Trans.Inst.Indian Geographers
ISSN 0970-9851

Detection of Water-Logged Areas Using Geoinformatics Techniques and Relationship Study in Panskura-Tamluk Flood Plain (India)

Abhay Sankar Sahu, Nadia - West Bengal

Abstract

The prime objective of this paper is the identification and measurement of the water-logged areas applying geoinformatics techniques and co-relationship between physical factors, waterlogged areas and applying techniques. For this, Panskura-Tamluk flood plain in India has been selected as the study area. Here, Survey of India (1972; 1973; 1976) topographical maps and Landsat 8 (2013 and 2014) have been used to observe relief, slope, canal density, road density, settlement density, supervised classification, normalised difference vegetation index, normalised difference water index, normalised difference moisture index and wetness index. Image classification revealed that the water-logged area is around 4-4.5 km2 during non-rainy and in the rainy season it is around 44 km2. Bhuvan (2005-2006) web-map shows about 12 km2. Statistical measures like absolute error, mean absolute error, percentage error and mean percentage error used to find out NDWI, a suitable technique. Co-relationships between observations have been made to corroborate the conclusion.

Keywords. *Water-logging, NDWI, Landsat 8, statistical errors, co-relationship*

Introduction

It is considered that water-logged situation as an environmental hazard (Bowonder et al., 1986; Tutu, 2005) as well as a global issue (Bastawesy and Ali, 2012) because of its problematic happening particularly in the low-lying areas. Sometimes water-logged is found to create due to geological as well as structural control, morphological factors (Merot et al., 1995; Holden et al., 2009; Sahu, 2014a) and sometimes it is due to anthropogenic activities like haphazard construction of roadways, buildings, built-up areas, etc. essentially in the urban areas (Li, 2012). Thus, they can be classified as natural, quasi-natural and anthropogenic based on their origin. Water-logging may be permanent and sometimes may be seasonal based on time scale. Water-logged areas are found in the low-lying areas with negligible slope variation since water remains stagnant therein. The obstructions of the drains create as well as increase the problem of water-logging (Hussain and Irfan, 2012). Generally, when an area has low relief variation surrounded by highlands then there accumulated water of rains and/ or intruded water from rivers/ canals/ seas creates water-logged environment. In this context surface soil (Hossain and Uddin, 2011; Maryam and Nasreen, 2012) is also important as it holds water and where surface water cannot penetrates into the deep interior from the ground level then there water-logging is found. In this context, groundwater level very near to the ground surface is also favourable for generating water-logging over the land surface in an area. In the lower Gangetic areas of India, where relief variation is feeble there due to complex factors of the nature-human relationship water-logged areas are found to be initiated in the low-elevated, low-sloped areas with haphazard distributions of embankments. For the proper landuse management it is necessary to measure and to prepare maps on waterlogged areas. But, it is a difficult tusk due to physical complexity in order to delineation of the water-logged areas to the researchers, planners and government authorities as well. Here, the prime objective of this paper is the identification and measurement of the water-logged areas applying geoinformatics techniques and to evaluate the most effective technique along with the co-relationships between physical factors and water-logging in the one hand and between physical factors and remote sensing factors on the other. There are several attempts to identify and to measure the water-logged as well as flooding areas primarily based on physical map and administrative map of an area and considering its areal extension of the low-lands along with the remote sensing methods (Jain and Sinha, 2003; Frappart et al., 2005). Singh et al. (2014) evaluated water-logged areas applying Normalised Difference Water Index (NDWI) and modified NDWI techniques in Punjab of India. Sahu (2014a) attempted to study Moyna basin water-logged area using remote sensing and Geographical Information System (GIS) methods. Sahu (2014b) again studied Keleghai river basin, Purba Medinipur part, India, water-logged areas from the remote sensing and GIS perspective. Here it is to identify the water-logged areas applying the geoinformatics techniques and also to measure the areal extension of them. Though there are several problems coming from the reflectance value of the electromagnetic radiation (EMR) particularly where there are number of small to large ponds, reservoirs and canals show similar type of reflection from water bodies and again where there is water in the water-logged areas covered by green hydrophytes therefore proper delineation of the water-logged areas is problematic based on remote sensing imageries. Based on green, red, near-infrared and short wave infrared several techniques of normalized differentiation like Normalised Difference Vegetation Index (NDVI), Normalised Difference Water Index (NDWI), Normalised Difference Moisture Index (NDMI) and also Wetness Index (WI) helped to understand water-logged areas along with the Supervised Classification (SC) method, but final rectification as well as editing is obviously necessary based on field observations for the purpose of final output of the map of water-logged areas.

Study area

Panskura-Tamluk Flood Plain (PTFP) has been taken into consideration for this study **(Fig. 1).** To delineate the study area Google Earth image (cited 2014 July 31) has been considered as it depicted very recent view of an area. Here it has been delineated following the high rising roads/embankments; those blocked the surface water in this comparatively low-lying area.

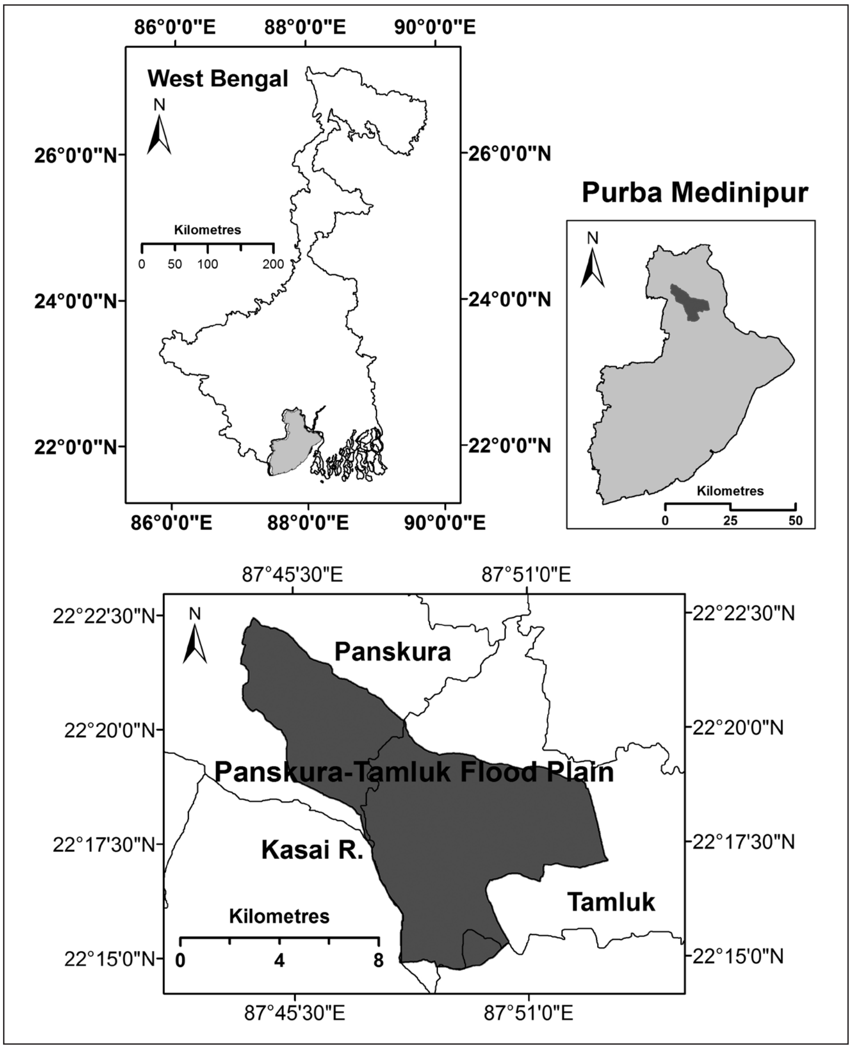

Fig. 1: Panskura-Tamluk Flood Plain (study area).

On the northern side it is Panskura-Tamluk roadway and on the eastern tip there is National Highway 41. Southern boundary follows the Moyna-Tamluk roadway and western line is on the Kasai river embankment as well. Total area under this study is about 82-km^2. It is extended from 22°14′45″N to 22°20′25″N and 87°44′15″E to 87°52′40″E respectively.

Materials and methods

Fig. 2 shows a flow-wise view of the attempts to fulfil our objective in this study. For the purposes of map preparation and data generation from the topographical maps and satellite images, different software have been used here. The physical parameters are natural and quasi-natural observations like relief, slope, canal density, road density, and

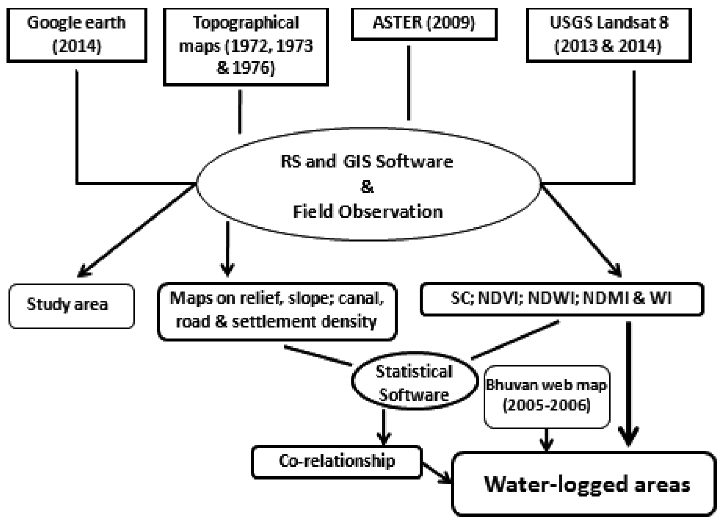

Fig. 2: Methodological steps.

settlement density; whereas, remote sensing and GIS parameters are the observations based on geoinformatics techniques like SC, NDVI, NDWI, NDMI, and WI aiming towards identification and measurement of the water-logged areas as well as to review the environment for their initiation.

United States Geological Survey (USGS) Global Visualisation Viewer (GLOVIS) Advanced Spaceborne Thermal Emission and Reflection [ASTER] (2009) data has been used here to understand the relief variation of the study area **(Fig. 3a).** As there has some possibility for wrong

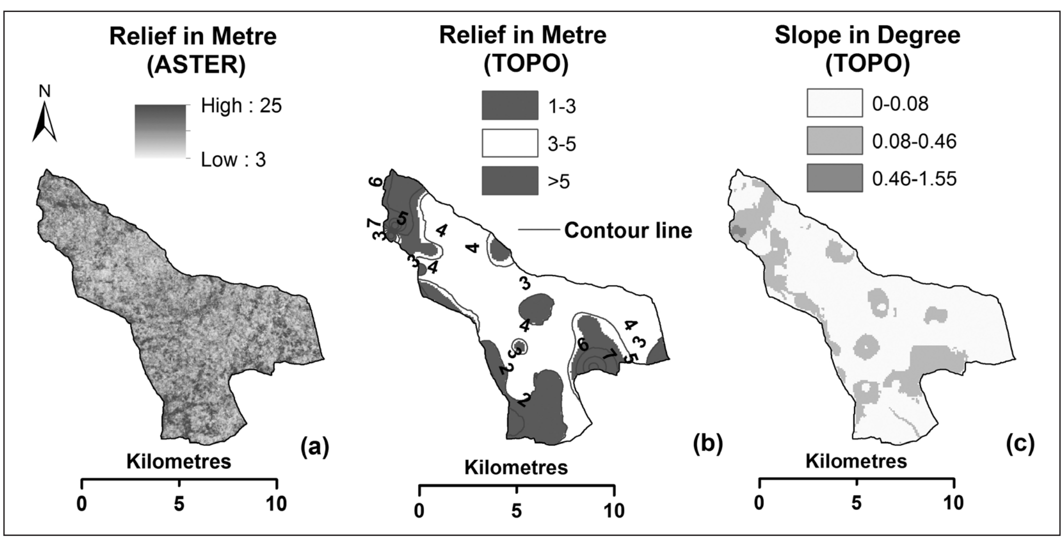

Fig. 3: (a) Relief based on ASTER (2009), (b) Relief based on SOI topographical maps (1972, 1973 & 1976) & (c) Slope variations based on SOI topographical maps (1972, 1973 & 1976) --- PTFP.

interpretation of the relief variation due to trees, high rising buildings, etc., another one relief map has been produced **(Fig. 3b)** based on Survey of India [SOI] (1972; 1973; 1976) topographical maps 73N/11, 73N/15, 73N/16 (scale - 1:50,000) taking spot elevations haphazardly spread over the study area and its surrounding, processing through interpolation methods, using software. From these SOI (1972; 1973; 1976) topographical maps, slope map **(Fig. 3c)** of the study area also has been processed to understand the physical nature of the area toward generating water-logging environment. Again, maps on canal density, road density and settlement density have been prepared **(Fig. 4)** based on information gathered in the SOI (1972; 1973; 1976) topographical maps. Now, from the USGS Landsat 8 images of the pre-rainy seasons (2013 April 26 and 2014 April 22) and during rainy season (2013 November 04) have been considered here to identify

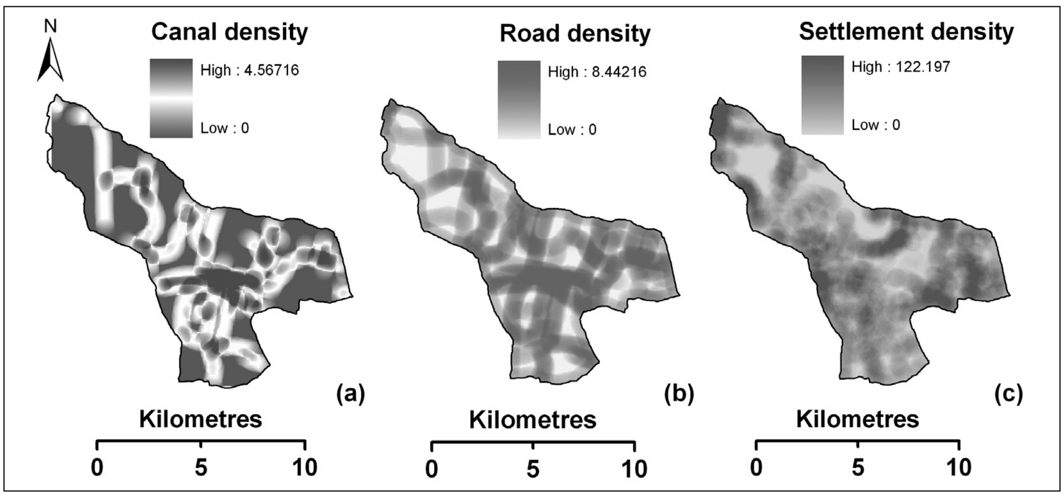

Fig. 4: (a) Canal density, (b) Road density & (c) Settlement density --- PTFP.

and also to calculate the water-logged areas, after band wise conversion (USGS, 2015) of the quantised and calibrated scaled Digital Number (DN) to Top of Atmosphere (TOA) radiance value using the radiance rescaling factors provided in the metadata file. After conversion of the values, using certain formula for the Landsat 8 bands (USGS, 2015), maps on SC **(Fig. 5)** and the NDVI, NDWI, NDMI and WI **(Fig. 6)** have been prepared following certain formulae. In this study, the surface extension of water-bodies is taken into consideration not to their depth. After identification of the water-logged areas with the help of geoinformatics techniques their areal extensions have been calculated. There are many attempts are found to measure water-bodies and vegetation covered areas by classifying images supervised or unsupervised processes. But, here, it is the study to incorporate some of the geoinformatics techniques. There is also Bhuvan (2005-2006) web map based on Resourcesat-1 Linear Imaging Self-Scanning (LISS) III data of the National Remote Sensing Centre (NRSC) Thematic

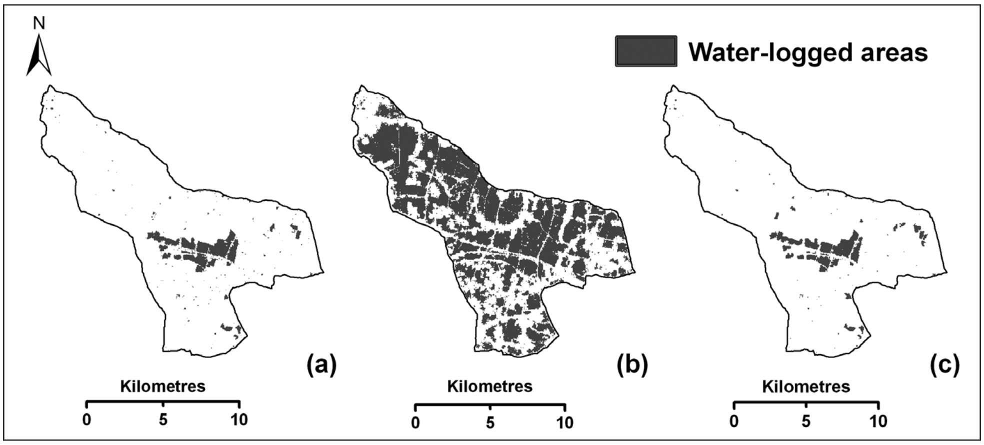

Fig. 5: (a) L8_ SC: 2013 April 26, (b) L8_ SC: 2013 November 04, & (c) L8_ SC: 2014 April 22.

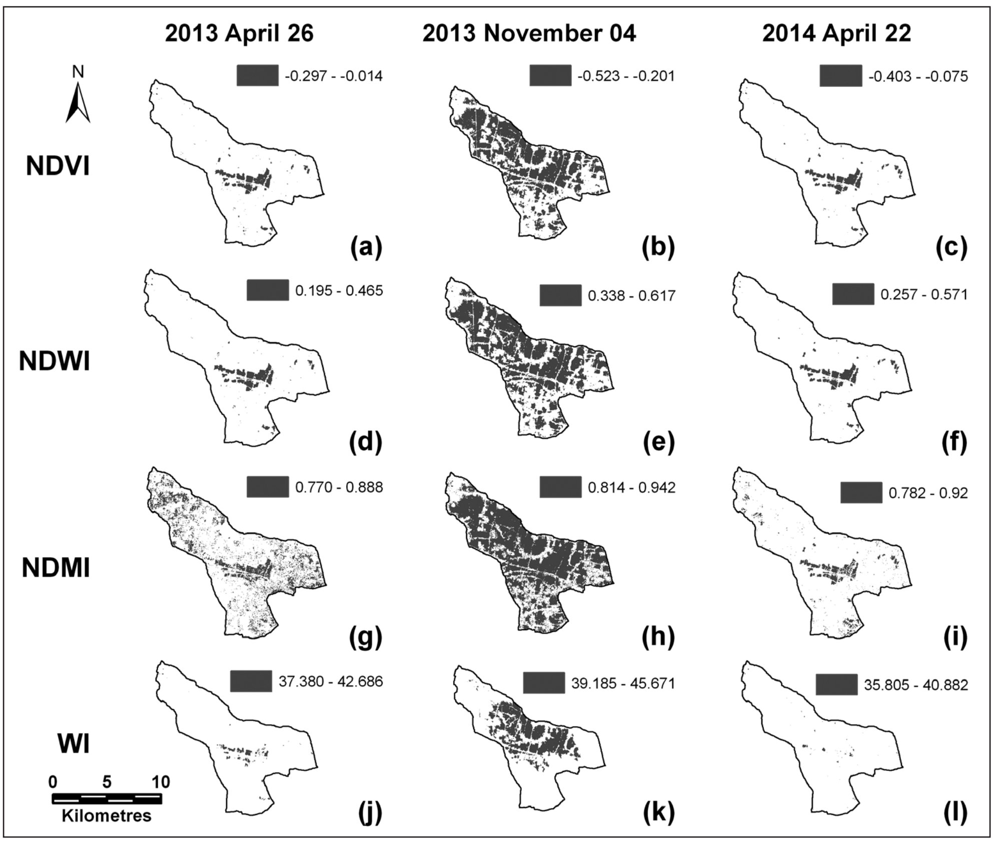

Fig. 6: (a) L8_ NDVI: 2013 April 26; (b) L8_ NDVI: 2013 November 04; (c) L8_ NDVI: 2014 April 22; (d) L8_ NDWI: 2013 April 26; (e) L8_ NDWI: 2013 November 04; (f) L8_ NDWI: 2014 April 22; (g) L8_ NDMI: 2013 April 26; (h) L8_ NDMI: 2013 November 04; (i) L8_ NDMI: 2014 April 22; (j) L8_ WI: 2013 April 26; (k) L8_ WI: 2013 November 04; (l) L8_ WI: 2014 April 22.

Services, which depicts water-logged areas of the study area. Above all, the study area has been surveyed for several times in pre-rainy seasons and also during rainy season towards field checking against the outcomes generated from the prepared maps.

For the purposes of data generation against the above-said parameters the study area has been divided into equal sized square grids (10″ X 10″), taking 1010 points (one middle most point / grid). Statistical techniques like Absolute Error (AE), Mean Absolute Error (MAE), Percentage Error (PE), and Mean Percentage Error (MPE) have been used to understand the highest favourable geoinformatics technique towards identification and measurement of the water-logged areas and in this context the SC value is taken into consideration as the primary value for the PE and MPE to test the others as the SC value depends on the personal technical control. In this study, statistical software has also been used here to calculate and to establish the co-relationships between the physical parameters and the remote sensing parameters.

Absolute Error (AE)

In statistics, it is the difference between two values (x and y). The formula 1 for the absolute error is as follow:

$$\mathbf{AE = (x \sim\sim y)} \sim y) \quad \ldots\ldots\ldots\ldots(1)$$

Mean Absolute Error (MAE)

It is the average of absolute errors for ‘n’ number of observations. The formula 2 for the mean absolute error is as follow:

$$\mathbf{MAE = (x \sim\sim y) / n} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Percentage Error (PE)

It, in statistics, measures the percentage of the relative error (RE). RE is the difference between observed value (O_t) and primary value (Pt) divided by the primary value (P_t) at a certain time (t). The formula 3 for the percentage error is as follow:

$$\mathbf{PE = [(O_t \sim\sim P_t) / P_t] * 100\%} \quad \ldots\ldots\ldots\ldots(3)$$

Mean Percentage Error (MPE)

It, in statistics, measures the average of percentage errors (PE). PE is the 100% of the relative error (RE). RE is the difference between observed value (O_t) and primary value (Pt) divided by the primary value (P_t) at a certain time ‘t’. Here, ‘n’ is the number of observations. The formula 4 for the mean percentage error is as follow:

$$\mathbf{MPE = \{[(O_t \sim\sim P_t) / P_t] * 100\%\} / n} \quad \ldots\ldots\ldots\ldots(4)$$

Physical observations

There is Holocene alluvial lowland, a physiographic division of the Bengal basin of the Ganga-Brahmaputra-Meghna system (Mukherjee et al., 2009), formed the part of Purba Medinipur district of West Bengal. Fig. 3(a) shows the relief variation based on ASTER (2009) data where it is found that maximum areas have very low elevations. Again, from the SOI (1972; 1973; 1976) topographical maps, scale - 1: 50000, for the study area, after collecting spot heights, it is found that maximum areas have less than five metres elevation (Fig. 3b) and slope changes within 0.46^o, except a negligible part between 0.46^o to 1.55^o, practically it is a ‘no slope’ plain region (Fig. 3c). Total study area is surrounded as well as encompassed by the high roadways and embankments. As the study area belongs to the Lower Gangetic Plain of West Bengal where practically slope has not been changed and a general slope is found towards south where Bay of Bengal is there high roadways and embankments play an important role behind the formation of water-logged and flooding environment, through blocking the surface water movement. River Kasai is situated on the west of this study area, thus this study area under a flood plain of the river Kasai, and Rupnarayan river is situated very closer position of this study area on the east and when any river-front embankment breached away then this area has been flooded and due to blocking by these high roadways water cannot passed towards another places following ground slopes practically.

In general, natural canals (*khals*) are found in the areas with number of water bodies and canal density is found to be high in the low-lying areas. Where slope is very low there natural canals and also manmade canals are found for water passing/ clearing and also for irrigation purposes. Here, canal density is high as much as 4.5 per km^2 (Fig. 4a). Road density normally is high in the highlands where water bodies are in less quantity but here as the study area, under South Bengal region, is a flood plain in nature and there to hold canal water within channels embankments had been constructed along the canal banks. Therefore, where canal density is high there road density is also high around 8 per km^2 (Fig. 4b). Indirectly settlement areas show relief variation as settlements developed on the highlands. Settlement density is high where the probability of stagnation of water be less. But, here, as relief variation is very low and total area is flat surfaced, there, many times high embankments are favoured for house building remaining gap in the central passage of the embankments for transportation and movements purposes. In the study area many settlements are also found on the comparatively high lands within the flat agricultural fields that remained water logged in the rainy season. Settlement density is high around 122 per km^2 (Fig. 4c).

Application of geoinformatics techniques and observations

Bhaker (2011) remarked on the surface expression of waterlogged areas and that can be captured from the satellite imagery. In this purpose, methods are water index, salinity index, normalized differential salinity index, brightness index, vegetation indices and wetness index in order to map the areas under risk of water-logging considering different band ratios of LISS data. Quan et al. (2010) also applied remote sensing and GIS methods to understand the water-logging extension and risk assessment.

In this study, with the help of remote sensing software, supervised classifications of the satellite images, dated – 2013 April 26; 2013 November 04; and 2014 April 22 , worked out to divide the PTFP area into two halves like water-logged areas and other areas where there is no water mark. In the non-rainy season of April there is only 4.36 km^2 water-logged area in the year of 2013 (Fig. 5a) and it is around 4.69 km^2 in the month of April next year again (Fig. 5c). In the rainy season of 2013 when there was a flooding happed through breaching of the river Kasai on the west of the PTFP then the water-logged area was increased to around 44.34 km^2 (Fig. 5b). This flooded water remained water-logged for some consecutive months after flooding due to surface level blocking by the roadways and high embankments as well. Here, one important observation is in the year of 2013 and then in the year of 2014 when it is April then the amount of water-logged area is very near to one another.

Normalised Difference Vegetation Index (NDVI) is a geoinformatics technique developed by Tucker (1979) to measure primarily the vegetation cover and on the other hand it is also to measure the water bodies over the earth surface (Tucker and Choudhury, 1987; Jackson and Huete, 1991). For Landsat 8 to calculate NDVI the formula 5 is as follow:

$$\text{NDVI} = \frac{\text{Band 5 (Near Infrared) - Band 4 (Red)}}{\text{Band 5 (Near Infrared)+ Band 4 (Red)}} \quad \text{...............(5)}$$

The NDVI value ranges from -1 to +1 Tucker (1979) and the areas from zero towards negative side of the range up to -1 denote the presence of surface water bodies. For the PTFP, in April 2013, the NDVI ranges from -0.297 to 0.551; in November 2013, it ranges from -0.524 to 0.444; and in April 2014, it again ranges from -0.404 to 0.581 as well. After dividing each range into three classes with equal width it is observed that the areas extended over maps containing extreme negative side of every NDVI range more or less similar to the supervised classification based water-logged areas, thus and therefore, in April 2013, the amount of water-logged areas is almost 4.26 km^2 when NDVI ranges from -0.297 to -0.014 (Fig. 6a); in November 2013, it is around 27.89 km^2 where NDVI ranges from -0.524 to -0.201 (Fig. 6b); and in April 2014, again it is around 4.15 km^2 having NDVI range from -0.404 to -0.075 (Fig. 6c). From here, one observation is that for dry non-rainy periods water-logged area is more or less similar with the outcome resulting from the supervised classification method as well. In November 2013, the NDVI range for water-logged area is something less than the area coming from supervised classification. It is due to water covering by green vegetations and other pollutants those reflected near infrared radiation more, therefore, instead of water it is observed as vegetation cover.

Normalised Difference Water Index (NDWI) is a geoinformatics technique developed by McFeeters (1996) to measure surface water where it ranges from -1 to +1 and +1 signifies the abundance of water surfaces, -1 for vegetation. For Landsat 8 to calculate NDWI the formula 6 is as follow:

$$\text{NDWI} = \frac{\text{Band 3 (Green) - Band 5 (Near Infrared)}}{\text{Band 3 (Green)+Band 5 (Near Infrared)}} \quad \text{...............(6)}$$

For the PTFP, in April 2013, the NDWI ranges from -0.344 to 0.465; in November 2013, it ranges from -0.221 to 0.618; and in April 2014, it again ranges from -0.372 to 0.571 as well. After dividing each range into three equal width classes it is observed that the areas extended over maps containing extreme positive side of every NDWI range more or less similar to the supervised classification based water-logged areas, thus and therefore, in April 2013, the amount of water-logged areas is around 4.09 km^2 when NDWI ranges from 0.195 to 0.465 (Fig. 6d); in November 2013, it is around

40.56 km^2 where NDWI ranges from 0.338 to 0.618 (Fig. 6e); and in April 2014, again it is around 4.12 km^2 having NDWI range from 0.257 to 0.571 (Fig. 6f). From here, one observation is that for dry non-rainy seasons and also for post rainy seasons water-logged area is more or less similar with the outcomes getting from supervised classification method.

Normalised Difference Moisture Index (NDMI), developed by Wilson and Sader (2002), is aiming to search the soil moisture. Normally in the areas of water-logging and flooding soil moisture will be high. For NDMI the same band composites are used like modified NDWI or $NDWI_{GAO}$ as Gao (1996) presented that to minimise the errors of NDWI. For Landsat 8 to calculate NDMI the formula 7 is as follow:

$$\text{NDMI} = \frac{\text{Band 5 (Near Infrared) - Band 6 (Middle Infrared)}}{\text{Band 5 (Near Infrared)} + \text{Band 6 (Middle Infrared)}} \quad \ldots\ldots\ldots\ldots(7)$$

In NDMI, the high values present the areas with more soil moisture where water-logging/ flooding environment existed and low values denote areas of low soil moisture content. For the PTFP, in April 2013, the NDMI ranges from 0.534 to 0.889; in November 2013, it ranges from 0.559 to 0.943; and in April 2014, it again ranges from 0.506 to 0.920 as well. After dividing each range into three equal width classes it is observed that the areas extended over maps containing extreme positive side (high soil moisture) of every NDMI range more or less similar to the supervised classification based water-logged areas, thus and therefore, in April 2013, the amount of water-logged areas is around 15.20 km^2 when NDMI ranges from 0.771 to 0.889 (Fig. 6g); in November 2013, it is around 51.00 km^2 where NDMI ranges from 0.815 to 0.943 (Fig. 6h); and in April 2014, again it is around 4.76 km^2 having NDMI range from 0.782 to 0.920 (Fig. 6i). From here, observations are that in April 2013, the NDMI value is something increased abruptly than the results coming from other remote sensing techniques in this year and also April 2014, which is more or less equal with the outcome of supervised classification, and in November 2013, the NDMI result again is something high based on this technique. Since it measures the soil moisture therefore apart from massive water bodies lands with high soil moisture also reflected into the result.

Wetness Index (WI) is a measure through which wetness of an area is calculated. Tasseled cap indices give a measure of the WI utilising a linear combination of six of Landsat 8 bands. For Landsat 8 to calculate WI the formula 8 is as follow:

$$\begin{aligned} \text{WI} = {} & (0.2626 * \text{Band 2 [Blue]}) + (0.2141 * \text{Band 3 [Green]}) + \\ & (0.0926 * \text{Band 4 [Red]}) + (0.0656 * \text{Band 5 [Near Infrared]}) + \\ & (-0.7629 * \text{Band 6 [Middle Infrared 1]}) + (-0.5388 * \text{Band 7 [Middle Infrared 2]}) \end{aligned} \quad \ldots\ldots\ldots\ldots(8)$$

Here the coefficients have been put forwarded by Huang et al. (2002). For the PTFP, in April 2013, the WI ranges from 26.771 to 42.686; in November 2013, it ranges from 26.213 to 45.672; and in April 2014, it again ranges from 25.652 to 40.883 as well. After dividing each range into three classes with equal width it is observed that the areas extended over maps containing extreme positive side (high wetness) of every WI range more or less akin to the water-logged areas, thus and therefore, in April 2013, the amount of water-logged areas is around 1.53 km^2

when WI ranges from 34.948 to 42.686 (Fig. 6j); in November 2013, it is around 19.51 km^2 where WI ranges from 39.185 to 45.672 (Fig. 6k); and in April 2014, again it is around 0.37 km^2 having WI range from 35.806 to 40.883 (Fig. 6l). From here, observations are that all the outcomes of three years are too less than the results coming from supervised classification and other remote sensing techniques as well. In April 2014, there is no signature of water-logged areas.

Table 1: Absolute errors and mean absolute errors of the water-logged areas resulted after application of the geoinformatics techniques.

RS Technique	**SC**	**NDVI**			**SC**	**NDWI**			**SC**	**NDMI**		
Date	Value (km^2)	Value (km^2)	AE	MAE	Value (km^2)	Value (km^2)	AE	MAE	Value (km^2)	Value (km^2)	AE	MAE
26-Apr-13	4.69	4.26	0.43	5.70	4.69	4.09	0.6	1.54	4.69	15.2	10.51	5.86
04-Nov-13	44.34	27.89	16.45		44.34	40.56	3.78		44.34	51	6.66	
22-Apr-14	4.36	4.15	0.21		4.36	4.12	0.24		4.36	4.76	0.4	
RS Technique	SC	WI			NDVI	NDWI			NDVI	NDMI		
Date	Value (km^2)	Value (km^2)	AE	MAE	Value (km^2)	Value (km^2)	AE	MAE	Value (km^2)	Value (km^2)	AE	MAE
26-Apr-13	4.69	1.53	3.16	10.66	4.26	4.09	0.17	4.29	4.26	15.2	10.94	11.55
04-Nov-13	44.34	19.51	24.83		27.89	40.56	12.67		27.89	51	23.11	
22-Apr-14	4.36	0.37	3.99		4.15	4.12	0.03		4.15	4.76	0.61	
RS Technique	NDVI	WI			NDWI	NDMI			NDWI	WI		
Date	Value (km^2)	Value (km^2)	AE	MAE	Value (km^2)	Value (km^2)	AE	MAE	Value (km^2)	Value (km^2)	AE	MAE
26-Apr-13	4.26	1.53	2.73	4.96	4.09	15.2	11.11	7.40	4.09	1.53	2.56	9.12
04-Nov-13	27.89	19.51	8.38		40.56	51	10.44		40.56	19.51	21.05	
22-Apr-14	4.15	0.37	3.78		4.12	4.76	0.64		4.12	0.37	3.75	
RS Technique	NDMI	WI	AE	MAE								
Date	Value (km^2)	Value (km^2)										
26-Apr-13	15.2	1.53	13.67	16.52								
04-Nov-13	51	19.51	31.49									
22-Apr-14	4.76	0.37	4.39									

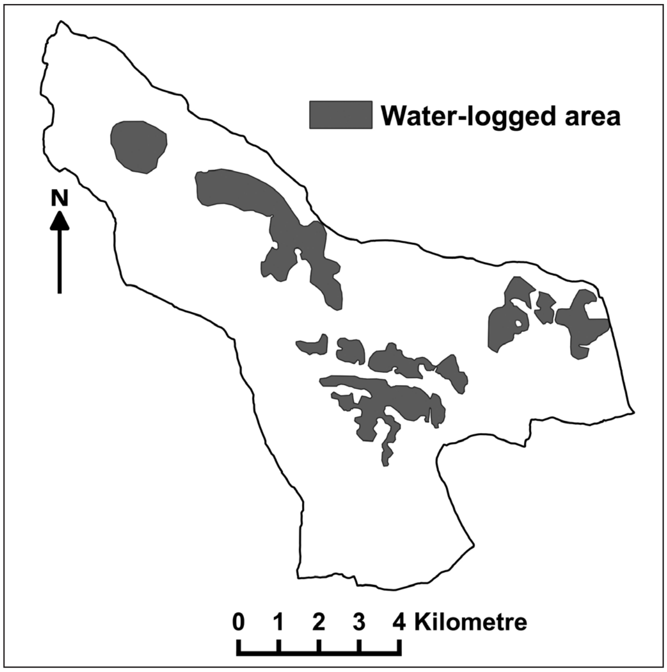

Fig. 7: Water-logged area processed from Bhuvan web map (2005-2006).

Bhuvan (2005-2006) data of the study area, developed through Q GIS software, reveals that the water-logged area within the study area is about 12 km^2 (Fig. 7) on an average without any time specificity.

Statistical discussion

Table. 1 shows the absolute errors on water-logged areas applying Formula 1 between two outcomes generated by different geoinformatics techniques like SC, NDVI, NDWI, NDMI and WI against three different dates of 2013 April 26; 2013 November 04; and 2014 April 22, and mean absolute errors applying Formula 2. Taking the results of Table. 1 under consideration, Table. 2 shows MAE matrix. From this matrix it is clear that the minimum MAE is about 1.54 between SC and NDWI for water-logged areas.

Table 2: Mean absolute error matrix.

	SC	NDVI	NDWI	NDMI	WI
SC	1	5.70	**1.54**	5.86	10.66
NDVI		1	4.29	11.55	4.96
NDWI			1	7.40	9.12
NDMI				1	16.52
WI					1

Table 3 shows percentage errors applying Formula 3 and mean percentage errors applying Formula 4. Here it is found that the lowest MPE is about 8.94 between SC and NDWI. It again proves the closer association between SC and NDWI.

Table. 3: Percentage errors and mean percentage errors of the water-logged areas resulted after application of the geoinformatics techniques (SC: primary value).

RS Technique	SC	NDVI			SC	NDWI			SC	NDMI		
Date	Value (km^2)	Value (km^2)	PE	MPE	Value (km^2)	Value (km^2)	PE	MPE	Value (km^2)	Value (km^2)	PE	MPE
26-Apr-13	4.69	4.26	9.17	17.03	4.69	4.09	12.79	8.94	4.69	15.2	224.09	82.76
04-Nov-13	44.34	27.89	37.10		44.34	40.56	8.53		44.34	51	15.02	
22-Apr-14	4.36	4.15	4.82		4.36	4.12	5.50		4.36	4.76	9.17	
RS Technique	SC	WI										
Date	Value (km^2)	Value (km^2)	PE	MPE								
26-Apr-13	4.69	1.53	67.38	71.63								
04-Nov-13	44.34	19.51	56.00									
22-Apr-14	4.36	0.37	91.51									

Table 4: Spearman's co-relationship matrix for physical and NDWI observations.

	Relief (Topo)	Slope	Canal density	Road density	Settlement density	NDWI April, 2013	NDWI Nov, 2013	NDWI April, 2014
Relief (Topo)	1	.289**	-.128**	.196**	.196**	-.147**	-.030	-.086**
Slope		1	.065	.101**	.101**	-.166**	-.058	-.096**
Canal density			1	-.130**	-.130**	.306**	.129**	.325**
Road density				1	1.000**	-.144**	-.336**	-.158**
Settlement density					1	-.144**	-.336**	-.158**

** Co-relationship is significant at the 99% level.

Table. 4 shows the Spearman's correlation matrix for physical and NDWI observations. Now, it is clear that more or less all the NDWI values on water-logged areas of three different dates are 99% level significant in their correlation with the natural and quasi-natural observations like relief, slope, canal density, road density and settlement density responsible for generating water-logging environment.

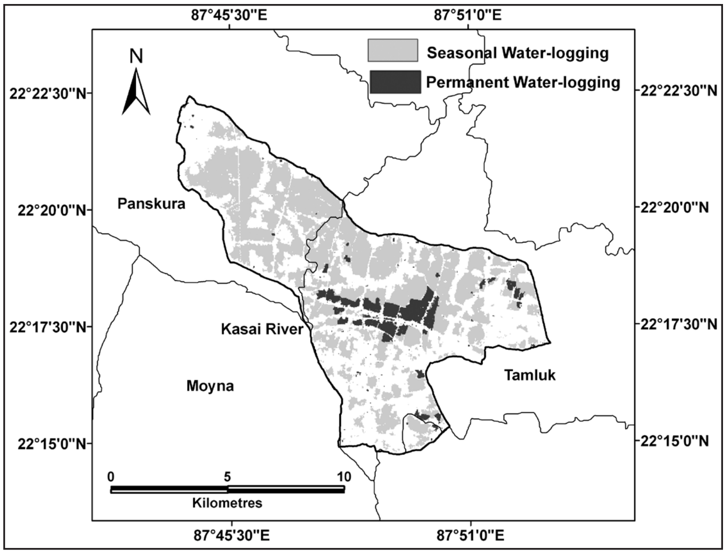

Fig. 8:

Conclusion

From the MAE and MPE results it is found that the NDWI value is very much closely associated with the SC value and therefore it can be stated the NDWI technique can be applied directly for identifying and measuring water-logged areas. Again, it can be stated that the NDWI, a geoinformatics technique, has a good correlation with the observations on natural and quasi-natural parameters like relief, slope, canal density, road density and settlement density, which can be regarded as a positive outcome towards considering it for the water-logged areas identification and measurement purposes. Supervised classifications of Landsat 8 image (2013 and 2014) of the study area reveal that the water-logged area is around 4-4.5 km^2 measured in the non-rainy seasons, i.e. April 2013 and 2014, and in the month of November, 2013, during rainy season, it is around 44 km^2 as well, on an average it is nearly 16 km^2, since we have considered three different dates. Considering NDWI of those three different dates we get the average water-logged area is again around 16 km^2. As per Bhuvan (2005-2006) web map, it is about 12 km^2 which is very much near to the calculated values from SC and NDWI. Therefore, to get a relative outcome on water-logged areas, the NDWI, a geoinformatics technique, is accepted remaining behind other techniques. Fig. 8 shows the permanent water-logged areas and the areas prone to be water-logged particularly during rainy seasons which are marked as seasonal water-logged areas based on NDWI mapping.

Acknowledgement

The author acknowledges University Grants Commission (UGC), New Delhi, India, for financial assistance. This paper is a part of study under UGC-BSR Start-up Grant Scheme [Ref. UGC Letter No – F.20-3(17)/2012(BSR) Date: February, 2013 (08 March, 2013)] on ‘Environmental Consequences of Water-Logging Problem in Purba Medinipur District, West Bengal: Evaluation, Mapping, and Management’.

References

- ASTER: Advanced Spaceborne Thermal Emission and Reflection [Internet]. 2009. United States Geological Survey Global Visualisation Viewer; [cited 2013 August 20]. Available from: http://glovis.usgs.gov.
- Bastawesy, M.E., Ali, R.R. (2012): The use of GIS and remote sensing for the assessment of waterlogging in the dryland irrigated catchments of Farafra Oasis, Egypt. Hydrological Processes, [Internet]. [cited 2013 December 28], Vol. 27. Available from: http://onlinelibrary.wiley.com/advanced/search/results. DOI: 10.1002/hyp.9218.
- Bhakar, R. (2011): Recent advances in geo-informatics based assessment of waterlogging and salinization hazards: a review of studies of the irrigated tracts in desert environments. Oikoassay, [Internet]. [cited 2013 December 30], Vol. 24. Available from: http://www.jnu.ac.in/sss/cssp/Rajesh1.pdf.
- Bhuvan [Internet]. c2005-2006. Gateway to Indian Earth Observation; National Remote Sensing Centre; [cited 2014 December 18]. Available from: http://bhuvan.nrsc.gov.in/gis/thematic/index.php.
- Bowonder, B., Ramana, K.V., Rajagopal, R. (1986): Waterlogging in irrigation projects. Sadhana, Vol. 9: 177-190.
- Frappart, F., Seyler, F., Martinez, J., Leo´n, J., Cazenave, A. (2005): Floodplain water storage in the Negro river basin estimated from microwave remote sensing of inundation area and water levels. Remote Sensing of Environment, Vol. 99: 387 –399.
- Gao, B.C. (1996): NDWI – A normalized difference water index for remote sensing of vegetation liquid water from space. Remote Sensing of Environment, [Internet]. [cited 2013 November 21], Vol. 58:257-266. Available from: http://ceeserver.cee.cornell.edu/wdp2/cee6150/Readings/Gao_1996_RSE_58_257-266_NDWI.pdf.
- Holden, J., Howard, A.J., West, L.J/, Maxfield, E., Panter, I., Oxley, J. (2009): A critical review of hydrological data collection for assessing preservation risk for urban waterlogged archaeology: a case study from the city of York, UK. Journal of Environmental Management, Vol. 90: 3197–3204.
- Hossain, M.A., Uddin, S.N. (2011): Mechanisms of waterlogging tolerance in wheat: Morphological and metabolic adaptations under hypoxia or anoxia. Australian Journal of crop Science, [Internet]. [cited 2015 April 16], Vol. 5:1094-1101. Available from: http://www.cropj.com/alamgir_5_9_2011_1094_1101.pdf.
- Huang, C., Wylie, B., Yang, L., Homer, C., Zylstra, G. (2002): Derivation of a tasseled cap transformation based on Landsat 7 at-satellite reflectance. International Journal of Remote Sensing, Vol. 23:1741-1748.
- Hussain, Z., Irfan, M. (2012): Sustainable land management to combat desertification in Pakistan. Journal of Arid Land Studies, Vol. 22: 127 -129.
- Jackson, R.D., Huete, A.R. (1991): Interpreting vegetation indices. Preventive Veterinary Medicine, Vol. 11:185-200.
- Jain, V., Sinha, R. (2003): Geomorphological manifestations of the flood hazard: a remote sensing based approach. Geocarto International, [Internet]. [cited 2015 April 16], Vol. 18: 51-60. Available from: http://re.indiaenvironmentportal.org.in/files/file/flood%20hazard.pdf .
- Li, C. (2012): Ecohydrology and good urban design for urban storm water-logging in Beijing, China. Ecohydrology & Hydrobiology, [Internet]. [cited 2015 April 16] Vol. 12: 287-300. Available from: http://www.ecohyd.org/sites/default/files/EH_2012-4_3_Li_www.pdf .

- Maryam, A., Nasreen, S. (2012): A review: water logging effects on morphological, anatomical, physiological and biochemical attributes of food and cash crops. International Journal of Water Resources and Environmental Sciences, [Internet]. [cited 2015 April 16], Vol. 1: 113-120. Available from: http://www.idosi.org/ijwres/1%284%2912/4.pdf .
- Mcfeeters, S.K. (1996): The use of Normalized Difference Water Index (NDWI) in the delineation of open water features. International Journal of Remote Sensing, Vol. 17:1425–1432.
- Merot, Ph., Ezzahar, B., Walter, C., Aurousseau, P. (1995): Mapping waterlogging of soils using digital terrain models. Hydrological Processes, Vol. 9: 27-34.
- Mukherjee, A., Fryar, A. E., Thomas, W. A. (2009): Geologic, Geomorphic and Hydrologic Framework and Evolution of the Bengal Basin, India and Bangladesh. Journal of Asian Earth Science, Vol. 34: 227-244. DOI:10.1016/j.jseaes.2008.05.011
- Quan, R.S., Liu, M., Lu, M., Zhang, L., Wang, J., Xu, S. (2010): Waterlogging risk assessment based on land use/cover change: a case study in Pudong New Area, Shanghai. Environ Earth Sci, Vol. 61: 1113–1121.
- Sahu, A.S. (2014a): A study on Moyna basin water-logged areas (India) using remote sensing and GIS methods and their contemporary economic significance. Geography Journal, [Internet]. [cited 2015 April 16], Vol. 2014:1-9. Available from: http://www.hindawi.com/journals/geography/2014/401324/.
- Sahu, A.S. (2014b): Identification and mapping of the water-logged areas in Purba Medinipur part of Keleghai river basin, India: RS and GIS methods. International Journal of Advanced Geosciences, [Internet]. [cited 2015 April 16], Vol. 2:59-65. Available from: http://www.sciencepubco.com/index.php/IJAG/article/view/2452
- Singh, K.V., Setia, R., Sahoo, S., Prasad, A., Pateriya, B. (2014): Evaluation of NDWI and MNDWI for assessment of waterlogging by integrating digital elevation model and groundwater level. Geocarto International, [Internet]. [cited 2015 April 05], Vol. 2014:1-12. Available from: http://dx.doi.org/10.1080/10106049.2014.965757.
- SOI: Survey of India. 1972, 1973, 1976. Survey of India topographical maps. Govt. of India. Scale – 1: 50,000.
- Tucker, C.J. (1979): Red and photographic infrared linear combinations for monitoring vegetation. Remote Sensing of Environment, Vol. 8:127–150.
- Tucker, C.J., Choudhury, B.J. (1987): Satellite remote sensing of drought conditions. Remote Sensing of Environment, Vol. 23: 243–251.
- Tutu, A. (2005): River management in Bangladesh: a people's initiative to solve water-logging. [Internet]. [cited 2014 January 01]. Available from: http://pubs.iied.org/pdfs/G02131.pdf .
- USGS: United States Geological Survey [Internet]. 2015. [cited 2014 November 20]. Available from: http://landsat.usgs.gov/Landsat8_Using_Product.php.
- Wilson, E.H., Sader, S.A. (2002): Detection of forest harvest type using multiple dates of Landsat TM imagery. Remote Sensing of Environment, Vol. 80: 385–396.

Abhay Sankar Sahu,
Assistant Professor,
Department of Geography,
University of Kalyani,
Kalyani, Nadia-741235,
West Bengal