

ASSESSMENT OF HYDRAULIC PERFORMANCE OF CANAL USING AERIAL SURVEY AND HEC-RAS MODEL: CASE STUDY OF GUJARAT, INDIA

ÉVALUATION DE LA PERFORMANCE HYDRAULIQUE DU CANAL À L'AIDE D'UNE ÉTUDE AÉRIENNE ET D'UN MODÈLE HEC-RAS : ÉTUDE DE CAS DE L'ÉTAT DE GUJARAT, INDE

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ABSTRACT

Irrigation canals are critical for sustaining agricultural productivity, and lined canals are expected to maintain their hydraulic efficiency and design discharge throughout their operational life. However, over time, canals experience reduction in conveyance capacity due to siltation, vegetation growth, bank erosion, and unrecorded field alterations. These changes modify the channel geometry, increase hydraulic roughness and head losses, and may create overtopping risks and undesirable hydraulic variations. Since siltation is often distributed gradually along the canal section and length, its impact on canal performance may remain unnoticed until severe hydraulic problems arise. Conventional approaches for assessing siltation, such as bathymetric surveys during flowing conditions or level surveys during canal closure, are generally time-consuming and expensive. The present study demonstrates an alternative and practical approach for rapid hydraulic assessment of irrigation canals using UAV-based aerial survey integrated with DGPS observations and HEC-RAS hydraulic modelling. A 26 km stretch of the Panam Left Bank Main Canal of the Panam High Level Canal System in Gujarat, India, including 13 syphon structures, was assessed using high-resolution UAV-DGPS survey data collected during canal closure. The survey achieved sub-meter-level horizontal accuracy and 5 cm vertical accuracy, enabling development of a detailed hydraulic model in HEC-RAS. The hydraulic assessment revealed severe and continuous bed aggradation between Chainage 1290 m and 9600 m, creating major hydraulic bottlenecks and reducing conveyance efficiency. Simulations carried out under the design discharge of 600 cusecs indicated localized overtopping risks, increased backwater effects, and significant hydraulic variations across several canal reaches and structures. The results also indicated reduction in downstream conveyance performance due to altered channel geometry and flow conditions. The study demonstrates that integration of UAV-based surveys with hydraulic modelling can provide a faster, reliable, and practical framework for canal performance assessment compared with conventional methods. The approach can support better planning of desiltation, maintenance prioritization, and operational management for sustainable canal system performance.

Keywords: Canal, Hydraulic performance, Siltation, DGPS, UAV survey, HEC-RAS.

RESUME

Les canaux d'irrigation sont essentiels pour maintenir la productivité agricole et on s'attend à ce que les canaux revêtus maintiennent leur efficacité hydraulique et leur débit de calcul tout au long de leur durée de vie opérationnelle. Cependant, au fil du temps, les canaux connaissent une réduction de leur capacité de transport en raison de l'ensablement, de la croissance de la végétation, de l'érosion des

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berges et des modifications non enregistrées sur le terrain. Ces changements modifient la géométrie du canal, augmentent la rugosité hydraulique et les pertes de charge, et peuvent créer des risques de débordement et des variations hydrauliques indésirables. Etant donné que l'ensablement est souvent distribué de manière progressive le long de la section et de la longueur du canal, son impact sur la performance du canal peut rester inaperçu jusqu'à ce que de graves problèmes hydrauliques surviennent. Les méthodes conventionnelles d'évaluation de l'ensablement, telles que les enquêtes bathymétriques en conditions d'écoulement ou les enquêtes de niveau lors de la clôture du canal, sont généralement longues et coûteuses. La présente étude démontre une approche alternative et pratique pour l'évaluation hydraulique rapide des canaux d'irrigation à l'aide des enquêtes aériennes menées par véhicule aérien sans pilote (UAV) intégrée aux observations DGPS et à la modélisation hydraulique HEC-RAS. Un tronçon de 26 km du canal principal de la rive gauche de Panam, dans le système de canaux à haut niveau de Panam, au Gujarat, en Inde, comprenant 13 structures de siphons, a été évalué à l'aide de données d'enquête UAV-DGPS haute résolution recueillies lors de la clôture du canal. L'étude a atteint une précision horizontale inférieure au mètre et une précision verticale de 5 cm, rendant possible le développement d'un modèle hydraulique détaillé dans le cadre de HEC-RAS. L'évaluation hydraulique a révélé un exhaussement sévère et continu du lit à Chainage entre 1290 m et 9600 m, créant d'importants goulets d'étranglement hydrauliques et réduisant l'efficacité du transport. Les simulations effectuées sous le débit de calcul de 600 cusecs ont indiqué des risques localisés de débordement, une augmentation des effets de bras mort et d'importantes variations hydrauliques dans plusieurs tronçons et structures du canal. Les résultats ont également indiqué une réduction des performances de transport en aval due à la géométrie modifiée du canal et aux conditions d'écoulement. L'étude démontre que l'intégration des enquêtes menées par véhicule aérien sans pilote (UAV) avec la modélisation hydraulique peut fournir un cadre plus rapide, fiable et pratique pour l'évaluation de la performance du canal par rapport aux méthodes conventionnelles. L'approche peut soutenir une meilleure planification en ce qui concerne le dessablement, la priorisation de la maintenance et la gestion opérationnelle pour une performance durable du système de canaux.

Mots-clés : Canal; Performance hydraulique; Ensablement; DGPS; Enquêtes menées par véhicule aérien sans pilote (UAV); HEC-RAS.

1. INTRODUCTION

Irrigation canals are lifelines for agriculture-based economies, but their long-term effectiveness depends on maintaining conveyance capacity and hydraulic integrity. Over time, unlined and partly lined canals frequently suffer reductions in discharge capacity because of progressive siltation, vegetation growth, bank erosion, and undocumented field modifications. These processes alter channel geometry, increase hydraulic roughness and head losses, and can lead to inequitable water distribution and overtopping hazards during higher operational discharges. Sediment transport and deposition can severely hamper canal performance, requiring frequent desilting and structural maintenance to maintain design capacity (Lund et al., 2023).

Recent advancements in canal asset management highlight the growing role of integrated geospatial technologies, especially DGPS survey, GNSS-based ground control, and UAV photogrammetry, in capturing high-resolution canal geometry. UAV-derived terrain data have been shown to provide detailed topographic information for hydraulic analysis and reduce geometric uncertainty compared with traditional sparse survey methods (Mazzoleni et al., 2020; Acharya et al., 2021). When these detailed datasets are used as inputs to numerical models such as HEC-RAS, both steady and unsteady flow simulations can deliver robust estimates of water surface profiles, velocity fields, and flow behavior, thereby supporting evidence-based operations and maintenance planning (Sereda et al., 2014).

This study uses a combined approach: high-accuracy field DGPS and drone surveys to derive a high-resolution DTM/DSM and cross-sections (at 30 m interval), followed by one-dimensional steady flow hydraulic modeling in HEC-RAS under the design discharge. The framework of this approach is built on three main components: (a) detailed topography and cross-sections reduce geometric uncertainty in hydraulic simulations; (b) HEC-RAS is a proven, flexible platform for modeling canal systems and inline

structures; and (c) the hydraulic behavior under the design discharge of 600 cusecs enables identification of overtopping-prone reaches and constricted cross-sections that require corrective measures.

2. OBJECTIVES OF THE STUDY

The primary objective of this study is to assess the hydraulic performance and structural adequacy of a 26 km stretch of the Left Bank Main Canal (LBMC) of the Panam High Level Canal (PHLC) system using high-resolution survey data and hydraulic modeling. The specific objectives are to:

- Develop accurate canal geometry inputs by extracting and validating cross-sections from DGPS and UAV-based surveys, ensuring that the hydraulic model reflects current field conditions.
- Simulate steady-flow hydraulic behavior under the design discharge of 600 cusecs to evaluate water surface profiles, flow depths, and conveyance efficiency along the canal reach.
- Identify overtopping-prone and hydraulically critical sections by comparing modeled water levels with existing embankment elevations.
- Assess the performance of 13 syphon structures, focusing on discharge adequacy, head losses, upstream and downstream velocity variations, and potential erosion.
- Support operational decision-making by providing data-driven recommendations for flow regulation, maintenance prioritization, and structural improvements.

3. STUDY AREA

The study focuses on a 26 km stretch of the Left Bank Main Canal (LBMC), a major conveyance component of the Panam High Level Canal (PHLC) system in the Panchmahal district of Gujarat, India. The location map of the study area is shown in Figure 1. The canal conveys irrigation water from the main headworks to downstream command areas through semi-undulating terrain dominated by agricultural land use and minor settlements. A total of 13 syphon structures are located within the study reach.

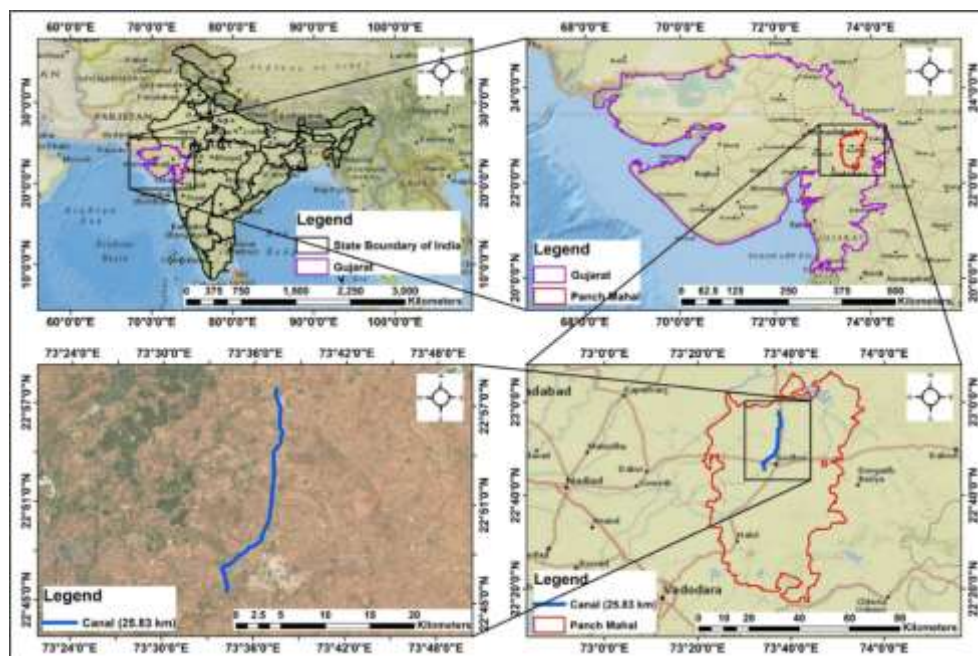


Figure 1. Location of the study area.

4. METHODOLOGY AND DATA

The methodology adopted for evaluating the hydraulic performance of the canal system integrates advanced survey techniques, terrain data processing, one-dimensional hydraulic modeling, and structural performance assessment into a unified analytical framework. The workflow follows a sequential structure beginning with field data acquisition and concluding with hydraulic performance evaluation, as illustrated in the methodology flowchart (Figure 2).

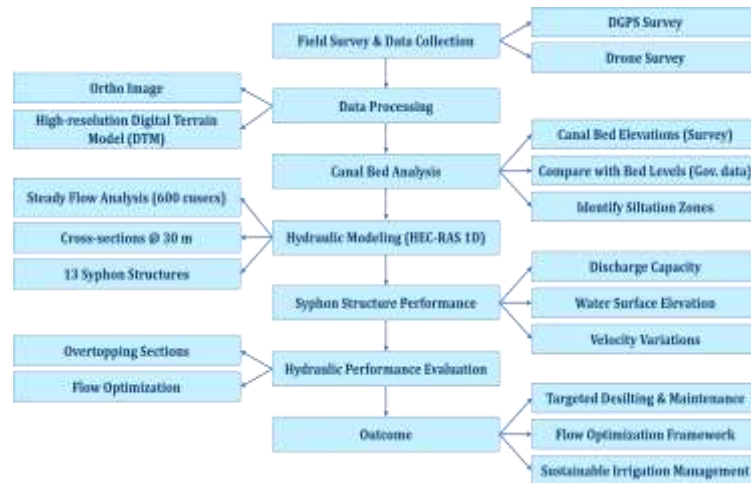


Figure 2. Methodology Flowchart

4.1 Field survey and data collection

The study commenced with an extensive field survey designed to obtain accurate geometric and positional information of the canal system. Differential Global Positioning System (DGPS) surveying was employed to establish precise ground control points (GCP) and to capture the spatial alignment of the canal with high positional accuracy. DGPS-supported data collection is widely recognized for enhancing the reliability of elevation and positional datasets required for hydraulic modeling (James et al., 2017; Turner et al., 2012). Photographs from the site visit are presented in Figure 3.

Drone-based ortho-image acquisition was conducted to generate high-resolution ortho-mosaic imagery. These images provided detailed information on canal geometry, existing structures, bank conditions, and surrounding terrain. UAV-based photogrammetry is increasingly used in hydraulic and irrigation channel studies due to its ability to capture fine-scale topography and structural details with centimeter-level precision (Nex & Remondino, 2014; Fonstad et al., 2013).



Figure 3. Site photographs

4.2 Data processing and canal bed analysis

The collected field data were processed to construct a detailed Digital Terrain Model (DTM) that accurately reflects the physical geometry of the canal system. Survey points, drone imagery, and elevation data were integrated using photogrammetric and terrain processing workflows to produce a high-resolution DTM capable of capturing both the canal bed and its adjoining features. Hydrologically relevant DTMs are essential for simulating flow behavior and assessing conveyance characteristics, as highlighted in modern geospatial hydrology research (Lindsay, 2016; Tarboton, 1997).

The canal cross-sections derived from the terrain model were checked against field observations to ensure geometric consistency. This included verifying bed levels, side slopes, and bank elevations. The processed DTM was further analyzed to identify elevation changes, and siltation effects that could influence conveyance capacity. The canal bed assessment formed the basis for identifying reaches where hydraulic performance might be impacted by sediment deposition or geometric constraints. The ortho image and DTM of the canal are shown in Figures 4 and 5.

4.3 Hydraulic modelling

A one-dimensional steady-flow hydraulic model was developed in HEC-RAS to evaluate the hydraulic behavior of the canal under the design discharge. The calibrated geometry, derived from the processed survey data, was used to represent the canal's longitudinal profile and cross-sectional variability. A discharge of 600 cusecs was simulated to examine flow conveyance and to determine whether the canal can safely accommodate the design flow requirement.

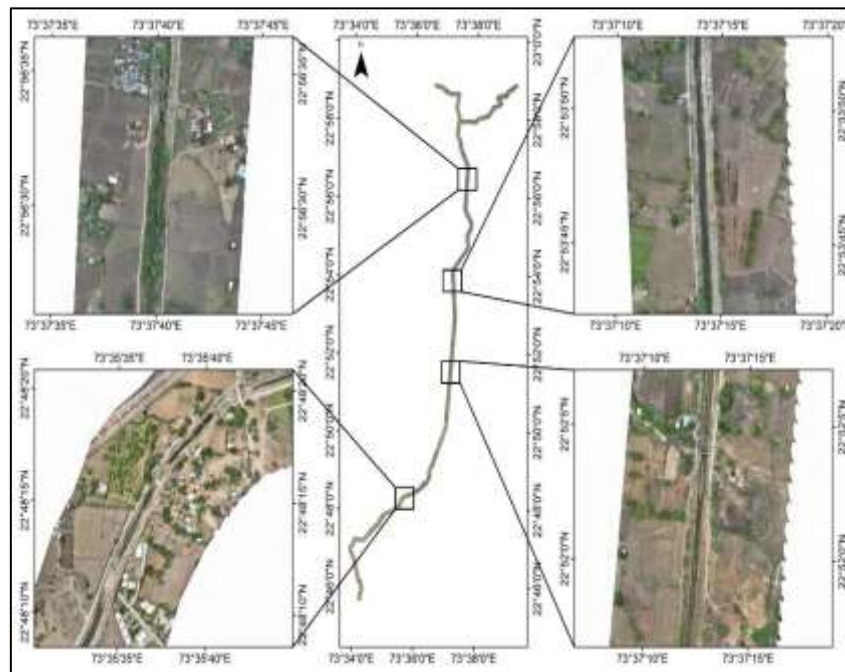


Figure 4. Ortho image of the canal

HEC-RAS is widely used for irrigation canal analysis and open-channel flow assessment due to its robust computational capabilities and suitability for steady-state simulations (Brunner, 2021). The model generated water surface profiles, depth distribution, and velocity patterns along the canal, enabling the identification of reaches where the banks may be vulnerable to overtopping or where hydraulic inefficiencies may arise. This modeling stage provided a scientific basis for evaluating both capacity constraints and flow adequacy.

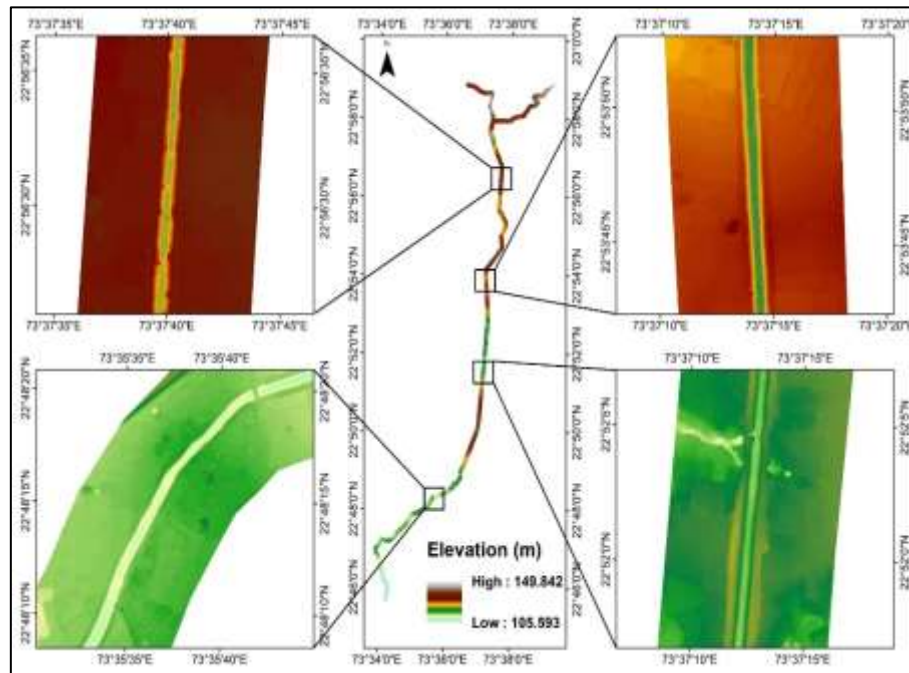


Figure 5. Digital terrain model of the canal

4.4 Syphon structure performance assessment

Along the modeled stretch, 13 syphon structures were examined to understand their influence on the canal's hydraulic performance. Using model-generated velocity fields, the upstream and downstream flow conditions of each syphon were evaluated to quantify head losses, turbulence zones, and potential flow disturbances. Structural flow-through capacity was assessed relative to the design discharge to determine whether each syphon can efficiently convey the required flow without causing upstream afflux or downstream scouring.

4.5 Hydraulic performance evaluation

The results from terrain processing, hydraulic modeling, and structural assessment were synthesized to evaluate the overall performance of the canal. Conveyance capacity under each modeled discharge was examined to determine whether the canal meets its design requirements or whether specific reaches experience hydraulic limitations. The integrated evaluation enabled the identification of stretches requiring flow optimization, structural improvements, or targeted desilting interventions. The outcomes of this combined methodology provide a robust decision-support framework for improving operational efficiency and ensuring safe water delivery under variable flow conditions.

5. RESULTS

5.1 Representation of canal cross-sections

The extraction and representation of the canal cross-sections along the 26 km study stretch formed the foundation for accurate hydraulic analysis. Using DGPS measurements and drone-derived datasets, the existing canal geometry was reconstructed with high spatial precision. During this process, several modifications were incorporated to ensure consistency with field conditions, including refining bed levels, adjusting side slopes, and correcting embankment elevations wherever deviations from surveyed data were detected. The finalized set of cross-sections thus represents a reliable geometric configuration for steady-flow simulation.

5.2 Hydraulic simulation under design discharge

A steady-flow simulation was carried out for the design discharge of 600 cusecs. The resulting water surface profile provides a detailed understanding of the hydraulic response of the system when subjected to peak design flow. The model outputs indicate that while several reaches safely convey the design discharge within the available geometric capacity, certain sections exhibit elevated water levels that approach or exceed the embankment crest.

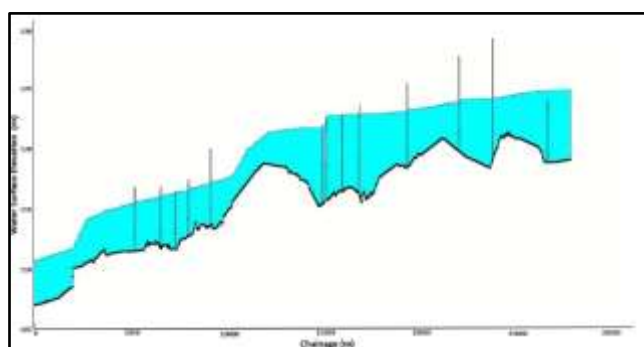


Figure 6. Water surface elevation profile (600 cusec flow)

The higher flow depth associated with the 600 cusecs discharge is especially evident at geometrically constricted or silt-affected cross-sections. In these locations, the simulated water surface elevation (WSE) surpasses the bank elevation, indicating overtopping vulnerability and highlighting the need for structural or maintenance measures. The WSE profile for the 600 cusecs simulation is presented in Figure 6.

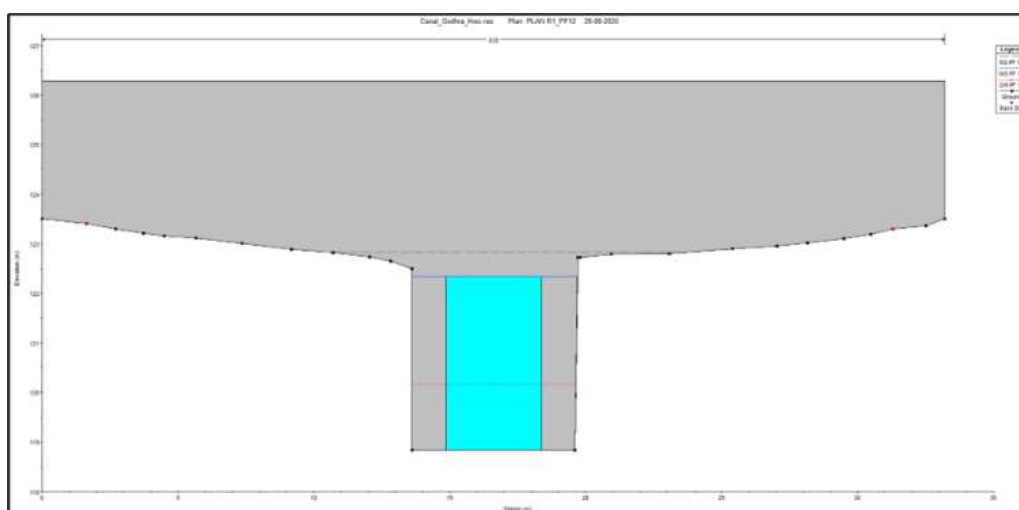
5.3 Performance of syphon structures

The hydraulic behavior of the 13 syphon structures along the canal was evaluated using upstream and downstream parameters obtained from the steady-flow simulation of the design discharge of 600 cusecs. Under this peak operating condition, most syphons were found to be operating at or near their full hydraulic capacity (Figure 7). In addition, several syphons exhibited noticeably elevated downstream velocities, indicating localized acceleration as the flow passed through the constricted geometry. This increase in velocity suggests enhanced turbulence and a higher likelihood of erosive forces acting on the downstream bed and banks.

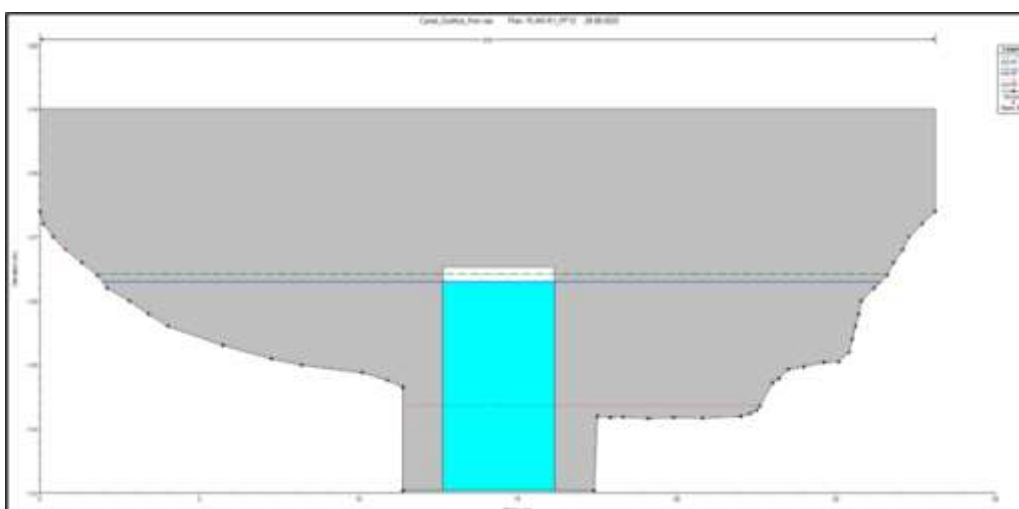
In a few cases, minor backwater effects were observed upstream of the syphons, reflecting restricted flow areas or geometric limitations within the structure. These hydraulic responses highlight the significance of routine inspection and structural upkeep, especially where clear-flow width has reduced over time due to sedimentation or material degradation.

5.4 Affected cross-sections associated with syphons

Under the design discharge of 600 cusecs, a number of cross-sections located in the vicinity of syphon structures were found to be sensitive to hydraulic adjustments induced by flow constriction. The complete list of these cross-sections for the 600-cusec simulation is compiled in Table 1. These cross-sections represent priority locations where syphon-induced hydraulic impacts may affect long-term stability and operational efficiency. The overtopped cross-sections at chainage 10.56 km and 12.66 km are presented in Figure 8.



(a)



(b)

Figure 7. Water level in syphon at chainage (a) 5.37 km and (b) 16.95 km

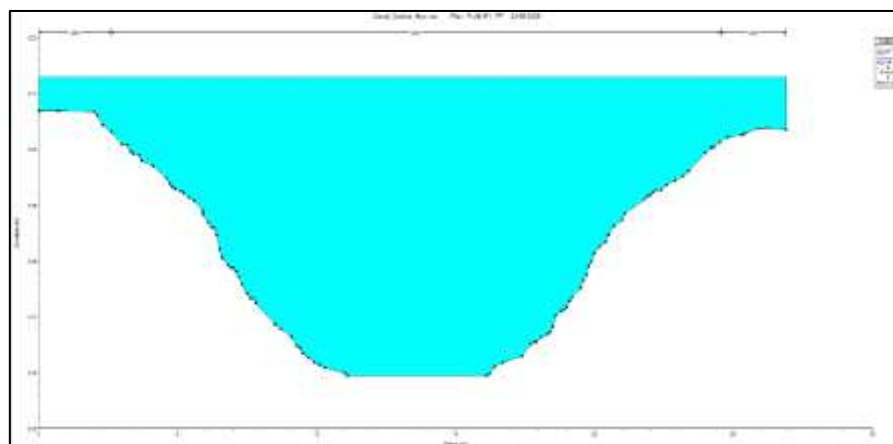
Table 1. Affected cross-sections corresponding to syphon structure (600 cusecs)

Sr. No.	Cross-section No.	Chainage (m)	Syphon No.	Chainage (m)
1	25680 - 24837	600 - 1450	25194	1020
2	24719	1570		
3	22554 - 22410	3750 - 3900	22543	3660
4	22204 - 22115	4110 - 4200		
5	21465	4860		
6	20993 - 20936	5330 - 5400		
			20926	5370
7	18360	7920		
			18339	7890

8	16613 - 13504	9610 - 12720	15924	10185
			15106	11150
			14353	11830
			14160	12010
9	8808 - 8779	17430 - 17490		
			8762	16950
10	7749 - 7453	18530 - 18830	7709	18060
11	7199 - 6879	19080 - 19410	7082	18690
12	6373 - 6366	19920 - 19930		
			6346	19170
13	5291 - 5168	20970 - 21090		
14	5124 - 5107	21120 - 21180		
			5053	20640
15	3996 - 3966	22280 - 22310		
16	1218 - 860	25020 - 25400		
17	143 - 24	26100 - 26220		

*The blue-highlighted cells indicate the syphons operating at full capacity under the design discharge.

The results demonstrate that the canal geometry has been accurately reconstructed and validated for modeling, enabling reliable simulation outputs. Under the design discharge of 600 cusecs, the hydraulic assessment indicates that several reaches of the canal exceed their safe conveyance limits. Water surface elevations at multiple cross-sections rise close to or above embankment levels, highlighting overtopping vulnerability and reduced hydraulic stability under peak operational conditions. The syphon structures, while capable of passing the design discharge, operate at or near their full hydraulic capacity and generate pronounced downstream velocities, leading to increased head losses, localized turbulence, and potential erosive stresses that may affect long-term structural durability. These findings provide critical evidence for operational planning, indicating the need for flow regulation, targeted maintenance, and structural strengthening to ensure safe performance at design flow.



(a)

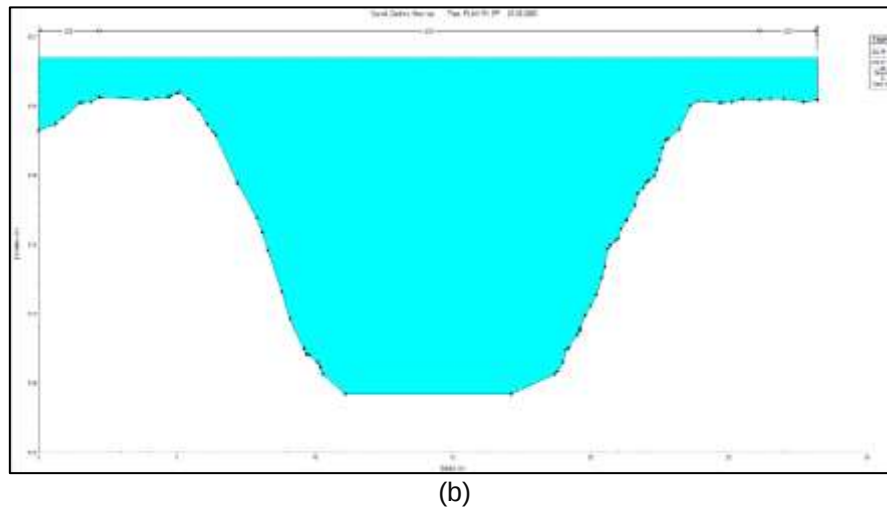


Figure 8. Overtopped cross-sections at chainage (a) 10.56 km and (b) 12.66 km

6. CONCLUSION

The present study successfully reconstructed the canal geometry and evaluated its hydraulic performance under the design discharge of 600 cusecs. Using a combination of DGPS-based ground surveying and drone-derived high-resolution topographic mapping, the canal alignment, embankments, cross-sections, and associated structures were accurately captured and validated for hydraulic modelling. The integration of DGPS elevation control with drone-based ortho-mosaics and digital terrain model provided a detailed and reliable spatial representation of channel, bank conditions, flow paths and micro-topographic variations that are not easily captured through conventional surveys.

The hydraulic simulation results for the design discharge indicate that several reaches of the canal exhibit elevated water surface levels, in some locations approaching or exceeding the embankment crest, thereby highlighting overtopping susceptibility under peak operational conditions. The performance evaluation of syphon structures shows that most units operate at or near their full hydraulic capacity at 600 cusecs, suggesting increased potential for erosive forces and long-term structural stress. These results collectively underscore the need for targeted interventions, such as desiltation, structural strengthening, and flow regulation measures, to ensure safe and reliable canal operation under the design discharge. Overall, the study demonstrates the effectiveness of integrating DGPS and drone-based datasets into a coherent hydraulic assessment framework for canal systems. The outputs generated, including validated elevations, detailed cross-sectional profiles, water surface elevation plots, and summary tables, offer a robust technical basis for future decision-making, thereby supporting safe and sustainable water conveyance within the system.

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