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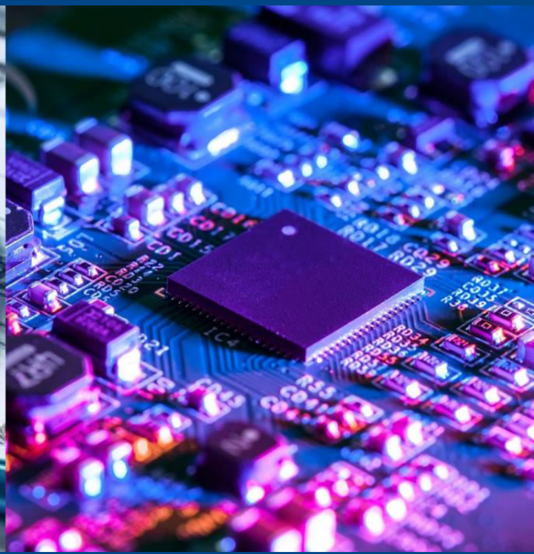

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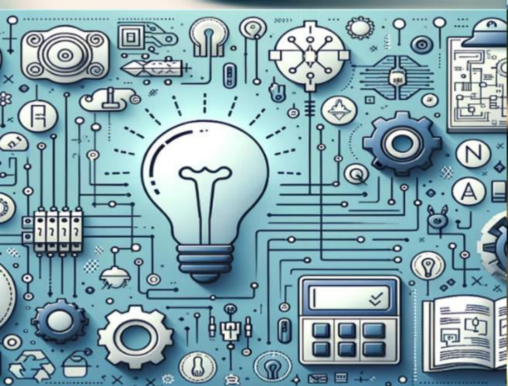

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Spatiotemporal Analysis of Water Spread, Storage Capacity, and Sedimentation in Manjalar Dam using Remote Sensing Techniques

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ABSTRACT: Information on the storage capacity of a reservoir is essential for irrigation, municipal and industrial water supplies, power, flood control, sediment storage. This study evaluates the water spread area, storage capacity, and sedimentation rate of the Manjalar Dam using temporal remote sensing data and advanced classification approaches. LANDSAT 5 multi temporal satellite images were analyzed using ArcGIS and ENVI software to extract water body layers. Three methodologies—Maximum Likelihood Classification (MLC), Neural Net Classification (NNC), and Normalized Difference Water Index (NDWI)—were employed to determine the water spread area. The sedimentation rate was calculated using the Normalized Difference Suspended Sediment Index (NDSSI). Findings reveal a decrease in water spread area and storage capacity over time, indicate progressive sedimentation in the reservoir. From the LANDSAT 8 data (2018), the water spread area was estimated as 0.9297 km² using MLC, 1.0035 km² using NNC, and 0.9009 km² using NDWI. The storage capacity and sedimentation rate were calculated as 10.62 Mm³ and 0.460 Mm³, respectively. From the LANDSAT 5 data (1993), the water spread area was found to be 0.8595 km² (MLC), 0.9207 km² (NNC), and 0.8712 km² (NDWI), with a storage capacity of 7.022 Mm³ and a sedimentation rate of 0.352 Mm³. The results highlight the utility of integrating remote sensing and geospatial techniques to monitor changes in reservoirs, informing effective water resource management.

KEYWORDS: ArcGIS, ENVI, Maximum Likelihood Classification, Neural Net Classification, NDWI, NDSSI, Sedimentation Rate, Temporal Analysis.

I. INTRODUCTION

Information on the storage capacity of a reservoir is essential for irrigation, municipal and industrial water supplies, power, flood control, and sediment storage. This study evaluates the water spread area, storage capacity, and sedimentation rate of the Manjalar Dam using temporal remote sensing data and advanced classification approaches [1, 2]. The study made by [3-5] explores sedimentation analysis using remote sensing techniques and NDWI for a large reservoir in India. It also provides insights into water body classification and sedimentation using LANDSAT and MODIS data. A case study on sedimentation using Landsat imagery and elevation-capacity reports focuses on integrating GIS with remote sensing data for sedimentation analysis [6-9]. Another study demonstrates how water spread estimation correlates with storage capacity calculations and reviews the application of NDWI and NDSSI for sedimentation and water quality monitoring in reservoirs. The classification techniques like MLC and NNC for geospatial studies highlights the application of advanced geospatial platforms for temporal reservoir analysis [10, 11]. The sedimentation challenges in Indian reservoirs with a focus on management strategies are given by [12, 13]. This study explores the use of remote sensing to detect suspended sediments in surface waters. The authors highlight the advantages of using satellite imagery for assessing water quality and sediment levels, employing the concept of spectral reflectance to differentiate water from suspended particles [14, 15]. This case study from the Phulang Vagu Watershed in India demonstrates how GIS and remote sensing techniques can be used to evaluate sediment yield [16, 17]. It

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focuses on monitoring and analyzing changes in water storage and sediment accumulation, offering methodologies for regular assessment [18, 19]. This work examines assessment of reservoir sedimentation at the Patratu Reservoir, India, using remote sensing and GIS. The study identifies areas of significant sedimentation and provides recommendations for reservoir management and desilting [20, 21]. Similar to their previous work, they investigated reservoir sedimentation in the Patratu Reservoir, providing a deeper analysis of sediment dynamics over time and stressing the importance of continuous monitoring using remote sensing tools [22-26]. This study compares different spectral analysis methods to estimate suspended material in coastal waters. Accordingly, this paper aims to estimate the reservoir water-spread area by maximum likelihood, neural net classification, and NDWI approaches and the storage capacity of the reservoir and sedimentation rate with temporal remote sensing data.

II. STUDY AREA

The Manjalar Dam, located in Periyakulam Taluk of Theni District, Tamil Nadu, is a crucial multipurpose reservoir constructed across the Manjalar between 1963 and 1967. Situated within the Manjalar sub-basin, part of the larger Vaigai River basin, the dam supports irrigation, fisheries, and drinking water needs, playing a significant role in the socio-economic development of the region.

III. METHODOLOGY

The methodology for calculating sedimentation in the Manjalar Dam involved a systematic approach combining geospatial analysis, satellite image processing, and data from field observations. The steps are detailed below:

1. Data Collection

1. **Satellite Imagery**:
   - LANDSAT 5 (March 14, 1993) and LANDSAT 8 (January 1, 2018) were obtained from the United States Geological Survey (USGS) website.
   - Specifications: Spatial resolution: 30 m, Swath width: 183 km, Path/row: 143/53.
   - Spectral bands used for analysis: Coastal Aerosol, Blue, Green, Red, Near Infrared (NIR), and Short-Wave Infrared (SWIR).
2. **Topographical Data**:
   - Survey of India (SOI) toposheets for geometrical corrections and georeference.
3. **Elevation-Capacity-Sedimentation Report**:
   - Data collected from the Water Resources Department (WRD) for sedimentation reference and elevation capacity.

2. Water Spread Area (WSA) Calculation

- WSA was computed using three methods to ensure robustness:
  1. **Maximum Likelihood Classification (MLC)**: Identifies WSA based on probability distributions of spectral classes.
  2. **Neural Net Classification (NNC)**: Handles mixed pixels for higher accuracy in heterogeneous areas.
  3. **Normalized Difference Water Index (NDWI)**: Enhances water information using the equation: NDWI=(Green−NIR)(Green+NIR)NDWI = \frac{(Green - NIR)}{(Green + NIR)}NDWI=(Green+NIR)(Green−NIR)

3. Sedimentation Calculation

1. **Normalized Difference Suspended Sediment Index (NDSSI)**:
   - Applied to analyze suspended sediment concentration using the equation: NDSSI=(Blue−NIR)(Blue+NIR)NDSSI = \frac{(Blue - NIR)}{(Blue + NIR)}NDSSI=(Blue+NIR)(Blue−NIR)
   - NDSSI values were used to classify sediment laden water

2. **Elevation Data Integration**:
   - Elevation data from WRD were incorporated as a reference for sediment volume calculation.

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4. Volume of Water Calculation

- Using the water spread area from satellite data, the volume of water was calculated via the **Prismoidal Formula**: V=H3(A1+A2+A1·A2)V = \frac{H}{3}(A_1 + A_2 + \sqrt{A_1 \cdot A_2})V=3H(A1+A2+A1·A2)

VVV: Volume of water, HHH: Elevation difference, A1A_1A1: Water spread area at Elevation 1, A2A_2A2: Water spread area at Elevation 2

5. Sedimentation Rate Estimation

- Sediment volume was determined using the Prismoidal Formula, replacing water spread area with sediment area.
- Sedimentation rate was calculated as: H=h2−h1H = h_2 - h_1H=h2−h1

HHH: Elevation difference, h1h_1h1: Elevation of sediment, h2h_2h2: Elevation of water surface.

6. Validation and Accuracy

- Results were validated using the WRD sedimentation and water capacity reports.
- Accuracy for each classification method was assessed based on their ability to delineate WSA accurately.

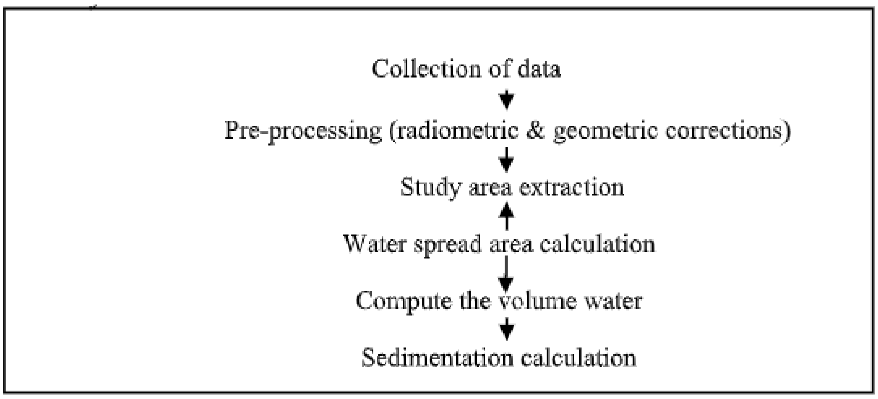

Figure 2: Methodology for Sedimentation calculation

IV. RESULT

WATER SPREAD AREA

The water spread area (WSA) was analyzed using three different classification approaches: Maximum Likelihood Classification (MLC), Neural Net Classification (NNC), and Normalized Difference Water Index (NDWI). The results demonstrate variations in WSA estimates depending on the technique employed:

- **Maximum Likelihood Classification (MLC)**:
    - 1993: The WSA was estimated at **0.8595 km²** with an accuracy of **99.71%**.
    - 2018: The WSA increased to **0.9297 km²** with an accuracy of **98.96%**.
- **Neural Net Classification (NNC)**:
    - 1993: The WSA was estimated at **0.9207 km²** with an accuracy of **99.93%**.
    - 2018: The WSA increased to **1.0035 km²** with an accuracy of **99.14%**.
- **Normalized Difference Water Index (NDWI)**:
    - 1993: The WSA was calculated as **0.8892 km²**.
    - 2018: The WSA increased to **1.1142 km²**.

These results indicate that while all methods capture changes in water spread, NDWI tends to overestimate water bodies due to its sensitivity to built-up land. NNC, on the other hand, provides finer spatial resolution and more reliable estimates by accounting for mixed pixels.

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A) Maximum Likelihood Classification

The maximum likelihood classification assumes that each pixel represents a single land cover class only. It ignores the mixed pixel problem typical of the peripheral regions of reservoirs (Fig 3). The maximum likelihood classification may give a high accuracy only if the scene is of a homogeneous nature or the image used is of high spatial resolution, probably with no mixed pixels (Fig 4). The maximum likelihood classification approach was adopted because of its robustness, versatility, and higher accuracy.

B) Neural Net Classification

Though maximum likelihood classification computes the reservoir area better, it fails to account for the spatial distribution of the class proportion (water, vegetation, soil) within a pixel. Neural net classification is a technique that allows mapping at the maximum likelihood classification scale (Fig 5). Several neural net classification techniques have been proposed, such as spatial dependence maximization sub pixel, neural network (NN) genetic algorithms and two-point histogram optimization with neural net classification, this pixel will be subdivided where every sub pixel can be assigned its own class (Fig 6). This will result in an image with a higher spatial resolution than the one obtained from the maximum likelihood classification approaches, but mathematical optimization, which will give a result with better efficiency than other approaches.

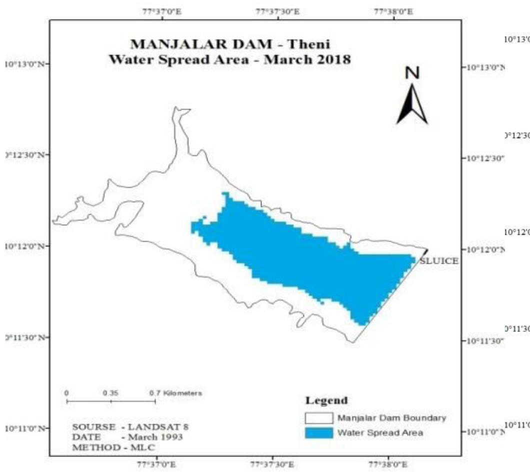


Figure 3: WSA in 1993 by MLC

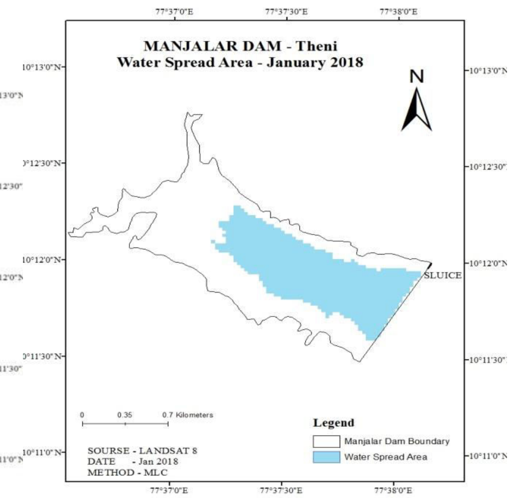
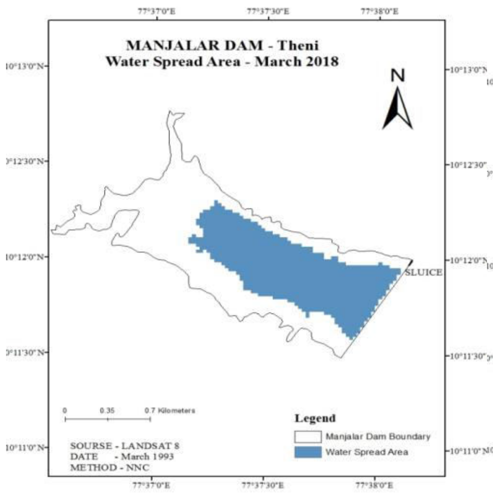


Figure 4: WSA in 2018 by MLC



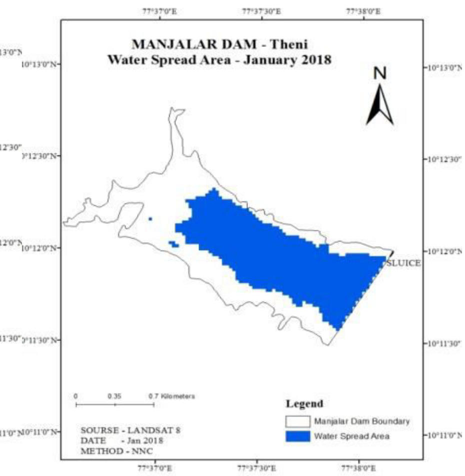


Figure 5: WSA in 1993 by NNC Figure 6: WSA in 2018 by NNC

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C)NDWI

The NDWI index is most appropriate for water body mapping. The water body has strong absorbability and low radiation in the range from visible to infrared wavelengths (Fig 7). The index uses the Green and NIR bands of remote sensing images based on the phenomenon. NDWI has range from -1 to +1 where 0 & positive values indicate the water level and negative values indicate the vegetation features. The NDWI can enhance the water information effectively in most cases (Fig 8). It is sensitive to built-up land and often results in over-estimated water bodies.

$$\textbf{NDWI} = \frac{\textbf{Green}-\textbf{NIR}}{\textbf{Green}+\textbf{NIR}}$$

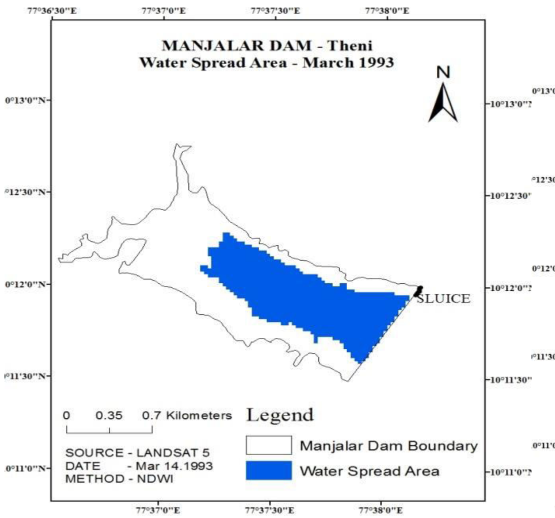

Figure 7: WSA in 1993 by NDWI

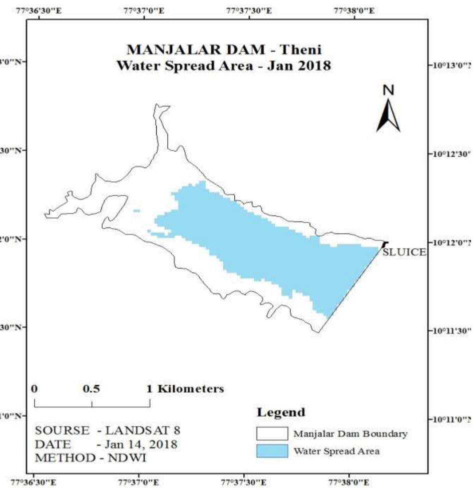

Figure 8: WSA in 2018 by NDWI

SUSPENDED SEDIMENTS IN WATER - NDSSI

NDSSI has been used by many authors to develop models of suspended sediments in rivers, lakes and many other water bodies. It has been observed that LANDSAT imagery is more sensitive to water transparency on the blue and near infrared bands (Fig 9). The index is applied by subtracting the NIR band from Blue band and dividing the result by the sum of both bands. NDSSI also range from -1 to +1 where higher values indicate the presence of more clear water and lower value indicates the presence of turbid water or land (Fig 10).

$$\textbf{NDSSI} = \frac{\textbf{Blue}-\textbf{NIR}}{\textbf{Blue + NIR}}$$

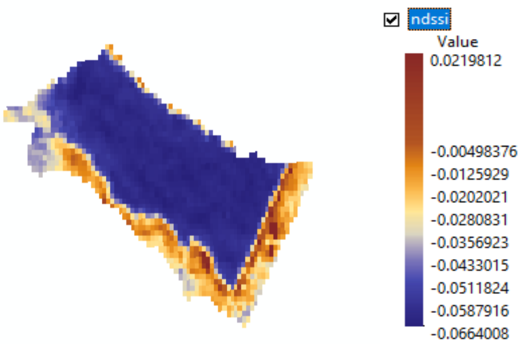

Figure 9: NDSSI in 1993

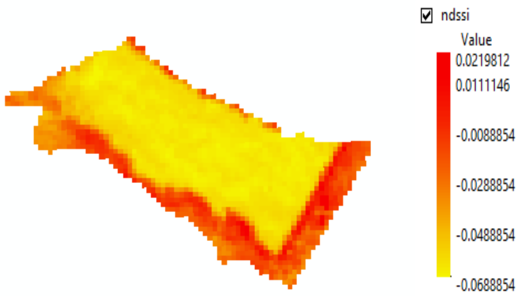

Figure 10: NDSSI in 2018

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VOLUME OF WATER

The reservoir capacity between two elevations was computed by Prismoidal formula using water spread areas obtained above:

$$V = \frac{H}{3}\left(A1 + A2 + \sqrt{A1 * A2}\right) \ldots\ldots\ldots. (1)$$

Where,

V = Volume of water, H = Difference in Elevations , A1 = Water spread area at Elevation 1, A2 = Water spread area at Elevation 2.

SEDIMETATION RATE

The sedimentation rate was calculated by using the prismoidal formula (equation 1).

Here,

V= Volume of sediment, H = Difference in elevation, A1= Area of sediment, A2 = Water surface area.

$$H = h2 - h1$$

h2 = Elevation of water surface from base, h1 = Elevation of water level

The water-spread area of the reservoir on the date of imaging was estimated by multiplying the number of pixels classified as water with the area (30 × 30 m) of a LANDSAT image pixel. For the image of January 14, 2018, the area estimated is 0.9297 sq. km and for the image of March 14, 1993, the area estimated is 0.8595 sq. km with the accuracy of 98.96% & 99.71 by maximum likelihood method. For the image of January 14, 2018, the area estimated is 1.0035 sq. km and for the image of March 14, 1993, the area estimated is 0.9207 sq. km with 99.14% & 99.93% by neural net method. For the image of January 14, 2018, the area estimated is 1.1142 sq. km and for the image of March 14, 1993, the area estimated is 0.8892 sq. km by NDWI method. The storage capacity of reservoir at January 14, 2018 is 10.628Mm^3 and March 14, 1993 is 7.02Mm^3. The sedimentation rate at January 14, 2018 is 0.460 Mm^3 and March 14, 1993 is 0.352 Mm^3.

V. DISCUSSION

The analysis of the Manjalar Dam's water spread area (WSA), reservoir storage capacity, and sedimentation rate over 25 years provides valuable insights into the reservoir's changing dynamics. These findings highlight both the potential and the challenges of managing this vital multipurpose resource.

Water Spread Area Dynamics

The comparison of WSAs between 1993 and 2018 across three different classification methods reveals notable variations. While all methods detect an increase in WSA over time, they differ in their precision and sensitivity.

1. **Maximum Likelihood Classification (MLC)** demonstrated reliable results but struggles to account for mixed pixels, leading to conservative estimates of WSA.
2. **Neural Net Classification (NNC)** emerged as the most effective technique, offering high accuracy and the ability to handle mixed pixels effectively.
3. **NDWI** proved effective in enhancing water detection but tended to overestimate WSA due to its sensitivity to built-up land and vegetation. The observed increase in WSA, particularly in 2018, could reflect variations in water management practices, seasonal rainfall patterns, or operational adjustments to maintain the reservoir's functionality. However, such an increase also raises questions about water availability trends and the reliability of historical rainfall data in the region.

The reservoir's storage capacity trends indicate a concerning issue with sedimentation. While the increase in estimated storage capacity in 2018 might appear contradictory, it may result from improved management strategies or discrepancies in hydrological modelling. Nevertheless, sedimentation remains a long-term threat that compromises the

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dam's primary purposes, including irrigation, fisheries, and water supply. The progressive sediment accumulation between 1993 and 2018 underscores the urgency of addressing sedimentation rates. The increased rate in 2018 compared to 1993 reflects accelerated deposition due to factors like deforestation, land-use changes, and increased soil erosion in the catchment area. These processes are exacerbated by the region's rugged topography and climatic extremes, which contribute to higher sediment transport during monsoon periods. The methodological comparison indicates that Neural Net Classification (NNC) is better suited for capturing WSA and sedimentation-related changes in reservoirs with mixed-pixel issues. NDWI, despite being a powerful tool for water body detection, requires additional calibration to minimize overestimation errors. The use of complementary indices like NDSSI can further refine sedimentation and water quality assessments. The results emphasize the importance of integrating advanced geospatial and hydrological analysis into reservoir management strategies. The interplay between sedimentation and water storage capacity necessitates targeted interventions to ensure the dam's long-term sustainability. Failure to address sedimentation will lead to a gradual decline in the reservoir's effectiveness, threatening agriculture, potable water supply, and regional ecology.

VI. CONCLUSION

The study of the Manjalar Dam's water spread area (WSA), storage capacity, and sedimentation dynamics over a 25-year period has revealed critical insights into the reservoir's sustainability. The results show that while all methods captured changes in WSA effectively, NNC provided more reliable and spatially detailed results by accounting for mixed pixels, whereas NDWI tended to overestimate water bodies due to its sensitivity to built-up land. The reservoir's storage capacity has been affected by sedimentation, which poses a challenge to long-term water resource management. The sedimentation rate analysis confirms that sediment accumulation is a significant concern, underscoring the need for proactive measures to manage sediment inflow and sustain the reservoir's multipurpose functionality. Neural Net Classification (NNC) is a preferred method for high-accuracy reservoir mapping, while NDWI and NDSSI provide complementary insights into water body and sediment characteristics. Increased sedimentation rates necessitate targeted interventions such as afforestation and watershed management to sustain reservoir capacity. Periodic analysis using remote sensing techniques is crucial for understanding spatiotemporal changes in reservoir dynamics and for planning sustainable water resource management strategies. By implementing the recommended measures and leveraging technological advancements, the Manjalar Dam can continue to play a pivotal role in supporting agriculture, fisheries, potable water supply, and overall socio-economic development in the region.

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