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CLIMATE CHANGE ADAPTATION IN INFRASTRUCTURE DEVELOPMENT: INSIGHTS FROM SCIENCE AND ISLAMIC ENVIRONMENTAL ETHICS

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Abstract:

Climate change has emerged as a growing challenge to transportation, water and energy supplies, and urban infrastructure. Such systems are vulnerable to increased temperatures, heavy rain, floods, droughts, and other risks and hazards that may impair their safety, performance, and service life. This is a narrative review of the research concerning climate-resilient infrastructure and Islamic environmental ethics. The three discussed concerns include the risk of infrastructure, adaptive mechanisms, and three Islamic ideals: Khalifah (stewardship), Mizan (balance), and Amanah (trust and responsibility). The scientific approaches are divided into four areas: resilient design and risk-based planning, sustainable materials and efficient resource use, green and

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nature solutions, and monitoring, modeling, and intelligent technologies. Islamic ethics introduces ethics to these technical approaches. Khalifah believes in planning and development of the community. Mizan stresses the necessity to work on the balance between development and environmental limitations. Responsible decisions must be made in the life cycle of infrastructure for Amanah. Malaysian examples, such as the Stormwater Management and Road Tunnel (SMART) and the Green Building Index, show how these ideas can be applied. The review identifies four main benefits of this integration: responsible use of resources, long-term resilience, fair distribution of benefits and risks, and responsibility to future generations. Future studies should develop and test an Islamic ethical assessment framework for climate-resilient infrastructure.

Keyword:

Amanah; Climate Change Adaptation; Infrastructure Development; Islamic Environmental Ethics; Khalifah; Mizan

Introduction

Climate change is increasing the risk of floods, heatwaves, storms, and droughts. These hazards threaten communities and important infrastructure, including roads, electricity systems, water-supply networks, and transport facilities (Hussein et al., 2024; Pal et al., 2025; Rathnayaka et al., 2023; Vlachogiannis et al., 2026). Many existing assets are old and were designed using past climate data. They must therefore be adapted to remain safe, functional, and sustainable under future climate conditions (Vlachogiannis et al., 2026).

Nature-based solutions and green infrastructure can reduce urban heat, improve air quality, control stormwater, and lower flood risk (Belčáková et al., 2019; Seidu et al., 2025). However, adaptation is often limited by lack of funding, ageing assets, weak institutional capacity, and policies that focus on technical performance but give less attention to ethics and social justice (Al-Jayyousi et al., 2023; Pal et al., 2025).

Islamic environmental ethics can contribute to improving the infrastructure decision-making system. Khalifah (stewardship), Mizan (balance), Amanah (trust), Adl (justice), and mas'-u liyyah (responsibility) are values that proffer an avenue to safeguard lives, public property, nature, and people who are considered vulnerable (Hussein et al., 2024; Islamy et al., 2025). In infrastructure developments, they facilitate judicious site selection, optimization of resources, equitable distribution of benefits and risks, maintenance, and sustainable public good.

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Although infrastructure resilience and Islamic environmental ethics are known and studied well separately, few studies associate them in practice.

This article reviews the contributions of Islamic environmental ethics toward climate-resilient infrastructure. It attempts to answer three questions: (1) How will climate change impact major system infrastructure? (2) What scientific techniques can minimize these risks? (3) How can planning, design, construction, operation, and maintenance of infrastructure be guided by Khalifah, Mizan, and Amanah?

Review Methodology

This study adopts a narrative review and a thematic analysis. It reviews peer-reviewed journal articles, review papers, conference papers, and related academic books. The sources address climate change, infrastructure vulnerability, resilient and sustainable infrastructure, green and nature-based solutions, and Islamic environmental ethics. The literature is split into three themes: (i) climate risks and their social and economic impact on infrastructure; (ii) scientific adaptation techniques including resilient design, sustainable materials, green or nature-based solutions and technology; and (iii) the role of infrastructure governance using the tools of Khalifah, Mizan and Amanah. The study then made a comparison between the purpose of each technical method and the duties that are associated with the three Islamic principles. This paper is a narrative review and thus provides a conceptual discussion. This is not a systematic review or meta-analysis.

Climate Change and Infrastructure Vulnerability

Climate change impacts infrastructure performance, longevity, and safety. Material damage and failure can occur at greater rates with higher temperatures and changing rainfall. Research conducted in various areas reveals greater physical damage, disturbances in service, and economic loss. The risks are greater in locations with outdated or under-resourced infrastructure, or where multiple hazards exist. The energy, transport, water, and industrial and social infrastructures can be impacted by heatwaves, heavy rainfall, droughts, storms and sea-level rise (Forzieri et al., 2018). This impact can occur simultaneously and compound one another, thereby exacerbating the harm.

Extreme weather and long-term climate change have impacts on transport infrastructure. Increasing temperature, sea-level rise, and increased precipitation are among the major threats (Chirisa et al., 2023; de Abreu, 2026; Hirsch & Kunstman, 2014). Both temperature and moisture fluctuations affect the performance of road pavements. Asphalt binders are susceptible to softening at high temperatures and may produce rutting. Prolonged rainfall could weaken the subgrade and lead to higher numbers of potholes. These issues can reduce the lifespan of pavements and make pavement maintenance and rehabilitation more expensive (Hosseini et al., 2024). Climate change can also alter the design conditions for pavements and lead to a greater risk of cracking. Thus, adaptation is required to ensure the safety of roads (Hemed et al., 2020). The railway network and air routes are also under threat. Sea-level rise and storm surge could affect airport functions, and high temperatures could lead to buckling of railways (Palin et al., 2021).

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Flash floods and the urban heat island effect are becoming a threat in urban areas. Flooding can be exacerbated by poor drainage conditions and increasing urbanization, particularly in areas where there are high population densities. Likewise, drought and precipitation variability may diminish assurance of water supplies. Sea-level rise and rapid development are a threat to the peri-urban and coastal areas. In some instances, peri-urban or suburban areas might be more vulnerable than the urban centers (Chang et al., 2017; He et al., 2019; Permana & Petchsasithon, 2020). Climate adaptation should therefore be included in urban planning. Useful measures include water-sensitive urban design, green infrastructure, and nature-based solutions (Peker, 2025).

Climate change also affects the economy and society. Its impacts include slower economic growth, lower labour productivity, health problems, social inequality, and migration. Some early effects may be small, and a few regions may receive short-term benefits. However, long-term damage is expected to be larger and unevenly distributed, especially among vulnerable people and developing countries (Tol, 2010). The main causes include environmental damage, loss of infrastructure and biodiversity, and wider social and economic inequality (Tol, 2009). Table 1 summarises the main economic sectors affected by climate change.

Table 1. Key Sectors Through Which Climate Change Affects Economies

Effect	Principal finding	References
Agriculture and food	Lower yields, crop failures, and food insecurity	Adom, 2024; Loucks, 2021
Labour productivity	Heat reduces outdoor and non-air-conditioned work, slowing growth	Adom, 2024; Méjean et al., 2024
Capital and land	Sea-level rise and storms damage infrastructure and coastal assets	Chen et al., 2020; Loucks, 2021
Health and mortality	Heatwaves, disease, and air pollution increase health costs and reduce welfare	Carleton & Hsiang, 2016; Rawat et al., 2024

Scientific Approaches to Climate-Resilient Infrastructure

The scientific methods can be grouped into four related areas. First, resilient design and risk-based planning use updated hazard data, suitable design criteria, system redundancy, better drainage, and planned maintenance. Second, sustainable materials and efficient use of resources can reduce environmental impacts and improve durability. Examples include longer-lasting materials, recycled materials, efficient water and energy use, and life-cycle assessment. Third, green infrastructure and nature-based solutions use vegetation, permeable surfaces, wetlands, retention systems, and ecosystem restoration to control runoff, heat, and erosion. Fourth, monitoring, modelling, and smart technologies use sensors, climate projections, digital models, and early-warning systems to detect damage and support early action (Belčáková et al., 2019; Mahmood et al., 2024; Seidu et al., 2025; Vlachogiannis et al., 2026). These four areas show that adaptation requires coordinated decisions throughout the asset life cycle.

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Islamic Environmental Ethics

In Islamic interpretation, it is a moral duty and religious mandate to take care of the environment. The Holy Book of the Quran and Hadiths encourage people to conserve nature, use resources wisely, and ensure a balance between nature and environment. Khalifah (stewardship), Mizan (balance), and Amanah (trust) concepts offer a guideline to the wise handling of the environment by human beings. They must also be environmentally friendly and consume as few natural resources as possible (Gulzar et al., 2021). Islam also instructs us not to be extravagant but to be moderate and to utilize resources fairly. These principles lead to sustainable growth and climate change adaptation, environmental safeguarding, and developing resilience infrastructure planning (Haider, 2025; Sadali, 2023).

The idea of Khalifah (Stewardship) means that man has a duty to take care of the earth. As far as infrastructure and city planning are concerned, this requirement can be used to minimize wastage, manage resources wisely, and protect the basic community demands. It is also useful in ensuring equitable ruling. When decisions are made about natural resources, communities, the environment, and living things should be considered. Khalifah and justice are associated with climate change, the environment, pollution, and unsustainable development. They encourage moderation, conservativeness and equal use of resources. The concept of Khalifah in Islamic environmental studies is regarded as both a moral and spiritual obligation, based on the notion of justice and balance. Its use can be expanded to policy, education, management and planning of water resources, and planning of community programs to enhance sustainability, climate resilience, and social equity among Muslim communities.

Mizan (Balance) is a concept that denotes balance, moderation, and harmony in the creation of Allah. Natural resources, human beings, plants, and animals depend on each other. However, this equilibrium can be disrupted by pollution and waste and by the uncontrolled use of resources. These activities can lead to climate change, loss of biodiversity, and environmental degradation. Thus, Islam calls for the proper utilization of available resources and abstaining from harmful activities. The Quran also emphasizes the need for balance in human life and environmental management. In sustainable development, Mizan promotes moderation, conservation, and fair use of resources. For climate adaptation, it facilitates infrastructure that is useful and resilient to protect ecosystems. Table 2 illustrates the interconnection of Mizan and other Islamic issues in relation to infrastructure decisions.

Infrastructure Applications of Khalifah, Mizan, and Amanah

These three principles come into play when they are applied to real infrastructure decisions. Khalifah considers engineers, planners, clients, and authorities to be stewards of public assets. It helps in risk-based planning, prevention and maintenance, public consultation, and protection of vulnerable users. Mizan aims to find the right balance between the service requirements and cost, environmental constraints and social implications. It facilitates life-cycle assessment, low-impact development, efficient use of resources, and avoidance of sub-optimal adaptation decisions. Amanah considers budgets, materials, land, data, and infrastructure performance as a trust. It involves open purchasing, skilled design, safety audits, and maintenance, and choices that do not pass the risks or costs on to later generations.

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Table 2. Ethical Principles Translated into Infrastructure Decisions

Principle	Infrastructure duty	Illustrative decisions	Expected contribution
Khalifah	Stewardship of public assets and ecosystems	Risk-informed planning; inclusive consultation; preventive maintenance	Protection of public welfare and vulnerable groups
Mizan	Balance development with ecological and social limits	Life-cycle assessment; nature-based solutions; demand and resource efficiency	Avoidance of overdesign, ecological damage, and maladaptation
Amanah	Accountable management of entrusted resources	Transparent procurement; safety assurance; monitoring; maintenance records	Reliability, integrity, and intergenerational responsibility

Integrating Science and Islamic Ethics in Infrastructure Development

Scientific methods outline ways that infrastructure can resist, absorb, recover, and adapt to climate hazards. Islamic ethics describes why it is necessary to make these decisions in a way that will preserve life, resources, justice, and future generations. Together, they contribute to making technical decisions by incorporating ethical considerations. A resilient option should not be selected just to satisfy a performance criterion. It should also be responsible in the use of resources, equitable in the sharing of benefits and risks, demonstrate good environmental stewardship, and be held accountable over time.

The Stormwater Management and Road Tunnel (SMART) is a good example of multifunctional climate adaptation in Malaysia. It is a combination of stormwater diversion and use of roads in order to reduce the frequent flooding in the center of Kuala Lumpur. The Green Building Index (GBI) is a green Malaysian rating tool. It has a set of measurable indicators of energy efficiency, water efficiency, materials and resources, indoor environmental quality, site planning, and innovation (Green Building Index, n.d.; SMART, n.d.). Khalifah, in an Islamic sense, is represented in SMART since it is a means of protecting urban communities and communal property. It also demonstrates the concept of Mizan since a single infrastructure system can serve more than a single purpose. During building deliveries, GBI helps Mizan use resources effectively and assists Amanah with commitments that are transparent and measurable.

The integration comes with four prominent advantages. First, it promotes the responsible use of materials, land, water and energy. The aforementioned options are evaluated based on life cycle evidence and the Islamic principle of 'not wasting'. Second, it serves to enhance long-term resilience by considering maintenance, adaptation and continuous service as

responsibilities. Third, it helps to promote fairness by raising the question, "Who gets protected and who remains at risk?" Fourth, it safeguards future generations by not taking short-term savings that could lead to safety, environmental, or maintenance issues. These are the benefits that relate engineering evidence to ethical governance.

Conclusion

Climate change poses risks to the safety, performance, and uninterrupted operation of infrastructure. The primary hazards are heat, heavy rains, flooding, drought, and climate multiphases. The adaptation strategies can be categorized into four domains: resilient design and risk-based planning; sustainable materials and efficient use of resources; green and nature-based solutions; and monitoring, modeling, and smart technologies. Islamic environmental ethics provides clear responsibilities in the development of infrastructure. Khalifah must attend to all the public assets and needs of people. Mizan needs to be achieved through a balance of development, environmental constraints, and social needs. The management of Amanah needs to be transparent, competent, and responsible throughout the life cycle of the assets. Together with science, these can be used to increase resource efficiency, sustainability, equity, and accountability for future generations. This approach can be seen in practice in Malaysian initiatives like SMART and GBI. Future studies should create and evaluate a framework of ethical assessment for climate-resilient infrastructure with an Islamic perspective. Indicators of resource efficiency, ecosystem protection, fairness, transparency, adaptability, maintenance responsibility, and long-term risk should be included in the framework. It can be tested for the first time in Malaysian transport, drainage, and public building projects.

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