is similar to views expressed by (Agboola & Zango, 2014), who imply that building systems, methods and patterns are associated with material availability, response to specific climates, local technology, and cultural belief systems. As (Costa, 1989) highlighted In his work, buildings in Nigeria emphasise socio-cultural factors, which are evident in most residential buildings' form. Sadly, these factors are considered more important than the impact of the designs and choice of materials on the environment. A significant part of the buildings built in the second half of the last century and the first decade of this century are characterised by massive consumption of natural resources and energy so that this unparalleled consumption that amounted to large waste generation, air and water pollution became the most considerable undesirable setback affecting the construction industry today (Concu, 2019; Thomas, 2020).

2.1.1 Concrete in Construction

Concrete has become a significant player in the construction industry, and its replacement in the climate of Nigeria appears to be a challenging task, even in the face of the challenge of global emissions reduction. This may be connected to a perceived cost increase or lack of technical expertise when alternative materials are considered, government policies and stakeholders' interests. All components of the building fabrics, including floors, walls, and roofs, have an element of concrete. This is one of the reasons why CO_2 emissions, with new buildings springing up, are on the increase. As (Marinković, 2013; Muneron et al., 2021) highlighted, the concrete industry is a heavy consumer of energy and natural resources due to the burning of fossil fuels during manufacturing. It was accentuated further that the production and use of concrete and its by-products have an enormous impact on the environment; therefore, the environmental assessment of concrete is of foremost importance in combating climate change.

2.1.2 Timber in Construction

The use of timber in the Nigerian CI is not gaining the much-needed acceptance for wall construction, even with huge reserves in the Tropical Rain Forest belt (Laryea, 2012) and numerous timber processing industries. This may be connected to industry policies, codes, and timber treatment to resist harsh weather conditions. Some of the disadvantages of using timber are exaggerated due to inadequate knowledge of its strength, durability and thermal performance (Temitope, 2019). Timber is predominantly used in constructing roof trusses, temporary sheds, and light storage houses. Although architects in Nigeria

consider the use of timber very appropriate for the construction of buildings, in light of its low initial cost and aesthetic appeal, it faces one of the significant challenges of being exposed to weather and termite attack (Afolami et al., 2019). Treating timber to resist termites and external conditions like high humidity does not come cheap (Alegbe, 2022). More importantly, sustainability and carbon storage, according to (Brischke, 2019), are some of the major benefits of using timber as a renewable resource for constructing buildings. The longer timber is kept in use, the more carbon is stored, reducing climate and global warming impacts.

Additionally, (Concu, 2019) in his book acknowledged wood as a building material par excellence that has undergone extraordinary evolution in its technology and engineering. However, this domination has been retrogressed in sub-Saharan countries like Nigeria, where reinforced concrete and steel have monopolised the market. This is regardless of the numerous opportunities the use of timber presents to mitigate negative building environmental impacts, such as greenhouse gas emissions (Soust-Verdaguer et al., 2020).

3. Methodology

The overall objectives of this study involve

- collecting primary data through an all-inclusive review of relevant literature,
- identifying helpful case studies and
- using dynamic thermal simulation to perform the requisite experiment.

The literature presented in the preceding section were collected from online library resources, with a more significant percentage comprising journal articles. Conference proceedings, government documents, published theses and dissertations, and eBooks were also consulted. An evaluation of the identified case study is presented in the following section. Energy Plus Weather (EPW) files for the location were generated using Meteonorm 8 for use in Climate Consultant (CC) 6.0, while modelling, testing and simulations were conducted using DesignBuilder (DB) V6.0 software. One-Click LCA tool was used to calculate the building materials' carbon emissions and life cycle metrics.

The key approach of Meteonorm is the interpolation of long-term mean monthly values from meteorological stations. Ideally, measurement data can only be used within the vicinity of a weather station. Elsewhere, where no meteorological station is available, the data must be interpolated between stations within 10-30 km based on satellite imagery. CC uses annual 8760-hour EPW format climate data available for free to access thousands of weather stations worldwide via its website. The general objective of Climate Consultant is to show a graphical representation of the hourly data of the chosen location and to help visualise them using distinct and subtle patterns in a way that would otherwise be lost in tables and figures. Energy Plus, on the other hand, is a simulation programme for building energy used by professionals to model energy consumption for heating, cooling, ventilation, and lighting and is integrated with the CC software (Milne, 2021).

The study relies chiefly on DesignBuilder (v6.1.8.021) simulation software based on EnergyPlus 8.9 simulation algorithms for analysing building parameters, environmental impacts, alternative materials, and operational scenarios. It is used in this study to initially assess the implications of alternative walling materials on indoor thermal comfort, especially on operative temperature difference, using the same building case study and climate data. It is integral in generating a wide range of outputs and reports to help make a reasonable comparison of the performances of design or material alternatives.

The original plan for each case study was drafted in AutoCAD and imported into the software for accurate system boundary characterisation. Additionally, the software offers a virtual environment where building parameters are established, modelled, monitored, and evaluated. The ASHRAE adaptive comfort model in the software is the choice used to simulate the building models. This standard is preferred because it relies on Naturally Ventilated Spaces NVSs, which depend on outdoor climatic conditions. Therefore, with specific outdoor conditions based on generated climate data, the indoor comfort environment was monitored and reported for the different wall materials used. NVSs, peculiar to Nigeria's tropical climate, allow for unconditioned zones in the building to respond to enveloping fabric and outdoor conditions only. This invariably serves as a model for accurately studying materials and their response to the natural environment.

According to (ASHRAE, 2013), the zone in which most people are comfortable is calculated using the Predicted Mean Vote model. This standard is specified to generate comfort conditions in CC that suit the simulation model objectives. In residential buildings, people adjust their clothing level to accommodate seasonal differences and feel comfortable in higher air velocities and so have a more comprehensive comfort range than in buildings with centralised HVAC systems. One of the critical factors in identifying the case studies used in this study is the reliability of climate data; thus, the location of the case study was first determined through Meteonorm to verify their proximity to weather stations.

3.1 Life cycle Assessment (LCA)

Life cycle assessment is a technique for investigating and evaluating the environmental impacts arising from the provision of a product or service (Reitinger, 2020). It is a method of considering the "cradle-to-gate" environmental consequences a material has during its entire life, from raw material extraction, through production, use, consumption and reuse or final disposal. The different life cycle modules of a building (Table 1) account for different amounts of environmental impacts (Ahlund, 2020). This study emphasises thermal performance and CO_2 emissions during the building's life cycle, A1-C4, which according to (Hernandez et al., 2019), covers the period from when the construction raw materials are supplied to when the building is deconstructed or demolished.

3.2 Case Study- Building Typology

The study methodology requires computer modelling and simulation of an existing tropical residential dwelling unit located in northern Nigeria. It is crucial for the identified building to fit within the context of the chief material (concrete), which is to be substituted with timber, and mud brick in a combination of distinctive design alternatives and analysed for impact. Modern residential buildings in Nigeria are predominantly made of the components specified in the table 2 below; these components are identified within the case studies adopted for the study but with a focus on walling systems of the buildings only.

Table 1 Life cycle Modules (BSI, 2012)

Building Assessment Information				
Building Life Cycle Information				**Information Beyond the Building Life Cycle**
A1-3	**A4-5**	**B1-7**	**C1-4**	**D**
Product Stage	**Construction Process Stage**	**Use Stage**	**End of Life Stage**	**Benefits and Loads beyond the System Boundary**
A1: Raw material supply **A2: Transport** **A3: Manufacturing**	A4: Transport A5: Construction installation process	B1: Use B2: Maintenance B3: Repair B4: Replacement B5: Refurbishment B6: Operational Energy B7: Operational water	C1: De-construction C2: Transport C3: Waste processing C4: Disposal	Reuse Recovery Recycling potential

Table 2 Building Typology- Basic Building Components in Nigeria

Building Level	**Component**	**Type**	**Commonly used material**
Sub-Structure	Foundation	Strip	225mm concrete hollow blocks with cement and aggregate mix
Super-Structure	Wall	Internal	150mm concrete hollow blocks with cement screed plaster
		External	225mm concrete hollow blocks with cement screed plaster
	Floor	monolithic	Ceramic tiles finish with cement screed
	Doors	Solid core	Timber/Metal
	Windows	Sliding/casement	Aluminum/glass composite
	Ceiling	Non-suspended	PVC/Hardboard
	Roof	Pitched	Timber carcass and Aluminum roofing sheet

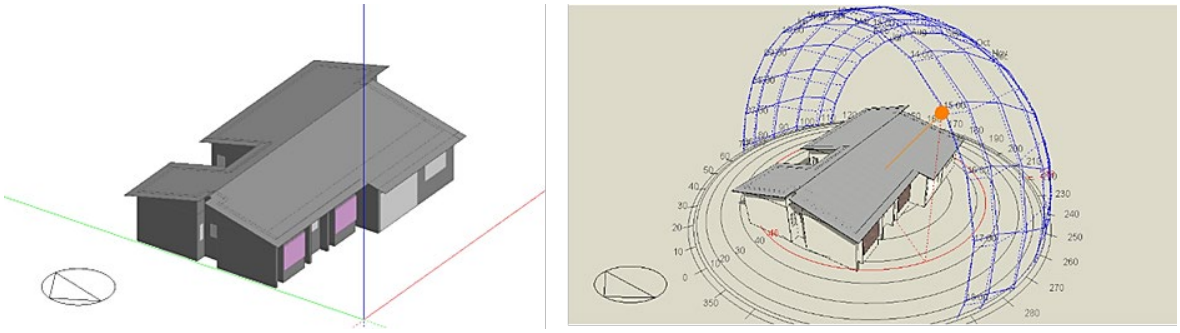


Figure 3 Case Building Model (Left), Building's Solar Path (Right) (DesignBuilder)

The case study building (Figure 3) adopted for this study is a residential bungalow belonging to a large polygamous family. It comprises five bedrooms, with only two of them ensuite, a livingroom, dining, a kitchen, and a storage room. A middle-aged businessperson owns it.

3.3 Site Location and Orientation

Case study two is in Kano, a city in northern Nigeria and the capital of Kano State. Kano City is the largest city in Nigeria after Lagos. Based on geographical coordinates collected from google maps, the building is sited within 11°58'06.4"N 8°33'51.5"E, with a tilt of 17^{0} west from the North (Figure 4). Residential buildings bound it to the North and West, with some unoccupied plots to the East and South.

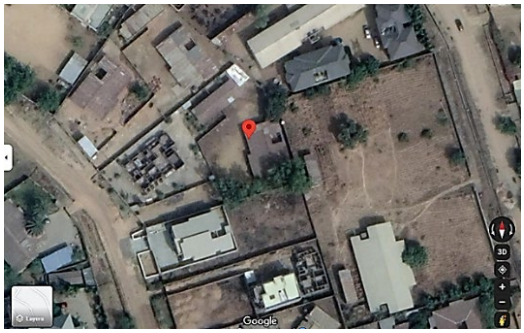


Figure 4 Kano Case Study Satellite Imagery (GoogleEarthPro)

3.4 Climate Classification / Justification

As extracted from DesignBuilder using imported Meteonorm EPW files, the climatic classification of the location according to ASHRAE climatic zone classification is 1B. Very hot temperatures and a dry atmosphere characterises this zone. Further to classifications by Koppen Geiger, and with reference to Figure 5A, the climate for this location is categorised as warm or hot semi-arid (BSh). The BSh climate, considered steppe, is an intermediate between the desert and humid climates and tends to have hot, sometimes extremely hot periods with very little precipitation. Also, a study by (Mobolade & Pourvahidi, 2020) identifies Kano city as a hot, dry climate according to the referenced map in Figure 5B.

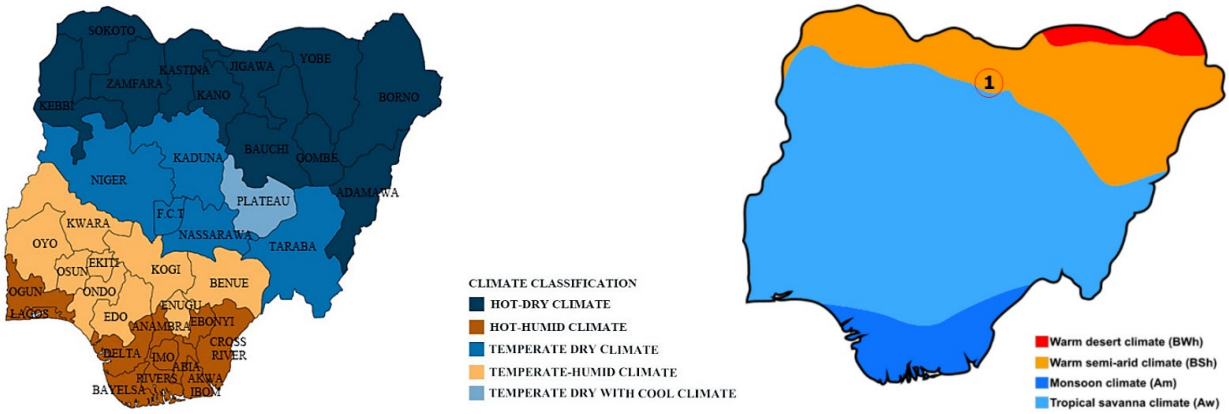


Figure 5 A- Bioclimatic Climate Classification (Left), B- Koppen Geiger Climate Classification (Right) of Nigeria- Kano in circle 1 *(Mobolade & Pourvahidi, 2020)*

4. Results/Findings

4.1 Climate Data

The table below shows the climate data for the case building location. As recorded, the lowest dry bulb temperature occurs in January at 20°C. In April and May, two months after the lowest recorded temperature, extreme temperatures are experienced with as high as 31°C for outside dry bulb temperature. The air in this region is primarily dry, with humidity levels as low as 18% and recorded in March. Two wind directions are predominant in this region, north-easterly and south-westerly winds (Figure 6A), blowing strong at a maximum speed of 2.9m/s during the coldest month of January. The psychometric chart in Figure 6B displays a relationship between the recorded dry bulb temperature, relative humidity, and various parameters of supplied air.

Table 3 Weather Data for Study Location (Climate Consultant/Meteonorm)

Weather Data Summary			Location: Kano (Nigeria) Data Source: MN7 999 WMO Station Number Elevation: 483m		
Months	**Dry Bulb Temp.** (°C)	**Rel. Hum.** (%)	**Global Hor. Rad.** (KWh/m²)	**Wind Speed** (m/s)	**Wind Direction** (Degrees)
Jan.	20	27	159	2.9	80
Feb.	24	22	157	2.8	70
Mar.	28	18	196	2.7	80
Apr.	31	27	199	2.5	70
May	31	46	197	2.7	250
Jun.	28	65	189	2.8	240
Jul.	26	74	194	2.7	250
Aug.	25	79	176	2.3	270
Sep.	26	78	181	2.1	240
Oct.	27	54	183	2.1	90
Nov.	24	33	168	2.5	70
Dec.	21	30	151	2.8	70
	Annual Lowest				
	Annual Highest				

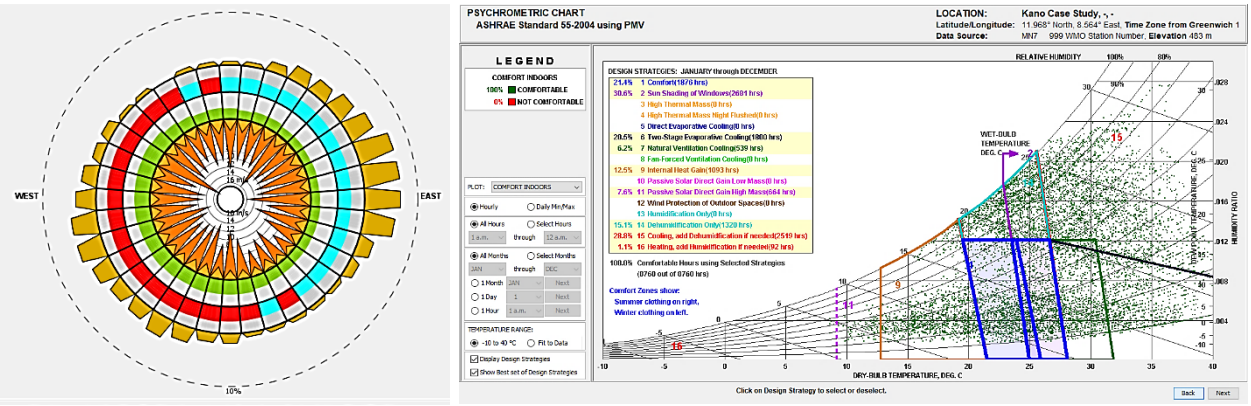
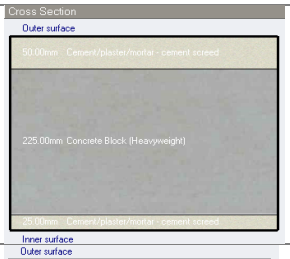
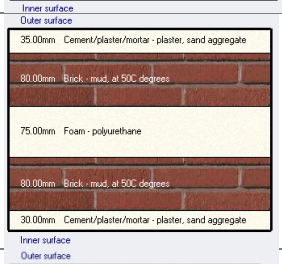
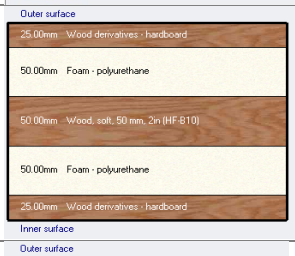


Figure 6 A- Wind Wheel (Left), B- Psychrometric Chart (Right) for Case Building Location (Climate Consultant)

Table 4 Wall parameters

Wall Type	U-Value External Wall (W/m²k)	Cross Section	U-Value Internal Wall (W/m²k)	Cross Section
CW	2.765		2.579	
MB	0.318		0.210	
TB	0.278		0.210	

5. Discussion

5.1 Thermal Comfort- Indoor Operative Temperature

Regarding the comfort temperature of 28°C, as purported by (MOP, 2016) for buildings in the tropics, the simulation carried out in this study shows that the mud brick (MB) alternative accounts for the most comfortable hours annually. On the other hand, the concrete wall (CW) case building contributes to the highest percentage of hours above the comfort temperature (Figure 7).

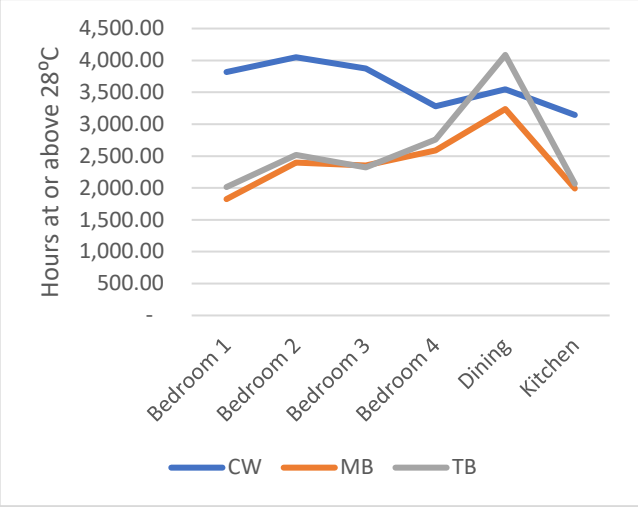


Figure 7 Hours above Comfort Temperature for the Wall Materials

According to (Datta & Mustafa, 2016), different building materials responds characteristically to different climate conditions due to their inherent properties. It is widely suggested that a material with a low U-value will provide better resistance to heat gain in the building; this is only in connection to the material properties. As presented in Table 4 above, the timber brick (TB) wall alternative has a u-value of approximately 13% less than the MB alternative but with a comparatively lesser performance regarding providing

better living conditions. The MB's performance and its variation to the TB alternative, as suggested by (Datta & Mustafa, 2016), is likened to the embodied energy of the material components. While the U-value significantly reduces indoor temperature (DesigningBuildings, 2022), a lower U-value does not always imply a lower indoor temperature, as the heat transfer rate into the building depends on the thermophysical properties of the wall materials (Alegbe, 2022).

The orientation of a building, among other factors like glazing, fabric, wind speed and direction, and outdoor temperature, affects the amount of solar gain and indoor temperature in indoor spaces. These materials, subjected to the same indoor and outdoor conditions, show different levels of operative temperature. In the areas presented in Table 5 below, the CW building has the highest percentage of hours above the comfort temperature of 28°c, with 41.31%, while the MB and TB options have 27.37 and 29.99%, respectively. Additionally, the annual performance temperature variance of the materials (Figure 8) shows the consistency of the MB alternative over TB and CW. The improved indoor temperature of the mud brick building is further evidenced in spaces like the dining and bedroom 4, positioned along the west-east orientation and with more solar exposure.

In May, the hottest month, the TB building recorded the least operative temperature of 29.73°C, which is approximately 3% less than the recorded peak temperature for the concrete building. The annual mean performance of the material alternatives shows that the MB building offers the best indoor comfort in terms of hours above the comfort temperature. Simulations conducted under naturally ventilated spaces have indoor temperatures influenced by outdoor conditions.

Table 5 Comfort Hours for Building Wall Materials

		CW		MB		TB	
		Hours at or above 28°C					
Space	Orientation	Hours	%	Hours	%	Hours	%
Bedroom 1	N	3,820.00	43.61	1,824.50	20.83	2,014.00	22.99
Bedroom 2	W	4,049.50	46.23	2,395.00	27.34	2,520.00	28.77
Bedroom 3	SW	3,872.00	44.20	2,351.00	26.84	2,321.00	26.50
Bedroom 4	E	3,278.50	37.43	2,590.50	29.57	2,757.00	31.47
Dining	NE	3,549.00	40.51	3,237.50	36.96	4,086.50	46.65
Kitchen	NE	3,144.50	35.90	1,988.50	22.70	2,064.50	23.57

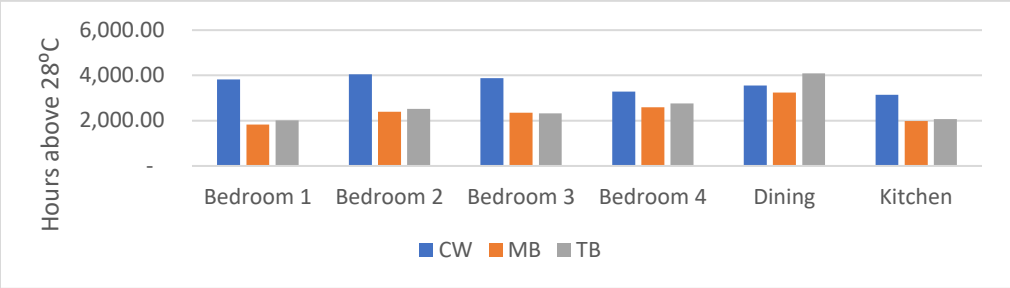


Figure 8 Annual Mean Performance Variance of Building Materials

One of the challenges posed by the alternative materials to concrete is that they offer low vapour resistance. Based on the glacier method analysis in the simulation model, when timber is introduced as the building fabric, the likelihood of mould growth on the surface results in increased humidity due to condensation. According to the dynamic simulation modelling, the interstitial condensation for the wall materials is calculated from the number of surfaces and thermal insulation properties of the walls. In this regard, the CW building offers the highest resistance to mould growth, while the timber brick, due to the presence of timber, a low vapour material, provides the least resistance to humidity (Figure 9).

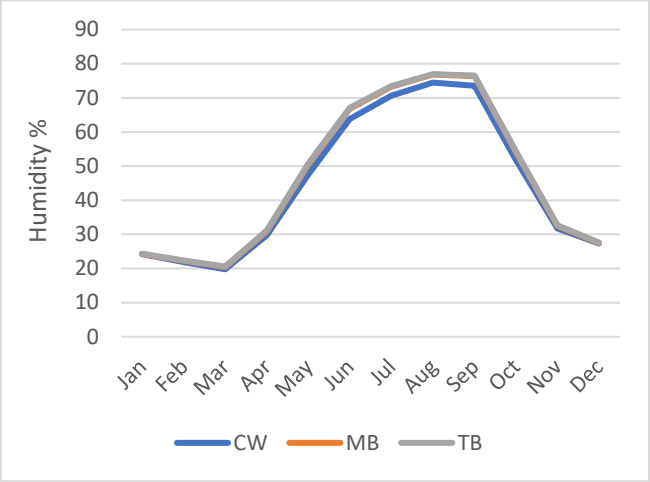


Figure 9 Humidity Levels- Interstitial Condensation of Wall Materials

August recorded the highest humidity level in this climate (Table 3). While all three material options provide a better indoor humidity level than the registered outdoor's, it is 74.47% for the CW, 76.83% for the MB building and 76.94% for the TB option. The concrete building shows better resistance to condensation and mould growth. As opined by (de Oliveira Fernandes et al.), a low-vapour resistant material increases the chances of condensation. This vapour condensation relationship between these materials and their impact on perceived thermal comfort calls for further investigation.

5.2 Global Warming Impacts (GWI)

The assessment of the materials' GWI on various life cycle stages shows different emission levels. This is expected as the materials embodied, and operational carbons vary. As stated by (Norton et al., 2021), one of the processes leading to GHG emissions from buildings is always connected to the "cradle-to-gate" life cycle stages of the material. The result of the LCA shows that the embodied carbon benchmark of the as-built CW building is 690 $KgCO_2e/m^2$ in class F, the MB building is in class D with 510 $KgCO_2e/m^2$, while the TB building is in class D with 542 $KgCO_2e/m^2$ of emissions (Table 6). While the embodied emission levels of the TB and MB alternatives are within the same benchmark, the MB building has approximately 6% less than the TB and about 26% less than the as-built CW building.

Table 6 Carbon Benchmark and Global Warming Life Cycle Stages of Wall Materials

Wall Type	Global Warming Life Cycle Stages ($KgCO_2e$)					Carbon Benchmark	
	A1-A3	A4	B1-B5	B6	C1-C4	$KgCO_2e/m^2$	Class
CW	92,506.99	3,859.96	5,442.19	1,010,408.80	5,667.68	690	F
MB	65,751.68	1,595.62	11,639.77	1,010,408.80	6,410.53	510	D
TB	62,900.27	1,075.59	22,264.82	1,051,059.81	8,139.44	542	D

Electricity (B6) which contributes to the highest emissions in the entire life cycle of the buildings, accounts for more than 90% of the total emissions (Table 6 and Figure 10A). Outside electricity, the MB building contributes 21% less emissions than the as-built concrete building, while the TB alternative contributes approximately 12% fewer emissions than the CW building (Figure 10B). More so, the total emissions in the life cycle stages for the CW building is 1,117,885.62 $KgCO_2e$; the MB building accounts for 2% less, while the TB building accounts for 2.4% more.

The results of the study by (Alegbe, 2022) show the timber/brick alternative as the relatively best substitute for concrete. A combination of timber and brick on the exterior contributes to a lower indoor temperature when compared to only timber and concrete fabrics. However, the introduction of mud bricks as an exterior wall element in this study shows a better performance than the TB. This implies the thermal performance and environmental friendliness of mud over other sustainable wall materials.

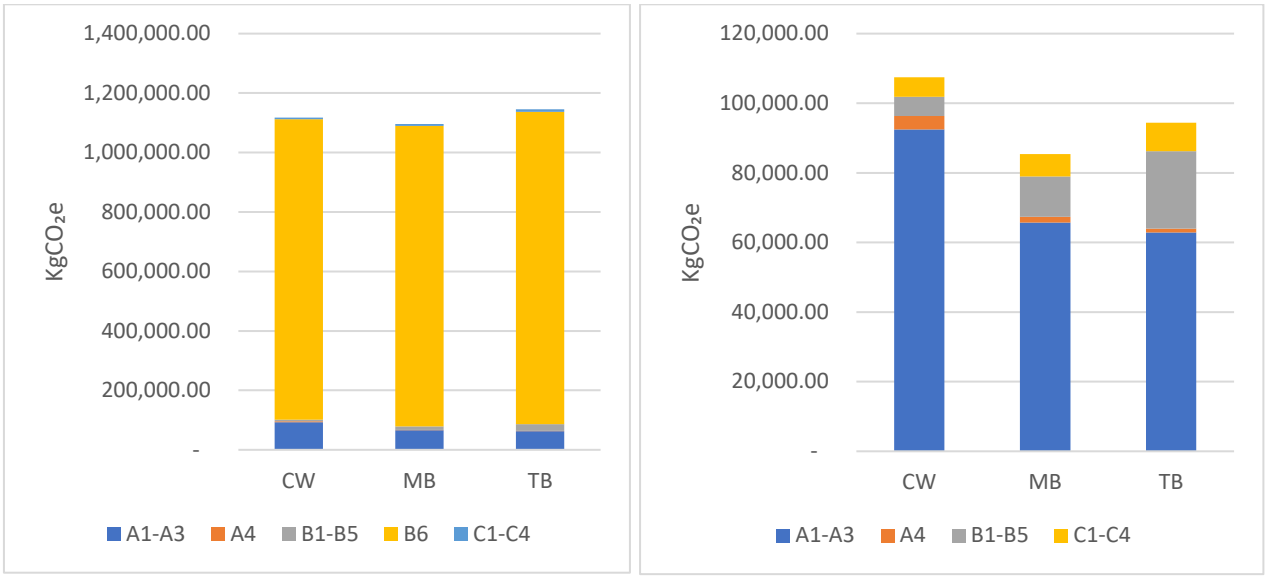


Figure 10 A- GWI of Buildings with Electricity (Left), B- GWI of Buildings without Electricity (Right)

The advantage of the as-built building lies in the maintenance and end-of-life stages. The TB alternative has the most significant benefits of fewer emissions in the material (A1-A3) and transportation (A4) stages (Table 6). The overall assessment of the buildings puts the MB alternative as the most suitable in terms of global warming potentials. The most significant embodied emissions of a building are in areas that contain steel and cement (Norton et al., 2021); this include foundations, floor slab and other structural components. Additionally, (Wesonga et al., 2021) emphasised the importance of analysing wall elements, as they form an integral part of the building's embodied energy. The life cycle impact of the wall systems alone, without other building elements was analysed and presented in table 7 below.

Table 7 Global Warming Life Cycle Stages of Wall Components Only

Wall Type	**Global Warming Life Cycle Stages ($KgCO_2e$) Walls Only**				
	A1-A3	A4	B1-B5	B6	C1-C4
CW	57,885.90	3,060.61	-	-	4,298.41
MB	39,122.37	1,077.84	-	-	4,783.98
TB	36,324.30	558.32	10,678.40	-	6,513.70

The case building (CW) had only the wall fabric replaced while maintaining other elements of the building component. This wall impact analysis influences the overall carbon emission levels. The result shows that the CW has the most significant emissions, with 65,244.92 $KgCO_2e$ of total carbon emissions (Figure 11). The MB alternative has 31% fewer emissions, while the TB alternative has 17% less emissions compared to the case building. In this regard, there are zero emissions for the CW and MB during the B1-B6. This is due to savings during the use stage for maintenance, repair, replacement, refurbishment, and operational energy.

The TB option, on the other hand, accounts for 10,678.40 $KgCO_2e$ of emissions. This is connected to the material composition of the wall component; timber and brick, which will require maintenance and replacement during the building use. However, the biocarbon storage of the TB building makes it a good material for consideration in terms of the ability to preserve carbon. In this regard, the TB building has about 49,778.10 $KgCO_2bio$ storage, while the MB alternative has only 16, 561.54 $KgCO_2bio$ storage. In this climate, protecting timber from mould growth, though expensive, can serve as a way of reducing the carbon count in building (Alegbe, 2022), and with solutions that limit fire risks, it can be engineered to replace concrete and steel (Norton et al., 2021). The amount of carbon storage accounted for in the mud bricks alternative is owed to the timber partitions in the building. Concrete has no carbon storage ability; hence the case building has zero carbon storage for the wall component.

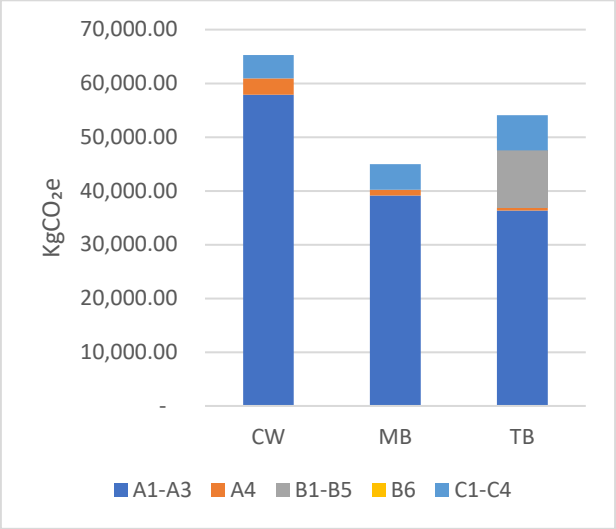


Figure 11 GWI of Walls

6. Conclusion

More than ever, the need to improve indoor thermal comfort and reduce emissions in tropical buildings, which rely significantly on natural means for ventilation, is necessary, given that rising temperatures are experienced globally, and non-renewable/non-recyclable natural resources are in depletion. Most buildings in Nigeria are not climate responsive, giving rise to occupants' discomfort and much energy for cooling (Akande & Adebamowo, 2010). Improving indoor comfort in tropical buildings should not be at the expense of overusing building materials, as emissions from non-green materials pose a severe threat to changing climate. (Norton et al., 2021) noted that reducing greenhouse gas emissions will involve reusing and recycling building materials. HCBs, the widely used wall materials in Nigeria accounts for a large percentage of emissions in the continent of Africa.

These emissions are primarily due to the extraction and processing of the raw materials and the transportation (A1-A4 LCA stages) to the site of the finished product for use (Alegbe, 2022). Buildings are hard to decarbonise as they consume a large and varied amount of natural resources (D'Amico et al., 2021), and studies show that using building materials with high recycling or reuse potential is considered one of the most productive ways of reducing the overall embodied energy impact of buildings (Chang et al., 2019). Overdependence on cement-based building materials negates the potential for recyclable and renewable materials to gain exigency in the Nigerian construction industry.

Thermal comfort, according to (Latha et al., 2015), "could be costly to handle if the choice of materials and construction techniques are not properly addressed". This study examines the potential for timber, aerated clay bricks and mud bricks to provide a better indoor comfort temperature and reduced emissions over the widely used concrete blocks. This research uses dynamic thermal simulation models and life cycle assessment techniques to determine the comfort levels and global warming impacts of concrete walls (CW), timber brick walls (TB) and mud brick walls (MB) in different design alternatives.

The results show that the MB building alternative performs better than the as-built CW building and the TB alternative regarding both operative temperature variance and overall global warming impacts. The MB alternative has 21% fewer emissions (without electricity generation) and 33.8% lesser hours above the comfort temperature compared to the concrete building. The poor performance of the CW option on indoor operative temperature is likened to limited or lack of insulation to address the heat balance between outdoor and indoor conditions. Manufacturing cement-based product amounts to excessive carbon emissions; hence, the case building is the least environmentally friendly one. Building material "greenness" is not only associated with its use in buildings but with its resource management, toxicity and environmental performance (de Castro et al., 2014). The TB wall alternative, comprising both timber and aerated clay bricks exterior, also has a better indoor comfort temperature and fewer emissions than the CW building. Due to its material component, the TB alternative accounts for the most significant emissions during the maintenance stage, but with a comparative advantage due to its carbon storage ability. The advantage of concrete regarding global warming life cycle stages is its low emissions at the maintenance and end-of-life stages.

The author, therefore, concludes that given the distinct advantages of mud bricks over timber, aerated clay bricks and concrete wall materials, in terms of providing lesser hours above the operative comfort temperature of 28^{o}C, environmental impact and de-construction potential, it is therefore recommended as the best alternative for use as external walling fabric in the tropical climate of Nigeria.

7. Future Research

This study does not clearly define the influence of the Interstitial condensation level of the materials on the operative temperature variance of the indoor spaces where they are used. The study focused on operative temperature, paying less attention to other factors like humidity and human factors like clothing level that affect thermal comfort. Therefore, further studies should be conducted on the humidity level of these materials when used for the specific building case study and location to ascertain their overall impact on indoor comfort.

Additionally, it is recommended that this study be conducted under "Fan-Simple HVAC" aeration as an alternative means of ventilation in tropical Nigeria. Since outdoor factors primarily affect indoor conditions in NVSs as modelled in this study, a similar investigation under a controlled environment could suggest a better indoor thermal environment.

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References

Afolami, A., Oluyede, T., & Amuda, M. (2019). Architects Perspective on The Use of Timber for Building Design and Construction in Ondo State, Nigeria. *2nd world conservation conference*.

Agboola, O. P., & Zango, M. S. (2014). Development of Traditional Architecture in Nigeria: A Case Study of Hausa House Form. *International Journal of African Society Cultures and Traditions*, *1(1)*: 61-64.

Ahlund, H. (2020, 2020). A comparative study of embodied and operational environmental impact of a multifamily building with different framework materials. Department of Applied Physics and Eletronics, Umea University. Retrieved 1st July, 2022 from http://urn.kb.se/resolve?urn=urn:nbn:se:umu:diva-172655

Akande, O. K. (2010). Passive design strategies for residential buildings in a hot dry climate in Nigeria [Conference Paper]. Eco-Architecture III, *WIT Transactions on Ecology and the Environment*, 128: 61-71. https://doi.org/10.2495/arc100061

Akande, O. K., & Adebamowo, M. A. (2010). Indoor Thermal Comfort for Residential Buildings in Hot-Dry Climate in Nigeria. Network for Comfort snd Energy use in Buildings NCEUB. Retrieved 5th June, 2022 fromhttps://repository.futminna.edu.ng:8080/jspui/handle/123456789/4675

Alegbe, M. (2022, 16th September). Comparative Analysis of Wall Materials Toward Improved Thermal Comfort, Reduced Emission, and Construction Cost in Tropical Buildings. [Conference Proceedings]. 11th Masters Conference: People and Buildings University of Westminster, London, United Kingdom. https://eprints.soton.ac.uk/471027/

Ashrae. (2013). 2013 ASHRAE Handbook - Fundamentals (I-P Edition). American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE). Retrieved 5th June, 2022 from https://app.knovel.com/hotlink/toc/id:kpASHRAEB2/ashrae-handbook-fundamentals/ashrae-handbook-fundamentals

Brischke, C. (2019). Timber. In Long-term Performance and Durability of Masonry Structures 129-168. https://doi.org/10.1016/b978-0-08-102110-1.00005-4

Broun, R., & Menzies, G. F. (2011). Life Cycle Energy and Environmental Analysis of Partition Wall Systems in the UK [Article]. *Procedia Engineering,* 21: 864-873. https://doi.org/10.1016/j.proeng.2011.11.2088

BSI. (2011). *Sustainability of construction works- Assessment of environmental performance of buildings-Calculation method*. BSI Standard Publication, EN 15978:2011. https://doi.org/doi.org/10.3403/30192730

Chang, C. C., Shi, W., Mehta, P., & Dauwels, J. (2019). Life cycle energy assessment of university buildings in tropical climate. *Journal of Cleaner Production,* 239: 117930. https://doi.org/https://doi.org/10.1016/j.jclepro.2019.117930

Concu, G. (2019). Timber Buildings and Sustainability. Intechopen, London, United Kingdom. Retrieved 7th July, 2022 from http://dx.doi.org/10.5772/intechopen.78428

Costa, R. (1989). Architecture in black Africa Between development and tradition. *Solar & Wind Technology*, 6(4): 383-387. https://doi.org/https://doi.org/10.1016/0741-983X(89)90057-X

Croce, S. (2020). Architecture and adaptation. TECHNE - *Journal of Technology for Architecture and Environment* 20: 33-38. https://doi.org/https://doi.org/10.13128/techne-9760

Czechowski, A. S. V. (2020). CDP Africa Report. Carbon Disclosure Project. Retrieved 6th July, 2022 from https://cdn.cdp.net/cdp-production/cms/reports/documents/000/005/023/original/CDP_Africa_Report_2020.pdf?1583855467

D'Amico, B., Pomponi, F., & Hart, J. (2021). Global potential for material substitution in building construction: The case of cross laminated timber. *Journal of Cleaner Production,* 279: 123487. https://doi.org/10.1016/j.jclepro.2020.123487

Datta, U. S., & Mustafa, B. (2016). A Comparative Study of the Thermal Performance of Mud and Brick Houses in Bangladesh Building the Future- Resilient Environments, Faculty of Architecture Research Unit (FARU), University of Moratuwa, Sri Lanka. http://dl.lib.mrt.ac.lk/handle/123/13031

de Castro, E. B. P., Mequignon, M., Adolphe, L., & Koptschitz, P. (2014). Impact of the lifespan of different external walls of buildings on greenhouse gas emissions under tropical climate conditions. *Energy and Buildings,* 76: 228-237. https://doi.org/https://doi.org/10.1016/j.enbuild.2014.02.071

de Oliveira Fernandes, E., Leal, V., & Craveiro, F. (2007, 12th-13th June). On Strategies to Prevent Condensation in Buildings EnVIE Conference on Indoor Air Quality And Health for EU Policy, Helsinki, Finland. https://www.aivc.org/resource/strategies-prevent-condensation-buildings

DesigningBuildings. (2021). Fabric first. Retrieved 5th September, 2022 from https://www.designingbuildings.co.uk/wiki/Fabric_first

DesigningBuildings. (2022). *U-values.* Retrieved 30th July, 2022 from https://www.designingbuildings.co.uk/wiki/U-values

Dodoo, A. (2020). Energy and indoor thermal comfort performance of a Swedish residential building under future climate change conditions. *E3S Web of Conferences*, 172: 02001. https://doi.org/10.1051/e3sconf/202017202001

Dunne, D. (2020, 21st August, 2020). The Carbon Brief Profile: Nigeria. Carbon Brief Ltd. Retrieved 6th July, 2022 from https://www.carbonbrief.org/the-carbon-brief-profile-nigeria/

FME. (2021). *2050 Long-Term Vision for Nigeria (LTV-2050).* Federal Ministry of Environment, Nigeria. Retrieved 06th July, 2022 from https://unfccc.int/sites/default/files/resource/Nigeria_LTS1.pdf

Gorse, C., Johnston, D., & Pritchard, M. (2020). *Adaptive comfort temperature*. Oxford University Press. Retrieved 10th July, 2022 from https://www.oxfordreference.com/view/10.1093/acref/9780198832485.001.0001/acref-9780198832485-e-8174

Gurupatham, S. V., Jayasinghe, C., & Perera, P. (2021). Ranking of walling materials using eco-efficiency for tropical climatic conditions: A survey-based approach. Energy and Buildings, 253: 111503. https://doi.org/10.1016/j.enbuild.2021.111503

Hannah Ritchie, Max Roser, & Rosado, P. (2020). *Nigeria: CO2 Country Profile*. Our World in Data. Retrieved 21st June, 2022 from https://ourworldindata.org/co2/country/nigeria

Hernandez, P., Oregi, X., Longo, S., & Cellura, M. (2019). *Life-Cycle Assessment of Buildings.* In Handbook of Energy Efficiency in Buildings (pp. 207-261). https://doi.org/10.1016/b978-0-12-812817-6.00010-3

HSE. (2022). Thermal Comfort (Six Basic Factors). Retrieved 5th July, 2022 from https://www.hse.gov.uk/temperature/thermal/index.htm

Huq, S., Reid, H., & Murray, L. A. (2006). Climate Change and Development Links. International Institute for Environment and Development, 27. http://www.jstor.org/stable/resrep01331

IPCC. (2021). Summary for Policymakers. Cambridge University Press. Retrieved 22nd March, 2023 from doi:10.1017/9781009157896.001.

Iso. (2005). Ergonomics of the Thermal Environment. Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria. European Committee for Standardization. Retrieved 6th July, 2022 from https://www.iso.org/standard/39155.html

Jayalath, A., Navaratnam, S., Ngo, T., Mendis, P., Hewson, N., & Aye, L. (2020). Life cycle performance of Cross Laminated Timber mid-rise residential buildings in Australia. *Energy and Buildings*, 223: 110091. https://doi.org/10.1016/j.enbuild.2020.110091

Jegede, O. E., & Taki, A. (2021). Optimization of building envelopes using indigenous materials to achieve thermal comfort and affordable housing in Abuja, Nigeria. *International Journal of Building Pathology and Adaptation*, 40(2): 219-247. https://doi.org/https://doi.org/10.1108/IJBPA-01-2021-0009

Jenkins, D. P., Patidar, S., & Simpson, S. A. (2015). Quantifying Change in Buildings in a Future Climate and Their Effect on Energy Systems. *Buildings,* 5(3): 985-1002. https://doi.org/doi:10.3390/buildings5030985

Kristl, Ž., Senior, C., & Temeljotov Salaj, A. (2020). Key challenges of climate change adaptation in the building sector. *Urbani Izziv,* 31(1): 101-111. https://doi.org/DOI:10.5379/urbani-izziv-en-2020-31-01-004

Laryea, S. (2012). *Construction in West Africa.* West Africa Built Environment Research (WABER) Conference and EPP Book Services Ltd. Retrieved 9th August, 2022 from https://www.academia.edu/17523289/Construction_in_West_Africa_Book

Latha, P. K., Darshana, Y., & Venugopal, V. (2015). Role of building material in thermal comfort in tropical climates – A review. *Journal of Building Engineering*, 3: 104-113. https://doi.org/10.1016/j.jobe.2015.06.003

Macrotrends. (2022). *Nigeria Population Growth Rate 1950-2022.* Retrieved 8th June, 2023 from https://www.macrotrends.net/countries/NGA/nigeria/population-growth-rate

Mahmoud, H., & Ragab, A. (2021). Urban Geometry Optimization to Mitigate Climate Change: Towards Energy-Efficient Buildings. *Sustainability*, 13(1): 27. https://dx.doi.org/10.3390/su13010027

Marinković, S. B. (2013). Life cycle assessment (LCA) aspects of concrete. In Eco-Efficient Concrete 45-80. https://doi.org/10.1533/9780857098993.1.45

Milne. (2021). Climate Consultant. The Society of Building Science Educators. Retrieved 3rd June, 2022 from https://www.sbse.org/resources/climate-consultant

Mobolade, T., & Pourvahidi, P. (2020). Bioclimatic Approach for Climate Classification of Nigeria. *Sustainability,* 12(10): 4192. https://doi.org/10.3390/su12104192

MOP. (2016). *Building Energy Efficiency Guideline for Nigeria*. Federal Ministry of Power, Works and Housing. Retrieved 12th July, 2022 from https://energypedia.info/images/c/c7/Building_Energy_Efficiency_Guideline_for_Nigeria_2016.pdf

Muneron, L. M., Hammad, A. W. A., Najjar, M. K., Haddad, A., & Vazquez, E. G. (2021). Comparison of the environmental performance of ceramic brick and concrete blocks in the vertical seals' subsystem in residential buildings using life cycle assessment. *Cleaner Engineering and Technology*, 5: 100243. https://doi.org/10.1016/j.clet.2021.100243

Norton, B., Gillett, W. B., & Koninx, F. (2021). Briefing: Decarbonising buildings in Europe: a briefing paper. *Proceedings of the Institution of Civil Engineers - Energy,* 174(4): 147-155. https://doi.org/10.1680/jener.21.00088

Ogbonna, A. C., & Harris, D. J. (2008). Thermal comfort in sub-Saharan Africa: Field study report in Jos-Nigeria. *Applied Energy,* 85(1): 1-11. https://doi.org/10.1016/j.apenergy.2007.06.005

Olotuah, A. O., & Taiwo, A. A. (2013). Housing the Urban Poor in Nigeria Through Low-cost Housing Schemes. *International Journal of Physical and Human Geography,* 1(3): 1-8. https://www.eajournals.org/wp-content/uploads/HOUSING-THE-URBAN-POOR-IN-NIGERIA-THROUGH-LOW-COST-HOUSING-SCHEMES.pdf

Özdamar Seitablaiev, M., & Umaroğulları, F. (2018). Thermal Comfort and Indoor Air Quality. *International Journal Of Scientific Research And Innovative Technology*, 5(1): 90-109. https://www.researchgate.net/publication/326324068

Ramos Ruiz, G., & Olloqui del Olmo, A. (2022). Climate Change Performance of nZEB Buildings. *Buildings,* 12(10): 1755. https://doi.org/doi:10.3390/buildings12101755

Reitinger, C. (2020). Life-cycle assessment. Salem Press. Retrieved 11th July, 2022 from https://liverpool.idm.oclc.org/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=ers&AN=89474279&site=eds-live&scope=site

Ryberg, M. W., Ohms, P. K., Møller, E., & Lading, T. (2021). Comparative life cycle assessment of four buildings in Greenland. *Building and Environment,* 204: 108130. https://doi.org/10.1016/j.buildenv.2021.108130

Salem, J., Lenzen, M., & Hotta, Y. (2021). Are We Missing the Opportunity of Low-Carbon Lifestyles? International Climate Policy Commitments and Demand-Side Gaps. *Sustainability,* 13(22): 12760. https://doi.org/10.3390/su132212760

Siti Handjarinto, & Veronica I, S. (1998, 1st-2nd June). Thermal Comfort Study in a Naturally Ventilated Residential Building in a Tropical Hot-Humid Climate Region [Conference Proceedings]. Symposium on Improving Building Systems in Hot and Humid Climate, Fort Worth, Texas, United States. https://core.ac.uk/works/39526217

Soust-Verdaguer, B., Llatas, C., & Moya, L. (2020). Comparative BIM-based Life Cycle Assessment of Uruguayan timber and concrete-masonry single-family houses in design stage. *Journal of Cleaner Production*, 277: 121958. https://doi.org/10.1016/j.jclepro.2020.121958

Temitope, O. O. (2019). Green Building and Energy Conserving Designs: Significance of Timber as a Sustainable Building Material in Nigeria. *World Journal of Innovative Research WJIR,* 6(5): 56-60. https://www.wjir.org/download_data/WJIR0605010.pdf

Thomas, G. (2020). Construction Waste Management/Construction & Demolition Waste/Classification. EngineeringCivil.org. Retrieved 16 August from https://engineeringcivil.org/articles/building-materials/construction-waste-management-construction-demolition-waste-classification/

Transparency, C. (2020). Nigeria's Climate Action and Responses to the Covid-19 Crisis. Climate Transparency. Retrieved 6th July, 2022 from https://www.climate-transparency.org/wp-content/uploads/2021/01/Nigeria-CT-2020.pdf

UN. (2006). United Nations Fact Sheet on Climate Change. United Nations. Retrieved 6th July, 2022 from https://unfccc.int/files/press/backgrounders/application/pdf/factsheet_africa.pdf

Wesonga, R., Kasedde, H., Kibwami, N., & Manga, M. (2021). A Comparative Analysis of Thermal Performance, Annual Energy Use, and Life Cycle Costs of Low-cost Houses Made with Mud Bricks and Earthbag Wall Systems in Sub-Saharan Africa. *Energy and Built Environment,* 4(1): 13-24. https://doi.org/https://doi.org/10.1016/j.enbenv.2021.06.001

Zeitz, A., Griffin, C. T., & Dusicka, P. (2019). Comparing the embodied carbon and energy of a mass timber structure system to typical steel and concrete alternatives for parking garages [Report]. *Energy & Buildings*, 199: 126. https://doi.org/10.1016/j.enbuild.2019.06.047

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Citizen's Perception on Eco-friendly Lifestyle for Conserving Endangered Oriental White Stork and Crested Ibis Bird Species in Japan – Case Studies in Toyoka, Sado and Konosu Cities

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ABSTRACT

This study aims to find out the relationship between an eco-friendly lifestyle and the attitude towards conservation of endangered Oriental White Stork and Japanese Crested Ibis bird species in Toyooka, Sado, and Konosu cities in Japan. Citizens were surveyed to assess their willingness to spend an eco-friendly lifestyle to protect the above-mentioned endangered bird species through questionnaire surveys. Ecological Mind Evaluation Scale (EM Evaluation scale) developed by Tanaka and Joh (2012) based on Hirose model and Bandura's research on Self Efficacy was applied in this research. This Ecological Mind Evaluation Scale includes 10 factors and it was applied to develop the questionnaire survey. The factor analysis was undertaken based on 4 groups of questionnaire results; environmental awareness, attitude towards environmental conservation, environmental consciousness and self-efficacy. Factor analysis was performed using the varimax method and sample data set comprised 686 valid responses from the three study sites. The KMO values were over 0.80 indicating the sampling was adequate. According to the factor analysis Sado city scored high for environmental awareness and environment consciousness. Toyooka city scored high on self-efficacy and environmental consciousness. Konosu city was compared with the Toyooka and Sado cities, where more advanced habitat conservation activities are already implemented. Findings displayed that the citizens in Konosu city had low awareness about these bird conservation activities, however, they are willing to contribute in such activities in the future. Thus, this study demonstrated that by engaging in environmentally friendly lifestyles, the citizens can contribute to habitat conservation of endangered bird species.

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1. Introduction

The Oriental White Stork (Ciconia boyciana) is a large white bird with black wing feathers. It has a red skin around the eye, whitish iris, and a black bill. The female bird is slightly smaller than the male, and young birds are white with orange bills (John, 1992). This species can be found in Japan, Manchuria, Korea, and Siberia, and it prefers to live in marshes, pond edges, coastal belts, and other wetlands. As apex predators in their habitats, they play a crucial role (Naito and Hiroshi, 2007). However, due to habitat loss and overhunting, the Oriental White Stork has been listed as an endangered species on the IUCN Red List (Bird Life International, 2018). The growth of paddy cultivation and the heavy use of chemicals severely affected their breeding grounds, leading to their extinction from their habitats. This bird species once became extinct in Japan in 1971, but there have been reintroduction efforts since then. Figure 1 displays a picture of the Oriental White Stork.

Figure 1
Oriental White Stork
Photography by Author

Figure 2
Japanese Crested Ibis
Source: Japan Atlas Nature

The Japanese Crested Ibis is a large white-plumaged bird native to Eastern Asia. It has a partially bare head showing red skin and a dense white plume on the back of the neck. It is the only living member of the genus Nipponia (Mie, 2012). This bird was originally found in Russia, Japan, and China. However, it has become extinct from most of its range, with only a natural population remaining in Shaanxi, China (Birds Life International, 2018). The last wild Crested Ibis in Japan died in 2003, but reintroduction efforts began in 2008. This bird is also a predator, and its extinction from its homelands was primarily caused by overhunting, excessive use of pesticides, limited range, and winter starvation (The Japan Times, 2022). Currently, Japan and Korea are the only countries outside China that are actively conserving this bird species. Figure 2 displays a picture of the Japanese Crested Ibis.

Currently, movements for these birds' restoration are spreading throughout Japan, following successes in Toyooka and Sado Island. However, a barrier to these movements is the impact of human land use and the built environment. Rapid urbanization in these areas over the last century has had a significant negative effect on biodiversity, resulting in the extinction of valuable flora and fauna from ecosystems. The built environment, which includes human-made infrastructure such as rivers, buildings, roads, and agricultural landscapes, has particularly impacted the natural habitats. Encroachment of the built environment onto natural habitats has led to habitat loss and fragmentation. Additionally, the built environment brings humans and wildlife into closer proximity, increasing the potential for conflicts that further contribute to the extinction of valuable flora and fauna from the ecosystem.

Moreover, the built environment has the potential to negatively impact the overall health of ecosystems, especially with the continuous increase in population and the excessive use of harmful chemicals in agriculture. These factors have resulted in a reduction in biodiversity within ecosystems.

Efforts have been made to reintroduce and conserve these bird species in Japan. By integrating green infrastructure development in the built environment and captive-breeding programs, undertaken by the Ministry of Environment, local governments, and NGOs, have been implemented to restore the populations of the Oriental White Stork and the Japanese Crested Ibis. Successful examples include the Oriental White Stork reintroduction program in the Toyooka basin, Hyogo Prefecture, and the Japanese Crested Ibis reintroduction in Sado Island, Niigata Prefecture.

In Toyooka City, the Oriental White Stork has become a symbol of the region and a biodiversity indicator. The city has implemented captive-breeding and reintroduction programs, along with various initiatives to restore the bird's natural environments, such as alternative and balanced rice farming schemes and the development of ecotourism hotspots. As a result, Toyooka City has become one of the top 100 green destinations in the world, with approximately 270 Oriental White Storks now flying in its skies (Japan Travel, 2022).

In Sado Island, the reintroduction of the Japanese Crested Ibis began as a citizen's movement through voluntary activities. Subsequently, the government provided support for the project, and habitat conservation efforts were initiated. The Ministry of Environment has also planned to introduce the bird to mainland areas and is currently accepting applications for habitat-building projects (Nippon.com, 2022).

In Konosu City, which has recently attempted to reintroduce the Oriental White Stork, collaborative works based on the successful experiences of Toyooka and Sado cities have been initiated. Raising awareness among citizens and farmers, improving the habitat environment, and promoting environmental education and conservation efforts are essential steps in reintroducing the Oriental White Stork to Konosu City.

It is essential to draw lessons from successful conservation projects and engage citizens in habitat conservation activities to ensure the long-term survival of these bird species. The impact of the built environment needs to be mitigated through sustainable land use practices, as well as by increasing public awareness of environmental conservation. Therefore, this study focuses on examining how urban residents can actively support green infrastructure from a regional planning perspective. The aim is to

determine the extent to which residents living in the built environment can positively influence the local natural environment through eco-friendly lifestyles, and how their awareness of such lifestyles can be enhanced through educational activities. This research will contribute to understanding the inseparable relationship between the city's-built environment and the surrounding natural environment, which provides a variety of ecosystem services to the urban setting.

In Japan, the development of green infrastructure holds significant importance in the pursuit of a sustainable society. For instance, the improvement of river infrastructure for flood control and the preservation of agricultural lands with stormwater retention functions are crucial aspects. An example of green infrastructure adopting a hybrid approach with nature restoration efforts can be observed in the Maruyama River, located in Toyooka City, Hyogo Prefecture. As part of flood control measures, wetlands are being created in the riverbed space to restore Oriental White Stork, which is integral to the river cross-section expansion. Additionally, the Watarase Reservoir Area in the Kanto region is an internationally recognized wetland under the Ramsar Convention on Wetlands, serving a flood control function. It is also one of the most significant sites for Oriental White Stork restoration in Japan. Another important consideration is that Storks display relatively low fear of humans. Therefore, there is a desire to develop tourist facilities that enable urban residents to become acquainted with storks in close proximity to the built environment of the city. This approach aims to foster a stronger connection between people and nature, promoting conservation efforts and enhancing public appreciation for these bird species.

2. Literature Review

During the past few decades, numerous studies have been conducted on the extinction, reintroduction, and continuation of conservation programs for bird species. This chapter provides an overview of relevant literature related to this study, emphasizing the importance of the built environment.

Kikuchi (2003) addressed critical issues concerning the conservation of the Oriental White Stork. He emphasized the necessity of raising awareness about the symbiotic relationship between humans and these bird species, dispelling misconceptions that storks trample and steal rice. Kikuchi highlighted that bird conservation encompasses two aspects: the biological protection of Oriental White Storks and the environmental issues that arise from human-bird coexistence. He also noted that the presence of Oriental White Storks promotes an ecological lifestyle that benefits both humans and other creatures in the ecosystem.

Nakajima et al. (2006), Ezaki et al. (2012), and Naito et al. (2007) emphasized the importance of paddy fields and rivers as crucial habitats for the Oriental White Stork. These birds rely on these areas for their diet, which consists of small wetland animals such as fish, frogs, and insects. However, the use of agrochemicals in paddy fields poses a significant threat to their survival as it affects their food sources. Farmers often hesitate to reduce agrochemical usage to support stork regeneration. On this issue, Onuma and Yamamoto (2009) highlighted that adopting pesticide-free farming practices to protect the paddy ecosystem can also bring economic benefits to farmers, positively impacting the regional economy.

Regarding reintroduction activities, Honda (2016) pointed out that citizens in respective areas hold a positive view of the Oriental White Stork. Their acceptance of these birds as environmental assets and regional symbols stems not from economic interests or direct benefits to their daily lives, but rather from an appreciation of their ecological significance.

Honda (2008, 2016) investigated the consciousness of citizens in Toyooka and Sado cities six and ten years after the reintroduction of the Oriental White Stork and Japanese Crested Ibis, respectively. In both cities, a relatively high percentage of the population recognized the importance of practicing environmentally conscious living, such as reducing waste and conserving energy, to successfully reintroduce a natural habitat for these birds.

Ryan et al. (2001) revealed that providing appropriate volunteer programs is essential for sustaining motivation in conservation activities. Additionally, Bruyere and Rappe (2007) identified seven major motivating factors for citizen involvement in environmental conservation through principal component analysis (PCA): helping the environment, learning about the natural environment, socializing with like-minded individuals, expressing personal values, project organization, work experience and career development, and improving areas used by volunteers for recreational purposes. They suggested that developing programs based on these motivating factors can attract a larger number of volunteers and facilitate their engagement in conservation activities.

Measham and Barnett (2008) highlighted six motivations for environmental volunteers and classified volunteer activities into five modes: activism, education, environmental monitoring, natural restoration, and sustainable living. They emphasized the importance of treating volunteers as supporting members rather than ordinary laborers, promoting community education as a vital aspect of environmental volunteer groups.

Liarakou et al. (2011) stated that volunteer activities in environmental conservation are influenced by both external and internal factors. External factors include social and cultural influences and organizational operations, while internal factors include motivation, environmental knowledge, previous experiences, attitudes, and locus of control. Among these, internal factors play a dominant role. The concept of locus of control is particularly useful for understanding the motivation behind activities aimed at revitalizing Oriental White Stork habitats. Liarakou et al. noted that individuals with an internal locus of control are more likely to take action, while those with an external locus of control may feel overwhelmed by the complexity and global scope of environmental issues. To encourage citizens' participation, it is important to cultivate an internal locus of control.

In the conservation activities for the Oriental White Stork and Japanese Crested Ibis, citizen consciousness has been recognized as

a crucial factor for the future (Honda 2008). Consequently, this study focuses on the significance of activities that raise citizens' environmental consciousness to encourage their involvement in conservation efforts. The study examines how general environmental awareness relates to understanding of conservation activities and the willingness to participate in such initiatives. Liarakou et al. (2011) suggest that a combination of various internal motivations serves as the driving force behind actions, such as participating in revitalization activities.

To establish a link between environmentally conscious behavior and awareness of existing environmental problems, this research incorporates three theories and models developed by Hirose in 1994, Tanaka and Joh in 2012, and Bandura in 1977.

2.1 Hirose Model of Environment Conscious Behavior

Yukio Hirose conducted research in 1994 to explore the determinants of environmentally conscious behavior. The study aimed to propose a tentative model of environment-conscious behavior and identify the factors influencing energy and water conservation, recycling, and detergent usage. Hirose's model suggests that there are two phases in the decision-making process of environmentally conscious behavior: "goal intention of a pro-environmental lifestyle" and "behavior intention of environment-conscious behavior." Each phase comprises three factors, as depicted in Figure 3, which presents a general model illustrating the factors and interrelationships between environmentally conscious behavior and its determinants. In this study, the Hirose model of environmentally conscious behavior was adapted to develop the research questionnaire.

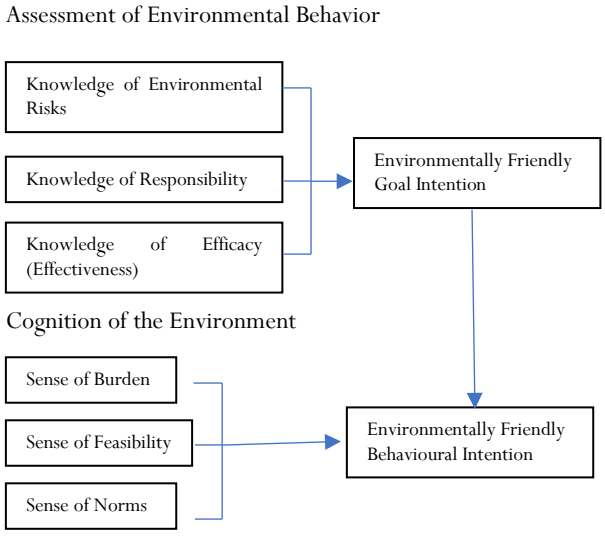

Figure 3 A General Model of Factors and Interrelationships Between Environmentally Conscious Behavior and its Determinants

2.2 Self-Efficacy Theory by Albert Bandura

The self-efficacy theory posits that psychological processes play a role in creating and strengthening expectations of personal efficacy. Efficacy expectations, different from response-outcome expectancies, involve individuals' beliefs in their ability to successfully execute the required behavior to achieve desired outcomes. While outcome expectancies refer to estimates of the consequences of a particular behavior, efficacy expectations focus on individuals' confidence in their own capabilities to perform the necessary activities. Figure 4 illustrates the distinction between outcome and efficacy expectations. In this study, the self-efficacy theory was employed, and 10 factors were selected to develop a new evaluation scale. Based on this scale, a questionnaire was created and used for the field survey in the selected study areas.

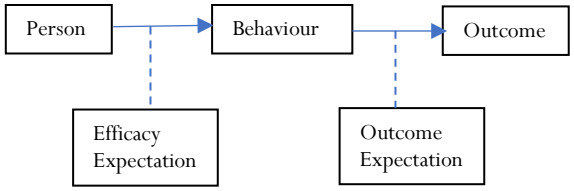

Figure 4 Difference Between Efficacy Expectation and Outcome Expectation

2.3 Ecological Mindset Evaluation Scale by Mikiya Tanaka and Hitoshi Joh

The purpose of this study conducted by Mikiya Tanaka and Hitoshi Joh was to develop an ecological mindset evaluation scale, referred to as the EM scale, to assess the environmental awareness and behavior of the general population. The development of this scale drew upon the revised Human Community Creation Scale (HC Scale) by Moriguci in 2009, the Hirose Model, and Bandura's self-efficacy theory. The EM scale consists of 10 factors, incorporating six factors from the Hirose Model and two factors from Bandura's Self-Efficacy theory. Additionally, two new factors, "Attitude" and "Behavior," were introduced by Tanaka and Joh, replacing the "Environmentally friendly goal intention" and "Environmentally friendly behavioral intention" from the Hirose model.

In this study, the same EM scale was employed to compare the environmentally conscious behavior and its influence on participation in Oriental White Stork conservation efforts across three cities. While successful reintroduction of the Oriental White Stork and Japanese Crested Ibis has already been achieved in the Toyooka Basin and Sado Island, the research aims to learn from these regions and improve awareness and environmental education initiatives in Konosu City. By utilizing insights from these theories and models, the study seeks to contribute to the promotion of sustainable behaviors and increased engagement in the conservation efforts related to these bird species.

3. Methodology

3.1 Study Area

The study was carried out in 3 cities of Japan. They are Toyooka, Sado and Konosu cities. Figure 5 displays the locations of these selected areas.

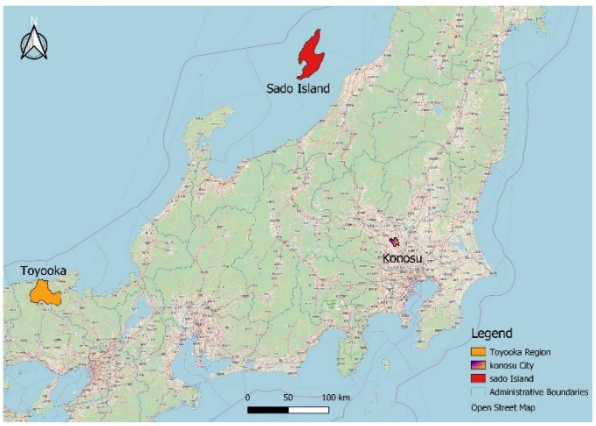

Figure 5 Study Area
Source: Prepared by Author

Toyooka is located in Northern part of Hyogo prefecture. The city has an estimated population of 78 348. The total area of the city is 697.55 km^2 (Toyooka city official statistics, 2022). Sado island is located in Niigata prefecture. It is an island with 854.8 km^2. Konosu is a city in Saitama prefecture. The city has an estimated population of 117 99. The total area of the city is 67.44 km^2 (GIS/National Land Information, 2014).

3.2 Method

3.2.1 The Ecological Mind Evaluation Scale

The Ecological Mind Evaluation Scale (EM Scale) developed by Tanaka and Joh (2012) based on the model and theory by Hirose (1994) and Bandura (1977) which were explained under literature chapter was applied in this research. This evaluation scale has 10 factors. Table 1 displays the EM scale with evaluation groups and the factors under each group.

Table 1: Modified EM Evaluation Scale

Evaluation Group	Factors	Theory referred
Environmental Awareness	Effectiveness	Based on Hirose Model (1994)
	Sense of risk	
	Sense of responsibility	
Behavioural Evaluation	Sense of burden	
	Sense of feasibility	
	Sense of norms	
Environmental Consciousness and Environmental Conscious Behavior	Attitude	Based on Hirose Model these two factors were redefined by Tanaka and Joh (2012)
	Behaviour	
Self-Efficacy	Efficacy expectation	Based on Self Efficacy theory explained by Bandura (1977)
	Outcome expectation	

3.2.2 Developing the Questionnaire

The purpose of this research is to see how people educationally understand the relationship between general environmental issues and habitat conservation. Using the EM evaluation scale, 30 questions were set covering three types of environmental issues; household wastewater management, solid waste disposal mechanisms, and energy conservation. These environmental issues were selected since they mainly affect the quality of environment causing threat to the biodiversity of the study areas. The questions were made to find out the degree of interest in the participation of endangered bird protection activities, as well as their intentions to purchase rice grown in Oriental White Stork-friendly paddy fields. These questions implied the thoughts and behaviour of citizens related to protection efforts of Oriental White Stork and Japanese Crested Ibis. However, the survey questions intentionally avoided directly asking questions about environmental consciousness on biodiversity, which was the goal of this research.

In terms of questions regarding protection efforts for the Oriental White Stork and Japanese Crested Ibis, four questions were set to understand the participants'
1.degree of interest in conservation activities,
2. support for the said activities,
3. intention to purchase farming products that support these activities, and
4. intention to participate in these activities.

Altogether, there were 34 questions in the questionnaire sheet to study about the citizens' awareness on the reintroduction of these bird species and their general awareness on the environmental issues.

3.2.3 Conducting the Survey

The developed questionnaire was used to undertake the survey in the selected 3 study sites. The purpose of the survey was to analyse the citizens' awareness on the reintroduction of these bird species and their general awareness on the environmental issues. Based on their responses, the relationship between their awareness about general environmental issues, the influence of said awareness on protection activities, and the increase of the Oriental White Stork and Japanese Crested Ibis populations in Sado, Toyooka, and Konosu was analysed. Survey distribution, collection, and dates are displayed in Table 2.

Table 2: Details of Questionnaire Survey

	No. of Questionnaire Distributed	No. of Questionnaire Collected	% Collected	Date
Toyooka	500	343	68.6	Dec.14-Dec.16, 2012
Sado	500	224	44.8	Jan.16-Jan.18, 2013
Konosu	500	237	47.4	Feb.1-Feb.4,2013

3.2.4 Factor Analysis

Factor analysis was conducted to analyze the EM evaluation scale, and the corresponding factor values can be found in Table 3. The EM model posits that ten distinct factors influence four evaluation group variables: environmental awareness, attitude towards environmental conservation, environmental consciousness, and self-efficacy. The questionnaire consisted of 30 observed variables related to perceptions and attitudes towards environmental issues. The aim of the factor analysis was to demonstrate that these observed variables align with the ten hypothesized factors in the model. Specifically, the analysis aimed to calculate ten factor scores to compare residents' attitudes across the three study sites.

Separate factor analyses were conducted for each of the four evaluation groups. Based on the model's hypotheses, three factors were specified for Environmental Awareness, three factors for Behavioral Evaluation, two factors for Environmental Consciousness and Environmental Awareness combined, and two factors for Self-efficacy.

The decision to extract the factors of the model as latent factors, rather than directly observed variables, was motivated by the need to validate the model. Given that the questionnaire was targeted at the general public, it was believed that using straightforward, everyday questions to explore whether latent factors are commonly manifested in relation to perceptions of various environmental issues (such as water quality, waste problems, and energy problems) would be more appropriate than directly addressing latent factors.

Factor analysis was performed using the varimax method, utilizing a sample data set comprising 686 valid responses from the three study sites. Observed variables with low commonality were excluded from the analysis. The Kaiser-Meyer-Olkin (KMO) values for the four factor analyses were 0.82 for Environmental Awareness, 0.73 for Behavioral Evaluation, 0.81 for Environmental Consciousness and Environmental Awareness combined, and 0.80 for Self-efficacy. These KMO values indicate that the sampling was adequate.

To compare the three study sites, factor scores of ten were computed for each of the four evaluation groups, as specified by the model. The factor scores for each subject were then averaged within the three study sites to obtain means. These means were subsequently examined for significant differences through an analysis of variance.

Table 3: Sample Questions of Modified EM Evaluation Scale and Their Factor Values

Criteria	No.	Questions	Factor 1	Factor 2	Factor 3
			Effectiveness (Efficacy)	**Sense of Risk**	**Sense of Responsibility**
Environmental Awareness	Q13	Influence of the lifestyle to increase waste generation in the future.	-0.15	-0.58	0.10
	Q15	Even if the ocean and rivers are polluted, it won't have an impact on me.	-0.18	-0.74	0.09
	Q20	Turning off the lights at home won't have much of an effect on the environment.	-0.35	-0.57	0.07
	Q22	Energy conservation is more effective at commercial facilities (convenience stores, supermarkets, etc.) than at residences.	-0.43	-0.10	0.34
	Q26	Consumers who buy and use products are not responsible for the increase in waste.	-0.40	-0.13	0.17
	Q27	I don't think household wastewater purification will help local streams to be clean.	-0.69	-0.25	0.15
	Q29	I don't think my personal effort to decrease waste will protect the environment.	-0.63	-0.29	0.08
	Q24	Industrial wastewater is more responsible for local river pollution than general household wastewater.	-0.26	-0.14	0.96
Contribution rate			18.34	17.59	13.83
			Factor 4	**Factor 5**	**Factor 6**
			Sense of burden	**Sense of feasibility**	**Sense of social norms**
Behavioral Evaluation	Q16	Energy conservation won't become effective because there are few methods for it.	-0.76	-0.25	-0.01
	Q17	Awareness of energy savings at home is annoying even it lowers my electricity bill.	-0.73	-0.22	-0.03

	Q25	It's annoying to wash high-waste products such as mayonnaise every time after using them.	-0.31	-0.28	0.19
	Q21	It is difficult to cooperate in the household wastewater purification, because I don't know how to properly dispose cooking waste and leftover food.	-0.19	-0.43	0.03
	Q23	Recycling paper at home is difficult because I have nowhere to store it.	-0.15	-0.73	-0.01
	Q28	Collecting and taking out empty cans and packing paper for recycling is annoying.	-0.40	-0.49	0.15
	Q10	I think families consider their kitchen and laundry household waste.	-0.13	-0.04	0.79
	Q18	I think families want to save energy used at home.	0.10	0.06	0.38
	Q30	Recycling resource waste by families or neighbors is a positive thing.	-0.07	-0.14	0.31
	Q11	With the development of new natural energy, we will not run out of energy in the future.			
Contribution rate			16.24	13.04	10.23
			Factor 7	**Factor 8**	
			Attitude	**Behavior**	
Environmental consciousness and environmentally conscious behavior	Q12	I want to keep energy conservation in mind in my daily life for the future because of energy problems.	-0.63	-0.28	—
	Q14	If local municipalities develop purification plans for household waste, I want to help.	-0.57	-0.23	—
	Q19	I want to try my best to reduce waste.	-0.57	-0.26	—
	Q7	To protect river water, I come up with new ways to cook and do laundry.	-0.21	-0.53	—
	Q8	I refuse excess packaging at convenience stores and department stores.	-0.24	-0.56	—
	Q9	I think of the environment when buying electronics and choose energy-saving models.	-0.31	-0.59	—
Contribution rate			20.73	19.17	—
			Factor 9	**Factor 10**	
			Efficacy expectations	**Outcome expectations**	—
Self-efficacy	Q4	I'm aware of the environment in my daily life and can frequently turn off lights in my home.	-0.63	-0.20	—
	Q5	I think of the environment and can try not to create more waste.	-0.79	-0.28	—
	Q6	I can properly and thoroughly dispose of cooking oil by wiping it up, etc.	-0.55	-0.24	—
	Q1	I can reduce my electric bill by buying energy-saving appliances.	-0.19	-0.57	—
	Q2	I can reduce the labor required by not buying disposable products and reducing waste.	-0.32	-0.61	—
	Q3	I can protect local rivers by purification of household wastewater from the kitchen and laundry.	-0.21	-0.69	—
Contribution rate			24.98	22.41	—

4. Results

4.1 Survey Results on the Awareness of Oriental White Stork and Japanese Crested Ibis Protection Activity

(1) Degree of interest

The degree of interest was particularly high in Toyooka, followed by Sado and Konosu, (Figure 6). Negative answers such as "Not very interested" and "No interest" constituted 20% of all responses in Konosu, however, such responses were extremely low in Toyooka and Sado.

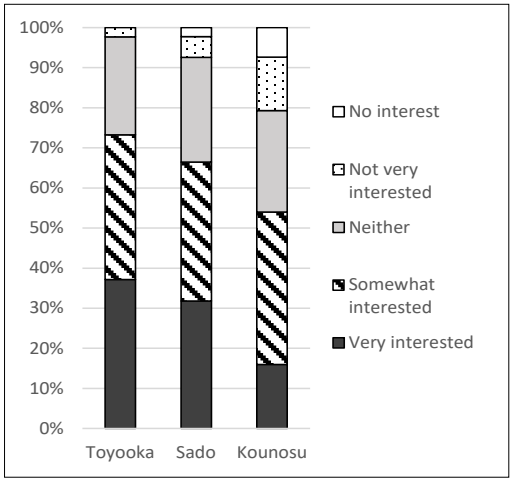

Figure 6 Interest on Oriental White Stork and Japanese Crested Ibis Reintroduction Activities

(2) Degree of support

All three cities demonstrated a high degree of support (Figure 7). The value was higher than the positive responses for the degree of interest. Comparatively, many respondents in Sado and Konosu answered, "Neither." Although few people in Sado are unaware of the Japanese Crested Ibis, many citizens of Konosu are unaware of activities supporting the Oriental White Stork

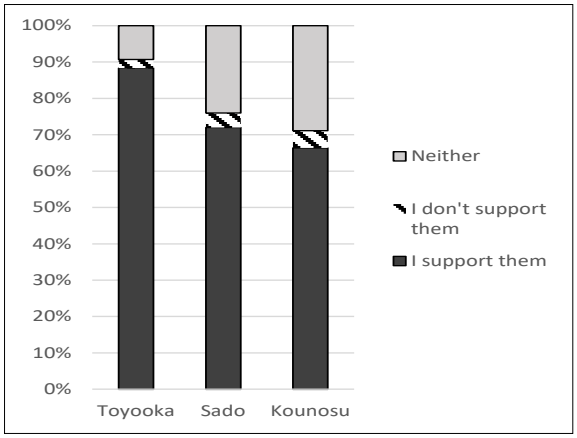

Figure 7 Degree of Support of Oriental White Stork/Japanese Crested Ibis Reintroduction Activities in the Three Cities.

(3) Consumption of Ecofriendly Agricultural Products

Regarding the purchase of agricultural products from farmlands which support Oriental White Stork protection, Toyooka had the highest purchase rate, followed by Sado and Konosu (Figure 8). Compared to Toyooka and Sado, only a few people in Konosu had previously purchased these products. This could be due to the low distribution of Oriental White Stork-friendly rice in this area. However, when counting the number of people who want to purchase said products, However, when considering the number of residents who wanted to try these products, the corporative awareness was same in all three cities.

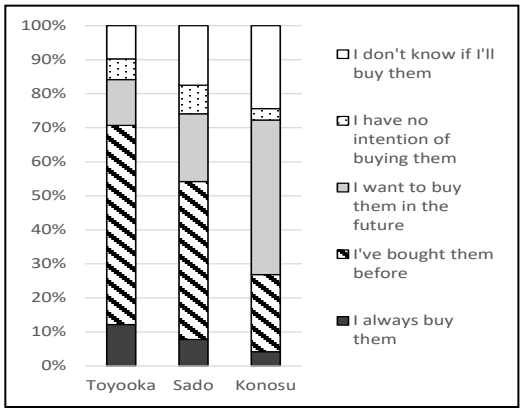

Figure 8 Consumption of Eco-friendly Agricultural Products in three Cities

(4) Degree of Participation in Conservation Activities

Toyooka had the highest degree of participation in conservation activities, followed by Sado and Konosu (Figure 9) A few respondents in Konosu had previously participated in said activities, and the city continues to lag behind in terms of substantial conservation activities. the survey did not inquire about the frequency of participation, however, fewer respondents had practical experience with participation in these activities than those who had purchased environmentally friendly agricultural products.

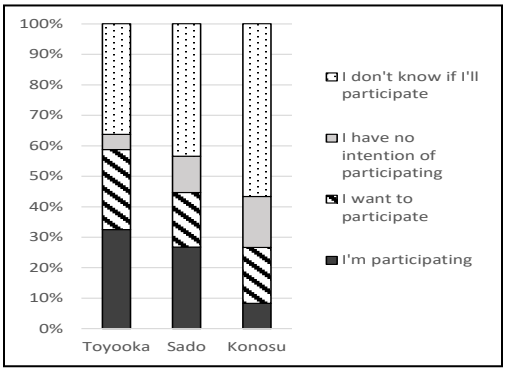

Figure 9 Degree of Participation in Conservation Activities

4.2 EM Evaluation Scale Analysis Results

The valid responses collected from Toyooka, Sado and Konosu for the factor analysis were 267, 192 and 227 respectively. The results of the factor analysis were displayed in table 3. To compare the three cities, their factor score average values were utilized. In terms of Oriental White Stork and Japanese Crested Ibis habitat conservation, the influence of local government and environmental group activities upon public awareness, attitudes, and activities had to be clarified; thus, the data from city residents were only taken into consideration. Respondent samples included 87 people in Toyooka, 178 people in Sado, and 152 people in Konosu. Comparison of the factor score average value of those respondents was conducted on each factor within four categories: environmental awareness, attitude towards environmental conservation, environmental consciousness, and self-efficacy. The difference between means of three sites was tested by ANOVA. No significant differences were found in sense of responsibility (environmental awareness, Figure10) and outcome expectation (self-efficacy, Figure 11).

- **Environmental Awareness**

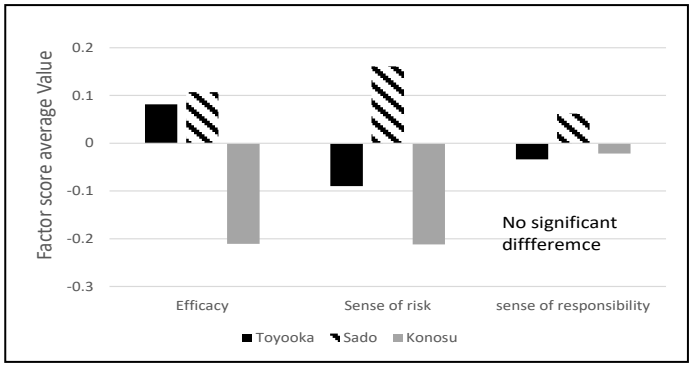

Figure 10 Factor Score for Environmental Awareness

With a cumulative contribution rate of 49.76%, the explanation of the three factors is considered valid. The sense of effectiveness and environmental risk among the three cities, Toyooka, Sado, and Konosu, exhibited a statistically significant difference ($\alpha<.001$). However, the sense of responsibility did not display a significant difference ($\alpha=.660$). Toyooka and Sado had a comparatively high value for efficacy, but Konosu had a comparatively low trend ($\alpha<.001$). Sado had the highest sense of environmental risk, Toyooka had a comparatively low trend, and Konosu had the lowest sense of risk (Figure 8).

- **Behavioural Evaluation**

Three factors had a cumulative contribution rate of 39.51%, and only those three factors had a low value (Figure 9).

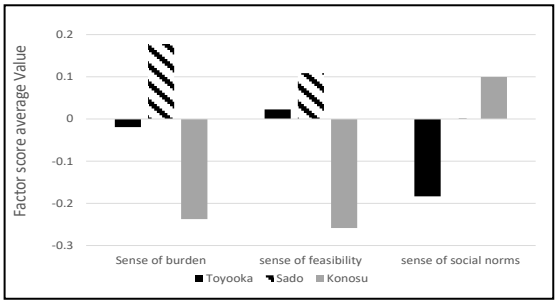

Figure 11 Factor Score for Attitude Towards Environmental Conservation

The sense of burden, feasibility, and social norms in the three cities, Toyooka, Sado, and Konosu exhibited a statistically significant difference ($\alpha<.001$, $\alpha=.046$ (social norms)). Sado had the lowest sense of burden, Konosu had the highest sense of burden, and Toyooka lays between the two. Sado tended to have a high sense of feasibility compared to Toyooka and Konosu. Toyooka had a particularly low sense of social norms. Sado, however, had an average sense of social norms. Konosu had a comparatively high value, indicating that local families and neighbours have a strong tendency to consider the environment when conducting their daily lives. In Konosu, environmental public awareness activities such as eco-friendly lives and related social norms have begun to take root. In Toyooka, the sense of social norms is low, which demonstrates that Toyooka is not trying to mirror environmental ethics from other societies in terms of their awareness of environmental protection.

- **Environmental Consciousness and Environmental Conscious Behavior**

Two factors had a relatively low value and a cumulative contribution rate of 39.90%, The semantic compositions of the two factors followed the hypotheses and were validated (Figure 12)

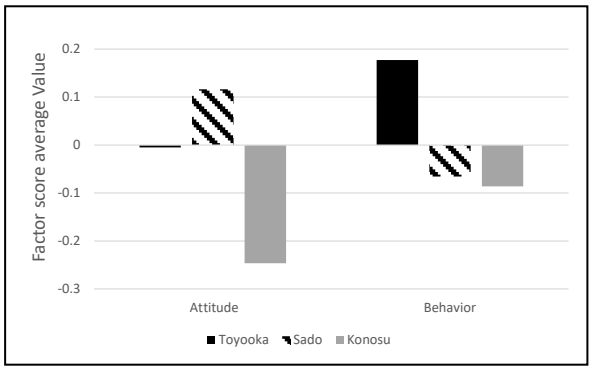

Figure 12 Factor Score Environmental Consciousness

Environmental consciousness in Toyooka, Sado, and Konosu were significantly different ($\alpha<.001$, $\alpha=.013$). Sado had a comparatively high level of environmental consciousness, but Toyooka had a highest level of environmental conscious behaviour. In Toyooka, strong expectations and belief in

environmentally conscious behaviour were demonstrated. Although environmental consciousness was high in Sado, said behaviour was noticeably lower than in Toyooka

- **Self-Efficacy**

Two factors had a cumulative contribution rate of 47.40% and were considered generally valid. The semantic compositions of the two factors followed the hypotheses and were validated (Figure 13)

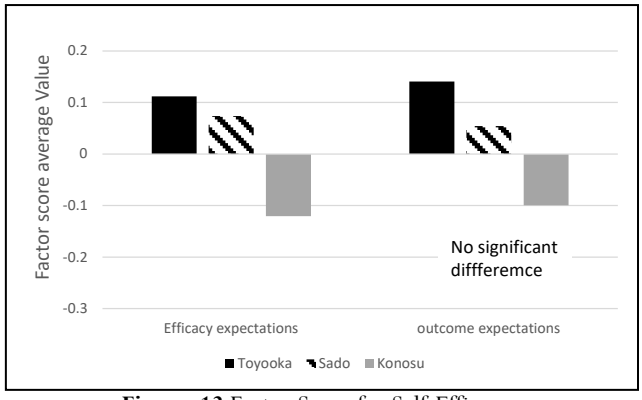

Figure 13 Factor Score for Self-Efficacy

Efficacy expectations were significantly different in the three cities (α=.041). They were slightly higher in Toyooka than in Sado, while Konosu tended to have lower efficacy expectations than the other two cities. No significant difference was determined for outcome expectations (α=.066), but Toyooka had a higher average value than Sado, and Konosu tended to be the lowest.

5. Discussion

5.1 Comparison of Awareness in Three Cities on Activities to Protect the Oriental White Stork and Japanese Crested Ibis

(1) Interest and support

When comparing the results of degree of interest and support, all three cities produced a high number of affirmative responses in terms of support. The increase of societal interest in environmental issues and the sense of social norms likely influenced these results, and some responses may have included support that does not involve any direct personal change. In the future, rather than focusing on people with negative views towards environmental conservation efforts, the majority of people who answered affirmatively should be targeted, and plans to create new activities with high participation should be investigated.

(2) Purchase of Agricultural Products And Participation In Activities

Both Toyooka and Sado had a high number of people who had purchased environmentally friendly agricultural products, but Konosu had half the number of people who had done so. However, when including the number of residents who wanted to try these products, the cooperative awareness was the same in all three cities. The availability of environmentally friendly agricultural products remains low in Konosu; thus, increasing the supply of these products will likely improve results. However, the percentage of people who continually purchased environmentally friendly agricultural products was low as 10% in Toyooka and Sado. These products cost more than generic rice, and the desire to contribute may be satisfied by one-time purchase. Thus, purchasing these products may be the first step towards public participation in conservation activities, it is also important to expand the range of environmentally friendly agricultural products, meet the needs of consumers, and develop ways to add value in order to allow the continuous purchase of these expensive products.

5.2 Comparison of Environmental Awareness among Three Cities based on the EM Evaluation Scale

Sado scored high in sense of efficacy and sense of risk under environmental awareness. Although Toyooka scored high for sense of efficacy, it scored low for sense of risk. Although there was no significant difference, Sado had the highest average value for sense of responsibility. Konosu had low scores for all items, and there was a particularly large gap in its sense of efficacy and sense of risk compared to Toyooka. This is probably due to the level of understanding of environmental issues provided by education, as evidenced by the high awareness in Sado due to comprehensive environmental action plans and their sense of environmental risk. Konosu is conducting public awareness activities such as Ecolife Day, but plans are necessary to deepen the understanding of the importance and effectiveness of daily energy conservation and solid and liquid waste disposal.

The questions regarding attitudes towards environmental conservation Sado exhibited a high value for sense of burden and sense of feasibility, Toyooka an average level, and Konosu a very low value. The results in Sado indicate a high awareness of both environmental issues and personal standards. Interestingly, Konosu exhibited a strong sense of social norms, while Toyooka had a very low value. Social norms involve rules set by society or people aside from oneself, which appear in the form of pressure to form ethical attitudes regarding environmental issues. Environmental awareness activities may have increased such awareness in Konosu. There is no clear reason why Toyooka has a low sense of social norms when there is a high degree of awareness of Oriental White Stork conservation activities, but in terms of environmental initiatives, the behaviours caused by these attitudes are unlikely to have been instigated by outside rules.

The self-efficacy results demonstrated that, in terms of environmental awareness and attitude towards environmental conservation, Sado's awareness was high, but contrary to "efficacy expectations," Toyooka had a higher value. Although there was no significant difference, Toyooka had a high average

value among the outcome expectations. A striking difference in environmental consciousness and environmentally conscious behaviour was found between Sado and Toyooka. Environmental consciousness was high in Sado, while environmentally conscious behaviour was particularly high in Toyooka. Konosu exhibited low values for both categories. When comprehensively comparing Sado and Toyooka, Sado displays more awareness, while Toyooka displays more behaviour. In Sado, in terms of environmental awareness and attitude towards environmental conservation, focus upon the level of recognition of personal ethics and environment is high. Konosu had a relatively low score compared to Toyooka and Sado, but it is also characterised by a high sense of social norms within the behavioural evaluation.

It is important to make awareness programs on green infrastructure development with the urbanization in such sensitive areas. Green infrastructure, which includes natural and semi-natural areas with environmental features, plays a vital role in preserving biodiversity, maintaining the natural environment, and improving the health of citizens (Biodiversity, 2023). Therefore, in order to reintroduce and preserve these two species of birds, it is crucial to prioritize the development of green infrastructure in urban areas.

One of the barriers to effectively integrating green infrastructure with the built environment is the limited understanding of ecosystems and the benefits of green infrastructure. Many people may not be aware of the positive impact that green spaces can have on the environment and their own well-being. Additionally, poor spatial planning regulations and conflicts between economic development and environmental preservation can hinder the successful integration of green infrastructure (Biodiversity, 2023).

To address these challenges and promote the conservation of the Oriental White Stork and Japanese Crested Ibis, it is essential to conduct a series of awareness programs in the selected study areas. These programs should aim to educate the local communities about the value of green infrastructure development and its significance in protecting these bird species. By raising awareness about the benefits of green infrastructure, such as enhancing biodiversity, improving air and water quality, and providing recreational opportunities, residents can become active participants in conservation efforts.

Furthermore, the awareness programs should emphasize the importance of proper spatial planning and the need to balance economic development with environmental considerations. By promoting sustainable development practices and demonstrating how green infrastructure can coexist with urbanization, it is possible to overcome conflicts between economic growth and the preservation of natural habitats.

Overall, raising awareness about green infrastructure development and its role in protecting the Oriental White Stork and Japanese Crested Ibis is crucial for their conservation. By conducting targeted awareness programs and addressing barriers such as limited understanding, lack of awareness, and conflicts, it is possible to foster a sense of responsibility and engagement among residents, ultimately contributing to the long-term preservation of these bird species in urban environments.

5.3 Relationship between Environmental Awareness and Awareness of Habitat Conservation Activities based on the EM Evaluation Scale

The relative gap between the three cities was confirmed via the EM evaluation scale for environmental awareness and awareness on conservation activities and initiatives. In terms of the degree of interest in conservation initiatives, degree of support for them, purchasing environmentally friendly agricultural products, and awareness to participate in conservation activities, the evaluation score for all categories from highest to lowest, was Toyooka, Sado, and Konosu. Several items among the three cities had differing trends in their evaluation levels according to the EM evaluation scale. Konosu exhibited several low EM evaluation scale levels and had a low awareness of conservation efforts.

Toyooka had a higher level of awareness than Sado. Sado had high values for environmental awareness, attitude towards environmental conservation, and environmental consciousness, however, Toyooka had the highest level of self-efficacy and environmental consciousness than Sado or Konosu. Social norms, self-awareness, self-efficacy and environmentally conscious behaviour are important for encouraging participation in Oriental White Stork and Japanese Crested Ibis conservation efforts.

Habitats for Oriental White Stork and Japanese Crested Ibis can currently be found in both Toyooka and Sado. In Toyooka the Oriental White Stork can be seen frequently. According to Honda (2016), the observation of the Oriental White Stork is connected to positive recognition of reintroduction projects. By creating an environment that allows residents to reap the benefits of conservation activities in their daily lives, locals realise that their efforts to protect these birds are not a waste, which is connected to the improve their sense of self-efficacy.

Although such efforts have been commenced in Konosu, yet there are no improvements on captive breeding (stork breeding has initiated from 2022.) or the release of the Oriental White Stork to the wild, and there are few reports of these Storks are flying in the city. In order to receive continuous support for Oriental White Stork habitat conservation activities from residents, plans are required to raise their sense of self-efficacy. Because Konosu residents have a high level of awareness of social norms related to environmental issues, however, it is not sufficient to raise awareness of conservation efforts. In terms of Oriental White Stork habitat conservation, it is required to foster more participation in support activities, and give more educational opportunities describing the purpose of conservation, to the citizens of the area.

6. Conclusion

This research study attempted to clarify the psychological mechanism by which people are motivated to engage in environmental conservation activities to protect the Oriental White Stork and Japanese Crested Ibis. The study was conducted

mainly based on the questionnaire surveys carried out in the selected three cities, Toyooka, Sado and Konosu. The questionnaire was prepared based on the EM Evaluation scale which was developed by Tanaka and Joh. The questionnaire had 34 questions covering four major sections; environmental awareness, attitude towards environmental conservation, environmental consciousness and self-efficacy. The questions basically focussed on energy conservation, solid waste disposal mechanisms and liquid waste disposal mechanisms and it was found that there are significantly different attitudes among people in Toyooka, Sado, and Konosu.

Toyooka exhibited a high level of awareness regarding the Oriental White Stork and Japanese Crested Ibis habitat conservation efforts. In Toyooka, the municipal government plays a leading role in conducting initiatives for facility maintenance, agriculture, tourism, and education. These initiatives have allowed residents to see the results of Oriental White Stork projects in their daily lives, which fosters sympathy. According to Honda (2008), Oriental White Stork was originally a local bird in Toyooka, and that information has triggered the reintroduction of these Storks to the Toyooka as a "local bird".
City residents can support habitat conservation efforts such as canal dredging, weeding, and pesticide-free/chemical-fertiliser-free farming methods simply by purchasing the eco-friendly rice. Social norms are not only a source of pressure from others to personally contribute, but also connect the desire to protect Stork habitat to protect their living environment, which is an important factor of self-awareness and environmental awareness. The EM evaluation analysis for Toyooka residents demonstrated a low sense of risk, low environmental awareness, and low attitude towards environmental conservation, however, the self-efficacy and the environmental consciousness were high, indicating a connection to their high awareness of conservation efforts.

In Sado, resident associations and the municipal government are cooperating in Japanese Crested Ibis captive breeding, wild breeding initiatives, and habitat preservation activities. Moreover, these activities are helpful to expand the number of participating residents in such activities. EM evaluation analysis for Sado residents found high score for the environmental awareness, attitude towards environmental conservation, and for environmental consciousness. However, the sense of self-efficacy was not higher as in Toyooka. Thus, future studies should investigate plans to increase residents' desire to personally contribute to these activities.

However, Konosu displays a lower score for most of the EM evaluation scale factors showing that Konosu is still at the initial stage of awareness about the endangered bird species and the knowledge about the value of protecting them by adopting eco-friendly lifestyles. Thus, it is required to pay a high attention to Konosu city to create eco-friendly lifestyles there in order to create safe environment to the endangered bird species by considering the lifestyles and other bird promotion campaigns in Toyooka and Sado regions.

There were such initiatives at the past, for example, in 2017, Konosu established the eco-change point system: As city residents participate in environmental conservation activities such as local clean-up events, depending on their contribution to such activities, they were entered into a lottery to receive rice. The municipality uses town planning funds to purchase eco-friendly rice from farmers who are supporting Oriental White Stork conversation efforts, which means that city residents indirectly support farmers by participating in conservation activities.

Thus, this study investigated the relationship between regional awareness on the Oriental White Stork and Japanese Crested Ibis habitat conservation efforts and general environmental awareness of city residents in their daily lives. The findings of this study highlight the importance of green infrastructure development as a key factor in protecting biodiversity and endangered flora and fauna. Green infrastructure encompasses the blue and green components in land use, providing crucial habitats for various species. However, with the process of urbanization, green spaces are gradually being encroached upon by brown and grey land use components, resulting in a decline in biodiversity and disrupting the balance of ecosystems. Therefore, it is imperative to prioritize the built environment to ensure the protection of wildlife species like the Oriental White Stork and Japanese Crested Ibis on Earth. Moreover, this research reveals that citizen engagement in eco-friendly lifestyles can significantly contribute to the conservation of habitats for the Oriental White Stork and Japanese Crested Ibis. By adopting sustainable practices and making conscious choices in their daily lives, individuals can play an active role in preserving the natural environments necessary for these bird species to thrive.

By emphasizing the importance of green infrastructure development, this study underscores the need for concerted efforts to create a harmonious balance between urbanization and the preservation of biodiversity. It is crucial to raise awareness among city residents about the significance of green spaces and the role they play in supporting diverse ecosystems and protecting endangered species. By promoting a deeper understanding of the benefits of green infrastructure, citizens can be encouraged to participate in conservation activities and take steps towards sustainable living.

This research contributed to understand the psychological mechanism hidden beneath the general answers on consciousness and attitudes towards environmental conservation by applying the modified EM evaluation scale. Further researches are required in terms of developing the regional conservation strategy, considering residents' participation with their intrinsic mindsets.

In conclusion, this study highlights the interplay between regional awareness of habitat conservation efforts for the Oriental White Stork and Japanese Crested Ibis and general environmental awareness in urban areas. The development of green infrastructure stands as a vital strategy to protect biodiversity and preserve the habitats of these bird species. By fostering citizen engagement and promoting eco-friendly lifestyles, individuals can actively contribute to the conservation and restoration of their natural environment, ensuring the long-term survival of these iconic birds.

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References

Bandura, A. (1977). Self-efficacy: Toward a Unifying Theory of Behavioral Change. Psychological Review, 84(2): 191-215.

BirdLife International. (2018). Nipponia nippon. IUCN Red List of Threatened Species. Retrieved from https://doi.org/10.2305/IUCN.UK.2018-2.RLTS.T22697548A132069229.en Retrieved Date: March 2nd 2023

Bruyere, B., & Silas, R. (2007). Identifying the Motivations of Environmental Volunteers. *Journal of Environmental Planning and Management,* 50(4):503-516. doi:10.1080/09640560701402034

Dunning, J. B. (Ed.). (1992). CRC Handbook of Avian Body Masses. CRC Press. ISBN 978-0-8493-4258-5

Ezaki, Y. (2012). Reintroduction of the Oriental White Stork Ciconia biyciana aiming at Reconstructing its Meta-population Structure in Japan. Reintroduction, 2: 3-10. (In Japanese)

Hirose, Y. (1994). Determinants of Environment-conscious Behavior. Japanese Journal of Social Psychology, 10(1):44-45. (In Japanese)

Hirose, Y., & Ohtomo, S. (2007). The Dual-Process of Reactive and Intentional Decision-Making Involved in Eco-Friendly Behavior. *Journal of Environmental Psychology*, 27: 117-125. doi:10.1016/j.jenvp.2007.01.005

Honda, Y. (2008). Considering Symbiosis with the Wild Reintroduced Stork from 'Being-fortified Symbiosis' to 'local things.' Harajuku (Genjinsya) June 2008. (In Japanese)

Honda, Y. (2015). Residents' Consciousness on the Wild Reintroduction of Japanese Crested Ibis after 6 Years of Release of Birds, Questionnaire Survey throughout Sado City. *Memoirs of Taisho University*, 100: 259-290. March 2015. (In Japanese)

Honda, Y. (2016). Concerning Residents' Consciousness on the Stork's Return to the Wild after 10 Years since its First Release in Toyooka City, Hyogo Prefecture. Memoirs of Taisho University, 101:210-223. March 2016. (In Japanese)

Ministry of Foreign Affairs, Japan. (2023) Japan Atlas Nature. from https://web-japan.org/atlas/nature/nat19.html Retrieved January 2023

Japan National Tourism Organization, United Kingdom (2023) JJapan Endless Discovery. from https://www.japan.travel/en/japans-local-treasures/oriental-white-storks-toyooka-2022/ Retrieved January 2023

Kikuchi, N. (2003). A Study of the Relationship between Local People and the Oriental White Stork in the Tajima District, Hyogo Prefecture - Reviewing the Terms 'Tsuru' and 'Kounotori.' *Journal of Environmental Sociology*, 9: 153-170. October 2003. (In Japanese)

Liarakou, G., Kotroni, E., & Gotsis, C. (2011). Environmental Volunteers: Factors Influencing their Involvement in Environmental Action. *Environmental Education Research,* 17(5): 651-673. doi:10.1080/13504622.2011.572159

Measham, T. G., & Barnett, G. B. (2007). Environmental Volunteering: Motivations, Modes and Outcomes. *Australian Geographer*, 39(4):537-552. doi:10.1080/00049180802419237

Mie, A. (2012). Efforts to save Japanese crested ibis take flight. Japan Times.

Ministry of Environment, Government of Japan. (2009). from https://www.env.go.jp/en/ Retrieved August 2009

Moriguchi, R., Higata, A., Oyamada, Y., Saito, S., Joh, H. (2009). Development of Revised Version of Human and Community Development Mindset Scale. Bulletin of the Graduate School of Human Development and Environment, Kobe University. 3(1)

Naito, K., & Ito, H. (2007). Habitat restoration for the reintroduction of Oriental white storks. *Global Environmental Research,* 11(2): 217.

Nakajima, T., Ezaki, Y., Nakagami, Y., & Osako, Y. (2006). Relative Value of Paddy Fields and Rivers as Foraging Habitats at an Oriental White Stork Reintroduction Site. *Japanese Journal of Conservation Ecology,* 11(1):35-42. June 2006. (In Japanese)

Konishi Yo (2022). Nippon.com. Retrieved May 2022 from https://www.nippon.com/en/japan-topics/g02153/

Official website of the Geospatial Information Authority of Japan. (2014). GIS/National Land Information. 2014 National Area Survey by Prefectures and Municipalities (PDF). Retrieved January 2023.

Onuma, A., & Yamamoto, M. (2009). Economic Analysis of Returning the White Storks to the Wild in Toyooka City, Hyogo Prefecture: Economic Rationale for Adopting White Stork Friendly Farming Method and the Effect of Returning the White Storks to the Wild on the Local Economy. *Keio Journal of Economics,* 102(2): 191(3)-211(23). July 2009. (In Japanese)

Ryan, R. L., Kaplan, R., & Grese, R. E. (2001). Predicting Volunteer Commitment in Environmental Stewardship Programs. *Journal of Environmental Planning and Management,* 44(5): 629-648. doi:10.1080/09640560120079948

Tanaka, M., & Joh, H. (2012). Development of Ecological Mindset Scale for Living Environment. *Bulletin of Graduate School of Human Development and Environment*, 4(1): 187-191. November 2012. (In Japanese) Kobe University,

The Japan Times. (2022). Modern phoenix: The bird brought back from extinction in Japan. Retrieved June 2022 from https://www.japantimes.co.jp/life/2022/06/29/general/sado-toki-birds-conservation/

Toyooka City Global Site. (2022). About Toyooka. Retrieved December 2022 from https://toyooka-city.jp/about-toyooka/

Toyooka City Global Site. (2023). The restoration and preservation of the Konotori. Retrieved January 2023 from https://toyooka-city.jp/stork-initiative/

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An Examination of Mass Housing Residents' Satisfaction with Social Sustainability

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ABSTRACT

With an increased demand for housing, mass housing focuses on speed and economic benefit and standardizes. Different user groups cannot find answers to some of their physical and social needs in this housing and its surroundings. This circumstance generates socially unsustainable regions. From this point of view, the study seeks answers to the questions "What is the social sustainability satisfaction level of the users?" and "Is there a statistically significant difference between the social sustainability satisfaction levels and the different characteristics of the users in the existing mass housing areas?" So, the study reveals the criteria necessary for ensuring social sustainability, defines the level of satisfaction with the fulfillment of these criteria, and determines the statistical difference in satisfaction based on resident characteristics. The link between housing and social sustainability was evaluated using the criteria of social equity and sustainability of community. 87 residents filled out the questionnaire form in a mass housing complex in Istanbul. Researchers used descriptive statistics, the Mann Whitney-U, and the Kruskal-Walis tests to define the statistical difference between social sustainability parameters and the demographic characteristics of the residents. The analysis revealed that inclusion and spatial diversity satisfaction on the housing scale were at the highest level and satisfaction with the Participation criteria was at the lowest level in ensuring social sustainability. The results of the Mann-Whitney U and Kruskal-Wallis tests are as follows: The spatial diversity satisfaction differed in terms of education, economic status, housing type, and length of residence; the social diversity satisfaction differed in terms of gender and age; and the accessibility sub-criterion differed in terms of gender. Only social interaction satisfaction differed by gender, education, and employment status among the sustainability of community criteria. The satisfaction of inclusion, security, community stability, sense of place, and participation were unaffected by demographic characteristics.

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1. Introduction

Housing is the most significant and prevalent building type in the built environment. Many natural, environmental, cultural, social, and legal factors influence housing's transformation into an objective product (Gür, 2000). Based on place and user, these factors differentiate the house's meaning and structure. While the factors that comprise housing necessitate a subjective structure, today's housing and its environments create single-type housing areas that indicate the use of a specific group.

Mass housing, which has an essential share in creating a living space, is favored in housing production due to its ability to respond to social, economic, technological, infrastructure, and transportation issues from a single source and its high demand rate (Arslan, 2007). Due to the housing production process's emphasis on speed and economic benefit, design considerations are limited, which makes it challenging to accommodate varied user needs within the same living space. That prevents the development of future-oriented models that can meet the demands of users throughout their life cycles. Socially and physically unsustainable living environments cause the formation of settlements that are in a state of perpetual alteration and adversely influence both their micro and macro environment and urban integrity (Ataöv & Osmay, 2007).

With its design, scale, and population, mass housing has the potential to change the physical and social structure of its surroundings. These settlements, together with their surroundings, should be handled meticulously and in a future-oriented manner. Maintaining the interaction, equality, and continuity of people who live in and around a building contributes to the social sustainability of the area. These favorable conditions can only be attained by comprehending social sustainability and implementing the criteria defining the phenomenon. The main reasons for social sustainability in a region is given below. The issue that researchers emphasize is egalitarianism, integration, interaction, and a sense of belonging to the community.

- Everyone should have equal rights regardless of social, physical, or economic differences (Sach, 1999).
- The cultural integration of society's many groups should be ensured. These groups should adapt to the community's changing and evolving character (Polese & Stren, 2000; Biart, 2002).
- Users should develop a range of community-beneficial activities (McKenzie, 2004; Partridge, 2005).
- Interactive and long-term social capital should be created in housing areas (City of Vancouver, 2005; HACT, 2015).
- The sense of belonging to the community should be reinforced (Chan & Lee, 2008; Colantonio & Dixon, 2009).
- Users should be able to continue their lives comfortably and satisfied (Bramley et.al, 2009).
- Desired results should be aimed not only at a part of society but also at everyone (Vallance et.al, 2011).

As of 2000, social sustainability has gained more importance and has chiefly been examined at the scale of the neighborhood unit (Woodcraft, 2012). The concept is still being examined within the scope of urban regeneration issues, especially at the scale of the neighborhood unit (Arısoy, 2014; LUDA, 2003; Var, 2015; Durand, 2018). However, social sustainability is a phenomenon that aims to be achieved not only in regeneration areas but also in all residential areas. Especially since the 2000s, the increase in housing supply and demand through TOKI (Housing Development Administration of the Republic of Turkiye) (Koca, 2016) and private initiatives in Turkiye have made the social sustainability of these areas an essential problem. By focusing on this problem, the study was carried out in existing mass housing areas, unlike many social sustainability studies. The expectations and demands of the users having different characteristics like age, skill, gender, and economic level, from their residences, the residential settlements, and their immediate surroundings are also various. However, these expectations and demands generally have not been met in the housing, which is thought to have a single type of user and accordingly designed almost as a single type. Therefore users' satisfaction with the settlement they live in becomes a significant issue for the quality of life. In this respect, the study seeks to answer the question of how social sustainability can be achieved in existing mass housing areas based on the descriptive characteristics of residents. So, the study aims to reveal the components of social sustainability for housing areas, determine the level of residents' satisfaction with these components and reveal whether there is a difference in satisfaction based on resident characteristics (gender, age, education, employement, economic, type of housing, duration of residence in the house) according to their satisfaction levels. Once and for all, explaining the relationship between the demographic features of residents and the level of satisfaction with these components is the main issue.

2. Theoretical Background

2.1. Sustainable Urbanization, Social Sustainability, and Physical Environment Correlation

Sustainable development means meeting the needs of the present generation without compromising the ability of future generations to meet their own needs. The notion of sustainable development arose in reaction to the damage to the natural environment caused by technological and industrial advancements in the 19th century (WCED, 1987). On the other hand, sustainable urban developments emerged in the last quarter of the 20th century and were formed based on ecology (WCED, 1987; Lele, 1991; Bozlağan, 2005). The concept of sustainable development is examined in terms of three criteria: environmental, economic, and social (Figure 1) (Harris, 2000; Chan & Lee, 2008; Colantonio, 2009).

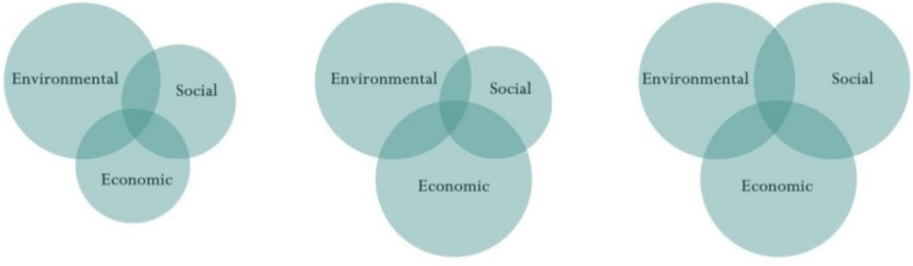

Figure 1 Relative importance levels of sustainable urban development criteria (Doğu & Aras, 2019)

Environmental sustainability is the ability of the ecosystem to maintain and improve its current state and to stabilize the quality of the ecosystem in the short and long term. Economic sustainability is meeting present consumption without compromising its capacity to meet future needs (Khan, 1995). The last component of sustainability, social sustainability, aims to provide a quality of life for communities today and in the future. Although the concept of sustainable urbanization was examined with these three components, the components gained equal importance in the 2000s (Colantonio, 2009; Woodcraft, 2012). Since the 2000s, there has been increased research and application of the notion of social sustainability in regard, and it is strongly tied to changes and destructions in the social structure of cities. More specifically, the struggle of cities with stresses that may lead to social disintegration, such as migration and overpopulation, has required a focus on the social issues of cities (Colantonio, 2009).

2.2. Social Sustainability Concept and Its Criteria

There is no agreed-upon definition of social sustainability; the concept is multidimensional and a dynamic phenomenon that can change over the years (Dempsey et al., 2011). The term is mainly based on equity, democracy, and social justice (Sach, 1999). It is also an expression of the quality of life of people now and in the future (Polese & Stren, 2000; Bacon et al., 2012). Social sustainability attempts to provide equitable, future-oriented, participatory and desired outcomes for all to build strong communities (Vallance et al., 2011). While the objectives and concerns are national and global, the application areas are mainly in a neighborhood unit (Bacon et al., 2012; Woodcraft, 2012).

The social sustainability concept is examined through its constituent themes to understand and apply social sustainability (Partridge, 2005). While social sustainability was defined with more measurable criteria at the time it was conceptualized, today concept has become more abstract and less measurable due to the increase in the number of people working on it and the expansion of application areas (Colantonio, 2009). The fact that the scope of social sustainability is quite broad and that many researchers address it has caused the subject to be evaluated within the framework of different criteria. Figure 2 displays the key concepts through which key researchers have predominantly addressed social sustainability.

The priorities, criteria, and implementation practices of social sustainability vary from region to region. For achieving social sustainability, it is vital to design each living environment according to its potential and expectations. Researchers have created diverse criteria frameworks customized to particular contexts for evaluating the concept of social sustainability in various levels of residential settings. The two concepts most frequently used at the neighborhood unit scale and discussed within this study's scope are social equity (Burton, 2000; Chan and Lee, 2007; Colantino & Dixon, 2009; Dempsey et.al, 2011; Yung & Chan, 2012; Bramley et al., 2009) and sustainability of community (Chiu 2003; Bramley et.al., 2009; Dave, 2011; Dempsey vd., 2011). social equity attempts to ensure that all members of a community can utilize their physical environment and community-provided opportunities equally (Bramley et al., 2009). Sustainability of community aims to transfer the community's healthy operating order into the future (Dempsey et al., 2011). In the context of the concepts of social equity and Sustainability of Communities, numerous sub-criteria are examined across different scales of the built environment. Upon examination of the common points among all the sub-criteria and the criteria about the scope of housing and its immediate surroundings, a comprehensive framework was developed. This framework was crafted based on identifying the most relevant sub-criteria that could be utilized effectively within the scope of the study. These sub-criteria are accessibility, inclusion, and diversity for social equity; security, social interaction, sense of place, community stability, and participation for sustainability of community (Figure 3).

Social Equity: The concept of social equity defines an equal right to use and access essential services, facilities, and units considered vital for that place within the scope of the residence and its surroundings (Bramley & Power, 2009). In the context of social equity, the criteria of accessibility, inclusion, and diversity take precedence.

• *Accessibility:* Within the social equity concept, Accessibility is the most broadly discussed sub-criteria in the social sustainability literature. Living in physically and socially accessible environments is a prerequisite for achieving social equity (Chan & Lee, 2008; Bramley et.al, 2009; Bramley & Power, 2009; Dave, 2011). Accessibility is the capacity of people of varying ages, talents, and disabilities to safely access all indoor and outdoor spaces without the need for the help of another person (Demirkan, 2015). To provide social sustainability to the housing and its immediate surroundings, accessibility is expected to be hassle-free (Barton, 2000). The importance of the units to be accessed varies from region to region. However, the literature includes the essential daily services of health (family health center, hospitals, etc.), education (school, kindergarten, course, etc.), transportation (public transport, etc.), dwelling (access to the dwelling site), commerce (grocery store, etc.), and social units (recreational areas, places of worship, etc.) (Mckenzie, 2004; Dempsey et al., 2011).

• *Inclusion:* Inclusion signifies that a variety of products, services, or units can be utilized by most of the community without adaptation or particular use (BSI, 2005, as cited in Ergenoglu, 2013). Through inclusion, social sustainability seeks to prevent social exclusion (Partridge, 2005). Inclusive environments has been highlighted as essential elements of social sustainability (Dempsey et.al., 2011). Equal opportunities and resources are necessary regardless of physical or social traits. Inclusive environments create a fairer society where everyone can reach their full potential and contribute to their community. At the scale of housing and its immediate surroundings, the availability of the facilities, units, and services that residents frequently use directly impacts the community's sense of equity and satisfaction.

• *Diversity:* To ensure social equity, diversity seeks to preserve the differences that constitute the community and carry them into the future (Table 1). Woodcraft et.al. (2011) considers diversity as the harmonious coexistence of individuals from different beliefs, cultures, and backgrounds. Environments lacking diversity will inevitably lead to social exclusion. This causes to inequity at various community groups (Taket et.al., 2014). To protect social diversity, it is crucial to make proper arrangements in the built environment that provide for the distinctive needs of diverse user groups (Colantonio & Dixon, 2009). To ensure the criterion,

social, cultural, and economic diversity should be supported, and the right solutions should be produced in the physical environment. In particular, the diversity of housing plans, the diversified physical environment, and the protection of the socio-economic differences of the communities are the indicators of this criterion.

Author	Feature	Author	Feature
Chambers and Conway (1992)	Livelihood Equity Capability to withstand external pressures Safety nets	**DFID (1999)**	Inclusion Equity Poverty Livelihood
Sach (1999)	Equity Democracy Human rights Social homogeneity Equitable income distribution Employment Equitable access to resources and social services	**Hans-Böckler-Stiftung (2001)**	Paid and voluntary work Basic needs Social security Equal opportunities to participate in a democratic society Enabling of social innovation
Thin et al. (2002) DIFD	Social justice Solidarity Participation Security	**Omann and Spangenberg (2002)**	Education Skills Experience Consumption Income Employment Participation
Baines and Morgan (2004), (Sinner et al., 2004)	Basic needs Personal disability Needs of future generations Social capital Equity Cultural and community diversity Empowerment and participation	**Bramley et al. (2006)**	Interactions in the community/social networks Community participation Pride and sense of place Community stability Security (crime)
Colantonio and Dixon (2009)	Demographic changes Education and skills Employment Health and safety Environmental and housing health Social capital Social mixing and cohesion; Identity, sense of place and culture	**Dave (2011)**	Access to facilities and amenities Amount of living space Health of the inhabitants Community spirit and social interaction Safety Satisfaction with the neighborhood
Dempsey et al. (2011)	Social interactions Participation Community stability Pride and sense of place Social equity Safety and security	**Larimian and Sadeghi (2021)**	Neighbourhood satisfaction Sense of place Safety and security Social equity Social interaction Housing satisfaction Social participation

Figure 2 Key themes for social sustainability (Expanded by the authors regarding Colantonio, 2009)

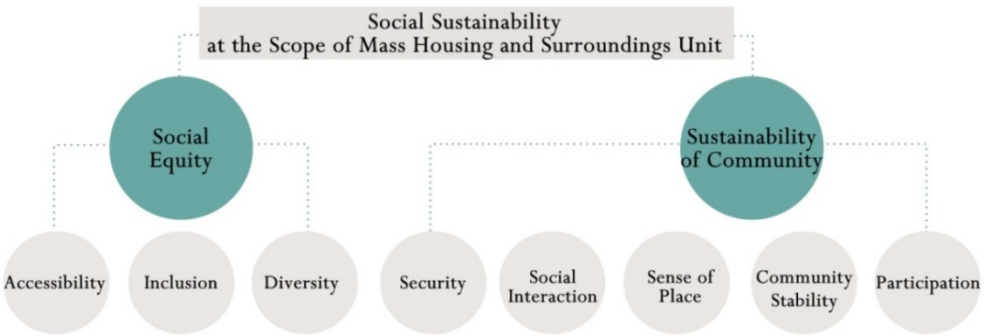

Figure 3 The Sub-criteria and Criteria of Social Sustainability.

Sustainability of Community: The concept is related to the quality of life in any region and the community's participatory interactions (Dempsey, 2011). In the literature, sustainability of community is examined primarily within the scope of security, social interaction, sense of place, community stability, and participation criteria. (Bramley & Power, 2009; Dave, 2011, Dempsey et.al., 2011). In the study, these concepts are focused on the scale of housing and its immediate surroundings.Table 1).

Table 1 The Sub-criteria of Social Equity and Sustainability of Community

Social Equity		
Sub-Criteria	Definitions	The Researchers
Accessibility	In terms of social and physical aspects, seamless access to services and units	Sachs, 1999; Mckenzie, 2004; Partridge, 2005; Chan & Lee, 2008; Colantonio & Dixon, 2009
Inclusion	Utilization of built environments by individuals of varying ages, abilities, and disabilities	Morgan & Baines, 2004; Partridge, 2005
Diversity	Conservation and maintenance of cultural, social and spatial diversity; ensuring social diversity and cohesion	Sachs, 1999; CSA, 2003; Mckenzie, 2004; Morgan & Baines, 2004; Colantonio & Dixon, 2009; Okumuş, 2017
Sustainability of Community		
Sub-Criteria	Definitions	The Researchers
Security	Ensuring health and life safety	Colantonio et.al, 2009; Bramley et.al, 2009
Social Interaction	Development that supports social cohesion	Polese & Stren, 2000; Bramley Colantonio et.al, 2009; Bramley et.al. 2009; Dempsey et.al., 2011
Sense of Place	Preservation of site-specific features, maintaining and promoting a sense of satisfaction and sense of belonging	Chan & Lee, 2008; Bramley et.al, 2009; Colantonio ve Dixon, 2009; Woodcraft et.al, 2011; Yung & Chan, 2012
Community Stability	Balancing migration and mobility concerns inside and outside the city	Mckenzie, 2004; Bramley et.al, 2009; Colantonio & Dixon, 2009
Participation	Collective actions to improve their living environments; participation in decisions and planning for community or geographical structures.	Mckenzie, 2004; Morgan & Baines, 2004; Partridge, 2005; Bramley et.al., 2009; Colantonio et.al, 2009; Yung & Chan, 2012

• Security: The criterion is the most basic human requirement. It has a direct impact on people's well-being and feelings of comfort. The sub-criterion of Security is typically addressed in social sustainability research within the context of residents' ability to feel safe against disorganization, chaos, a high police intervention rate, and criminal elements in their living space (Colantonio & Dixon, 2009; Darchen & Ladouceur, 2013).

• Social Interaction: People's behavioral and affective interactions with one another are referred to as social interaction. It is the most fundamental and natural process in the formation of a community's social order (Wirth, 1967; as cited in Bramley et al., 2009). Knowing their neighbors, meeting them frequently, organizing activities together, and being satisfied with them are all important indicators of social interaction. Fair, strong, and progressive community order can only be achieved with a group that can build social capital through interaction (Bramley et al., 2009). Coleman (1988) argues for establishing an interconnected and productive social interaction to enable social capital formation.

• Sense of Place: The notion means the appreciation of the characteristics of the living space by the inhabitants (Tuan, 1980). The criterion encourages an individual to be satisfied with his or her surroundings by making him or her feel positive about the environment (Bramley et al., 2009). Satisfaction and a sense of belonging are essential indicators of the criterion. The preservation of heritage sites (Chan & Lee, 2008), establishing positive interactions with the environment and people (Heller & Adams, 2009), and ensuring spatial quality (Karuppannan & Sivam, 2011) enhance the sense of place in residential environments and contribute to social sustainability.

• Community Stability is the long-term preservation of human capital and order in a living space. Long-term communities, areas with low residential mobility, areas where social capital can be established, and especially residents who have spent part of their lives in the same residential neighborhood and want to continue living in the same area are important measures of the criterion (Bramley & Power, 2009.). community stability aims to preserve the community's social, cultural, and economic diversity (Potter, 1995). The high housing mobility is attributed to low social cohesion and a sense of belonging among residents, indicating the neighborhood unit's failure to achieve social sustainability (Baines & Morgan, 2003).

Participation: The criterion is frequently examined in the context of social sustainability as participation in design (Chan & Lee, 2008), participation in governance (Sach, 1999; Hans-Böckler-Stiftung, 2001), and participation in community groups (Bramley et al., 2006; Bramley & Power, 2009; Dempsey et al., 2011). Participatory processes strengthen people's relationships with each other, increase residents' commitment to their communities, and build social capital (Woolever, 1992; Bramley et al., 2006; Heller & Adams, 2009). Individuals who can actively participate in the community are concerned about the development of the environment and tend to work for the good of the place (Chan & Lee, 2008).

3. Methodology

The study, investing whether the level of satisfaction with determined social sustainability criteria in mass housing areas varies according to various demographic characteristics of the residents, was designed in a quantitative research model. The survey method was used for the study. The data collected by the questionnaire, developed by the researchers, and data of face-to-face interviews were analyzed using the SPSS for Windows (Statistical Package for Social Sciences) program. In the data analysis descriptive statistics, the Mann-Whitney U, and the Kruskal-Wallis tests were used for analysis.

3.1. Study Area and Study Group

The research area is located in Umraniye district of Istanbul. The social and economic diversity of the residents, the diversity of

housing and social facilities, the fact that the complex has been in use for a long time (16 years), the size and quality of the complex, and the similarity of its relationship with its immediate surroundings and with many mass complexes built in Istanbul all influenced the choice of the study area. Near the complex where the study was conducted, there are various mass housing and single housing blocks and many social (children's playground, green area, sports equipment at a distance of 300-500 m), commercial (market, grocery store, bazaar, tailor, hairdresser, florist, butcher, butcher, haberdashery, dry cleaning at a distance of 50-200 m), educational (primary and secondary schools at a distance of 500 m, high schools at a distance of 1.3 km, kindergartens and nursery schools at a distance of 450-950 m), and medical (health center at a distance of 400 m and 1.2 km, pharmacies at a distance of 300 m, private and public hospitals at a distance of 2-3 km) buildings. Public transportation stops are within accessible distances (the nearest is 400 m away), but the number of timetables is low, and the time interval is long. The TEM highway provides the connection between the complex and the city (Figure 4).

The complex is built on an area of approximately 50,000 m². With a total construction area of 125,000 m², there are a total of 31 blocks and 376 housing units, including 11 Type A, 6 Type B apartment blocks, and 14 Type C detached housing blocks. There are six different design types in total: 1+1 (34 units), 2+1 (34 units), 3+1 (226 units), 4+2 (34 units), 5+2 (34 units), and detached (14 units). The complex has an administrative building, cafeteria, outdoor swimming pool, kindergarten, gymnasium, outdoor playgrounds, outdoor sports fields, security unit, indoor and outdoor parking lots, water features, pond, green areas, and seating units (Figure 5).

Figure 4 Location of the study area relative to Istanbul and Umraniye district

Figure 5 Site overview and site plan analysis

The sample of the study consists of residents living in the mentioned complex. The study group consisted of 87 resident from the complex of 376 houses (calculated 95 % confidence level and 10% margin of error). Participants were chosen by a simple random selection procedure. In the study, only one participant from each house was interviewed, who volunteered to participate in the study and agreed to be interviewed face-to-face.

3.2. Data Collection Tools and Scoring

A structured interview form prepared by the researchers was used as the data collection tool in the study. While preparing the form, an extensive literature review had been carried out and particularly the studies of various researchers on social sustainability and neighborhood unit scale were analyzed and those related to the issue were used (Bacon et al., 2012; Barton

et al., 2012; Egan, 2004; Chan & Lee, 2008). After preparing the survey form expert opinions were taken for developing the questionnaire form. Then the form applied to 10 person for eliminating incomprehensible statements. After the pilot study, the survey form took its final shape. Survey form consists of 10 sections in total, is a 5-point Likert-type form that includes demographic information in the first section and a total of 65 statements in the other ten sections to measure the satisfaction levels from the social sustainability criteria defined according to literature review. Those are accessibility (in-site/near residential neighborhood), spatial diversity (housing/in-site/near residential neighborhood), social diversity, inclusion (housing/in-site), social interaction, community stability, sense of place, security and participation (Appendix 1). Responses to the questionnaire are ranked from most negative (1= strongly disagree) to most positive (5= strongly agree as 1,2,3,4,5. The semantic equivalents of the score values are interpreted as follows: "1.00-1.80: Very Low", "1.81-2.60: Low", "2.61-3.40: Moderate", "3.41-4.20: High", and "4.21-5.00: Very High" (Tekin, 1993).

3.3. Statistical Methods

To state the satisfaction levels and to specify the statistically significant difference in satisfaction based on residents' characteristics (gender, age, education, employment, economic, type of housing, duration of residence in the house), sub-criteria mean scores were used. In determining the statistical methods to be used in the study, firstly, it was taken into account whether the subscale mean scores showed a normal distribution. The Shapiro-Wilk normality test was applied to the data, and it was concluded that the data did not show a normal distribution. Therefore, non-parametric tests were used in the examinations. In this regard, the number of groups was taken as the basis for comparing the sub-criteria mean scores of different groups. Accordingly, the Mann-Whitney U test was used to compare the means of two independent groups, while the Kruskal-Wallis test was used to compare the means of three or more groups. The Mann-Whitney U test was performed in pairs between the groups to ascertain from which groups the difference if any, results from the Kruskal-Wallis test. Bonferroni Correction was used to determine the significance level of the Mann-Whitney U comparison tests conducted in pairs. Accordingly, the significance level was calculated by dividing the significance level α=0.05 by the number of pairwise comparisons.

4. Results and Discussions

Cronbach's Alpha coefficients, mean, and standard deviation values were calculated for all criteria to assess data reliability. According to Table 2, the internal consistency reliability of the sub-criteria of community stability and spatial diversity within the site is acceptable, while the reliability coefficient of all other sub-criteria is good (Kılıç, 2016). These findings demonstrate that the data are reliable.

Table 2 shows the levels of satisfaction with the sub-criteria of the social equity criterion. As a result, residents are very satisfied with the diversity of units at the housing scale (Mean:4,61), highly satisfied with units within the complex (Mean:3,51), and moderately satisfied with units in the neighborhood in terms of spatial diversity(Mean:3,06).

Table 2 Cronbach α Coefficients of Sub-criteria

Criteria	Sub-criteria	Number of Variables	Mean	S.D.	Cronbach α Coefficient
Social Equity	Spatial Diversity (House scale)	5	4,61	3,28	0,887
	Spatial Diversity (Complex scale)	3	3,51	2,23	0,656
	Spatial Diversity (Neighborhood scale)	5	3,06	4,49	0,764
	Social Diversity	6	2,76	3,97	0,722
	Accessibility (Complex scale)	6	4,18	4,77	0,832
	Accessibility (Neighborhood scale)	5	3,43	4,96	0,833
	Inclusion (House scale)	6	4,64	2,87	0,747
	Inclusion (Complex scale)	6	3,87	4,35	0,716
Sustainability of Community	Social Interaction	5	3,22	4,10	0,759
	Security	6	4,16	4,11	0,738
	Community Stability	3	2,76	3,52	0,631
	Sense of Place	5	3,50	4,22	0,800
	Participation	4	2,27	4,67	0,761

According to the interviews, the participants were particularly dissatisfied with the neighborhood's diversity of social, commercial, medical, educational, cultural, and public transportation units. In terms of social diversity, the average respondent is pleased with the neighborhood's social diversity (Mean:2,76). This situation demonstrates that most participants want to avoid living in the complex with people from different economic and social backgrounds and do not want to see persons from outside in the complex. The overall level of satisfaction with accessibility is high. The complex has a higher level of satisfaction with accessibility (Mean:4,18) than the immediate surroundings (Mean:3,43). While residents value access to recreational areas within the complex, access to key services (social, commercial, medical, education, cultural, and public transportation) in the immediate vicinity is viewed as problematic.

Regarding inclusion, there is a high level of satisfaction with the utilization of the spaces inside the residence and the units inside the complex (means of 4.64 and 3.87, respectively). This demonstrates that the housing unit's rooms and wet areas can be used in conjunction with its equipment. The usefulness of the complex's parks and leisure units, stairs, and paths is reduced, although they are still fully usable.

When the satisfaction levels of the sustainability of community criterion's sub-criteria (Table 2) are examined, the overall satisfaction level in terms of social interaction is moderate (Mean:3.22). Although the participants get along well with their small number of neighbors and enjoy meeting and interacting with them, the fact that the complex and neighborhood residents do not know each other in general, as well as the inadequacy of the number and quality of interaction venues, reveal this situation. Security has a high overall level of satisfaction

(Mean:4,16). Within the complex, residents generally feel safe both during the day and at night. The level of satisfaction with the community stability sub-criterion is moderate (Mean:2,76). Therefore, it is assumed that residents' views on moving out of their house and neighborhood when experiencing life events like marriage, having children, or becoming older are on the average level. The average level of satisfaction with the sense of place sub-criterion is high (Mean:3.50). This is related to the fact that users can use their homes effectively and have an active say in their homes. Residents' overall satisfaction with participation is low (Mean:2,27) both within the complex and at the neighborhood scale. This shows that residents are unable to effectively participate in activities, projects, and designs that take place at the scale of the neighborhood unit at the idea or implementation stage.

4.1. Analysis Results for Demographic Characteristics of Residents and Sub-Criteria

Table 3 displays the participants' gender, age, education, employment, economic and ownership status, housing type, and residence duration in the house. Among the participants, 62.1% are female, 37.9% are male, 47.1% are between the ages of 41 and 64 of the participants, 70.1% are homeowners, 29.9% are renters, 50.6% live in 3+1 housing type, 50.5% have lived in their current homes for less than six years. Most participants were university graduates (58.6%), working (50.6%), and considered themselves to be moderate (55.2%).

Table 3. Frequency and Percentages of Demographic Variables

	N	%		N	%
Gender			**Housing Type**		
Female	54	62,1	1+1	7	8,0
Male	33	37,9	2+1	9	10,3
Age			3+1	44	50,6
≤ 20	6	6,9	4+2	11	12,6
21-40	33	37,9	5+2	13	14,9
41-64	41	47,1	Villa	3	3,4
65 ≤	7	8			
Education			**Employment**		
Postgraduate	10	11,5	Student	6	6,9
Undergraduate	51	58,6	Retired	14	16,1
High-school	17	19,5	Non-working	23	26,4
Primary-school	9	10,3	Working	44	50,6
Economic			**Ownership**		
High	15	17,2	Homeowner	61	70,1
High-Moderate	15	17,2	Renter	26	29,9
Moderate	48	55,2	**Residence Duration in the House**		
Low- Moderate	9	10,3	≤ 6 years	44	50,5
			7 years ≤	43	49,5

The social sustainability sub-criteria were analyzed separately based on the demographic characteristics of the participants; in this section of the study, only the analysis results that showed a significant difference are included (Figure 6).

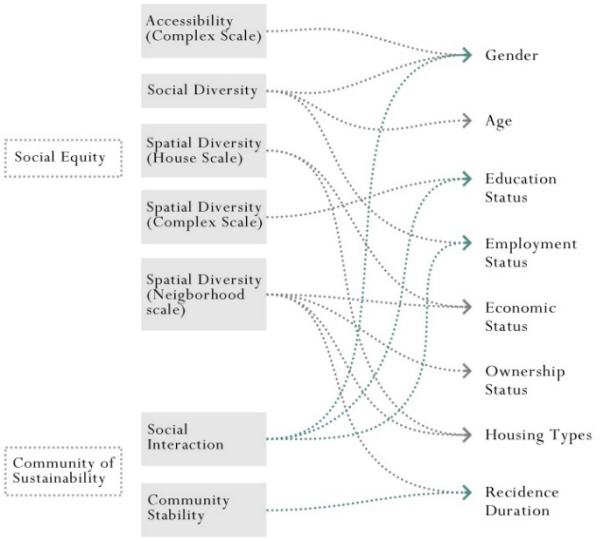

Figure 6. The significant differences between the sub-criteria and the demographic characteristics

Mann-Whitney U test was used to analyze whether participants' levels of social sustainability sub-criteria display significant differences in terms of gender (Table 4). Participants' level of satisfaction with accessibility differs significantly based on gender ($p<0.05$). Men have higher levels of satisfaction than women. Women's dissatisfaction can be attributed to their concerns about their children and their security. The level of satisfaction with social diversity also differed significantly by gender ($p<0.05$), and the median value showed that men had a higher level of satisfaction (Table 4). This shows that men have a more positive view of social diversity than women. The level of satisfaction with social interaction differs significantly based on gender ($p<0.05$). According to the median values, it is seen that women are more satisfied with social interaction than men. In light of this, women have stronger neighborhood relations in the complex and neighborhood than men.

Table 4 Mann-Whitney U test results in terms of gender

Sub-criteria	Gender	N	Median	U Stats	Z	p
Accessibilty, CS	Male	33	4,67	661,000	-2.032	,042
	Female	54	4,18			
Social Diversity	Male	33	3,00	665,500	-1,993	,046
	Female	54	2,80			
Social Interaction	Male	33	3,17	559,500	-2,906	,004
	Female	54	3,67			

CS: Complex scale

Kruskal-Wallis test was used to analyze whether participants' levels of social sustainability parameters display significant differences in terms of age (Table 5). When the satisfaction levels of the sub-criteria are compared in terms of age, social diversity ($p<0.05$) differs significantly (Table 5). As a result of the Bonferroni correction, the significance level for social diversity was set at 016/6=,0027. As a result of the findings and median values of the groups, it is clear that people aged 20 and younger are more satisfied with living in social diversity in and around their residence than people aged 21–64 years (Table 5). As participants' ages increase, their attitudes toward social diversity become more protective. It is found that individuals below the

age of 20 are more open to interacting with people from diverse ethnic groups, varying economic statuses, and different household backgrounds.

Table 5 Kruskal-Wallis test results in terms of age

Sub-criteria	Age	N	Median	sd	X^2	p	Mann-Whitney U Test		
							X^2	p	Groups
Social Diversity	**1.** 0-20	6	4,10	3	10,313	,016	25,500	,002	1-2
	2. 21-40	33	3,00				25,500	,001	1-3
	3. 41-64	41	3,00						
	4. 65-	7	3,00						

Mann-Whitney U test was used to analyze whether participants' levels of social sustainability sub-criteria display significant differences in terms of education status (Table 6). When the social sustainability criteria were compared to the individual's educational level, no significant differences were discovered. As a result, the test was updated by combining the 'primary school' and 'high school' graduates into group 1 and the 'undergraduate' and 'postgraduates' into group 2.

Participants' satisfaction with the complex's spatial diversity varies significantly according to their educational level ($p<0.05$). Undergraduate and postgraduate graduates are less satisfied with spatial diversity at the complex scale than primary and high school graduates (Table 6). This is because people with higher education levels have higher spatial demands than others. Primary and high school graduates were significantly more satisfied than the other group on the social interaction (Table 6). The finding can be attributed to the high amount of time spent by primary and high school graduates in their residential and immediate surroundings.

Table 6. Mann-Whitney U test results in terms of education status

Sub-criteria	Education	N	Median	U Stats	Z	p
Spatial Diversity, CS	1. Primary and High school	26	4,00	552,000	-2,285	,022
	2. Undergraduate, Postgraduate	61	3,33			
Social Interaction	1. Primary and High school	26	4,00	434,500	-3,331	,001
	2. Undergraduate, Postgraduate	61	3,33			

CS: Complex scale

When the sub-criteria were compared to the individual's employment status, the social diversity ($p<0.05$) and social interaction ($p<0.05$) criteria differ significantly (Table 7). The Bonferroni correction yielded a significance level of .009/6=.0015 in terms of social diversity. In this regard, when the median values are also considered within the context of the social diversity criterion, the students' satisfaction averages are significantly higher than those of the employees. The significance level was set at .001/6=.000 as a result of the Bonferroni correction for the social interaction criterion. As a result, the non-working are significantly more satisfied with social interaction than the working. This can be explained by the fact that the non-working group, entirely composed of women, meets more frequently (Table 7).

Table 7 Kruskal-Wallis test results in terms of employment status

Sub-criteria	Employment	N	M	sd	X^2	p	Mann-Whitney U Test		
							X^2	P	G
Social Diversity	1.Working	44	2,80	3	11,518	,009	23,500	,000	1-4
	2.Non-working	23	3,00						
	3.Retired	14	3,00						
	4.Student	6	4,10						
Social Interaction	1.Working	44	3,17	3	16,850	,001	230,000	,000	1-2
	2.Non-working	23	4,00						
	3.Retired	14	3,50						
	4.Student	6	2,92						

G:Groups, M: Median

The Mann-Whitney U test was used to determine whether participants' levels of social sustainability sub-criteria differed significantly in terms of economic status (Table 8). When the social sustainability criteria were compared to the individuals' economic status, no significant differences were discovered. As a result, the test was updated by combining the 'moderate' and 'moderate-low' groups as well as the 'high' and 'high-moderate' groups.

The level of satisfaction with spatial diversity at the scale of housing and neighborhood varies significantly by economic status ($p<0.05$). Participants with a 'high-moderate' or 'high' economic status are significantly more satisfied with housing diversity than those with a 'low-moderate' or 'moderate' economic status (Table 8). On the neighborhood scale, those with 'high-moderate' and 'high' economic levels have significantly lower average satisfaction values than those with low-moderate, and moderate economic levels (Table 8). Based on the data, the fact that people with higher incomes can organize diversity within housing according to their preferences and live in larger houses explains their higher satisfaction with housing diversity. However, it was discovered that the neighborhood's diversity needed to be improved for them. Moderate-low-income individuals tend to value **spatial diversity** at the neighborhood level more than high-income individuals.

Mann-Whitney U test was used to analyze whether participants' levels of social sustainability sub-criteria display significant differences in terms of economic status and ownership (Table 8).

Table 8 Mann-Whitney U test results in terms of economic and ownership status

Sub-criteria	Economic	N	Median	U Stats	Z	p
Spatial Diversity, HS	**1.**moderate ; moderate-low	57	4,80	644,000	-2,095	,036
	2.high-moderate; high	30	5,00			
Spatial Diversity , NS	**1.**moderate ; moderate-low	57	3,40	582,000	-2,445	,014
	2.high-moderate; high	30	2,80			
	Ownership					
Spatial Diversity (NS)	**1.**Homeowner	61	3.20	543,000	-2,325	,020
	2. Renter	26	3.68			

HS: House scale, NS: Neighborhood scale

The Kruskal-Wallis test was used to analyze whether participants' levels of social sustainability sub-criteria display significant differences in terms of housing type (Table 9). When the social sustainability criteria were compared to the housing type, no significant differences were discovered. For this reason, the test was renewed by combining 1+1 and 2+1 housing types as group 1, 3+1 housing type as group 2, 4+2, and 5+2, and the villa housing type as group 3 according to the size of the housing types. This situation indicates that 1+1 and 2+1 plan types are insufficient in terms of functionality and flexibility for their residents.

Table 9 Kruskal-Wallis test results in terms of the housing type

Sub-criteria	Housing Type	N	M	sd	X^2	p	Mann-Whitney U Test		
							X^2	p	G
Spatial Diversity (House scale)	**1:** 1+1; 2+1	16	4,20	2	16,229	,000	214,500	,015	1-2
	2: 3+1	44	5,00				87,500	,000	1-3*
	3: 4+2, 5+2, villa	27	5,00						
Spatial Diversity (Complex scale)	**1:** 1+1; 2+1	16	3,00	2	8,573	,014	184,500	,004	1-2*
	2: 3+1	44	4,00						
	3: 4+2, 5+2, villa	27	3,33			,004			

G:Groups, M: Median

When the sub-criteria were compared to the participants' housing types, spatial diversity at the residential and complex scales varies significantly (Table 10). The new significance level is .000/6=.000 as a result of the Bonferroni correction in terms of spatial diversity at the residential scale. Those who live in Group 3 housing types are more satisfied with the spatial diversity at the housing scale, according to the median values. The new significance level for spatial diversity at the complex scale is .0014/6=.004 due to Bonferroni correction. It is assumed that residents of 3+1, i.e., Group 2 housing types, are more satisfied with spatial diversity at the complex scale than residents of Group 1 housing types. As a result, it is understood that those living in 1+1 and 2+1 plan types will not be able to achieve spatial satisfaction.

Mann-Whitney U test was used to analyze whether participants' levels of social sustainability sub-criteria display significant differences in terms of the living period of residence (Table 10). Satisfaction with spatial diversity at the complex scale varies significantly with residence length ($p<0.05$). Those who have lived for 6 years or less are more satisfied than those who have lived for 7 years or more. As a result, satisfaction with spatial diversity at the complex scale influences the length of residence. The level of satisfaction with community stability differed significantly by the length of residence ($p<0.05$), and according to the median values, those who have lived for 7 years or more are more satisfied. People who have been residing for 7 years and more are more willing to live in the same residential neighborhood (Table 10).

Table 10 Mann-Whitney U test results in terms of residence duration

Sub-criteria	Residence Duration	N	Median	U Stats	Z	p
Spatial Diversity, CS	**1:** ≤ 6 years	44	3,33	644,000	-2,622	,009
	2: 7 years ≤	43	4,00			
Community Stability	**1:** ≤ 6 years	44	2,50	679,500	-2,269	,023
	2: 7 years ≤	43	2,67			

CS: Complex scale

5. Conclusions and Recommendations

As its conceptual background suggests, social sustainability is an umbrella concept/approach that expresses many dimensions and their interrelationships. As a result, defining, implementing, and monitoring the approach becomes multidimensional, indicating a situation that requires improvement through continuous feedback and monitoring. On the other hand, social change and migration are caused by a variety of factors such as disasters, climate crises, wars, economic crises, and urbanization, the effects of which we are acutely aware and highlight the importance of social sustainability for cities and settlements. So, it is crucial to examine the healthy relationship that mass housing establishes within itself and its environment regarding social sustainability.

Today, it is crucial to examine the healthy relationship that mass housing, which many people demand at both production and usage levels, establishes within itself and with its environment regarding social sustainability. This study aims to define the main criteria of social sustainability at the scale of housing and its environment and to reveal how a more socially sustainable environment can be achieved. For this purpose, how the social sustainability situation differs depending on user characteristics (gender, age, education, employment, economy, ownership, housing type, residence) was investigated through the satisfaction levels of the residents. Satisfaction with social sustainability varies according to demographic data and sub-criteria of people.

According to the study, spatial diversity satisfaction is very high at the residential scale, high on the complex scale, and moderate on the residential neighborhood scale. Satisfaction with spatial diversity at the complex scale varies according to the participants' economic status and housing types. Education, housing type, and length of residence all influence satisfaction with spatial diversity in the complex. In terms of economic and ownership status, satisfaction with spatial diversity in housing and its immediate surroundings varies. It is necessary to target spatial quality in the housing neighborhood to ensure that people from different income and educational backgrounds live in the same housing neighborhood for many years. This necessitates the creation of high-quality social spaces (restaurants, recreation areas, libraries, youth centers, etc.), health units (hospitals or family health centers inaccessible areas), and a public transportation network. The diversity of plans contributes to the spatial diversity of housing.

The satisfaction level of social diversity in the study is moderate, and participants are reluctant to live in the same environment with people from different social, economic, and social levels to develop mutual interactions and participate in activities. It differs by gender and age: men, over 20-aged users, and younger users

are more satisfied. In this sense, for the development of social diversity, safe interaction areas where individuals can get to know each other through different activities should be established.

Satisfaction with accessibility is at a high level and it is varied by gender. Accessibility comes to the forefront for women, whose satisfaction is low, to benefit from the facilities in and around the complex and to participate in the environment, especially with their children. To increase the quality of accessibility, residents should be provided with unobstructed, barrier-free, and landscaped walking paths that facilitate walkability and access to key services and public transportation stops.

The satisfaction level of inclusion is very high in housing units and at the neighborhood scale, and participants found the units within the houses and the complex mostly usable. For inclusion, no differences were found in terms of the changing characteristics of the participants. The inclusion of the needs of individuals with different capabilities (children, elderly, disabled, etc.) in terms of inclusion within the framework of universal design principles is important in terms of planning usable and sustainable areas.

The fact that the level of social interaction satisfaction is moderate indicates that a well-connected social capital could not be established within the scope of the study area. Satisfaction with social interaction differed based on gender, education, and employment status. It is understood that women, the non-working group, and people with primary and high school education levels are more active in establishing social interaction with their neighbors in and around the housing. To increase social interaction, it is necessary to design interaction spaces of different scales that allow individual and collective use and to organize participatory environments and activities that will allow residents to get to know each other.

The level of satisfaction with security is generally high but lower at the neighborhood scale. This result shows that a healthy relationship between the neighborhood and the complex has yet to be achieved. The feeling of insecurity here basically consists of concerns for the security of life and property. It has been observed that way. The level of security satisfaction does not differ in terms of the demographic characteristics of the residents. To increase the level of security satisfaction to a very high level among all people, social interaction should be increased, security of the physical equipment around the housing should be ensured, and visibility and walkability in the neighborhood unit should be increased by local governments, and measures should be taken against crime and disturbances.

Satisfaction with community stability is moderate, and satisfaction does not differ according to the characteristics of the residents. Considering the participants, this situation is an indication that community stability has not been established in the area and that there is a thought of moving in the future. To increase community stability, it is important to increase the diversity of housing plans in the immediate surroundings of the housing, as well as the ease of access to social, cultural, etc. units in the neighborhood and the activation of the public transportation system.

Sense of place satisfaction is at a high level, and no significant difference is observed in terms of the descriptive characteristics of the participants. Residents feel a greater sense of place in their housing and complexes than in their neighborhoods. Developing a sense of place for all in residential areas is based on multifaceted factors. To develop a sense of place, it is necessary to meet basic needs within walkable distances in the physical environment, to increase the number of spaces that will allow social interaction, to protect the area's common cultural values, and to create social capital.

Participation is the criterion with the lowest level of satisfaction, and there is no significant difference based on the participants' descriptive characteristics. One reason is that the housing and its surroundings need to provide participatory organizations for residents of various abilities. To increase participation, complex and neighborhood-level decisions (design, political, social, etc.) and practices should be based on participatory processes accessible to all residents.

The positive contribution of settlements with high economic, environmental, or social sustainability to both the environment and the residents should be addressed. If it is desired to plan/design cities and living spaces where coexistence in prosperity, peace, health, and security will continue for a long time, the driving force of social sustainability criteria must be utilized. Providing a single criterion will not be sufficient to ensure social sustainability, and political and economic support must be provided continuously to create more livable environments. Furthermore, the study indicates that considering the changing demographic characteristics of the participants and incorporating the wishes of the participants with different abilities, ages, genders, etc. into the design and planning processes will contribute to their quality of life and the improvement of the social and spatial quality of their living environments.

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References

Arısoy, A. (2014). T*he Yeldegirmeni experience: a different approach to urban renewal,* Cekul Foundation Publication, Istanbul.

Arslan, I. (2007). *Housing economics*, Sakarya Publishing, Istanbul.

Ataöv, A. & Osmay, S., (2007). A methodological approach to urban regeneration in Turkey, *METU Journal Of The Faculty Of Architecture*, 24(2): 57-82.

Bacon, N.; Cochrane, D., & Woodcraft, S. (2012). *Creating strong communities: how to measure the social sustainability of new housing developments*. The Berkeley Group: London, UK.

Barton H. (2000). Conflicting perceptions of the neighborhood. In Sustainable Communities: The Potential for Eco–Neighbourhoods, Barton H (ed.). Earthscan: London; 3–18.

Barton, H., Horswell, M., & Millar, P. (2012). Neighbourhood accessibility and active travel. *Planning Practice and Research*, 27(2): 177-201. https://doi.org/10.1080/02697459.2012.661636

Bramley, G., & Power, S. (2009). Urban form and social sustainability: the role of density and housing type. *Environment and Planning B: Planning and Design*, 36(1): 30-48. https://doi.org/10.1068/b33129

Bramley, G., Dempsey, N., Power, S., Brown, C., & Watkins, D. (2009). Social sustainability and urban form: evidence from five British cities. *Environment and Planning A*, 41(9): 2125-2142. https://doi.org/10.1068/a4184

Chan, E., & Lee, G. K. (2008). Critical factors for improving social sustainability of urban renewal projects. *Social Indicators Research,* 85(2): 243-256.

Chambers, R., & Conway, G. (1992). *Sustainable rural livelihoods: practical concepts for the 21st century*. Institute of Development Studies (UK).

Colantonio, A. (2009). *Social sustainability: a review and critique of traditional versus emerging themes and assessment methods*. In Second International Conference on Whole Life Urban Sustainability and its Assessment: Conference Proceedings. Loughborough: Loughborough University, 865- 885.

Colantonio, A., Dixon, T., Ganser, R., Carpenter, J., & Ngombe, A. (2009). Measuring Socially Sustainable Urban Regeneration in Europe. *Oxford Institute for Sustainable Development (OISD).*

Coleman, J. (1988). Social capital in the creation of human capital. *American Journal of Sociology*, 94: 95–120.

Darchen, S., & Ladouceur, E. (2013). Social sustainability in urban regeneration practice: A case study of the Fortitude Valley Renewal Plan in Brisbane. *Australian Planner*, *50*(4): 340-350. https://doi.org/10.1080/07293682.2013.764909

Dave, S. (2011). Neighbourhood density and social sustainability in cities of developing countries. *Sustainable development*, *19*(3): 189-205. https://doi.org/10.1002/sd.433

Dempsey, N., Bramley, G., Power, S., & Brown, C. (2011). The social dimension of sustainable development: Defining urban social sustainability. *Sustainable Development*, 19(5): 289-300. https://doi.org/10.1002/sd.417

Doğu, F. U., & Aras, L. (2019). Measuring social sustainability with the developed MCSA model: güzelyurt case. *Sustainability*, 11(9): 2503. https://doi.org/10.3390/su11092503

Durand, R., H., (2018). *A Framework for Socially Sustainable Urban Transformation: Sulukule Case Study*, Master Thesis, İstanbul Technical University, Institute of Science and Technology, İstanbul.

Egan, J., (2004). *The Egan Review: Skills for Sustainable Communities*, ODPM, London.

Gur, S.O. (2000). *Housing culture in the example of Eastern Blacksea Region*, YEM Publishing, Istanbul.

Harris, J. M. (2000). Basic principles of sustainable development. *Dimensions of Sustainable Development*, 21-41.

Hans-Boeckler-Foundation (Ed.), (2001). *Pathways Towards a Sustainable Future*, Setzkasten, Düsseldorf.

Heller, A. & Adams, T. (2009). *Creating healthy cities through socially sustainable placemaking*, Australian Planner, 46(2): 18-21.

Heller, A., & Adams, T. (2009). Creating healthy cities through socially sustainable placemaking. *Australian Planner*, 46(2): 18-21. https://doi.org/10.1080/07293682.2009.9995305

Kiliç, S. (2016). Cronbach's alpha reliability coefficient. Psychiatry and Behavioral Sciences, 6(1): 47. https://doi.org/10.5455/jmood.20160307122823

Koca, C. (2010). *Barrier-free city planning information report*. 4. World Disability Foundation, Istanbul.

Larimian, T., & Sadeghi, A. (2021). Measuring urban social sustainability: Scale development and validation. *Environment and Planning B: Urban Analytics and City Science*, 48(4): 621-637. https://doi.org/10.1177/2399808319882950

McKenzie, S., (2004). Social sustainability: towards some definitions, *Hawke Research Institute Working Paper Series,* 27.

Baines, J., & Morgan, B. (2004). Sustainability appraisal: A social perspective. *Sustainability Appraisal. A Review Of International Experience And Practice, Dalal-Clayton B And Sadler B,(Eds), First Draft of Work in Progress,* International Institute for Environment and Development, London.

Özdamar, K. (1999). Paket programlar ile istatistiksel veri analizi 1. Kaan Kitabevi, Eskisehir.

Partridge, E., (2005). *Social sustainability: a useful theoretical framework*. The Australasian Political Science Association Annual Conference, Dunedin, New Zealand.

Partridge, E. (2005). *Social sustainability': a useful theoretical framework*. In Australasian Political Science Association Annual Conference. 28-30.

Polèse, M., Stren, R. E., & Stren, R. (Eds.). (2000). *The social sustainability of cities: Diversity and the management of change*. University of Toronto press.

Potter, P. (1995). *Alternatives to the concept of integration in the struggle against exclusion, Others' Housing Issues*. 488-497. Chamber of Architects of Turkey Publication, Ankara.

Sachs, I. (1999). Social sustainability and whole development: exploring the dimensions of sustainable development. *Journal of sustainability and the social sciences*, 2: 25-36.

Taket, A., Crisp, B. R., Graham, M., & Hanna, L. (2013). Scoping social inclusion practice. In Practising social inclusion 17-56. Routledge.

Tekin, H. (1993). *Assessment and evaluation in education.* Ankara: Yargi Publishing.

Thin, N., Lockhart, C., & Yaron, G. (2002). Conceptualising socially sustainable development. *A paper prepared for DFID and the World Bank, DFID. Unpublished work*.

Tuan, Y. F. (1980). Rootedness versus sense of place. *Landscape*, *24*: 3-8.

Ozsoy, A., (2011) An assessment for the development of mass housing practices. *Journal of Ecological Structures and Settlements*, 3: 42-46.

WCED, (1987). Report of the World Commission on Environment and Development: Our Common Future. Oxford: Oxford University Press.

Var, E., B., (2015). Urban rehabilitation and social sustainability: In case of Ortahisar: Trabzon, Master Thesis, Istanbul Technical University, Institute of Science and Technology, İstanbul.

Vallance, S., Perkins, H. C., & Dixon, J. E. (2011). What is social sustainability? A clarification of concepts. *Geoforum*, 42(3): 342-348. https://doi.org/10.1016/j.geoforum.2011.01.002

Woodcraft, S. (2012). Social sustainability and new communities: Moving from concept to practice in the UK. *Procedia-Social and Behavioral Sciences*, 68: 29-42. https://doi.org/10.1016/j.sbspro.2012.12.204

Woolever, C. (1992). A contextual approach to neighbourhood attachment. *Urban Studies*, 29(1): 99-116. https://doi.org/10.1080/00420989220080081

Yung, H. K. E., & Chan, H. W. E. (2012). Critical social sustainability factors in urban conservation: The case of the central police station compound in Hong Kong. *Facilities*. 30(9/10): 396-416.

Appendix 1: Variables' Contents of the Sub-criteria

Social Equity's Sub-criteria	**Variables' Contents**
Accessibility	**Complex Scale:** Access to units within the complex scale (Units: House; Buildings; Sports fields; Children's playgrounds; Recreation areas) **Neighborhood Scale:** Pedestrian accessibility to key units neighborhood-scale (Key Units: Social; Educational; Commercial; Health; Public transportation stops)
Inclusion	**House Scale**: Utility of units within the house scale (Units: Kitchen furnishings; Wet areas' furnishings; Living spaces' furnishings; Bedrooms' furnishings; Balconies' furnishings; Residential entrances) **Complex Scale**: Utility of units within the complex scale (Units: Building entrances; Building stairs/elevators; Sports fields; Children's playgrounds; urban equipment in recreation areas; Car park area)
Spatial Diversity	**House Scale:** Sufficiency of the units within the house scale (Units: House type, Size of rooms, Number of rooms, Size of wet areas, Size of kitchen) **Complex Scale:** Sufficiency of the units within the complex scale (Units: Recreation areas; Children's playgrounds; Sports fields). **Neighborhood Scale:** Sufficiency of the units within the neighborhood scale (Units: Social; Educational; Commercial; Health; Public transportations)
Social Diversity	**For All Scales:** The satisfaction of users living in the same environment with individuals from different socio-cultural, ethnic, and household backgrounds has been examined.
Sustainability of Community's Sub-criteria	**Variables' Contents**
Social Interaction	**For All Scales:** The variables include questions about users' familiarity with their neighbors, the levels of satisfaction derived from neighborly relationships, and the nature of their interactions with neighbors.
Security	**For All Scales:** The variables include questions related to users' perceptions of safety during daytime and nighttime, their satisfaction with security services, and their overall satisfaction concerning safety.
Community Stability	**For All Scales:** The variables ask users' perspectives on living in their current residence, another unit within the same housing complex, or a different nearby residence, considering their life cycles.
Sense of Place	**For All Scales:** The variables investigate users' satisfaction and sense of belonging derived from their residences, the mass housing complex, and the neighborhood they live in.
Participation	**For All Scales:** The variables encompass users' participation in the site management and activities within the housing complex and in community events organized within the neighborhood.