Mapping and Change Detection of Water Bodies in the Godavari Delta using Geospatial Technology

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Abstract*: *Geospatial technology has been used to map the water bodies of the Godavari Delta in 2005, 2009, 2014, and 2019. The Normalized Water Difference Index (NDWI) and the Modified Normalized Water Difference Index (MNDWI) have been used to map water bodies in the summer months (April / May). The Godavari Delta has been divided into two regions. One is the upland, and the other is the coastal region. Comparing NDWI and MNDWI with the APSAC assessment of water bodies in 2019 (May) indicated that the MNDWI is close to the APSAC assessment in the Godavari delta. The MNDWI displayed that from the year 2005 to 2019, water bodies have been increased from 0.96% to 3.2% in the upland region and from 11.42% to 20.91% in the coastal region. The improved water bodies are compared with the local precipitation within the delta, and found that there has been no impact of rainfall on the increase of water bodies in the delta. This boom in the water bodies changes due to the construction of artificial drinking water ponds and conversion of paddy fields into aquaculture in the upland and coastal areas regions. Further investigations are required to identify freshwater and saline water bodies in the Godavari Delta.

***Keywords*: NDWI, MNDWI, Godavari Delta, GIS**

(Article history: Received: March 2022 and accepted May 2022)

I. Introduction

Surface waters are the principal supply for domestic use, irrigation, and industrial development. The coastal and deltaic region supports numerous land-based activities but intensive activities may degrade the coastal ecosystems. Therefore, water bodies monitoring is one of the key factors of sustainable development of any region. Spatial technology is one of the prominent tools to map and monitor water bodies in any given region. The fragile geomorphologic unique landform of Godavari delta, Andhra Pradesh has been chosen for detailed mapping of water bodies and its changes to find any environmental threat to this region. Remote sensing and GIS applications widely used for spatial and temporal change detection of water bodies and Land use [6, 8, 11, 12]. Remote sensing and GIS tools are used to find spatial-temporal variations of water bodies at different spatial scales with real-time monitoring. In the present paper, the Normalized Difference Water Index (NDWI) developed by [9] and Modified Normalized Difference Water Index (MNDWI) by [15] have been used for the water body mapping and change detection in the Godavari delta. The NDWI cannot efficaciously suppress the sign from built-up land so that more advantageous or extracted water capabilities with built-up land noise. Therefore, index development is essential, and the NDWI is changed right here to treat this problem as MNDWI [15].

A. NDWI and MNDWI

The details of NDWI is as follows [9]:

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

Where, green is band 2, and near Infrared (NIR) is band 4 and details of Landsat data bands are given in Table I. The NDWI is designed to (1) maximize reflectance of water by using green wavelengths; (2) minimize the low reflectance of NIR by water features; and (3) take advantage of the high reflectance of NIR by vegetation and soil features. As a result, water features have positive values and thus are enhanced, while vegetation and soil usually have zero or negative values and therefore are suppressed [9].

TABLE I. Details of satellite data used Landsat 5 TM

Bands	Wavelength (micrometers)	Resolution (m)
Band 1 - Blue	0.45-0.52	30
Band 2 - Green	0.52-0.60	30
Band 3 - Red	0.63-0.69	30
Band 4 - Near Infrared (NIR)	0.76-0.90	30
Band 5 - Near Infrared (NIR)	1.55-1.75	30
Band 6 - Thermal	10.40-12.50	120
Band 7 - Mid-Infrared	2.08-2.35	30

However, the application of the NDWI in water regions with a built-up land background does not achieve its goal as expected. The extracted water information in those regions mixed with built-up land noise. It means that many built-up land features also have positive values in the NDWI image. Therefore, MNDWI provides improved results and details are given by [15].

The modified NDWI (MNDWI) is as follows:

$$MNDWI = \frac{Green - SWIR1}{Green + SWIR1}$$

Where, green (OLI band 3), and SWIR1 is a Short-Wave infrared band (OLI band 6) are used in MNDWI and other details about Landsat 8 OLI are given in Table II. The computation of the MNDWI will produce three results: (1) water will have greater positive values than in the NDWI as it absorbs more SWIR1 light than NIR light; (2) built-up land will have negative values as mentioned above; and (3) soil and vegetation will still have negative values as soil reflects SWIR1 light more than NIR light and the vegetation reflects SWIR1 light still more than green light.

TABLE II. DETAILS OF SATELLITE DATA USED LANDSAT 8 OLI

Bands	Wavelength (micrometers)	Resolution (m)
Band 1 - Coastal aerosol	0.43-0.45	30
Band 2 - Blue	0.45-0.51	30
Band 3 - Green	0.53-0.59	30
Band 4 - Red	0.64-0.67	30
Band 5 - Near Infrared (NIR)	0.85-0.88	30
Band 6 - SWIR 1	1.57-1.65	30
Band 7 - SWIR 2	2.11-2.29	30
Band 8 - Panchromatic	0.50-0.68	15
Band 9 - Cirrus	1.36-1.38	30
Band 10 - Thermal Infrared (TIRS) 1	10.6-11.19	100
Band 11 - Thermal Infrared (TIRS) 2	11.50-12.51	100

Consequently, compared with the NDWI, the contrast between water and built-up land of the MNDWI will be considerably enlarged owing to increasing values of water feature and decreasing values of built-up land from positive down to negative. The greater enhancement of water in the MNDWI-image will result in more accurate extraction of open water features as the built-up land, soil and vegetation all have negative values and thus are notably suppressed and even removed [15]. The Normalized Water Difference Index (NDWI) and the Modified Normalized Water Difference Index (MNDWI) are the most effective indicators for monitoring and mapping surface waters to identify changes and also warn against the use of moisture content to extract soil moisture from water bodies [2, 4, 5, 14, 15]. The results of this study would be helpful in various environmental protection measures initiated in the delta and coastal regions.

II. STUDY AREA

The Godavari River is the second-longest river in India, draining approximately 10% of India's total geographical area. Its supply is in Triambakeshwar, Nashik, and Maharashtra. It flows the East for 1,465 km length, draining the states of Maharashtra, Telangana, Andhra Pradesh, Chhattisgarh and Odisha. The Godavari delta is blanketed with coastal alluvium and intensive paddy, coconuts gardens and an intensive irrigation canal network. The river ultimately flows into the Bay of Bengal via river branches. These branches are Gowthami, Vasishta and Vainateyam Rivers in the Godavari delta, Andhra Pradesh. Geographically, the Godavari Delta is located in the south-eastern path of India, with latitudes 16° 20' to 16° 50'N to longitude 81° 20 to '82° 30'E and with the geographical area of 4485 km². The study area boundary covered in SOI Topo-sheet bearing the numbers (65H6, 7, 9, 10, 11, 11, 13, 14 & 15, 65L1, 2, 3, 5, & 6) on a 1:50000 scale. The study area has been divided into two regions. The upland (1860 km²) and the coastal (2625 km²) region. The coastal region has been delineated based on Mandals/Blocks boundaries that have the Bay of Bengal as the boundary. The location map of the study areas is shown in Figure1.

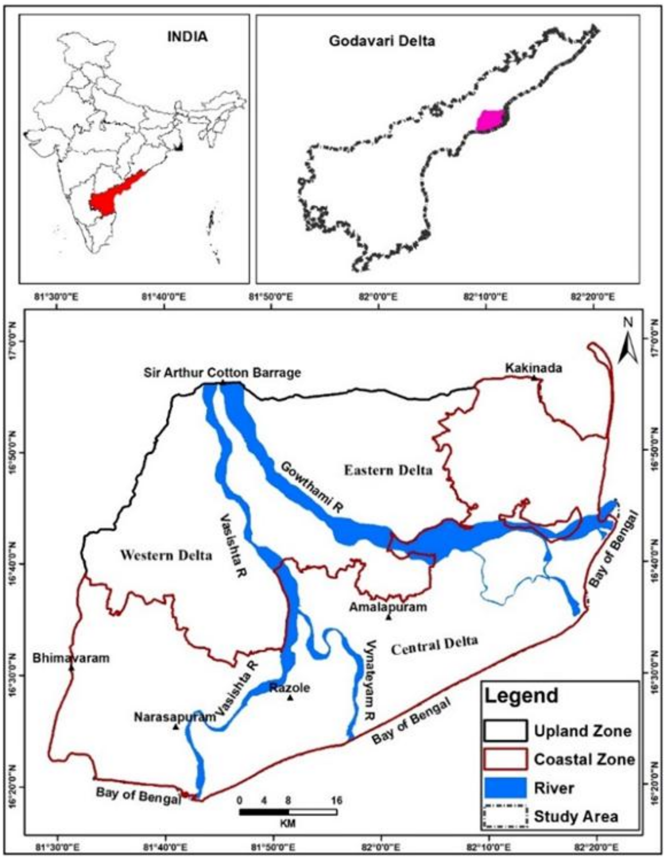

Fig. 1. Location map of the Godavari Delta, Andhra Pradesh

III. METHODOLOGY

The NDWI (Normalized Difference Water Index) is defined by [9] to enhance the water-related features of the landscapes. This index uses the near-infrared (NIR) and the short wave infra-red (SWIR) bands. MNDWI (Modification of Normalized Difference Water Index) is also a water-index defined by [15]. It uses the green (GREEN) and the short wave infrared (SWIR1) bands. For NDWI, water had the same pixel value as forests and grasslands. MNDWI enhanced water bodies (rivers, oxbows, ponds) but all the other land cover classes did not seem to be discriminated. However, NDWI is unable to extract the surface in shallow water and not able to distinguish between urban and water objects. To improve the accuracy of the results, both indexes (NDWI and modified NDWI, or MNDWI) have used in the present study. The satellite data used for the water body mapping NDWI, MNDWI are given in Table III.

TABLE III. DETAILS OF SATELLITE DATA USED AND NDWI/MNDWI FORMULA

S No	*Satellite/ sensor/period*	*Index*	*Formula*
1	Landasat-5 TM (2005 & 2009)	NDWI	(Green(B2)-NIR(B4))/ (Green(B2)+NIR(B4))
2	Landsat-8 OLI (2014 & 2019)	NDWI	(Green(B3)-NIR(B5))/ (Green(B3)+NIR(B5))
3	Landasat-5 TM (2005 & 2009)	MNDWI	(Green(B2)-SWIR1(B5))/ (Green(B2)+SWIR1(B5))
4	Landsat-8 OLI (2014 & 2019)	MNDWI	(Green(B3)-SWIR1(B6))/ (Green(B3)+SWIR1(B6))

The Landsat 5 TM and 8 OLI images have three advantages. They are having good spatial, temporal, and spectral resolutions. These three advantages of these images are beneficial for managing natural resources in the coastal and marine areas. The most popular Landsat 8 data applications are coastline identification, mangrove forest identification, coral reef and sea grass ecosystem identification, water depth information extraction, and water quality information acquisition including chlorophyll. However, the extraction result of water index-based methods (NDWI and MNDWI) may not be ideal for snow areas. For example, pixels with ice/snow or clouds can also show a high value, sometimes even higher than water pixels when using these indices. The main reason is, it usages only partial spectral information, and have not taken the background information into consideration. In other words, a simple band combination like NDWI or AWEI cannot differentiate pixels containing liquid water from pixels containing water in another form, such as ice/snow or cloud. One way to solve this problem is to use information from all bands and the statistical differences between water and background [10]. In general, remote sensing data in coastal and marine applications can be divided into two parts depending on the characteristics of the electromagnetic waves and on the water column. As a result, the water function has a positive value and is upgraded. Vegetation and soil characteristics generally point to zero or negative values and are suppressed. The NDWI and MNDWI have been used to map the water bodies in the Godavari delta and identified the mandals showing the highest increase in water bodies in the Godavari delta. Further, these mandals are compared with local rainfall to assess the impact of rainfall on these increased water bodies.

A. Topographical maps Pre-Processing

The study area covered in Survey of India (SOI) toposheets (65H6, 7, 9, 10, 11, 11, 13, 14 & 15, 65L1, 2, 3, 5, & 6) on 1:50000 scale. These maps were imported in Arc GIS 9.1 software. Subsequently theses maps were geo-referenced using (Geographic Coordinate System) GCS 1984. Geo-referenced maps were mosaiced for delineating base map of Godavari delta. Further processing was done in Arc-GIS 9.1 as suggested by [17].

B. Image pre-processing

In this study, Landsat 5 TM (2005 & 2009) & Landsat 8 OLI (2014 & 2019) imageries with a spatial resolution of 30 x 30 m in the optical bands was downloaded from the United States Geological Survey (USGS) Earth Explorer website (www.earthexplorer.usgs.gov). The detailed methodology for preparing index mapping is given by [16] and followed in the present investigations.

IV. RESULT AND DISCUSSION

The Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI) maps had been created for the summer month (May) of the years 2005, 2009 with Landsat 5 (30 m resolution) and for the years 2014 and 2019 with Landsat 8 (30 m resolution). These water-bodies maps developed using NDWI and MNDWI for the years 2005, 2009, 2014 and 2019 are shown in Figures 2 (a) & (b), respectively.

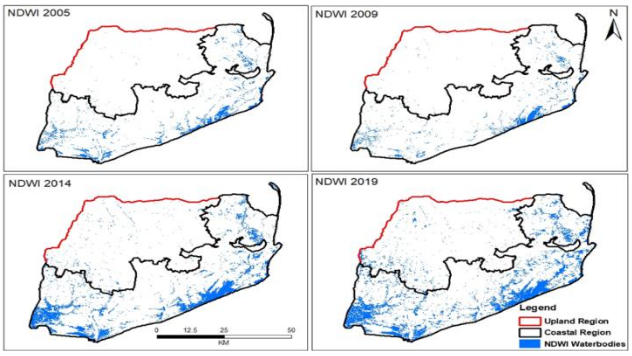

Fig 2. (a). Mapping of water bodies in the Godavari delta using NDWI for the years 2005, 2009, 2014 & 2019

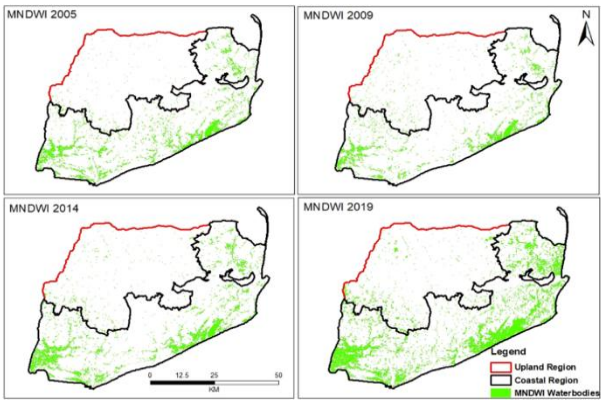

Fig 2. (b). Mapping of water bodies in the Godavari delta using MNDWI for the years 2005, 2009, 2014 & 2019

The extracted information of water bodies further classified into upland and coastal regions separately in the Godavari delta and details are given in Table IV.

TABLE IV. WATER BODIES CHANGES COMPUTED USING NDWI AND MNDWI FOR THE YEARS 2005 TO 2019

Years	NDWI		MNDWI	
	Water bodies Area (Sq.km)		Water bodies Area (Sq.km)	
	Upland region	Coastal region	Upland region	Coastal region
2005	4	183	18	300
2009	3	135	24	229
2014	25	373	28	310
2019	49	472	54	549

The result of the NDWI and MNDWI reveals that the water bodies of the Godavari delta have been increased in both upland and coastal regions. The NDWI indicated that water-bodies area in the year 2005 was 4 sq. km (0.22%) in upland and 183 sq. km (6.9%) in the coastal region and increased to 49 sq. km (2.63%) in upland and 472 sq. km (17.98%) in the coastal region in the year 2019. The MNDWI indicated that water-bodies areas in 2005 was 18 sq. km (0.96%) in upland and 300 sq. km (11.42%) in the coastal region and increased to 54 sq. km (2.90%) in upland and 549 sq. km (20.91%) in the coastal region for the year 2019. Further, the APSAC [1] water-bodies assessment and MNDWI assessment for the year 2019 was found to be 605 and 603 sq. km respectively in the Godavari Delta. The MNDWI performs best in delineating water from land, with a threshold value close to 0.2, making the water pixels and land pixels most separable [6] and also validated with 2019 APSAC information [1]. Further analysis has been carried out on NDWI and MNDWI water body mapping for the years 2005, 2009, 2014 and 2019.

The Mandal boundaries (Administrative boundaries) have been superimposed on the Godavari delta water-bodies maps and identified the highest changes in water bodies in mandals which are located in upland and coastal regions. Three mandals are showing the highest increase of water bodies in the upland region and details are given in Table V.

TABLE V. HIGHEST WATER BODIES IN UPLAND REGION (SQ.KM) IN THE GODAVARI DELTA

Mandals	NDWI				MNDWI			
	2005	2009	2014	2019	2005	2009	2014	2019
Poduru	1.1	0.8	3.8	6.3	4.5	4.7	4.8	8.2
Attili	0.7	0.3	2.2	6.9	4.0	3.0	2.9	7.4
Penumatra	0.4	0.2	4.2	9.0	1.5	2.6	5.0	10.7

These three upland mandals are Poduru, Attili and Penumantra. The increase in these mandals from the year 2005 to 2019 was found using MNDWI are 3.74, 3.37, and 9.21 sq. km respectively. Similarly, eight mandals in the coastal region show the highest increase in water bodies. They are Bhimavaram, I. Polavaram, Mogalthur and Narasapuram in the Western Delta, Sakhinetipalle, Uppalaguptam, and Katrenikona in the Central Delta and Thallarevu in the Eastern delta over the past 15 years. The increase of water bodies in these mandals are 14, 18.74, 7.93, 22.88, 16.68, 11.05, 29.74 and 43.7 sq. km, respectively. The details of water bodies computed using the NDWI and MNDWI for these eight mandals are given in Table VI.

TABLE VI. HIGHEST WATER BODIES IN COASTAL REGION (SQ.KM) IN THE GODAVARI DELTA

Mandals	NDWI				MNDWI			
	2005	2009	2014	2019	2005	2009	2014	2019
Bhimavaram	13.4	9.7	38.4	43.3	28.5	24.2	34.0	47.2
I. Polavaram	6.4	4.2	8.6	12.3	9.1	6.6	9.0	17.0
Mogalthur	16.1	11.7	44.7	47.2	28.4	24.8	38.1	51.2
Narasapuram	23.1	10.5	39.6	45.0	29.9	19.2	33.0	46.6
Sakhinetipalle	9.9	5.8	20.0	26.3	14.3	8.0	13.7	25.3
Uppalaguptham	18.4	18.4	39.7	53.1	22.5	24.1	31.6	52.3
Katrenokona	40.5	38.9	70.1	86.7	51.5	47.1	51.0	95.2
Thallarevu	21.8	16.8	39.0	46.6	32.0	26.5	29.7	69.0

The mapping water bodies in each Mandal in Tables V and VI are in good agreement with the Andhra Pradesh Space Application Centre [1] aquaculture region maps for the year 2019 (May). Therefore, it would be concluded that the change in water bodies from the year 2005 to 2019 is mainly due to the increase of aquaculture practices and new drinking water ponds in the Godavari delta. However, the water-bodies area is very less in the year 2009 as compared to other years. This is mainly due to extreme climatic conditions, aquaculture diseases, export regulations, crop holidays, etc.

A. Impact of rainfall on water bodies in the Godavari Delta

The analysis of rainfall and its impact on the surface water-bodies of above upland and coastal region mandals in the Godavari delta has been carryout. The cumulative rainfall from December to April has been considered to compare rainfall and water bodies in the years 2005, 2009, 2014 and 2019. The comparisons of rainfall and water bodies in three mandals in upland regions are shown in Figure 3.

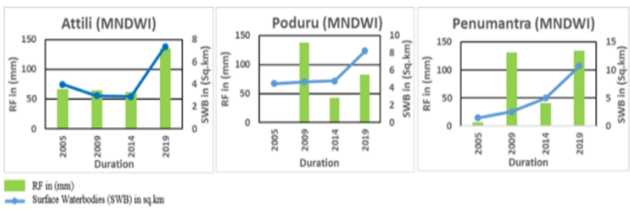

Fig. 3. Comparison of rainfall with surface water bodies in various mandals (Upland region) in the Godavari delta

It is found that there is no direct impact of rainfall on surface water bodies in these three mandals. Similarly, the comparison between rainfall and water bodies in eight mandals in the coastal region of the Godavari delta is shown in Figure 4.

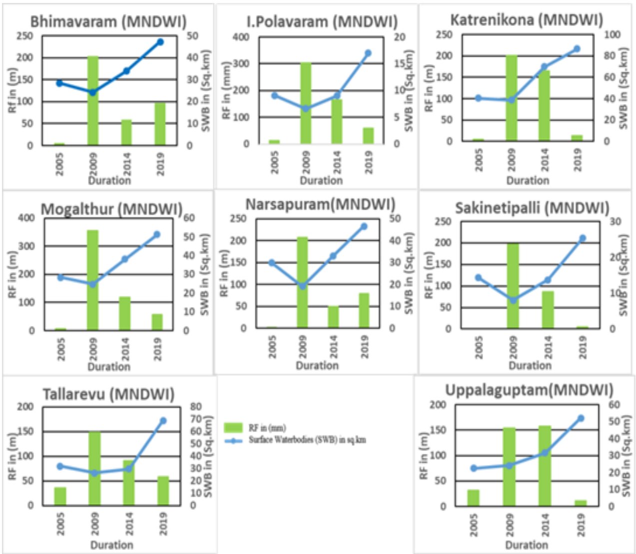

Fig. 4. Comparison of rainfall with surface water bodies in various mandals (Coastal region) in the Godavari delta

It was found from Figure 4, that there is a significant increase in the surface water bodies in all eight mandals but the rainfall pattern is not supporting the water bodies' trend. In order to avoid the rainfall impact on water bodies only summer months satellite data has been considered for water bodies mapping (May) in the Godavari delta. This suggests that aquaculture is growing in these upland and coastal regions. However, it is observed that freshwater aquaculture (Canal water) is dominant in the upland regions. In coastal regions, the saline water aquaculture is expanded due to the advantage of existing creek water/ backwater.

V. Conclusion

The NDWI and MNDWI were used to map water bodies for the summer month (May) for the years 2005, 2009, 2014 and 2019 using satellite data (Landsat 5 and 8) and identified the changes of water bodies in the Godavari delta. The increase in water bodies from 2005 to 2019 in the Godavari delta using NDWI and MNDWI is 4.17 to 11.61% and 7.1 to 13.57%, respectively. The MNDWI assessment is compared with the APSAC assessment for the year 2019 and found that they are 603 and 605 sq km respectively. The comparison of local precipitation and water bodies in the various mandals in the Godavari delta showed that rainfall did not increase water bodies. Therefore the increase in water bodies in the Godavari delta was primarily due to increased aquaculture activities over a period time. Further research is needed to distinguish between salt and freshwater areas of coastal and delta areas.

Acknowledgment

The authors are thankful to the National Hydrology Project and Ministry of Jal Shakti, Govt. of India for funding the project.

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