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ENVIRONMENTAL MONITORING IN SMART CITY – SMARTPHONE APPLICATIONS ASPECTS

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Purpose: The purpose of this publication is to present the usage of smartphone application in Smart Cities in environmental monitoring.
Design/methodology/approach: Critical literature analysis. Analysis of international literature from main databases and polish literature and legal acts connecting with researched topic.
Findings: This publication delves into the multifaceted role of smartphone applications within smart cities, with a specific focus on key areas like air quality, noise pollution, water quality, and weather conditions. The integration of these applications not only tackles environmental issues but also empowers citizens to actively participate in the protection of their surroundings. Notably, air quality monitoring emerges as a standout domain, leveraging built-in sensors to measure pollutants in real-time, thereby enabling informed decision-making and contributing to public health awareness. The comprehensive overview presented in this publication underscores the transformative impact of smartphone applications, emphasizing their role in fostering smarter and more sustainable urban environments. The democratization of environmental data through these tools not only raises awareness but also encourages behavioral changes, cultivating a sense of environmental stewardship among citizens. As citizens increasingly engage in assessing air quality, noise pollution, water quality, and weather conditions, the publication highlights the transformative leap that smartphone applications represent in the journey towards smart cities. This evolution not only enhances individual decision-making but also nurtures a collective responsibility for creating urban environments that are both sustainable and resilient. Looking ahead, as technology continues to advance, smartphone applications are poised to play an increasingly pivotal role, promising a future where citizens and smart cities collaborate to ensure the well-being of both urban dwellers and the planet.
Originality/value: Detailed analysis of usage smartphone applications in environmental monitoring area.

Keywords: Smart City, energy efficiency, energy efficiency management, smartphone applications, environmental monitoring.

Category of the paper: literature review.

1. Introduction

Smartphone applications have emerged as powerful tools in the realm of environmental monitoring, particularly in the context of smart cities. As urbanization continues to advance at an unprecedented pace, the need for efficient and real-time monitoring of environmental parameters has become increasingly crucial. Smartphones, equipped with a myriad of sensors and connectivity options, have proven to be invaluable instruments in this regard.

One of the key areas where smartphone applications excel is air quality monitoring. With built-in sensors such as GPS, accelerometers, and ambient light sensors, smartphones can provide real-time data on air quality by measuring parameters like particulate matter (PM), nitrogen dioxide (NO2), and ozone (O3). Citizens can leverage these applications to access up-to-date information about air quality in their vicinity, allowing them to make informed decisions about outdoor activities and contributing to their overall health and well-being (Rachmawati et al., 2021; Dutta et al, 2021; Ivanyi, Biro-Szigeti, 2019).

The purpose of this publication is to present the usage of smartphone application in Smart Cities in the case of environmental monitoring.

2. The usage of smartphone applications in environmental monitoring

Smartphone applications play a pivotal role in noise pollution monitoring. By utilizing the device's microphone, these applications can measure ambient noise levels and identify sources of excessive noise. This functionality not only empowers individuals to avoid noisy areas but also aids city planners in identifying and mitigating noise pollution hotspots. This, in turn, contributes to the creation of more livable and sustainable urban environments (Herdiansayah, 2023; Rose et al., 2021).

In the realm of water quality monitoring, smartphones equipped with specialized sensors can be employed to assess the quality of water sources. Users can collect data on parameters such as pH, turbidity, and dissolved oxygen by utilizing external attachments or built-in sensors. This democratization of water quality monitoring enables citizens to actively participate in safeguarding their water resources and alerts authorities to potential issues in real time, fostering a more responsive and adaptive approach to environmental management (Jonek-Kowalska, Wolniak, 2021; 2022; Gajdzik et al., 2023). Additionally, smartphone applications contribute significantly to weather monitoring in smart cities. The devices' GPS capabilities allow for precise location-based weather forecasting, enabling users to receive hyper-local weather updates. This functionality proves invaluable in disaster preparedness and response, allowing authorities to disseminate timely information to citizens and plan for extreme weather events effectively (Rahman, Dura, 2022).

The integration of smartphone applications into environmental monitoring also fosters a sense of environmental stewardship among citizens. By actively engaging with these applications, individuals become more aware of their surroundings and the impact of their actions on the environment. This heightened awareness can lead to behavioral changes, such as adopting eco-friendly practices and participating in community-driven environmental initiatives. The utilization of smartphone applications in environmental monitoring represents a transformative leap in the quest for smart cities. These applications empower citizens to actively engage with and contribute to the monitoring of air quality, noise pollution, water quality, and weather conditions. The democratization of environmental data not only enhances individual decision-making but also fosters a collective sense of responsibility towards creating sustainable and resilient urban environments. As technology continues to advance, the role of smartphone applications in environmental monitoring is poised to grow, promising a future where citizens and smart cities work hand in hand to ensure the well-being of both urban dwellers and the planet (Chmielarz et al., 2021).

Smartphone applications have revolutionized the field of environmental monitoring, offering versatile tools that empower individuals to actively engage in safeguarding the planet. These applications leverage the capabilities of modern smartphones, including GPS, sensors, and connectivity, to collect, analyze, and share real-time environmental data. The integration of technology into environmental monitoring has democratized access to information, transforming ordinary citizens into contributors to scientific research and environmental conservation efforts.

One prominent aspect of smartphone applications in environmental monitoring is air quality assessment. Apps like AirVisual and Breezometer utilize smartphone sensors to measure concentrations of pollutants such as PM2.5, PM10, ozone, and nitrogen dioxide. Users can access up-to-date air quality information, receive alerts, and contribute to a collective understanding of air pollution levels, promoting public health awareness and advocacy for cleaner air. Water quality assessment is another critical domain where smartphone applications play a pivotal role. Apps such as WaterRangers and Clean Swell enable users to monitor and evaluate water quality by inputting data from water tests or leveraging built-in sensors. This fosters citizen science, empowering individuals to contribute valuable information to environmental initiatives, track water pollution trends, and promote responsible water management practices (Simonofski et al., 2023; Chmielarz et al., 2021).

Biodiversity tracking applications leverage the GPS and camera features of smartphones to enable users to document and share observations of plants, animals, and insects. Platforms like iNaturalist and eBird encourage citizen scientists to contribute to biodiversity databases, aiding conservation efforts and providing valuable insights into the distribution and health of various species.

Smartphone apps also address noise pollution, a pervasive environmental issue in urban areas. NoiseTube and SoundPrint, for instance, utilize smartphone microphones to measure and map noise levels. Users can actively participate in noise mapping initiatives, raising awareness

about the impacts of noise pollution and advocating for policies to create quieter and healthier living environments. Climate change tracking applications provide users with weather data, temperature trends, and climate event information. Apps like Climate Reality and Climate Monitor not only offer insights into global climate patterns but also engage users in contributing their observations to climate databases, fostering a sense of shared responsibility in addressing climate-related challenges.

Waste management and recycling applications, such as Recycle Coach and TrashOut, provide users with information on recycling locations, waste sorting guidelines, and reminders for collection days. By promoting responsible waste disposal practices, these apps contribute to environmental sustainability and encourage communities to reduce their ecological footprint (Dutta et al, 2019).

Table 1 contains descriptions of how smartphone applications are used in environmental monitoring. This table illustrates the diverse ways in which smartphone applications are employed for environmental monitoring across various aspects, promoting citizen engagement, data collection, and awareness in environmental conservation efforts.

Table 1.
How smartphone applications are used in environmental monitoring

Aspect of Environmental Monitoring	Use of Smartphone Applications
Air Quality Monitoring	Smartphone applications measure and report air quality levels, including pollutants such as PM2.5, PM10, ozone, and nitrogen dioxide. Apps like AirVisual, Plume Labs, and Breezometer provide real-time air quality data, alerts, and historical trends, aiding public awareness and health protection.
Water Quality Assessment	Apps enable users to monitor and assess water quality by inputting data from water tests or using built-in sensors to measure pH, turbidity, dissolved oxygen, and nutrient levels. WaterRangers and Clean Swell engage citizens in collecting water quality data, contributing to environmental initiatives and raising awareness about water pollution.
Biodiversity Tracking	Smartphone apps support biodiversity monitoring by allowing users to record observations of plants, animals, and insects. iNaturalist and eBird use GPS and image recognition to identify species, facilitating citizen science and contributing valuable data to conservation efforts and scientific research.
Noise Pollution Measurement	Applications with sound sensors enable users to measure and monitor noise pollution levels. NoiseTube and SoundPrint provide real-time noise data, track trends, and empower individuals to contribute to noise mapping initiatives, fostering advocacy for quieter and healthier living environments.
Climate Change Tracking	Apps contribute to climate change monitoring by providing weather information, temperature trends, and climate event data. Climate Reality and Climate Monitor allow users to access climate data, forecasts, and contribute observations to global databases, promoting awareness and participation in climate action initiatives.
Waste Management and Recycling	Smartphone apps provide information on recycling locations, waste sorting guidelines, and track personal waste reduction efforts. Recycle Coach and TrashOut offer features such as recycling reminders, educational resources, and community engagement, encouraging responsible waste disposal and recycling practices.
Soil Health Assessment	Apps equipped with soil sensors or user input facilitate soil health monitoring, analyzing composition, moisture levels, and nutrient content. Agrobase and SoilGrids support farmers and gardeners in optimizing agricultural practices, promoting sustainable soil management, and contributing to soil health initiatives.

Cont. table 1.

Wildfire Detection and Prevention	Smartphone applications use satellite data and user reports to detect and track wildfires. Apps like FireChat and Wildfire Alert provide real-time information, evacuation alerts, and prevention tips, empowering users to stay safe and participate in early response efforts to mitigate the impact of wildfires.
Energy Consumption Monitoring	Apps help users monitor and analyze energy consumption patterns in homes or businesses. EnergyHub and Sense provide real-time energy data, insights, and recommendations, promoting energy efficiency and enabling individuals to make informed decisions to reduce their environmental footprint.
Urban Green Spaces Mapping	Smartphone applications contribute to mapping and monitoring urban green spaces. Apps like CityNature Challenge and TreeSnap enable users to document and share information about parks, trees, and greenery, fostering community engagement in preserving and enhancing urban ecosystems.
Ocean and Marine Conservation	Apps support marine conservation by providing information on marine life, coral reefs, and ocean conditions. Ocean Wise and Seafood Watch help users make sustainable seafood choices, contribute to marine research through data collection, and stay informed about threats to ocean health, encouraging responsible consumption and conservation efforts.

Source: (Kalasova et al., 2021; Chmielarz et al., 2021; Rose et al., 2021; Dutta et al., 2019; Ivani, Biro-Szigeti, 2019; Leal et al., 2023; Chowdhury et al., 2023; Sanchez et al., 2018; Aguilera, Boutueil, 2018).

Smartphone applications have emerged as powerful tools in the realm of environmental management, offering a host of advantages that enhance efficiency, accessibility, and overall effectiveness in addressing environmental challenges. These applications leverage the ubiquity of smartphones and their integrated features to engage individuals, communities, and organizations in active participation in environmental monitoring and conservation efforts. One of the key advantages is real-time data collection. Environmental management applications enable the collection of data in real-time, providing instant insights into various parameters such as air quality, water quality, and biodiversity. This real-time capability facilitates timely decision-making, allowing for quick responses to emerging environmental issues and the implementation of effective mitigation strategies.

Cost-effectiveness is another notable advantage. Smartphone applications often offer cost-effective solutions compared to traditional monitoring methods. They capitalize on existing technology infrastructure, minimizing the need for additional hardware or specialized equipment. This cost-effectiveness makes environmental monitoring more accessible to a wider audience, including resource-constrained communities. The widespread accessibility of smartphones ensures that environmental management information is within reach of a broad user base. This democratization of data allows individuals and communities to actively participate in monitoring efforts, transforming ordinary citizens into contributors to scientific research. This increased participation fosters a sense of community ownership and responsibility for environmental stewardship (Kalasova et al., 2021).

Efficient data management is facilitated through environmental management applications. These apps often incorporate features such as cloud storage, data synchronization, and automated analysis, streamlining the handling of large volumes of environmental data. Such efficiency not only saves time but also enhances the overall organization and accessibility of valuable environmental information. The integration of various sensors and technologies within smartphones enhances their capabilities for environmental monitoring. Innovative

sensor integration allows these applications to measure an array of parameters, from air and water quality to noise levels and soil health. This diversity in monitoring contributes to a comprehensive understanding of ecosystems, supporting informed decision-making in environmental management (Boichuk, 2020).

Smartphone applications also promote public awareness and education. Many environmental management apps serve as educational tools, providing information about environmental issues, sustainable practices, and the impact of individual actions. By raising awareness and fostering environmental literacy, these apps contribute to a more informed and environmentally conscious society. The ability to visualize environmental data on maps supports geospatial mapping and visualization. This feature aids in understanding spatial patterns and trends, enabling environmental managers to make informed decisions based on the geographical distribution of environmental parameters.

Table 2 highlighting the advantages of using smartphone applications in environmental management within smart cities. The advantages outlined in this table underscore the transformative role of smartphone applications in enhancing the efficiency, accessibility, and impact of environmental management initiatives.

Table 2.
Advantages of using smartphone applications in environmental management

Advantage	Description
Community Empowerment	Smartphone applications empower local communities by providing them with the tools to actively participate in environmental monitoring, fostering a sense of ownership and responsibility.
Continuous Monitoring	The ability of smartphone apps to operate continuously allows for ongoing environmental monitoring, capturing dynamic changes and trends over time, which is essential for effective management and decision-making.
Data Standardization	Many environmental monitoring apps adhere to standardized data formats and protocols, promoting consistency and compatibility, facilitating data sharing and collaboration among different stakeholders.
Education and Outreach	Applications serve as educational tools, providing information about environmental issues, sustainable practices, and the impact of individual actions, contributing to environmental literacy and awareness.
Efficient Resource Allocation	The real-time nature of data collection and analysis enables more efficient allocation of resources, allowing organizations and policymakers to address environmental challenges based on current and accurate information.
Innovative Sensor Integration	Smartphone apps can integrate with a variety of innovative sensors and IoT devices, expanding the range of environmental parameters that can be monitored, offering a more comprehensive understanding of ecosystems.
Remote Monitoring and Control	Environmental managers can remotely monitor and control monitoring devices through smartphone apps, facilitating efficient management of dispersed monitoring stations and reducing the need for physical presence.
Data Privacy and Security Features	Many environmental apps prioritize data privacy and security, implementing features such as encryption and user authentication to protect sensitive information, ensuring the integrity of environmental data.
Public Participation in Research	Smartphone apps facilitate public participation in scientific research, allowing individuals to contribute valuable data to research projects and environmental studies, thereby enhancing the scope and depth of research efforts.
Easier Regulatory Compliance	Organizations can use environmental monitoring apps to simplify regulatory compliance by automating data collection, analysis, and reporting processes, reducing the administrative burden associated with compliance.

Cont. table 2.

Global Collaboration and Data Sharing	Environmental apps enable global collaboration by facilitating the sharing of environmental data across borders. This international data sharing enhances our understanding of global environmental challenges and promotes collaborative solutions.

Source: (Kalasova et al., 2021; Chmielarz et al., 2021; Rose et al., 2021; Dutta et al., 2019; Ivani, Biro-Szigeti, 2019; Leal et al., 2023; Chowdhury et al., 2023; Sanchez et al., 2018; Aguilera, Boutueil, 2018).

While smartphone applications offer promising solutions for environmental management within smart cities, they also present several challenges that need careful consideration and mitigation. These problems encompass issues related to data security, accessibility, reliability, and community engagement. One significant challenge is data privacy concerns. The collection of environmental data through smartphone applications often involves the gathering of personal information, raising privacy issues. The potential misuse, unauthorized access, or data breaches can undermine public trust and compromise the integrity of environmental monitoring initiatives.

Unequal access to technology poses another problem. Not all residents may have equal access to smartphones or the necessary technological infrastructure, leading to disparities in participation. This digital divide can result in incomplete or biased datasets, limiting the inclusivity and effectiveness of environmental management efforts. The reliance on user-generated data introduces challenges related to data accuracy and reliability. Users may provide inconsistent or inaccurate information, affecting the quality of the collected environmental data. Ensuring the reliability of data becomes crucial for making informed decisions and implementing effective environmental policies (Dutta et al, 2019).

Limited representativeness is a concern, as the user base of environmental apps may not fully represent the diverse demographics of a smart city. This lack of diversity in participants can lead to biased data collection and exclude certain communities, impacting the comprehensiveness of environmental monitoring and management. Digital literacy barriers represent a significant hurdle. Despite the increasing prevalence of smartphones, some residents may lack the necessary digital literacy skills to effectively use environmental monitoring applications. Overcoming these barriers is essential to ensure the active and meaningful participation of all segments of the population.

The integration of sensors into environmental apps introduces challenges related to sensor calibration and maintenance. Ensuring the accuracy of sensor readings over time requires regular calibration and maintenance efforts. Sensor malfunctions or inaccuracies can lead to unreliable data, impacting the overall effectiveness of environmental monitoring. Security vulnerabilities present a substantial risk. Both the applications and the underlying infrastructure are susceptible to hacking, malware, or unauthorized access. Protecting sensitive environmental and personal data requires robust cybersecurity measures to prevent potential breaches and data manipulation (Boichuk, 2020).

The lack of standardization in data formats and protocols among different environmental apps hinders interoperability and data sharing. Standardization challenges may impede collaboration between different stakeholders and limit the comprehensive analysis of environmental data collected from various sources. Community engagement barriers are significant challenges in smart city environmental management. Despite the potential for increased community involvement, factors such as language barriers, cultural differences, and a lack of incentives may hinder active participation, affecting the effectiveness of environmental initiatives (Benevolo et al., 2016; Kalasova et al., 2021).

Table 3 highlighting some of the common problems and challenges associated with the usage of smartphone applications in environmental management within smart cities. These problems underscore the need for careful consideration and strategic planning when integrating smartphone applications into environmental management initiatives within smart cities. Addressing these challenges is crucial to ensure the effectiveness, equity, and ethical use of technology in urban environmental monitoring.

Table 3.
Problems of using smartphone applications in environmental management within smart cities

Problem	Description
Data Privacy Concerns	The collection of personal and environmental data through smartphone apps raises concerns about data privacy. Unauthorized access, misuse, or data breaches can compromise the privacy and security of individuals and communities.
Unequal Access to Technology	Not all residents may have equal access to smartphones or the necessary technology infrastructure, potentially leading to disparities in environmental data collection and participation in smart city initiatives.
Limited Representativeness	The user base of environmental apps may not be fully representative of the city's population, leading to potential biases in collected data and excluding certain demographics from participating in environmental monitoring.
Data Accuracy and Reliability	Reliance on user-generated data may introduce challenges related to accuracy and reliability. Users may provide inconsistent or erroneous data, impacting the quality of environmental information and decision-making processes.
Digital Literacy Barriers	Limited digital literacy among certain demographics may hinder effective participation in environmental monitoring initiatives. Ensuring inclusivity requires addressing barriers related to technology literacy and access.
Sensor Calibration and Maintenance	Environmental monitoring apps that integrate with sensors require proper calibration and maintenance. Issues such as sensor drift, calibration errors, or malfunction can compromise the accuracy of collected data.
Security Vulnerabilities	Smartphone apps and the underlying infrastructure may be susceptible to security vulnerabilities, including hacking, malware, or unauthorized access. Ensuring robust cybersecurity measures is crucial to protect sensitive data.
Lack of Standardization	The absence of standardized data formats and protocols among different environmental apps can hinder interoperability and data sharing. Standardization challenges may impede collaboration and comprehensive analysis of environmental data.
Technological Obsolescence	Rapid advancements in technology may lead to the obsolescence of smartphones and sensors, rendering certain environmental monitoring apps and devices outdated. This can pose challenges in maintaining a consistent and up-to-date monitoring system.
Community Engagement Barriers	Despite the potential for community engagement, some residents may face barriers to active participation, such as language barriers, cultural differences, or a lack of incentives, impacting the effectiveness of smart city environmental initiatives.

Cont. table 3.

Infrastructure Dependency	Environmental monitoring apps heavily depend on the availability of robust technology infrastructure, including network connectivity and server capabilities. Cities with inadequate infrastructure may face limitations in implementing such solutions.
Regulatory and Ethical Challenges	The use of environmental monitoring apps may raise regulatory and ethical challenges, such as compliance with data protection laws, consent for data collection, and ethical considerations related to the use of technology for surveillance.

Source: (Kalasova et al., 2021; Chmielarz et al., 2021; Rose et al., 2021; Dutta et al., 2019; Ivani, Biro-Szigeti, 2019; Leal et al., 2023; Chowdhury et al., 2023; Sanchez et al., 2018; Aguilera, Boutueil, 2018).

3. Conclusion

Smartphone applications have become indispensable tools in the field of environmental monitoring, particularly in the dynamic landscape of smart cities. The relentless pace of urbanization necessitates efficient, real-time monitoring of environmental parameters, and smartphones, equipped with an array of sensors and connectivity options, have emerged as invaluable instruments for this purpose. This publication explores the role of smartphone applications in environmental monitoring within the context of smart cities, focusing on key areas such as air quality, noise pollution, water quality, and weather conditions. The integration of smartphone applications addresses critical environmental challenges and empowers citizens to actively participate in safeguarding their surroundings.

Air quality monitoring stands out as a prominent domain where smartphones excel, utilizing built-in sensors to measure pollutants such as particulate matter, nitrogen dioxide, and ozone. This real-time data enables citizens to make informed decisions about outdoor activities, contributing to public health awareness. The publication emphasizes the usage of smartphone applications across various aspects of environmental monitoring, presenting a comprehensive overview of their role in creating smarter and more sustainable urban environments. Furthermore, the publication delves into the democratization of environmental data facilitated by smartphone applications. These tools foster a sense of environmental stewardship among citizens by promoting awareness and encouraging behavioral changes. The transformative impact of smartphone applications on environmental monitoring is evident, with citizens actively engaging in the assessment of air quality, noise pollution, water quality, and weather conditions.

The publication underscores the transformative leap that smartphone applications represent in the journey toward smart cities. By enabling citizens to actively contribute to environmental monitoring, these applications not only enhance individual decision-making but also cultivate a collective sense of responsibility for creating sustainable and resilient urban environments. As technology continues to advance, the role of smartphone applications in environmental monitoring is poised to grow, promising a future where citizens and smart cities collaboratively ensure the well-being of both urban dwellers and the planet.

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