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Water spread mapping using remote sensing and geographic information system (GIS) techniques for Samastipur, Bihar

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Abstract
Samastipur district of Bihar is facing the problem of floods every year. Most areas are submerged in the water for 4 to 5 months in the monsoon season. Water spread mapping is used to find out the total water submerged area of Samastipur during pre-monsoon and post-monsoon seasons to calculate the differences in the study area for future planning of policy making. This study has mapped water spread areas in Samastipur, situated in Bihar, from 2018 to 2021 (pre-monsoon and post-monsoon) using Landsat-8 OLI satellite imagery. Water spread areas were evaluated based on the band rationing indices, namely Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), Water Ratio Index (WRI). The results suggested a significant increasing trend in the water surface area of Samastipur for the period 2018 to 2021.The maximum differenced values of NDVI, NDWI, MNDWI and WRI were 165.42 km^2, 220.6386 km^2, 391.8456 km^2 and 90.9117 km^2 respectively in 2021. The minimum differenced values of NDVI, NDWI, MNDWI and WRI were 15.954 km^2, 10.0179 km^2, 17.208 km^2 and 14.0526 km^2 respectively in 2018. The general trend of indices value is WRI<NDVI<NDWI<MNDWI for every year between 2018 to 2021.

Keywords: Water spread, NDVI, NDWI, MNDWI, WRI, remote sensing, GIS

Introduction
Water is an essential component for the survival of living and non-living beings. Rivers, groundwater bodies, lakes, ponds, wells and small depressions are the main sources of water bodies on earth. Considering surface water bodies, it is necessary to have knowledge of their extent in any watershed. Their expansion and shrinkage in water spread area effects directly the productivity of agricultural land resulting from flood and drought. Therefore, mapping of water spread area of the watershed is imperative for agricultural land. Therefore, mapping floodplains using satellite image data has increased importance and significance in recent decades (Chen *et al.* 2020) [2]. Scientists have been using different satellite information changes in spatial, ghastly, and temporal characteristics to produce thematic maps of land utilizing cover or maps with a noteworthy accentuation on water bodies. Different remote sensing methods have their own merits and demerits. The role of remote sensing is important in surface water mapping. This technique has important capabilities to identify and map surface water features. In past years, many contributions were made toward distinguishing and identifying water bodies from remote sensing techniques. However, it remains a challenge because of the complexity of the investigation study area's landscape, selected remotely sensed information, and classification method. This method additionally has imperatives identified with size and shadows. The threshold value determines whether a pixel belongs to a water body or not. Chen *et al.* (2020) [2] suggested a modification in NDWI. They called it MNDWI, removing the built-up area, soil, and vegetation to extract water bodies. Thus, from the research mentioned above work, it is clear that water indices are broadly used to identify water bodies because of simplicity, low cost, and predominant execution-dependent specific noises. Some of the commonly used water indices are Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI), Automated Water Extraction Index (AWEI), Water Ratio Index (WRI).

This study provides knowledge's of certain frequencies of flood hazard and identify areas susceptible to living, agricultural practices etc. in the floodplain. Keeping these facts in mind, the following objectives were constructed.

Material and Methods

Study area: The study area Samastipur is situated in the Northern part of Bihar. Samastipur district is a part of the Darbhanga Division. Samastipur district of Bihar is spread over an area of 2624.82 sq. km. The district is situated between 25°30'00'' to 26°05'00'' latitudes North & 85°37'50'' to 86°23'30'' longitude East. The district headquarter is located at Samastipur, which is situated on the bank of the Budhi Gandak River. Fig. 1 showed the location map of the study area.

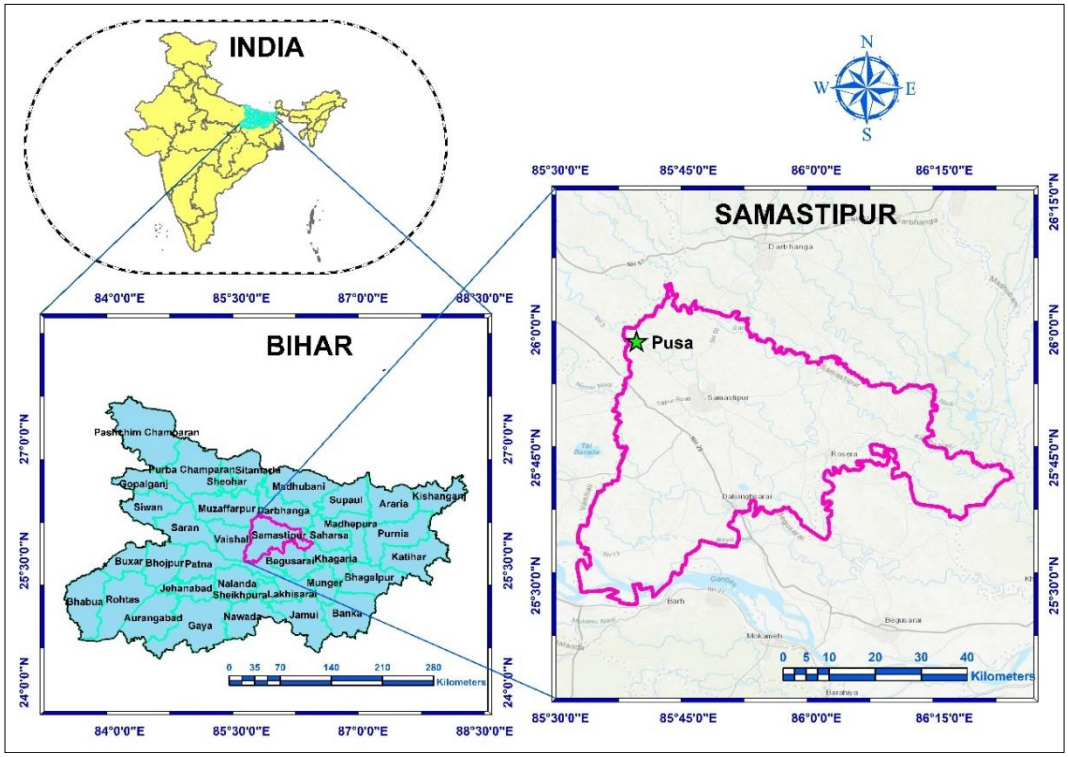

Fig 1: Location map of the study area

Data

For analyzing Landsat imagery, "ArcGIS 10.7.1" software has been used to analyze satellite imagery. ArcGIS software can be used for water body extraction from non-water bodies to calculate land cover area, built-up area, and temperature changes (Nielsen *et al.* 2017) [4]. Physical measurement is essential to verify mapping and check the accuracy of the study area obtained from Landsat imagery analysis (Table-1).

Table 1: Cloud-free Landsat-8 imageries used in this study

Satellite	Year	Pre-monsoon	Post-monsoon
Landsat-8	2018	15 -04-2018	25-11-2018
	2019	02-04-2019	12-11-2019
	2020	04-04-2020	14-11-2020
	2021	07-04-2021	01-11-2021

Normalized difference vegetation index (NDVI)

It is a very commonly used vegetation index in land use land cover image analysis, which highlights the areas with vegetation. NDVI (Jensen, 2000) has been used widely in the literature to separate vegetation from non-vegetated areas. NDVI formula is as follows:

$$NDVI = \frac{NIR-RED}{NIR+RED} \quad (1)$$

$$NDVI = \frac{B5-B4}{B5+B4} \quad (2)$$

Normalized difference water index (NDWI)

The Normalized Difference Water Index is a spectral index which has been created to highlight the presence of open water features in remotely sensed data. It is also used as a metric for covering out black bodies-water and shadows. The main aim was to use NDWI to classify water bodies. The NDWI formula is.

$$NDWI = \frac{GREEN-NIR}{GREEN+NIR} \quad (3)$$

$$NDWI = \frac{B3-B5}{B3+B5} \quad (4)$$

Modified normalized difference water index (MNDWI)

The signal noise coming from the land covers in built-up areas can not be suppressed efficiently by NDWI which is the lacking criteria of this index. Xu (2006) [2] found out that water areas with stronger absorbability and built-up areas have higher radiation in the SWIR band than NIR band. Based on his study, the MNDWI emerged and its formula is:

$$MNDWI = \frac{GREEN-MIR}{GREEN+MIR} \quad (5)$$

$$MNDWI = \frac{B3-B7}{B3+B7} \quad (6)$$

Water ratio index (WRI)

The water ratio index is defined as the ratio between the total spectral reflectance in the red and green bands to that of the near infrared (NIR) and middle infrared (MIR) bands. The equation for WRI is shown below. WRI for Landsat-8 satellite is given below,

$$WRI = \frac{NIR-RED}{NIR+RED} \quad (7)$$

$$WRI = \frac{B5-B4}{B5+B4} \quad (8)$$

Results and Discussion

The present study was undertaken to determine the spatiotemporal changes in the Samastipur district of Bihar. The overall water features extraction using satellite images and multiband water indices was first determined using ArcGIS 10.7.1.

In this section, results obtained from the spatiotemporal water spread maps of the study area have been discussed.

Comparison among band ratios for accurate water spread mapping for Samastipur

Pre-Monsoon

Table 2 showed the water spread using NDVI, NDWI, MNDWI and WRI for Samastipur during pre-monsoon season. The average water spread area for the pre-monsoon season was 20.5368 km^2 with SD 6.1386 km^2 by NDVI, 34.2029 km^2 with SD 6.9031 km^2 by NDWI, 41.9501 km^2 with SD 9.7846 km^2 by MNDWI method, and 25.4918 km^2 with SD 6.3154 km^2 by WRI. Water spread mapping using NDVI, NDWI, MNDWI and WRI are shown in Fig. 2-5, respectively.

Table 2: Water spread area using NDVI, NDWI, MNDWI and WRI for Samastipur during pre-monsoon season

Year	NDVI (km^2)	NDWI (km^2)	MNDWI (km^2)	WRI (km^2)
2018	20.1780	32.1345	35.2719	24.1020
2019	20.9619	24.6294	33.8832	17.2305
2020	29.1762	36.3555	40.2516	25.6923
2021	11.8314	43.6923	58.3938	34.9425

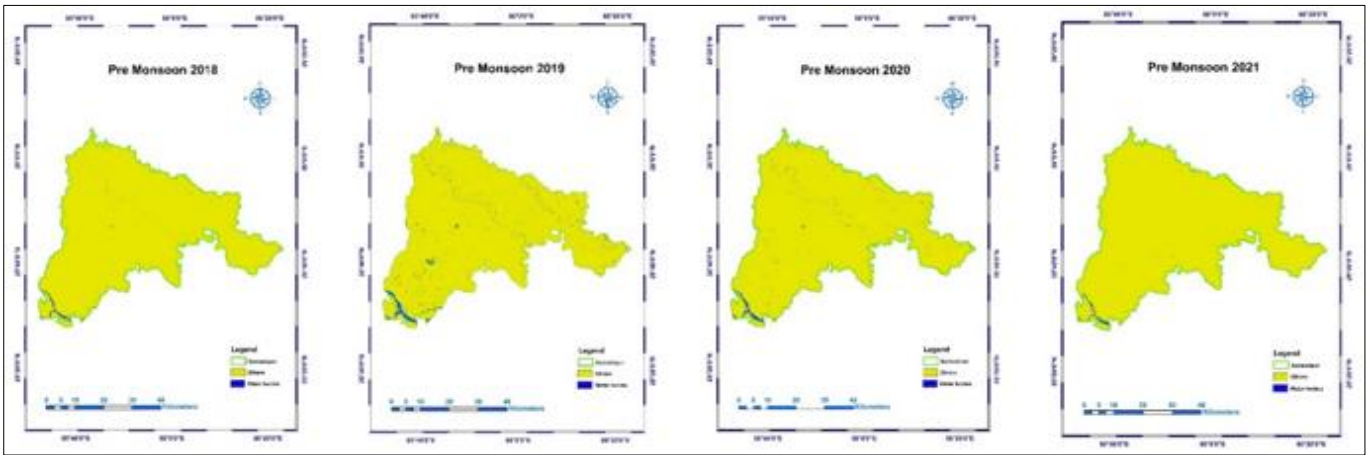

Fig 2: Water spread area mapping using NDVI during pre-monsoon for Samastipur during 2018-2021

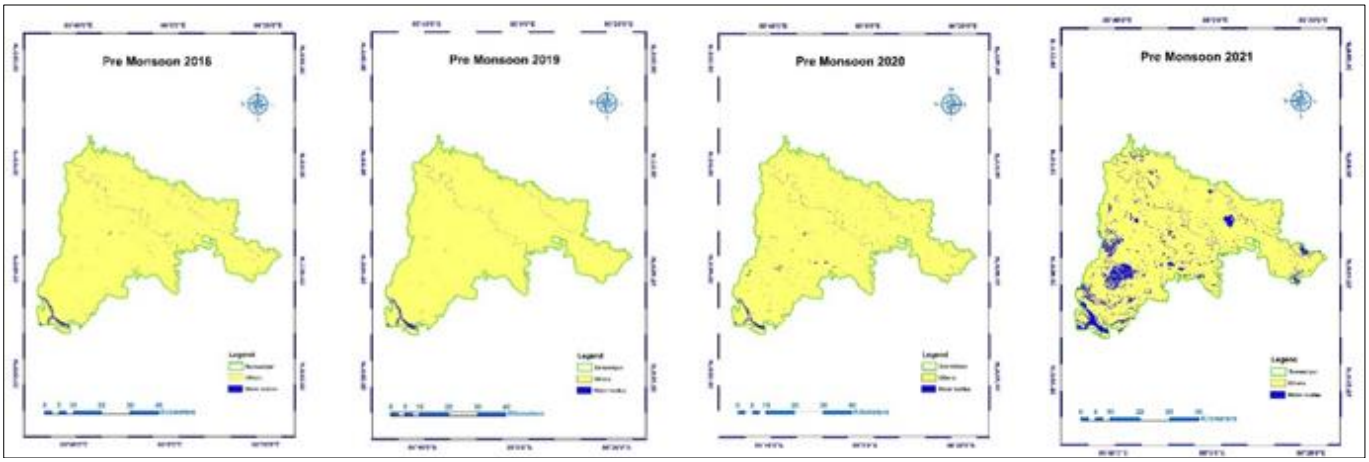

Fig 3: Water spread area mapping using NDWI during pre-monsoon for Samastipur during 2018-2021

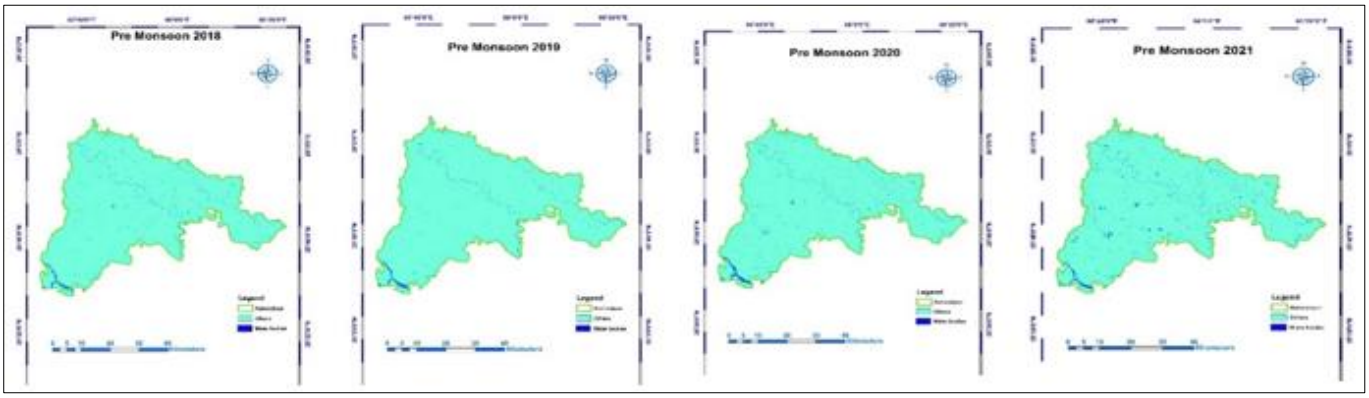

Fig 4: Water spread area mapping using MNDWI during pre-monsoon for Samastipur during 2018-2021

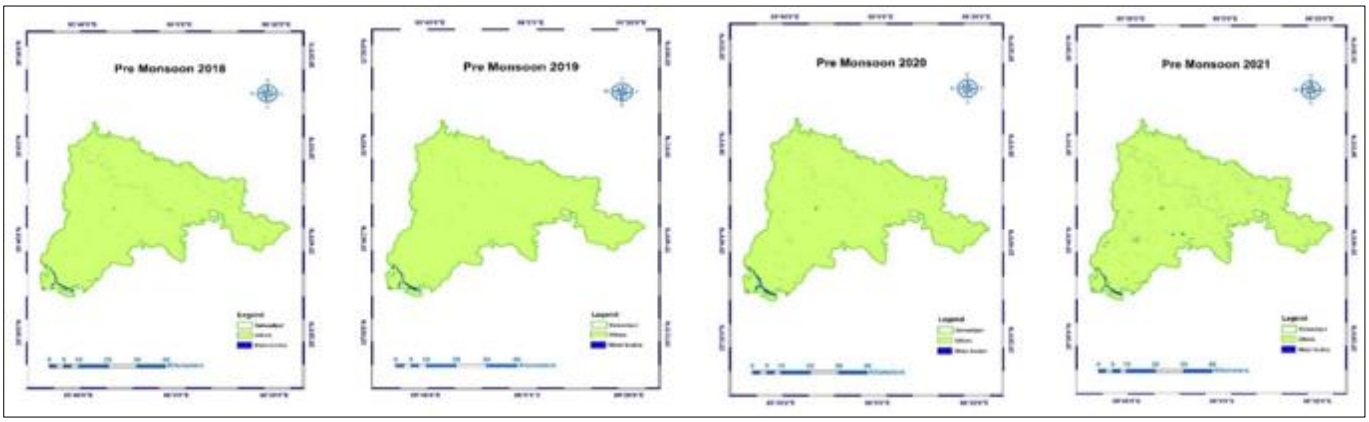

Fig 5: Water spread area mapping using WRI during pre-monsoon for Samastipur during 2018-2021

Post-Monsoon

Table 3 showed water spread area using NDVI, NDWI, MNDWI and WRI for Samastipur during post-monsoon season The average water spread area for the post monsoon season was 103.752 km^2 with SD 75.574 km^2 by NDVI method, 124.896 km^2 with SD 85.813 km^2 by NDWI, 191.464 km^2 with SD 163.100 km^2 by MNDWI, and 124.066 km^2 with SD 77.54 km^2 by WRI method respectively. The water spread is represented by a map for NDVI, NDWI, MNDWI and WRI is shown in Fig. 6-9, respectively.

Table 3: Water spread area using NDVI, NDWI, MNDWI and WRI for Samastipur during post-monsoon season

Year	NDVI(Km^2)	NDWI(Km^2)	MNDWI(Km^2)	WRI($Km^{2)}$
2018	36.132	42.1524	52.4799	38.1546
2019	55.0998	68.6223	109.6992	44.2746
2020	94.2624	124.461	195.4026	77.5287
2021	177.2514	264.3309	450.2394	125.8542

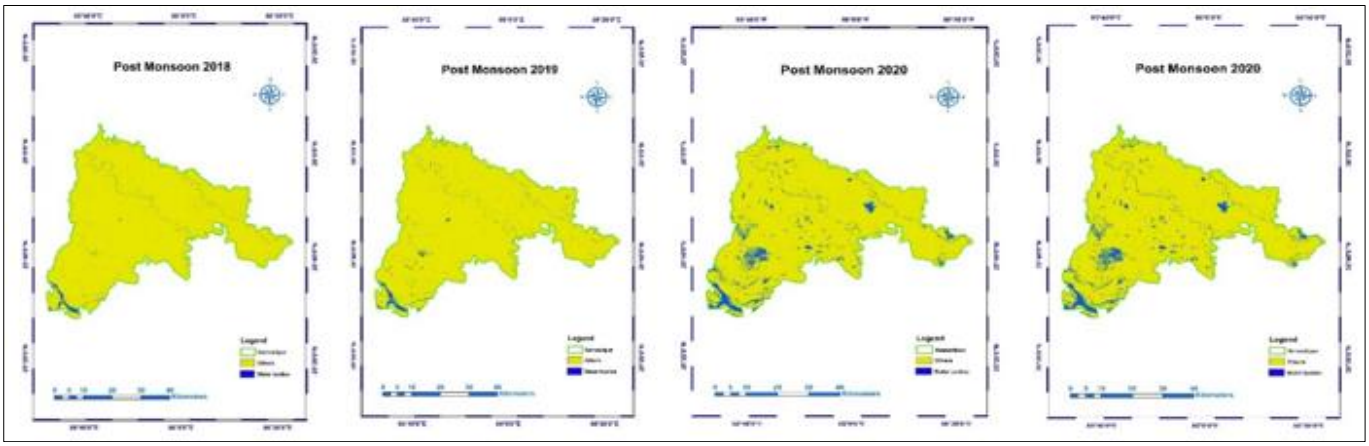

Fig 6: Water spread area mapping using NDVI during Post-monsoon for Samastipur during 2018-2021

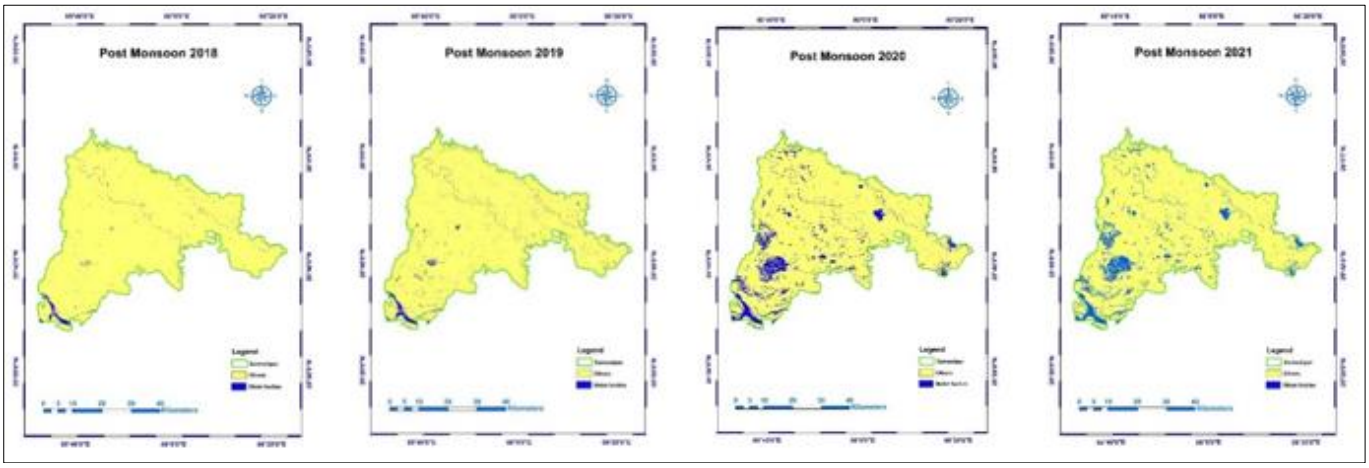

Fig 7: Water spread area mapping using NDWI during Post-monsoon for Samastipur during 2018-2021

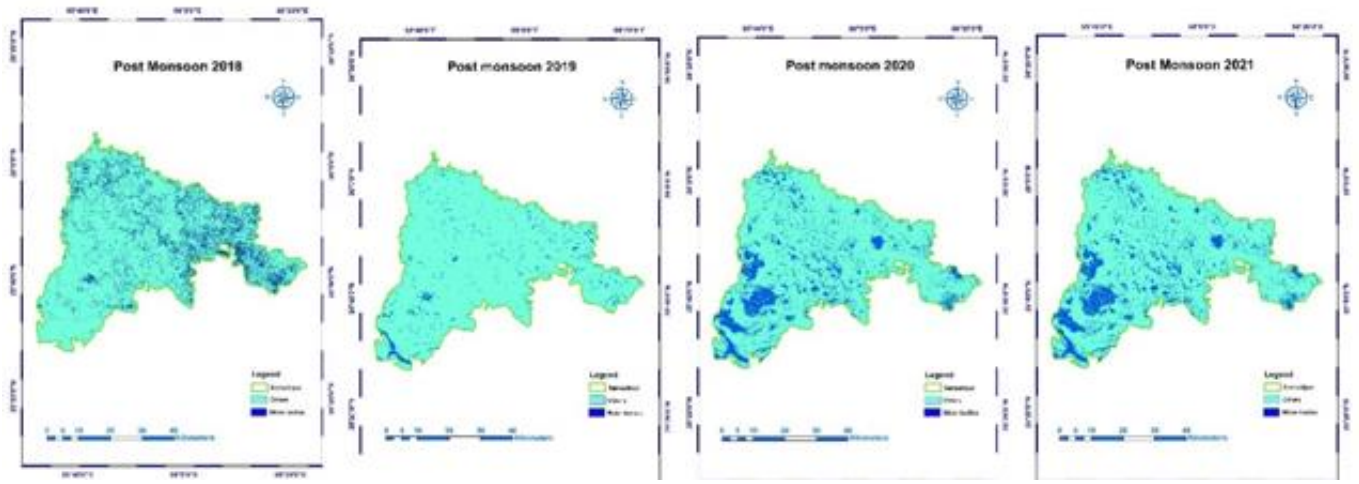

Fig 8: Water spread area mapping using MNDWI during Post-monsoon for Samastipur during 2018-2021

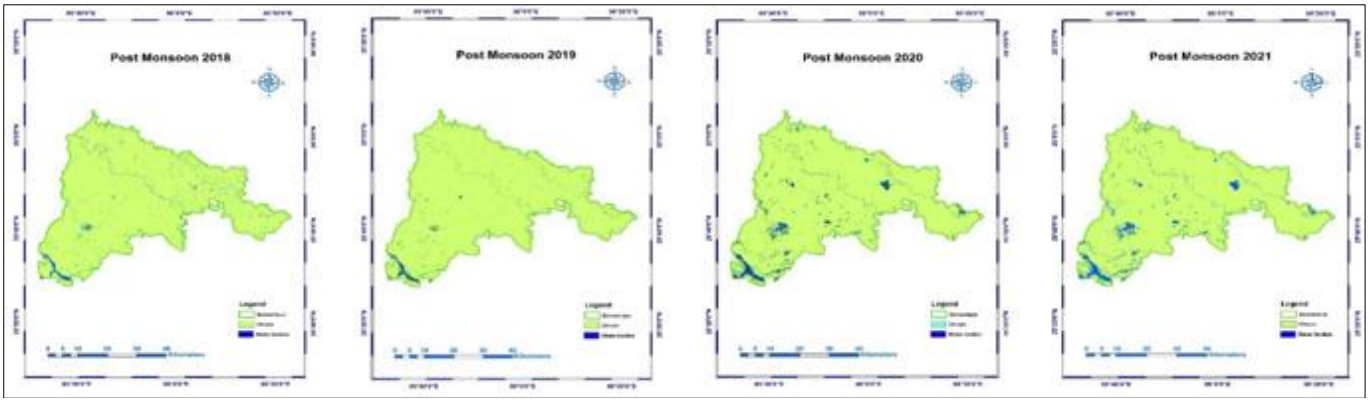

Fig 9: Water spread area mapping using WRI during Post-monsoon for Samastipur during 2018-2021

Table 4 showed the water spread area differences during pre-monsoon and post-monsoon. The maximum water spread area by NDVI, NDWI, MNDWI and WRI were 165.42 km^2, 220.638 km2, 391.845 km^2, 391.845 km^2 and 90.912 km^2 during the year 2021. The minimum spread area was obtained during the year 2018 for all methods. The average differenced water spread area is 70.1495 km^2 with SD 66.6735 km^2 by NDVI, 90.6887 km^2 with SD 92.3434 km^2 by NDWI, 160.0052 km^2 with SD 164.5725 km^2 by MNDWI method, and 45.9612 km^2 with SD 33.8185 km^2 by WRI method.

Table 4: Water spread area differences during pre-monsoon and post-monsoon

Year	NDVI(km^2)	NDWI(km^2)	MNDWI(km^2)	WRI(km^2)
2018	15.954	10.018	17.208	14.052
2019	34.138	43.993	75.816	27.044
2020	65.086	88.105	155.151	51.836
2021	165.420	220.638	391.845	90.912

In the context of these findings, our results are suitable for calculating the spreading water area over the given study area. Furthermore, based on the results, it is also found that the water spread over Samastipur was more in the year 2021, which indicates the heavy rainfall and hence occurrence of flood in the particular year. Thus, these parameters are useful in evaluation of water spread area.

Conclusions

In this study, the spatiotemporal analysis of the water spread area of the Samastipur district of Bihar has been done using Landsat 8 imageries and band rationing (multiband water indices) techniques. The period of study was from 2018 to 2021. ArcGIS 10.7.1 has been used for mapping the water spread area. NDVI, NDWI, MNDWI, and WRI were the band ratios used to extract the studied area's water spread mapping.

- The average water spread area for the pre-monsoon season was 20.5368 km^2 with SD 6.1386 km^2 by NDVI, 34.2029 km^2 with SD 6.9031 km^2 by NDWI, 41.9501 km^2 with SD 9.7846 km^2 by MNDWI method, and 25.4918 km^2 with SD 6.3154 km^2 by WRI.
- The average water spread area for the post monsoon season was 103.752 km^2 with SD 75.574 km^2 by NDVI method, 124.896 km^2 with SD 85.813 km^2 by NDWI, 191.464 km^2 with SD 163.100 km^2 by MNDWI, and 124.066 km^2 with SD 77.54 km^2 by WRI method respectively.
- The percentage water spread area change occurred from 2018 to 2021 via NDVI, NDWI, MNDWI, and WRI were 90.35546%, 95.45959%, 95.60847%, and 84.54258% respectively.
- It was observed that a significant increasing trend over the year in the water surface area of Samastipur has taken place.

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