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Application of UAV based High Resolution DEM for Flood Management – Case of Mata-no-Madh, Kachchh, Gujarat India

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Abstract

Mata-no-Madh, a culturally significant village in the Lakhpat Sub-District of Kachchh, Gujarat, has experienced recurrent flooding in recent years. These events have disrupted daily life, damaged temple precincts, and exposed critical gaps in the village's drainage infrastructure — highlighting the urgent need for a strategic and data-driven intervention. To address this, a comprehensive geospatial assessment was undertaken using open-source tools, satellite datasets and UAV based survey. The watershed and catchment areas were delineated using Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) data, while terrain features such as contours, drainage patterns, and hillshade models were generated to understand runoff behavior. ISRO's BHUVAN portal was employed to enhance elevation accuracy and validate hydrological parameters. Advanced 2D and 3D visualizations were created to support planning and decision-making. A UAV-based photogrammetry survey provided high-resolution DEMs and updated land use classifications, resolving ambiguities around land ownership and enabling precise site selection. Based on this refined spatial analysis, a suitable location was identified for a flood mitigation and water retention structure — a Water Recharge Tank. The design was aligned with IS: 6966 (Part-1):1989 standards and the Government of Gujarat's check dam guidelines, ensuring regulatory compliance and technical feasibility. This rapid, data-centric approach enabled timely intervention and has since become a replicable model for similar flood resilience projects in the region, including Kamala Sarovar and Taliyari. The initiative demonstrates the transformative potential of geospatial technologies in climate-adaptive infrastructure planning and rural water management.

1. Introduction

1.1 Study / Project Area - Mata-no-Madh:

Mata-no-Madh, a prominent public place, 105 Kms from Bhuj is located in the Lakhpat Sub-District of Kachchh, extreme west of Western region of Gujarat Western state of India, and it holds significant cultural and historical importance and had large no of visitors, moreover during recent years the Kachchh region has attracted large number of tourists. The village experienced flooding events recently.

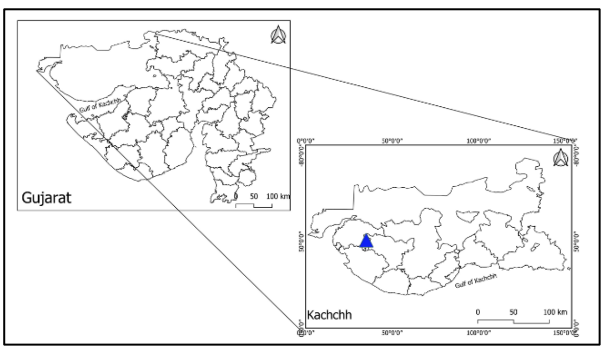

Figure 1 Key map of Mata-no-Madh

Mata-no-Madh study area is geographically defined by top left coordinates of 23.5419401 N,68.9487327 E and bottom right coordinate of 23.53785868 N ,68.95244973 E. and subsequently proposed intervention Site is located at longitude 68.95108E & latitude 23.54102N . The site is approachable by cart road from village Mata-no-Madh during fair weather.

1.2 Issues of Flooding

Mata-no-Madh village experienced recurring flood events in recent years, affecting the public premises and surrounding areas of settlement. During periods of heavy rainfall, runoff water from the hilly terrain on the north-eastern side of the highway flows through an existing roadside drain and flooding settlement areas. Excess runoff crossed and flooded the precincts of the monumental built up and area surrounding within the village disrupting the central business areas of the village. Villagers and people of local areas also highlighted choking of existing drains and insufficient drain culverts.

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2. Mitigating Flood

2.1 Structural intervention and Study Objectives

Data gathering and Analysis: Gather essential topographical, hydrological, and settlement data to support informed decision-making and effective design implementation.

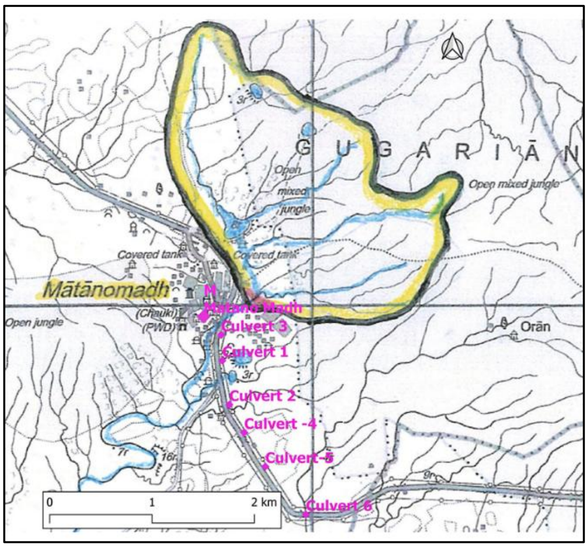

Figure 2 Index plan of Mata no Madh

Design Flood Protection Infrastructure: Plan and construct a flood protection wall along the northeastern side of the state highway to prevent low lying areas of the settlement, and maintain business areas accessible during monsoon.

Divert Runoff: Develop a structural solution to redirect stormwater away from the village and monument premises to reduce flood impact.

Groundwater Recharge: Identify a suitable location and design a groundwater recharge tank to harness floodwater for aquifer replenishment and long-term water sustainability.

Ensure Environmentally Sensitive Planning: Strategize any construction or flow diversion with careful consideration of local settlements and the steep to moderately steep catchment terrain.

The above objectives needed data.

2.2 Geo Spatial Approach

The topographic Survey data was almost more than 25 years old. Although a conventional topographical Theodolite and DGPS (Differential Global Positioning System) survey was initially considered, the speed and topography details required could not be achieved during earlier efforts owing to the steep and very shallow channels changing course often. Therefore, to work out quick estimates of the catchment and affected area a comprehensive geospatial approach was adopted using open-source tools to delineate the watershed, catchment area, drainage patterns, contour lines and hillshade models.

Datasets used : Various global satellite data, UAV based photogrammetric data. SRTM data on https://earthexplorer.usgs.gov/, BHUVAN based watershed boundaries, local geographical and infrastructure data of stake holder govt departments, local self government regarding ownerships, flooding information. SRTM DEM was used for preliminary assessment. The delineated watershed was cross-validated with datasets from the ISRO’s BHUVAN portal outputs—utilizing its hydrology and elevation layers and other national geospatial resources.

At first, index map of location (Figure 2) was prepared and rough catchment area had been marked on legacy topographic map.

To support location-specific reconnaissance and conceptual design of proposed weirs, dams, and water-retaining structures, the initiative leveraged open-source Digital Elevation Models (DEMs) to generate detailed 2D and 3D geospatial maps. The satellite imagery was draped on these coarse DEM /DTM. Figure 3.

To facilitate quick assessment of the catchment and affected area a comprehensive geospatial approach was adopted leveraging open-source tools to delineate the watershed, catchment area, drainage patterns, contour lines and hillshade models. For the preliminary analysis, a 30-meter resolution Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM) was utilized.

An open-source DEM was used to define the Area of Interest (AOI). Among the delineated catchments, the one with the maximum spatial extent was selected as the input for subsequent UAV-based surveys, ensuring optimal coverage and data acquisition. Catchment for each culvert and associated parameters are presented in Table 1. The overall methodology for is illustrated in Chart 1.

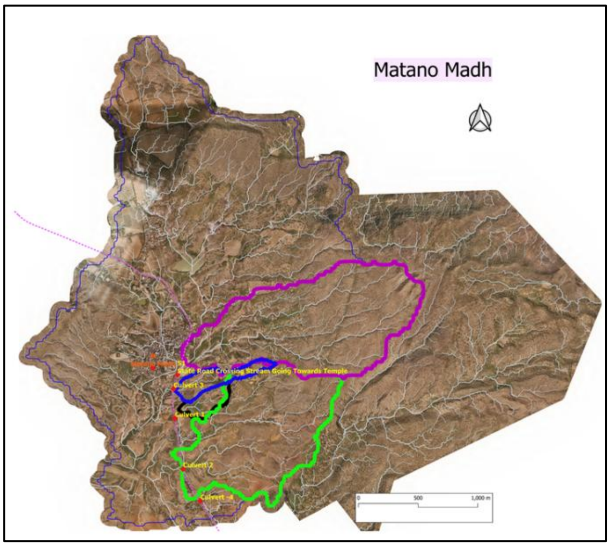

Figure 3 Watershed / catchment delineated culverts derived from SRTM data.

Catchments	Area in ha
Culvert-1	7 ha
Culvert-2	104 ha
Culvert-3	10 ha

Table 1. Catchment area assessment for each culvert

State highway was crossing the premises and it was containing culverts in-line to cross the natural drains beneath it. The catchment areas of all these culverts identified with its maps to obtain holistic view of local site.

The delineated watershed were cross-validated with datasets from the ISRO's BHUVAN portal using its hydrology and elevation layers and later on more precise was computed using UAV survey based DEM in QGIS Hydrological Analysis module.

2.3 UAV photogrammetry, Topography and Land use

The absence of high-resolution land use data—especially detailed classifications like private/public built-up areas, industrial zones, and catchment boundaries—created significant ambiguity. Inaccuracies in land use–land cover (LULC) and elevation levels delayed critical decisions during the design and approval phases. Traditional datasets lacked the precision and timeliness required for field-level clarity and intervention planning. UAV-based rapid mapping provided a breakthrough by generating high-resolution, up-to-date land use maps, clear demarcation of built-up categories and catchments and most importantly seamless integration with Digital Elevation Models (DEMs) for terrain analysis

The preliminary information suggested a feasibility for a water retaining structure.

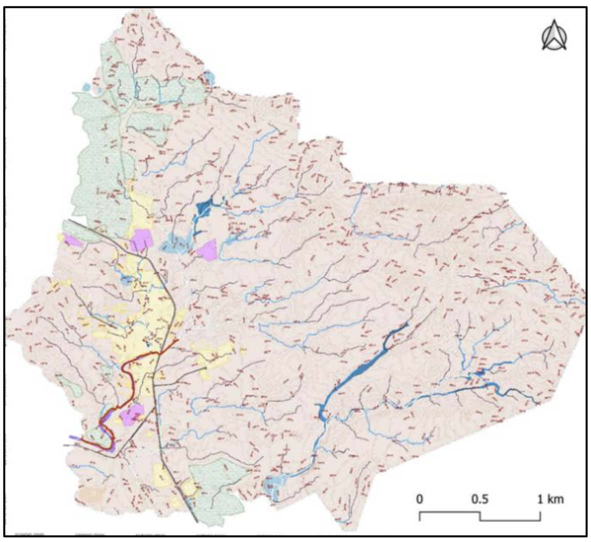

Figure 4 UAV based High resolution Landuse and Stream Map

Sr. No	UAV Survey Data	
1	Images Collected	6081 nos.
2	Flying Altitude	156m
3	Ground Resolution	3.2 cm/pix
4	Coverage Area	14.2 Km2
	Ground Control Points	
1	Number of GCP	26 nos
2	X error	4.35 cm
3	Y error	4.24 cm
4	Z error	0.31 cm
5	XY error	6.07 cm
6	Total RMSE (cm)	6.08 cm
7	Coordinate System	WGS 84 UTM Zone 42N EPSG:32642

Table 2 UAV Survey data

The UAV high resolution data created a landuse land cover map much needed for the planning of the flood diversion structure. Figure 4 is the LULC & Figure 5 is the legend for land use land cover map.

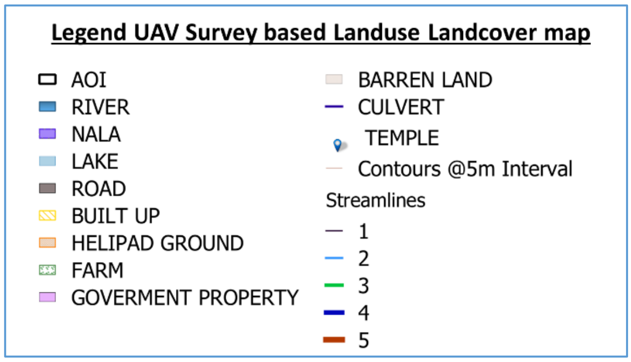

Figure 5 Legend for the LULC map

Various longitudinal sections` and cross sectiosn were worked out as elevation profile of site (Figure 6) to propose the structures such as culverts and tail channel.

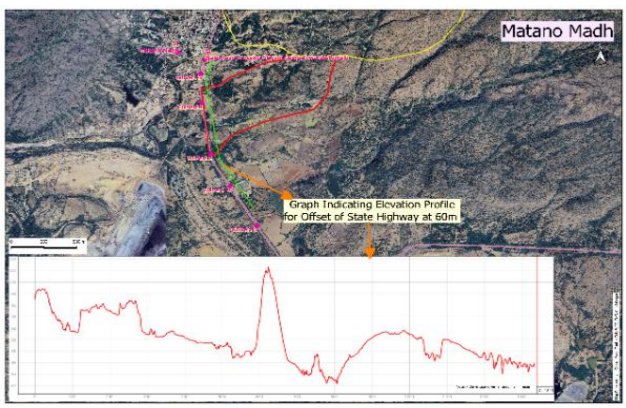

Figure 6 Elevation profile besides highway

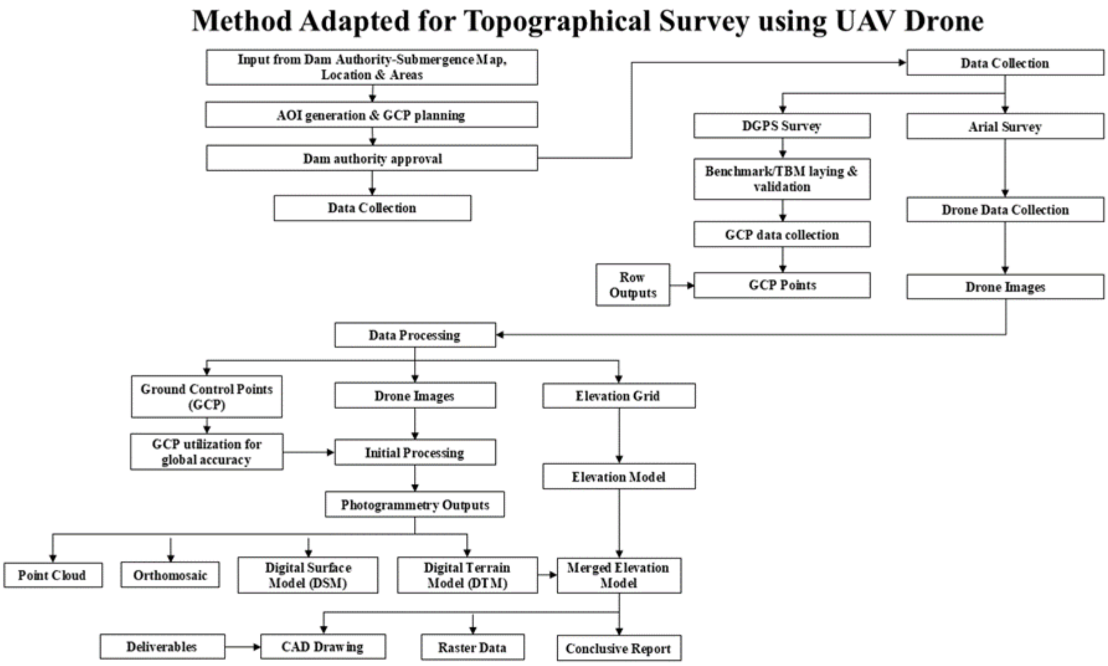

Chart 1 Workflow for UAV data capture and processing

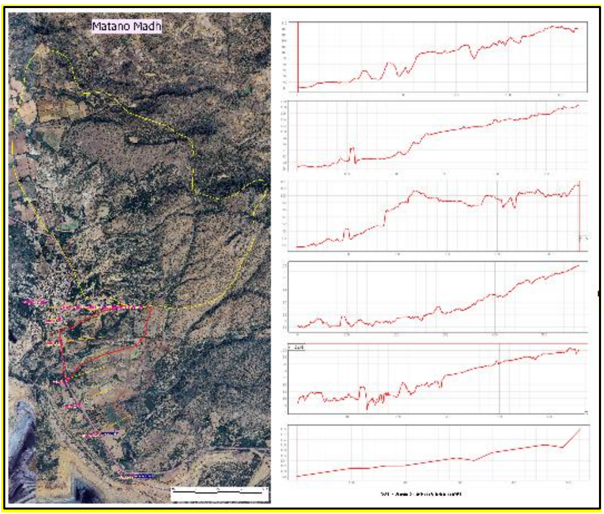

Figure 7 Cross sections along river, road and local depressions

Elevation profiles adjacent to the state highway were utilized to identify potential locations for additional culverts. Similarly, elevation profiles along the river and road corridor (Figure 7) were generated to explore various design alternatives. These analyses were made possible by the high-resolution Digital Elevation Model (DEM) derived from UAV photogrammetry.

2.4 UAV Survey Method and Equipment

UAV Used and its Specifications

UAV used hexacopter (Figure 8) was used, its important specifications are as under:

Figure 8 Hexacopter Falcon used for UAV Survey

- PPK/RTK Enabled – Centimeter-level accuracy
- High-Res Camera – Sharp images for 3D mapping
- 3D Outputs – Orthomosaic, point cloud, DEM
- Flight Altitude – Up to 120 m AGL
- Flight Speed – 10 to 15 m/s
- Flight Time – ~30 minutes per battery
- Max Takeoff Weight – 25 kg
- Stable & Reliable – Perfect for survey, mapping, and inspection

Phase 1

- AOI Prepared : Site area marked about 1200 hectares
- GCP Planning: 6 GCPs per sq. km, selected via satellite imagery.
- GCP Placement: In open areas, away from trees/buildings for visibility.
- Ground Survey (DGPS): Used Emlid RS2, base averaged for 30 minutes
- GCP Marking: Marked clearly for accurate georeferencing.
- Drone Used: Falcon Hexacopter with PPK.
- Flight Settings: 2.5 cm GSD, 70% front & side overlap.

- Purpose: Capture high-resolution data for 3D mapping.
- Pre-Flight Checks: camera calibration done onsite.
- Post-Flight Image Checks: No heavy shadows/blurs Full AOI coverage verified

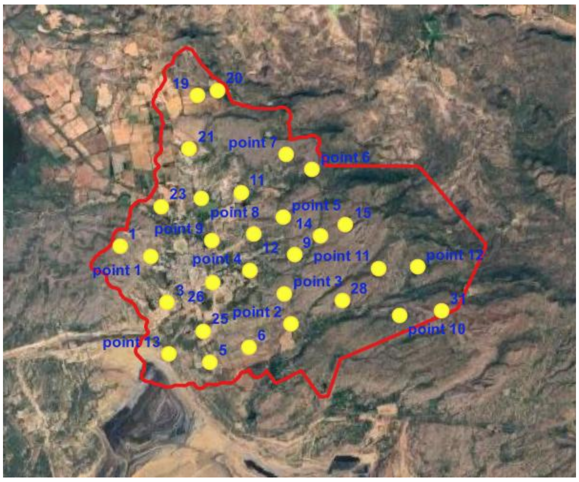

Figure 9 Ground Control Points established

Phase 2 – Aerial data capturing

- 26 nos GCP demarcation completed before flight.
- Drone Survey at 70/70% overlap, 2.5 cm GSD.
- Flight Timing: 0800–1700 hrs for good lighting, minimal shadows.

PPK Survey Workflow:

- Base Setup: Emlid RS2 base set in average SINGLE mode for ~30 minutes.
- Base Verification: Used RS2 rover, connected to base, verified known points — perfect match.
- Survey Start: Continued with same base point for the entire survey.
- Drone Flight (PPK Mode): Drone captured images with Emlid M2 PPK module. The flight paths are Figure 10.

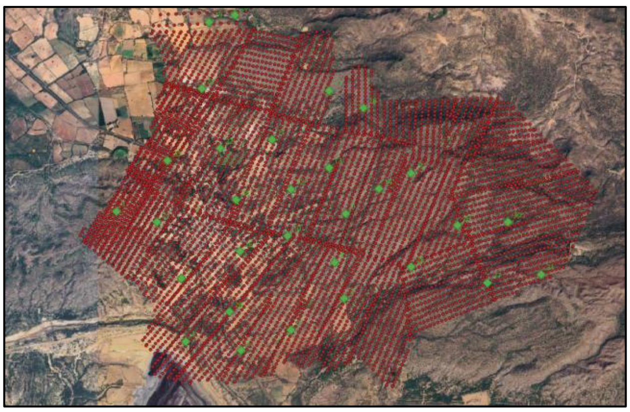

Figure 10 UAV Flight Paths

Phase-3 Aerial Data Processing

Data Processing: Used Emlid Studio for PPK processing — got 100% FIXED solution. Accuracy Check: Final outputs cross-verified with DGPS team – results matched well.

Processing Preparation: Ensured GCPs present & No data gaps. Aero-Triangulation & Adjustment: GCPs marked, Mean RMSE < 10 cm, Mata-no-Madh RMSE = 4.9 cm

Horizontal Accuracy Check: GCPs in Orthomosaic ≦10 cm from banner center.

Vertical Accuracy Check: DSM/DTM spot elevations ≦10 cm from GCPs.

Softwares used:

a. Aerial data processing- Agisoft Metashape For performing Aero-triangulation and Bundle block adjustments, producing outputs as Orthomosaic, DSM, and DTM.
b. Post-processing- Emlid Studio
   Overall Data processing - Global Mapper

Orthomosaic images was created by stitching high-resolution aerial imagery - 6000 drone photos - Figure 11. Geometrically corrected — no distortions. All features were are at uniform scale – which proved useful for accurate measurements of distance, area, and mapping

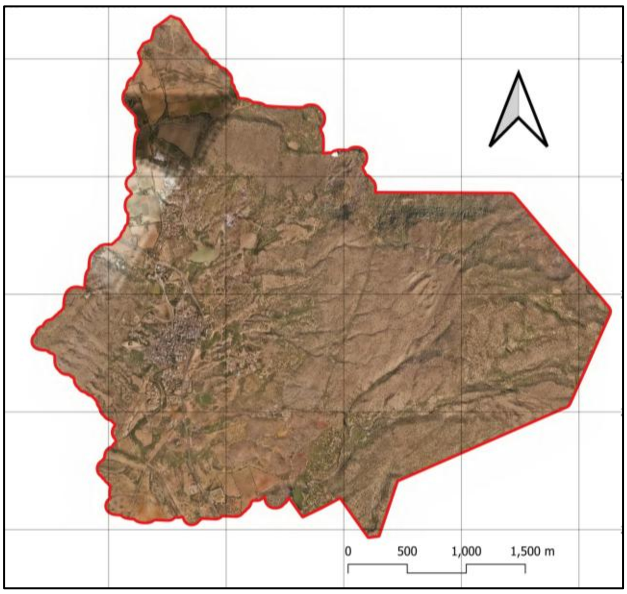

Figure 11 Orthomosaic imagery of the terrain

2.5 Generation of Digital Terrain Model (DTM)

The digital terrain mode, DTM showing the bare earth surface — without buildings, trees, or vegetation, i.e. Natural ground elevation in 3D which helped in analysing slopes, drainage, water flow. Landform was generated at 25.6cm / pixel, having elevation ranges from 69 m to 208.39 m.. Low elevation areas (green/blue) are mainly in the west and southwest. High elevation areas (orange/red) are concentrated in the east and northeast.

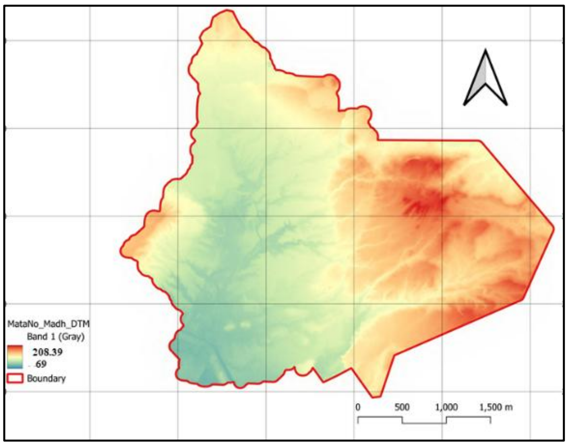

Figure 12 Digital Terrain Model

Contour Map

Contour lines—representing areas of equal elevation—were generated and compiled into a detailed topographic map for the design engineers, with elevations ranging from 69 meters to 208 meters, illustrated in Figure 13. Lower elevation zones, primarily located in the southwest and central regions, are depicted in blue-green shades. In contrast, higher elevations in the east and northeast are shown in orange-red tones. Steep slopes are particularly evident in the eastern highlands, indicating significant elevation gradients that may influence drainage and structural design.

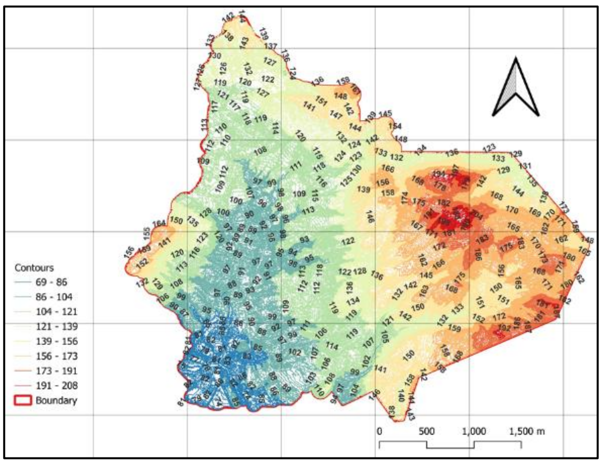

Figure 13 Contour Maps

3. Design of Water Recharge Tank

Utilizing UAV-based high-resolution Digital Elevation Models (DEMs) and detailed land-use data, a well-informed site selection selection and design process adhered to the following standards and manuals:

a. IS: 6966 (Part-1): 1989 – Hydraulic Design of Barrages and Weirs
b. Revised Manual on Percolation Tank, WRD Gujarat (dated 21-11-1988)
c. IS: 12169-1987 (Reaffirmed 1997) – Earth Dam Design
d. Check Dam Manual, Government of Gujarat (dated 22-03-2010)

This approach ensured that key criteria were satisfactorily met, including natural bank integrity - sufficiently high, firm, and stable banks to safely contain afflux water within the reservoir limits. It concluded that constructing a weir on a permeable foundation was the most viable solution. UAV-derived geospatial insights expedited the finalization of the weir alignment., The crest level of the weir was determined by analyzing water inflow, in accordance with the Revised Manual on Percolation Tank,WRD Gujarat Manual (1988). Using reservoir survey data, an area–capacity table was prepared to quantify inflow volume calculated using 80% of the Central Water and Power Commission (CWPC) catchment yield curve.

The design of the proposed structure was informed by subsurface investigations, which revealed sandy and clayey strata. The design followed the principles of the Weir on Permeable Foundation Theory. A stability analysis was conducted using a spreadsheet-based computational model compliant with IS 6512., Apron lengths were determined as per IS 4997

Earthen embankment design was completed using an in-house spreadsheet-based tool aligned with IS 12169

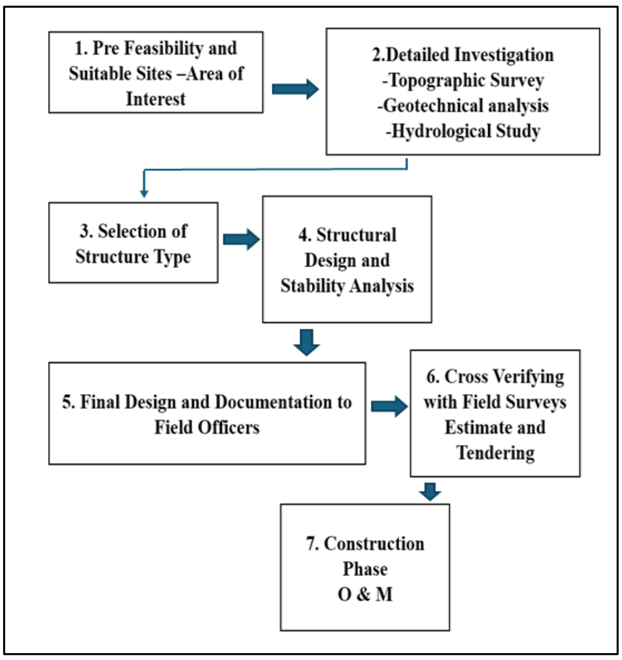

Figure 14 Overall Design Methodology

The tail channel was strategically designed and positioned to safely convey excess water downstream, bypassing the village. This intervention forms a critical component of the broader flood management strategy.

Despite the challenging hilly terrain, the contour plan derived from the UAV / photogrammetrically derived survey demonstrates exceptional precision, resulting in highly accurate contour areas. Consequently, the weir's crest level, adjusted for water inflow, was determined with a high degree of accuracy.

In addition, the positioning of both the weir and the earthen embankment is strategically optimized to achieve the best cost-benefit ratio, thereby enabling the project to be executed with minimal expenditure. For instance, the weir — constructed as a concrete dam — is designed to have the shortest feasible length, ensuring unobstructed passage of floodwaters. Simultaneously, an appropriately designed diversion channel was excavated to efficiently direct water downstream, thereby maximizing storage capacity.

The location of the earthen embankment selected carefully based on the detailed contour derived from UAV survey.

The finalized layout for the intervention is Figure 15, consisting of Waste weir 21 m long, total height 4 m with height above average ground level 1.0 m, and 2.20 m above stilling basin (being 12.20m long) , creating an upstream gross storage of 114560 m3, and earthen embankment length of 201 meters to close the adjoining drains. The length of tail channel 560 m for safe diversion of design discharge and additional culverts were proposed to pass the design discharge of 96 cumecs.

3.1 Outcomes and Impact:

The project shall be facing the first wet season in 2025, the expected outcomes are

a) Stormwater Management: Successfully diverted stormwater away from the village and temple precincts, reducing erosion and protecting built structures.

b) Flood Mitigation: Prevented seasonal flooding of the temple, residential areas, and surrounding properties, preserving both cultural and economic assets.

c) Groundwater Sustainability: Facilitated natural recharge of groundwater through improved drainage design, contributing to long-term water security.

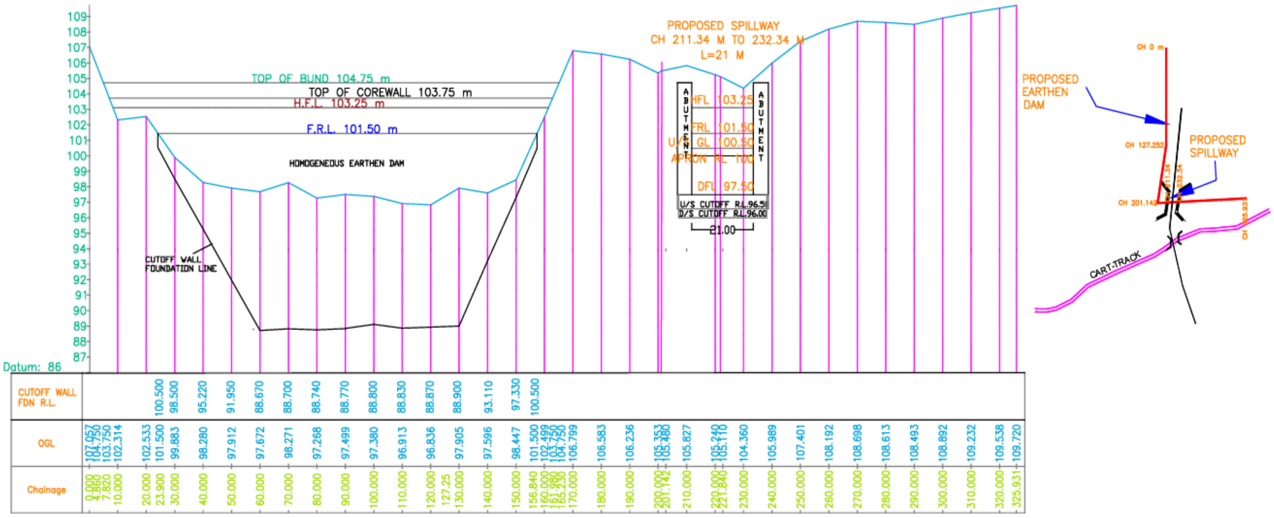

Figure 15 Layout & Design Cross Section for Mata no Madh Recharge Structure

d) Improved Access: Shall ensure safe and uninterrupted access to the village and public places during the monsoon season, enhancing community engagement and community participation.

3.2 Replicability and Conclusion

This project exemplifies how modern geospatial technologies can revolutionize rural infrastructure planning, especially in regions with complex topography. By leveraging tools such as the global satellite / shuttle radar data like SRTM, BHUVAN portal and UAV-based surveys, planners achieved faster, more accurate, and cost-effective results compared to conventional methods.

The success of this approach has already inspired similar interventions in nearby areas like Kamala Sarovar and Taliyari, demonstrating its scalability and adaptability. These outcomes underscore the untapped potential of existing geospatial resources in driving sustainable, data-driven development across rural landscapes.

Photographs of the Works

Quick Design and equally Fast Consrruction of the Recharge Tank realised the intervention in a time frame of 18 months, photograph is Figure 16.

Figure 16 Photograph of Work

4. References :

QGIS Training Manual/17. The QGIS processing guide/17.16. Hydrological analysis

Design Guidelines references

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