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A QGIS-Assisted Terrain Evaluation and Drainage Performance Assessment of the Shivajinagar Underpass.

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***Abstract* -Flooding at depressed roadway structures such as underpasses is a persistent urban challenge, predominantly caused by inadequate hydraulic design and unfavorable site topography. The Shivajinagar Underpass in Chhatrapati Sambhajinagar experiences repeated monsoon flooding that disrupts mobility and deteriorates pavement conditions. This study applies a QGIS-based Digital Elevation Model (DEM) analysis to identify the terrain-related and drainage-related shortcomings responsible for the recurrent inundation. DEM-derived elevation profiles, slope rasters, contour maps, and flow-accumulation models reveal a significant central depression (583 m) situated below the entry (586 m) and exit (585 m) elevations. This inverted grade eliminates the possibility of gravity-driven discharge. Field observations confirm insufficient drain invert depth, absence of sump wells, lack of pumping facilities, and non-compliance with IRC:SP:42-2014 and IS 17482:2020. Comparative assessment with functional underpasses demonstrates the need for sump-pump systems, grated inlets, and deeper drain geometry. Engineering interventions such as sump construction, dual pump installation, inlet redesign, and drain regrading are recommended. The study establishes QGIS as an effective diagnostic tool for evaluating drainage performance in urban underpasses.**

Keywords— Digital Elevation Model, Underpass Flooding, QGIS, Slope Analysis, Urban Drainage, IRC Standards.

I. INTRODUCTION

Underpasses are designed to provide uninterrupted movement of traffic across major corridors; however, their depressed geometric profile makes them highly susceptible to surface runoff accumulation during rainfall. If site-specific terrain characteristics and hydraulic requirements are not adequately incorporated into design, the structure becomes vulnerable to chronic flooding. The Shivajinagar Underpass is a prominent example where ineffective drainage planning leads to long-lasting water stagnation during monsoon conditions.Accurate terrain modeling is crucial for diagnosing such failures. Digital Elevation Models processed in QGIS provide a comprehensive understanding of elevation variations, slope distribution, and flow-accumulation behaviour. This study integrates DEM analysis with field-based surveys to evaluate the root causes of drainage failure at the Shivajinagar Underpass and to propose feasible engineering solutions.

Fig 1. Shivajinagar Underpass, Chhatrapati Sambhajinagar

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II. LITERATURE REVIEW

GIS and DEM Applications in Hydrological Analysis

[1]According to Gopinath et al. (2019), Geographic Information Systems (GIS) provide an efficient framework for analyzing terrain and hydrological features using spatial datasets. Their research highlighted that QGIS can be effectively used to create contour, slope, and aspect maps, which are critical for identifying flow accumulation and drainage direction in urban regions.

[2]Similarly, Rao and Jha (2020) used SRTM-based DEM data to assess elevation variations and locate potential waterlogging areas in city corridors. Patel et al. (2021) demonstrated that integrating DEM and rainfall data within QGIS allows accurate simulation of runoff concentration zones, which helps in designing surface drainage for urban infrastructure. They concluded that elevation-based analysis in GIS provides a scientific foundation for mitigating monsoon-related flooding.

[3]Sharma and Bansal (2018) used ArcGIS and QGIS tools to perform slope and watershed delineation in low-lying regions. Their study found that even small elevation differences (<0.2%) can significantly alter drainage efficiency, underscoring the importance of accurate digital terrain modeling in underpass design.

GIS-based hydrological techniques are widely used for flood susceptibility analysis and surface drainage planning. DEMs enable detailed investigation of micro-topography, which is essential for understanding runoff pathways in urban environments. Researchers have demonstrated that slope mapping, contour extraction, and flow-accumulation models significantly enhance the reliability of drainage assessments. Studies on underpass flooding highlight recurring problems: insufficient longitudinal slope, inefficient drain geometry, absence of sump wells, and unavailability of pumping systems. While numerous international works focus on GIS-based flood assessment, Indian case-specific analyses of underpass drainage performance—particularly using QGIS—are still limited. This research contributes to bridging this knowledge gap through a detailed terrain and drainage evaluation of an Indian underpass.

III. NEED AND NECESSITY

The Shivajinagar Underpass frequently becomes impassable during rainfall, forcing road closures and causing congestion on adjacent routes. Flooding not only affects traffic but also accelerates pavement deterioration, increases the cost of maintenance, and poses safety hazards to commuters. Traditional inspection methods are insufficient to diagnose terrain-driven drainage deficiencies. Therefore, a DEM-supported assessment is essential to determine the exact elevation profile, identify runoff convergence zones, and evaluate hydraulic feasibility.

IV. STUDY AREA DETAILS

The study focuses on the Shivajinagar Underpass located at Level Crossing No. 55 in Chhatrapati Sambhajinagar, Maharashtra, a critical urban link that provides uninterrupted vehicular movement beneath the railway line. The structure was constructed to reduce surface-level congestion and improve connectivity between the northern and southern parts of the city. The underpass is a Reinforced Cement Concrete (RCC) box-type structure consisting of two parallel box units, each designed to support bidirectional traffic. Each box has a clear height of 4.50 m and an internal length of 5.50 m, while the overall underpass length (including approach ramps) is approximately 22.76 m. The carriageway width within each box is adequate for the movement of light and medium vehicles, and pedestrian pathways are provided along the edges for user safety. A corrugated roofing system is installed at the entry and exit zones to restrict direct ingress of rainfall and reduce surface runoff entry during monsoon conditions. The underpass floor is equipped with a central longitudinal grated drain designed to capture stormwater and convey it toward the downstream outlet chamber. Field observations reveal seepage marks, minor cracking near drainage trenches, and sediment accumulation at the central low point, indicating inefficient stormwater disposal and inadequate maintenance. These issues contribute to frequent flooding during monsoon events, raising operational and safety concerns. This study therefore aims to evaluate the terrain slope, drainage geometry, and structural drainage performance of the Shivajinagar Underpass using QGIS-derived elevation profiles and field data. The analysis supports the development of redesign and retrofitting recommendations in line with IRC:SP:42-2014, IRC:92-2017, and IS 456:2000 for enhanced durability and drainage efficiency.

V. DATA COLLECTION

The data required for this study were collected through a combination of primary field surveys and secondary sources to ensure accurate assessment of the waterlogging issues at the Shivajinagar Underpass. Primary data included geometric measurements, elevation points, slope observations, and photographic documentation. Field measurements confirmed that the underpass comprises two RCC box units, each 5.50 m in length with a 4.50 m clear height, while the total underpass length is 22.76 m including approach ramps. Carriageway width was recorded as sufficient for light and medium vehicles, with a pedestrian footpath provided along the sides. QGIS,Secondary data, such as DEM (Digital Elevation Model) and satellite imagery, were integrated to analyze the topographical and hydrological behaviour of the site. The field-verified longitudinal elevation profile revealed that the roadway slope is less than 0.5%, which falls below the recommended 0.5–1.0% slope specified in IRC:SP:42-2014, contributing significantly to water stagnation. All collected datasets were processed using QGIS to evaluate terrain characteristics, drainage pathways, and structural conditions that influence stormwater accumulation at the underpass.

VI. RELEVANT STANDARDS AND CODES FOLLOWED

- IS 456:2000 — for design of reinforced concrete sump structures
- IRC:SP:42-2014 — Guidelines for Road Drainage
- IRC:103-2012 — Geometric Design of Urban Roads
- IS 6934:1998 & IS 8414 — Pumping installations for drainage
- IS 17482:2020 — Stormwater drainage design
- IS 3043 — Groundwater and pump chamber electrical safety

VII. METHODOLOGY

The methodology adopted in this study consists of a structured, GIS-based workflow supported by field verification. QGIS and SRTM-based DEM data were used to analyze terrain characteristics, slope behaviour, and hydrological flow influencing stormwater accumulation at the Shivajinagar Underpass. The complete procedure is summarized in ten systematic steps:

1. Data Acquisition from OpenTopography

- Elevation data were downloaded from the OpenTopography portal, which provides freely accessible global DEM datasets suitable for hydrological and terrain studies.

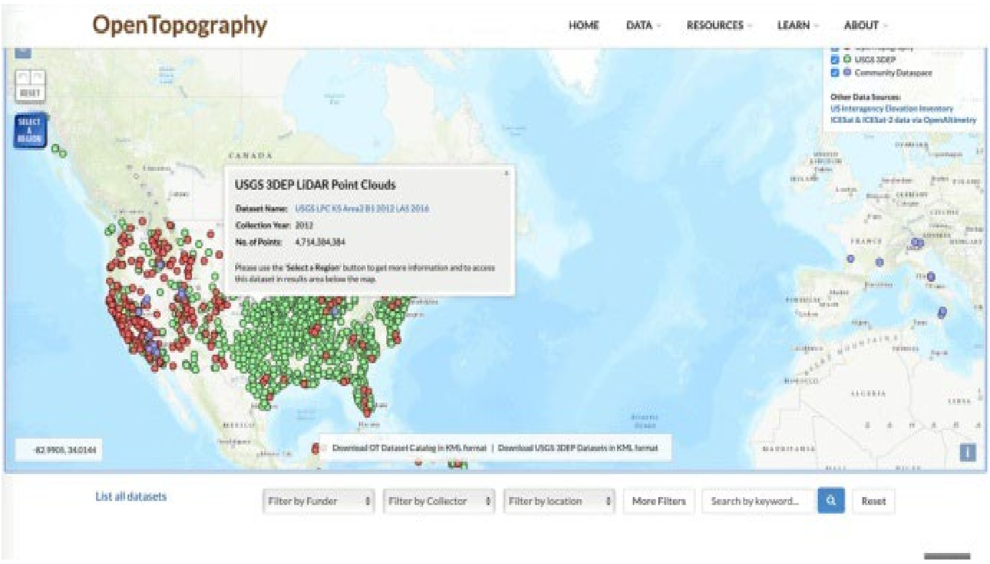

Fig 2. OpenTopography Interface Used for Elevation Data Access

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Fig 3. OpenTopography Dataset Selection Screen

2. Selection of Appropriate DEM Dataset

- SRTM Global 1 Arc-Second (GL1) DEM (~30 m resolution) was selected for its reliability and suitability for urban-scale topographic analysis.

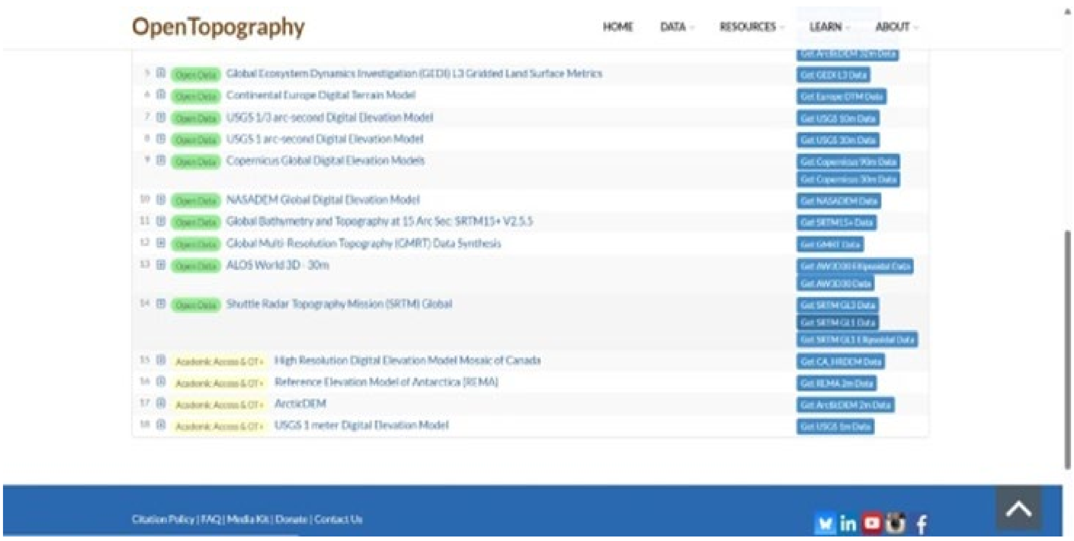

Fig 4. SRTM GL1 Global DEM Selection from OpenTopography

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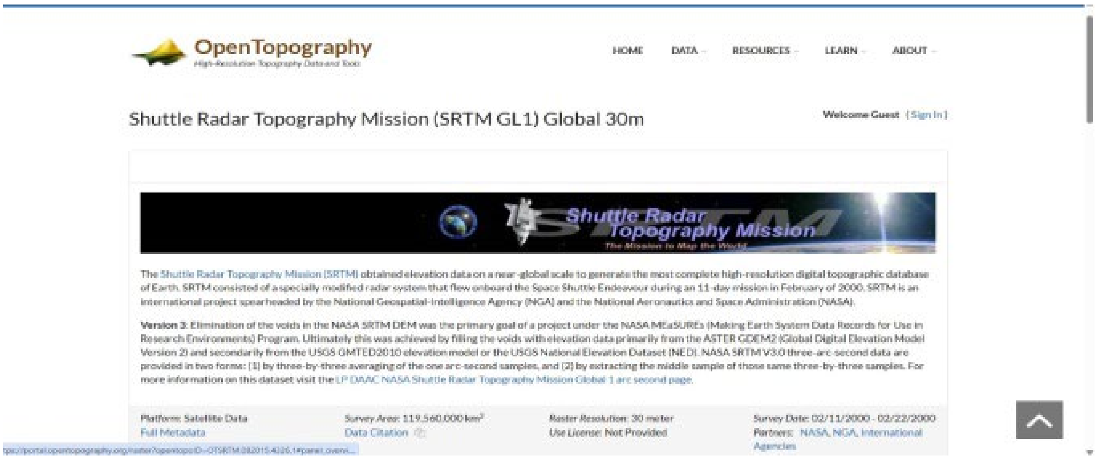

Fig 5. Opening window of SRTM GL 1 Data Selection

3. Extraction of Global DEM Data

- Within the global DEM catalogue, SRTM GL1 was chosen due to its balance of accuracy, data size, and compatibility with QGIS.

4. Delineation of Study Area

- The Shivajinagar Underpass and its approach roads were outlined on the OpenTopography map using a polygon to ensure precise extraction of site-specific elevation data.

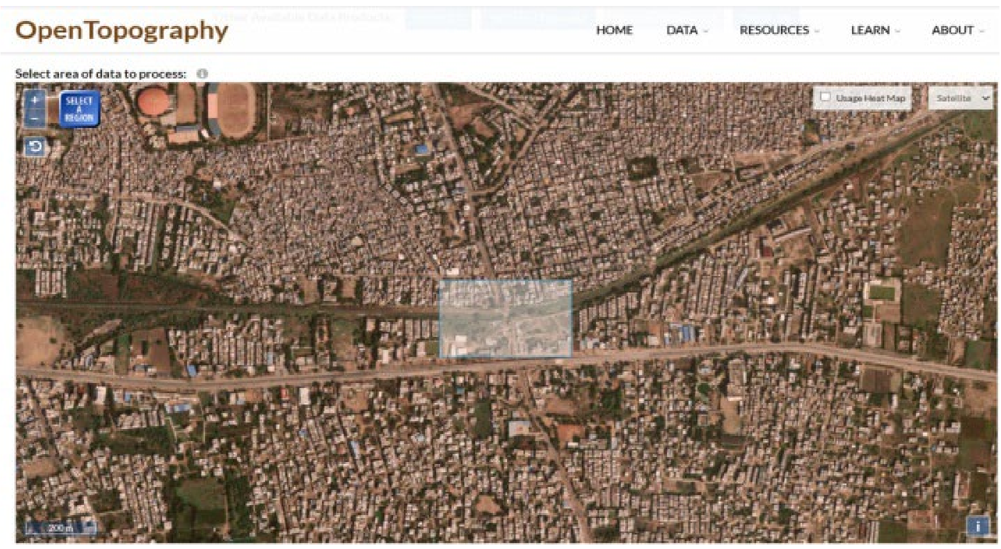

Fig 6. Study Area Boundary Delineated on OpenTopography Map

5. Downloading and Preparing DEM File

- The selected DEM was downloaded in GeoTIFF (.tif) format, which is directly compatible with QGIS for raster-based spatial analysis.

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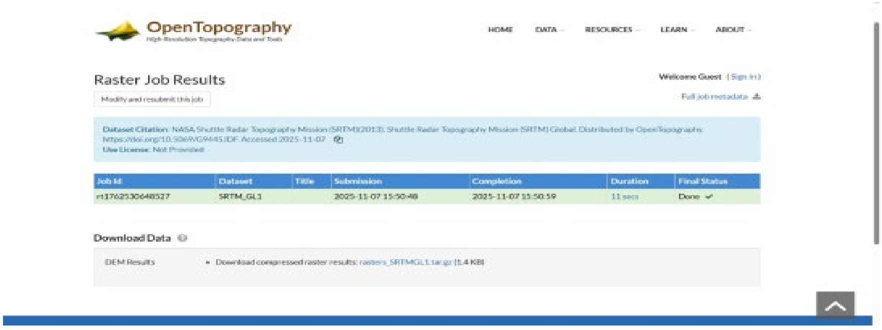

Fig.7. Download Summary of SRTM GL1DEM in GeoTIFF Format

6. Importing DEM into QGIS

- The GeoTIFF file was imported using the Add Raster Layer tool, enabling visualization and further analysis of elevation patterns.

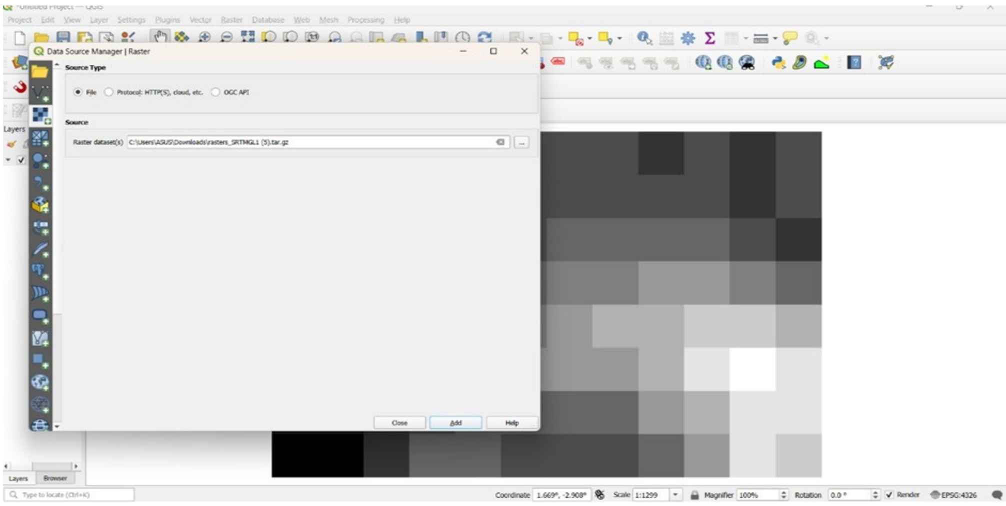

Fig 8. Importing the DEM File into QGIS Using ‘Add Raster Layer’

7. Generation and Symbolization of DEM

- A color-scaled DEM was generated to visually distinguish high and low elevation zones and to identify the central depression of the underpass.

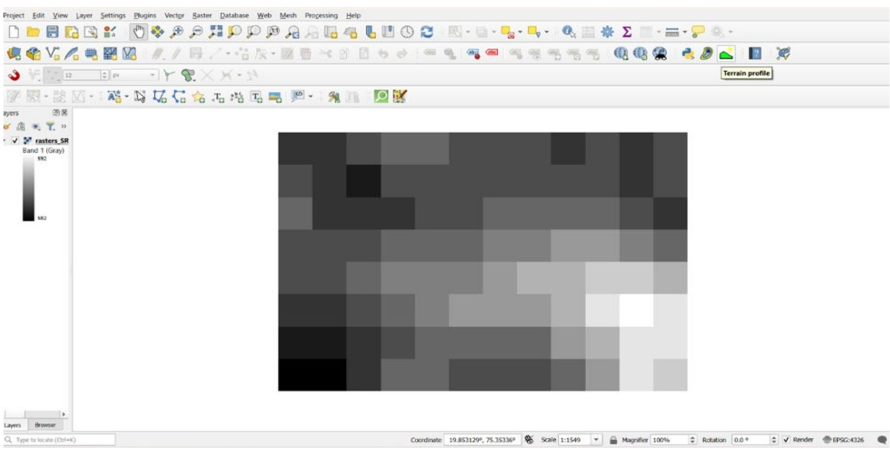

Fig 9. Digital Elevation Model (DEM) Generated in QGIS

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8. Extraction of Elevation Profile

- Using the Profile Tool Plugin, a longitudinal elevation profile was extracted along the centerline of the underpass. The profile revealed a longitudinal slope of <0.5%, which is lower than the IRC:SP:42–2014 recommended 0.5–1.0%.

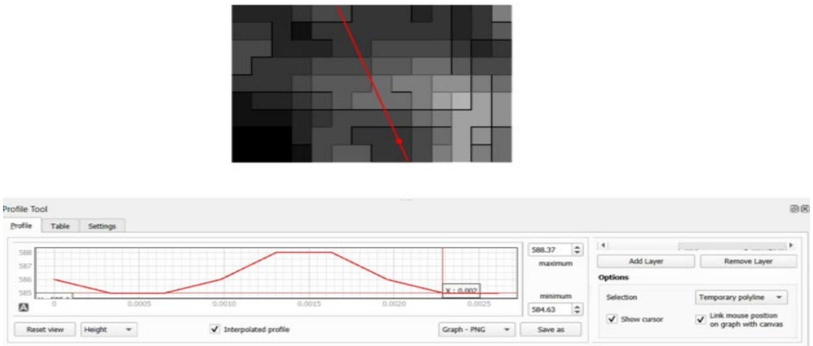

Fig 10. Extracted Elevation Profile and Raster Visualization in QGIS

9. Slope, Contour, and Flow Analysis

- QGIS Slope and Contour tools were used to compute gradient distribution and generate 0.5-m contour intervals. Flow accumulation maps identified convergence zones where stormwater collects.

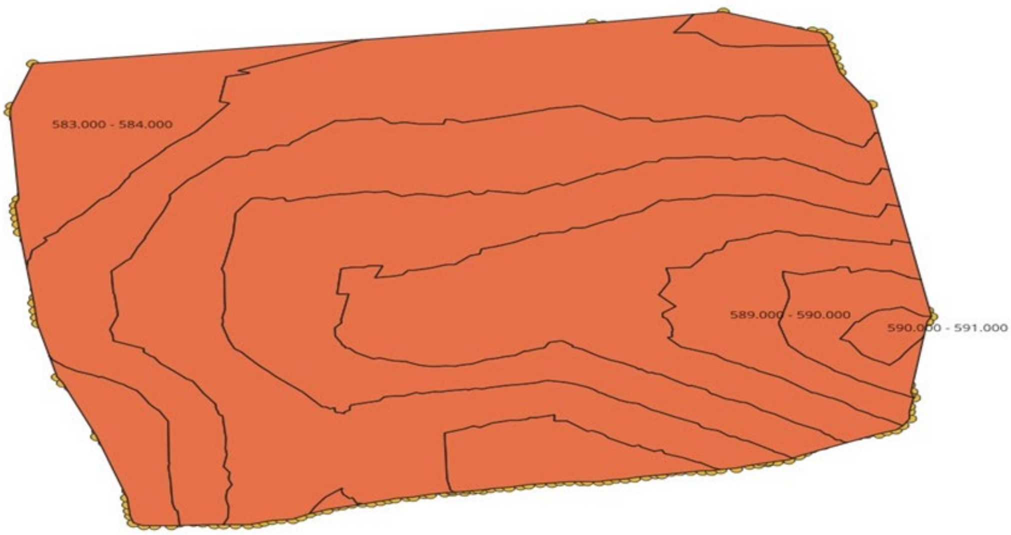

Fig .11. Contour Map Extracted from QGIS of the selected study area

10. Interpretation and Field Validation

- All GIS-derived elevation and slope results were verified through on-site observations and photographic evidence. Validation confirmed that both approaches slope toward the underpass center, causing stormwater stagnation.

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VIII. PROBLEM IDENTIFICATION

The Shivajinagar Underpass experiences frequent and prolonged waterlogging during rainfall because the structure functions as a natural topographic depression. QGIS-based elevation analysis confirms that stormwater from both approaches converges toward the center, resulting in stagnation and disruption of vehicle movement. The existing drainage layout lacks the capacity to remove water efficiently, leading to recurring flooding even under moderate rainfall conditions.

1. Depressed Geometry (Primary Cause) :The elevation profile (Entry: 586 m → Center: 583 m → Exit: 585 m) shows that the underpass lies below both approach levels. Since water cannot flow uphill, gravity drainage is impossible, causing the structure to behave like a closed basin.

2. Side Drains at Road Level : Field observations and QGIS visualizations show that drain inverts are almost flush with the road surface, violating IRC:SP:42-2014 requirements. Such drains cannot intercept runoff, resulting in water accumulation at the center.

3. Absence of a Sump at the Lowest Point : No sump has been provided at the 583 m depression, despite IRC and IS provisions mandating sump pits in depressed underpasses. Without a sump, stormwater has no designated collection point.

4. No Pumping System Installed : Although IS 6934:1998 prescribes pumps when gravity drainage is infeasible, the underpass lacks any pumping arrangement, forcing water to stagnate during rainfall.

5. Insufficient Longitudinal Slope : The measured roadway slope is less than 0.5%, below the IRC-specified minimum gradient of 0.5–1.0%. This inadequate slope prevents self-cleansing flow and promotes ponding.

6. Lack of Effective Drainage Inlets : The absence of grated or trench-type inlets reduces the ability of the system to direct stormwater into drains or a discharge chamber.

Fig 12. Water Accumulation At the Shivajinagar Underpass Site

XI. COMPARATIVE ANALYSIS OF SHIVAJINAGAR UNDERPASS WITH OTHER UNDERPASS DRAINAGE MODELS

A comparison of the Shivajinagar Underpass with properly functioning flat-level and modern concave underpasses reveals major geometric and hydraulic deficiencies in its drainage design. While successful urban underpasses in cities like Hyderabad and Bengaluru maintain efficient drainage through deep drain inverts (1.0–1.5 m below road level), purpose-built sump pits, closely spaced grated inlets, and duty–standby pumping systems as per IRC:SP:42-2014, IS 17482:2020, and IS 6934, the Shivajinagar Underpass lacks all such features. QGIS-derived elevations show that the entry (586 m) and exit (585 m) are higher than the center (≈583–583.5 m), forming a 2.5 m uncontrolled depression, but the side drains are constructed nearly at road level, creating zero hydraulic head and preventing gravity flow. The roadway slope is <0.5%, below IRC requirements, and no sump pit or pumping mechanism is provided despite the underpass functioning as a natural basin. These deviations—flat drain inverts, absence of a sump, inadequate slope, and lack of pumps—explain why modern underpasses drain efficiently even with flat pavements, while Shivajinagar experiences unavoidable waterlogging during rainfall.

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X. DATA ANALYSIS AND RESULTS

QGIS and field observations consistently show that the Shivajinagar Underpass has a distinct concave elevation profile, with levels dropping from 586.0 m at the entry to ≈583.5 m at the center and rising again to 585.0 m at the exit along a total length of 22.76 m. This confirms that the underpass floor lies at the lowest elevation, forming a natural depression. DEM-based interpretation further shows a 2–3 m elevation fall from both approaches toward the center, causing runoff from both sides to converge at the midpoint.

The QGIS elevation sampling (Z-values such as 586.4 m, 583 m, and 585.5 m) verifies that the minimum elevation lies exactly at the roadway center and not at the drain locations. Because the side drain inverts are nearly at the same level as the carriageway, there is no hydraulic head to drive gravity flow. As a result, the drains act only as structural elements and not as functional outlets, and the ponding zone aligns precisely with the lowest DEM pixels. The elevation peak of ~588 m above the railway track reflects the original ground level before excavation, confirming that the internal road level at 583.5 m is significantly lower due to the underpass construction beneath a raised embankment.

QGIS slope interpretation indicates a longitudinal gradient of <0.5%, well below the IRC-recommended 0.5–1.0% slope for effective drainage. Consequently, stormwater cannot move toward any outlet, and gravity drainage is entirely absent. From both DEM and field assessments, it is scientifically valid to conclude that the underpass functions as a closed catchment depression without a working drainage path. The combination of low central elevation, flat or level drains, inadequate slope, and absence of a hydraulic fall fully explains the persistent waterlogging observed during rainfall events.

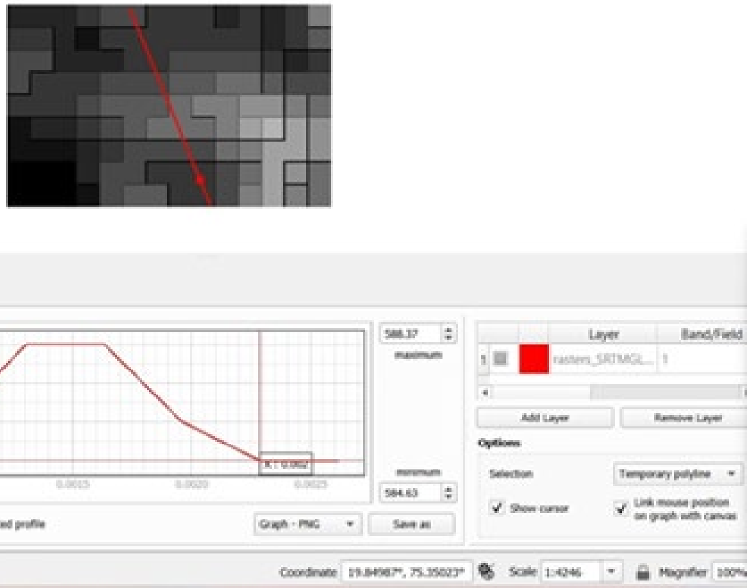

Fig 13. Elevation Profile at the Entry Point of the Shivajinagar Underpass(586 m)

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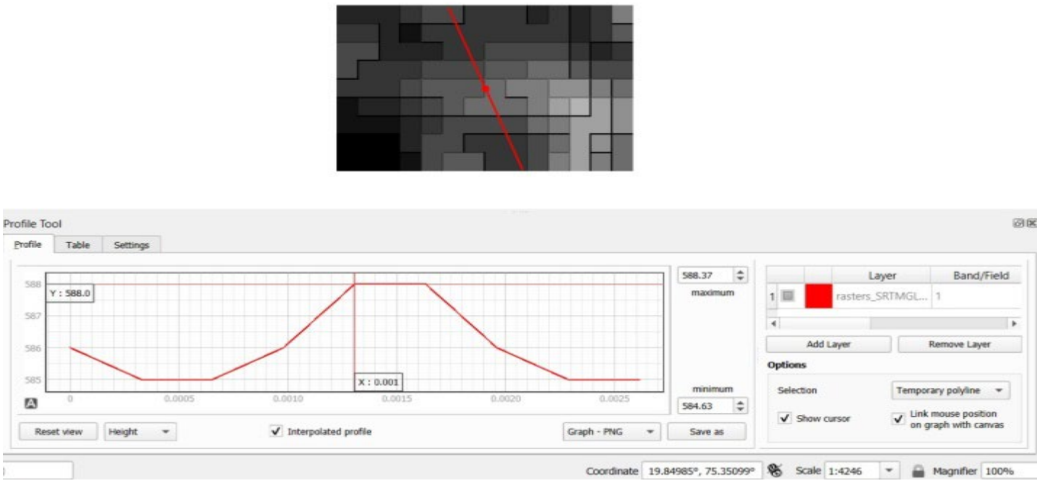

Fig 14. Elevation Profile Beneath the Railway Embankment (583m) Surface Elevation 588m
And height of underpass 4.5 m (588- 4.5= 583 m)

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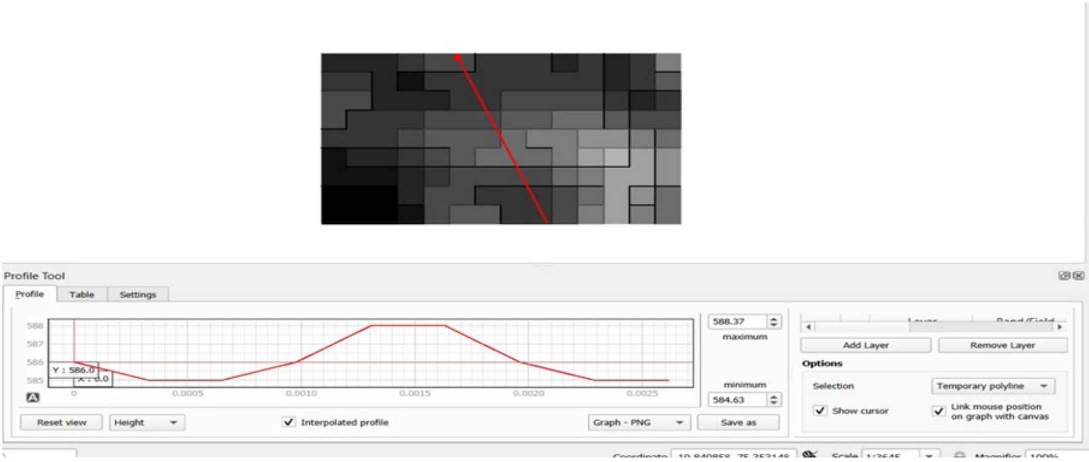

Fig 15. Elevation Profile at the Exit Point of the Underpass (585m)

XI. SOLUTIONS AND RECOMMENDATIONS

QGIS elevation analysis confirms that the Shivajinagar Underpass forms a closed depression (≈583–583.5 m) situated below the approach elevations (585–586 m), making gravity drainage impossible. As per IRC and IS standards for urban underpass drainage, the system must therefore be redesigned to incorporate a sump, pump-based evacuation, lowered drain inverts, and effective inlet structures.The first requirement is the construction of a dedicated RCC sump well at the 583 m low point, designed in accordance with IS 456:2000 and watertightness provisions of IS 3370. The sump invert should lie about 0.5–1.0 m below the pavement level (≈582–582.5 m) as recommended in IRC:SP:42-2014. Since the discharge level (585–586 m) is higher than the depression, a force-drainage system is mandatory. Under IS 6934:1998 and IS 8414, a pump installation comprising one duty and one standby submersible pump must be provided, with a pumping head of approximately 3 m based on the QGIS-derived elevation difference. Automatic float control and redundancy are essential to ensure uninterrupted operation during rainfall.

The existing side drains must be corrected by lowering the drain invert at least 300 mm below the road surface, as mandated by IRC:SP:42-2014, to establish a positive hydraulic gradient directing flow toward the sump. The redesigned drains should be provided with a 1–2% longitudinal slope within the underpass zone to maintain self-cleansing velocity. To enable rapid interception of stormwater, trench or grated inlets must be installed along the depression area at elevations 10–20 mm below the pavement, in compliance with IS 17482:2020.The pumped discharge must be conveyed through a pressure pipeline designed according to IS 17482, fitted with a non-return valve, isolation valve, and an inspection chamber. All electrical components of the pump chamber should conform to IS 3043 for grounding and safety.

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In summary, a code-compliant drainage upgrade for the Shivajinagar Underpass requires:

(1) There should be a Provision of a sump at the 583 m low point;

(2) It is Mandatory to Provide a duty–standby pumping to lift water to 586 m; By following the strict provision of IS Codes Standards.

(3) It is recommended to lowering the drain inverts to ~582.5 m;

(4) There should be an installation of grated inlets; and

(5) It is necessary to provide a safe pumped discharge line.

Adopting these measures will correct the geometric deficiencies identified through QGIS analysis and provide a reliable, standards-based drainage solution for the underpass.

X. CONCLUSION

The QGIS-based DEM assessment conclusively shows that the recurring waterlogging at the Shivajinagar Underpass is the result of fundamental geometric and hydraulic design deficiencies rather than maintenance issues. The elevation profile—586 m at the entry, ≈583.5 m at the center, and 585 m at the exit—confirms a pronounced central depression created due to excavation beneath the elevated railway embankment. This produces an inadequate longitudinal gradient of <0.5%, which contradicts IRC and IS requirements for minimum drainage slope in underpasses. The analysis further indicates that the side drains are positioned at the same elevation as the carriageway, eliminating hydraulic head and making gravity-based discharge impossible. As a result, stormwater consistently accumulates at the lowest point during rainfall.Comparative evaluation with well-designed flat and concave underpasses demonstrates that effective drainage systems rely on lowered drain inverts, purpose-built sump pits, grated inlet systems, and duty–standby pumping arrangements—all of which are absent in the current configuration. These deviations clearly explain why the underpass performs poorly compared to standard-compliant systems. Based on these findings, the study concludes that the underpass requires design-level corrective intervention, including:

• construction of a sump well at the 583–583.5 m depression,

• installation of an automated pumping system as per IS/IRC standards,

• lowering of drain invert levels to restore hydraulic gradient,

• provision of grated inlets, and

• establishing positive drainage connectivity to a suitable outfall.

This study demonstrates that QGIS-based elevation analysis is a reliable diagnostic tool for identifying geometric inconsistencies and drainage failures in urban underpasses. By integrating DEM data with field observations, the analysis provides a clear basis for engineering redesign, ensuring improved long-term performance, safety, and flood resilience of the Shivajinagar Underpass and similar infrastructure elsewhere.

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