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Flood Resilient Smart Cities and Urban Safety in a World Affected by Climate Change

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Abstract

The paper aims to investigate how smart cities can utilize new technologies to enhance their flood resistance and overall security for their populations. The paper addresses the increasing challenges posed by urbanization, climate change, and their associated impacts on flooding and extreme weather events. The theme is justified considering that the UN reports 55% of people live in cities, which produce 70% of global CO_2 emissions. Human activities causing greenhouse gases contribute to rising global temperatures. Urban soil's poor water absorption disrupts the hydrological cycle, increasing flood risks. The development of "smart cities" and the application of "Internet of Things" technology can increase our awareness of cities' risks. Therefore, decision-makers have access to more information, allowing them to act in the relevant places and achieve beneficial results regarding urban security and flood resilience. The subject that needs to be researched is, "How can smart cities leverage new technologies to become flood-resistant and more secure for their populations?" The paper's hypothetical-deductive methodology had support from both American and international bibliographic and documentary data.

Keywords

Smart Cities and Development, Metropolitan Sustainability Areas, CO_2 Emissions, Greenhouse Gases, Flood Resilience

1. Introduction

Water, an item necessary for human survival, has meant that since the earliest times, from the beginning of life in community, cities were emerging and forming near access points to the waters, often using them for food production, but modern cities increasingly distance the inhabitants as individuals from nature. But it does not alienate them as a group, because it is always dependent more and more on the environment in which it lives for food production and logistics (especially naval), which leads us more and more to disastrous situations.

Cities make up more than 80% of the world's GDP (United Nations, 2018). This means that urban development has been a big part of the world's economic growth. Industrialization, globalization, and technological advancements are just a few of the factors that have contributed to cities' growth. But urban development has also been linked to a number of problems, such as pollution and damage to the environment.

One of the biggest worries about urban growth is how it affects pollution levels. Cities are major air and water pollution sources, which can negatively affect human health and the environment (World Bank, 2019). Also, urbanization can destroy natural habitats and lead to biodiversity loss.

The process of urbanization changes how impermeable the soil is. This makes it harder for the soil to absorb rainwater and return it to the natural hydrological cycle. This can cause drought in watersheds. The microclimate of cities is also directly affected by higher greenhouse gas emissions and less porous soil. This causes heat islands and affects how often floods happen, which have become more common in the last 20 years.

Floods cause damage worth millions of dollars and hurt billions of people. Over the last 20 years, this has cost the economy $651 billion. Moreover, the outlook is not positive, as the urban population is expected to grow and cities are likely to be even more affected by floods in the coming years, posing an imminent concern for decision-makers.

Despite these challenges, urban development remains a crucial component of economic growth. The World Bank has emphasized the importance of sustainable urban development, balancing economic growth with environmental and social sustainability (World Bank, 2020). By investing in green infrastructure and promoting sustainable practices, cities can reduce their environmental footprint while continuing to drive economic growth.

In the 1990s, the idea of "smart cities" came up in a technical setting, where the main concern was putting technology into city infrastructure. At first, the social aspect wasn't a big deal. The change in this paradigm leads to the development of a perception of the social element, meaning that the smart city should not only optimize infrastructure and produce more satisfactory economic results but also improve the population's quality of life by providing more security and resilience to the city.

The contemporary concept of a smart city implies that it must also be sustainable. Therefore, it is not enough to incorporate information technologies, the Internet of Things (IoT), and other sensing and monitoring technologies into the city, giving it greater capacity to manage data and information and optimize urban flows. It is also necessary to promote sustainability and urban resilience. Improving waste management, energy, access to the city, security, resilience, and the management of floods, storms, earthquakes, droughts, and other extreme weather events that put the lives and health of the population at risk is essential to establishing a smart and sustainable city.

IoT, 5G Internet, sensors and digital twins are some of the technologies that make smart cities possible tied to the new worldwide custom of every human being having a smartphone (Mawston, 2021), and facilitates the diffusion of information (*Usar O Sistema De Notificações De Exposição À COVID*-19 *No Seu Smartphone Android - Ajuda Do Google Play*, n.d.). These technologies are used to collect information and improve urban management actions, and also have functionalities that analyze the flows of the smart city. These technologies can also predict floods or other disaster scenarios using their collected data.

Considering all these things, the research question of this article is, "How can smart cities use new technologies to become less vulnerable to flooding and safer for their residents?" The paper took a hypothetical-deductive approach, supported by data from the United States, Europe, Asia, Africa, and other places.

The first part talks about how a growing urban population and the process of urbanization that comes with it lead to more impermeable soil, more air pollution, and more greenhouse gases, all of which make floods worse. In the second section, we look at how "smart cities" has changed, from its beginnings as a technical idea to its current focus on sustainability. In the third section, we elaborate on the new technologies used in smart cities and how they can be used to make cities less likely to flood.

2. Urban Development, Climate Change, and Flood Risk

Last April 2023, the World Bank (n.d.) estimated that, by 2050, 56 percent of the global population, or 4.4 billion people, would reside in cities and towns, as well as that, by 2045, the number of urban dwellers/would increase by 1.5 times to 6 billion.

This proportion is anticipated to increase, with the urban population projected to more than double by 2050, indicating that nearly 7 out of 10 people will reside in urban areas. In developing nations, where urbanization is occurring faster than in developed ones, the growth of urban populations has been especially rapid.

The global rate of urbanization is projected to increase from 56% in 2021 to 68% in 2050, resulting in a 2.2 billion increase in urban residents, primarily in Africa and Asia (UN-Habitat, 2022).

Multiple factors, including economic development, rural-urban migration, and natural population growth, contribute to urbanization despite a variety of social, economic, and environmental issues which it enhances, such as housing shortages, traffic congestion, air pollution, and increased greenhouse gas emissions (Glaeser, 2014). Many cities are implementing policies and initiatives to promote sustainable urban development in response to these challenges. For instance, one of the Sustainable Development Goals of the United Nations is to "ensure inclusive, safe, resilient, and sustainable cities and human settlements" (United Nations, 2015).

Rapid urbanization and global warming have had substantial repercussions for environmental sustainability in many regions of the world, particularly in terms of pollution and climate change. Policymakers and urban planners around the world are growing increasingly concerned about urbanization and the concomitant increase in pollution and greenhouse gas emissions. In this context, we underlie that rapid urbanization and industrialization should be concerned with environmental issues ranging from local ones, such as cities, where smoke disrupts the vision and health of residents and workers, to global ones, such as global warming, which has had significant implications for environmental sustainability, particularly in relation to pollution and climate change, in many parts of the world. It has done, particularly in the case of smart cities, to emphasize better integration of planning and public administration while protecting the natural environment to ensure resource preservation for future generations (Suzuki et al., 2010).

The impact of urban expansion on the environment can vary depending on a range of factors, including government policies, local practices, and measures taken at both the federal and local levels. Neglecting important considerations related to quality of life and ecological sustainability can result in an imbalance between the urban population and their surroundings, ultimately leading to adverse environmental outcomes for generations to come (Schiavon, 2021; Racchini et al., 2022). As smart cities continue to expand, it's important to consider how this growth impacts both the local environment and the city's functionality. To ensure the sustainability of these urban areas, efforts must be made to preserve and optimize natural resources while mitigating environmental pollution. Additionally, efficient management of facilities is crucial in maintaining a healthy and thriving city. This requires a collaborative effort from all stakeholders to create a sustainable and constructive future for smart cities. In the process of urban development, the fauna and flora may change as a result of decisions made by public authorities, private entities, and citizens, motivated by various reasons, some legally grounded and others not. These interventions can generate various outcomes and impacts on the environment and society. Therefore, urban expansion must be conducted with due consideration for both specific environmental issues and structural aspects, aiming to promote sustainability in urban areas (Aieta, 2016; Romani et al., 2023).

Many countries have specially suffered the natural climate phenomenon called El Niño Southern Oscillation (ENSO). Two opposite states, El Niño and La Niña, can cause the rise of surface temperatures due to the further surface to the east or west than normal. This typically occur every two to seven years and usually last for less than a year (Stallar, Poyinting, 2023).

The necessity of prevention to a regular situation also must lead countries to adopt mechanisms to face the problems related. The rise of rivers and lack of water or temperature increase are situations that must combine legislative measures with use of technology.

Governments and civil society can obtain information about when these situations could happen, what to do in order to prevent some damages and mainly how to interact with new technologies in order to live with climate change.

2.1. Urban Development and Climate Change

According to United Nations (n.d.), despite occupying less than 2% of the Earth's surface, cities are significant contributors to climate change, consuming 78% of the world's energy and producing over 60% of greenhouse gas emissions.

Human activities, such as transportation, industrial processes, power generation, trade, and the use of household fuels, are responsible for the release of air pollutants, which can be categorized according to their sources (Mayer, 1999: p. 4029). Even though cities are home to only 50% of the world's population, they are responsible for 70% of global CO_2 emissions, according to the OECD (2020).

As outlined before, approximately 70% of the world's population is projected to reside in urban areas by 2050, as urbanization continues to expand. In addition, urban land cover is projected to increase by a factor of five. In addition, transportation is responsible for 33% of all greenhouse gas emissions in major cities.

According to the findings of Diez et al. (2018), urban transportation within the European Union is responsible for almost 40% of CO_2 emissions from the overall transport sector, as well as 70% of emissions from other pollutants. The authors report that the European Commission, along with the Green Paper on Urban Mobility, emphasizes that urban areas witness 69% of road accidents, with one out of every three fatal accidents occurring within these city environments. These accidents disproportionately impact pedestrians and cyclists, who constitute the most vulnerable groups in this context. Moreover, the study highlights that urban congestion leads to an annual economic loss of approximately one hundred billion euros in the European economy, equivalent to around 1% of the EU's GDP.

Urban development has exacerbated climate change by causing greenhouse gas (GHG) emissions and making the soil less permeable. According to the United Nations Habitat (n.d.), urban areas account for 71% to 76% of CO_2 emissions from global final energy use. 70% of greenhouse gas (GHG) emissions originate from urban areas, and 90% of urban disasters are hydrometeorological in nature.

There are strong feedback loops between urban GHG emissions, and the risks posed by extreme weather events, making it impossible to ignore the interconnectedness of these issues, considering the association between disaster risk reduction and climate change in urban areas and the risks of cascading effects from such events (IPCC, 2018: p. 122).

The increase in global temperatures exacerbates a variety of human health problems, including heat exposure, waterborne and insect-borne diseases, as well as respiratory and cardiovascular diseases. However, both the costs of climate change on human health and the benefits of implementing climate change mitigation options remain difficult to estimate (IPCC, 2018: p. 57).

The relationship between urbanization and climate change is well-established, with cities contributing significantly to global carbon emissions (UN-Habitat, 2016). Goal 11 of the United Nations' Sustainable Development Goals (SDGs) calls for sustainable cities and communities, recognizing the need to address the environmental impact of urbanization (United Nations, 2015).

It is evident that the environmental impact of urbanization must be taken seriously if we are to address the urgent problems of pollution and climate change. Adopting sustainable practices and policies can help guarantee that our cities remain healthy and habitable for future generations.

2.2. Urban Development, Flood Risk, and Economic Damage

Water is an essential component for the sustainability of the environment and the development of smart cities (Oye, 2017). However, the process of urbanization is indispensable and brings about significant changes to the landscape and the environment. These changes manifest in the form of deforestation, degradation of natural areas, soil sealing, and inadequate urban drainage systems, all of which have a profound impact on the hydrological cycle (Corte, 2015).

Urbanization modifies the landscape and the environment through deforestation, degradation of natural areas, impermeabilization of soil, and inadequate urban drainage systems that change the hydrological cycle (Corte, 2015).

Urbanization makes the soil less permeable, a problem for groundwater sources and aquifers. This is especially true in large cities where the water supply comes from water that sinks into the soil from the surface. The time for this process to complete can vary greatly, from days to years (Cavalcanti, 2013).

The growth and spread of impermeable surfaces in cities pose major risks to both the natural and built environments. These hazards encompass heightened stormwater overflow, decreased water quality, elevated temperatures during summer, destroyed habitats for aquatic and land-based creatures, and reduced visual attractiveness of streams and surroundings (Barnes, Morgan, & Roberge, 2000).

The expansion of urbanization typically replaces natural vegetation cover with impermeable surfaces like roads, buildings, and parking lots (Hua et al., 2020). While urbanization offers many social and economic advantages, it poses environmental challenges, including forming urban heat islands (UHIs), water quality degradation, and reduced biodiversity (Xian & Crane, 2006).

The deforestation of urbanized areas (Buckeridge, 2015) generates great discomfort to the population, which begins to live on heat islands, and urban afforestation is an issue of relevance that must be inserted in environmental planning at all levels of government.

An urban heat island (UHIS) is a place where the land surface temperature is higher than in the nearby rural areas. UHIs can have wide-ranging impacts, affecting the local and mesoscale climate and human health, air quality, and ecosystem functions (Grimm et al., 2008).

Tucci (2004) says that flooding is a problem in big cities because of how the land is used, how much space is taken up, and how poorly urban drainage is managed. Floods often happen in urban areas because of bad planning, inappropriate land use, heavy rain, and changing tides.

Due to population growth in urban areas and the urbanization of cities with its natural processes of soil impermeabilization, reduction of the green regions, and alteration of the hydrological cycle, the chances of flooding in large urban centers increase by six to seven times (Tucci, 2015: p. 91).

24 factors cause floods, and 12 of those factors scored above 10% in the review of 45 sources. Floods were most often blamed on heavy rain, which was mentioned by 62% of sources. The second most frequently cited cause, urbanization-induced increased imperviousness, came in at 40%, then inadequate or poor drainage (33%), poor waste management leading to blocked drains (31%), and haphazard and unplanned development (24%). Floods were said to be caused by a lack of drainage facilities only 2% of the time. Climate change was considered a direct cause of floods by only 9% of the literature sources (Asiedu, 2020: p. 26).

In the same literature review, 62% of the sources said heavy rain was the most common reason for floods. Various terms were used to describe this phenomenon, including short extreme rainfall, extreme rainfall, heavy rainfall, heavy and intense rainfall, heavy storms, and torrential rains. Urbanization was the second most cited cause of flooding, usually linked to intense downpours, impervious surfaces, and inadequate drainage (Asiedu, 2020: p. 28).

This serves as compelling evidence that the impacts of a world where the global average temperature in 2019 exceeded preindustrial levels by 1.1 C are being felt through an increase in the frequency of extreme weather events such as heatwaves, droughts, flooding, winter storms, hurricanes, and wildfires. Despite improvements in early warnings, disaster preparedness, and response, resulting in fewer fatalities in single-hazard scenarios, it is evident that the increasingly systemic nature of disaster risk demands stronger disaster risk governance. The risks exacerbate the interplay between risk drivers such as poverty, climate change, air pollution, population growth in hazard-prone areas, uncontrolled urbanization, and loss of biodiversity (Undrr, 2020: p. 7).

Between 2000 and 2019, floods were the most prevalent type of disaster, resulting in 651 billion US dollars in economic damage and 104,614 deaths, accounting for 44% of all such events and affecting 1.6 billion individuals across the globe, which is the highest figure for any disaster type. On average, there were 163 flood events per year during this time period, making it the most common type of event. Asia has been the most affected continent by flooding, with 41% of all flooding events occurring there and a total of 1.5 billion people impacted, representing 93% of all people affected by floods globally. The deadliest flood events during this time frame occurred in India in June 2013 (resulting in 6054 fatalities), Haiti in May 2004 (resulting in 2665 deaths), and Pakistan in July 2010 (resulting in 1985 deaths). Even though floods can have severe consequences, they are a type of disaster that can often be prevented through affordable primary prevention mechanisms, such as constructing dams, dykes, and drainage systems (Undrr, 2020: pp. 16-25).

The heavy rains that hit the Brazilian state of Sao Paulo on February 12, 2023, resulted in more than 50 deaths, more than 2251 evictions of people at preventive risk, 1815 cases of homelessness, more than 14 partial operations, and three highway closures. Furthermore, the SMS alert system triggered 2.6 million alerts; however, only 30,000 devices received the message, preventing knowledge of the imminent risk of flooding (Rocha, Lorenzetti, & Magalhães, 2023).

3. The Evolution of Smart City Definition

The pursuit of a liberated and equitable existence, coupled with a sustainable ecosystem, for present and future inhabitants, can be facilitated through the utilization of web-based interactive systems. These systems are deemed fundamental to the concept of citizen science, which we posit should be a customary practice in the context of smart cities. By employing such systems, the advancement of fairness can be fostered and harmonized with the principles of competition according to Batty et al. (2012).

In that regard, the dynamic nature of urban areas results in an ongoing process of defining a smart city, with multiple stakeholders offering diverse perspectives on the matter, according to Yin et al. (2015).

According to Samih (2019), the concept of smart cities emerged in the 1990s in the United States, focusing on the impact of new information and communication technologies (ICTs) integrated into the infrastructure of cities. At that time, the California Institute for Smart Communities was concerned with planning and implementing information technology in cities and how communities would become smarter (Alawadhi et al., 2012). Later, the Governance Center at the University of Ottawa (Canada) began criticizing the idea that smart cities disregarded social aspects (Samih, 2019).

Aieta (2016) says that the first idea of smart cities is related to individuality, especially in terms of the existence of certain parts of daily life, like infrastructure and transportation, as well as the use of communication and information technologies that can help with the management and development of the economy, based on a model and standard that emphasizes good governance for the people who live there.

The initial concept of smart cities is based on a spectrum of dualism between the lack of conscious collective goals and what the true values and responsibilities of the state as a unit would be, in a liberal and minimal interventionist manner, focusing on economic, organizational, and managerial issues without considering social influence as a whole (Aieta, 2016; Guimarães & Araújo, 2018).

According to Lima et al. (2021), smart cities exhibit general characteristics such as a smart environment, smart economy, smart people, smart governance, and smart living. These encompass specific and comprehensive dimensions that can aid in creating factors and elements for city ranking, evaluation, and indication. The economy plays a competitive role, with a focus on social aspects and human capital in people, increased community participation in governance, urban mobility and transportation with enhanced local and international accessibility, along with the necessary infrastructure to support efficient, innovative, secure, and sustainable functioning of Information and Communication Technologies (ICTs).

An integral component of a modern metropolis is the conscientious utilization of natural resources, which necessitates sustainable administration and safeguarding against contamination. These practices are vital for maintaining a superior standard of living. Furthermore, guaranteeing the safety of individuals and the community, furnishing superior educational institutions, cultivating social unity, exhibiting reverence for local infrastructure, and advocating for healthy living environments and adequate housing for citizens are all indispensable elements of intelligent urban living and quality of life. These concepts have been investigated and expounded upon by Lima et al. (2021) and Brasil (2021).

Harrison et al. (2010: p. 12) define a smart city as a city that is "connected to the physical infrastructure, the IT infrastructure, the social infrastructure, and the business infrastructure to leverage the collective intelligence of the city."

Smart cities must have key IT aspects, such as being instrumented, interconnected, and intelligent. The first element allows for the effective connection of the physical and virtual worlds through interconnected systems using sensors, kiosks, meters, personal devices, appliances, cameras, smartphones, implanted medical devices, the web, and other networks of human sensors to capture and integrate real-world data in real-time. The second element uses the data obtained from the first and integrates it into an end-to-end process, system, organization, industry, or value chain. This data can also be interconnected across multiple functions, systems, organizations, industries, or value chains. The third element analyzes the interconnected information and should result in new insights that lead to decision-making and actions to enhance process outcomes, systems, organizations, and value chains within the industry (Harrison et al., 2010).

The combination of these three elements provides a valuable framework for developing information technology (IT) solutions to address problems in urban environments, such as urban heat islands, flood prevention, and flood recovery.

According to Nam e Prado (2011: p. 284), a city can become more intelligent by integrating information into its physical infrastructure, leading to enhanced convenience, mobility, efficiency, energy conservation, air and water quality, rapid problem identification and resolution, disaster recovery, improved decision-making through data collection, effective resource deployment, and collaborative data sharing across domains and entities. However, adding intelligence to individual subsystems of a city, such as transportation, energy, education, healthcare, buildings, physical infrastructure, food, water, and public safety, is insufficient to make the city smarter.

A smarter city should be viewed as an organic whole that operates as a network or interconnected system. Additionally, authors such as Hall (2000), Washburn et al. (2009), and Marsal-Llacuna, Colomer-Llinàs, and Meléndez-Frigola (2015) associate the concept of smart cities with the incorporation of technology into physical networks and infrastructure to improve city management.

Washburn et al. (2009) and Marsal-Llacuna, Colomer-Llinàs, and Meléndez-Frigola (2015) incorporate social concerns into their concepts, departing from the original definition and developing a new one that focuses on enhancing the quality of life and services offered to the population. However, these authors do not explicitly address sustainability, so the smart city described in these concepts is not a sustainable city.

According to Samih (2019), the Internet of Things (IoT) is a crucial component of smart cities because it enables activities, distributions, management, and scheduling to occur in different locations while considering environmental, economic, and social factors. Transport, health, energy, education, public safety, and physical and digital infrastructure, among others, should be unified, i.e., in harmony with one another and based on sound reasoning.

According to the European Commission (n.d.), technology and innovation have been viewed as the basis for the development of certain regions and locations since the inception of smart city concepts, with an emphasis on economic growth and optimizing the results produced by various sectors.

The European Commission (n.d.) defines a smart city as a location where digital solutions make traditional networks and services more efficient for its residents and businesses. A smart city extends beyond the use of digital technologies to improve resource utilization and reduce emissions. It entails smarter urban transport networks, upgraded water supply and waste disposal facilities, and more energy-efficient lighting and heating systems for buildings. In addition, it requires a more interactive and responsive city administration, safer public spaces, and fulfilling the needs of an aging population.

Calgaro, Reato, and Hermany (2020) identify parallels between smart cities and sustainable cities. They examine the current organization of cities, which is based on the development and implementation of a plan that considers the particulars of the location and certain aspects of sustainability.

In the contemporary concept of smart city, technology and innovation should be geared toward promoting citizens' social and environmental needs within the existing dynamics of human development. In the contemporary concept, the smart city is envisioned as a sustainable city, with technologies serving as vectors for this transformation, which will dispense with participatory urban governance and whose application can benefit all city residents.

The Brazilian Charter for Smart Cities, which is an official document of the Government of Brazil under the supervision of the Ministry of Regional Development, defines smart cities as follows: They are cities committed to sustainable urban development and digital transformation in their economic, environmental, and sociocultural aspects, which act in a planned, innovative, inclusive, and networked manner, promote digital literacy, collaborative governance and management, reduce environmental impact, and increase social inclusion (Brasil, 2020: p. 28). The definition of a smart city must incorporate sustainability challenges and the use of IoT technologies to provide a sustainable urban environment that ensures its population's safety and security and promotes the city's resilience.

Smart Cities Features

According to Giffinger et al. (2007: pp. 9-12) there are six characteristics of a smart city: smart economy, smart people, smart governance, smart mobility, smart environment and smart living. The authors also associate each characteristic with factors. So, the:

- smart economy (competitiveness) encompasses the factors: innovative spirit, entrepreneurship, economic image and trademarks, productivity, flexibility of labour market, international embeddedness, ability to transform;
- smart people (Social and Human Capital) encompass the level of qualification, affinity to lifelong learning, social and ethnic plurality, flexibility, creativity, cosmopolitanism/Open-mindedness, participation in public life;
- smart mobility (Transport and ICT) encompasses the following factors: local accessibility, (Inter-)national accessibility, availability of ICT-infrastructure, sustainable, innovative and safe transport systems;
- smart environment (natural resources) encompasses the attractivity of natural conditions, analyses the need to reduce the pollution, environmental protection Sustainable resource management;
- smart living (quality of life) encompasses: cultural facilities, health conditions, individual safety, housing quality, education facilities, touristic attractivity and social cohesion;
- smart governance (participation) encompasses: Participation in decision-making, public and social services and transparent governance.

While emphasized the features and factors of smart cities, their paper lacks a comprehensive explanation, in their analysis of the six characteristics of smart cities, propose a different perspective on the relationship with urban life. Additionally, Nam and Pardo (2011) assert that a smart city consists of three essential components: technology, the population, and institutional structures. In order to produce a better understanding of the exiting analyzes, after reviewing the literature, compiled the following table summarizing the theories:

Characteristic	Definition	Author
Smart Economy	[…] knowledge-based economy, promoting creativity […] public-private partnerships and international connections (research exchange). Innovation capacity.	Cunha, Przeybilovicz, Macaya, and Burgos (2016)

Continued

Smart People	[…] citizens are the greatest source of urban development and driving force for knowledge creation, better education, social infrastructure, and fostering creativity with collective intelligence.	Gil-Garcia, Pardo, and Nam (2015)
Smart Governance	[…] based on transparency, public participation, interaction with public and private agents, cooperation, and free access to information data through ICTs. The structure allows collaboration, data exchange, service integration, and city administration communication.	Giffinger et al. (2007)
Smart Mobility	[…] transport resources and technological infrastructure of the city to manage the flow of demand and movement of the population. Accessibility is essential to promote greater social inclusion and avoid the isolation of modern urban ghettos.	Benevolo, Dameri, and D'Auria (2016)
Smart Environment	[…] attractive natural conditions, resource management, and environmental protection efforts (sustainability). It seeks to reduce the impacts caused by urbanization with the help of technology, proposing optimized alternatives for environmental management problems. In addition, it is essential to have awareness projects.	Braun et al. (2018); Giffinger et al. (2007)
Smart Life	[…] increased quality of life, accessibility, practicality, and efficiency in the relationship with the city. From the perception of safety and housing conditions to access to health and education resources. Greater focus is on integrating with the city, seeking greater social cohesion and a sense of community belonging.	Cunha et al. (2016); Giffinger et al. (2007)

Source: Romani et al. (2023: p. 5).

Developing countries such as Brazil, Ecuador, Colombia, Chile, Indonesia, India, China, Malaysia, and Vietnam, as noted by Schiavon (2021), are progressing in the development of smart cities through similar elements, characteristics, and objectives. These include the establishment of practical and standardized ecosystems using information technologies, emphasizing economic value, environmental preservation, sustainability, and the determination of economic worth related to the digital infrastructure of these urban areas.

Another common element among these countries in the development of smart cities is the adoption of financing models. This includes fiscal incentives, budget allocations, the utilization of state resources in conjunction with social technologies, subsidies, grants, direct measures, and the encouragement of private sector investments through partnerships with government and public administration. These collaborations aim to benefit the community, particularly in the fields of urban management and environmental conservation (Schiavon, 2021).

Public policies, environmental considerations, infrastructure, governance, legislation, the Internet of Things, urban management, energy, geology, entrepreneurship, healthcare, security, sustainability, information and communication technologies, as well as transportation and mobility-related issues, are all factors taken into account by developing countries in the establishment of smart cities. Hence, it is plausible to assert that there is alignment with the objectives and characteristics pursued in smart cities compared to already developed nations (Schiavon, 2021; Raccichini et al., 2022).

Câmara et al. (2017) argues that for a deeper understanding of the development of Smart Cities in developing countries, it is crucial to elaborate on how innovative capabilities and population empowerment evolve and accumulate over time. These capabilities are defined as the set of urban resources and potentials that, through technological change, primarily in Information and Communication Technologies (ICT), enable the population to play an active role in improving the quality of life in cities.

4. Flood-Resilient Smart Cities

The adaptation of smart cities to climate change necessitates investment in specific fields to increase competitiveness, such as urban flooding, which requires the implementation or use of technologies such as "GIS-based risk assessment on flood damages; real-time options analysis; simulation of inundated extent and depth; and modeling sea-level rise scenarios," which will result in benefits such as the "ability to estimate the net benefits of climate adaptation measures for the future scenario" (Huang-Lachmann, 2019: p. 763).

The creation of a smart city necessitates its integration with IoT systems as well as its ability to collect and process large amounts of data. The Internet of Things sensors installed throughout such city provide information on the strength and storage capacity of the dam, lake, or street levels and the ability to predict incoming water levels to prevent flooding. The sensor data is stored in the cloud for management analysis and can be reviewed by artificial intelligence (Smys, Basar & Wang, 2020).

Priya et al. (2017) describe how to create an alerting system using Internet of Things (IoT) technology to measure the height of the water using an ultrasonic distance measuring sensor, send this information to a website, and then call residents to alert them of the flood risk via voice message.

According to Li, Yu and Shao (2021: p. 2), the establishment of a digital twin city necessitates two crucial pillars: a data foundation and a technical foundation. The data foundation encompasses the immense urban big data that is incessantly generated by various sensors and cameras throughout the city, and the digital subsystems constructed by the municipal management departments. In contrast, the technical foundation encompasses several relevant technologies such as IoT, cloud computing, big data, AI, and 5G. In essence, these two foundations are vital for the successful implementation of a digital twin city.

Yuan et al. (2022) highlight several types of data sources that can offer improved insights into the city's dynamics. The sources include community-scale big data, such as sensor data from infrastructure, population activity data, mobility data, and crowd sourced data. These sources can provide valuable information about the community's status, flooding evolutions, and the built environment. The remote sensing data, such as satellite and drone images, can be used for rapid impact assessment and predictions of system recovery for various disaster types, including floods. Machine learning models are employed to analyze these images. Social media data, especially Twitter data, has been employed for rapid impact assessment, predictive infrastructure failure predictions, and monitoring response and recovery. Location-based human activity datasets reveal human movement patterns, assessing flood impact and community recovery. Telemetry-based cellphone activity data and GPS-based human mobility data are used to track fluctuations in activity indices and understand mobility patterns. The authors allege that the advancements in technology and research are expected to improve the resolution and availability of these heterogeneous datasets. This provides opportunities for developing and testing machine learning and deep-learning models to enhance various smart flood resilience capabilities.

The digital twin is another useful technology for smart city flood management. It is a technology that allows the simulation of a physical model, the use of sensors, and full integration in virtual space. This technology has the potential to be used in smart cities, but it requires a data foundation as well as a technical foundation. The first refers to the massive amount of data generated daily by the city's numerous sensors and cameras, as well as the digital systems gradually developed by municipal management departments. The second includes various technologies such as the Internet of Things (IoT), cloud computing, big data, artificial intelligence (AI), and the most recent 5G technology (Li, Yu, & Shao, 2021).

The same smart city enablement technology can be used to develop its digital twins. The smart city flood monitoring and service system based on digital twins has three major components: flood big data monitoring, flood knowledge mapping, and flood service applications. Flood big data monitoring entails gathering real-time flood data and information at both the urban and watershed scales, utilizing IoT technology and real-time monitoring techniques that integrate space, air, and earth.

The emphasis is on gathering information about river and lake water conditions, rainfall data from urban meteorological stations, and dynamic information about people and vehicles from ground sensors. This is possible thanks to satellite remote sensing technology, which allows for large-scale monitoring of cloud and rainfall volumes, water levels, and changes in upper and lower basin rivers and reservoirs (Li, Yu, & Shao, 2021).

The flood knowledge map is created using big data analysis and AI technology to infer and discover knowledge based on dynamic flood disaster monitoring and big data. This knowledge map contributes to providing a smart city flood service application that includes real-time simulation of big data flood monitoring in urban areas.

Using flood knowledge analysis, knowledge mining, modeling, and flood disaster prediction technologies, flood-related knowledge is visualized throughout the life cycle of urban flood disasters. This flood service application aids in providing urban flood control management services (Li, Yu, & Shao, 2021).

According to Ford and Wolf (2020: p. 4), the use of smart city digital twins is important for community disaster management because the data collected by smart city tools can be used immediately by decision-makers and the public. In contrast, the data used by digital twins provides information on future conditions. Furthermore, a smart city digital twin (SCDT) must use current data (the smart city) to conduct a simulation (the digital twin) that allows decision-makers to assess current and future conditions based on information and predict the possible impacts of decisions.

5. Conclusion

The urban population currently accounts for 56% of the global population, with projections indicating that such figure will rise to 68% by 2050. Rapid urbanization in developing countries is expected to increase 2.2 billion urban inhabitants, primarily in Africa and Asia. As discussed above, cities' expansion and development are related to floods through various environmental and urban planning factors. Neglecting ecological sustainability, mismanagement of natural resources, and inadequate urban planning can all contribute to increased flood risk in urban areas, especially in the context of changing climate patterns (Schiavon, 2021; Raccichini et al., 2022).

Many cities are implementing sustainable development initiatives to address these issues and achieve the UN's Sustainable Development Goals. Urbanization has seriously affected environmental sustainability, particularly concerning pollution and climate change. Cities consume 78% of the world's energy and generate over 60% of greenhouse gas emissions, despite occupying less than 2% of the earth's surface, making them significant contributors to climate change.

Furthermore, cities account for 70% of GHG emissions and are extremely vulnerable to climate change, with 90% of urban disasters being hydrometeorological. The connection between urbanization and climate change is well established, with cities accounting for a sizable portion of global carbon emissions.

The Sustainable Development Goals, on the other hand, recognize the need to address the environmental impact of urbanization, with Goal 11 promoting sustainable cities and communities. Implementing sustainable practices and policies is critical to ensure that our cities remain healthy and livable for future generations. By altering the hydrological cycle by increasing runoff and decreasing groundwater recharge, urban development and its associated impermeable surfaces contribute to flood risk in large urban areas. This can lead to insufficient drainage and waste management, exacerbating flood chances and causing economic damage. Heavy rainfall and increased imperviousness caused by urbanization are the two most commonly cited causes of floods, accounting for 62% and 40% of sources, respectively, highlighting the strong link between urban development, flood risk, and economic damages. In the 1990s, the concept of "smart cities" emerged, with a focus on the impact of new information and communication technologies (ICT) integrated into city infrastructure (Samih, 2019: p. 1).

Smart cities were initially focused on economic, organizational, and managerial aspects, but they have evolved to include social influence. They now encompass crucial IT elements such as instrumentation, interconnection, and intelligence. The expansion includes social aspects and sustainability considerations.

A smart city operates as an interconnected organism, forming a cohesive network encompassing various domains such as transportation, health, energy, education, public safety, and digital infrastructure. These cities leverage digital solutions to optimize conventional networks and services, benefiting residents and businesses. The scope extends beyond resource efficiency and emissions reduction, embracing smarter sustainable living, upgraded transportation systems, enhanced water supply and waste management, and more efficient building systems.

Several key characteristics come to the forefront in the context of smart cities. These cities prioritize economic competitiveness, foster innovation through technology, champion environmental sustainability, and aspire to elevate the quality of life for their citizens. These attributes are vital in the contemporary era, embodying a holistic approach to urban development that transcends geographical boundaries, equally applicable to developed and developing nations.

The synergy between technology, effective governance, and active citizen participation is the core of a successful smart city. These components collaborate seamlessly to address the ever-evolving challenges of urban life. With advancing technology and the increasing empowerment of populations, smart cities are well-positioned to navigate the future with adaptability and resilience.

Smart cities are the ultimate fusion of urban living, technology, and governance, resulting in a thriving environment that fosters innovation and sustainability. Each component contributes to the city's overall well-being and advancement, making it a blueprint for modern urban development.

Smart cities are taking action to mitigate the effects of climate change, particularly in flood-prone regions. These initiatives include incorporating flood-prevention technologies and utilizing various data-driven strategies:

- Risk assessments using Geographic Information Systems (GIS) help evaluate flood damage by considering real-time options, simulating inundation extents and depths, and modeling sea-level rise scenarios to estimate the benefits of climate adaptation measures.
- Integration of Internet of Things (IoT) systems and sensors enables the collection and processing of vast amounts of data for forecasting water levels and preventing floods.
- Digital twin technology enables the virtual simulation and integration of physical models for flood monitoring and service systems.
- Flood big data monitoring uses IoT technology and real-time monitoring techniques, gathering data from urban and watershed scales to provide timely flood insights.

Big data plays a transformative role in this process, allowing for more precise and prompt flood detection, evaluation, and response. Ongoing advancements in data analytics and technology are poised to enhance our ability to predict and mitigate flood impacts, bolstering urban resilience in the face of complex environmental challenges.

By analyzing big data and using AI technology, a flood knowledge map can be created, which contributes to smart city flood service applications that offer real-time simulations of flood monitoring in urban areas. These technologies empower decision-makers and the public with current and future condition information, enabling them to anticipate potential consequences of their choices.

Investing in technologies that can help mitigate the impact of climate change is critical for effective disaster management within communities. Smart city approaches can be adopted by cities to prevent flooding, enhance competitiveness, and provide crucial services to residents. These approaches encompass a variety of technologies such as GIS-based risk assessments, real options analysis, simulation, IoT sensors, cloud computing, big data, artificial intelligence, and digital twins. By leveraging these technologies, smart cities can predict and prevent flooding, alert residents, and offer flood-related services.

Digital twins have a crucial role in community disaster management, providing valuable insights into both current and future conditions. A smart city flood monitoring and service system that utilizes digital twins can gather real-time flood data and information, create flood knowledge maps, and support urban flood control management.

By incorporating these technologies into smart city planning and development, cities can adapt to climate change, increase competitiveness, and establish safer and more sustainable living environments for their residents. These advancements in technology pave the way for smarter, more resilient, and environmentally responsible urban futures.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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