PAPER 15

SMART SKIES, RESILIENT WATER: UAVS IN INFRASTRUCTURE MANAGEMENT, THE ROLE OF DRONE TECHNOLOGY IN ADVANCING WATER AND SANITATION MANAGEMENT

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ABSTRACT

The water and sanitation sector is under increasing pressure from aging infrastructure, rapid urbanization, climate change, and limited operational resources. Traditional methods for monitoring, inspection, and planning are often costly, slow, and pose significant safety risks to personnel. In this context, drone technology-also known as unmanned aerial vehicles (UAVs)-has emerged as a valuable tool to support more efficient, safe, and data-driven water and sanitation management. Drones are increasingly used to inspect critical water infrastructure such as dams, reservoirs, pipelines, water towers, and wastewater treatment facilities. Equipped with highresolution cameras and advanced sensors, drones enable rapid identification of leaks, structural defects, corrosion, and operational failures without interrupting services or exposing workers to hazardous environments.

This capability supports preventive maintenance and helps reduce water losses, including nonrevenue water. In wastewater and sanitation systems, drones improve monitoring of sewer networks, treatment plants, and overflow points. They allow utilities to detect blockages, overflows, and infrastructure damage efficiently, improving regulatory compliance and reducing environmental and public health risks. In addition, drones play a growing role in water quality monitoring by collecting realtime data and physical water samples from rivers, lakes, and reservoirs, particularly in remote or polluted areas. Beyond infrastructure management, drone technology supports sanitation mapping and Water, Sanitation and Hygiene (WASH) interventions by providing accurate spatial data for planning sanitation facilities in informal settlements and underserved communities. Drones are also crucial during disasters such as floods and droughts, where they provide rapid situational awareness, support emergency response, and assist in the protection and restoration of water services. Overall, drone technology offers significant benefits to the water and sanitation sector, including enhanced safety, reduced operational costs, faster data collection, improved decisionmaking, and greater resilience to climaterelated risks.

While challenges remain-such as regulatory constraints, skills requirements, and data management needs-the strategic integration of drone technology presents a strong opportunity to modernize water and sanitation services and contribute to sustainable, reliable service delivery.

1. INTRODUCTION

Reliable water supply and safe sanitation underpin public health, environmental protection, economic activity, and community well-being. Yet many water and sanitation institutions are expected to maintain dependable services while working with ageing networks, constrained budgets, expanding settlements, climate-related shocks, and increasing public expectations (IPCC, 2022; World Bank, 2024; Department of Water and Sanitation, 2025). Pipelines, reservoirs, pump stations, treatment works, sewer systems, and stormwater interfaces all require regular condition monitoring, but the scale and complexity of these assets make comprehensive inspection difficult. Conventional approaches often depend on manual site visits, ground surveys, scaffolding, confined-space entry, and reactive maintenance. These methods can be slow, costly, disruptive, and unsafe, particularly where access is limited or infrastructure has already failed. As a result, problems are sometimes detected only after water losses, overflows, flooding, service interruptions, environmental impacts, or community complaints have occurred.

Against this background, drone technology provides a practical means of strengthening inspection, monitoring, planning, and emergency response. UAVs equipped with optical cameras, thermal sensors, multispectral sensors, LiDAR, gas detection equipment, or sampling devices can collect visual, spatial, and environmental information without placing personnel in unnecessary danger (Sibanda et al., 2021; Hamzah et al., 2024). Their ability to operate above, around, or within difficult locations makes them suitable for dams, reservoirs, pipelines, treatment works, river corridors, informal settlements, and disaster-affected areas. This paper considers how drones can be integrated into water and sanitation workflows to support safer operations, better evidence, proactive maintenance, and more resilient service delivery.

2. OVERVIEW OF DRONE TECHNOLOGY

Drones are aerial platforms that are either remotely piloted or programmed to fly autonomously for the purpose of collecting information from a site or asset. Their design varies according to endurance, operating range, payload capacity, stability, data requirements, and the complexity of the mission. Within water and sanitation environments, they are commonly applied to aerial surveys, infrastructure condition assessments, mapping, environmental observation, construction monitoring, security support, and disaster response (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024).

Typical payloads include high-resolution cameras for visual inspection, thermal sensors for detecting temperature differences, LiDAR units for three-dimensional mapping, multispectral sensors for environmental analysis, and specialised probes or sampling devices for water quality work (Sibanda et al., 2021; Lu et al., 2021; Wasehun et al., 2024). The value of these payloads increases when the outputs are processed through GIS, artificial intelligence tools, asset registers, engineering models, and maintenance systems. In that form, drone data moves beyond images and point clouds and becomes engineering evidence that can inform defect identification,

condition ratings, maintenance priorities, renewal planning, risk assessment, construction verification, and operational decisions (Institute of Public Works Engineering Australasia, 2024; ISO, 2024).



FIGURE 1: *M400 UAV with Lidar payload*

Examples of engineering intelligence applications include automated defect detection from drone imagery, point cloud comparison to identify settlement or deformation, vegetation encroachment analysis along pipeline servitudes, reservoir embankment stability monitoring, volumetric measurement of earthworks and sludge stockpiles, erosion and scour mapping near river crossings, thermal anomaly detection at pump stations or electrical panels, access-road condition assessment, construction progress verification, and risk-based maintenance prioritisation (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024).

When these outputs are linked to GIS, asset registers, hydraulic models, SCADA data, and maintenance systems, they enable engineers and asset managers to move beyond visual reporting and produce actionable insights such as condition ratings, failure likelihood, consequence-of-failure mapping, maintenance triggers, rehabilitation priorities, and capital renewal forecasts (Institute of Public Works Engineering Australasia, 2024; ISO, 2024).

3. LIDAR PAYLOADS, POINT CLOUDS, DIGITAL TWINS AND 3D ASSET MODELLING

LiDAR, or Light Detection and Ranging, is a key sensing technology for producing engineering-grade spatial information from drone platforms. Instead of relying only on photographs, a LiDAR sensor transmits laser pulses and records the return signal to calculate the position of millions of points in three-dimensional space. When this information is combined with GNSS, RTK or PPK correction, inertial measurement data, and appropriate ground control, UAV LiDAR can generate accurate datasets for terrain, structures, corridors, reservoirs, treatment works, pump stations, riverbanks, embankments, and other water and sanitation assets (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024).

The resulting point cloud provides a measurable digital record of the physical environment. Individual points can be processed and classified to separate ground levels, vegetation, buildings, tanks, pipe routes, channels, embankments, access roads, and other features. This is particularly useful where original drawings are missing, outdated, or inconsistent with actual site conditions. Along partially hidden or buried infrastructure corridors, LiDAR-derived models can also support surface profiling, servitude mapping, slope and drainage assessment, vegetation encroachment review, and volume calculations (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024).

LiDAR datasets can also serve as a spatial foundation for digital twins and three-dimensional asset models. In this context, a digital twin is a dynamic digital representation of a physical asset or system that can be enriched over time with inspection results, operating data, maintenance history, sensor readings, photographs, and condition assessments (American Water Works Association, n.d.; Ghorbani Bam et al., 2025). For water and sanitation authorities, this may include digital representations of reservoirs, wastewater treatment works, pump stations, pipe bridges, outfalls, culverts, canals, access roads, river crossings, and flood-prone service corridors.

The main advantage of a digital twin is that it creates a common spatial reference for planning, operations, maintenance, and decision-making. Repeat surveys can be compared to show changes such as settlement, deformation, erosion, embankment movement, vegetation growth, altered stockpile volumes, or unauthorised activity near servitudes. Asset managers can connect the model to registers, inspection records, risk scores, photographs, maintenance notes, and renewal programmes. This supports better budgeting, stronger design coordination, predictive maintenance, and clearer communication between engineers, managers, contractors, operators, and municipal departments (Ghorbani Bam et al., 2025; WSP, 2026).

For municipalities such as eThekwini, LiDAR-enabled digital twins can support long-term infrastructure resilience by creating a living record of critical assets and their surrounding environments. This is particularly useful for flood-prone areas, steep terrain, reservoirs, pump stations, wastewater works, and informal settlement interfaces where infrastructure condition and environmental risk change over time (eThekwini Municipality, 2022; Ghorbani Bam et al., 2025). To achieve this, drone LiDAR outputs should be processed into interoperable formats such as point clouds, digital terrain models, digital surface models, contours, orthophotos, meshes, CAD layers, GIS datasets, and BIM-compatible models.

Examples of digital twin applications in water and sanitation infrastructure include hydraulic performance modelling of water distribution networks, real-time monitoring of pump station efficiency, reservoir level and storage optimisation, wastewater treatment process simulation, sewer overflow prediction, flood-risk scenario modelling, leak and pressure anomaly detection, asset health dashboards, and construction progress verification (American Water Works Association, n.d.; Ghorbani Bam et al., 2025; WSP, 2026). For example, a reservoir digital twin can combine drone-derived 3D geometry, level sensor data, inspection photographs, maintenance history, and security information to support storage planning, condition assessment, and risk-based maintenance.

A wastewater treatment works digital twin can combine process data, equipment condition, drone imagery, and BIM or GIS models to optimise treatment performance, energy use, sludge handling, and maintenance scheduling. Similarly, a pump station digital twin can model pump duty cycles, vibration readings, power consumption, flooding exposure, and access constraints to support predictive maintenance and emergency response planning (Ghorbani Bam et al., 2025; WSP, 2026).

Digital twin case study examples:

A reservoir digital twin can be developed by combining drone LiDAR, orthophotography, level sensors, inspection photographs, access records, security information, and maintenance history into a single operational model. This allows engineers to monitor structural condition, storage capacity, roof integrity, embankment stability, vegetation encroachment, and security risks over time. It also supports scenario planning for drought conditions, emergency storage management, planned maintenance

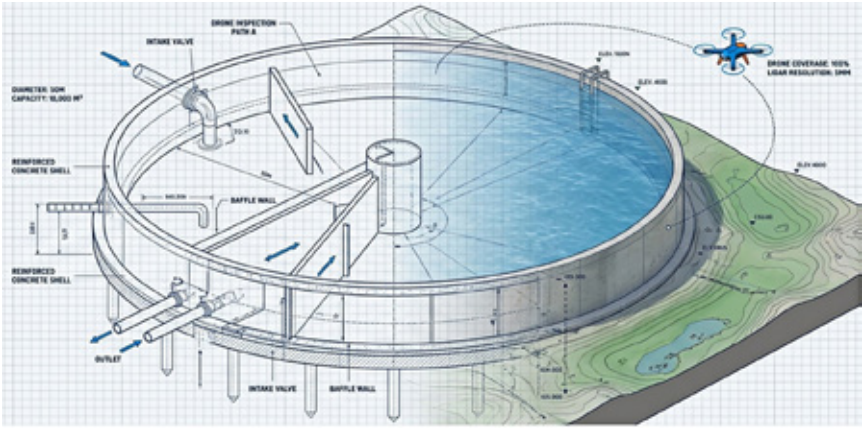


FIGURE 2: *Image of Intelligent Digital twin mapping*

shutdowns, and rehabilitation budgeting (American Water Works Association, n.d.; Ghorbani Bam et al., 2025).

A pump station digital twin can integrate 3D asset geometry, pump specifications, telemetry, flow and pressure data, power consumption, vibration readings, flooding exposure, access constraints, and maintenance records. This enables operators to test pump duty scenarios, identify inefficient operating patterns, predict mechanical failure, optimise energy use, and plan emergency response. For remote or flood-prone pump stations, the twin can also assist with understanding access routes, backup power needs, and risks to continuous service delivery (Ghorbani Bam et al., 2025; WSP, 2026).

A wastewater treatment works digital twin can combine drone-derived 3D models, process data, laboratory results, equipment status, sludge handling information, energy consumption, and compliance records. The model can be used to simulate hydraulic loading, optimise aeration and chemical dosing, monitor clarifier performance, identify maintenance risks, and assess the effect of stormwater inflow or industrial discharges. This supports better compliance management, lower operating costs, improved energy efficiency, and more reliable effluent quality (Ghorbani Bam et al., 2025; WSP, 2026).

A water distribution network digital twin can link hydraulic models, GIS pipe records, valve and meter data, pressure zones, district metered areas, SCADA information, and customer demand patterns. This allows utilities to test network behaviour under pipe bursts, fire-flow demand, pressure fluctuations, valve closures, load shedding, and planned outages. It can also support leak detection, non-revenue water reduction, pressure management, and capital planning by showing how failures in one part of the system affect service delivery elsewhere (American Water Works Association, n.d.; Ghorbani Bam et al., 2025).

A flood-prone infrastructure corridor digital twin can be created from repeated drone surveys, LiDAR point clouds, digital terrain models, rainfall data, flood levels, asset locations, and historical damage records. This twin can be used to model erosion, scour, embankment instability, riverbank movement, culvert blockage, pipe exposure, and access-road vulnerability. It provides a practical decision-support tool for climate adaptation, emergency response, servitude protection, and resilient redesign of pipelines, crossings, and sanitation infrastructure (IPCC, 2022; eThekwini Municipality, 2022; Ghorbani Bam et al., 2025).

A construction and asset handover digital twin can be used during capital projects to record site conditions, construction progress, installed assets, quality inspections, test results, as-built information, and contractor deliverables. Drone imagery and point clouds can verify earthworks, pipe alignments, structures, access roads, stockpiles, and completed works before handover. Once the project is completed, the digital twin becomes part of the operational asset record, reducing the gap between design, construction, and long-term maintenance (Institute of Public Works Engineering Australasia, 2024; ISO, 2024).

Challenges of implementing digital twins

Despite their value, digital twins can be difficult to implement in municipal water and sanitation environments. Key challenges include high initial costs

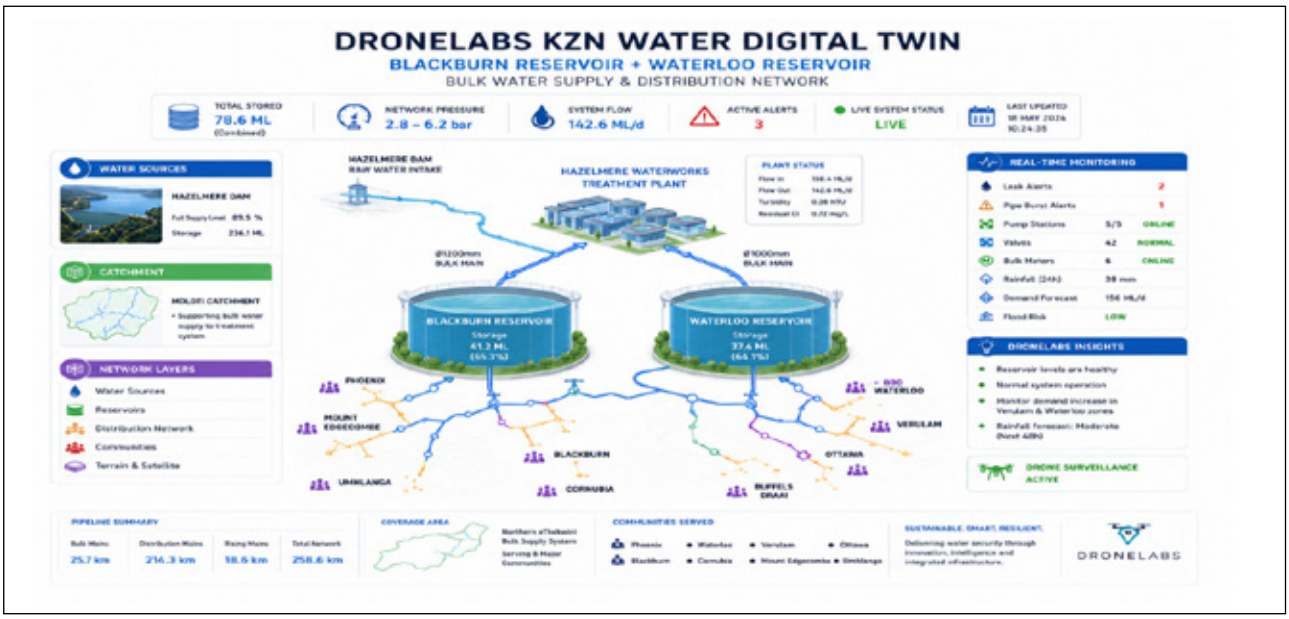


FIGURE 3: *Examples of digital twin applications in water infrastructure*

for LiDAR surveys, sensors, software, cloud storage, modelling platforms, and specialist skills. Data quality is also critical: inaccurate asset registers, incomplete as-built records, inconsistent GIS layers, poor telemetry coverage, and unclassified point clouds can reduce the reliability of the digital twin. Integration is another major challenge, as drone data, SCADA systems, maintenance records, hydraulic models, BIM files, and financial systems often sit in separate platforms that do not communicate easily. Municipalities must also manage cybersecurity, data ownership, privacy, version control, long-term maintenance of models, and institutional capacity. Without clear governance, digital twins risk becoming static visual models rather than living decision-support systems that actively improve operations, budgeting, resilience, and service delivery (Ghorbani Bam et al., 2025; WSP, 2026; ISO, 2024).

4. APPLICATIONS IN WATER INFRASTRUCTURE INSPECTION

One of the most established applications of drones in the water sector is the inspection of critical infrastructure. Drones can be deployed to inspect dams, reservoirs, water towers, bulk pipelines, pump stations, treatment facilities, intake structures, canals, and elevated assets, particularly where access is restricted, expensive, or unsafe (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024). High-resolution aerial imagery allows engineers and asset managers to identify cracking, corrosion, spalling, vegetation encroachment, settlement, erosion, leakage indicators, damaged roofs, failed coatings, and security risks. Thermal imaging may assist in identifying moisture variation or hidden leakage in certain contexts, while LiDAR can generate accurate three-dimensional models for asset condition assessments and volumetric measurements (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024). By reducing the need for scaffolding, rope access, elevated work platforms, and confined manual inspections, drones improve worker safety and reduce operational disruption. They also support preventive maintenance by enabling more frequent and consistent inspections. This helps utilities move from reactive maintenance to condition-based asset management, improving service reliability and extending asset life (Institute of Public Works Engineering Australasia, 2024; ISO, 2024).

5. APPLICATIONS IN WASTEWATER AND SEWER SYSTEMS

Wastewater and sewer systems present significant inspection challenges because they often include confined spaces, hazardous gases, biological contamination, deep chambers, culverts, tunnels, and inaccessible routes. Drone technology is increasingly being used to inspect sewer networks, manholes, wastewater treatment plants, pump stations, overflow points, and stormwater interfaces (Sibanda et al., 2021; Department of Water and Sanitation, 2025). In treatment works, drones can provide rapid visual assessment of clarifiers, basins, channels, tanks, sludge handling areas, roofs, access roads, and perimeter infrastructure. In sewer and stormwater systems, specialised drones can assist with detecting blockages, structural damage, illegal connections, infiltration, overflow risks, and areas requiring cleaning or rehabilitation (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024). This improves operational planning and supports compliance with environmental and public health requirements (Department of Water and Sanitation, 2025; ISO, 2024). Drone-based inspections can also reduce human exposure to hazardous environments. This is particularly important in confined-space inspections where oxygen deficiency, toxic gases, unstable surfaces, and biological hazards present serious risks. When integrated with digital maintenance systems, drone inspection outputs can support prioritisation of repair works, budgeting, and long-term rehabilitation planning (Institute of Public Works Engineering Australasia, 2024; ISO, 2024).

6. WATER QUALITY MONITORING AND ENVIRONMENTAL ASSESSMENT

Drones are becoming increasingly useful for monitoring water quality in rivers, dams, reservoirs, wetlands, estuaries, and coastal areas (Hamzah et al., 2024; Wasehun et al., 2024). Traditional monitoring normally depends on field teams collecting samples at selected points, followed by laboratory analysis. Although this remains essential, it can be limited by site access, safety conditions, staff availability, sampling frequency, and the difficulty of representing large or changing water bodies. Drone-based monitoring can complement these methods by rapidly covering wider areas and capturing high-resolution information in locations that may be difficult or unsafe to reach (Sibanda et al., 2021; Wasehun et al., 2024). Depending on the equipment fitted, drones can capture imagery, assess surface conditions, identify turbidity patterns, detect algal bloom indicators, track sediment plumes, locate potential pollution sources, and collect water samples (Lu et al., 2021; Long et al., 2025; Hamzah et al., 2024). Current research also shows that UAVs can help address spatial data gaps, particularly for small inland water bodies where satellite imagery may not provide sufficient resolution (Long et al., 2025; Wasehun et al., 2024). In municipal operations, this capability can assist with raw water monitoring, post-flood contamination checks, illegal discharge investigations, environmental compliance, catchment management, erosion control, wetland protection, and pollution response planning (Department of Water and Sanitation, 2025; Hamzah et al., 2024).

7. SANITATION MAPPING AND WASH PLANNING

Drone technology can play an important role in sanitation planning, particularly in informal settlements, rural areas, rapidly urbanising communities, and underserved regions where reliable spatial data may be limited (Sibanda et al., 2021; Department of Water and Sanitation, 2025). High-resolution drone imagery can support the mapping of dwellings, footpaths, drainage routes, water points, sanitation facilities, informal discharge points, flood-prone areas, and service access constraints (Sibanda et al., 2021; Department of Water and Sanitation, 2025). For Water, Sanitation and Hygiene programmes, accurate mapping is essential for understanding service gaps, prioritising interventions, and designing appropriate infrastructure. Drones can help planners identify where communal ablution blocks, household sanitation upgrades, drainage improvements, or emergency water points are required. This supports more equitable and evidence-based service delivery (Department of Water and Sanitation, 2025). Drone-derived mapping can also support community engagement by providing visual evidence of settlement conditions and infrastructure constraints. However, the use of drones in inhabited areas must be managed carefully to address privacy, consent, community trust, and data protection requirements (Cliffe Dekker Hofmeyr, 2024; South African Civil Aviation Authority, n.d.).

8. DISASTER RISK MANAGEMENT AND CLIMATE RESILIENCE

Climate change is increasing the frequency and intensity of floods, droughts, storms, heat events, and infrastructure stress (IPCC, 2022; World Bank, 2024). Water and sanitation systems are particularly vulnerable to these hazards because they depend on functioning networks, treatment capacity, water sources, and access routes (World Bank, 2024; Department

of Water and Sanitation, 2025). Drone technology provides rapid situational awareness before, during, and after disaster events (Sibanda et al., 2021; eThekwini Municipality, 2022).

During flooding, drones can map inundated areas, identify damaged pipelines and pump stations, assess access constraints, locate blocked culverts, and support emergency response planning (Sibanda et al., 2021; eThekwini Municipality, 2022). During droughts, drones can support monitoring of reservoirs, wetlands, abstraction points, and environmental stress indicators (IPCC, 2022; World Bank, 2024). After extreme events, drone imagery can help quantify damage, prioritise repairs, and support funding or insurance documentation (Sibanda et al., 2021; eThekwini Municipality, 2022). The speed of deployment is a major advantage. Instead of waiting for full ground access, response teams can use drone data to make early decisions, protect critical assets, and restore services faster. In this way, drones contribute directly to climate resilience and continuity of essential services (World Bank, 2024; Institute of Public Works Engineering Australasia, 2024).

9. CLIMATE CHANGE ADAPTATION AND RESILIENCE

Climate change is increasingly recognised as a water and sanitation challenge because its impacts are experienced through changes in rainfall intensity, drought frequency, flooding, coastal hazards, heat stress, and water quality deterioration (IPCC, 2022; World Bank, 2024). For municipalities and utilities, these changes place pressure on bulk water supply, wastewater treatment, stormwater interfaces, access roads, reservoirs, pump stations, river crossings, and sanitation services in vulnerable communities (World Bank, 2024; eThekwini Municipality, 2022). Drone technology supports climate adaptation by improving the speed, accuracy, and frequency of environmental and infrastructure monitoring. Drones can be used to map flood-prone areas, monitor erosion, assess slope instability, inspect riverbanks and servitudes, track changes in wetlands and water bodies, and identify infrastructure exposed to extreme weather (Sibanda et al., 2021; eThekwini Municipality, 2022). When combined with LiDAR, GIS, hydrological modelling, and asset management systems, drone data can help utilities understand which assets are most vulnerable and where adaptation investments should be prioritised (Institute of Public Works Engineering Australasia, 2024; ISO, 2024).

In drought conditions, drones can assist with monitoring reservoir levels, exposed infrastructure, vegetation stress, catchment degradation, sedimentation, and illegal abstraction risks (IPCC, 2022; World Bank, 2024). In high-rainfall and flood conditions, drones can rapidly identify damaged pipelines, flooded pump stations, blocked culverts, scoured embankments, sewer overflow pathways, and communities cut off from services (Sibanda et al., 2021; eThekwini Municipality, 2022). This creates a stronger evidence base for climate-resilient planning, emergency response, insurance claims, infrastructure redesign, and capital budgeting (World Bank, 2024; Institute of Public Works Engineering Australasia, 2024). Drone-based climate resilience work should also consider social vulnerability. Informal settlements, low-lying communities, steep terrain settlements, and areas with limited formal drainage are often most exposed to climate impacts (eThekwini Municipality, 2022; Department of Water and Sanitation, 2025). High-resolution drone mapping can help identify where sanitation services, access roads, drainage improvements, emergency water points, and flood mitigation measures are most urgently required. In this way, drones can support both technical resilience and more equitable service delivery (Department of Water and Sanitation, 2025; World Bank, 2024).

10. SECURITY OF CRITICAL INFRASTRUCTURE USING DRONES

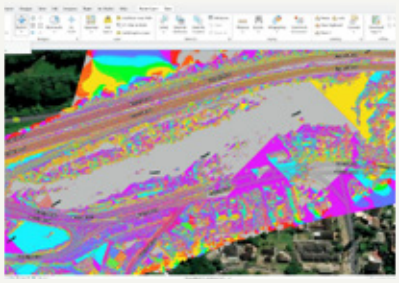
Water and sanitation assets are part of critical infrastructure and are therefore exposed to a range of physical, operational, environmental, and security risks. Reservoirs, pump stations, water treatment works, wastewater treatment plants, chemical storage areas, bulk pipelines, service reservoirs, and control facilities may be vulnerable to vandalism, theft, illegal access, sabotage, contamination risks, and unauthorised surveillance (Department of Water and Sanitation, 2025; Cliffe Dekker Hofmeyr, 2024). Drone technology can strengthen infrastructure security by providing rapid aerial visibility over large or difficult-to-monitor sites (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024). Security drones can be used for perimeter patrols, fence-line inspections, night-time surveillance, intrusion detection, incident verification, and monitoring of remote assets where permanent security presence may be limited. When fitted with high-resolution cameras, thermal imaging, night-vision capability, spotlights, loudspeakers, and automated flight planning, drones can assist security teams in identifying unusual movement, unauthorised vehicles, damage to fencing, open access points, and suspicious activity near sensitive assets (Sibanda et al., 2021; South African Civil Aviation Authority, n.d.).

For municipal water and sanitation systems, drone-based security monitoring can be particularly valuable for reservoirs located in isolated areas, pump stations affected by cable theft, wastewater works with large perimeters, and project sites where construction materials and plant are exposed. Drones allow security personnel to verify alarms quickly before dispatching ground teams, reducing response time and improving situational awareness (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024). In emergency situations, drones can



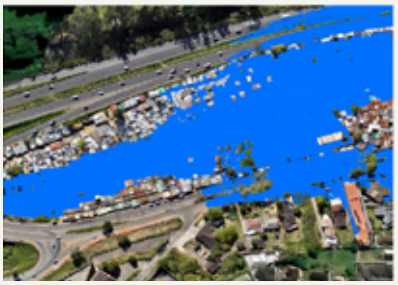
01 CAPTURE THE BASELINE

High-resolution aerial mapping records the road, river corridos, structures, and access routes.



02 BUILD SURFACE INTELLIGENCE

Terrain and surface data establish elevation, drainage paths and assets requiring closer analysis.



03 MODEL POTENTIAL INUNDATION

Scenario outputs reveal where people, structures and transport links may be exposed.

FIGURE 4: *M19 flood-risk intelligence exposure before an incident*

provide live visual information to operations managers, law enforcement, disaster management teams, and facility supervisors. However, drones also introduce new security considerations. Unauthorised drones operated by third parties may be used to observe security arrangements, map vulnerable access points, interfere with operations, or support criminal activity. Critical infrastructure owners should therefore consider both the beneficial use of drones and the risks posed by hostile or unauthorised drone activity. A balanced security strategy should include authorised drone patrols, clear airspace procedures, incident reporting protocols, cyber-secure data handling, and coordination with security providers and relevant authorities (South African Civil Aviation Authority, n.d.; Cliffe Dekker Hofmeyr, 2024; ISO, 2024).

11. ETHEKWINI MUNICIPALITY USE CASES

eThekwini Municipality provides a relevant South African municipal context for demonstrating the potential value of drone technology in water and sanitation management. The municipality operates across a complex coastal and inland urban environment that includes dense settlements, steep terrain, flood-prone catchments, ageing infrastructure, wastewater treatment facilities, reservoirs, pump stations, and rapidly expanding service areas (eThekwini Municipality, 2022; Department of Water and Sanitation, 2025). These conditions create a strong case for using drones as part of a wider digital infrastructure, disaster resilience, and asset management strategy (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024).

Use Case 1: Flood damage assessment and emergency response. Following major flood events in Durban and surrounding areas, drone mapping can support rapid assessment of damaged water and sanitation infrastructure (eThekwini Municipality, 2022; IPCC, 2022). UAVs can be used to capture current imagery of washed-away pipelines, damaged access roads, blocked culverts, unstable embankments, eroded servitudes, affected pump stations, and inaccessible wastewater assets (Sibanda et al., 2021; eThekwini Municipality, 2022). This provides engineers and disaster management teams with early situational awareness before full ground access is restored. In practical terms, this can improve repair prioritisation, contractor mobilisation, insurance documentation, and communication with affected communities

Use Case 2: Reservoirs, water towers, and pump station inspections. eThekwini's dispersed water supply network includes reservoirs, elevated storage structures, pump stations, and bulk supply routes that require regular condition monitoring (Department of Water and Sanitation, 2025; ISO, 2024). Drone inspections can assist with identifying cracks, corrosion, roof defects, vegetation encroachment, leakage indicators, vandalism, and perimeter security weaknesses (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024). Thermal or high-resolution imaging may also support targeted follow-up inspections where abnormal moisture, surface deterioration, or access constraints are present. This approach reduces the need for scaffolding or elevated access equipment and enables more frequent asset condition assessments (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024).

Use Case 3: Wastewater treatment works and sewer overflow monitoring. Wastewater infrastructure within the municipal environment is exposed to high operational, environmental, and compliance pressures (Department of Water and Sanitation, 2025; ISO, 2024). Drones can assist with monitoring treatment works, clarifiers, sludge drying beds, oxidation ponds, outfalls, access roads, perimeter fencing, and overflow-prone areas (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024). Where sewer blockages or overflow incidents occur, aerial imagery can help identify affected drainage routes, contamination pathways, and nearby sensitive receptors such as rivers, wetlands, schools, and residential areas. This supports faster incident response and more defensible environmental reporting (Department of Water and Sanitation, 2025; Sibanda et al., 2021).

Use Case 4: Sanitation planning in informal and peri-urban settlements. In dense or difficult-to-access settlements, conventional field surveys may be slow and incomplete. Drone-derived orthophotos and terrain models can help planners map dwellings, footpaths, drainage channels, flood risk areas, existing sanitation points, informal discharge routes, and potential sites for communal ablution facilities or decentralised sanitation solutions (Sibanda et al., 2021; Department of Water and Sanitation, 2025). For eThekwini, this type of mapping can strengthen Water, Sanitation and Hygiene planning by linking spatial evidence to infrastructure design, community engagement, and phased service delivery (eThekwini Municipality, 2022; Department of Water and Sanitation, 2025).

Use Case 5: City-wide drone mapping and GIS integration. A city-wide drone mapping approach can support multiple departments by producing LiDAR, orthophotography, three-dimensional models, and processed spatial datasets for use on municipal GIS platforms (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024). Within eThekwini, this would allow drone outputs to be shared across engineering, water and sanitation, stormwater, disaster management, environmental management, and project delivery teams. The value of this approach lies in avoiding isolated drone projects and instead creating a common spatial evidence base for planning, emergency response, maintenance prioritisation, and capital investment decisions (Institute of Public Works Engineering Australasia, 2024; ISO, 2024). These use cases show that drone technology is most effective when deployed as part of an integrated municipal workflow. For eThekwini, the priority should not be limited to acquiring drone imagery but should include converting that imagery into usable engineering information through GIS integration, asset registers, maintenance systems, environmental reporting, and disaster response protocols (ISO, 2024; Institute of Public Works Engineering Australasia, 2024).

12. ASSET SUSTAINABILITY AND LIFE-CYCLE MANAGEMENT

Asset sustainability refers to the ability of infrastructure owners to plan, operate, maintain, rehabilitate, and replace assets in a manner that preserves service delivery, reduces whole-life costs, manages risk, and supports long-term environmental and financial resilience (ISO, 2024; Institute of Public Works Engineering Australasia, 2024). In the water and sanitation sector, this is particularly important because many assets are buried, dispersed, difficult to access, and costly to replace once failure occurs. Drone technology strengthens asset sustainability by improving the quality and frequency of condition assessment. Instead of relying only on periodic manual inspections or reactive maintenance after breakdowns, drones enable utilities to capture repeatable visual, thermal, spatial, and environmental data. This allows asset managers to identify deterioration trends, detect early warning signs, compare asset condition over time, and prioritise maintenance based on risk rather than guesswork (Sibanda et al., 2021; Institute of Public Works Engineering Australasia, 2024). From a life-cycle management perspective, drone data can support every stage of an asset's life. During planning and design, drone surveys provide accurate terrain and site information. During construction, drone imagery

supports progress monitoring, quality control, measurement verification, and contractor oversight. During operation, drones assist with routine inspections, security monitoring, environmental compliance, and emergency response. During rehabilitation or replacement, historical drone records provide evidence for renewal decisions, funding motivation, and technical scoping (ISO, 2024; Institute of Public Works Engineering Australasia, 2024).

For municipalities such as eThekwini, asset sustainability also requires integration between drone outputs, GIS platforms, asset registers, maintenance management systems, capital planning, and financial reporting (ISO, 2024; Institute of Public Works Engineering Australasia, 2024). A drone inspection is only valuable if the findings are linked to a specific asset, assigned a condition rating, prioritised according to consequence of failure, and converted into a practical maintenance or renewal action. This approach supports more defensible budgeting and helps municipalities move from reactive repairs to planned, evidence-based asset stewardship (Institute of Public Works Engineering Australasia, 2024; ISO, 2024). Sustainable asset management further supports environmental performance. Early identification of leaks, overflows, erosion, sedimentation, failing embankments, and damaged infrastructure can reduce water losses, contamination events, energy waste, emergency repairs, and avoidable replacement. In this way, drones contribute not only to operational efficiency, but also to long-term infrastructure resilience, climate adaptation, and responsible use of public resources (World Bank, 2024; ISO, 2024).

13. BENEFITS OF DRONE INTEGRATION

The integration of drones into water and sanitation operations provides several practical benefits. These include improved safety, faster inspections, reduced operational costs, enhanced data quality, better asset condition records, more informed decision-making, and improved environmental compliance. Drones also enable utilities to inspect assets more frequently without the same level of disruption associated with manual methods. From a financial perspective, drones can reduce the cost of access equipment, specialist inspection teams, emergency callouts, and repeated field visits. While drone programmes require initial investment in equipment, training, software, and governance, the long-term value lies in improved maintenance planning, reduced asset failure, and better prioritisation of limited budgets. From a governance perspective, drone outputs improve documentation and auditability. Photographs, videos, point clouds, maps, and inspection reports provide a stronger evidence base for regulatory reporting, contractor monitoring, project planning, and management decision-making.

14. IMPLEMENTATION CONSIDERATIONS

Successful implementation requires more than purchasing drone equipment. Utilities and municipalities need a clear operational framework that defines use cases, responsibilities, approvals, safety procedures, data standards, and reporting requirements (Institute of Public Works Engineering Australasia, 2024; ISO, 2024). Drone operations must comply with applicable aviation regulations, privacy requirements, health and safety obligations, and internal governance processes (South African Civil Aviation Authority, n.d.; Cliffe Dekker Hofmeyr, 2024).

Key implementation requirements include trained pilots, competent data analysts, standard operating procedures, risk assessments, maintenance plans, insurance, secure data storage, and integration with geographic information systems or asset management platforms (South African Civil Aviation Authority, n.d.; ISO, 2024; Institute of Public Works Engineering Australasia, 2024). Organisations should also determine whether to build internal drone capacity, outsource specialist services, or adopt a hybrid model.

Data management is particularly important. Drone missions can generate large volumes of imagery and spatial data. Without proper classification, storage, processing, and interpretation, the value of the data may be lost (Ghorbani Bam et al., 2025; WSP, 2026). A structured data workflow should therefore be established from mission planning through to reporting and decision-making (ISO, 2024; Institute of Public Works Engineering Australasia, 2024).

15. CHALLENGES AND LIMITATIONS

Despite their benefits, drones are not a complete replacement for conventional engineering inspections, laboratory testing, or detailed condition assessments. They are best understood as a complementary tool that improves the speed, safety, and coverage of data collection. Some defects may still require physical verification, specialist testing, or intrusive investigation. Operational limitations include restricted flight endurance, weather sensitivity, payload constraints, communication limitations, regulatory approvals, no-fly zones, and the need for skilled operators. In urban areas, privacy concerns and public acceptance must also be addressed. In confined spaces such as sewers and tunnels, specialised drones and experienced operators are required to manage collision risks, poor lighting, signal loss, and hazardous conditions.

Another challenge is institutional readiness. Organisations may collect drone data but fail to use it effectively if there is no link to maintenance planning, budgeting, engineering design, or management reporting. Therefore, drone adoption should be linked to broader digital transformation and asset management strategies.

16. STRATEGIC RECOMMENDATIONS

1. Develop a drone strategy aligned with water and sanitation asset management priorities.
2. Start with high-value use cases such as reservoir inspections, treatment works assessments, sewer overflow monitoring, disaster response, and sanitation mapping.
3. Establish standard operating procedures for flight planning, safety, approvals, community engagement, and data handling.
4. Train internal staff or appoint competent service providers with relevant technical and regulatory experience.
5. Integrate drone outputs with GIS, asset registers, maintenance management systems, and engineering reports.
6. Adopt LiDAR payloads and point cloud workflows for priority assets to create accurate digital twins, three-dimensional asset models, terrain models, and repeatable condition baselines for long-term monitoring.
7. Develop clear digital twin governance standards covering data quality, interoperability, cybersecurity, ownership, version control, model updates, and integration with municipal decision-making processes.
8. Use pilot projects to demonstrate value before scaling the programme across wider operations.
9. Ensure that privacy, data protection, public communication, and ethical considerations are addressed, particularly in residential and informal settlement areas.
10. Combine drone data with ground inspections, laboratory testing, hydraulic modelling, and engineering judgement for robust decision-making.
11. Include infrastructure security applications in drone programmes, including perimeter monitoring, alarm verification, remote asset surveillance, and protocols for responding to unauthorised drone activity.
12. Use eThekwini Municipality pilot use cases to demonstrate drone

value in flood response, reservoir inspection, wastewater monitoring, sanitation mapping, security surveillance, and GIS-based municipal decision-making.

13. Embed climate adaptation objectives into drone programmes by using UAV data to identify flood-prone assets, drought-sensitive water sources, erosion risks, vulnerable settlements, and priority areas for resilient infrastructure investment.
14. Use drone inspection data to support sustainable asset management by linking condition evidence to asset registers, risk ratings, maintenance priorities, renewal planning, and long-term capital budgeting.

17. CONCLUSION

Drone technology has become a valuable tool for modernising water and sanitation management. Its ability to collect high-resolution data safely, quickly, and cost-effectively makes it especially relevant in a sector challenged by aging infrastructure, limited resources, climate risks, and increasing service delivery demands.

Drones support infrastructure inspection, wastewater monitoring, water quality assessment, sanitation mapping, disaster response, and evidence-based decision-making. However, successful adoption depends on more than the technology itself. It requires regulatory compliance, skilled personnel, sound data governance, integration with existing systems, and clear institutional objectives.

When implemented strategically, drones can strengthen preventive maintenance, reduce operational risks, improve environmental compliance, and contribute to more resilient and sustainable water and sanitation services.

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