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Original Research Article

Systemic Intersections of Ecological Resilience, Urban Heat Islands, and Public Health*

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Abstract | With the growth of urbanization and the increasing vulnerability caused by climate change, urban resilience has emerged as a key approach in planning for sustainability. One of the major challenges in this field is the lack of interdisciplinary research that comprehensively analyzes the systemic interactions between ecological resilience, urban heat island mitigation, and human health. The primary objective of this study is to identify the shared criteria between ecological resilience, urban heat island mitigation, and human health through an interdisciplinary approach. Additionally, this research seeks to answer how ecological resilience can enhance biological, psychological, and social health by reducing urban heat islands and whether a multi-layered, systemic model can explain the non-mechanical (network-based) relationship among these factors. The PRISMA systematic methodology was employed to identify common criteria among the three mentioned domains. By analyzing previous studies and reviewing existing data, a conceptual framework was developed to better understand the systemic interactions among these components. This research proposes a multi-layered resilience framework, conceptualizing ecological resilience, urban heat island mitigation, and public health as interdependent components within an adaptive urban system. The findings indicate that integrating these three concepts into a systemic approach can enhance cities' adaptive capacity and reduce environmental stressors. Furthermore, this study highlights the necessity of considering urban resilience as a multi-scalar and interdisciplinary challenge, extending beyond conventional ecological or health-focused interventions. Future research is recommended to develop operational models for assessing and predicting the impacts of these interactions.

Keywords |*Climate Change, Urban Ecosystem, Social Well-being, Environmental Sustainability, PRISMA, Systematic Review.*

Introduction|In today's world, the expansion of urbanization and human activities has gradually intensified, becoming the primary driving force behind environmental changes (Crutzen & Brauch, 2016; IPCC, 2014). This phenomenon has led to alterations in the structure and functioning of ecosystems, exacerbating ecological issues such as landscape degradation, environmental pollution, water resource scarcity, energy crises, and biodiversity loss (Liu et al., 2023; Luederitz et al., 2015; O'neill et al., 2017). The impact of these hazards on regional ecosystems and human health is inevitable (Adger et al., 2003; Mackay, 2008). Therefore, it is essential to develop appropriate strategies to address climate crises and various ecological challenges. Rapid and unplanned urbanization has simultaneously reduced urban green spaces, consequently increasing temperatures compared to non-urban areas (Das, 2022). The latest report by the World Health Organization (WHO) on resilient urban environments identifies temperature-

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related events as one of the key challenges in urban planning and policymaking (World Health Organization, 2022).

Moreover, the consequences of climate change, particularly the urban heat island phenomenon, have significant impacts on human health in cities (Parker et al., 2019; Patz et al., 2005; Paz et al., 2016). Research also indicates that public health and well-being are highly dependent on ecosystem health (Billiot, 2017). Therefore, appropriate urban planning and strategies based on ecosystem health and thermal comfort are essential for achieving overall well-being.

Despite various studies on climate change and ecological resilience, there has been no systematic research developing a multi-layered and network-based model to address how resilience approaches can enhance thermal comfort by mitigating urban heat islands to promote human and community health.

Thus, the objective of this study is to answer the question: What are the common evaluation criteria among the three concepts of ecological resilience, urban heat islands, and human and community health? To address this, the present research aims to identify shared components across these three areas and elucidate their interconnections.

Research Method

The PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) methodology was employed to develop a systemic resilience approach related to climate change and health. The systematic review included sources from SCOPUS and Web of Science over the past two decades (Fig. 1). The review process followed established steps, including identification, screening, eligibility assessment, and final inclusion of studies, along with data analysis (Tricco et al., 2018).

The PRISMA method has been widely endorsed by researchers globally (Gonzalez-Quintero & Avila-Foucat, 2019; Suppakittpaisarn et al., 2017) and is commonly used in environmental management studies (Shaffril et al., 2018).

The reliability of this research was assessed from two perspectives:

1.The use of a standard PRISMA methodology for identifying and screening studies ensures a transparent and replicable process for selecting sources and extracting key indicators.

2.The incorporation of established metrics and indicators from the scientific literature—such as vegetation indices, urban heat island intensity, and bio-psycho-social health criteria—enhances the study's comparability and reproducibility with previous research.

The validity of this research was ensured through the alignment of the theoretical framework and layered model structure with existing literature and empirical findings. The consistency of the study's results with well-established theoretical frameworks (Holling, 1973; Folke, 2006) and recent empirical studies in ecological resilience, urban heat islands, and human health supported the content validity of the proposed model.

Research Background

Through the analysis of the research literature, this study has identified four thematic categories related to three key areas: health, ecological resilience, and the urban heat island effect:

1. Ecological resilience as a response to climate change
2. The impact of ecological resilience on the urban heat island effect
3. Resilience approaches for achieving health
4. Effects of the urban heat island on human health

• Category one: Ecological resilience as a response to climate change

In the pursuit of sustainable urban development, the ecological dimension of urban resilience plays a crucial role in the sustainable management of ecosystems and the improvement of human life quality (Pamukcu-Albers et al., 2023). Natural hazards pose significant challenges for developing countries, causing severe damage and negating developmental achievements (Resilience, 2014). Today, some natural hazards stem from climate change, a global phenomenon affecting Earth, which has led to serious problems for humans and the environment (Childers et al., 2015).

In this study, most research focuses on ecological resilience as a concept applied to dealing with uncertainties such as climate change(Fig.2) (Collier et al., 2009; Lavorel et al., 2020; Liu et al., 2023; Pamukcu-Albersetal.,2023;Paolissoetal.,2019;Zhangetal.,2023). Sabokro et al. (2022) argue that ecological sustainability, as one of the most recognized conceptual frameworks, is based on the interpretation of human-environment relations through ecological knowledge. However, this perspective mainly focuses on physical dimensions while overlooking cognitive and perceptual processes. In contrast, landscape knowledge, as a more comprehensive approach, examines this relationship in both physical and mental dimensions, providing more effective strategies for achieving sustainability. Similarly, Hemmati (2015) emphasize that to enhance resilience in urban design, ecological approaches should be integrated with cultural and social considerations to achieve sustainability on a broader scale. In this regard, Bahrami & Hemmati (2020) highlight the necessity of designing flexible and adaptive systems to cope with environmental changes.

Urban resilience is dependent on biodiversity conservation and habitat provision (ecological resilience), sustainable water management (water resilience), mitigation of urban heat island effects (climate resilience), and ensuring

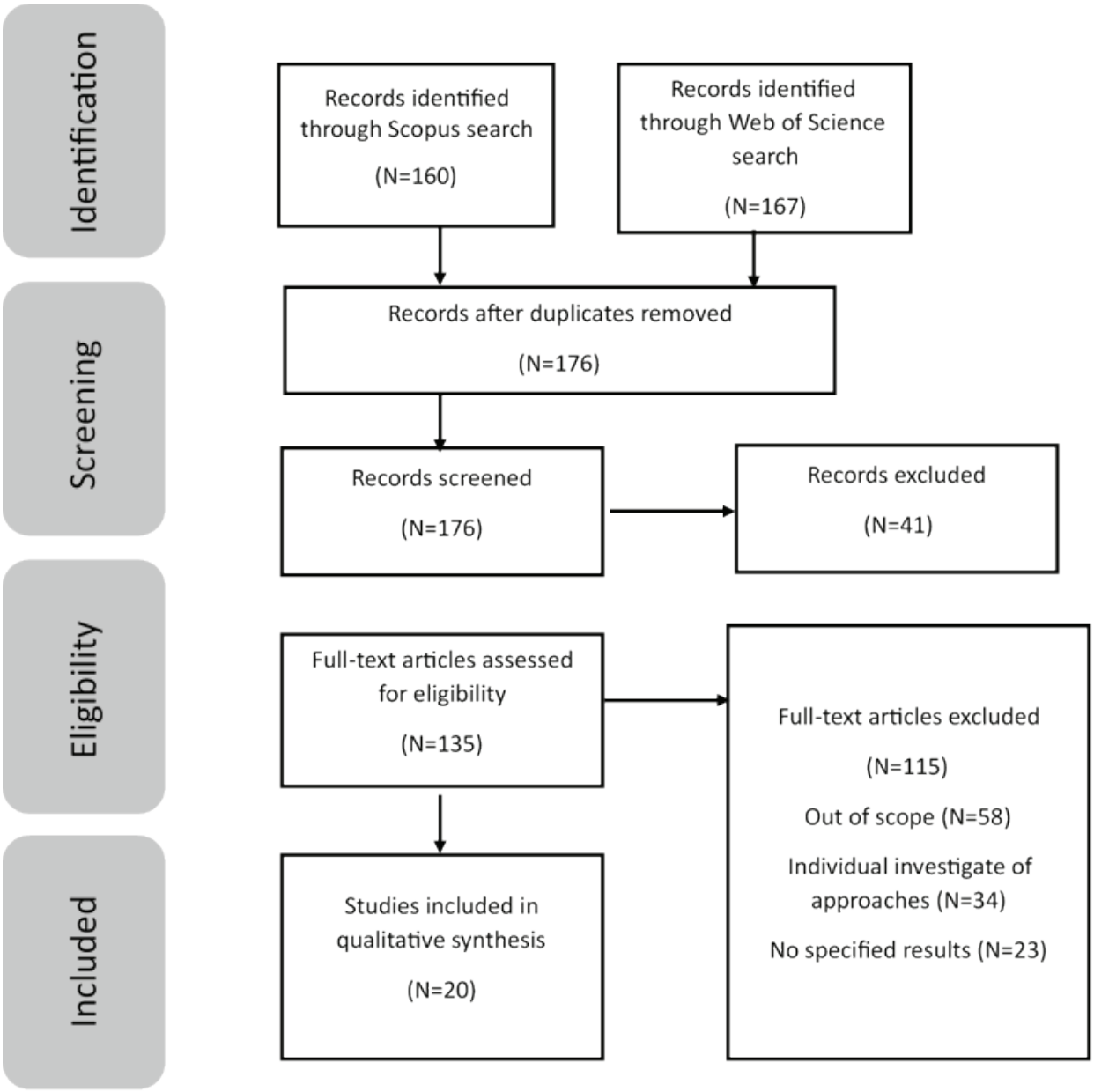

Fig. 1. Flowchart of Literature Review and Analysis in the Study. Source: Authors.

human health and social cohesion (social resilience) (Pamukcu-Albers et al., 2023). In essence, resilience is introduced as a dynamic systemic concept with an adaptive and holistic perspective, offering a framework for identifying and analyzing climate change adaptation policies (Collier et al., 2009). Therefore, effective adaptive capacity and increased ecological-social resilience are necessary to reduce risks and vulnerabilities in communities (Paolisso et al., 2019), highlighting the necessity of establishing an urban resilience assessment system and implementing "climate-adaptive city" guidelines (Liu et al., 2023).

Ecosystems require high ecological resilience to ensure sustainable regional development. Studies indicate that areas with high levels of urban expansion and increasing human activity intensity exhibit lower resilience compared to suburban areas. These regions, due to habitat degradation and biodiversity loss, have weaker sustainability and are more vulnerable to climate change. Strategies such as expanding ecological zones, enhancing biodiversity, controlling urban development, and optimizing water and soil resources can effectively improve resilience and adaptability (Zhang et al., 2023).

Ecosystems can adapt to environmental changes by protecting people from climate change impacts and providing solutions to preserve both material and non-material benefits through restructuring ecological functions. In the adaptation process, ecological resilience serves as an initial phase in ensuring ecosystem sustainability (Lavorel et al., 2020). Sabokro et

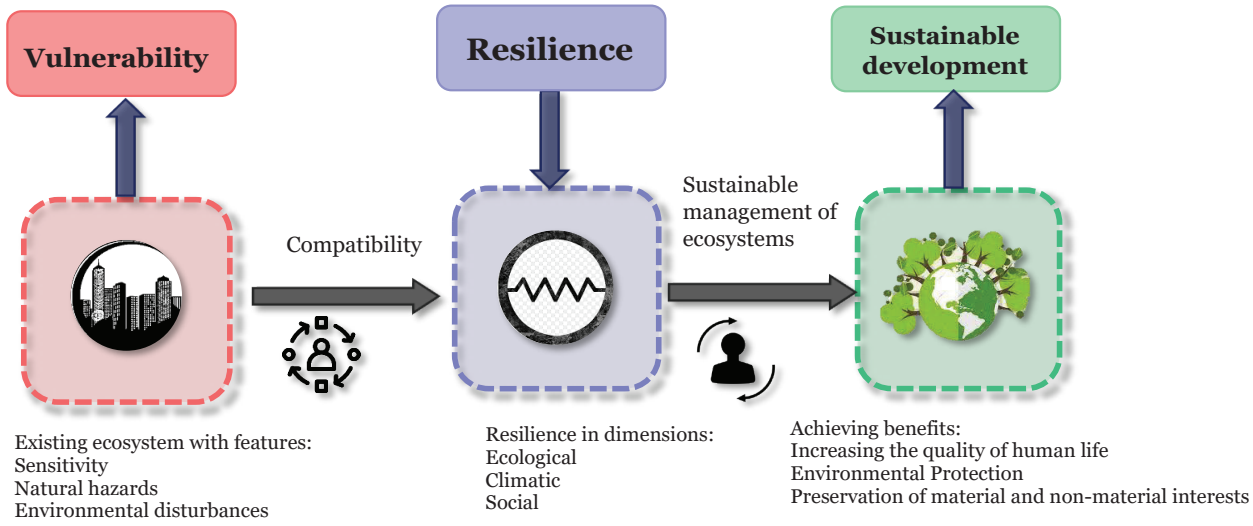

Fig. 2. Conceptual model for building resilience in response to climate change. Source: Authors.

al. (2023) assert that integrating theoretical and practical perspectives in natural environment planning not onlyaids in preserving urban ecosystems but also reduces associated social challenges.

Alongside ecological and social considerations, landscapes can provide a deeper understanding of human-environment interactions, contributing to improved urban living quality (Habibi, 2017). In this context, arid regions should be examined beyond merely being climatic phenomena, incorporating cognitive and perceptual human interactions to develop sustainable solutions for climate change adaptation (Ghiassee et al., 2019). Furthermore, research by Mansouri & Habibi (2011) underscores the importance of landscapes in maintaining urban environmental sustainability and reducing ecological vulnerability.

• Category two: The impact of ecological resilience on urban heat islands

With the rapid expansion of urbanization, ecosystems face increasing stress, leading to intensified ecological issues such as global warming (Davoudi, 2012). One of the major consequences of climate change is the formation of urban heat islands (UHIs). Since UHIs can have both direct and indirect negative impacts on urban populations, adopting appropriate strategies to address this phenomenon is essential (Geneletti & Zardo, 2016). Numerous studies have examined the phenomenon of UHIs, urban vulnerability to climate change, and resilience strategies (Duo et al., 2022; Leal Filho et al., 2018; Meerow & Newell, 2017; O'Malley et al., 2014; Qiao et al., 2023).

Given the expansion of urban development, ecological resilience is crucial for mitigating the effects of UHIs and is a prerequisite for sustainable community development. The urban ecological resilience assessment model, based on three fundamental resilience characteristics—resistance, adaptability, and vitality—was introduced by Duo et al. (2022). Studies indicate that resilience declines while UHIs intensify in dense urban areas with high construction activity. Enhancing urban sustainability and resilience through spatial land-use planning involves adopting an "ecosystem-based approach," where effective land management plays a crucial role in reducing climate change impacts. Identifying UHI hotspots and increasing ecological infrastructure have been proposed as solutions to enhance urban sustainability and resilience, thereby mitigating UHI effects (Meerow & Newell, 2017).

Several potential adaptation and mitigation strategies for UHIs have been suggested by urban designers and planners. These include improving open space design, increasing urban greenery, optimizing building materials, and emphasizing urban geometry. However, selecting an appropriate resilience strategy depends on the specific urban context (Leal Filho et al., 2018). Furthermore, the use of suitable vegetation—such as tall trees with dense canopies and hedges—has been found to significantly reduce UHIs, scoring 6.25 out of 10 in effectiveness. Water features, with a resilience score of 6.67 out of 10, are also impactful. Additionally, high-albedo materials, building orientation, and spatial arrangement contribute to UHI mitigation (O'Malley et al., 2014).

A related study highlights that the most significant impact on UHI reduction comes from managing the spatial expansion of identified heat-prone areas. To improve urban

thermal conditions and resilience, a structured management approach for these zones is necessary (Qiao et al., 2023). Thus, ecological resilience plays a crucial role in reducing UHI effects and enhancing building energy efficiency. Green infrastructure solutions such as green walls and green roofs not only lower energy consumption but also significantly improve microclimatic conditions and reduce ambient temperatures (Habibi & Kahe, 2024).

• Category three: The resilience approach to achieving health

Today, more than half of the world's population resides in urban areas, where city life significantly impacts human health. Climate change, depending on local conditions and vulnerabilities, affects human health and well-being in urban environments (Elmqvist et al., 2019). Most studies (Table 1) have explored the relationship between ecological resilience and public health across three dimensions: physical, mental, and social well-being (Billiot & Mitchell, 2019; Burrows et al., 2023; Thibodeaux, 2021; Wells, 2021; White et al., 2023).

Resilience research offers a broad avenue for understanding the factors that support health and well-being in the face of various stressors. In other words, health and well-being emerge from the balanced interactions among individuals, communities, and ecosystems (Athayde & Silva-Lugo, 2018; Willox et al., 2012). Nature-based solutions developed in collaboration with vulnerable communities (Seddon, 2022) enhance socio-ecological resilience at the community level (Adger et al., 2005; Folke, 2006; Lafortezza et al., 2018). Building ecological resilience can help individuals and communities respond more effectively to both acute and chronic stressors by improving emotional states and cognitive function. Additionally, it reduces the risk of physical diseases such as cardiovascular disease, stroke, and diabetes, ultimately decreasing mortality rates (White et al., 2023).

Thibodeaux (2021) defines multi-scale resilience as the ability of health-promoting factors (ranging from individuals to communities and socio-ecological systems) to maintain health and well-being despite chronic and intermittent stressors. In a model proposed by Billiot & Mitchell (2019), resilience serves as a response mechanism to counteract community vulnerabilities, ultimately achieving health and well-being as an outcome. Ecosystem resilience, as a mitigating factor against hazards and adversities, has positive effects on individual health and performance (Wells, 2021).

To link individual health with broader community resilience, implementing an ecological resilience framework focused on critical growth periods can enhance adult well-being. Additionally, fostering individual resilience contributes to building social resilience (Burrows et al., 2023).

Table 1. Reviews on the impacts of resilience on individual and community health. Source: Authors.

	Recovery resilience (Faster and more complete recovery,achieving balance after responding to a stressor)	Response resilience (Reduced reactivity to a potential stressor)	Preventive resilience (Reduced exposure to potential stressors)
Biological health	Improvement of the nervous system (Dedoncker et al., 2021) Reduced risk of mortality (Crouse et al., 2019; James et al., 2016) Enhanced immune system function (Roslund et al., 2020) Improved cardiovascular health (Jimenez et al., 2020; Lanki et al., 2017) Lower risk of stroke (Villeneuve et al., 2012)		
Psychological health	Emotional well-being Increased positive emotions (e.g., vitality), reduced negative emotions (e.g., anxiety, anger) (Beute & De Kort, 2018) Lower risk of mood disorders and reduced psychological distress (Dzhambov et al., 2019) Improved ability to cope with acute and chronic stress (Wells, 2021)		
	Cognitive health Restoration of attention and increased focus (Sianoja et al., 2018) Enhanced mindfulness (Fletcher & Sarkar, 2013) Reduction in rumination (Bratman et al., 2021) Strengthened cognitive resources (e.g., creativity, problem-solving, improved thinking and reflection) (Meuwese et al., 2021) Boosted self-esteem, self-confidence, and self-efficacy (Marselle et al., 2019)		
Social health	Improved interpersonal relationships (Davydov et al., 2010) Reduction in antisocial behaviors such as crime (Kuo & Sullivan, 2001) Decreased tendency toward social isolation (Astell-Burt et al., 2022; Pasanen et al., 2023) Increased social interaction and cohesion (Liu et al., 2020)		

•Category four: The impact of urban heat island on human health

Cities, due to increasing population and complex infrastructure and service patterns, are more vulnerable to climate change. The effects of these changes have numerous consequences on health, social well-being, and human capital (Le Tertre et al., 2006). Numerous studies (Table 2) have examined the impact of urban heat islands (UHI) on individual and community health(Heaviside etal., 2017; Huang etal., 2020; Shahmohamadi et al., 2011; Wong et al., 2018).

The urban heat island effect is recognized as one of the most significant hazards affecting public health and quality of life. The direct impacts of this phenomenon on physical health include an increase in various diseases such as heatstroke, cardiovascular diseases, and mortality risks (Wong et al., 2018), with vulnerable groups, particularly the elderly, experiencing the most adverse health effects due to rising temperatures (Heaviside et al., 2017).

Studies on the impact of rising temperatures on emotional states, including mood swings, restlessness, irritability, aggression, and even suicide, indicate a significant shift from thermal comfort stability to emotional instability as temperatures increase (Huang et al., 2020).

Table 2. Examples of studies and reviews on the impact of urban heat island on individual and community health. Source: Authors.

	Biological health	Psychological health	Social health
Urban heat island	Increased mortality risk (Hajat et al., 2014; Li & Bou-Zeid, 2013) Respiratory diseases (D'Ippoliti et al., 2010) Increased cardiovascular diseases (Jenkins et al., 2014) Heatstroke (Glaser et al., 2016) Increased infectious diseases (Campbell-Lendrum et al., 2015)	Depression and anxiety, emotional disorders (Huang et al., 2020;Isaksen et al., 2015)	Reduced social interactions, and decreased work performance (Kjellstrom et al., 2016)

The urban heat island effect can also have broader indirect consequences on communities and infrastructure. Agricultural health, human settlement patterns, changes in rainfall patterns, energy consumption, transportation, industry, environmental quality, and other infrastructure-related aspects that influence human quality of life are all within the scope of UHI impacts. Additionally, mitigating the urban heat island effect can lead to energy savings, improved air quality, enhanced environmental conditions, and consequently, improved public health in urban spaces (Shahmohamadi et al., 2011).

Discussion

The results of this study indicate that the connection betweenecological resilience, the urban heat island (UHI), and bio-psycho-social health can be explained within a multilayered and systemic framework. In the proposed model (Fig. 3), four main layers are identified: the ecological resilience layer within the natural environment, the urban heat island layer within the urban context, the bio-psycho-social health layer, and finally, the overarching layer representing "bio-psycho-social health based on nature-centered ecological resilience." Each of these layers consists of specific concepts and components that dynamically interact to create a cohesive structure for analyzing and improving resilience and health in urban environments.

In the lower layer of the model, key concepts of ecological resilience such as diversity, modularity, vitality, disturbance absorption, resistance, distribution, and density are positioned. These concepts serve as the foundation of resilience in natural and urban ecosystems, reflecting the ecosystem's ability to withstand and absorb environmental disturbances. For example, biodiversity and modularity help maintain system dynamics and prevent collapse in the face of disruptions, while resistance and disturbance absorption indicate the system's capacity for rapid response and functional recovery following external stresses (such as climate change or pollution).

From the perspective of indicators and metrics derived from previous research, this layer includes criteria such as vegetation cover percentage, species diversity index, connectivity of green patches, urban form indicators (e.g., permeable surface ratio), and ecosystem habitat quality. These metrics play a crucial role in quantitatively assessing ecological resilience and have been widely utilized in previous studies.

In the second layer, concepts such as resistance, density, thermal patterns, energy efficiency, urban morphology, and internal system reorganization are included. This layer illustrates how land use changes, high building density, low-albedo materials, and reduced green spaces contribute to the formation and intensification of the urban heat island (UHI) phenomenon.

The primary metrics in this layer include surface temperature, the temperature difference index between the city center and suburbs, green coverage percentage, the type and color of building materials, and the height and form of structures. Numerous studies have demonstrated that modifying urban spatial patterns, using reflective

materials, and expanding green spaces can significantly mitigate UHI effects and
enhance urban resilience.

The third layer of the model focuses on the three dimensions of human health: biological, psychological, and social health. Key concepts in this layer include interaction, recovery, capacity building, resistance, and adaptation. Findings indicate that ecological resilience and mitigating UHI effects can lead to substantial improvements in biological health indicators (such as reduced cardiovascular disease risks, enhanced immune function, and lower mortality rates). Moreover, providing natural environments and controlling ambient temperature contribute to improved psychological health (reducing stress, anxiety, and depression) and enhanced social health (increasing interactions and social cohesion). Indicators related to this layer include heat-related disease prevalence, psychological health metrics (such as anxiety, depression, and anger), social cohesion levels, interpersonal interactions, and a sense of vitality. These metrics have been widely validated in urban health and ecological studies.

In the final layer of the model (Fig. 3), there is a complete overlap between ecological resilience, UHI mitigation, and human health components. Key concepts in this section include integration, stressor reduction, self-regulation, and recovery. This layer highlights that adopting a nature-based approach can systematically reduce climatic pressures on cities while simultaneously ensuring overall community well-being and health. In other words, improving a city's ecological conditions and controlling UHI effects reinforce bio-psycho-social resilience in an interconnected manner.

Conclusion

This systematic review examines the relationships between ecological resilience, urban heat islands, and human health within the context of climate change and urban sustainability. By analyzing 28 scientific studies from a pool of 188 research articles, this study identifies key assessment criteria and common components among these three interrelated concepts. The findings emphasize the multidimensional nature of resilience in urban environments and demonstrate that achieving urban sustainability is not possible solely through ecological interventions or health-oriented policies. Instead, addressing complex urban challenges requires a comprehensive, multilayered, and system-based approach (Fig. 3).

First, ecological resilience is recognized as a fundamental strategy for mitigating climate change-related disturbances, particularly in cities affected by UHIs. This study confirms that key resilience attributes—such as diversity, modularity, connectivity, adaptive capacity, and transformation potential—play a crucial role in strengthening urban sustainability. However, the precise quantitative impact of each of these attributes on reducing UHI effects and improving public health has not been fullyestablished, highlighting the need for further empirical research using simulation-based modeling.

Second, the findings emphasize that UHIs create significant vulnerabilities in densely populated areas, affecting thermal comfort, energy consumption, and overall human well-being. While previous studies have primarily focused on biophysical mitigation strategies (such as increasing urban vegetation, modifying building materials, and optimizing urban morphology), fewer studies have examined the social and behavioral dimensions of UHIs and their interaction with community resilience. This study underscores the importance of integrating nature-based solutions, adaptive urban design, and participatory governance into resilience frameworks, which can enhance both ecological and human-centered responses to urban heat challenges.

Third, this systematic review highlights the strong interconnection between human health outcomes and urban resilience strategies for thermal adaptation. Specifically, biological, psychological, and social health indicators are significantly influenced by exposure to UHI effects. When ecological resilience is effectively implemented, it can reduce cardiovascular risks, strengthen the immune system, and improve mental health by fostering restorative environments and enhancing social cohesion. However, this study also identifies significant research gaps in social resilience, particularly regarding mental health, social adaptation, and climate resilience planning justice, which require further interdisciplinary investigations.

From a theoretical perspective, this study proposes a network-based resilience framework that conceptualizes ecological resilience, UHI mitigation, and public health as interdependent components within an adaptive urban system. This framework illustrates how feedback loops between environmental stressors, resilience mechanisms, and health outcomes influence urban livability and long-term sustainability. Future research should focus on quantitative models to assess resilience thresholds, longitudinal studies on health adaptation, and policy-driven interventions that integrate climate adaptation with public health strategies.

Finally, this study emphasizes that urban resilience should be regarded as a multi-scalar and interdisciplinary challenge that goes beyond conventional ecological or health-centered interventions. Addressing UHI effects requires synergistic urban planning strategies that integrate ecological, social, and technological dimensions. Future research should explore how dynamic adaptive processes—such as self-organization, recovery potential, and socio-ecological transformation—can shape novel urban resilience frameworks that actively enhance both environmental sustainability and human well-being.

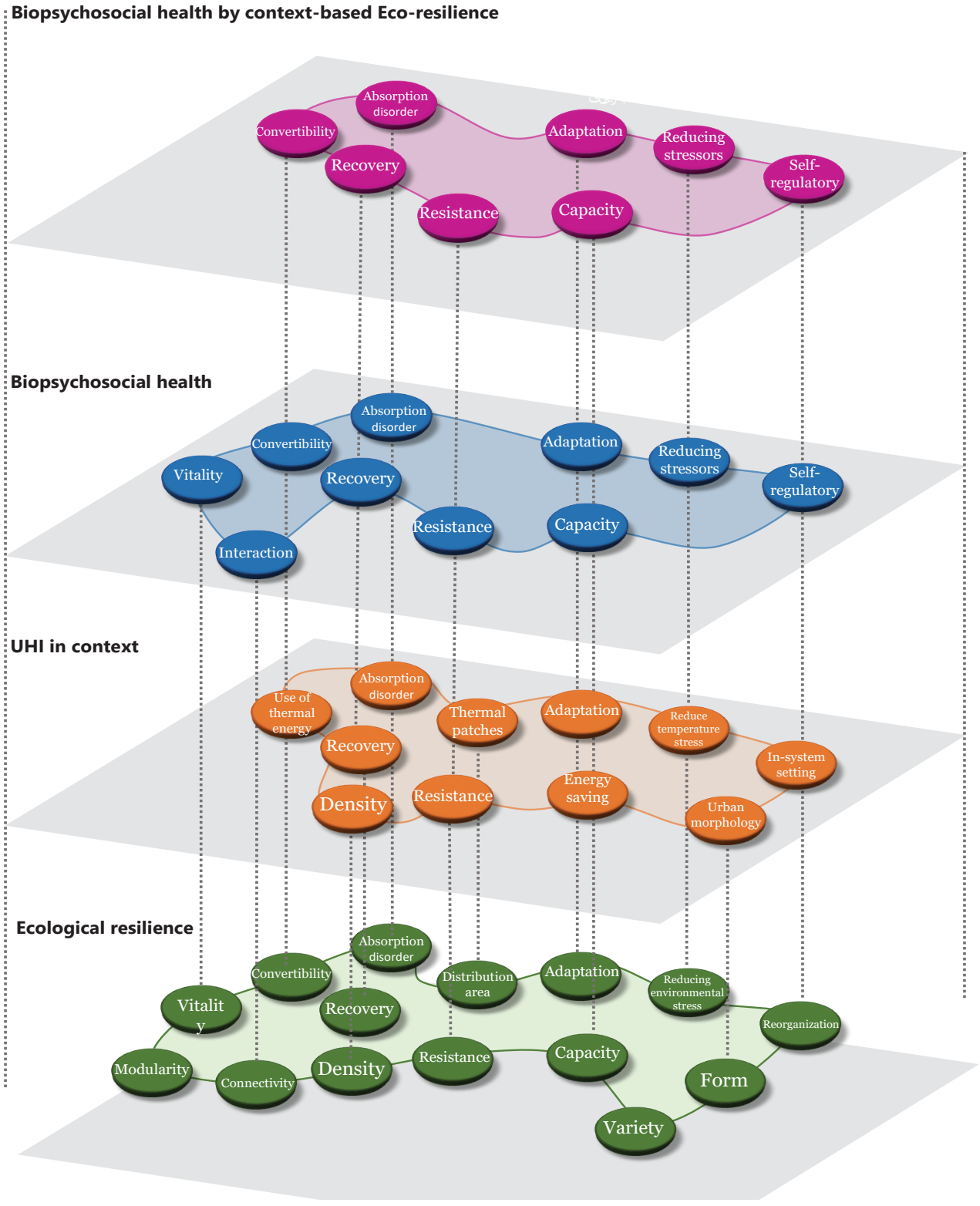

Fig. 3. Integrated network of health, ecological resilience, and urban heat island. Source: Authors.

Endnotes

*This article is derived from the master's thesis in landscape architecture by " Mohaddeseh Heidari", titled "Redesigning the Urban Landscape of Kasa'i Street in Shiraz with an Ecological Resilience Approach, Focusing on Health and Mitigating the Urban Heat Island Effect", under the supervision of Dr. "Amin Habibi", which was defended in 2024 at Shiraz University.

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