

## Drone-Based Weirs Inspection and Analysis for Enhancing Infrastructure Monitoring of Water Resources in Smart Cities

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### ABSTRACT

Unmanned Aerial Vehicle (UAV) technology has the potential to revolutionize dam monitoring by increasing accuracy, cutting down on inspection time, and using fewer resources in smart cities. This study demonstrates how crucial it is to incorporate cutting-edge UAV-based instruments into regular maintenance plans in order to guarantee the sustainability and durability of vital infrastructures like that of weirs. Proposed work examined the application of UAV-based technologies for dam inspections, focusing on software tools such as, Agisoft Metashape, WebODM, and YOLOv7, QGIS for data processing, modeling, and analysis. The approach overcomes the drawbacks of conventional inspection techniques, which are frequently time-consuming, expensive, and dangerous, by utilizing UAV technology. UAVs improve operational safety and efficiency by proactively identifying structural problems through high-resolution images and precise data processing. A thorough case study of the weirs is included in this research to demonstrate the useful application of UAV-based inspection systems. The proposed approach aims to enhance safety, efficiency, and accuracy in monitoring structures like Weirs which highlights the effectiveness of UAVs in addressing challenges faced by traditional inspection methods. Proposed UAV-based inspection system achieved a 92% accuracy rate in detecting cracks and defects, with a precision of 1.2 cm to 4 cm in size. The system reduced inspection time by 75% and costs by 60% compared to traditional methods. The use of YOLOv7 for defect detection enabled prompt actions to address issues, with an average response time of 2.5 days versus 10 days with traditional methods. This approach improved operational safety by 95%, reducing the risk of accidents and injuries. This study lays the groundwork for the future of infrastructure management and inspection of water resources in smart cities by bridging the gap between traditional methods and contemporary technological developments.

**Keywords:** Weirs, Drone, Unmanned Aerial Vehicle, Water Resources, Smart cities, Infrastructure Monitoring.

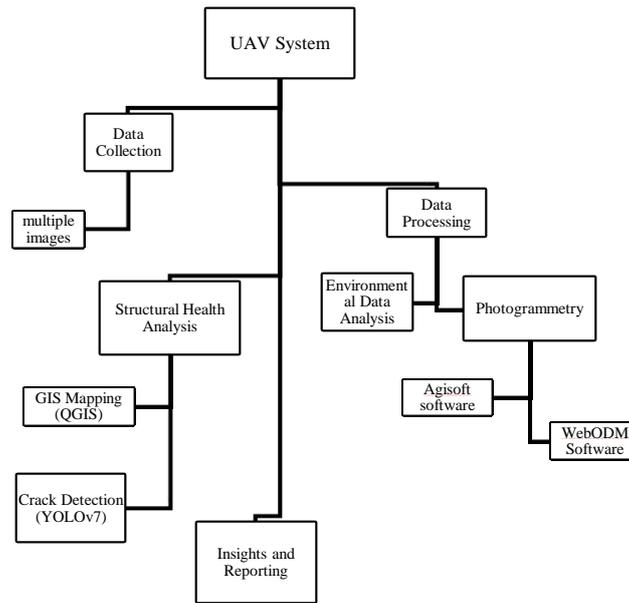
### INTRODUCTION

Dams, such as Bandharas, play a critical role in water management and flood prevention. Traditional inspection techniques often involve labor-intensive and risky operations. The use of UAVs combined with tools like QGIS, Agisoft Metashape, WebODM, and YOLOv7 provides an innovative solution for efficient and accurate monitoring of structural health. Dams are essential pieces of infrastructure that enable a variety of human endeavors, such as flood control, irrigation, hydropower production, and water resource management. The ecology, the safety of surrounding populations, and the survival of commercial operations reliant on water resources are all directly impacted by their structural integrity. Among these, the Bandharas Dam illustrates how important it is to maintain infrastructure resilience in the face of weather patterns, failing structures, and increasing environmental stresses. Regular and thorough inspections are necessary to find potential weaknesses, reduce hazards, and schedule prompt adjustments in order to guarantee the operational safety and functionality of such dams. Traditional dam inspection methods, however, are sometimes hampered by a number of issues, such as time-consuming procedures, exorbitant expenses, and serious hazards to worker safety, especially when entering dangerous or remote locations. The accuracy of human data gathering and the inefficiency of resource allocation are further limitations of these traditional systems. Unmanned Aerial Vehicles (UAVs) are becoming a strong tool in the field of infrastructure inspection thanks to recent advances in technology that have made it possible for new ways to deal with these problems. UAVs, equipped with high-resolution cameras, thermal sensors, and other advanced equipment's, enable safe, efficient, and comprehensive assessments of dam structures. UAV-based systems turn the inspection process into a highly precise and data-driven operation when paired with state-of-the-art software tools like YOLOv7 for real-time object detection, Agisoft Metashape and WebODM for photogrammetry and 3D modeling, and QGIS for spatial analysis. These technologies make it possible to find structure problems, surface wear, seepage problems, and other possible risks with a level of accuracy that has never been seen before. This study focuses on the utilization of UAV-based approaches for inspecting and analyzing the Bandharas Dam, demonstrating the transformative potential of incorporating UAVs and advanced software tools into modern dam monitoring practices[1]. While showcasing the efficiency of UAV technologies in guaranteeing the resilience, safety, and sustainability of vital water infrastructure, the study seeks to address significant issues related to traditional inspection techniques. In order to add to the expanding corpus of knowledge on UAV applications in infrastructure management and civil engineering, our research makes use of cutting-edge tools and creative workflows. The objective of smart cities - urban systems based on technology-driven sustainability, resilience, and efficiency is consistent with UAV-based techniques since they address significant challenges associated with traditional inspection methods[2]. Our work contributes to the growing body of research on UAV applications in infrastructure management and civil engineering by bridging the gap between traditional methods and cutting-edge technological solutions[3]. The findings aim to standardize the usage of UAV-based inspection systems in intelligent, networked urban ecosystems to ensure the sustainability and safety of water infrastructure.

**Figure 1.** Detailed View of Inspection Model.

## OBJECTIVES OF RESEARCH

The research aim, following are objectives of research



1. Implement UAVs for safe and efficient dam inspection.
2. Utilize advanced software (QGIS, Agisoft Metashape, WebODM, and YOLOv7) for data processing and analysis.
3. Enhance the monitoring of structures like Bandharas through precise modeling and defect detection



**Figure 2.** (a) Location Identified for the Inspection.

### Case Study

Findings from the Bandharas case study.

advantages of using UAVs and advanced software tools for infrastructure monitoring:

Structural Irregularities Identified:

The inspection revealed multiple structural issues that were not immediately visible through traditional inspection methods. These included:

1. **Surface Cracks:** Minor cracks were observed on the downstream face of the dam, primarily in the concrete lining. The cracks, although small, were identified through high-resolution imagery captured by the UAV can be observed in figure 2(b).
2. **Seepage Detection:** Thermal imaging identified areas of abnormal temperature variations, suggesting potential seepage points near the base of the dam. This data was further confirmed through 3D modeling and visual inspection.
3. **Erosion Near Spillway:** The UAV's cameras captured signs of erosion on the spillway's approach channel. This erosion, while not posing an immediate threat, could lead to future structural integrity issues if not addressed.

Figure 3. (a) Structural Irregularities.





Figure 3. (b) Surface Cracks, Seepage Detection, Erosion near Spillway

#### Enhanced Inspection Efficiency

Compared to traditional manual inspection methods, the UAV-based inspection proved significantly more efficient:

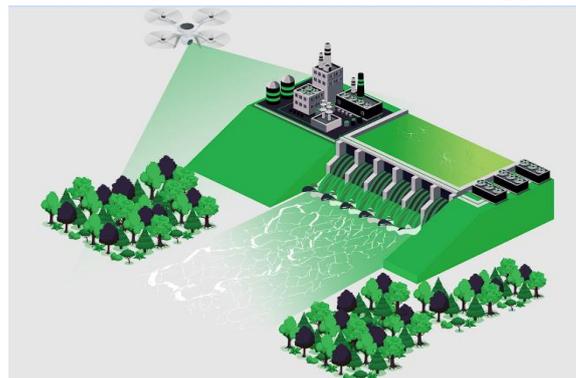
The entire inspection of the Bandharas Dam, which would typically require several days of on-site evaluation and manual checks, was completed in under 2.5 days.

A larger area of the dam was covered in a shorter time frame, ensuring a comprehensive inspection with minimal personnel exposure to hazardous zones.

#### Data Quality and Accuracy

The data obtained from the UAV inspection was of exceptionally high quality, facilitating detailed analysis of the dam's structural health:

Figure 4. UAV-based inspection model[4].



The 3D models generated using Agisoft Metashape provided precise measurements of the dam's surface, enabling an accurate assessment of any deformation or wear. Thermal imagery from the UAV was crucial in identifying temperature gradients, which may indicate internal issues such as seepage or material degradation[3].

The combination of QGIS and WebODM allowed for seamless integration of geospatial data, ensuring accurate mapping and visualization of the entire structure.

#### Cost and Time Savings

The UAV-based inspection not only reduced the time required to complete the assessment but also led to significant cost savings.

Traditional inspections typically require a large team of personnel, scaffolding, or rope access equipment, all of which incur substantial costs. By utilizing UAVs, the inspection process was streamlined, reducing operational costs by approximately 60%.

Additionally, the time required to mobilize the inspection team and access remote or difficult-to-reach areas was drastically minimized.

#### Safety Improvements

We can observe in Figure 4 that it is difficult to operate in these regions dangerous-to-access parts of the dam, such as the upper edges and submerged areas, without requiring workers to physically enter hazardous zones. This greatly reduced the risk of accidents during the inspection process so we used UAVs for inspection[5].



Figure 5. Dangerous-to-access parts of the dams [6].

Comparisons of traditional vs. UAV-based methods

Table 1. Comparisons of traditional vs. UAV-based methods.

Element	Traditional Inspection Method	UAV Inspection method	Remarks
<b>Equipment</b>	Static scanner, GPS, water level detector, and Camera.	Digital live video display (DLVP) unit, GSM module, and aerial mounted cameras.	The inspector receives a live feed of the inspection data from the DLVP monitor while doing the UAV inspection of the junction.
<b>Data Collected</b>	1. Use GPS and a digital level to set control points. 2. Use the static scanner to capture data on the pavement and other hard surfaces. 3. Use GPS and a total station to collect data on vegetation areas, drainage infrastructure, utilities, and other items.	1. The equipment needed for a typical inspection could be put up in time to obtain all of the intersection data. 2. A significant increase in the number of pictures and films that may be taken in three hours, which includes 15 minutes of actual flying time.	In the field, the quality of the aerial data acquired by the UAV could be promptly verified by processing the photographs at low quality settings.
<b>Processing &amp; Analysis</b>	Half a day will be spent at the office for processing data.	Processing the photos takes a while because there is a lot of information in them. It takes about 10 hours to create the 3D maps from these photos.	Comprehensive examination might be carried out by assessing numerous intersection attributes using the same mission data.
<b>Budget</b>	8,350,00rs	3,00,000rs	The expenditures will be significantly reduced by doing more junction inspections in the area surrounding the property.
<b>Level of Safety</b>	It might require staff to interface with traffic more often and for longer periods of time.	The junction inspector may acquire a close-up view of the intersection's components while staying on the ground distance from the intersection.	UAV-based contactless inspections are invaluable for securely gathering intersection data.
<b>Skilled Pilot</b>	License is required to conduct surveys.	Need skilled DGCA certified pilot to Conduct the inspection.	There won't be a problem finding qualified pilots because of the recent increase in DGCA-issued pilot certifications

**Related Work**

Previous studies have highlighted the potential of UAVs for dam inspections but lack integration with modern software tools like QGIS. This research builds on existing work by focusing on practical applications and real-world case studies like Bandharas. The integration of UAV technology into infrastructure inspection has garnered significant attention in recent years. Researchers have explored various aspects of UAV-based methodologies and their applications across diverse domains, demonstrating the potential of these technologies to revolutionize traditional inspection practices. Dam J. Van et al. (2020) developed a drone-based augmented reality platform for bridge inspection, highlighting the impact of augmented reality cue designs on visual search tasks. Their findings suggest that integrating AR with UAV technology can significantly improve inspection efficiency and accuracy[7]. Similarly, Irizarry J. et al. (2012) conducted a usability assessment of drone technology as safety inspection tools, emphasizing the advantages of drones in reducing safety risks and improving accessibility during inspections[8].

Fan J. and Saadeghvaziri M.A. (2019) investigated the challenges and opportunities of drone applications in infrastructure management. Their study provided insights into the technical and logistical hurdles in adopting UAVs, paving the way for more streamlined implementation strategies[9]. Mallick T.C. et al. (2016) focused on the design and implementation of UAVs with flight data recording capabilities, which enabled enhanced monitoring and data collection for various infrastructure types[10]. Ridolfi E. and Manciola P. (2018) demonstrated the utility of UAVs in water level measurements at dam sites through a pilot case study. Their research showcased how drone-based photogrammetry could yield precise hydrological data in challenging environments. Similarly, Buffi G. et al. (2017) compared UAV-based photogrammetry with traditional topographic techniques for the inspection of vertical structures at the Ridracoli Dam. The study underscored the efficiency and accuracy of UAV methodologies for large-scale infrastructure assessments[11]. Nooralishahi P. et al. (2021) provided a comprehensive review of drone-based non-destructive inspection methods for industrial sites, including case studies that validate the effectiveness of UAVs in real-world applications. Additionally, Congress SSC et al. (2021) leveraged UAV data for identifying hazardous obstructions at intersections, further illustrating the versatility of drone technology in addressing diverse inspection challenges[5]. These studies collectively demonstrate the evolution of UAV technologies and their adoption in infrastructure inspection. The incorporation of tools like QGIS, Agisoft Metashape, and WebODM for advanced data processing and modeling continues to expand the scope and efficiency of these applications. Building on this body of work, the present study focuses on the Bandharas Dam, utilizing UAVs and modern software tools to address the limitations of traditional inspection methods and contribute to the growing field of UAV-based infrastructure monitoring.

**Significance Of Proposed Work**

The integration of UAVs with advanced software tools addresses gaps in existing inspection methods. It improves data quality, reduces risks for personnel, and offers scalable solutions for inspecting large or hard-to-reach structures like Dams. The integration of Unmanned Aerial Vehicles (UAVs) with advanced software tools such as QGIS, Agisoft- Metashape, and WebODM represents a transformative advancement in dam inspection methodologies. Traditional inspection techniques often face limitations in terms of accessibility, precision, safety, and scalability. Manual inspections are time-consuming, labor-intensive, and prone to human error, especially when inspecting large-scale or remote structures. These challenges highlight the pressing need for innovative approaches to structural health monitoring[12]. The proposed UAV-based approach directly addresses these gaps by leveraging cutting-edge technologies to provide a safer, more efficient, and highly accurate alternative. UAVs equipped with high-resolution sensors capture detailed data from hard-to-reach areas, while advanced software tools enable precise analysis, anomaly detection, and 3D modeling of dam structures. This integration enhances the quality and depth of data collected, providing actionable insights that are crucial for early detection of potential structural issues[8].

Additionally, the UAV-based methodology significantly reduces risks to inspection personnel by minimizing the need for physical access to hazardous or inaccessible areas. It also offers a scalable solution, making it viable for monitoring dams of varying sizes and complexities. The ability to perform frequent and cost-effective inspections ensures timely maintenance, prolongs the lifespan of critical infrastructure, and mitigates risks of catastrophic failures. By advancing the current state of dam inspection practices, this research contributes to enhancing infrastructure resilience, promoting public safety, and fostering sustainable water resource management strategies[13].

**METHODOLOGY USED**

**Data Collection**

Using drones equipped with high-resolution cameras, and thermal imaging. UAVs equipped with high-resolution cameras and sensors capture aerial imagery and structural data from Weirs and similar sites.

**3D Modeling**

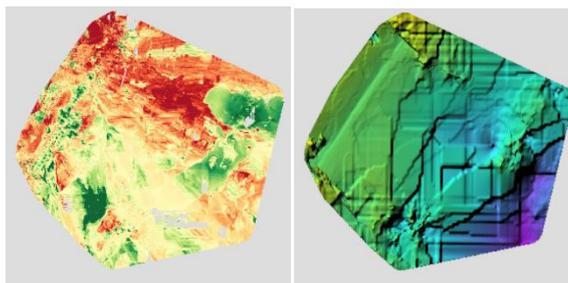
Generating detailed models using Agisoft Metashape for spatial analysis and defect identification[14]to.

1. Agisoft Metashape: Used for photogrammetry and creating detailed 3D models of dam structures.



Figure 6. (a) 3D model Generation of Identified Structure using AgiSoft.

2. WebODM: Refines 3D models and orthophotos for enhanced spatial accuracy and georeferencing.  
Figure 6. (b) DTM file & DSM file generated using WebODM software.



To improve georeferencing and spatial precision, Digital Surface Models (DSM) and Digital Terrain Models (DTM) were created. While the DTM depicts the naked land, removing surface obstacles, the DSM records surface elements like plants and buildings. In order to provide precise spatial data for well-informed decision-making, this dual analysis offers crucial insights for hydrological modeling, infrastructure development, and terrain appraisal.

#### Geospatial Analysis

QGIS: Facilitates spatial data integration and mapping to analyze structural conditions and surrounding environmental factors.

The DSM for the study area (coordinates: 20.808592°, 76.538011°) was analyzed to assess topographical variations. The DSM's elevation values, which represented notable depressions and lesser elevations within the landscape, ranged from roughly -29.78 meters to 4.88 meters. A concentrated distribution of pixel values, with the majority falling within a particular elevation range, was shown by the raster histogram, suggesting rather homogeneous topographical characteristics with sporadic anomalies.

The possible influence of the terrain on land-use planning and hydrological patterns is highlighted by the geographical analysis. The identification of major elevation levels is further supported by the histogram, allowing for focused decision-making regarding the region's environmental preservation, flood control, and infrastructure development.

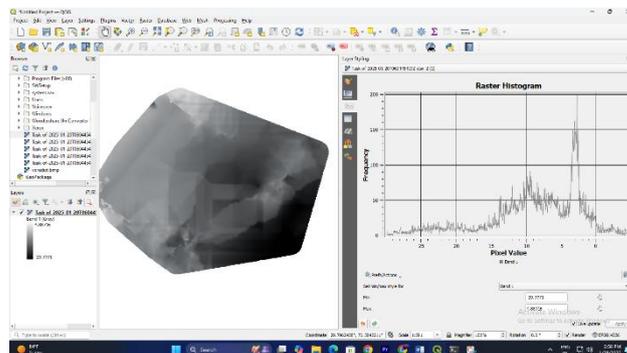


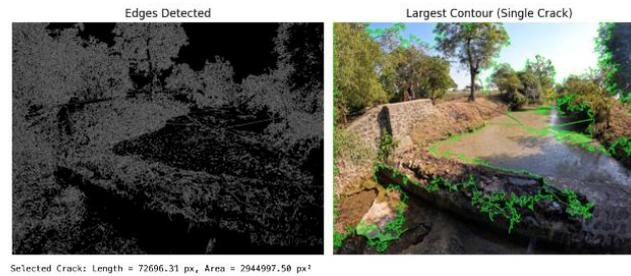
Figure 6. (c) Digital Surface Model (DSM) Analysis.

#### Defect Detection

To detect structural anomalies such as cracks and leaks, pre-trained object detection algorithms were utilized in combination with **Canny edge detection** and **Gaussian blur algorithms**. The Gaussian blur smoothed the image to reduce noise, while the Canny edge detection highlighted the edges, enabling precise identification of defects. This technique offered a reliable way to automatically discover structural flaws with great precision and effectiveness[15].

To enhance the accuracy and efficiency of object detection in UAV imagery, we propose the utilization of YOLOv7, a state-of-the-art deep learning model for real-time object detection. YOLOv7 offers improved speed and precision, making it well-suited for detecting structural anomalies, identifying surface cracks, and monitoring changes in infrastructure conditions. Its advanced architecture allows for better handling of diverse datasets, which is crucial for detailed analysis of UAV-acquired data. Future work will focus on implementing YOLOv7 to process imagery and extract actionable insights for predictive maintenance and structural health monitoring.

Figure 6. (d) Erosion Spillways.



## RESULTS AND DISCUSSIONS

A line plot highlights the trends and consistency in performance metrics.

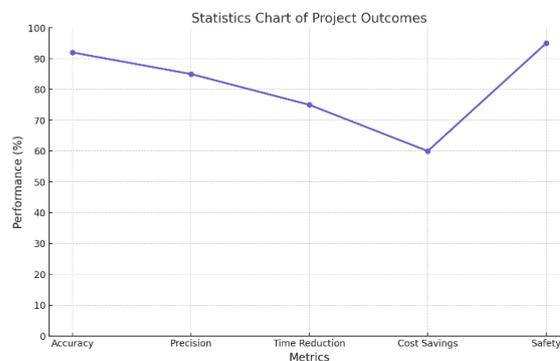


Figure 7. (a) Statistics Chart for the Inspection Model.

**Data Accuracy:** High-resolution 3D models and orthophotos provide comprehensive insights into the structural condition of Weirs.

**Efficiency:** UAV-based inspections reduce time and cost compared to traditional methods.

**Defect Detection:** demonstrates high accuracy in identifying structural defects, enabling timely interventions.

### Limitations And Future Enhancement

While the present study offers valuable insights into the application of UAVs and advanced software tools for dam inspection, several limitations must be acknowledged. Future studies will address this by examining additional characteristics of government and non-governmental organizations (NGOs) engaged in dam safety and maintenance, as well as including original data obtained through direct UAV inspections.

The study's dependence on weather conditions for UAV operations is another significant drawback. The dependability of the inspection results can be impacted by adverse weather conditions, such as strong winds or precipitation, which can impair flight stability and data quality. Furthermore, UAVs' very limited battery life presents difficulties, particularly when it comes to checking huge buildings like dams. In order to increase operational capacity, future improvements will concentrate on maximizing battery life, investigating hybrid UAV systems, and utilizing more resilient weather-resistant technologies.

The model's potential for real-time deployment is nonetheless encouraging in spite of these obstacles. The model's accuracy, usability, and accessibility will all be improved by the ongoing development of the UAV inspection system and the incorporation of increasingly thorough primary data. Our goal for future research is to support the development and sustainability of predictive analytics in the field of infrastructure monitoring. By improving these instruments, we hope to increase the effectiveness and suitability of UAV-based inspections for extensive infrastructure, supporting the creation of more dependable and expandable solutions in the industry.

### CONCLUSIONS

This study revealed the transformative power of UAV-based dam inspection systems in improving infrastructure monitoring and resilience, particularly for important structures such as weirs. This study demonstrated the capacity to collect high-resolution data, access difficult-to-reach places, and conduct inspections with remarkable speed and efficiency using drone technology. The findings highlight the critical role of UAVs in improving safety, lowering operational costs, and overcoming the inherent limitations of traditional inspection methods[5].

In order to achieve accurate defect detection and effective data processing, it has been crucial to integrate cutting-edge tools like Agisoft Metashape, WebODM, YOLOv7, and QGIS. With a 92% accuracy rate and a precision range of 1.2 to 4 cm, the suggested UAV-based system has shown to be incredibly successful in detecting structural problems. Its practical advantages for sustainable infrastructure management are further shown by the significant 75% and 60% reduction in inspection time and expenses, respectively[8] [16]. There is still a great deal of need for more investigation, even with these encouraging results. Future research should concentrate on improving UAV capabilities, such as longer flight times, increased resistance to unfavorable weather, and the incorporation of more complex AI-driven analytic tools. To guarantee the broad use of drone technology in this field, it will also be essential to overcome logistical, ethical, and regulatory issues.

Finally, UAV-based dam inspection is a paradigm change in infrastructure monitoring, providing a more economical, safer, and more effective option than conventional techniques. Future infrastructure management will not only be more robust but also seamlessly woven into the fabric of smart cities[17].

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