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Effective Drainage of the Built Environment in the Ai Era: Opportunities for Smart and Climate-Responsive Drainage Management in Jos, Plateau State, Nigeria

LAGASI, J.E[1], LAGASI, J. J.[2], IREEBANIJE, O.O[3]
[1]*Department of Civil Engineering, University of Jos. Plateau State Nigeria*
[2,3]*Department of Architecture, Faculty of Architecture, University of Jos, Plateau State, Nigeria*

Abstract- Effective drainage is essential to the performance, safety and sustainability of the built environment. Rapid urbanisation, increased impervious surfaces, inadequate drainage infrastructure, poor maintenance and indiscriminate waste disposal have increased urban flood risks in many Nigerian cities. Climate change adds another layer of difficulty by increasing the likelihood of intense rainfall events and associated runoff. Traditional drainage systems are largely passive. They collect and convey stormwater but have limited capacity to predict changing conditions, identify blockages in real time or adjust their operation before flooding occurs. This paper reviews the emerging application of artificial intelligence, machine learning, Internet of Things, geographic information systems, remote sensing and real-time monitoring in urban drainage management. Existing literature shows that machine learning can support flood prediction, drainage system diagnosis, infrastructure maintenance and real-time control. Recent reviews also identify artificial intelligence as a promising tool for improving the resilience of urban drainage systems under climate change and rapid urbanisation. Nigerian evidence confirms the relationship between poor drainage, waste disposal and urban flooding. The paper argues that AI should not replace conventional drainage infrastructure but should improve the way drainage systems are planned, monitored, maintained and operated. For Jos, a smart drainage framework should integrate catchment mapping, rainfall monitoring, water-level sensors, blockage detection, GIS-based drainage inventories, predictive models and coordinated maintenance. The paper concludes that effective drainage in the AI era requires both physical infrastructure and intelligent information systems. However, successful implementation depends on reliable data, technical capacity, institutional coordination, funding and appropriate regulatory frameworks.

Keywords: Artificial intelligence, urban drainage, stormwater, flood management, smart drainage.

I. INTRODUCTION

Drainage is one of the fundamental infrastructure systems of the built environment. It protects buildings, roads, pedestrian routes, public spaces and urban services by collecting and conveying excess surface water.

The conventional approach to urban drainage is largely passive. Drainage channels, culverts, gutters, pipes and outfalls are designed to convey water away from developed areas. Once constructed, however, many systems receive limited monitoring until a failure occurs.

This approach is becoming increasingly inadequate. Urbanisation increases the proportion of impermeable surfaces, reducing natural infiltration and increasing runoff. Climate change is also altering rainfall patterns. The IPCC reports that heavy rainfall intensity is projected to increase in West and Central Africa under future warming scenarios, with implications for flooding.

Nigeria is already experiencing significant challenges associated with urban flooding. Research has linked flooding to both natural and human factors, including poor drainage infrastructure and waste disposal practices. Echendu’s study of Port Harcourt found that solid waste commonly blocks available drainage infrastructure and reduces the ability of drains to convey stormwater.

The problem is therefore not simply a question of constructing more drains. A drainage system can fail because its hydraulic capacity is inadequate, because its catchment has changed, because its outlet is blocked, because waste has accumulated or because maintenance is delayed.

Artificial intelligence offers a new dimension to the problem. Recent research identifies machine learning applications in urban drainage under three broad areas: real-time operation, flood-inundation prediction and infrastructure maintenance.

More recent reviews have expanded this application to include system diagnosis, real-time control, digital twins and resilience planning. A 2025 review in ACS ES&T Engineering identifies deep learning, including long short-term memory models, deep reinforcement learning and graph neural networks, as promising approaches for improving urban drainage resilience.

A 2026 review further organises machine learning applications around water quality, flow modelling, infrastructure management and real-time control. It notes that the greatest value occurs where stormwater systems involve heterogeneous data, nonlinear behaviour and adaptive decision-making.

The significance of these developments for Jos is considerable. The city contains urbanised catchments, roads, buildings, open spaces and drainage corridors that interact during intense rainfall. Effective drainage management therefore requires both physical infrastructure and better information.

This work is set out to

The objectives of this paper are to: examine the major challenges affecting effective drainage of the built environment; examine the application of artificial intelligence and related digital technologies in drainage management and to propose an integrated framework for effective and climate-responsive drainage management in the AI era.

II. MATERIALS AND METHODS

Research Design

The study adopted a literature review approach. Published studies on urban drainage, stormwater management, flooding, artificial intelligence, machine learning, Internet of Things and smart stormwater systems were examined.

Sources of Information

The review drew from peer-reviewed scientific literature, international climate assessments and Nigerian studies on flooding and urban drainage. Particular attention was given to recent literature on AI-supported drainage management because the subject is rapidly developing. (Echendu 2023).

Analytical Procedure

The analytica procedure considered the conventional drainage; climate and urbanisation pressures; drainage monitoring and data collection; and artificial intelligence and predictive management; and the results were synthesised to develop a conceptual framework for smart drainage management.

III. RESULTS

Challenges of Conventional Urban Drainage

The review identified several recurring problems such as inadequate hydraulic capacity, blocked drains, poor maintenance, inappropriate development around drainage corridors, inadequate catchment planning, poor waste management and limited monitoring.

Flooding is therefore often the result of interacting failures rather than a single technical problem. These problems are summarized and presented in table 1 below

TABLE 1: MAJOR DRAINAGE PROBLEMS AND POTENTIAL AI RESPONSES

Problem	Conventional response	Potential AI-supported response
Blocked drains	Periodic inspection	Camera and image-based blockage detection
Unexpected rainfall	Reactive response	Rainfall forecasting and flood prediction
Rapid water-level rise	Manual observation	Real-time water-level sensors and alerts
Poor maintenance	Scheduled inspection	Predictive maintenance
Unknown drainage condition	Physical survey	GIS and digital drainage inventory

Flood-prone locations	Historical observation	Machine-learning flood-risk mapping
Complex drainage networks	Static hydraulic modelling	Hybrid physics and AI models
Climate uncertainty	Fixed design assumptions	Scenario-based predictive analysis

Climate Change and Drainage

Climate change creates two major challenges for drainage.

The first is rainfall intensity. Higher rainfall intensity can produce runoff rates that exceed the capacity of existing drainage channels.(Sikib 2026).

The second is uncertainty. Historical rainfall data may not fully represent future rainfall conditions.

The IPCC reports high confidence that the intensity of extreme precipitation will increase in West and Central Africa under future warming scenarios.

Drainage systems therefore need to move beyond historical design assumptions and incorporate climate-risk assessment.Yan (2025).

Urbanisation and Surface Runoff

Urban development replaces natural ground surfaces with roofs, roads, concrete paving and other impervious surfaces. These surfaces reduce infiltration and increase the speed at which rainfall reaches drainage channels.

This creates a direct relationship between urban form and drainage performance.

The implication is important for architects and planners. Drainage should not be considered only after the building layout has been established. Site planning, road alignment, open spaces, landscaping and building footprints should contribute to stormwater management.

Waste and Drainage Blockage

Waste disposal is a major operational problem.

Echendu’s 2023 study of Port Harcourt identified poor waste disposal as a contributor to flooding and reported that solid waste commonly blocks drainage infrastructure. The study also identified inadequate drainage infrastructure and the absence of comprehensive drainage planning as important concerns.

The lesson for Jos is straightforward. Increasing drainage capacity without addressing blockage may produce limited improvement.

Drainage Monitoring Through IoT

Internet of Things technology allows physical drainage infrastructure to become measurable.

Water-level sensors can provide continuous information on the depth of water in drains. Rain gauges can provide rainfall information. Cameras can monitor visible conditions. Flow sensors can provide information on hydraulic performance.

The information can then be transmitted to a central platform for analysis.

Smart stormwater literature identifies IoT as an important component of coordinated catchment management. However, current implementation remains relatively limited and technical, institutional and socio-economic barriers continue to affect adoption.

Artificial Intelligence for Flood Prediction

AI can process large volumes of rainfall, water-level, terrain, land-use and historical flood data.

Machine-learning models can identify relationships that are difficult to capture through simple rules. These models can estimate the likelihood of flooding based on current and forecast conditions.

Potential inputs include:

rainfall intensity; rainfall duration; water level; drainage capacity; catchment area; land cover; terrain; soil characteristics; previous flooding; waste or blockage observations; and weather forecasts.

The output can be a flood-risk probability or warning level.

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AI for Drainage Maintenance
One of the strongest opportunities is predictive maintenance.

Conventional maintenance often follows a fixed schedule. A drainage channel may be inspected once every few months regardless of its actual condition.
AI-supported maintenance can combine historical blockage records, rainfall, water levels, inspection images and location data to identify drainage segments that require greater attention.

Computer vision can also be used to identify visible obstructions. Such systems are already being explored in Nigeria through experimental IoT and edge-AI drainage monitoring projects, although these should not yet be treated as established city-scale infrastructure.

AI for Real-Time Control
The most advanced smart drainage systems do not merely observe the drainage network. They can support operational decisions.

For example, an intelligent system could monitor rainfall and water levels and recommend or initiate actions such as opening or closing controlled structures, activating pumps or redirecting flows where appropriate.

Recent research identifies real-time control as one of the major areas of AI application in urban drainage.

Digital Twins
A digital twin can provide a digital representation of a physical drainage network.

For a city such as Jos, a drainage digital twin could contain:
drainage channels; culverts; bridges; roads; buildings; catchment boundaries; elevation; rainfall stations; water-level sensors; flood-prone locations; maintenance records; waste accumulation points; and historical flood events.

The model could then be used to test different rainfall and development scenarios.

Recent research identifies digital twins as an important future direction for AI-supported drainage resilience.

IV. DISCUSSION

From Passive Drainage to Intelligent Drainage
The major difference between conventional and intelligent drainage is the ability to respond to information such as; conventional drain waits for water. monitored drain measures water. predictive drainage system anticipates water and intelligent drainage network can potentially support decisions before critical conditions occur.

This does not mean that AI makes physical infrastructure unnecessary. The opposite is true. AI is most useful when it is connected to functioning physical infrastructure.

The Physical-Digital Relationship
An effective smart drainage system should therefore have two layers.

The first is the physical layer. This includes drains, culverts, channels, detention facilities, road drainage, green infrastructure and outfalls.

The second is the digital layer. This includes sensors, GIS, communication networks, databases, predictive models and decision-support platforms.

Proposed Smart Drainage Framework for Jos
A practical framework for Jos can be organised into six stages as follows.

Stage 1: Map the drainage network.
A GIS database should identify existing drains, culverts, outfalls, waterways and catchment boundaries.

Stage 2: Identify critical locations.
Historical flood locations, low-lying areas, blocked drainage points and major road crossings should be identified.

Stage 3: Install strategic sensors.
Sensors should be placed at selected critical locations rather than everywhere. Water-level sensors, rain gauges and cameras can provide initial monitoring.

Stage 4: Develop a predictive model.
Historical rainfall, water levels and flood events should be combined with terrain and land-use information.

Stage 5: Establish an alert system.
When predicted water levels exceed defined thresholds, responsible agencies should receive alerts.
Stage 6: Link prediction to maintenance.

The system should generate maintenance priorities rather than merely producing maps or warnings and shown in table 2 below.

TABLE 2: PROPOSED AI-BASED DRAINAGE MANAGEMENT FRAMEWORK FOR JOS

System component	Data required	Main function	Expected benefit
GIS database	Drainage and land-use data	Network mapping	Better planning
Rain gauges	Rainfall data	Rainfall monitoring	Early warning
Water-level sensors	Drain depth	Condition monitoring	Rapid response
Cameras	Drain images	Blockage detection	Faster maintenance
Machine learning	Historical rainfall and flood data	Flood prediction	Early intervention
Digital twin	Integrated drainage data	Scenario testing	Better planning
Maintenance database	| Inspection records	Predictive maintenance	Reduced failures
Public reporting platform	Location and incident information	Citizen reporting	Faster identification of problems

Limitations and Implementation Challenges
AI-based drainage management is not automatically successful.

The first challenge is data. Machine-learning models require reliable historical and real-time information. Poor data can produce unreliable predictions.

The second challenge is technical capacity. Engineers, planners, architects, surveyors and infrastructure managers need sufficient digital skills to interpret and use the outputs.

The third challenge is infrastructure. Sensors require power, communication networks, maintenance and replacement.

The fourth challenge is institutional coordination. Drainage systems cross administrative boundaries. A predictive system is ineffective if warnings do not reach the institution responsible for action.

The fifth challenge is cost. Smart systems require initial investment in equipment, software and training.

The sixth challenge is trust. AI predictions should support professional decision-making rather than operate as unexplained black-box systems.

Recent research emphasises these limitations. Reviews of AI and stormwater management identify data quality, model transferability, uncertainty, operational integration, regulatory support, professional capacity and economic sustainability as major barriers.

AI Should Complement, Not Replace, Conventional Engineering
AI should not be regarded as a substitute for hydrological and hydraulic engineering. rather, drainage capacity must still be calculated, channels must still be properly constructed, culverts must still be sized appropriately, outfalls must still be protected and maintenance must still be undertaken.

The role of AI is to improve information, prediction, monitoring and decision-making.

This distinction is particularly important in developing cities where there may be a tendency to introduce technology before addressing basic infrastructure deficiencies.

Implications for Architects
Architects influence drainage through site planning and building design.

Building orientation, roof drainage, paving, landscape design, site levels, pedestrian routes and open-space planning all influence surface-water movement.

The AI era therefore creates an opportunity for architects to work with engineers and digital specialists at an earlier stage.

A future building site could be assessed through a digital model that predicts where rainfall will accumulate before construction begins.

Implications for Urban Planning
Drainage should be planned at catchment scale. A building may have adequate site drainage while contributing to flooding downstream. Therefore, development approvals should consider the cumulative effects of impervious surfaces, stormwater discharge and drainage capacity.

Green infrastructure should also be integrated. Permeable surfaces, rain gardens, detention areas, vegetated channels and infiltration systems can reduce the volume and speed of runoff entering conventional drainage networks.

V. CONCLUSION

Effective drainage remains essential to a safe and functional built environment. However, climate change, urbanisation, increased impervious surfaces, waste accumulation and inadequate maintenance are placing additional pressure on conventional drainage systems.

The emergence of artificial intelligence provides an opportunity to improve the way drainage systems are planned, monitored and maintained. Existing research demonstrates applications in flood prediction, system diagnosis, predictive maintenance and real-time control.

For Jos, the most realistic approach is not to replace conventional drainage with expensive automated infrastructure. The priority should be to establish a reliable drainage inventory, map flood-prone areas, introduce targeted monitoring, improve maintenance records and gradually add predictive capabilities.

An effective AI-enabled drainage system should therefore follow a simple principle:

better physical infrastructure + better data + better prediction + faster maintenance = greater drainage resilience.

The AI era should not be viewed as a departure from sound drainage engineering. It should be viewed as an opportunity to make drainage systems more informed, responsive and adaptable.

It is therefore recommended that Jos should develop a GIS-based inventory of major urban drainage infrastructure. Drainage surveys should identify critical flood points, blocked channels, undersized culverts and damaged infrastructure. Rainfall and water-level monitoring should be introduced at strategically selected locations. AI-based flood prediction should initially be piloted in high-risk catchments before wider implementation and AI predictions should remain subject to professional verification, particularly during extreme rainfall events.

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