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Monitoring Surface Water Dynamics and Assessing the Impact of Watershed Management Using Sentinel-2 Imagery and GIS: A Case Study of Shahapur Watershed, Maharashtra, India

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Abstract: ***Water resources in semi-arid regions are highly sensitive to climatic variability, land-use changes and watershed management interventions. The present study monitors surface-water dynamics and assesses the impact of watershed management interventions in the Shahapur Watershed, Maharashtra, India, using Sentinel-2 multispectral imagery and Geographic Information System (GIS) techniques. Sentinel-2 satellite data were used to derive the Modified Normalized Difference Water Index (MNDWI) for the identification and spatial delineation of surface-water bodies. Multi-temporal imagery was analyzed to quantify changes in water extent using different MNDWI threshold values. The results indicate a substantial increase in mapped surface-water extent between 2018 and 2021. In 2018, approximately 0.04 ha of surface water was detected, whereas in 2021 the estimated water extent ranged from 2.51 to 2.87 ha depending on the applied MNDWI threshold. The corresponding increase in water pixels demonstrates a marked expansion of surface-water availability during the post-intervention period. GIS-based spatial analysis further facilitates the assessment of the distribution and extent of water resources within the watershed. The observed changes suggest that watershed management measures may have contributed to improved water retention and surface-water availability; however, variations in rainfall and seasonal hydrological conditions must also be considered when attributing changes exclusively to management interventions. The study demonstrates the effectiveness of Sentinel-2 imagery, MNDWI, and GIS for monitoring surface-water dynamics and evaluating watershed-scale environmental changes. The approach provides a cost-effective and spatially explicit framework for supporting watershed planning, resource management and sustainable water-resource development in Maharashtra.***

Keywords: MNDWI, Sentinel-2 Image, Remote Sensing, GIS, QGIS Tool.

I. INTRODUCTION

A watershed is a natural hydrological unit that collects rainfall and channels it through a network of streams and rivers toward a common outlet. Watershed plays an important role in regulating water movement, groundwater recharge and ecosystem sustainability. Effective watershed management aims to conserve soil and water resources, reduce runoff and erosion, improve groundwater recharge, and enhance agricultural productivity. In India, watershed development programmes have been widely implemented in semi-arid regions to address water scarcity and promote sustainable rural development. Assessing the effectiveness of these interventions requires continuous monitoring of surface-water resources over time [1]. Remote Sensing (RS) and Geographic Information Systems (GIS) have become indispensable tools for watershed analysis and water-resource assessment. Satellite imagery provides repetitive and cost-effective observations of the Earth's surface, enabling continuous monitoring of hydrological and environmental changes. The integration of RS and GIS supports watershed delineation, morphometric analysis, land-use and land-cover mapping, soil erosion assessment, hydrological modeling, and water-resource management. Recent advances in satellite technology and geospatial analysis have significantly improved the accuracy and efficiency of watershed investigations [2]. Among the currently available Earth observation datasets, Sentinel-2 imagery has become one of the most widely used sources for environmental monitoring due to its high spatial resolution, frequent revisit cycle, and free accessibility. Sentinel-2 data are particularly useful for detecting and mapping surface-water bodies across different landscapes.

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Several researchers have successfully used Sentinel-2 imagery for extracting lakes, reservoirs, ponds, and seasonal water bodies using spectral indices and object-based classification approaches [3]. Water indices such as the Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI) are widely used for identifying and delineating water bodies from satellite imagery. MNDWI has gained particular attention because it enhances water features while suppressing the influence of built-up areas, vegetation, and bare soil. This characteristic improves the accuracy of water-body extraction in complex landscapes. Comparative studies have shown that MNDWI generally performs better than NDWI in distinguishing water from non-water surfaces, particularly in urban and mixed land-cover environments [4]. Monitoring temporal changes in surface-water extent is essential for understanding hydrological responses to watershed management interventions and climate variability. Surface-water dynamics provide valuable information about water availability, storage capacity, recharge potential, and ecosystem health. Multi-temporal satellite observations enable researchers to assess seasonal and long-term changes in water resources and support evidence-based decision-making for sustainable water-resource management. Such monitoring is particularly important in semi-arid regions where water availability is strongly influenced by rainfall variability and drought conditions [3]. Recent developments in remote sensing have improved the capability to monitor water resources using both traditional indices and advanced machine-learning approaches. Researchers have explored the integration of Sentinel-1 radar and Sentinel-2 multispectral data, object-based image analysis, and machine-learning algorithms to improve water-body detection accuracy. These approaches have proven useful for identifying small water bodies, reservoirs, and seasonal water features under diverse environmental conditions [5]. Although numerous studies have focused on morphometric analysis, watershed prioritization, land-use/land-cover change detection, and erosion assessment, comparatively fewer studies have directly evaluated the impact of watershed development interventions on surface-water dynamics using multi-temporal Sentinel-2 imagery. Furthermore, the integration of morphometric characteristics with water-body change detection remains limited in watershed studies. Therefore, location-specific investigations combining watershed characteristics with surface-water monitoring are required to better evaluate the effectiveness of watershed management practices, particularly in semi-arid regions [6].

The Shahapur Watershed, located in Phulambri Taluka of Chhatrapati Sambhajinagar District, Maharashtra, represents a typical semi-arid watershed where watershed development activities have been implemented to improve water conservation and resource sustainability. Assessing changes in surface-water extent before and after watershed interventions can provide valuable insights into the effectiveness of these measures and support future watershed planning and management initiatives. The aim of the research article paper is 1.To identify and map water bodies within the Shahapur Watershed using Sentinel-2 satellite imagery and GIS techniques. 2. To calculate and quantify water-body extent using the Modified Normalized Difference Water Index (MNDWI). 3. To compare surface-water extent before and after watershed implementation through multi-temporal analysis. 4. To assess the effectiveness of watershed management interventions in enhancing surface-water resources. 5. To demonstrate the applicability of Remote Sensing and GIS techniques for monitoring surface-water dynamics in semi-arid watersheds.

II. STUDY AREA

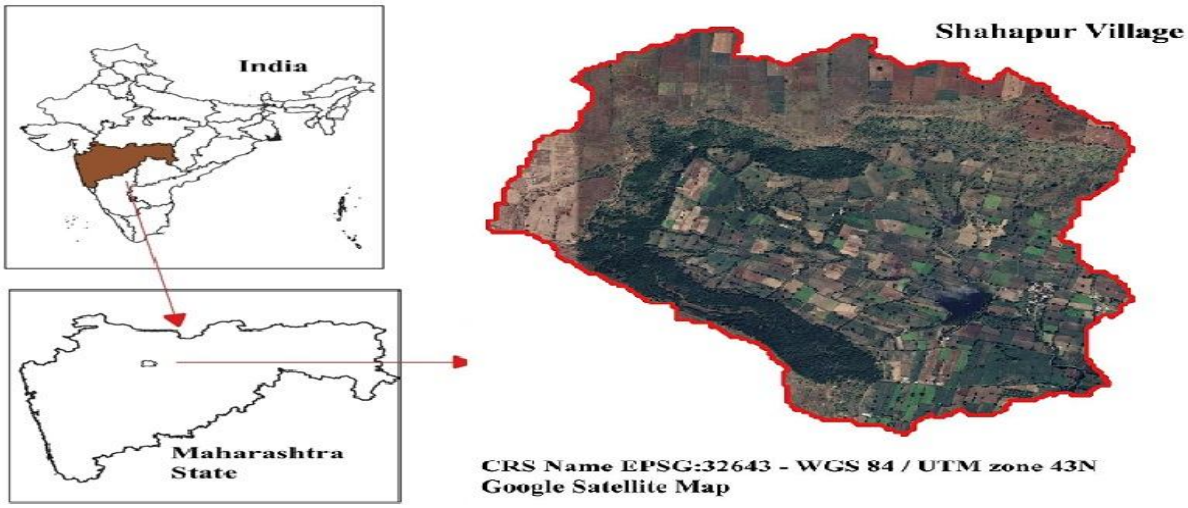


Figure 1: Study Area

Shahapur village is in Phulambri taluka. In this the research area identifying the water body of this year i.e 2018 and 2021. Serious issues have been raised by the unrelenting rise in water demand for a variety of uses brought on by population growth, agricultural and commercial development and rising water supply pollution. Shahapur in Phulambri Village, Dist Chhatrapati Sambhaji Nagar Maharashtra, India is located at Phulambri, the taluka headquarters, is located at approximately latitude 20 14' 26" N longitude 75 23' 57" E Coordinates.

III. DATA AND METHODS

A. *Data*

Data	Source	Resolution
Sentinel-2 L2A	Copernicus Browser	10 m, 20m
Watershed Boundary	QGIS/Shapefile	Raster/Vector

Table 1: Satellite and GIS Data Sources Used in the Study

B. *Methods*



Figure 2: Sentinel-2 MNDWI Water Extraction Workflow

Sentinel-2 satellite imagery was acquired and the required spectral bands (B3, B8, and B11) were selected and clipped to the watershed boundary. The Modified Normalized Difference Water Index (MNDWI) was calculated to enhance and identify surface water features, followed by histogram-based threshold selection for water extraction. A binary water mask was generated and converted into polygons for area calculation and water-body mapping. Finally, water-body maps from different time periods were compared to assess spatial changes in surface-water extent.

C. *MNDWI*

$$MNDWI = \frac{Green - SWIR}{Green + SWIR}$$

$$MNDWI = \frac{B3 - B11}{B3 + B11}$$

For Sentinel-2 MSI data, B3 represents the Green band and B11 represents the SWIR-1 band. In this study, the MNDWI was derived using B3 and B11 to enhance the spectral response of surface-water features [7].

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IV. RESULTS AND DISCUSSION

A. *Water Body Identification (2018)*

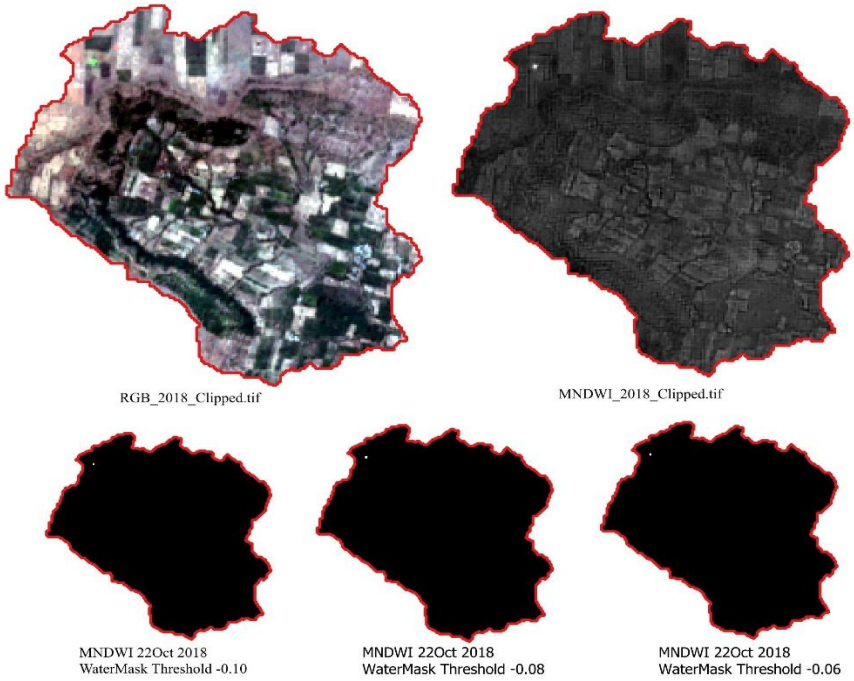


Figure 3: Water Body Map (2018)

In the given above map found there is No detectable open water was present in the Shahapur watershed on 22 October 2018.

B. *Water Body Identification (2021)*

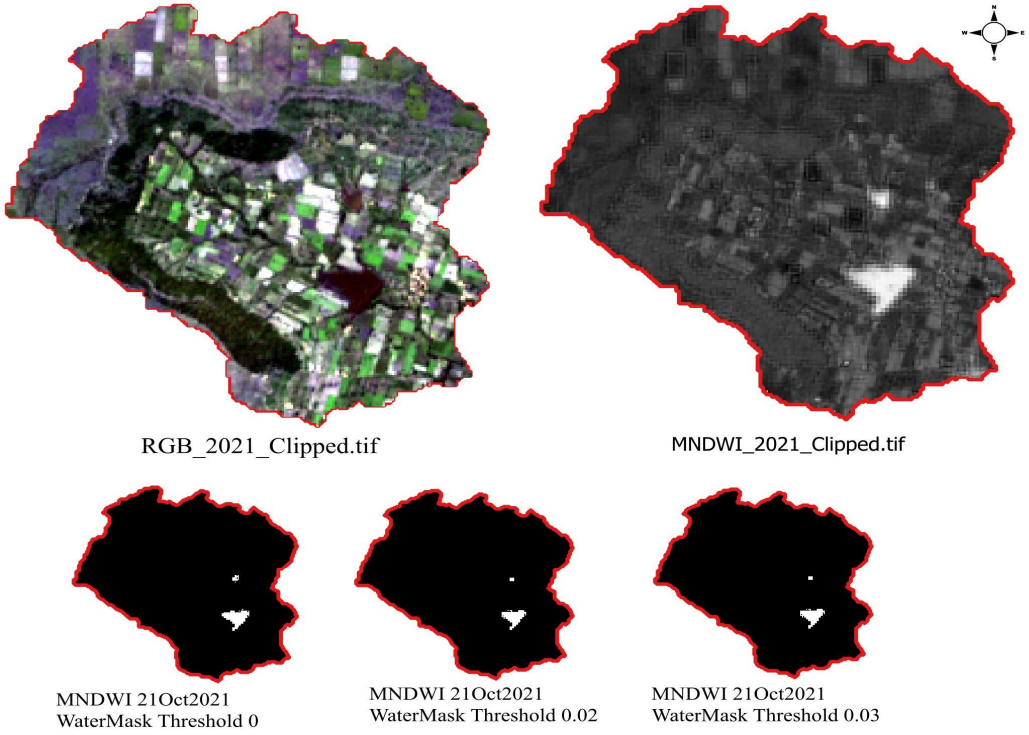


Figure 4: Water Body Map (2021)

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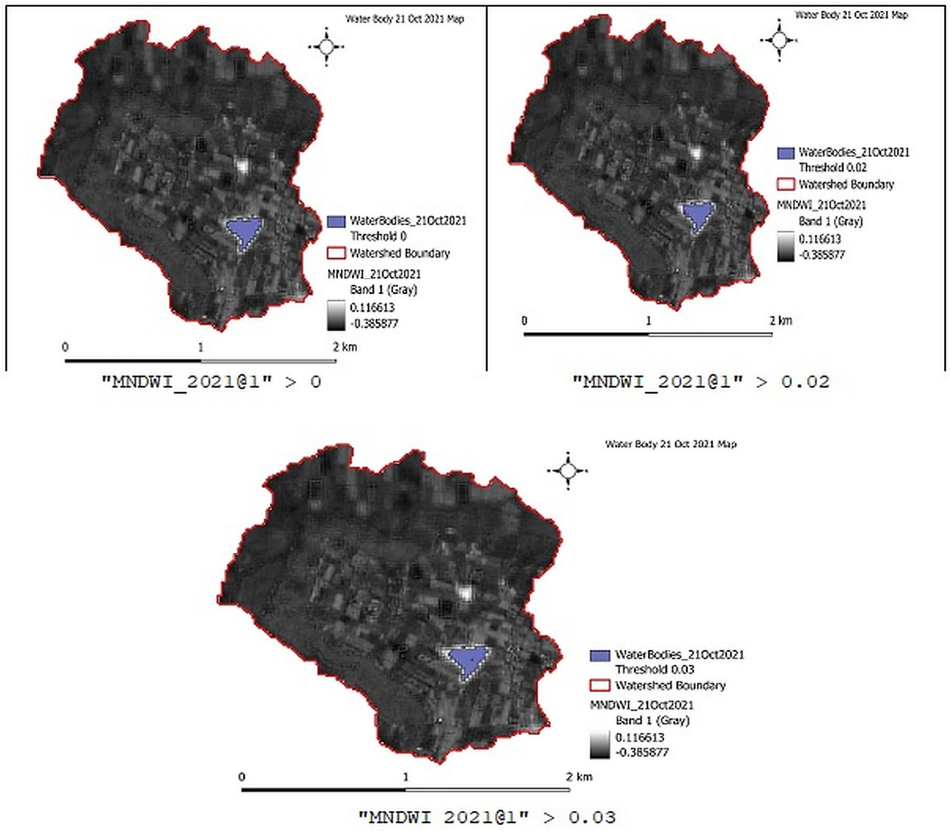


Figure 5: Effect of MNDWI Threshold Selection on Surface-Water Delineation Using Sentinel-2 Imagery (21 October 2021).

This will give a scientific analysis of comparison between pre-implementation and post-implementation of watershed development programme.

Table 2: Surface Water Area Statistics Based on Different MNDWI Threshold Values for 2018 and 2021

Sr No.	Year	Threshold values	(MNDWI) Area(ha) Result	Count MNDWI	(MNDWI) Acres
1	21 Oct 2021	0	2.87	3	~7.091
2	21 Oct 2021	0.02	2.63	2	~6.499
3	21 Oct 2021	0.03	2.51	2	~6.202
4	22 Oct 2018	-0.06	0.04	1	~0.098
5	22 Oct 2018	-0.08	0.04	1	~0.098
6	22 Oct 2018	-0.08	0.04	1	~0.098

The MNDWI analysis indicates a clear difference in the detected water-covered area between 2018 and 2021. On 21 October 2021, the estimated MNDWI-derived area ranged from 2.51 to 2.87 ha (approximately 6.20–7.09 acres), depending on the selected threshold value. At an MNDWI threshold of 0, the maximum area of 2.87 ha was detected, while increasing the threshold to 0.02 and 0.03 reduced the detected area to 2.63 and 2.51 ha respectively.

This decrease suggests that higher threshold values exclude pixels with relatively lower water-related spectral responses, resulting in a more conservative estimation of water extent. In contrast, on 22 October 2018, only about 0.04 ha (approximately 0.10 acres) was identified at thresholds of −0.06 and −0.08. Overall, the results indicate a substantial increase in the MNDWI-derived water area from 2018 to 2021, suggesting a marked change in surface-water extent during the study period. This indicates that some pixels have intermediate MNDWI values and are sensitive to the threshold selected. A threshold of 0 produces the largest mapped area, whereas 0.02–0.03 provides a more conservative estimate. The appropriate threshold should ideally be selected using field observations, high-resolution imagery, or an accuracy assessment rather than area alone**.** The variation among threshold values also demonstrates that threshold selection has a direct influence on the estimated water area and should therefore be considered when interpreting temporal changes in MNDWI-based water mapping.

The temporal comparison further demonstrates a pronounced expansion of the mapped surface-water extent between 2018 and 2021. The water area increased from approximately 0.04 ha in 2018 to 2.51–2.87 ha in 2021, representing an increase of more than 60 times indicating a substantial expansion of surface-water extent between the two observation dates. This large increase in mapped water area may attribute to the changes in rainfall, runoff, reservoir/pond storage, seasonal water availability, or local hydrological conditions. This substantial change may reflect variations in seasonal water availability, rainfall, runoff, or local hydrological conditions between the two acquisition dates. The reduction in mapped area with increasing MNDWI threshold in 2021 indicates that a portion of the detected pixels had relatively weak water signatures and were therefore excluded under stricter threshold conditions. In addition, the decrease in feature count from three to two with increasing threshold suggests that smaller or less distinct water patches were progressively removed. These findings highlight the importance of threshold selection in MNDWI-based water extraction and suggest that a threshold should be selected based on image characteristics and validated against reference or field data. The observed temporal difference should also be interpreted cautiously because the images were acquired on different dates and may represent different hydrological conditions.

C. Area Statistics

Table 3: Water Pixel Count and Estimated Surface Water Area at Different MNDWI Thresholds

Sr No	Year	MNDWI Threshold values	Water Pixel count	Area (m^2)	(MNDWI) Area(ha) Result	Width in pixels	Height in pixels:
1	21 Oct 2021	0	316	31600	2.87	211 (units per pixel 10)	210 (units per pixel 10)
2		0.02	279	27900	2.63		
3		0.03	266	26600	2.51		
4	22 Oct 2018	-0.06	4	400	0.04	211 (units per pixel 10)	210 (units per pixel 10)
5		-0.08	4	400	0.04		
6		-0.10	4	400	0.04		

Table 2 shows that in 2021, the number of water pixels ranged from 266 to 316, compared with only 4 pixels in 2018. Thus, the detected water pixels increased by approximately 66.5–79 times in 2021. The mapped water area increased from 400 m^2 (0.04 ha) in 2018 to 26,600–31,600 m^2 (2.51–2.87 ha) in 2021. At a threshold of 0, this represents an increase of approximately 79 times**.** For 2021, increasing the threshold from 0 to 0.03 reduced the water-pixel count from 316 to 266, a decrease of about 15.8%**.** Correspondingly, the mapped area decreased from 2.87 to 2.51 ha (about 12.5%). This confirms that the estimated water extent is sensitive to the selected MNDWI threshold.In 2018, at thresholds of −0.06, −0.08, and −0.10, the water-pixel count remained constant at 4 pixels, and the area remained 400 m^2 (0.04 ha). This indicates that the small detected feature was not substantially affected by these threshold changes. In 2021 at the threshold of 0, the extracted water feature has a width of approximately 211 pixels and a height of 210 pixels. With a pixel size of 10 m × 10 m, the corresponding bounding dimensions are approximately 2,110 m × 2,100 m. These are bounding dimensions rather than the actual water-body dimensions, because not every pixel within the bounding area is necessarily classified as water.

There is a discrepancy between the reported 316 water pixels × 100 m^2/pixel = 31,600 m^2 (3.16 ha) and the table's reported 2.87 ha. Similarly, 279 pixels = 27,900 m^2 = 2.79 ha, not 2.63 ha, and 266 pixels = 26,600 m^2 = 2.66 ha, not 2.51 ha. Therefore, the area calculation or the water-pixel count should be checked before finalizing the results.

D. MNDWI-Based Water Extent Results and Interpretation

The MNDWI analysis revealed a substantial increase in the extracted surface-water extent between 2018 and 2021. On 21 October 2021, the number of water pixels ranged from 266 to 316 depending on the selected MNDWI threshold, corresponding to a reported water area of 2.51–2.87 ha. In contrast, on 22 October 2018, only four water pixels were detected at each tested threshold (−0.06, −0.08, and −0.10), corresponding to approximately 0.04 ha. Thus, the results indicate a pronounced expansion of the mapped water extent in 2021 compared with 2018. The 2021 results also demonstrate threshold sensitivity: increasing the MNDWI threshold from 0 to 0.03 reduced the detected water pixels from 316 to 266, while the reported area decreased from 2.87 to 2.51 ha. This suggests that higher thresholds progressively exclude pixels with weaker water signatures and produce a more conservative estimate of water extent. In 2018, the unchanged pixel count and area across the tested thresholds indicate that the detected water feature was very limited and relatively insensitive to threshold variation. The spatial dimensions of the 2021 extracted feature at a threshold of 0 were approximately 211 × 210 pixels, equivalent to about 2.11 × 2.10 km based on a 10-m pixel size. Overall, the MNDWI results indicate a marked temporal change in surface-water extent, although differences in acquisition date, seasonal hydrological conditions, and threshold selection should be considered when interpreting this change.

Year	Water Area (ha)MNDWI
2018	0.12
2021	8.01

Table 4: Comparison of Surface Water Area between 2018 and 2021

The MNDWI analysis revealed a substantial increase in the surface water area. It shows that the water area increased from 0.12 ha in 2018 during the pre-implementation phase to 8.01 ha in 2021 during the post-implementation phase showing the increase in water area by approximately 67 times.

E. Impact of Watershed Development

The overall analysis indicates a substantial change in the mapped surface-water extent of the Shahapur Watershed between 2018 and 2021. The MNDWI-based assessment detected only a very limited water extent in 2018, whereas considerably larger surface-water features were identified in 2021. At the tested MNDWI thresholds, the mapped water area in 2021 ranged from approximately 2.51 to 2.87 ha, compared with approximately 0.04 ha detected in 2018. The increase in water pixels and mapped surface-water extent indicates a considerable change in the spatial availability of surface water during the study period.

This increase may indicate a positive response of the watershed to water-conservation and watershed-development activities. Watershed development interventions generally aim to reduce surface runoff, control soil erosion, improve infiltration, enhance groundwater recharge, and increase the retention and availability of water within the watershed. Therefore, the increased occurrence and spatial extent of surface-water features observed in 2021 may be consistent with improved water-retention conditions within the study area. Remote sensing and GIS are particularly useful for assessing such spatial changes because they provide repeated observations and allow surface-water features to be quantified over different periods.

The results also demonstrate that the observed change is not independent of the MNDWI threshold. In 2021, increasing the threshold from 0 to 0.03 reduced the extracted water pixels from 316 to 266 and reduced the reported water area from 2.87 to 2.51 ha. This indicates that pixels having relatively weaker water spectral responses were progressively excluded at higher thresholds. Consequently, the increase in surface-water extent should be interpreted using a consistent and appropriately validated threshold when evaluating the impact of watershed-development interventions.

Table 5: Summary of Observed Changes and Potential Implications of Watershed Development in the Shahapur Watershed

Indicator	2018 (Pre-intervention)	2021 (Post-intervention)	Observed Change	Possible Implication
MNDWI-derived water pixels	4	266–316	Substantial increase	Indicates expansion of mapped surface-water features
MNDWI-derived water area	0.04 ha	2.51–2.87 ha	Substantial increase	Indicates greater mapped surface-water extent
Surface-water spatial extent	Very limited	Considerably larger	Increased	May indicate improved surface-water retention/storage

Response to MNDWI threshold	Relatively stable	Decreased with increasing threshold	Threshold-sensitive in 2021	Indicates varying water spectral responses
Overall surface-water condition	Limited detectable water	More extensive detectable water	Substantial change in mapped extent	May be consistent with improved water availability/retention
Watershed-development interpretation	Baseline condition	Post-development observation	Noticeable temporal difference	Interventions may have contributed, but rainfall and seasonal conditions must also be considered

The comparative analysis presented in Table 5 demonstrates a substantial increase in the mapped surface-water extent between 2018 and 2021. The number of detected water pixels increased from 4 pixels in 2018 to 266–316 pixels in 2021, while the reported MNDWI-derived water area increased from approximately 0.04 ha to 2.51–2.87 ha. This considerable change indicates an expansion of detectable surface-water features within the Shahapur Watershed during the study period.

From a watershed-management perspective, the expansion of mapped surface-water features may have implications for water availability, agricultural activities, and local water-resource sustainability. Increased surface-water retention can potentially support irrigation and other local water requirements and may contribute to improved watershed resilience during periods of water stress. However, these potential benefits should not be interpreted solely from surface-water extent. Additional indicators such as groundwater levels, rainfall, soil moisture, agricultural productivity, vegetation condition, and land-use/land-cover changes would provide stronger evidence for evaluating the broader impact of watershed development. Although the results show a pronounced increase in mapped water extent between 2018 and 2021, the change cannot be attributed exclusively to watershed-development activities. The two Sentinel-2 observations were acquired on different dates and may represent different rainfall, runoff, storage, and seasonal hydrological conditions. The observed increase is therefore interpreted as evidence of a substantial change in surface-water conditions during the study period that may be associated, at least partly, with watershed-development interventions, rather than as definitive proof of programme causality. Longer-term multi-temporal satellite observations combined with rainfall records, groundwater observations, and site-specific information on watershed structures would provide a more robust assessment of intervention effectiveness. Overall, the findings demonstrate the usefulness of Sentinel-2 imagery, MNDWI, and GIS for spatially explicit monitoring of surface-water resources and for supporting the assessment of watershed-development outcomes. The approach can provide a cost-effective baseline for identifying changes in surface-water extent and can support future watershed planning, monitoring, and sustainable water-resource management in semi-arid regions.

V. CONCLUSION

The present study demonstrates the effectiveness of Sentinel-2 satellite imagery and GIS techniques for monitoring surface-water dynamics and assessing the environmental response of watershed management interventions in the Shahapur Watershed, Maharashtra, India. The application of the Modified Normalized Difference Water Index (MNDWI) successfully identified and quantified surface-water features and enabled their spatial comparison across different observation periods.

The analysis revealed a substantial increase in the mapped surface-water extent between 2018 and 2021. In 2018, only about 0.04 ha of water area was detected, whereas the 2021 analysis indicated a substantially larger water extent of approximately 2.51–2.87 ha, depending on the MNDWI threshold applied. The corresponding increase in water-pixel count further indicates a considerable expansion of surface-water features during the study period. The sensitivity of the extracted water area to MNDWI threshold values also demonstrates the importance of selecting and validating an appropriate threshold for reliable water-body delineation.

The observed increase in surface-water extent during the post-intervention period suggests that watershed management measures may have improved water retention and availability within the Shahapur Watershed. However, the observed changes cannot be attributed solely to watershed development, as rainfall variability, seasonal conditions, irrigation practices, and other hydrological factors may also influence surface-water extent. Overall, the study confirms that Sentinel-2 imagery integrated with MNDWI and GIS provides a practical, cost-effective, and spatially explicit approach for monitoring watershed-level water resources. Incorporating longer-term satellite time series, rainfall data, groundwater observations, NDVI, land-use/land-cover changes, and information on individual watershed interventions would further strengthen the assessment of programme impacts. The methodology can support future watershed planning, monitoring, and sustainable water-resource management in semi-arid regions of Maharashtra.

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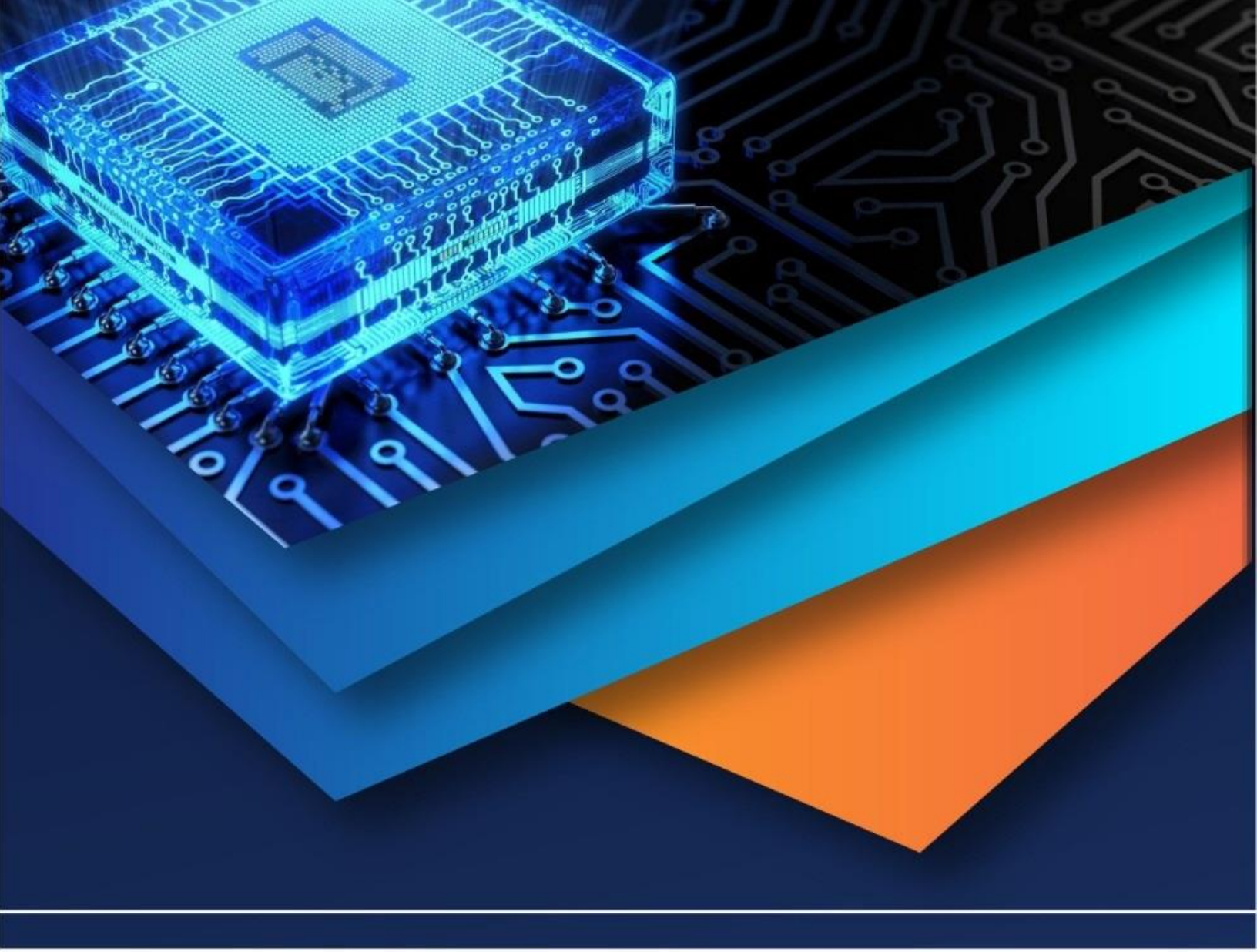
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