ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

Vol 6, Issue 5, May 2021

Application of Sentinel 2 Data for Extraction of Flood Inundation Along Ganga River, Bihar

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Abstract--- **Flood inundation mapping is one of the most important and essential step to understand the intensity of the natural disaster. The Sentinel 2 satellite providing fine spatial resolution and frequent revisit capabilities makes it potential for accessing imageries and monitor the changes in flood water. The spectral water index methods: Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI) were used to delineate the inundated areas. Threshold values were used to separate the water from the non water surface. The error matrix table and calculation of the Producer Accuracy (PA), User Accuracy (UA) and Overall Accuracy (OA) identified the amount of falsely classified pixels into another feature. For the post flood event, MNDWI 1 yield better results with the highest Kappa and Overall Accuracy (OA) while the pre flood period NDWI had the better accuracy. The optimum thresholds for all the different indices differ in every index for both pre and post flood occurrences.**

Keywords--- **Water Index, NDWI, MNDWI, Flood Inundation, Sentinel 2, natural disaster, Accuracy Assessment**

I. INTRODUCTION

According to National Geographic Floods "A flood occurs when water inundates land that's normally dry, which may happen during a multitude of the way". River floods represent the most frequent and expensive natural disaster affecting most of the countries (Zwenzner, H., et al. 2009). Floods are among the foremost devastating natural cosmopolitan resulting in significant economic and social damages than the other phenomenon (DMSG, 2001). Remote sensing and GIS play an important role in mapping, monitoring and providing spatial database for all flood related studies (Rastogi, A.K, et al. 2018). Remote sensing technology due to its repetitive and synoptic coverage, cost- effectiveness can be used for monitoring the river shifting, proximity of river course to the embankments and channel aggradation by the planners for taking measures required for channel stabilization and strengthening of embankments (Bhatt, C. M, et al. 2010). Flood inundation maps are very essential for municipal planning, emergency action plans, flood insurance rates, and ecological studies (Goodell, C., et al. 2006). GIS data base plays a major role in delineating flood and overcoming its related issues in the affected area (Rai, Praveen Kumar, et al. 2014). To maximize the reflection of water, the NDWI index is designed such that the Green wavelength is minimized by the low reflectance of NIRs by water features (Xu, et al. 2006). The Sentinel– 2 mission that was launched newly provides multispectral images with fine spatial resolution. Its free access and frequent revisit capabilities makes the dataset potential and significant for the mapping of regional water bodies (Du Yun et.al 2016). The modified MNDWI proved to be a significant role in extracting flooded water areas. Due to the differences in the reflectance pattern of water and moist soil it can also delineate the open water body and also moist soil from non – water features (Ho L. T. K., et al. 2010).

II. STUDY AREA AND DATASETS

The study area for the paper is located in the Central Bihar along the River Ganga. The research area will cover the major flood affected zone of the state i.e the Northern part of Bihar. The state of Bihar is extended from *24°20'10" N to 27°31'15" N latitude and 83°19'50" E to 88°17'40" E longitude.* The River Ganga which flow from west to east through the middle of the Bihar plain divides the state two unequal halves (North Bihar and South Bihar). The Ganges flows west–east and, along with its tributaries, regularly floods parts of the Bihar plain. The Mahananda, Gandak, Kosi, Bagmati, Kamala, Balan, Budhi Gandak are the major rivers of North Bihar. While Gandak and Koshi,

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ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

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originates in the Nepalese Himalayas, and the Bagmati, originating in the Kathmandu Valley are the main northern tributaries of the River.

For this purpose, the water indices were calculated using the temporal data of Sentinel 2B L2A data that was obtained from the ESA Copernicus. For pre flood period, March, April and May 2019 data is used while for post flood period; imageries from the month of October 2019 were used. While TRMM (Tropical Rainfall Measuring Mission) the rainfall maps during the inundation period are generated using TRMM data.

Figure 1: Study Area map

III. METHODOLOGY

Calculation of water indices i.e. Normalized Difference Water Index (NDWI), Modified Normalized Difference Water Index (MNDWI) was the major task in this study. The software used for the study is SNAP, QGIS, ArcGIS, and Google Earth Engine. Since the Sentinel's Level 2A data is already atmospherically corrected thus, no further pre processing was to be carried out. The satellite provides data in different resolution of 10m and 20m, the calculations are accessed with 20m resolution and the bands with 10m resolution are resampled to 20m resolution.

NDWI = (B03 - B08) / (B03 + B08) McFeeters (1996).

MNDWI 1 = (B03 - B11) / (B03 + B11)
MNDWI 2 = (B03 - B12) / (B03 + B12) } Gao in 1996

For the evaluation of the produced maps accuracy assessment is conducted. To assess the performance of the different methods and the results of the produced NDWI, MNDWI 1 and MNDWI 2 images and the final water bodies' maps were analyzed. To obtain the reference data for accuracy assessment, validation points were generated over the imagery and they were labelled as water and non water with the help of Google Earth Engine. The threshold values used are the certain values of each of the water indices to detect water. On the comparison of the water map with reference data, the outcomes are resulted as four types of pixels: TP (True positive) = The number of correctly extracted water pixels; FN (False negative) = The number of undetected water pixels; FP (False positive) = The number of incorrectly extracted water pixels; and TN (True negative) = The number of correctly rejected non-water pixels. Based on above four outcomes, the overall accuracy (OA) and kappa coefficient (kappa) were used to assess the accuracy of the produced maps with different water indices. It is performed by the following equations:

Producer's Accuracy = TP/TP + FN

User's Accuracy = TP/TP + FP

Overall Accuracy = TP + TN/T

Kappa Coefficient $= T(TP+TN) - \Sigma / T^2 - \Sigma$

Where Σ is the chance accuracy represented by (TP + FP)(TP + FN) + (FN + TN)(FP + TN), and T is the total number of pixels in accuracy assessment. The correct predictions are represented by Producer Accuracy, User Accuracy and Overall Accuracy i.e. PA, UA, and OA respectively. The optimum thresholds were chosen based upon the highest OA and Kappa resulted

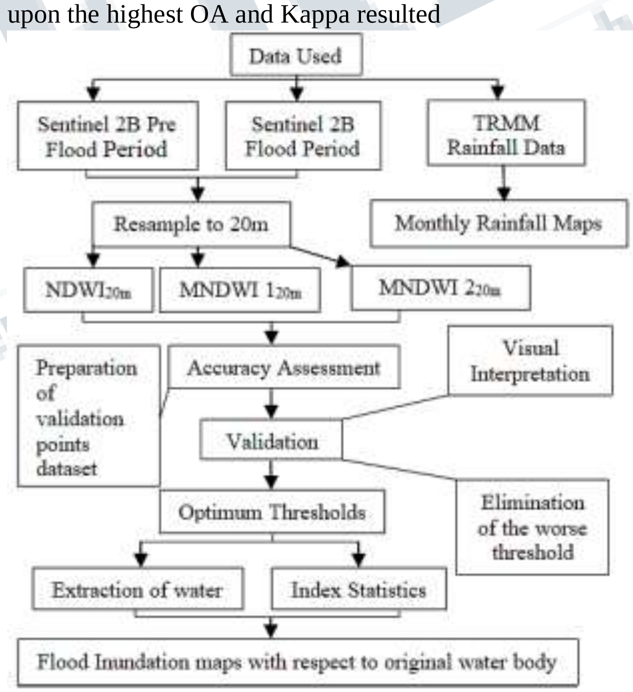

Figure 2: Methodology Flowchart

IV. RESULTS AND DISCUSSIONS

A. Comparison between different water indices

Figure 3 represents the water indices for both pre and post flood. During the pre time the $NDWI_{20m}$ index for Scene A evaluated a lowest value of -0.74 and a highest of 0.42. While for Scene B, $NDWI_{20m}$ ranged between -0.58 to

ISSN (Online) 2456-1290

International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)

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0.70. MNDWI 1_{20m} index for Scene A resulted -0.74 as the highest of 0.63 and lowest of -0.55. The lowest values for all the indices in Scene B were similar. MNDWI 2_{20m} for Scene B resulted highest with 0.75.

For the post flood period it was observed that Scene A $NDWI_{20m}$ yield between -0.76 to 0.73. MNDWI 1_{20m} showed results from -0.60 to 0.96. MNDWI 2_{20m} has values between -0.57 to 0.99. For Scene B, $NDWI_{20m}$ ranged from -0.84 to 0.79. MNDWI 1_{20m} resulted between -0.69 to 0.98. While MNDWI 2_{20m} for Scene B resulted between -0.69 to 0.98.

It is observed that MNDWI 1_{20m} had dissimilarity in the highest values obtained for both Scenes of pre and post flood period. In both MNDWI 1_{20m} and MNDWI 2_{20m} indices spatial details of water bodies were represented more clearly by resulting greater values for the post flood period.

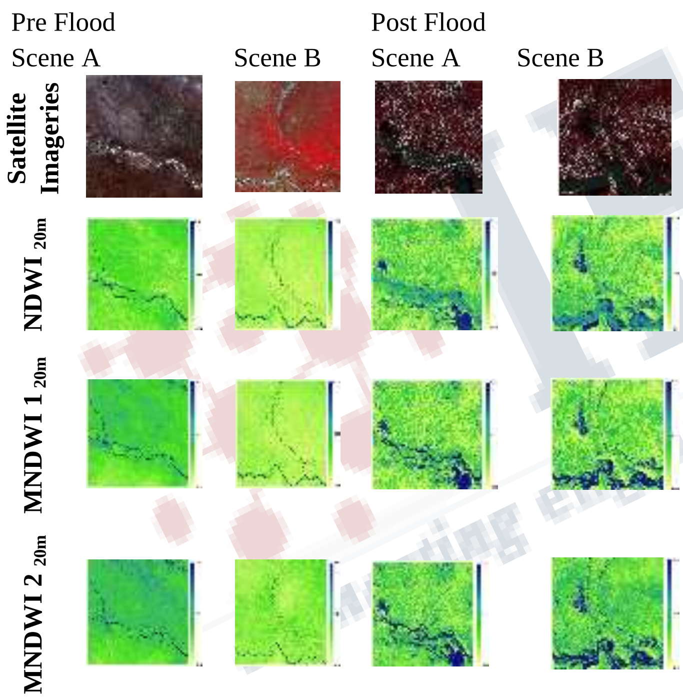

Figure 3: Comparison between the water indices – pre and post flood period

B. Accuracy Assessment

Table 1 represents the performance of all the water indices for the extraction of flood water is assessed for the entire study area and a comparison has been conducted to evaluate the performance by each of the methods. Using the three proposed methods, the results for delineating water bodies shows the highest OA of 0.93 by $NDWI_{20m}$ in the pre period and for MNDWI 1_{20m} it resulted to be 0.91 for the post flood period. MNDWI 2_{20m} shows the lowest OA in both the scenario. While it is observed that for the highest OA also has the highest Kappa of 0.96 in $NDWI_{20m}$ and 0.95 in MNDWI 1_{20m} for the two periods. The OA was increased in the flood time with a maximum of 0.91 along with the Kappa of 0.95 that was resulted by MNDWI 1_{20m}. **Figure 4** shows the graphical representation of the assessment.

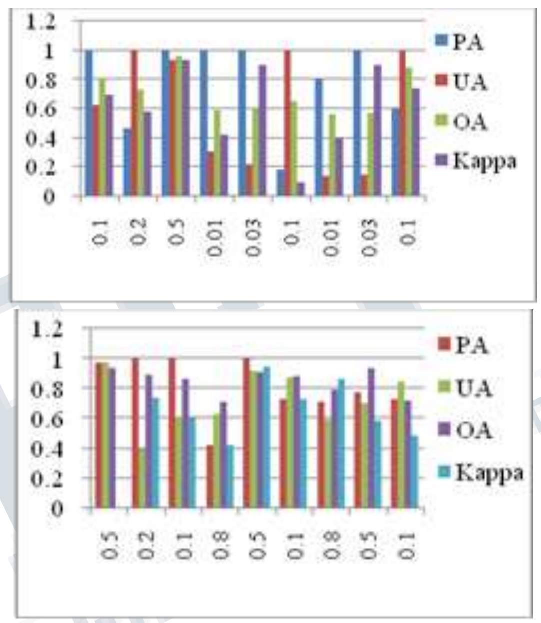

Figure 4: Accuracy Assessment of water index for pre (A) and post (b) flood period

It is observed that for all the thresholds in both pre and post flood scenario **(Table 1)** PA is higher in most of the indices. Simultaneously, the lower UA is evident that non water surfaces were misclassified to be water. In order to lessen the misclassification an optimum threshold **(Table 2)** has to be established that can represent the actual flood inundation on the surface. One of the challenges faced for in this study was the selection of optimum threshold in during the flood period data. This was due to atmospheric disturbances. The presence of clouds misclassifies the pixels as water. For this the binary imagery is carried forward with the trial and error method with the index maps as validation data. The optimum threshold with highest OA and Kappa is selected thereafter to determine the inundated areas for both pre and during flood event. Using the water indices index maps was derived each for pre and post flood scenario. For each scene, at first binary classification was conducted for the threshold values. This was followed by the selection of optimum thresholds.

IFERP
ISSN (Online) 2456-1290
International Journal of Engineering Research in Mechanical and Civil Engineering (IJERMCE)
Vol 6, Issue 5, May 2021

Table 1: Accuracy Assessment for the different indices of all the four scenes for pre and post flood period

	Water Index	$NDWI_{20m}$			$MNDWI\ 1_{20m}$			$MNDWI\ 2_{20m}$		
PRE FLOOD	Threshold	0.5	0.2	0.1	0.1	0.03	0.01	0.1	0.03	0.01
	PA	1	0.46	1	0.18	1	1	0.6	1	0.8
	UA	0.93	1	0.62	1	0.21	0.3	1	0.14	0.13
	OA	0.96	0.73	0.81	0.65	0.60	0.59	0.88	0.57	0.56
	Kappa	0.93	0.58	0.69	0.09	0.9	0.42	0.74	0.9	0.39
POST FLOOD	Threshold	0.5	0.2	0.1	0.8	0.5	0.1	0.8	0.5	0.1
	PA	0.97	1	1	0.42	1	0.73	0.71	0.77	0.73
	UA	0.97	0.39	0.61	0.63	0.92	0.87	0.59	0.7	0.85
	OA	0.94	0.89	0.86	0.71	0.91	0.88	0.79	0.94	0.72
	Kappa	0.001	0.74	0.6	0.42	0.95	0.73	0.86	0.58	0.48

C. Comparison between resulting water bodies' maps

The **Figure 5** represents a comparison of water bodies for the for pre and post flood moment. In **Scene A,** the $NDWI_{20m}$ omitted some linear features. MNDWI 2_{20m} in Scene B misclassified some areas as water.

For the post flood event the $NDWI_{20m}$ index resulted a large amount of isolated pixels are mapped particularly in the **Scenes B**. This might be due to the existence of clouds in the imagery which merged with the water pixels. For **Scene A**, it is also observed that the $NDWI_{20m}$ index have more water logging part and the water body maps created by both the $MNDWIs_{20m}$ precisely removed the isolated pixels that were susceptible of clouds. MNDWI 2_{20m} had eliminated some details of the water logging patches **Scene A**. The streams are also not visible as compared to the other indices. Yet overall due to the coarse spatial resolution of 20 m there was lack in detailed mapping for the water bodies which resulted as jagged in many areas.

D. Statistical Calculations

The estimation results of $NDWI_{20m}$, MNDWI 1_{20m} and MNDWI 2_{20m} values in the water bodies' samples as yield by the indices in the pre and post flood event with the changes in the values are displayed in **Table 3**. For the pre flood time the minimum values of water bodies were -0.3 for MNDWI 1_{20m} and -0.4 for MNDWI 2_{20m} while for $NDWI_{20m}$ the minimum values were -0.6. The minimum and maximum values of MNDWI 2_{20m} are all larger than those of $NDWI_{20m}$. The mean MNDWI 2_{20m} value increases to 0.40 when compared to the mean $NDWI_{20m}$ value it has 0.26. MNDWI 2_{20m} has the highest SD of 0.7 while $NDWI_{20m}$ has the lowest of 0.14 in the water bodies for the pre flood period.

Table 2: Optimum Thresholds

Period	Optimum Threshold	
Water Index	Pre Flood	Post Flood
$NDWI_{20m}$	0.5	0.2
MNDWI 1_{20m}	0.03	0.5
MNDWI 2_{20m}	0.03	0.8

For the post flood event the threshold values for water bodies resulted from -0.6 to 0.9 for $NDWI_{20m}$ and for MNDWI 1_{20m} min value for the water bodies area -0.4 and it ranged upto 1. While for MNDWI 2_{20m} it yields between -1 to 1. MNDWI 2_{20m} yields the lowest SD of 0.07 while it shows the highest mean of 0.9 for the post flood period.

Table 3: Statistics in water bodies for pre and post flood period

Period	Pre Flood			Post Flood		
Water Indices / Statistics	$NDWI_{20m}$	MNDWI 1_{20m}	MNDWI 2_{20m}	$NDWI_{20m}$	MNDWI 1_{20m}	MNDWI 2_{20m}
Min	-0.6035	-0.3842	-0.4106	-0.6955	-0.4920	-1.0000
Max	0.7073	1.0000	0.9981	0.9968	1.0000	1.0000
Mean	0.2628	0.3779	0.4039	0.3511	0.8065	0.9019
SD	0.1476	0.1556	0.1711	0.1698	0.1427	0.0730

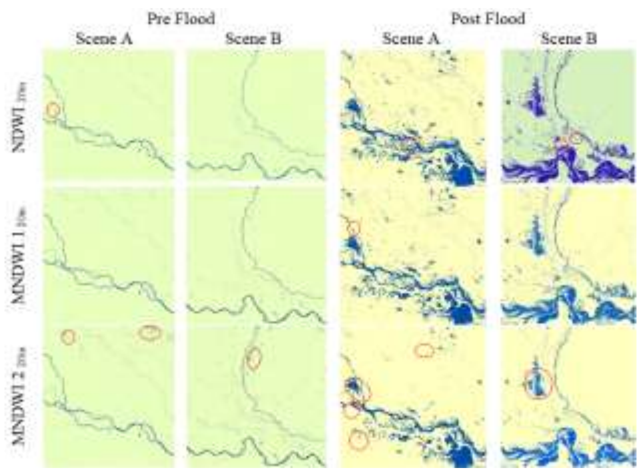

Figure 5: Comparison of water classification for different water indices with the optimum thresholds for pre and post flood period

E. Metherological Observations

The northern Bihar is evident to receive the heaviest rainfall which is a major cause to flooding in the state. The region experience monsoon from the months of June and reaches its peak by July and gradually decrease by August onwards. The North Bihar region received the heaviest rainfall of 2019 with 1264 mm in the month of July, and further decreased in August to 638 mm and 473 mm in September. It is observed that the area to the extreme north east and west of the state towards the foothills gets the heaviest rainfall **(Figure 6).**

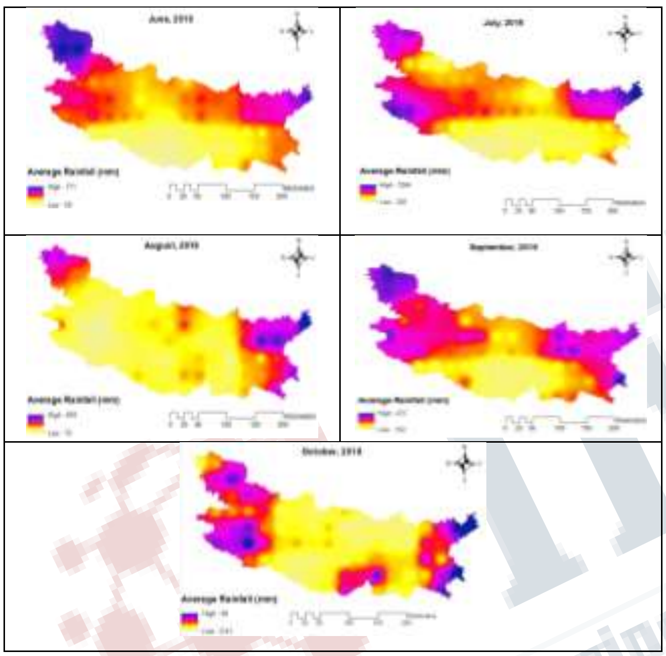

Figure 6: Monthly Rainfall Distribution

F. Inundated Areas

Figure 7 shows the areas of Central Bihar along the Ganga River was severely affected by flood in 2019. The most flood affected areas of 2019 are the districts of Patna, Begusrai, Saran, Samastipur of northern and Central Bihar.

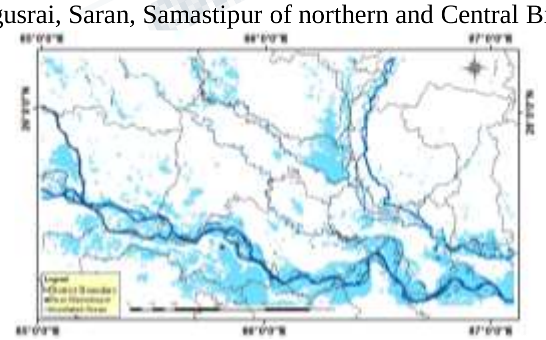

Figure 7: Flood Inundated Areas of Central Bihar Districts for 2019

V. CONCLUSION

For the extraction of the inundated area from multispectral imagery various approaches are developed. In this study spectral water index method is used. The Normalized Difference Water Index (NDWI) and Modified Normalized Difference Water Index (MNDWI) were calculated using the green and Shortwave-Infrared (SWIR) bands to identify the flood water. While Green and SWIR bands of Sentinel – 2 bands are provided in different spatial resolutions. For the purpose of the calculations of the water index its spatial resolution was upscaled to 20m. The three methods – NDWI, MNDWI 1 and MNDWI 2 played a vital role in delineation of the inundated areas. These methods are used to extract water and separate them from the non water surface on the basis of threshold values. The selection of optimum threshold value is a challenging task. Due to the presence of atmospheric disturbance such as clouds there are misclassifications of pixels which affect the accuracy of the extracted feature. Among the entire evaluated water index MNDWI 1 resulted to be the best as it has highest Kappa of 0.95 and Overall Accuracy (OA) of 0.91 for the post flood event while NDWI results to better for the pre flood scenario as it has highest Kappa of 0.93. The lower threshold values for the pre flood time gave more accurate results then the higher ones while this was the opposite for the post flood event. The optimum thresholds for all the different indices differ in every index for both pre and post flood occurrence.

VI. ACKNOWLEDGMENT

Authors are thankful to IIRS, Dehradun for providing the lab facility to complete this work. First author is also thankful to IIRS, Dehradun for giving her permission to undertake Masters' Degree Dissertation at IIRS Dehradun. Extensive support given by the Department of Remote Sensing and GIS, Kumaun University, SSJ Campus, Almora is also acknowledged.

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