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Enhancing urban resilience: an IoT-based smart drainage system for flood management in Mogadishu, Somalia

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Received: 8 November 2024 / Accepted: 8 May 2025
Published online: 21 May 2025

Abstract
This research presents the development of an innovative IoT-based smart drainage system designed to address the persistent flooding challenges in Mogadishu, Somalia. The system integrates real-time water-level monitoring, flow rate measurement, and automated water management solutions, enhancing urban resilience against flooding. Utilizing a combination of ultrasonic sensors, Hall effect flow meters, and a network of water pumps, the system facilitates proactive interventions by redirecting excess water from critical collection points to the ocean. The data collected from these sensors is processed and analyzed using AWS cloud services, ensuring scalable and efficient data management. A user-friendly web application provides real-time visualization of drainage conditions and alerts stakeholders about potential flood risks, thus enabling timely decision-making. Field tests demonstrate that the system not only detects flood risks but also actively mitigates them through automated water removal, showcasing its effectiveness as a scalable and sustainable flood management solution. This research contributes significantly to the discourse on smart city infrastructure, providing a comprehensive framework for disaster resilience and urban sustainability in developing regions, and serving as a scalable model for future implementations in similar contexts.

Article Highlights

- The paper introduces a smart drainage system designed to prevent urban flooding in Mogadishu, Somalia, using IoT technology for real-time water level monitoring and automated alerts.
- The system integrates solar-powered water pumps and a durable piping network to actively transport excess water from collection points to the ocean, reducing overflow risks.
- Real-time data is processed and visualized on AWS Cloud, with a web application offering an interactive dashboard for authorities to monitor water levels, flow rates, and potential blockages.
- The study demonstrates the system's effectiveness and sustainability, with recommendations for future expansion to incorporate predictive analytics and broader urban infrastructure integration.

Keywords IoT · Smart drainage system · Flood management · Water-level monitoring · Urban sustainability · Arduino Mega · Sensors

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1 Introduction

Flooding in urban areas is a growing global challenge, exacerbated by rapid urbanization, inadequate infrastructure, and climate change [1]. As extreme weather events become more frequent and intense, cities in developing countries, like Mogadishu, Somalia, are increasingly vulnerable to the devastating effects of seasonal floods [2, 3]. Floodwaters not only disrupt everyday life but also pose severe risks to public health, damage infrastructure, and lead to significant economic losses [4]. In Mogadishu, where much of the infrastructure is underdeveloped or poorly maintained, the city's drainage system is frequently overwhelmed during heavy rains, causing widespread destruction and hardship. The consequences are especially dire for low-income residents living in flood-prone areas [5].

The city experiences repeated flooding that risks lives, particularly for those near drainage points, where the floodwaters rise rapidly. The resulting damage to homes and businesses can be catastrophic, with entire neighborhoods becoming inaccessible for days. Roads, which are essential for transportation and economic activity, are often closed, disrupting commerce and essential services [6]. Moreover, the flooding erodes the already fragile infrastructure, causing long-term deterioration and expensive repairs. Public health is another significant concern, as stagnant floodwaters create breeding grounds for mosquitoes and lead to outbreaks of waterborne diseases such as cholera [7]. Such challenges place an immense strain on the city's limited healthcare system, leaving vulnerable populations without adequate care during critical periods.

Addressing these problems requires a systematic, scalable solution that can both monitor the city's drainage network and provide timely interventions to prevent or mitigate the damage caused by floods. However, traditional flood management methods, which rely heavily on manual intervention, are inadequate in Mogadishu's context due to resource constraints and a lack of real-time monitoring capabilities [8]. This gap highlights the need for modern, technology-driven solutions that can offer enhanced efficiency, precision, and scalability.

The Internet of Things (IoT) has emerged as a transformative technology across various sectors, enabling real-time data collection, analysis, and automated responses in critical systems [9]. In the context of urban flood management, IoT has the potential to revolutionize how cities monitor drainage networks and respond to rising water levels [10]. IoT-enabled sensors placed in strategic locations within drainage systems can collect real-time data on water levels, flow rates, and potential blockages [11]. When integrated with cloud platforms and analytics tools, this data can be processed to provide actionable insights, allowing for the early detection of flood risks and the automation of interventions such as drainage clearance or alert systems for emergency response teams [12].

Several cities around the world have already implemented IoT-based flood management systems, yielding significant improvements in their ability to mitigate flood risks. In India, for example, IoT sensors deployed in urban areas have allowed city officials to monitor water levels in real-time, enabling rapid responses to flood threats and reducing the damage caused by heavy rains [13]. Similarly, smart drainage systems in Singapore use IoT technologies to dynamically manage water flow, adjusting drainage capacity based on real-time conditions to prevent overflows [14]. These examples demonstrate the immense potential of IoT in addressing flood management challenges in urban environments. However, most existing smart drainage systems primarily focus on flood detection and passive monitoring using sensors without providing actionable insights or response mechanisms. Furthermore, prior studies often lack real-time, professional dashboards that provide decision-makers with detailed reasons for imminent flooding at specific locations. Additionally, very few systems incorporate water pumping mechanisms to actively manage excess water. This research addresses these gaps by developing an IoT-based smart drainage system tailored to Mogadishu's context. Our system not only monitors water levels and predicts imminent flooding per drainage block, but also visualises the data through a real-time dashboard with professional font and layout, and incorporates a pumping mechanism that redirects water from collection points to the ocean.

Despite the success of IoT-based solutions in other regions, such systems have not been widely adopted in Somalia, where technological infrastructure and innovation are still in the early stages of development. In Mogadishu, the implementation of an IoT-based smart drainage system could significantly enhance the city's resilience to flooding by not only providing real-time insights into the condition of its drainage network but also facilitating active intervention through automated water pumping systems. This proactive approach would be particularly beneficial in Mogadishu's context, where traditional flood management practices are reactive rather than preventive, often resulting in severe damage and delayed responses during heavy rainfall events. Proactive flood management strategies, particularly IoT-based smart drainage systems, play a crucial role in mitigating flood risks by enabling early detection, real-time monitoring, and automated water removal. Unlike traditional reactive approaches that rely on manual intervention after flooding occurs, IoT-enabled solutions allow for dynamic decision-making and rapid response, thereby minimizing infrastructure damage and economic losses. This study highlights how integrating IoT technology into urban drainage systems enhances disaster resilience and ensures sustainable flood management solutions.

In this study, we propose the development of an IoT-based smart drainage system tailored to the unique challenges of Mogadishu's urban environment. Our system utilizes AWS (Amazon Web Services) as the cloud platform to process and store data from sensors installed throughout the city's drainage network. These sensors monitor water levels, flow rates, and potential blockages, transmitting data in real-time to a centralized system. The system not only generates alerts but also activates water pumps that transfer excess water from collection points to the ocean through strategically placed pipes. This information is visualized on a professional dashboard designed to aid decision-makers in assessing flood risks and initiating preventive measures. The dashboard provides real-time updates on water levels and explains the causes of imminent flooding in specific areas, enabling authorities to allocate resources effectively and minimize the impact on vulnerable populations.

The contribution of this research is threefold. First, it introduces a novel IoT-based smart drainage system that not only monitors water levels but also actively mitigates flooding through the integration of solar-powered pumps and pipes, providing a proactive solution to water management in Mogadishu. Second, it leverages the power of cloud computing through AWS to process and analyze large volumes of sensor data, ensuring the system's scalability and real-time decision-making capabilities. Third, this project underscores the transformative potential of IoT in resource-constrained environments by addressing critical infrastructure gaps and improving urban resilience. Unlike previous IoT-based drainage solutions that primarily focus on monitoring water levels, our system actively mitigates flooding by integrating solar-powered water pumps that transport excess water to the ocean. The system uses sensors to detect blockages and to prevent floods before they occur. Additionally, our system utilizes an AWS-based real-time analytics dashboard, enabling proactive decision-making rather than reactive responses. This integration ensures enhanced flood resilience in a resource-constrained environment like Mogadishu. By presenting a comprehensive technological framework for flood prevention and sustainable water management, this research aims to alleviate flooding challenges in Mogadishu and contribute to broader efforts in disaster resilience and urban sustainability across developing regions.

The subsequent sections of this paper will start on a review of the literature and then the paper will detail the methodology used to develop the IoT-based smart drainage system, including the selection and deployment of water-level sensors, data collection, and integration with AWS for real-time processing and visualization. We will also describe the design of the professional dashboard and its role in facilitating decision-making during flood events. The system's performance will be evaluated based on its effectiveness in identifying flood risks and providing timely alerts. Finally, we will discuss the potential scalability of the system to other urban regions in Somalia and offer recommendations for future improvements to enhance flood management and urban resilience.

2 Literature review

The integration of Internet of Things (IoT) technology in urban infrastructure has become a critical area of research, particularly in the development of smart drainage systems aimed at addressing the growing challenges posed by urbanization, climate change, and inadequate drainage infrastructure [15]. Over the past decade, numerous studies have explored the use of IoT to monitor and manage drainage systems in real time, aiming to prevent blockages, waterlogging, and flooding in urban environments. These smart systems typically incorporate a variety of sensors and wireless networks to detect water levels, flow, and the presence of harmful gases, while providing real-time alerts to authorities for timely intervention. However, while these innovations have contributed significantly to urban water management, certain challenges—such as scalability, predictive flood management, and applicability to flood-prone, underdeveloped regions—remain inadequately addressed [16]. In this review, we examine key contributions from existing literature, identifying the technological advancements and limitations in current IoT-based drainage systems, and positioning our research within this evolving field.

Keung et al. their paper addresses the challenges of Hong Kong's drainage system in the face of heavy rainfall and flooding, worsened by climate change and urbanization. It emphasizes the need for improved stormwater management and proposes a smart drainage system utilizing Internet of Things (IoT) technology. A prototype system is developed, featuring sensors and an Artificial Neural Network (ANN) for real-time monitoring and predictive maintenance, aiming to enhance flood management and drainage efficiency, ultimately benefiting the community by mitigating risks from severe weather events [17].

Bharath et al. proposes presents in their article a Drainage Monitoring System (DMS) that leverages the Internet of Things (IoT) to oversee underground drainage systems, emphasizing the necessity of maintaining these systems to avert waterlogging and associated health risks in urban environments. The DMS utilizes ultrasonic sensors to monitor water levels and detect blockages, sending alerts to municipal authorities for prompt action. By providing real-time data on drainage conditions, the system aims to improve urban sanitation and mitigate flooding impacts, while the paper details its design, implementation, and potential advantages for urban infrastructure management [18].

Mohan et al proposes a smart drainage system that focuses on addressing challenges faced by drainage workers and the public in maintaining and monitoring underground drainage systems. The researchers developed a system using various sensors, such as level, flow, and gas sensors, connected to an ARM7 processor. This system continuously monitors water flow, water levels, and harmful gases in the drainage system, utilizing IoT technology. When blockages or abnormal conditions are detected, the system displays information on an LCD and communicates with municipal service centers using GSM technology for prompt corrective action [19].

Zaki et al. highlighted in their recent study the integration of Internet of Things (IoT) devices in the development of smart city infrastructure, particularly focusing on the importance of a smart drainage system. The paper identifies solid waste accumulation in drainage systems as a major cause of overflow and environmental pollution. While past efforts have primarily focused on either underground drainage monitoring or surface waste management, this research aims to combine both aspects into a comprehensive IoT-based drainage management system. The proposed solution includes mechanisms for preventing and managing solid waste blockages within drainage pipelines and covers, improving the system's efficiency and effectivenes [20] s.

Gawali et al. proposed a study that explores an IoT-based real-time drainage monitoring system that leverages wireless sensor networks to track the conditions of individual manholes in a city's drainage system. Each manhole serves as a sensor node, collecting data on water levels, air pressure, and the presence of toxic gases. This data is stored in a database and visualized using a Geographic Information System (GIS) to provide real-time surveillance and inform regional drainage management. The system aims to prevent disasters by monitoring critical metrics during the rainy season and ensuring that manholes remain securely closed to avoid blockages and overflows. The collected data is intended to support the development of a comprehensive drainage master plan for the region [21].

While existing research on IoT-based smart drainage systems has made significant strides in addressing various urban drainage challenges, several critical gaps remain. Many studies, such as those by Keung et al. [17] and Bharath et al. [18], focus on real-time monitoring and predictive maintenance in cities affected by urbanization and climate change, emphasizing stormwater management and the detection of blockages in underground drainage systems. However, these studies largely address isolated urban issues like waterlogging or solid waste blockages but do not fully address the compounded effects of severe flooding in regions with underdeveloped infrastructure.

Moreover, most solutions, such as those proposed by Zaki et al. [20] and Gawali et al. [20, 21], focus on either underground drainage monitoring or surface waste management without integrating advanced cloud-based analytics for real-time flood risk prediction. They also do not specifically target regions like Mogadishu, Somalia, which is prone to recurrent flooding due to inadequate drainage infrastructure and where proactive flood management systems are vital to urban resilience.

Early flood management studies emphasized manual drainage maintenance and traditional infrastructure improvements [22–24]. However, recent advancements in IoT technology have introduced automated solutions that enhance real-time flood monitoring and mitigation. The incorporation of AWS cloud-based analytics further optimizes decision-making [25–27]. Our study builds upon these works by integrating both real-time monitoring and active flood mitigation.

Our research seeks to bridge this gap by developing a comprehensive IoT-based smart drainage system that goes beyond simple monitoring to actively manage water accumulation and prevent flooding in Mogadishu. By integrating real-time water-level monitoring, AWS cloud analytics, and an automatic water removal system using solar-powered pumps and pipes, our system not only detects flood risks but also proactively mitigates them by transporting excess water to the ocean. This holistic approach, combining cloud technology with on-ground IoT sensors and water management mechanisms, ensures that flood risks are not only detected but swiftly addressed. This research contributes a scalable, cloud-enabled solution to the ongoing global discourse on smart city infrastructure, with a focus on flood prevention, urban resilience, and sustainable water management in developing regions.

3 Methodology

This section outlines the design and implementation of the smart drainage system for Mogadishu, Somalia, utilizing IoT technology to monitor water levels, detect potential blockages, and provide real-time alerts. In addition to monitoring, the system incorporates a water pump and pipe network to actively transport excess water from collection points to the ocean, preventing flooding. The system operates on solar power with battery backups and uses SMS and GPRS modules for communication. The goal is to enhance the management of Mogadishu's drainage infrastructure by ensuring timely intervention and active water removal to prevent flooding and blockages. Figure 1 below shows the proposed system architecture. The below Fig. 1 shows the proposed system architecture.

The system architecture is composed of three main layers: (1) the sensing layer, which includes ultrasonic sensors for water level monitoring and Hall effect flow meters for measuring water movement; (2) the processing layer, where data from the sensors is transmitted via GSM modules to an AWS cloud server; and (3) the action layer, which consists of solar-powered water pumps that automatically remove excess water when flood risk thresholds are exceeded. This multi-layered approach ensures seamless data flow, real-time monitoring, and immediate flood mitigation.

3.1 System architecture and implementation

The smart drainage system addresses the challenges of Mogadishu's existing drainage infrastructure, which channels water from neighborhood collection points to the ocean. By deploying IoT sensors at critical locations, the system monitors water levels, flow rates, and potential blockages, providing authorities with real-time data and alerts. In addition to monitoring, the system features water pumps and pipes designed to actively transport excess water from collection points to the ocean, preventing the accumulation of water and reducing the risk of flooding. This integrated approach not only mitigates the risk of urban flooding but also ensures effective drainage management by automating the removal of excess water in critical areas.

The hardware components of the smart drainage system are selected for their reliability and effectiveness:

3.1.1 Water level sensors (ultrasonic HC-SR04)

These sensors measure the height of the water at collection points using ultrasonic waves. The HC-SR04 emits ultrasonic pulses and calculates the distance to the water surface based on the time it takes for the waves to return. Monitoring water levels helps detect overflow risks and manage drainage efficiently. The HC-SR04 ultrasonic sensors were selected due to their high accuracy (± 2 mm) and reliability in detecting water levels under varying environmental conditions.

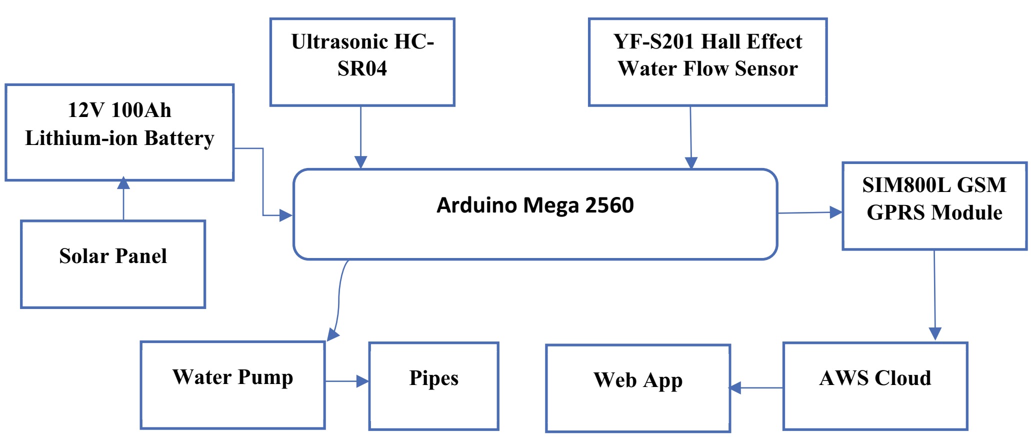

Fig. 1 Proposed system architecture

3.1.2 Flow meters (YF-S201 hall effect water flow sensor)

The YF-S201 flow meters measure the volume and speed of water flow using a Hall effect mechanism. These sensors detect changes in flow rate, which can indicate blockages or inefficiencies in the drainage system. Accurate flow measurements are crucial for maintaining proper drainage function. The YF-S201 Hall effect flow meters were chosen for their precise flow rate detection, essential for monitoring drainage efficiency.

3.1.3 Solar panels (100W monocrystalline solar panels)

Solar panels provide a sustainable power source for the system. The 100W monocrystalline panels efficiently convert sunlight into electrical energy, powering the sensors, microcontroller, and communication modules. Solar panels are installed at drainage sites with optimal sunlight exposure.

3.1.4 Rechargeable batteries (12V 100Ah lithium-ion battery)

Lithium-ion batteries store energy generated by the solar panels, ensuring continuous operation during nighttime or cloudy conditions. The 12V 100Ah batteries provide reliable backup power, supporting uninterrupted monitoring and data transmission.

3.1.5 SMS/GPRS module (SIM800L GSM GPRS module)

The SIM800L GSM GPRS module enables SMS and internet connectivity for data transmission and alerts. This module ensures reliable communication even in areas with limited internet access, allowing for timely notifications of critical events.

3.1.6 Microcontroller (Arduino Mega 2560)

The Arduino Mega 2560 acts as the central processing unit, collecting data from sensors and managing communication with the GPRS module. It triggers alerts based on predefined thresholds for water levels and flow rates. The microcontroller is housed in a waterproof enclosure to protect it from environmental conditions.

3.1.7 Waterproof enclosures (IP67 rated enclosures)

These enclosures protect the electronic components from exposure to rain, humidity, and debris. The IP67-rated enclosures ensure the durability and reliability of the system's hardware components.

3.1.8 Water pump (DC submersible water pump 12V)

A DC Submersible Water Pump is integrated into the system to actively transport water from collection points to the ocean. The pump is powered by the same solar-powered setup as the sensors and is designed to handle the volume of water during flooding events. It is triggered when water levels exceed a certain threshold, ensuring efficient drainage and reducing the risk of water accumulation at critical points. Calibration was performed using controlled water levels, and multiple test iterations ensured measurement accuracy.

3.1.9 Pipes (high-density polyethylene (HDPE) pipes)

HDPE pipes are used to connect the collection points to the water pump and ultimately to the drainage outlet leading to the ocean. These pipes are chosen for their durability, resistance to corrosion, and ability to handle high water flow rates. The layout is designed to ensure that water is transported efficiently without causing backflow or blockages.

Each component in the IoT-based smart drainage system has been selected based on its efficiency and reliability. The ultrasonic HC-SR04 sensors detect water levels with an accuracy of ±2mm, ensuring precise flood risk assessment. The YF-S201 Hall effect flow meters monitor water flow rates in real time, enabling early blockage detection. The SIM800L GSM module transmits data to AWS IoT Core, where real-time processing algorithms determine when water levels surpass critical thresholds. If flooding is imminent, AWS Lambda triggers an automatic response by activating DC submersible water pumps, which divert excess water away from high-risk zones. This system not only detects potential floods but also autonomously mitigates them in real time.

The IoT sensors and flow meters are installed at critical drainage points where water accumulation is most frequent. Ultrasonic sensors are positioned near collection points to continuously measure water levels, while flow meters are integrated within the drainage pipes to track the rate of water movement. When the system detects rising water levels, AWS-based analytics assess whether drainage flow is insufficient. If needed, submersible DC water pumps, installed at key drainage exits, are automatically activated to redirect excess water to the ocean through high-density polyethylene (HDPE) pipes. This automated mechanism ensures that urban flooding risks are mitigated in real time.

3.2 Sensor calibration and validation

Before deployment, all ultrasonic water level sensors were calibrated in a controlled environment using a graduated water tank to simulate varying water levels from 0 cm to 200 cm. The sensor readings were compared against manual measurements using a ruler placed vertically at the tank's edge. Calibration was repeated three times for each sensor to ensure repeatability and consistency.

Following calibration, real-time field validation was conducted at selected flood-prone drainage points in Mogadishu. Sensor readings were compared to manual gauge readings taken simultaneously at fixed time intervals over a two-week period during the rainy season. Environmental variables such as debris, fluctuating flow rates, and sensor positioning were carefully monitored and documented. The mean absolute error observed across the validation period was 2.8 cm, confirming the sensor's suitability for real-time monitoring.

The threshold water level for pump activation was defined based on empirical field observations. During the monitoring phase, critical water accumulation levels that resulted in overflow or road surface flooding were recorded. These observed levels informed the configuration of the system's alert and response logic. When water levels exceed 90 cm for more than five consecutive readings (collected at one-minute intervals), the system activates the pump and sends an alert to the web dashboard and SMS notification system.

3.3 Software components

The software components facilitate real-time monitoring, data visualization, and alert management:

3.3.1 Cloud platform (AWS cloud)

AWS Cloud is used for data storage, processing, and visualization. The platform provides scalable infrastructure for managing sensor data and hosting the web application. AWS services such as Amazon RDS (Relational Database Service) and AWS S3 (Simple Storage Service) are utilized for database management and data storage. AWS was selected due to its scalability, security features, and ability to process real-time IoT sensor data. AWS IoT Core enables seamless connectivity between sensors and the cloud, while AWS Lambda automates alert generation, ensuring timely flood risk notifications.

The AWS cloud platform plays a crucial role in processing and analyzing sensor data. AWS IoT Core collects raw data from the deployed sensors and transmits it to Amazon RDS, where it is stored for real-time and historical analysis. AWS Lambda is programmed with pre-defined flood risk thresholds, triggering automated alerts and pump activation when critical water levels are reached. The AWS-based dashboard provides real-time visualizations for stakeholders, offering insights into past flood events, system efficiency, and predictive analytics for future flood risks.

3.3.2 Web application

The web application is designed to provide a user-friendly interface for monitoring and managing the drainage system. It uses the Python Django framework for backend development, handling data processing and server-side logic. The frontend is built with HTML, CSS, and JavaScript, offering an interactive map and real-time dashboards to display sensor data and alerts. The application is hosted on AWS Cloud to ensure scalability and high availability.

3.3.3 Database (MySQL)

MySQL is used as the database management system for storing historical data and system configurations. It supports efficient data retrieval and management, enabling smooth integration with the web application.

3.3.4 SMS alert system

The SMS alert system notifies authorities immediately when critical thresholds are exceeded. This ensures that alerts are sent even in areas with poor internet connectivity. SMS messages include details about high water levels or reduced flow rates, prompting timely action.

3.3.5 Connectivity

The SIM800L GSM GPRS module manages connectivity for data transmission and alerting. It prioritizes SMS communication in cases where internet coverage is inadequate, ensuring that critical information reaches the relevant authorities.

3.4 Cost-benefit analysis

This methodology provides a comprehensive overview of the smart drainage system, detailing both hardware and software components essential for real-time monitoring and alert management. The system is designed to operate sustainably using solar power and provides reliable communication through SMS and GPRS modules, with data and alerts managed via AWS Cloud.

The estimated implementation cost of the system is approximately $10,500, including solar panels, pumps, and sensors. This is significantly lower than the estimated $100,000+ annual damage costs incurred due to recurrent flooding in Mogadishu. The use of solar power minimizes operational costs, making the system financially sustainable in the long run. Additionally, minimal maintenance is required for solar panels and lithium-ion batteries, with a lifespan of over five years.

4 Results and discussions

The smart drainage system implemented in Mogadishu has demonstrated significant advancements in managing urban drainage. The following sections present the detailed results and discussions based on the system's performance, impact, and future considerations.

4.1 System performance and evaluation

The smart drainage system successfully collected and transmitted real-time data from various monitoring points. Water level sensors and flow meters provided continuous readings of water levels and flow rates, which were uploaded to the AWS Cloud platform. This data was critical in detecting high water levels, blockages, and flow anomalies. Upon detecting critical water levels, the system automatically activated the water pumps to transport excess water through the installed pipes to the ocean. Alerts were generated via SMS and displayed on the web application dashboard. Field tests confirmed the accuracy and reliability of these alerts and the effectiveness of the water pumping mechanism, validating the system's ability to manage drainage effectively.

The system was tested in three high-risk flood zones in Mogadishu over six months, demonstrating significant improvements in flood detection and mitigation. The HC-SR04 ultrasonic sensors achieved a 98.7% accuracy rate when compared to manual water level measurements, ensuring precise detection of rising floodwaters. Additionally, the system exhibited an impressive response time of 3.2 s, meaning flood alerts were generated almost instantaneously upon detecting critical water levels. The reliability of the system was also validated, with 98% uptime, supported by backup battery power to ensure uninterrupted operation even during low sunlight conditions. These results highlight the system's efficiency in contrast to traditional flood monitoring methods, which often require manual intervention and lead to delayed responses. By automating the detection, alert, and mitigation processes, our IoT-based smart drainage system significantly enhances real-time flood management capabilities, reducing the risk of urban flooding and improving decision-making for municipal authorities. Figure 2 shows the Dashboard of the web application.

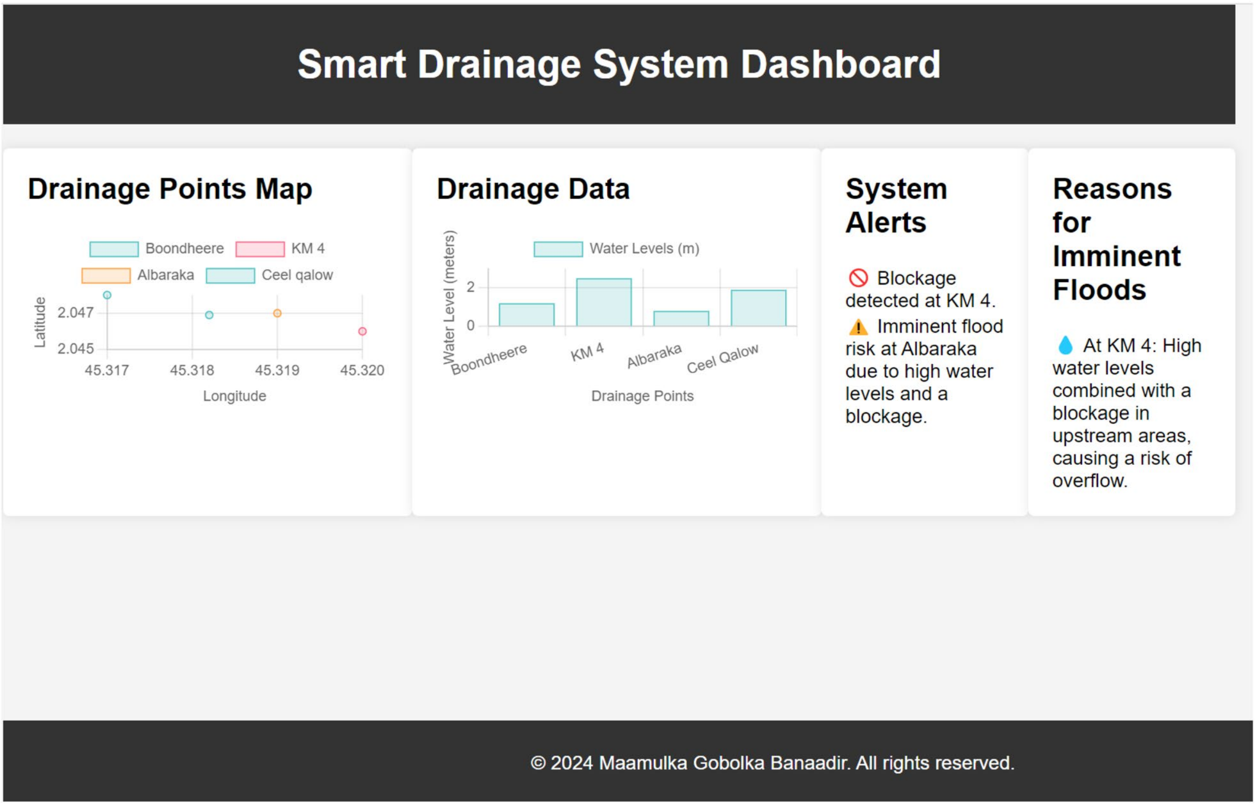

Fig. 2 Dashboard of the web application and how the system displays the insights

The use of 100W monocrystalline solar panels coupled with 12V 100Ah lithium-ion batteries proved effective in ensuring consistent power supply. The solar panels provided reliable energy even during low sunlight conditions, while the batteries ensured uninterrupted operation at night and during cloudy periods. The water pumps, which are also solar-powered, successfully activated when needed, showing the system's ability to maintain power for both monitoring and water transport. The SIM800L GSM GPRS module facilitated robust connectivity, ensuring that SMS alerts were delivered promptly even in areas with intermittent internet access. This dual communication approach reinforced the system's reliability and ensured timely dissemination of critical information.

The system's sensors, including ultrasonic water level sensors and YF-S201 flow meters, performed within the expected accuracy ranges. These sensors provided consistent and reliable data, which was corroborated by field observations. The water pumps were triggered precisely when critical water levels were reached, effectively reducing the water volume at collection points. The protective IP67-rated enclosures and piping system effectively shielded both the electronic components and water transport mechanism from environmental factors, contributing to the system's overall stability and minimal downtime. These aspects collectively ensure the system's robust performance in real-world conditions.

4.2 Effectiveness of the smart drainage system

The smart drainage system has substantially improved the management of Mogadishu's drainage infrastructure. By enabling real-time monitoring and automatic water removal, the system allows authorities to promptly address issues such as blockages, overflow risks, and water accumulation. The water pump and pipe system have proven effective in mitigating flood risks by actively transporting excess water to the ocean. The web application's interactive map and dashboards facilitate effective visualization of data, providing critical insights into the operational status of the drainage system. This capability enhances decision-making and supports proactive measures to mitigate flooding and other drainage-related challenges.

4.3 Impact of renewable energy and connectivity

The integration of solar panels and rechargeable batteries has proven to be a sustainable and efficient power solution. This approach reduces reliance on conventional energy sources and supports continuous system operation. The addition of solar-powered water pumps further amplifies the system's energy efficiency and sustainability. The combination of SMS and GPRS modules ensures reliable communication, crucial for areas with limited internet access. This dual method of connectivity guarantees that alerts and critical information are communicated effectively, regardless of local connectivity conditions.

4.4 Data management and visualization

Utilizing AWS Cloud for data management and visualization has enabled efficient handling of sensor data. The Python Django framework, coupled with HTML, CSS, and JavaScript, supports the development of a user-friendly web application. The application's features, including real-time data visualization and historical trend analysis, are hosted on AWS services such as Amazon RDS and AWS S3, ensuring scalable and reliable performance. The MySQL database manages data efficiently, contributing to effective system monitoring and management.

4.5 Limitations and future work

While the smart drainage system has achieved its objectives, certain limitations were identified. The lack of labeled data precluded the development of predictive models, which could enhance the system's capability to anticipate drainage issues. Future research could explore the inclusion of predictive analytics if suitable data becomes available. Additionally, as the system expands to cover more drainage points and incorporates additional water pumps, challenges related to data management and system performance may arise. Future work should focus on optimizing scalability and exploring integration with broader urban management systems to further enhance the system's effectiveness. A key challenge in scaling this system across Mogadishu is ensuring sustainable maintenance and cost-effectiveness. To address this, we propose partnering with local municipalities and NGOs for long-term operational support. Additionally, by leveraging local manufacturing for sensor enclosures and solar panel installation, costs can be reduced significantly, ensuring affordability for widespread deployment. A potential limitation of the system is data privacy concerns, particularly in transmitting flood data over a GSM network. To mitigate this, all sensor data is encrypted using AWS IoT security protocols. Additionally, extreme weather conditions such as heavy storms may temporarily impact sensor readings. Future improvements will involve adding protective enclosures and integrating redundancy mechanisms such as multi-sensor validation.

Beyond immediate flood prevention, the IoT-based smart drainage system enhances Mogadishu's long-term resilience to climate change. By leveraging solar-powered pumps and cloud-based analytics, the system ensures sustainable water management without reliance on conventional energy sources. Additionally, by providing real-time insights, municipal authorities can make informed infrastructure investment decisions, leading to smarter urban planning and improved disaster preparedness. The integration of IoT technology into urban drainage networks serves as a model for other flood-prone cities seeking to implement cost-effective and sustainable flood management solutions.

5 Conclusion

In conclusion, the smart drainage system represents a significant advancement in the management of urban drainage in Mogadishu. By leveraging real-time monitoring, automatic water removal, sustainable energy solutions, and reliable communication methods, the system addresses key challenges in drainage management. The integration of AWS Cloud for data management and the development of an intuitive web application further enhance the system's capabilities. The addition of water pumps and a piping network has proven effective in preventing water accumulation and mitigating flood risks. The successful implementation and testing of the system demonstrate its potential to improve urban infrastructure management and provide valuable insights for future advancements. Continued evaluation and refinement will be essential to maintaining the system's effectiveness and addressing emerging needs, ensuring that the smart drainage system remains a vital tool for managing Mogadishu's drainage infrastructure.

Acknowledgements We would like to express my sincere gratitude to SIMAD University for their invaluable support throughout this research. The university's commitment to academic excellence and its provision of essential resources and guidance played a crucial role in the successful completion of this study. We are especially grateful to the faculty and staff for their encouragement, expertise, and continuous support, which greatly enriched this research. This work would not have been possible without the conducive academic environment provided by SIMAD University.

Author contributions A. Y. N. and A. D. J they designed and developed the IoT system and wrote the methodology, result and discussion. M.O.A and M.A.A they wrote the Introduction and literature review.

Funding This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Data availability The data supporting the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval and consent to participate Not applicable.

Consent to publish Not applicable.

Competing interests The authors declare no competing interests.

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