Water inundation hazard and micro level basin hydromorphological relationships: a geographical assessment

Abhay Sankar Sahu¹

Received: 11 December 2015 / Accepted: 9 January 2016 / Published online: 23 January 2016
© Springer International Publishing Switzerland 2016

Abstract This paper is to evaluate the relationships between basin hydromorphological factors and water inundation issue delineating five broad watersheds in a micro level study area, Moyna basin of West Bengal, India, using remote sensing and GIS techniques along with mapping and measurement of the hazard affected areas. It is observed that hydromorphological characteristics have systematic non-linear complex co-relationships with this hazard. Drainage frequency, drainage density, drainage texture, form factor, elongation ratio, ruggedness index, and mean slope proportionate with water inundation; and constant of channel maintenance, length of overland flow, shape factor, basin relief, relief ratio, and embankment density disproportionate with it. Some factors response not significantly. Besides, high rainfall and low depth of groundwater level of Moyna basin increases inundation problem. Bhuvan web data, based on Resourcesat 1 (LISS III), during 2005–2006, has been considered here as the primary value and Resourcesat 2 (LISS IV) image data during pre and post rainy seasons of 2012–2014 as observed value. There it is observed that in Moyna basin water inundation is a permanent hazard but its area changes with time. Finally, there a water inundation model has been formed to evaluate and to compare water inundation/waterlogging based on considering ranks. In result, it is found that the central Moyna watershed has maximum water inundation/waterlogging problem. Small scale basin area study sometimes shows difficulties and also distortions from the general.

Keywords Flood basin · Waterlogged · Water inundation · Drainage congestion · NDWI

Introduction

The study of hydromorphology, a sub-field of hydrology, deals with structure, evolution, and dynamic morphology of hydrologic systems over time (Vogel 2011). There are many studies of Todd and Mays (2005), Biswas et al. (1999), Avinash et al. (2011), Rao (2009), and Roy and Sahu (2015) to understand the inter-relationships between morphometric indices and groundwater development. On the other side, surface water inundation controlled by hydromorphological factors is a field of exploration to assess the nature and extension of its hazardous attainment and adjustments with physical environment. Moyna basin, a typical trough shaped region almost encircled by rivers and canals from all sides, is situated in the district of Purba Medinipur of West Bengal, India. It is a relic of palaeo-Medinipur coast. In Bengali language, Moyna is equivalent to *Mohana* which refers to an area where river meets ocean or other water bodies. It is extended from 22°09'37"N to 22°18'58"N latitude and 87°42'17"E to 87°49'53"E longitude as well. Total area is around 131 km². This micro level Moyna basin is selected as the study area (Fig. 1). The prime objective of this paper is to evaluate the relationships between various basin hydromorphological factors as well as parameters and water inundation hazard after flooding and waterlogging in the Moyna basin using remote sensing and geographical information system (GIS) techniques. It is a geographical as well as a spatial study highlighting space and time relationships. Here it is to observe the nature of water inundation hazard over chorological and chronological scale. Finally, it is to assess

✉ Abhay Sankar Sahu
sahu.abhaysankar@gmail.com

¹ Department of Geography, University of Kalyani,
Kalyani 741235, West Bengal, India

Fig. 1 Moyna basin along with five watersheds, and water inundated areas (2005–2006) based on Bhuvan, NRSC (ISRO) web data

the strength of associations among the hydromorphological factors and water inundation, and issues of these relationships. Both flooding and waterlogging are two hazards known as problem of water inundation in the low-lying coastal areas where waterlogging sometimes found to be created as the after action of flooding and sometimes it is created due to accumulation of much rainwater on the lowlands after heavy rainfall within a very short time and both the hazards are water related quasi-natural and/or manmade inundation. Geological condition, morphological characteristics, surface and sub-surface water relation have significant role behind these flooding and/or waterlogging problems.

Materials and methods

For this study, topographical maps [Survey of India (SOI) 1972, 1973, 1976] of the scale of 1:50,000; Shuttle Radar Topography Mission (SRTM) Digital Elevation Map (DEM) of 30-m spatial resolution (USGS 2014); and Resourcesat 2 Linear Imaging Self-Scanning (LISS) IV images of the years of 2012 and 2014 of National Remote Sensing Centre (NRSC), Hyderabad, Indian Space Research Organisation (ISRO), India, have been used (NRSC 2012, 2014) to generate quantitative data along with other administrative and irrigation maps. Here, for the observation of relationships between basin hydromorphological factors/parameters and

water inundation, the study area, Moyna basin, has been divided into five broad watersheds (Fig. 1), north, west, central, east, and south, based on SRTM DEM of 30-m spatial resolution (USGS 2014), with the help of TNT Mips (version 2013) software. Again, all canal lines, small to large embankments, and surface elevation of the basin area taken into consideration extracting from topographical sheets (SOI 1972, 1973, 1976) to calculate watershed-wise basin hydromorphometric factors or parameters. Bhuvan web map (2005–2006) of NRSC (2014) based on Resourcesat 1 (LISS III) images for waterlogging has been taken to calculate watershed-wise water inundated areas during 2005–2006 which are the primary values (P_i) and observed values (O_i) are the water inundated areas digitised from the Resourcesat 2 LISS IV images during 2012–2014 (NRSC 2012, 2014) after processing through supervised classification, Normalized Difference Water Index (NDWI) with threshold zero (McFeeters 1996) and field experiences as well. The formula (Eq. 1) for NDWI, based on LISS IV bands, is as follows:

$$\text{NDWI} = \frac{(\text{Green i.e. Band 2} - \text{Near - infrared [NIR] i.e. Band 4})}{(\text{Green i.e. Band 2} + \text{Near - infrared [NIR] i.e. Band 4})} \quad (1)$$

NDWI ranges from -1 to $+1$ (McFeeters 1996). To delineate the water inundated areas, NDWI values ranges from 0 to $+1$ (Chowdary et al. 2008) have been considered. Chowdary et al. (2008), Sahu (2014a, b) studied the water-logged areas using NDWI values. The upper limit is $+1$ and it refers to the presence of extensive deep water bodies.

Simple statistical techniques like absolute error (AE) and percentage error (PE) used here to understand the spatial variation of water inundation with time. AE is the difference between two values, primary (P_i) and observed (O_i). And, PE is the difference between observed value (O_i) and primary value (P_i) divided by the primary value (P_i) at a certain time (t), 2005–2006 to 2012–2014.

In this study, basin hydromorphometric parameters like stream order (u), drainage frequency (D_f), drainage density (D_d), drainage texture (D_t), constant of channel maintenance (C_m), length of overland flow (L_o), form factor (F_f), shape factor (S_f), elongation ratio (E_R), circularity ratio (C_r), compactness co-efficient (C_c), basin relief (B_r), relief ratio (R_r), ruggedness index (R_i), mean slope (S), and embankment density (E_d) have been considered to observe the hydromorphological responses in Moyna basin and their relationships with water inundation (WI) hazard as well (Table 1).

Here, watershed-wise basin hydromorphometric variables calculated both for the time periods during 2005–2006 and 2012–2014 to observe which parameters are responding significantly against water inundation on

Table 1 Hydromorphometric parameters

Serial no	Hydromorphometric parameters	Formulas	Based on
1	Stream order (u)		Strahler (1964)
2	Drainage frequency (D_f)	$D_f = \Sigma N_u / A$; where D_f = drainage frequency; ΣN_u = total no. of drainage channels of different types; A = Area of the basin (km^2)	Horton (1932, 1945)
3	Drainage density (D_d)	$D_d = \Sigma L_u / A$; where D_d = drainage density (km/km^2); ΣL_u = Total length of all types of drainage channels; A = area of the basin (km^2)	Horton (1932, 1945)
4	Drainage texture (D_t)	$D_t = D_d \times D_f$; where D_f = drainage frequency and D_d = drainage density (km/km^2)	Horton (1945)
5	Constant of channel maintenance (C_m)	$C_m = 1/D_d$; where, D_d = drainage density	Schumm (1956)
6	Length of overland flow (L_o)	$L_o = 1/2D_d$; where, D_d = drainage density	Horton (1945)
7	Form factor (F_f)	$F_f = A/L^2$; where, A = area of the basin (km^2); L = basin length (km)	Horton (1932, 1945)
8	Shape factor (S_f)	$B_s = L^2/A$; where, L = basin length (km); A = area of the basin (km^2)	Horton (1932)
9	Elongation ratio (E_R)	$E_r = 1.128\sqrt{A/L}$; where, A = area of the basin (km^2); L = basin length (km)	Schumm (1956)
10	Circularity ratio (C_r)	$C_r = 4 \pi A/P^2$; where, A = area of the basin (km^2); P = perimeter (km); $\pi = 3.1415$	Miller (1953); Strahler (1964)
11	Compactness Co-efficient (C_c)	$C_c = 0.2821 P/A^{0.5}$; where, P = perimeter (km); A = area of the basin (km^2)	Gravelius (1914)
12	Basin relief (B_r)	$B_r = H - h$; where, H = maximum elevation in meter and h = minimum elevation in meter (topographical map based)	Hadley and Schumm (1961)
13	Relief ratio (R_r)	$R_r = R/L$; where, R = basin relief; L = longest axis in kilometre	Schumm (1956)
14	Ruggedness index (R_i)	$R_i = B_r \times D_d$; where, R_i = ruggedness index; B_r = basin relief; D_d = drainage density	Schumm (1956)
15	Mean slope (S)		Topographical map
16	Embankment density (E_d); (km/km^2)	$E_d = \Sigma E_u / A$; where E_d = embankment density (km/km^2); ΣE_u = total length of all types of embankments; A = area of the basin (km^2)	Topographical map

the one hand and also to highlight the observed problems of such inter-relationships on the other. Scatter diagram with best fit linear regression and Pearson's co-relationship with water inundation during 2005–2006 and 2012–2014 have been made to observe the strength of association along with directions of relationships. Finally, a model on water inundation/waterlogging hazard introduced highlighting responsible factors behind this type of hazard creation and watershed-wise of the Moyna basin five ranks (one, two, three, four and five), as there are five watersheds, implied for a comparison as well as to evaluate the area of water inundation/waterlogging like very high (rank one) when hydromorphometric relationship is positive to very low (rank five) when hydromorphometric relationship is negative. In a relationship study it is important to consider independent and dependent sides of the parameters. Here, water inundation is dependent variable and hydromorphometric variables are independent as they have physical nature of origin but obviously they are also continuously modified within human environment.

Flooding, waterlogging, and water inundation

In general, flooding, waterlogging, and water inundation are very loosely referred to the condition as well as environment of water submergence. Flooding is something larger concept than waterlogging condition and both are hazards referred as water inundation. Fluctuating river regime, water inundation, and embankments ab initio are interrelated. Both flooding, through breaching of the river-front embankments, and waterlogging, the result of blockage of water in the low-lying land surface, are two hazards found in Moyna basin. In this study water inundation (WI) and waterlogging (WL) are environmentally considered as the function of water accumulation over an area, non-economic, hazardous, and excluding ponds and reservoirs. Blocking of water is controlled by local geology, topography, drainage and the amount of water supplied to the site (Holden et al. 2009). Waterlogging in Moyna basin is a regular phenomenon every year found in the rainy season and also in the post rainy season,

particularly in the months of September to November, and in some certain areas it is found throughout the year as a permanent hazard (Sahu 2014a). In the flood history of West Bengal, Moyna has been shown as an endemic flood prone basin. In the years of 1950, 1958, 1978, 1982, and 1986 severe floods happened there due to breaching of the river-front embankments and significant drainage-congested waterlogging problem due to heavy rainfall was in the years of 1959 and 1981 though waterlogging every year more or less persisted there in rainy seasons.

WI study based on Bhuvan and Resourcesat 2 LISS IV (NRSC, ISRO)

Row 1 of Table 2 shows five broad watersheds (WS) of Moyna basin and their areal extensions. North Moyna watershed is the largest (36.34 km²) and then the central Moyna watershed is 35.45 km², followed by south Moyna watershed (31.22 km²), west Moyna watershed (16.42 km²), and lastly the smallest is east Moyna watershed of the area of 11.52 km². There is Bhuvan web map (2005–2006) based on Resourcesat 1 LISS III data of the NRSC thematic services (NRSC 2014), it depicts waterlogged as well as water inundated areas around 45 km² of the study area. These are considered as primary value (P_i) of water inundation for the calculation of PE. Bhuvan (NRSC, ISRO) web data extracted with the help of QGIS (version 2.6.1) software and then watershed-wise areas of Moyna basin have been calculated (Table 2; Row 2).

Images of Resourcesat 2 LISS IV (NRSC, ISRO), dated 06 May 2012 and 04 November 2014, have been analysed to understand the pre-rainy season and post rainy season water inundation respectively (Fig. 2a, b). After supervised classification and NDWI raster calculation (Fig. 2c, d) of

the LISS IV images (NRSC 2012, 2014), with the help of software, Moyna basin five watershed-wise final WI polygons have been digitised and then rectified them taking field observations under consideration (Fig. 2e, f; Table 2).

Row 3 of Table 2 shows five watershed-wise areal extensions of water inundated areas of the dated of 06 May 2012. There, it is found that in summer season central WS contains around 15.53-km² water inundated areas and it is more or less permanent feature used for fishing activity at present and other watersheds have negligible areas of water inundation which were dried due to natural and also for paddy cultivation. Table 2, row 4 shows water inundated areas of the dated of 04 November 2014 in the post-rainy season. Here also central WS contains maximum water inundated areas of about 24.06 km². Taking these two in consideration there is average WI for 2012–2014 in Table 2, row 5. There, it is found that central WS has maximum WI (19.79 km²). For comparison between WI (2012–2014) and WI (2005–2006), AE has been calculated (Table 2; Row 6). There, less difference (0.22) is found against central WS and maximum (9.43) is found to south WS. It is also supported by PE calculation in respect to 2005–2006 WI (Table 2; Row 7). This is due to the fact that central Moyna has permanent water inundation therefore temporal variation in-between 2005–2006 and 2012–2014 is less and other areas of Moyna basin have seasonal attestation of water inundation hazard and therefore calculation shows some problem of undertaken dates of images as observed values. Much number of images can overtake this problem obviously. And, it is also clear through field experiences that central portion of Moyna basin has maximum water inundation problem than other areas. Thus, Moyna basin has experienced temporal and spatial variations of water inundation hazards.

Table 2 Moyna basin watersheds (WS) and water inundation (WI) statistics

Row	Features	North Moyna WS	West Moyna WS	Central Moyna WS	East Moyna WS	South Moyna WS
1	Watershed area (km ²)	36.34	16.42	35.45	11.52	31.22
2	Water inundated area (km ²) based on Bhuvan (NRSC; ISRO) 2005–2006	4.01	1.19	20.01	1.24	10.47
3	Water inundated area (km ²) based on Resourcesat 2 (LISS IV) 06-May-2012	0.15	0.54	15.53	0.34	0.27
4	Water inundated area (km ²) based on Resourcesat 2 (LISS IV) 04-November-2014	2.79	0.69	24.06	0.62	1.81
5	Water inundated area (km ²) based on Resourcesat 2 (LISS IV) Average 2012–2014	1.47	0.62	19.79	0.48	1.04
6	Absolute error (AE) between 2005–2006 and 2012–2014	2.54	0.57	0.22	0.76	9.43
7	Percentage error (PE) between 2005–2006 and 2012–2014	63.34	47.90	1.10	61.29	90.07

Fig. 2 **a** and **b** Resourcesat 2 (LISS IV) FCC, **c** and **d** NDWI with threshold zero, **e** and **f** water inundated areas

Relationship: hydromorphometric parameters and water inundation (WI)

Basin morphometry is very significant to study on the surface and sub-surface hydrological condition of a drainage basin (Obi Reddy et al. 2004; Rao 2009; Martin and Gadiga 2015). Table 3 shows hydromorphometric parameters, their watershed-wise values, and values of their Pearson co-relationship with water inundation against the years of 2005–2006 and 2012–2014 respectively. Figs. 3 and 4 show scatter diagram along with linear trend for these hydromorphometric variables against WI values of 2005–2006 and 2012–2014 respectively.

Moyna basin is surrounded by the rivers Kasai and Chandia from the east and west respectively. River Chandia and Keleghai are on the south and the Baksi canal is on the north as well. This Moyna flood basin is situated on the Lowe Gangetic drainage basin where stream orders of Kasai river, Chandia river and Keleghai river in respect to this Lowe Gangetic drainage basin are high following the hierarchical rank considering all the rivers generated from Chotonagpur plateau and western parts of West Bengal. On a larger scale, if we consider plain lands formed on both the banks of a river, very near to the mouth on ocean, with wide width and larger stream order, then there it is generally found the low-lying areas where onset of flooding and waterlogging have larger probability or chances.

The high value of stream frequency indicates greater surface run-off and a steep ground surface (Horton 1932, 1945). Following Horton (1932, 1945), taking all the canals in consideration, drainage frequency (D_f) and drainage

density (D_d) of them have been calculated, and in Moyna basin they are positively co-related with water inundation (Table 3), and for the period of 2012–2014 association is much significant than the period of 2005–2006. In general, high drainage frequency (D_f) and high drainage density (D_d) on a large extended area show total number of drainage channels and their lengths in respect to area and there surface water could be clear rapidly through these channels which will lead to low chances of water inundation in that area. But, in Moyna basin (131 Km^2), which is not extended highly, where, Chandia, Kasai and Keleghai rivers are found to surrounding it, but topographic condition (central and south-east low-lying) of this area overtakes drainage frequency and drainage density characteristics thus there has not established high significant relationship with water inundation. In Moyna basin, the drainage system presents a sewerage condition and maximum water drained by natural and manmade canals. During the rainy season, water is not clearly drained out from the basin due to its negative slop. Consequently, waterlogging is generated in the drainage-congested areas during rainy season every year and once there flood happened after breaching the river-front embankments, the accumulated water cannot drain out. If we consider the total number of drainage channels of different types of canals then and therefore for a small area like Moyna basin it has positive relationship with water inundation since in a drainage-congested area number of drainage channels particularly number of canals is high. Likely, high drainage density (D_d) including all types of drainage channels for a particular small low-lying area indicates the probability of

Table 3 Basin hydromorphometric parameters and relation with water inundation (WI)

Hydromorphometric Parameters	North Moyna WS	West Moyna WS	Central Moyna WS	East Moyna WS	South Moyna WS	Pearson's co-relationship with WI (2005–2006)	Pearson's co-relationship with WI (2012–2014)
Drainage frequency (D_f)/km ²	0.69	0.91	1.27	1.13	0.38	0.20	0.60
Drainage density (D_d) in km/km ²	1.05	0.88	2.02	1.52	0.79	0.58	0.82
Drainage texture (D_t)/km	0.72	0.80	2.57	1.71	0.30	0.53	0.81
Constant of channel maintenance (C_m)	0.96	1.14	0.49	0.66	1.26	−0.41	−0.70
Length of overland flow (L_o)	0.48	0.57	0.25	0.33	0.63	−0.41	−0.70
Form factor (F_f)	0.32	0.20	0.44	0.46	0.20	0.26	0.51
Shape factor (S_f)	3.15	4.93	2.27	2.19	5.12	−0.22	−0.49
Elongation ratio (E_R)	2.08	1.52	2.24	1.71	1.77	0.73	0.75
Circularity ratio (C_r)	0.50	0.27	0.42	0.60	0.31	−0.18	0.00
Compactness co-efficient (C_c)	1.42	1.93	1.54	1.29	1.80	0.04	−0.12
Basin relief (B_r) in m	14.00	4.00	4.00	3.00	9.00	−0.08	−0.29
Relief ratio (R_r) in m/km	1.31	0.44	0.45	0.60	0.71	−0.26	−0.35
Ruggedness index (R_i)	14.63	3.51	8.09	4.55	7.14	0.18	0.11
Mean slope (S) in degree	0.0199	0.0161	0.0173	0.0078	0.0182	0.40	0.21
Embankment density (E_d) in km/km ²	1.36	1.90	1.59	2.44	2.16	−0.33	−0.42

drainage-congestion which further leads to water inundation positively. D_f and D_d are maximum in central WS than other areas where WI areas are also high.

Drainage texture (D_t) is another vital factor to understand the basin water inundation character. It helps to understand the relationship between vegetation cover, soil texture and structure, and channel spacing (Horton 1945; Smith 1950; Schumm 1956). It is based on drainage frequency (D_f) and drainage density (D_d) of an area, and is positively correlated with water inundation hazard. Smith (1950) classified D_t as coarse (<4/km), intermediate (4–10/km), fine (10–15/km) and ultra-fine (>15/km). In Moyna basin coarse texture surface is found because the highest value is 2.57 of central WS. Here strength of association is also high during 2012–2014.

Constant of channel maintenance (C_m) and length of overland flow (L_o) are the inverse of drainage density (D_d). C_m depends on rock type, permeability, climatic regime, vegetation cover and relief. As per Horton (1945), L_o has a crucial role towards controlling hydrological and physiological developments of a drainage basin. L_o indicates the length of flow path-way of water over the land surface

before it reaches to the nearest drainage channels. In Moyna basin, they are negatively correlated with water inundation as they are the inverse of D_d as well.

Shape of the basin is an important parameter of basin hydrological analysis (Horton 1932). Form factor (F_f), shape factor (S_f) and elongation ratio (E_r) are calculated considering area and length of the WS. Both high F_f and high E_r lead to low relief. High E_r value indicates high infiltration capacity and low run-off, and low E_r value indicates higher elevation of the basin (Obi Reddy et al. 2004; Manu and Anirudhan 2008). Where percentage of clay soil is high in a trough region there low run-off indicates water inundation condition after a heavy rainfall. It is found to be applicable for Moyna basin. According to Schumm (1956), E_r value close to 1.0 indicates low relief regions (in Moyna basin all values are more than 1.50) and the values ranges from 0.6 to 0.8 are generally associated with high relief and steep ground slopes. In the low relief areas with low run-off like Moyna basin have high F_f and high E_r values positively correlated with water inundation. Level of significance of S_f is very less (−0.22 and −0.49) and it shows a negative trend.

Fig. 3 Relationship between WI (2005–2006) and hydromorphometric factors

Circularity ratio (C_r) is more influenced by drainage length and drainage frequency (D_f). If the C_r value is 1.0 then the basin will be a perfect circle in shape and discharge quantity would be high (Miller 1953). Compactness coefficient (C_c) referred to the ratio between the length of the watershed boundary (the perimeter) and the perimeter

of a circle having the same area, where, the resultant value 1.0 indicates to a perfect circle basin (Gravelius 1914; Hidore 1964; Reddy 2005). In Moyna basin both C_r and C_c values show insignificant relationship with WI.

Different relief based parameters are helpful to understand the hydromorphological characteristics of any basin

Fig. 4 Relationship between WI (2012–2014) and hydromorphometric factors

area (Strahler 1957; Schumm 1956). Basin relief (B_r), relief ratio (R_r), ruggedness index (R_i), and basin average slope (S) of a basin show the geomorphological characteristics of that area. High to low values of these parameters indicate rugged to flat or gentle topography of the area respectively

(Schumm 1956; Strahler 1957; Hadley and Schumm 1961; Sreedevi et al. 2005). In general, low values of basin relief (B_r) and relief ratio (R_r) lead to high probability of water inundation. In Moyna basin it is found that both B_r and R_r negatively correlated with WI. Ruggedness index (R_i)

depends on basin relief (B_r) and drainage density (D_d). In Moyna, R_i positively correlated with WI. High mean slope (S) leads to low WI. In Moyna basin, settlements and embankments only bring relief variations at the micro level. Maximum areas have elevation within 3 m and the slope is varying from 0° to 0.98° . Since slope is very feeble in Moyna basin and there from the outer riverine embankments toward centre the basin gets deep gradually which is marked as negative slope for the purpose of water discharging from the basin therefore it is not responded with high significant level and also shows positive relationship with WI, while it is not happened in general. There are two depressions, one in the centre and another in the south-east corner. In Moyna basin, R_i and slope show insignificant relation with water inundation. Embankment density (E_d) is negatively correlated with water inundation. There, it is also found that due to surface blockage through embankments surface waterlogging initiated in the south-eastern part.

Climate, soil, groundwater and embankments

Recent data shows based on Indian Meteorological Department i.e., IWD (2014), the district Purba Medinipur received in the year of 2013 rainwater much than the normal. There was annual rainfall about 2152.40 mm whereas the normal was about 1669.60 mm; and particularly in the monsoon period, 2013, it was about 1908.90 mm when the normal was around 1417.20 mm. In Moyna basin, average annual rainfall is around 1500 mm of which 80 % takes place during monsoon period (Sahu 2009). In general, Moyna basin in the district Purba Medinipur receives much rainfall within a very short span of time during monsoon period. Particle distribution of soil of the Moyna basin proved that the clay (48.3 %) is much more than silt (43 %) and sand (8.7 %). Here it is referred to as coastal alluvium type of soil which in the district of Purba Medinipur is around 1842 km² (DDMP 2007). Higher percentage of clay indicates slower rate of vertical accretion under standing water. In Moyna basin the groundwater depth ranges in-between 4 and 7 m (Basack and Bhattacharya 2012). After analysing average groundwater depth for the months of April, August and November, during 2000–2008, collected from SWID (2015), it is also observed that in Moyna basin it ranges in-between 5 and 15 m below the ground level as well, which is positively significant for the creation of water inundated environment quite permanent in nature on the such a low-lying trough region of Moyna basin. Through field observations, it is revealed on micro scale that small to large embankments take a vital role to initiate waterlogging condition through interrupting the natural surface water flow,

particularly in the areas where embankment density is high. But, in this study, based on topographical sheets (SOI 1972, 1973, 1976), Table 3 shows negative relationship between embankment density and WI, it is because of number of high embankments is less where water inundation found extensively throughout the year and number of population as well as number of settlements is also low therein.

Model of water inundation/waterlogging (WI/WL) evaluation and watershed-wise comparative study

Water inundation is the consequence of all round intra and inter-relationship of climatic, geomorphic, hydrologic, vegetative and anthropogenic factors in our planetary environment. It shows non-linear complex relationships with various hydromorphological factors. Here, in Moyna basin, it is observed that stream order, drainage frequency, drainage density, drainage texture, form factor, elongation ratio, ruggedness index, and mean slope proportionate with WI; and constant of channel maintenance, length of overland flow, shape factor, basin relief, relief ratio, and embankment density disproportionate with it. There some factors response not significantly like circularity ratio and compactness coefficient; and also some are different from the wide accepted general laws like slope and embankment density. Particularly embankment density reveals both the facts like in some areas where WI is high there embankment density is low (negative relationship) as there settlement density is low, here water inundation or waterlogging is independent factor, again in some areas where embankment density is high there WI is also high (positive relationship) due to surface blockage, here water inundation or waterlogging is dependent factor on embankments. WI relationships with hydromorphological factors sometimes vary with changing time and place from a general nomothetic consensus; therefore, idiographic study is necessary for a small scale basin area like Moyna. After analysing all the considered hydromorphological parameters and their relationships with WI, comprising field experiences, present results, and general laws, it could be stated maximum that water inundation/waterlogging is the function (f) of rainfall (R), basin relief (B_r), relief ratio (R_r), mean slope (S), drainage frequency (D_f), drainage density (D_d), embankment density (E_d), groundwater depth (G_d), and soil type (S_t). It could be shown as formula (Eq. 2) as follow:

$$WI = f(R, B_r, R_r, S, D_f, D_d, E_d, G_d, S_t) \quad (2)$$

Using this Eq. 2 we can evaluate the comparative state of WI putting the ranks against types (positive or negative) of relationship in-between WI/WL as dependent variable

Table 4 WI model hydromorphometric parameters rank comparison Moyna basin WS-wise

Hydromorphometric parameters	North Moyna WS	West Moyna WS	Central Moyna WS	East Moyna WS	South Moyna WS
Rainfall in mm (R)	3	3	3	3	3
Basin relief (B_r) in metre	1	2.50	2.50	5	2
Relief ratio (R_r) in metre/km	5	1	2	3	4
Mean slope (S) in degree	5	2	3	1	4
Drainage frequency (D_f)/km ²	4	3	1	2	5
Drainage density (D_d) in km/km ²	3	4	1	2	5
Embankment density (E_d) in km/km ²	5	3	4	1	2
Groundwater depth in metre (G_d)	1	1	1	1	1
Soil type (S_t)	1	1	1	1	1
Total score (low value refers to high WI)	28	20.50	18.50	19	27
%	25	18	16	17	24

and hydromorphometric factors as independent variables. Table 4 shows watershed-wise Moyna basin hydromorphometric ranks in relation to WI where low value refers to high water inundation/waterlogging. When WI and hydromorphometric variable positively correlated then rank one is for high hydromorphometric value and rank five is for low hydromorphometric value. Again, when WI and hydromorphometric variable negatively correlated then rank one is for low hydromorphometric value and rank five is for high hydromorphometric value as well.

Since Moyna basin is a small scale basin therefore watershed rainfall calculation is meaningless (it is applicable for larger region). Based on IMD (2015), very low rainfall: 250–500 mm (rank five), low rainfall: 500–1000 mm (rank four), moderate rainfall: 1000–2000 mm (rank three), high rainfall: 2000–3000 mm (rank two), and very high rainfall: >3000 mm (rank one), Moyna basin comes under rank three considering its rainfall amount on an annual average (1500 mm). Very low groundwater depth (4–7 m) and soil type (clay—48.3 %) considered here in Moyna basin as highly favourable for the creation of WI therefore rank one is given to all watersheds (as it is a micro level study area) in Table 4.

Finally, total score shows that central Moyna basin watershed area ranked very low (18.50) which refers to maximum WI area, around 20 km² (Tables 2, 4).

Conclusions

There are many hydromorphological favourable conditions like drainage density, basin relief, slope, and embankment density of Moyna basin for the onset of water inundation every year especially after waterlogging and flooding as well. Extensive central and south-east low-lying areas, low and negative slope, heavy rainfall within a short span of time, favourable soil to hold water on the surface, presence

of groundwater within a very short depth from the ground level, and high canal density with haphazard embankments as well as high embankment density also create condition toward water inundation. When, river-front embankments breaches then this water inundation becomes more devastating. Flood history of Moyna indicates drainage-congestion and thereafter waterlogging situation. Drainage-congestion for a short period may create a break in natural flow of water temporarily, but if a basin remains flooded and/or waterlogged for months together then the environmental system cannot restore balance by homeostatic mechanism or it requires a long lag time to strike a balance. From 1985 to 1986, the Moyna-drainage-basin canal has drained out the excess accumulated water from the basin. Local inhabitants once were worried about the waterlogged environment for a certain period, but today they taking this environmental condition as an offer for fishing activity and thus they are becoming economically benefitted as well.

Acknowledgments This paper is a part of study under UGC-BSR Start-up Grant Scheme on ‘Environmental Consequences of Water-Logging Problem in Purba Medinipur District, West Bengal: Evaluation, Mapping, and Management’. The author acknowledges University Grants Commission (UGC), New Delhi, India, for this project.

References

- Avinash K, Jayappa KS, Deepika B (2011) Prioritization of sub-basins based on geomorphology and morphometric analysis using remote sensing and geographic information system (GIS) techniques. *Geocarto Int* 26(7):569–592
- Basack S, Bhattacharya AK (2012) Significance of hydro-geological and hydro chemical analysis in the evaluation of groundwater resources: a case study from the east coast of India. *IOSR J Eng* 2(9):61–71
- Bhuvan web map (2005–2006) <http://bhuvan.nrsc.gov.in/gis/thematic/index.php>. Accessed 12 Feb 2015
- Biswas S, Sudharakar S, Desai VR (1999) Prioritization of sub-watersheds based on morphometric analysis of drainage basin: a

- remote sensing and GIS approach. *J Indian Soc Remote Sens* 27:155–166
- Chowdary VM et al (2008) Assessment of surface and sub-surface waterlogged areas in irrigation command areas of Bihar state using remote sensing and GIS. *Agric Water Manag* 95:754–766. doi:[10.1016/j.agwat.2008.02.009](https://doi.org/10.1016/j.agwat.2008.02.009)
- DDMP (2007) District disaster management plan (DDMP) of Purba Medinipur, Tamluk. Office of the District Magistrate, Purba Medinipur, West Bengal
- Gravelius H (1914) *Grundrifi der gesamten Gewissserkunde*. Band I: Flufkunde (Compendium of hydrology, vol I. Rivers, in German). Germany, Goschen, Berlin
- Hadley RF, Schumm SA (1961) Sediment sources and drainage basin characteristics in upper Cheyenne River basin. *US Geol Surv Water Supply Pap* 1531-B:137–198
- Hidore JJ (1964) Landform characteristics affecting watershed yields on the Mississippi–Missouri interfluv. In: Moore GA (ed) *Proceedings of the Oklahoma academy of science*. University of Central Oklahoma, Oklahoma, pp 201–203
- Holden J, Howard AJ, West LJ, 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. *J Environ Manag* 90:3197–3204. doi:[10.1016/j.jenvman.2009.04.015](https://doi.org/10.1016/j.jenvman.2009.04.015)
- Horton RE (1932) Drainage basin characteristics. *Trans Am Geophys Union* 13:350–361. doi:[10.1029/TR013i001p00350](https://doi.org/10.1029/TR013i001p00350)
- Horton RE (1945) Erosional development of streams and their drainage basins: hydro physical approach to quantitative morphology. *Geol Soc Am Bull* 56:275–370. doi:[10.1130/0016-7606\(1945\)56\[275:EDOSAT\]2.0.CO;2](https://doi.org/10.1130/0016-7606(1945)56[275:EDOSAT]2.0.CO;2)
- IMD (2015) Indian Meteorological Department (IMD). [http://hydro.imd.gov.in/hydrometweb/\(S\(1kubsr45rfqvclqoisobtu45\)\)/PdfPa gelImage.aspx?imgUrl=PRODUCTS/Rainfall_Maps/Normal_Rain fall_Maps/Annual/State/annual_STATE_NORMAL_RAINFALL_MAP_COUNTRY_INDIA_c.JPG&landingpage=landing](http://hydro.imd.gov.in/hydrometweb/(S(1kubsr45rfqvclqoisobtu45))/PdfPa gelImage.aspx?imgUrl=PRODUCTS/Rainfall_Maps/Normal_Rain fall_Maps/Annual/State/annual_STATE_NORMAL_RAINFALL_MAP_COUNTRY_INDIA_c.JPG&landingpage=landing). Accessed 09 Dec 2015
- IWD (2014) Irrigation and Waterways Directorate (IWD), government of West Bengal. Annual Flood Report for the year 2013. Advance planning, project evaluation and monitoring cell, Jalasampad Bhavan, Salt Lake, Kolkata, West Bengal. http://www.wbiwd.gov.in/pdf/ANNUAL_FLOOD_REPORT_2013.pdf. Accessed 16 Jun 2015
- Manu MS, Anirudhan S (2008) Drainage characteristics of Achankovil river basin, Kerala. *J Geol Soc India* 71:841–850
- Martin AK, Gadiga BL (2015) Hydrological and morphometric analysis of upper Yedzaram catchment of Mubi in Adamawa State, Nigeria using geographical information system (GIS). *World Environ* 5(2):63–69. doi:[10.5923/j.env.20150502.03](https://doi.org/10.5923/j.env.20150502.03)
- Mcfeeters SK (1996) The use of normalized difference water index (NDWI) in the delineation of open water features. *Int J Remote Sens* 17:1425–1432
- Miller VC (1953) A quantitative geomorphic study of drainage basin characteristics in the Clinch mountain area, Virginia and Tennessee. Department of Navy, Office of Naval Research, Technical Report 3, Washington DC, Project NR 389-042
- NRSC (2012) 2014 Resourcesat 2 LISS IV images. National Remote Sensing Centre (NRSC). ISRO, Hyderabad
- NRSC (2014) Salt-affected and waterlogged areas of India. Soil and land resources assessment division. Land Resources Use and Monitoring Group. National Remote Sensing Centre (NRSC). Hyderabad, India. <http://bhuvan.nrsc.gov.in/gis/thematic/tools/document/ALK/alk.pdf>. Accessed 26 Feb 2015
- Obi Reddy GP, Maji AK, Gajbhiye KS (2004) Drainage morphometry and its influence on landform characteristics in a basaltic terrain, central India: a remote sensing and GIS approach. *Int J Appl Earth Obs Geoinf* 6(1):1–16. doi:[10.1016/j.jag.2004.06.003](https://doi.org/10.1016/j.jag.2004.06.003)
- Rao SN (2009) A numerical scheme for groundwater development in a watershed basin of basement terrain: a case study from India. *Hydrogeol J* 17:379–396. doi:[10.1007/s10040-008-0402-2](https://doi.org/10.1007/s10040-008-0402-2)
- Reddy JR (2005) A textbook of hydrology. University Science Press, New Delhi
- Roy S, Sahu AS (2015) Investigation for potential groundwater recharge area over the Kunur river basin, Eastern India: an integrated approach with geosciences. *J Geomat* 9(2):165–177
- Sahu AS (2009) Embankments in relation to the physical and economic systems in the Moyna drainage Basin, W.B. *Geogr Rev India* 71(1):61–68
- Sahu AS (2014a) A study on Moyna basin water-logged areas (India) using remote sensing and GIS methods and their contemporary economic significance. *Geogr J* 2014:1–9. doi:[10.1155/2014/401324](https://doi.org/10.1155/2014/401324)
- Sahu AS (2014b) Identification and mapping of the water-logged areas in Purba Medinipur part of Keleghai river basin, India: RS and GIS methods. *Int J Adv Geosci* 2(2):59–65. doi:[10.14419/ijag.v2i2.2452](https://doi.org/10.14419/ijag.v2i2.2452)
- Schumm SA (1956) Evolution of drainage system and slope in badlands at Perth Amboy, New Jersey. *Geol Soc Am Bull* 67:597–646. doi:[10.1130/0016-7606\(1956\)67\[597:EODSAS\]2.0.CO;2](https://doi.org/10.1130/0016-7606(1956)67[597:EODSAS]2.0.CO;2)
- Smith KG (1950) Standards for grading texture of erosional topography. *Am J Sci* 248:655–668
- Sreedevi PD, Subrahmanyam K, Ahmed S (2005) The significance of morphometric analysis for obtaining groundwater potential zones in a structurally controlled terrain. *Environ Geol* 47:412–420
- Strahler AN (1957) Quantitative analysis of watershed geomorphology. *Trans Am Geophys Union* 38(6):913–920
- Strahler AN (1964) Quantitative geomorphology of drainage basins and channel networks. In: Chow VT (ed) *Handbook of applied hydrology*. McGraw Hill, New York, pp 39–76
- SWID (2015) State Water Investigation Directorate (SWID). Government of West Bengal, Kolkata
- Todd DK, Mays LW (2005) *Groundwater hydrology*, 3rd edn. Wiley, New York
- USGS (2014) Shuttle radar topography mission (SRTM) Digital elevation map (DEM) of 30 m spatial resolution. United States Geological Survey (USGS), USA. Available from web data products of <http://www.usgs.gov/> or <http://earthexplorer.usgs.gov/>. Accessed 24 Feb 2015
- Vogel RM (2011) Hydromorphology. *J Water Resour Plan Manag* 147–149. <http://engineering.tufts.edu/cee/people/vogel/documents/hydromorphologyEditorial.pdf>. Accessed 23 Sep 2015