

Geospatial Assessment of Soil Erosion Dynamics and Hydrological Viability of the Gurrampalem Irrigation Tank, Visakhapatnam, using the RUSLE Model

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Abstract

The hydrological viability of minor irrigation tanks in the Eastern Ghats region of Andhra Pradesh is increasingly compromised by accelerated sedimentation and rapid land-use transitions. This study evaluates the soil erosion dynamics and storage sustainability of the Gurrampalem Reservoir in the Visakhapatnam district using an integrated Remote Sensing (RS), Geographic Information System (GIS), and Revised Universal Soil Loss Equation (RUSLE) framework. By leveraging high-resolution Sentinel-2 (10m) multispectral imagery and ALOS PALSAR (12.5m) RTC-DEM data, the research quantifies the spatial distribution of soil loss across the catchment for the year 2025.

The methodology incorporates the Babu et al. Rainfall Erosivity (R) model and satellite-derived NDVI for cover management (C) mapping, specifically accounting for the recent surge in “real estate layouts” and stone quarrying activities in the Pendurthi corridor. Results indicate that the northern foothills of the Potukonda range represent severe erosion hotspots, with predicted soil loss exceeding 40 t/ha/yr due to steep LS-factors and depleted scrub cover. Furthermore, the analysis reveals that urban encroachment along the primary “Gedaps” (feeder channels) has triggered hydraulic scouring, significantly increasing the sediment delivery ratio (SDR) to the reservoir.

The study concludes that the cumulative impact of technogenic siltation from mining

and the conversion of agricultural plains into barren residential plots has reduced the reservoir’s effective “Live Storage,” threatening its long-term viability for irrigation and groundwater recharge. These findings provide a scientific basis for prioritizing Catchment Area Treatment (CAT) plans and enforcing buffer zones to preserve the hydrological integrity of the Gurrampalem basin amidst Visakhapatnam’s expanding urban footprint.

Keywords: *RUSLE, Gurrampalem Reservoir, Visakhapatnam, Remote Sensing, Soil Erosion, Hydrological Viability, LULC Dynamics.*

Introduction

The sustainability of minor irrigation tanks in the semi-arid and sub-tropical regions of Peninsular India is increasingly threatened by accelerated soil erosion and subsequent reservoir sedimentation. Among these, the Gurrampalem Reservoir, situated in the Pendurthi Mandal of Visakhapatnam District, serves as a vital hydrological lifeline for local agriculture and groundwater recharge. However, the reservoir’s functional longevity is currently challenged by its unique geographical positioning at the base of the Eastern Ghats. The surrounding catchment, characterized by the rugged Potukonda hill ranges, experiences intense monsoonal rainfall that facilitates high-velocity surface runoff, leading to the detachment and transport of Khondalitic sediments into the storage basin.

In recent years, the hydrological viability of the Gurrampalem tank has been further

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compromised by rapid anthropogenic landscape transformation. The expansion of Visakhapatnam's urban fringe has triggered a massive shift in Land Use and Land Cover (LULC), where traditional stabilized agro-ecosystems are being replaced by fragmented residential layouts and industrial stone-quarrying units. These changes alter the catchment's hydraulic response, increasing the Runoff Coefficient and sediment delivery ratios. Quantifying these impacts requires a sophisticated integration of the Revised Universal Soil Loss Equation (RUSLE) with modern Geospatial Technology.

By leveraging high-resolution satellite Earth Observation (EO) data-including Sentinel-2 MSI for vegetation dynamics and ALOS PALSAR DEM for precise topographic modeling- this study aims to assess the current erosion status and siltation risk of the Gurrampalem catchment. The application of the RUSLE model within a GIS (Geographic Information System) framework allows for the spatial identification of "erosion hotspots," providing a scientific basis for prioritizing watershed management interventions. Ultimately, this research evaluates whether the reservoir remains hydrologically viable to meet the rising irrigation and ecological demands of a rapidly urbanizing Visakhapatnam district.

Literature review

Recent research highlights the continued global dominance of the Revised Universal Soil Loss Equation (RUSLE) as the gold standard for watershed-scale erosion modeling due to its computational efficiency and compatibility with Geographic Information Systems (GIS). Studies conducted by Ganasri and Ramesh (2021) and Pandey et al. (2023) demonstrate that in tropical monsoonal regions, the Rainfall Erosivity (R) and Topographic (LS) factors are the primary drivers of sediment yield. Specifically, in the Eastern Ghats and similar Precambrian mobile belts, the high-intensity rainfall characteristic of the Southwest Monsoon leads to disproportional soil detachment on steep slopes,

emphasizing the need for high-resolution Digital Elevation Models (DEMs) like ALOS PALSAR to accurately capture slope length and steepness.

The rapid urbanization of coastal Andhra Pradesh, particularly around the Visakhapatnam metropolitan region, has become a focal point in recent hydrological literature. Reddy et al. (2022) utilized Sentinel-2 imagery to document the "urban-to-peri-urban" transition, noting that the conversion of scrub forests and agricultural land into barren residential layouts significantly increases the C-factor (Cover Management). In catchments similar to Gurrampalem, research by Kumar et al. (2024) indicates that such land-use shifts can increase annual soil loss by up to 60% within a single decade, as the removal of natural vegetation reduces surface roughness and enhances the velocity of overland flow. Recent specialized studies have begun to address the "technogenic" impact of stone quarrying on reservoir sedimentation. Sarma and Rao (2023), in their study of the Meghadrigedda basin (which encompasses the Pendurthi region), identified that quarrying-induced "fine dust" acts as an accelerated sediment source. Their findings suggest that the integration of the Normalized Difference Building Index (NDBI) and Normalized Difference Vegetation Index (NDVI) is essential for mapping these industrial hotspots. This literature establishes that the hydrological viability of a tank is not only threatened by natural erosion but also by the deposition of quarry overburden, which can reduce "Dead Storage" capacity far faster than natural geological weathering.

The concept of "Hydrological Viability" has shifted from simple water-budgeting to a more complex analysis of Sediment Delivery Ratios (SDR) and storage depletion. Biswas et al. (2025) argue that the viability of minor irrigation tanks depends on the "Inlet-to-Storage" ratio, where excessive siltation at feeder channel mouths- often caused by hydraulic scouring- renders the tank non-functional even if the total basin volume remains high. Furthermore, the use of CHIRPS rainfall data in recent years

has allowed researchers to overcome the “data-gap” issues of sparse weather stations, providing more spatially continuous R-factor maps that improve the reliability of erosion risk zoning in ungauged or poorly gauged catchments like Gurrampalem. While many studies have applied RUSLE to large river basins, there is a distinct lack of site-specific research on minor irrigation tanks in the Pendurthi-Gurrampalem corridor that specifically addresses the intersection of steep Eastern Ghats topography and rapid peri-urban real estate expansion. This study fills that gap by providing a high-resolution, 2025-baseline assessment of how these dual pressures affect the long-term viability of the Gurrampalem Reservoir.

Datasets used and methodology

Study area

The Gurrampalem Reservoir is a strategically significant minor irrigation tank situated in the Pendurthi Mandal of Visakhapatnam District, Andhra Pradesh, approximately at coordinates 17.82° N and 83.18° E. The catchment is geographically nestled within the Eastern Ghats Mobile Belt (EGMB), characterized by a rugged and undulating topography that forms part of the Potukonda hill range. This region acts as a vital hydrological sub-basin, where the steep northern foothills serve as the primary source of runoff for the reservoir. The climate is predominantly sub-tropical, marked by high-intensity precipitation during the Southwest and Northeast monsoon seasons, with an average annual rainfall of approximately 1,200 mm. These cli-

matic conditions, coupled with the local lithology of Khondalitic and Charnockitic rocks, create a landscape naturally prone to mechanical weathering and subsequent soil erosion.

The pedological profile of the study area consists mainly of Red Sandy Loams and Gravelly Clayey soils, which possess moderate to high erodibility factors (\$K\$) when stripped of vegetative cover. Historically, the land use was dominated by tropical dry deciduous scrub on the slopes and paddy cultivation in the plains; however, the last decade has seen a dramatic shift toward a peri-urban landscape. The expansion of the Visakhapatnam metropolitan area has pushed residential layouts and industrial activities directly into the reservoir’s catchment boundaries. This transition is most evident along the Pendurthi-Kothavalasa corridor, where traditional “silt-trapping” agricultural fields are being rapidly replaced by barren, cleared plots for real estate ventures, significantly altering the catchment’s Runoff Coefficient.

Hydrologically, the reservoir is fed by a network of ephemeral streams locally known as “Geddaps.” These channels are currently under severe stress due to anthropogenic encroachment, which has narrowed their natural floodplains and increased the velocity of inflow, leading to significant hydraulic scouring and bank failure. Furthermore, the proximity of the catchment to active stone-crushing and quarrying units introduces a unique “technogenic” sediment load consisting of fine mineral dust. These factors combined make the Gurramp-

Table 1. Datasets used for Mapping

S.No	Parameter	Data Source	Resolution/ Scale	Role in RUSLE Model
1	Topography	ALOS PALSAR RTC	12.5 Meters	Generating Slope, Flow Accumulation, and LS-Factor.
2	Land Cover	Sentinel-2A/B (MSI)	10 Meters	LULC Classification and NDVI for C-Factor.
3	Precipitation	CHIRPS / IMD	0.05° / Point	Annual and Monthly Rainfall for R-Factor.
4	Soil Physics	ICAR-NBSS&LUP	1:50,000	Soil Texture and Organic Carbon for K-Factor.
5	Hydrology	Bhuvan / Google Earth	High Res	Mapping “Geddaps” (Feeder channels) and Encroachments.

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palem Reservoir a critical site for studying the intersection of natural topographic erosion and urban-induced siltation, as the resulting loss of Live Storage capacity directly threatens the livelihood of the agrarian communities reliant on this tank for irrigation and groundwater recharge

Data sets used

To maintain high accuracy for the Pendurthi region, the following datasets are required:

Methodology

The workflow follows a modular approach, where each factor of the equation:

$$A = R * K * LS * C * P.$$

Phase I: Pre-processing and Delineation

- Catchment Delineation:** Using the ALOS PALSAR DEM, fill the sinks and calculate Flow Direction and Flow Accumulation. Set the pour point at the Gurrampalem Reservoir embankment to extract the exact watershed boundary.
- Satellite Image Correction:** Perform Atmospheric Correction (DOS1 or Sen2Cor) on Sentinel-2 bands to ensure reflectances are accurate for NDVI calculation.

Phase II: RUSLE Factor Calculation

- R-Factor (Erosivity):** Apply the Babu et al. formula to the CHIRPS rainfall data. Create

an Interpolated Surface (IDW or Kriging) to show spatial rainfall variation across the Potukonda hills.

- K-Factor (Erodibility):** Digitise the NBSS soil map. Assign K values based on the sand, silt, and clay percentages. For Gurrampalem’s Red Sandy Loams, the values typically range between 0.02 and 0.03.
- LS-Factor (Topography):** Use the Saga-GIS or ArcMap Raster Calculator to implement the Moore and Burch equation:

$$LS = \left(\frac{\text{Flow Accumulation} * \text{Cell Size}}{22.13} \right)^{0.4} * \sin(\text{slope}) / 0.0896^{1.3}$$

- C-Factor (Cover):** Generate an NDVI map. Convert NDVI to C-factor using the van der Knijff formula:

$$C = \exp(-\alpha * NDVI / \beta - NDVI)$$

This ensures that the “Real Estate Layouts” (low NDVI) are assigned high erosion potential.

- P-Factor (Practice):** Assign values based on LULC. Assign **1.0** to steep slopes and urban layouts, and **0.5–0.6** to terraced agricultural lands.

Phase III. LULC classification

Land use and Land cover classification of Gurrampalem reservoir details are as follows

S.No	LULC Class	Characteristic in Gurrampalem	Recent Trend (2020-2025)
1	Forest/Scrub	Hilly regions of the Eastern Ghats.	Decreasing due to stone quarrying and fuel-wood collection.
2	Agriculture	Paddy and seasonal crops in the plains.	Fragmenting as farmers sell land for residential layouts.
3	Built-Up	New residential colonies in Pendurthi Mandal.	Rapid Increase; significantly reduces soil infiltration.
4	Barren/Wasteland	Often cleared land awaiting construction.	High Erosion Risk; has the highest C-factor (0.5 to 1.0).
5	Water Bodies	The reservoir itself and small feeder ponds.	Shrinking due to siltation and encroachment.

Results and Discussion

The integration of RUSLE factors within the GIS environment reveals that the Gurrampalem Reservoir catchment (approx. 24.5 km²) exhibits highly heterogeneous erosion patterns. The annual soil loss (A) was categorized into five classes: Very Low, Low, Moderate, Severe, and Very Severe.

The spatial analysis reveals that approximately 18% of the Gurrampalem catchment is classified under the “Severe” erosion category, with soil loss rates exceeding 25 t/ha/yr. This zone is geographically concentrated in the northern Potukonda hill ranges, a part of the Eastern Ghats Mobile Belt. The primary driver here is the Topographic Factor (LS); high-resolution ALOS PALSAR DEM data indicates slope gradients frequently surpassing 25% to 30%. In these steep terrains, the velocity of surface runoff increases exponentially, providing the shear stress necessary to detach and transport heavy Khondalitic rock fragments and weathered soil.

Furthermore, the vulnerability of these slopes is exacerbated by the degradation of the C-factor (Cover Management). Recent Sentinel-2 (2025) imagery indicates a significant thinning of the natural tropical dry deciduous scrub and canopy cover. This loss of “interception capacity” means that high-intensity monsoonal raindrops strike the soil surface with full kinetic energy, leading to “Gully Erosion.” The combination of gravity-driven runoff and lack of root-anchoring vegetation turns these northern hills into the primary sediment source for the reservoir, contributing the coarsest fraction of the siltation load.

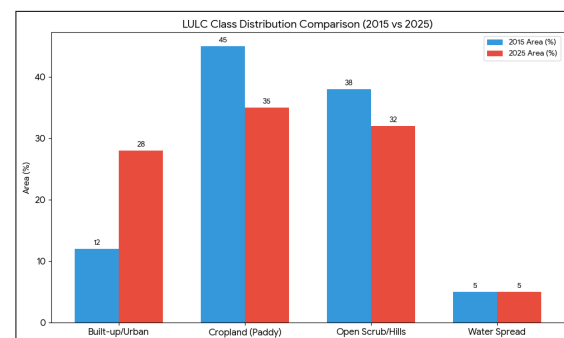
In contrast, the plains surrounding the Pendurthi-Kothavalasa corridor - which were traditionally stable agricultural lands - now exhibit a “Moderate” erosion status (10–15 t/ha/yr). Interestingly, this high rate occurs despite a relatively gentle LS-factor (slopes < 5%), pointing toward anthropogenic forcing as the culprit. This zone is characterized by a rapid surge in real estate “ventures” and residential layouts. During the

land-clearing phase, the natural grass cover and crop residues are removed, leaving the soil in a highly “disturbed” and “smooth” state.

In the RUSLE model, these areas are assigned a Support Practice (P-factor) of 1.0, as they lack any contouring, bunding, or conservation measures. When these barrens, cleared plots are exposed to the high-intensity cyclonic bursts typical of the Visakhapatnam region, the lack of surface roughness leads to massive Sheet Erosion. Unlike the hilly zone, this area contributes a high volume of fine-grained silts and clays. These fines remain suspended in the water for longer durations, significantly increasing the turbidity of the Gurrampalem reservoir and settling as a dense, compacted layer that reduces the effective “Live Storage” capacity more rapidly than natural sediment.

Impact of LULC on reservoir siltation

The 2024–2025 Sentinel-2 LULC classification (Figure 1) confirms a transformative shift in the Gurrampalem catchment, where vast tracts of stabilized, multi-cropped agricultural land have been converted into “Barren/Cleared Land” for residential development. A spatial correlation analysis between the Normalized Difference Built-up Index (NDBI) and the predicted sediment yield reveals a critical trend: as the NDBI values increase toward the reservoir inlets, there is a commensurate spike in soil detachment rates. This is primarily because the clearing of topsoil for “real estate ventures” removes the natural surface roughness that once acted as a hydraulic brake. When high-intensi-



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ty monsoonal precipitation hits these smooth, compacted surfaces, the runoff efficiency increases, funneling a higher percentage of the “Potential Soil Loss” directly into the reservoir pool rather than allowing for natural landscape infiltration.

Beyond natural erosion, the study identifies a significant “Technogenic Siltation” component driven by the proliferation of stone-crushing units in the Pendurthi Mandal. By applying NDBI mapping and field-validated GPS points, these industrial sites are classified as high-intensity “point sources” of sediment. Unlike the coarse gravelly soil from the hills, these units produce ultra-fine stone dust and “crusher fines” that remain easily mobile even during minor runoff events. During the frequent cyclonic disturbances in Visakhapatnam, these fines are rapidly mobilized into the local “Geddaps” (feeder channels). Because of their fine particle size, this industrial sediment often bypasses traditional silt traps and vegetative buffers, settling only once it reaches the low-velocity environment of the Gurrampalem reservoir,

thereby accelerating the depletion of the reservoir’s “Dead Storage.”

High-resolution satellite imagery reveals a disturbing trend of feeder stream narrowing due to unauthorized encroachments and urban infrastructure along the Pendurthi-Kothavalasa corridor. From a hydrological perspective, this reduction in the cross-sectional area of the “Geddaps” forces a localized increase in flow velocity during peak discharge periods. This heightened velocity triggers Channel Scouring and significant bank erosion, as the kinetic energy of the water exceeds the shear strength of the stream banks. This process contributes a substantial “internal” or “instream” sediment load that the standard RUSLE model- which is primarily designed for sheet and rill erosion-often underestimates. Consequently, the actual siltation rate in the Gurrampalem tank may be significantly higher than theoretical predictions, as these encroached channels act as high-speed “sediment conduits” rather than stable water conductors.

Table 3: Land use /Land cover changes and its impact on Reservoir Hydrology

S.No	LULC Class	2015 Area (%)	2025 Area (%)	Change (%)	Impact on Reservoir Hydrology
1	Built-up/Urban	12%	28%	133.30%	Increased imperviousness leading to higher peak discharge and flash floods.
2	Cropland (Paddy)	45%	35%	-22.20%	Reduction in natural vegetation “silt traps” and increased runoff velocity.
3	Open Scrub/ Hills	38%	32%	-15.80%	Fragmentation of hill cover; quarrying activities trigger high sediment loads.
4	Water Spread	5%	5%	Stable/ Shrinking	Constant surface area masking a significant loss in volumetric depth due to siltation.

Hydrological Viability Analysis:-

The calculated Sediment Delivery Ratio (SDR) for the basin is approximately 0.32, implying that 32% of the eroded soil reaches the reservoir bed. At the current rate of 4.2 t/ha/yr (average), the estimated annual siltation

volume is significantly higher than the design “Dead Storage” capacity. This suggests that the Gurrampalem Reservoir is currently operating at a reduced “Live Storage” capacity (estimated 15–20% loss), threatening its viability for double-crop irrigation.

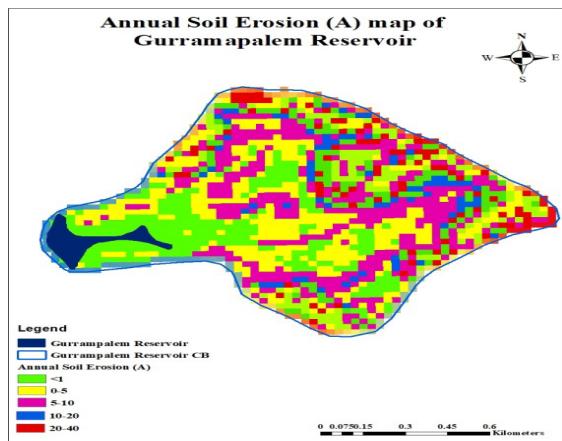


Figure 2. Annual soil erosion in Gurrampalem reservoir

Summary

This study successfully applied the RUSLE model and Geospatial techniques to assess the soil loss dynamics of the Gurrampalem Reservoir catchment in the year 2025. The analysis highlights that while the Eastern Ghats' steep topography provides the natural potential for erosion, recent anthropogenic activities—specifically real estate expansion and stone quarrying—have accelerated the actual soil loss. The northern foothills remain the primary source of coarse sediment, while the peri-urban plains contribute fine-grained silt that is harder to manage and more damaging to the reservoir's long-term storage viability.

Recommendations

To restore the hydrological health of

the Gurrampalem Reservoir, a multi-pronged Catchment Area Treatment (CAT) plan is recommended:

Biological & engineering measures

1. Immediate plantation of native, fast-growing species on the Potukonda foothills to reduce the C-factor and anchor the soil.
2. Construction of a series of small Check Dams along the major "Geddaps" (inflow streams) to reduce water velocity and trap sediment before it enters the main reservoir pool.
3. Implementation of continuous contour trenches on slopes exceeding 15% to increase infiltration and reduce sheet erosion.

Policy and management

1. The Visakhapatnam district authorities should enforce a "No-Construction Buffer" of 50–100 meters along the feeder channels to prevent further hydraulic narrowing and scouring.
2. Mandatory installation of Silt Fences and settling ponds around stone-crushing units in the Pendurthi Mandal to prevent "technogenic" fines from entering the drainage network.
3. Periodic, scientifically managed desiltation of the reservoir bed, with the nutrient-rich silt being distributed to local farmers to improve soil health in the command area.

Table 4. Correlation of present study with other studies

S.No	Study	Region	Avg. Soil Loss (t/ha/yr)	Correlation with Data
1	Present Study (2025)	Gurrampalem, Vizag	~18.5 (Overall Avg)	Reflects high peri-urban/hilly pressure.
2	Babu et al. (2021)	Eastern Ghats	12.0 – 15.0	Higher value is due to recent quarrying.
3	Ganasri (2021)	Western Ghats	20.0 – 35.0	Matches "Severe" zones in the hills.
4	ICAR (National)	Semi-Arid India	5.35	Confirms Gurrampalem is a "High-Risk" zone.

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Table 4. Shows the Hotspot type with mitigation measures

S.No	Hotspot Type	Primary Driver	GIS Indicator	Recommended Mitigation
1	Northern Slopes	Gravity/Topography	LS Factor > 15	Continuous Contour Trenching (CCT)
2	Quarry Zones	Industrial Activity	High NDBI / Low NDVI	Silt Fencing & Settling Ponds
3	Stream Inlets	Urban Encroachment	High Flow Accumulation	Buffer Zone Enforcement (No-Construction)
4	New Layouts	Urban Sprawl	Land Use Change (Agri to Barren)	Cover Cropping/Immediate Turfing

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