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# Impact of flood and seasonality on wetland changing trends in the Diara region of West Bengal, India

Kaustuv Mukherjee[1,2] (iD) · Swades Pal[3] · Malay Mukhopadhyay[2]

**Abstract** The hydrological condition of any floodplain wetland depends on the water availability through surface run-off from adjacent areas. The seasonal variation of rainfall and resultant flood bring massive change in the wetlands of that region. The present study focuses on identifying wetland inventories and trend of wetlands of the Diara region of West Bengal. Diara region of Eastern India is a highly dynamic physical region bounded by two frequently shifting rivers (River Ganga and Kalindri) and relatively tightly bound river Mahananda in its three sides. Two types of Normalised Difference Water Index, water presence frequency and hydrological stability analysis using LANDSAT data of 1973–2016 have been done for this study. The result shows that the wetland area was 14,124.78 ha during 1999 and it has turned into 4885.92 ha during 2016 which indicates the extreme flood event of 1998–1999 over entire region has brought a boost in the wetland scenario for a shorter period but it is in the decaying phase now-a-days. Total 1552.56 ha of wetland in this area is identified as stable based on the regular appearance of water over there.

✉ Kaustuv Mukherjee
kaustuv2000@gmail.com

Swades Pal
swadeshpal82@gmail.com

Malay Mukhopadhyay
malaygeo56@gmail.com

1   Department of Geography, Chandidas Mahavidyalaya, Khujutipara, Birbhum 731215, India

2   Department of Geography, Visva-Bharati University, Santiniketan 731235, India

3   Department of Geography, University of Gour Banga, Malda 732103, India

**Keywords** Floodplain · Diara region · Wetland inventory · NDWI · Stability

## 1 Introduction

Wetlands are the transitional ecosystems of the earth where the characteristics of both land and water are present. According to Ramsar Convention, wetlands can be defined as "…areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed 6 m" [1, 2]. Wetland identification in that particular region is quite a tedious job but essential for delineating wetland of immense ecological importance for initiating wetland conservation plan and management strategies [3]. Numerous studies have been already performed to identify the wetlands with the aid of RS-GIS [4, 5] addressing wetland issues. O'Hara [5] has portrayed the application of hyper-spectral imageries and RS-GIS tools for mapping and assessing of wetlands. Klemas and Pieterse [6] have shown the use of remote sensing product in mapping and monitoring the water resources. Talukdar and Pal [3, 7], Mondal and Pal [8], Das and Pal [9] and Pal and Saha [10] have highlighted changing wetland dynamics in different hydro-ecological stages of Barind regions and Lower Gangetic flood plain wetlands using RS-GIS. Sarkar et al. [11] applied fuzzy rules in GIS environment for assessing risk on east Kolkata wetland of International importance. Pal and Talukdar [12] used logistic regression and frequency ratio models for assessing wetland vulnerability in Punarbhaba river basin.

Dutta et al. [13] briefly stated that flood-plain wetlands are more common in eastern and north-eastern India,

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mainly along the basin of River Ganga, Brahmaputra and Barak. About 42,000 ha of area in West Bengal are floodplain wetlands which constitutes 22% of total freshwater area of the state [13, 14]. But these flood plain wetlands are highly dynamic in their appearance, ecosystem instability and ensuing semi-natural and anthropogenic interventions [8, 15] like de-linking of wetland from parent river [3], agricultural extension toward wetland [15, 16], reduction of river flow [9, 17]. Spencer et al. [18] focused on the wetland change due to sea level rise. So, preservation of wetlands, continuous monitoring of wetland is highly essential. Categorisation of wetland is also required for exploring proper idea about the nature, pattern and stability conditions of the wetlands. Frequency and magnitude of flood can determine spatial extent of seasonal wetlands. Large flood incidents connect the isolated wetlands and present as an extensive one in the flood plain region [8]. In this study, the major objective is to explore the status of wetlands overtime so that major hydrological determinants of wetland changes can be identified from multi temporal satellite imageries.

## 2 The study area

Fluvially originated Diara region covers an area of 880.79 km$^2$ (Fig. 1) out of which half of the area (447 km$^2$ or 50.79%) is of active flood plain and that is due to the wide (average 15 km) shifting corridor of river Ganga over this region [21]. Geologically, about 62% of the region is composed of recent deposit where alternate sequence of sand, silt and clay are present and rest part composed with relatively older alluvium. Most of the region ranges in between 19 and 29 m elevation as per Aster DEM, 2011. Annual average rainfall is 1500 mm and of this 80% happens during monsoon months (June to September). This physical region is highly dynamic in its spatial extension mainly due to frequent shifting of channel of river Ganga and Kalindri [20]. In between 1973 and 2016, the total reduction in the areal coverage of this Diara region is about 40 km$^2$ (it was 920.78 km$^2$ in 1973 and 880 km$^2$ in 2016) which signifies the impact of Ganga River on the land loss of this area [19]. Therefore, the wetland present within the channel shifting corridor is prone to frequent change. The study area experienced massive flood in 1998 and 1999.

## 3 Materials and methods

To delineate the boundary of the Diara region, we have used Survey of India topographical sheet of 1975 (Scale = 1:50,000) and False Colour Composite (FCC) prepared from LANDSAT imageries of 15 years in between 1973 and 2016. Wetlands identification, validation, classification and analysis are done using LANDSAT imageries, supervised classification maps, Fishery Department's data of Govt. of West Bengal, Google Earth data and field survey data. The details of LANDSAT imageries used in this study are shown in Table 1.

### 3.1 Identification of wetlands

Atmospheric and radiometric corrections of all the necessary imageries have been done using ERDAS IMAGINE 9.2 before preparing Normalized Difference Water Index (NDWI). After such calibrations, all the calculations and mapping are performed using ArcGIS 10, ENVI 4.7, GRASS GIS 7.2.1 and Surfer 8 softwares.

NDWI has been calculated using the following equations [21]:

$$NDWI_{Mcfeeters} = \frac{R_{Green} - R_{NIR}}{R_{Green} + R_{NIR}} \tag{1}$$

This equation has been mainly helpful to extract the open water-bodies from the multispectral satellite imageries. But, we know that wetlands are not only the open water-bodies, it also includes the aquatic vegetation [1, 2, 22] which has high content of water in their stems and leafs. For identifying those areas, NDWI$_{Gao}$ equation has been applied (Eq. 2) [23].

$$NDWI_{Gao} = \frac{R_{NIR} - R_{SWIR}}{R_{NIR} - R_{SWIR}} \tag{2}$$

In these two equations, NIR (Near Infra-Red), SWIR (Short Wave Infra-Red) and Green bands of the LANDSAT data have been used. In both the cases, the value of NDWI ranges between $-1$ to 1 where positive values indicate water bodies.

After preparing the NDWI$_{Mcfeeters}$ and NDWI$_{Gao}$, only water pixels are taken into consideration. After that these raster images are combined together where we get only the water-body area for a particular year using Eq. 3. The similar procedure has been followed for all other years from 1973 to 2016. Next, the common area of water-body has been validated over the supervised image classification from IRS LISS IV imageries (5.8 m spatial resolution) and Google Earth data 2016. GPS survey is also conducted for field verification.

$$WI_{Y_1} = [(NDWI_{Mcfeeters})_{Y_1} + (NDWI_{Gao})_{Y_1}] - NW_p \tag{3}$$

where $WI_{Y_1}$ is the wetland inventory of the initial year (here 1973), $(NDWI_{Mcfeeters})_{Y_1}$ and $(NDWI_{Gao})_{Y_1}$ are the results of Eqs. 1 and 2 and $NW_p$ is the non-water pixels which are removed from the combined image of that particular year. The same procedure has been followed for 'n' number of
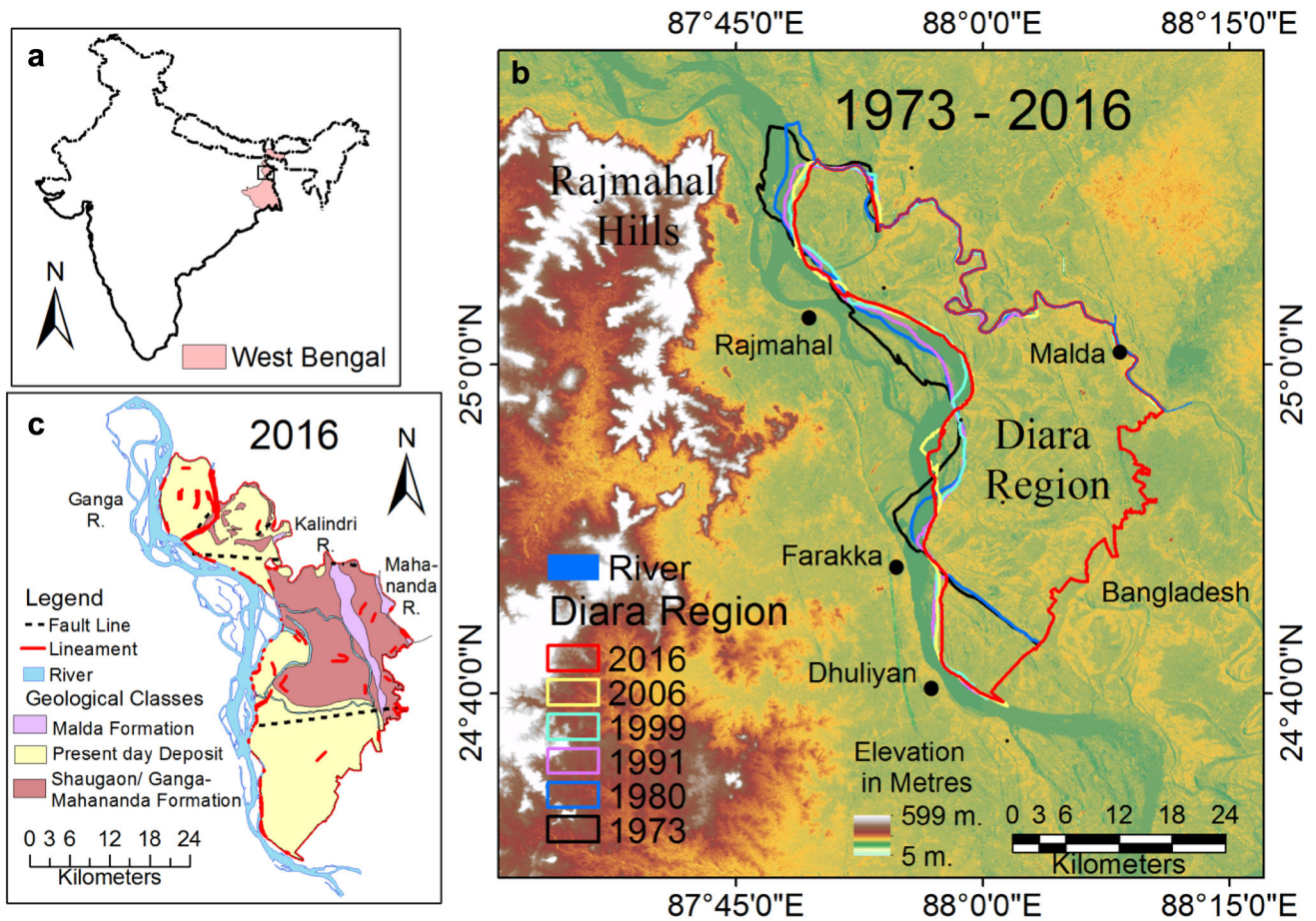
**Fig. 1** Study area map **a** location of the Diara region within India, **b** dynamic character of the Diaraboundary due to shifting of river Ganga in between 1973 and 2016 over the elevation map and **c** geological background of the Diara region

**Table 1** Details of LANDSAT MSS (multi-spectral sensor), TM (thematic mapper), ETM (environmental thematic mapper) and OLI-TIRS (operational land imager-thermal infra-red sensor) data used in this study. *Source*: USGS Earth Explorer, 2016

| Satellite | Sensor | Path/Row | Year | Spatial resolution (m.) |
|---|---|---|---|---|
| LANDSAT-1, 2 & 3 | MSS | 149/43 | 1973–1979 | 60 |
| LANDSAT-5 | TM | 139/43 | 1991, 2006–2011 | 30 |
| LANDSAT-7 | ETM | 139/43 | 2000–2003 | |
| LANDSAT-7 | ETM+ | 139/43 | 1999 | 30 |
| LANDSAT 8 | OLI-TIRS | 139/43 | 2013–2016 | 30 |

years ($WI_{Y_n}$). Now, wetland area for present day has been calculated with the help of Eq. 4.

$$WI_P = \left\{ \sum (WI_{Y_1} + \cdots + WI_{Y_n}) \right\} + \left( Val_{GE_{Y_n} + SC_{Y_n} + FI_{Y_n}} \right) \tag{4}$$

where $WI_P$ is the wetland inventory for present days, $WI_{Y_1}$ and $WI_{Y_n}$ are the outputs of Eq. 3, $Val_{GE_{Y_n} + SC_{Y_n} + FI_{Y_n}}$ is the validation of the wetland inventory images based on

Google Earth ($GE_{Y_n}$) data, supervised classification ($SC_{Y_n}$) and field investigation ($FI_{Y_n}$) of nth year (here 2016).

Such kind of operations has been done for both pre 1998–1999 and post 1998–1999 situations. Total 5 sample years for pre 1998 and 13 sample years for post 1998 have been taken to identify wetlands of the Diara region as per the clarity and availability of images.

Total 105 reference sites have been taken for validation of wetlands where all points are used for validation from supervised classification and Google Earth data. Among

these sites, 35 sites have been selected for field verification and the rest 70 sites are validated over only supervised classification and Google Earth data (Fig. 2). For accuracy assessment kappa statistics has been performed [24].

## 3.2 Method of trend analysis

Before analysing trend of wetlands, the homogeneity of the wetland data has been calculated. It is because of justifying why 1998–1999 is considered as dividing year. Here, Pettitt's test [25] which is a non-parametric test has been

adopted for finding out the homogeneous character of the data and to evaluate the abrupt changes in a time series data [25, 26]. The methodology has been shown in Eqs. 5–7.

$$U_k = 2 \sum_{i=0}^{1} m_i - k(n+1) \qquad (5)$$

where $m_i$ is the rank of the i-th observation when the values $X_1, X_2 \ldots X_n$ in the series are arranged in ascending order. Then statistical change point (SCP) has been calculated using Eq. 6.



Fig. 2 Identification of wetlands a water-body extraction through combination of NDWI & NDWI$_{Gao}$ from LANDSAT imageries of 1973 to 2016, b ground control points for validation of the extracted waterbodies through Google Earth, supervised classification and field investigation in 2016 and c identified wetlands of the Diara region after these two processes
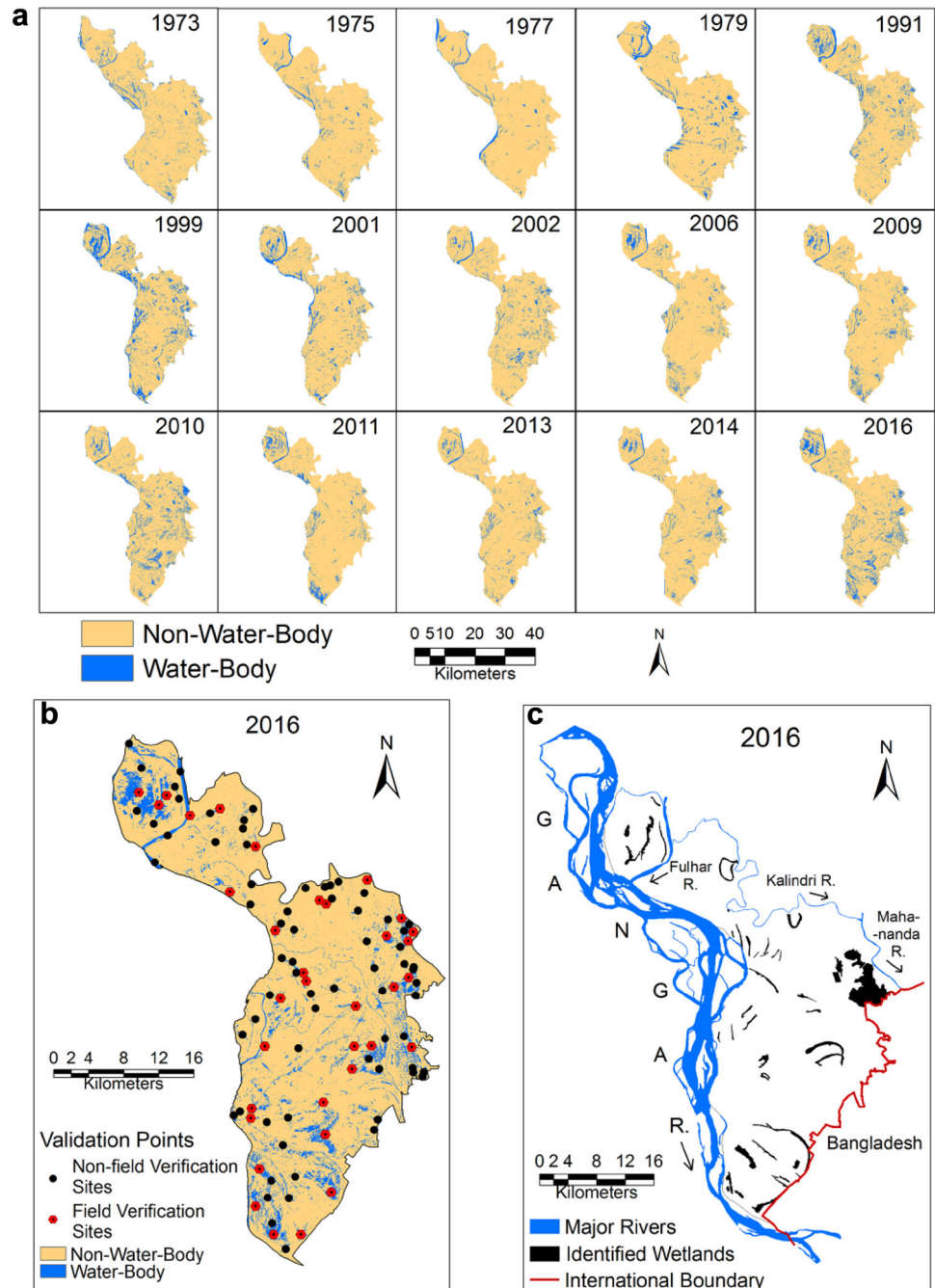
**Table 2** Wetland area of the Diara region in different years from 1973 to 2016

| Year | Wetland area (Hectares); 100 ha = 1 km$^2$ |
| --- | --- |
| 1973 | 5628.6 |
| 1975 | 1526.43 |
| 1977 | 3753.36 |
| 1979 | 6111.72 |
| 1991 | 8195.49 |
| 1999 | 14,124.78 |
| 2001 | 8671.59 |
| 2002 | 6729.3 |
| 2006 | 5773.77 |
| 2009 | 6322.23 |
| 2010 | 9570.96 |
| 2011 | 6347.52 |
| 2013 | 5056.11 |
| 2014 | 5707.89 |
| 2016 | 4885.92 |

$$K = \frac{max}{1 \leq k \leq n} |U_k| \qquad (6)$$

When $U_k$ will gain maximum value of K in a series then a change point will occur in the series. The critical value is computed using Eq. 7.

$$K_\propto = \left[ -1n \propto \left( n^3 + n^2 \right)/6 \right]^{\frac{1}{2}} \qquad (7)$$

After homogeneity test, simple linear regression model has been applied to identify the trend of wetland area of the Diara region in between 1973 and 2016 using linear regression.

### 3.3 Method of compositing year wise wetland inventories

After identification of NDWI images of both pre and post flood periods, they are integrated separately for both the phases. Before integrating, all the wetland images have been converted into binary form denoting 1 as water body

and 0 as non-water body. The Eqs. 8 and 9 respectively shows year wise wetland inventories for both pre flood and post flood conditions.

$$WI_{Pre-Flood} = \left\{ \sum \left( WI_{Y_{1973}} + \cdots + WI_{Y_{1998}} \right) \right\} \qquad (8)$$

$$WI_{Post-Flood} = \left\{ \sum \left( WI_{Y_{1999}} + \cdots + WI_{Y_{2016}} \right) \right\} \qquad (9)$$

where $WI_{Pre-Flood}$ and $WI_{Post-Flood}$ are the composited single wetland inventories of both pre-flood phase and post-flood phase respectively; $WI_{Y_{1973}}$ to $WI_{Y_{2016}}$ are the output of Eq. 3.

After compositing, the water presence frequency values in percentages have been categorised which helps to identify the hydrological consistency state of the wetlands.

## 4 Results and analysis

### 4.1 Year wise wetland inventories and trend of wetland

Wetlands are identified based on the algorithms performed like NDWI$_{Mcfeeters}$ and NDWI$_{Gao}$ which give a clear distinction between the water bodies and non-water-bodies in a binary raster image (Fig. 2a). Such satellite imagery derived water body detection leads to identification of some extra water areas which are not actually wetlands [27, 28]. For that filed and satellite data reference validation and accuracy assessment have been performed (Fig. 2b). Cohen's kappa co-efficient [24] of 0.89 and overall accuracy of 92.68% establishes the validity of the location and extent of the wetlands of this region. There are total 42 wetlands in this region with an areal coverage of about 4885.92 ha (48.85 km$^2$) (Fig. 2c). Most of the wetlands are of riverine origin mainly ox-bow lakes and channel cut-offs.

In Fig. 2a, c, we can observe the shape of the wetlands which are quite corresponding to the shape of the river channels. The wetlands present in the northern part of the Diara region are the ox-bow and cut-off meanders of the

**Table 3** Summary statistics of trend of wetlands

| Homogeneity test statistics (after Pettitt [25]) | | Linear regression statistics | |
| --- | --- | --- | --- |
| Parameter | Value | Parameter | Value |
| K$_\alpha$ | − 32.00 | Model fit equation | y = 46.204x + 6190.4 |
| SCP | – | R$^2$ | 0.08 |
| $p$ value (one-tailed) | 0.092 | Standardized coefficient | 0.28 |
| alpha | 0.05 | RMSE | 2958.21 |
| | | Maximum standardized residual | 2.52 (1999) |
| | | Standard error | 0.27 |
| | | Validation year | 2011 |

**Fig. 3** Pettitt's Homogeneity
Test of wetland area in between
1973 and 2016 **a** simple linear
regression model of the wetland
area shows the regression line
and confidence interval lines.
This figure portrays the wetland
area of the year 1999 as outlier,
**b** prediction of the wetland
areas in respect of the observed
values, where the confidence
intervals allow us to identify the
outliers. Here also the wetland
area of 1999 has emerged as
outlier, **c** distribution of
standardized residuals of the
wetland area of the Diara region
where maximum residual of
2.52 is seen in the year 1999
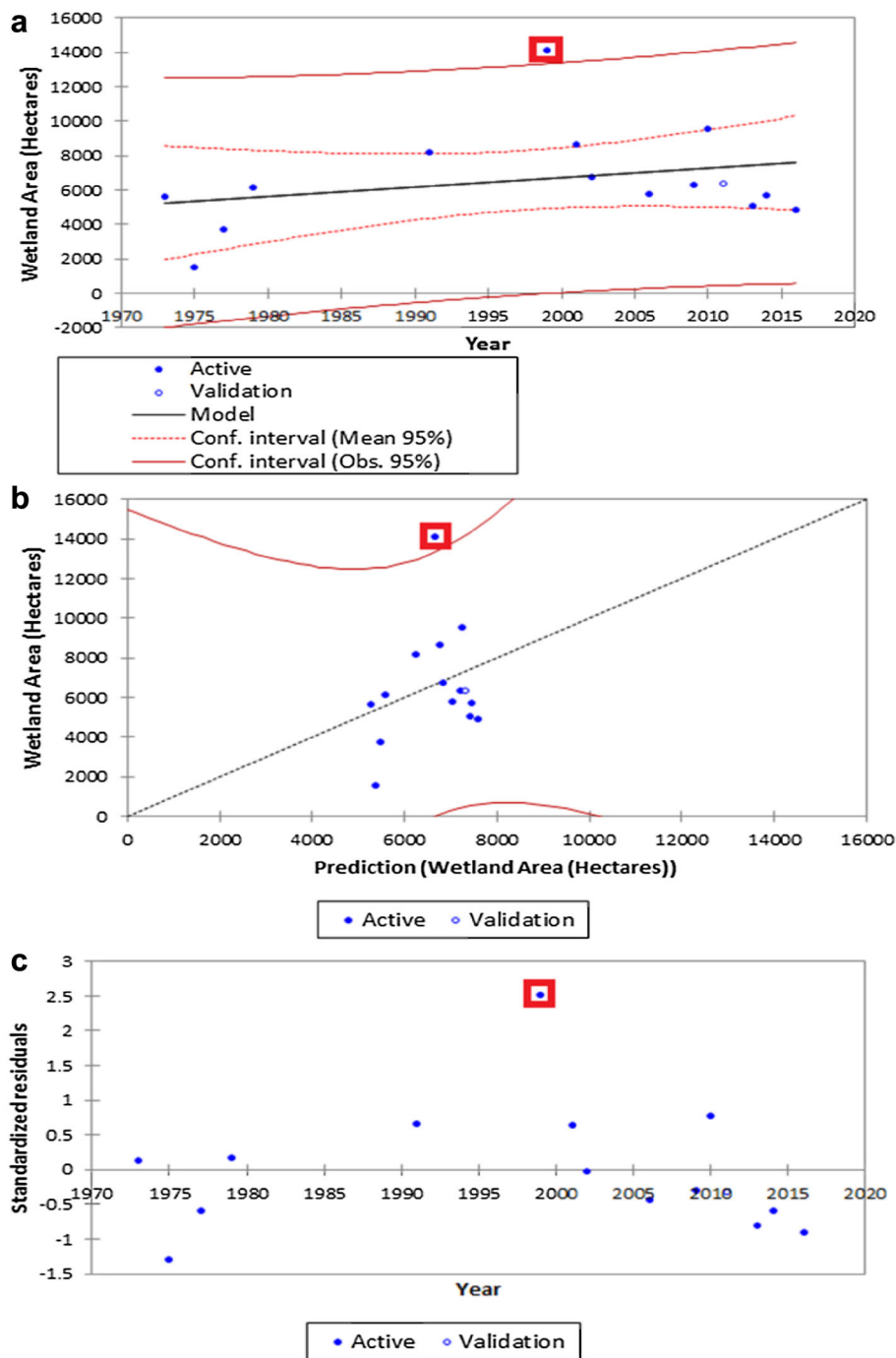


Kalindri River. On the other hand, those present in the
western part are the cut-offs channels and river scars of
Ganga. River Ganga is the major river here; therefore, the
formation and modification of all the wetlands in this
region are directly and indirectly related with the flow
character, discharge pattern and oscillation of this river
[19]. Henceforth, it is quite pertinent to show the trend of
these wetlands within the stipulated timeframe of 43 years.

Wetlands of the Diara region are also quite dynamic as
these are basically the output of the channel-dynamics of

River Ganga and River Kalindri (Fig. 1). Farakka barrage
(established in 1971) boosts to the shifting of River Ganga
in both upstream and downstream part which results the
shifting of the Diara region (physical unit) too [19].
Therefore, it is quite clear that as the whole region is
dynamic in nature so the wetlands present in this region
also portrays the dynamicity in its character. Here, the
trend of the wetland area has been put forth (Table 2)
which can help us to identify any un-conformal situation
during the entire time period of 43 years (1973–2016). The

**Table 4** Change matrix of the wetland area during pre-flood and post-flood conditions

| Water presence frequency class (in %) | A.H. | | | | $d_f(Pos_F - Pre_F)$ | | Change in % | |
|---|---|---|---|---|---|---|---|---|
| | Pre-monsoon | | Post-monsoon | | Pre-monsoon | Post-monsoon | Pre-monsoon | Post-monsoon |
| | $Pre_F$ | $Pos_F$ | $Pre_F$ | $Pos_F$ | | | | |
| ≤ 20 | 9403.2 | 9563.04 | 9632.16 | 11,825.64 | 159.84 | 2193.48 | 1.7 | 22.8 |
| 21–40 | 2405.16 | 2660.04 | 2540.16 | 3732.84 | 254.88 | 1192.68 | 10.6 | 46.9 |
| 41–60 | 963 | 1696.23 | 1139.04 | 1461.87 | 733.23 | 322.83 | 76.1 | 28.34 |
| 61–80 | 521.64 | 701.01 | 549 | 2080.44 | 179.37 | 1531.44 | 34.4 | 278.9 |
| > 80 | 351.36 | 1438.65 | 1395.36 | 2867.67 | 1087.29 | 1472.31 | 309.5 | 105.5 |

A.H., area in hectares; $d_f$, deviation in hectares; $Pre_F$, pre-flood; $Pos_F$, post-flood

wetland area of 1975 has been recorded as the lowest (1526.43 ha), 1999 as highest (14,124.78 ha) and present days i.e. 2016 as 3rd lowest (4885.92 ha). The reason of lowest wetland area in 1975 cannot be properly justified due to lack ancillary data of that time but the reason of highest wetland area in 1999 is justified with the availability of abundant supporting data. During 1998 and 1999 massive flood have been occurred in almost entire part of Malda district [29–31]. Water level of Ganga was as high as 26 m at Manikchak gauge station where extreme danger level was 25.30 m [32] in few days of monsoon months in 1998 and 1999. Since 24.08.1998 to 11.09.1998 water level at Manikchak gauge station was above 26 m and recoded maximum water level was 26.56 m on 06.09.1998 to 07.09.1998. Water level was > 26.8 m since 24.09.1999–29.09.1999. Similarly at Farakka barrage, water level was 25.40 m, increased 3.45 m from original pond level [33, 34]. The peak discharge of the river may be to the tune of 75.90 × 103 cumec, as was observed in September 1998. This causes massive hike in water area within the wetlands therefore, the wetland area also increased. But after 1999, the wetland area started falling down and came to 4885.92 ha in 2016 except in 2010 i.e. 9570.96 ha (Table 2). This is also due to a regional flood event occurred in Malda during 2009–2010 [35, 36].

Pettitt's homogeneity test shows that the 'p' value is greater than 'alpha' value which means null hypothesis is accepted and the data are homogeneous (Table 3). The result also indicates that there is no change point in this data set. In this regard linear regression has been used for trend analysis of the whole wetland area data. The result has been shown in Table 3.

Figure 3 portrays that the wetland area of 1999 is not normal like other years although Pettitt's test does not give any change point in this series. No definite trend is identified in wetland area ($R^2 = 0.08$) but present area of wetland is 1461.6 ha lower than average.

## 4.2 Pre and post flood wetland state with seasonal dynamics

The result shows that water presence frequency has positively increased during the post-flood period (1999–2016) in all its categories (Table 4) which indicates the perennial character of the wetland also increased after the flood. In this case, Flood has acted as a boost for the dying wetlands of the Diara region. Table 4 describes the seasonal change in wetlands before and after flood conditions. During the field survey, we have received feedback from the aged people who used to say that after the flood of 1998 and 1999 all the swamps and marshes of the locality has been filled with water which remained dry earlier. According to them, fishing also became higher during the post-flood phase that leads to more earnings of the local people. There is an increase of migratory birds in the wetlands after the flood as more number of birds is coming in these riverine wetlands. But the extended state of the wetland has not last for long time because overall trend in post flood year is declined (y = − 6.5x + 68,304; $R^2 = 0.489$).

The wetland ecosystem of this region has got a boost after the flood of 1998. But, how long the water availabilities continue in a year is a major concern. For this, seasonal water presence status of the wetlands has been observed in pre-monsoon and post-monsoon season (Fig. 4). From Table 4, it is clear that most of the area of the wetlands have increased during post-monsoon period. Therefore, it may be inferred that the wetlands of the Diara region are mainly fed by monsoonal rain and inundated water of the rivers. The full developments of wetlands are observed during the post-monsoon season and ecosystem service is progressive at that time. Again it started decreasing and during pre-monsoon phase, the wetlands look drier. So, a cyclic regime of water presence in these wetlands is well recognized.

**Fig. 4** Seasonal dynamics of water presence area under different water presence frequency of the Diararegion during **a** pre-flood (1973–1998) in pre-monsoon season, **b** post-flood (1999–2016) in pre-monsoon season, **c** pre-flood (1973–1998) in post-monsoon season, **d** post-flood (1999–2016) in post-monsoon season
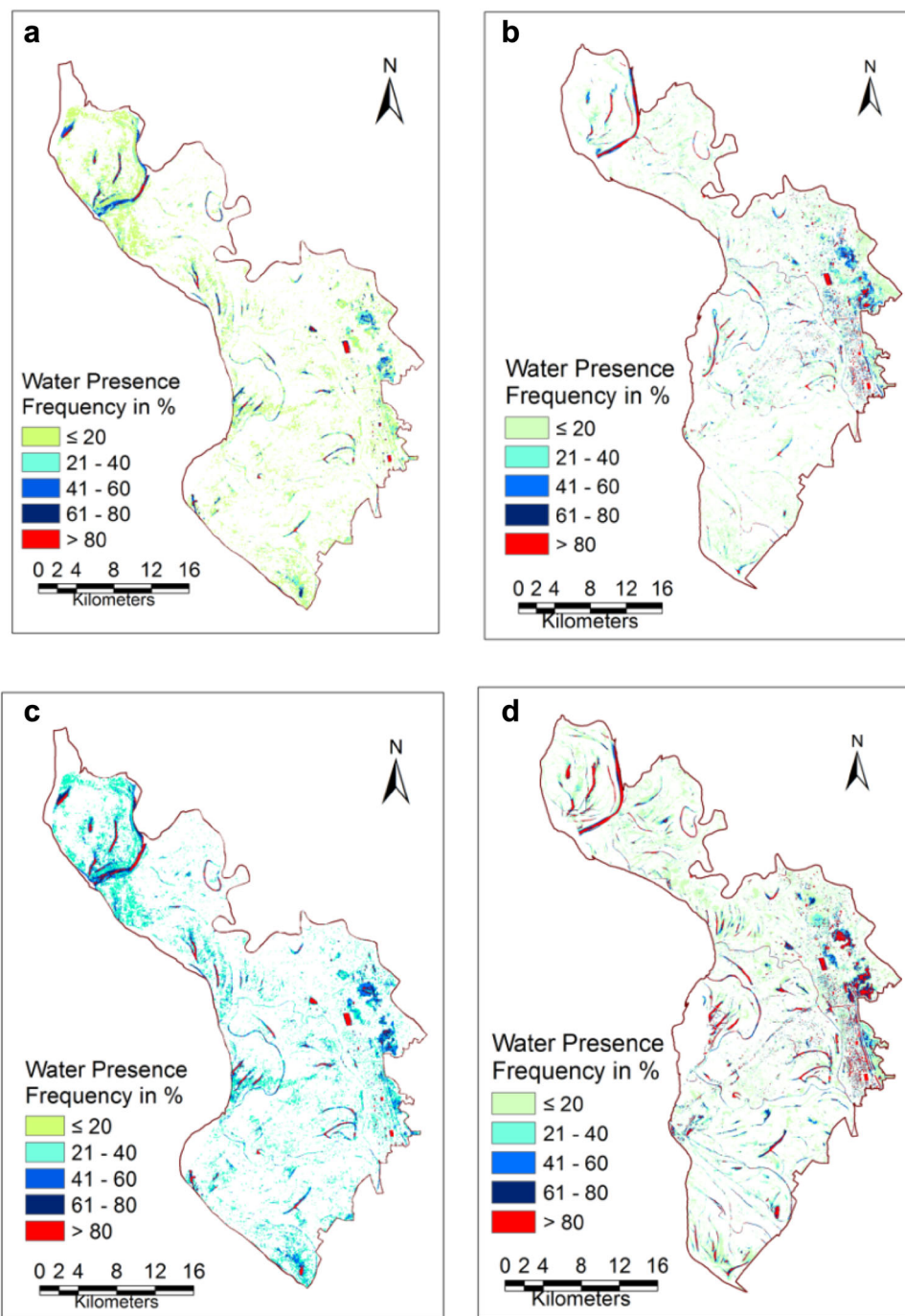


**Table 5** Stability status of the wetlands of the Diara region in between 1973 and 2016

| Wetland stability status (1973–2016) | Area in hectares | Remarks |
| --- | --- | --- |
| Unstable | 10,097.3 | Highly prone to loss |
| Very low stable | 2932.68 | Prone to loss |
| Low stable | 1373.7 | Needs proper management to stop the loss |
| Moderately stable | 1101.03 | Semi-consistent |
| Highly stable | 1552.56 | Consistent |
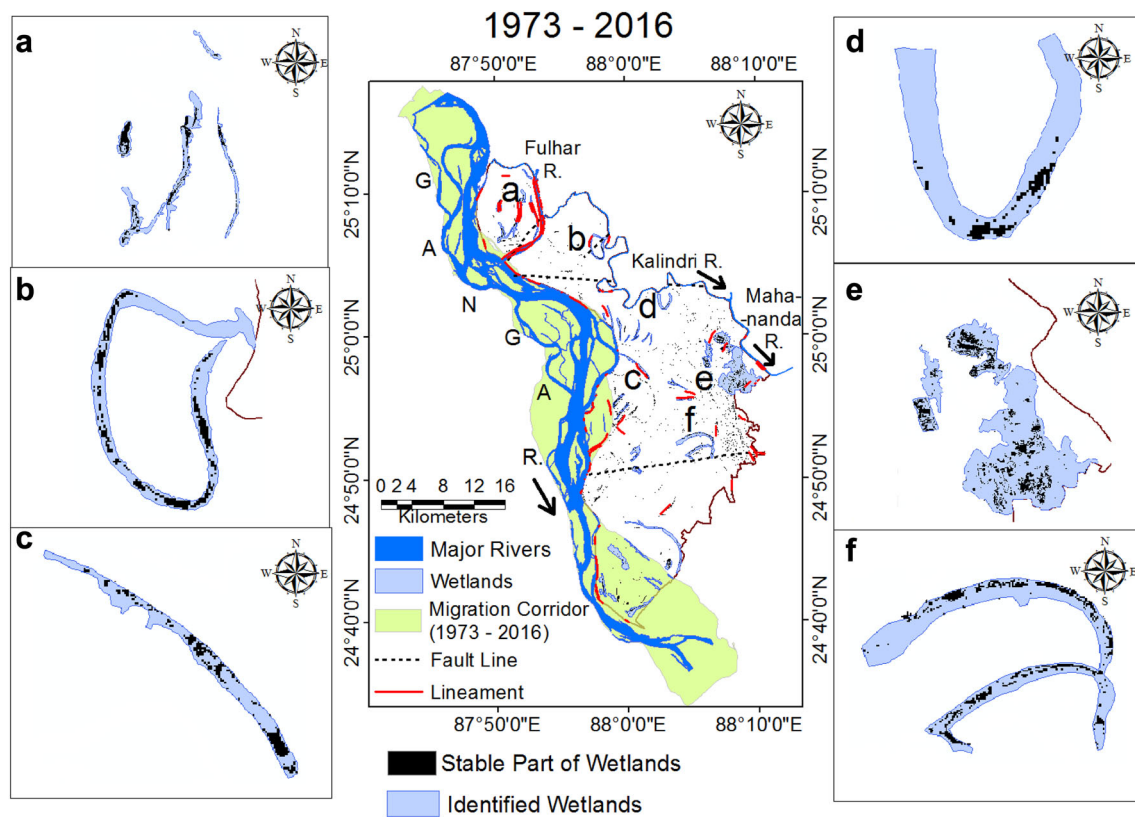
**Fig. 5** Hydrological stability assessment of the wetlands of the Diara region in between 1973 and 2016; Stable part of six sample wetlands **a** Bhutni Complex, **b** Pirpur, **c** Babla, **d** Amrati, **e** Chakra Sagardighi Complex and **f** Kaliachak Complex

## 4.3 Hydrological stability assessment of wetlands

The stability of the wetlands in this case is determined through the availability of water, aquatic flora and fauna constantly during the period of 1973 to 2016. Five quasi-qualitative categories have been made based on water presence frequency values, permanency classification and depth wise classification ranging from unstable to highly stable (Table 5). Field verification at 105 locations (Fig. 2) over the entire Diara region have been finally adopted to delineate only the stable part of the wetlands (Fig. 5). The details of the stability status of the wetlands have been shown in Table 5. In Fig. 5, only six corresponding locally well-known wetlands of the Diara region have been shown through zooming but all other wetlands are also been incorporated in this study. During the field survey it has been observed that the stable parts are mostly utilised for fishing whereas moderately stable to low stable parts are used for fishing and cultivation.

## 5 Conclusion

From the study it is revealed that wetland of this region is strongly regulated by the rainfall and inundation regime of the area. Just after the flood event, the wetland area is recorded as highest (14,124 ha in 1999) in compare to the initial period (5628.6 ha in 1973) and present period (4885.92 ha in 2016). As the wetlands are somehow linked to the river channels, therefore, the rise of water level in the rivers put direct boost in the hydrological regime of the wetlands too. As per the study of 1973 to 2016, near to 10,000 ha of wetland areas are highly prone to loss whereas only 1552.56 ha are stable. Conversion of riverine wetland to waterlogged area is very evident. Isolated wetlands are more prone to loss and cost effective for generating economic turnover. So, regular basis discharge rise is very vital for the survival of the wetlands. Linkages between river and wetland should be renovated where required, new linkages could be made for making this precious landscape safe and productive.

# References

1. Ramsar. (2011). *The Ramsar manual, Ramsar and its mission, brief history*. http://www.ramsar.org/cda/en/ramsar-march11/main/ramsar/1%5E25044_4000_0__. Accessed March 31, 2015.

2. MedWet. (2016). *The Ramsar convention*. http://medwet.org/aboutwetlands/ramsarconvention/. Accessed January 10, 2017.

3. Talukdar, S., & Pal, S. (2017). Impact of dam on inundation regime of floodplain wetland of Punarbhaba river basin of Barind tract of Indo-Bangladesh. *International Soil and Water Conservation Research*. https://doi.org/10.1016/j.iswcr.2017.05.003.

4. Ji, L., Zhang, L., & Wylie, B. (2009). Analysis of dynamic thresholds for the normalized difference water index. *Photogrammetric Engineering & Remote Sensing, 75*(11), 1307–1317.

5. O'Hara, C. G. (2016). *Remote sensing and geospatial application for wetland mapping, assessment, and mitigation*. http://www.isprs.org/proceedings/XXXIV/part1/paper/00079.pdf. Accessed December 14, 2016.

6. Klemas, V., & Pieterse, A. (2015). Using remote sensing to map and monitor water resources in arid and semiarid regions. In T. Younos & T. E. Parece (Eds.), *Advances in watershed science and assessment: The handbook of environmental chemistry* (pp. 33–60). Basel: Springer. https://doi.org/10.1007/978-3-319-14212-8_2.

7. Talukdar, S., & Pal, S. (2017). Impact of Dam on flow regime and flood plain modification in Punarbhaba river basin of Indo-Bangladesh Barind Tract. *Water Conservation Science and Engineering*. https://doi.org/10.1007/s41101-017-0025-3.

8. Mondal, D., & Pal, S. (2016). Monitoring dual-season hydrological dynamics of seasonally flooded wetlands in the lower reach of Mayurakshi river, Eastern India. *Geocarto International*. https://doi.org/10.1080/10106049.

9. Das, R. T., & Pal, S. (2017). Exploring geospatial changes of wetland in different hydrological paradigms using water presence frequency approach in Barind Tract of West Bengal. *Spatial Information Research*. https://doi.org/10.1007/s41324-017-0114-6.

10. Pal, S., & Saha, T. K. (2017). Identifying dam-induced wetland changes using an inundation frequency approach: The case of the Atreyee River basin of Indo-Bangladesh. *Ecohydrology & Hydrobiology*. https://doi.org/10.1016/j.ecohyd.2017.11.001.

11. Sarkar, S., Parihar, S. M., & Dutta, A. (2016). Fuzzy risk assessment modelling of East Kolkata Wetland Area: A remote sensing and GIS based approach. *Environmental Modelling and Software, 75*(2016), 105–118. https://doi.org/10.1016/j.envsoft.2015.10.003.

12. Pal, S., & Talukdar, S. (2018). Application of frequency ratio and logistic regression models for assessing physical wetland vulnerability in Punarbhaba river basin of Indo-Bangladesh. *Human and Ecological Risk Assessment: An International Journal*. https://doi.org/10.1080/10807039.2017.1411781.

13. Dutta, M. P., Kalita, K., & Phukan, B. (2017). Floodplain wetlands of India. *Aquafind*. http://aquafind.com/articles/Floodplain_Wetlands_Of_India.php. Accessed June 17, 2017.

14. Sugunan, V. V., Vinci, G. K., Bhattacharjya, B. K., & Hassan, M. A. (2000). Ecology and fisheries of beels in West Bengal. *CIFRI Bulletin, 103,* 1–53.

15. Mondal, D., & Pal, S. (2017). Evolution of wetlands in lower reaches of Bagmari–Bansloi–Paglarivers: A study using multidated images and maps. *Current Science, 112*(11), 2263–2272. https://doi.org/10.18520/cs/v112/i11/2263-2272.

16. Pal, S., & Akoma, O. C. (2009). Water scarcity in wetland area within Kandi Block of West Bengal: A hydro-ecological assessment. *Ethiopian Journal of Environmental Studies and Management, 2*(3), 1–17.

17. Pal, S. (2016). Impact of water diversion on hydrological regime of Atreyee river of Indo-Bangladesh. *International Journal of River Basin Management*. https://doi.org/10.1080/15715124.2016.1194282.

18. Spencer, T., Schurch, M., Nicholls, R. J., Hinkel, J., Vafeidis, A., Reef, R., et al. (2016). Global coastal wetland change under sea-level rise and related stresses: The DIVA Wetland Change Model. *Global and Planetary Change, 139,* 15–30. https://doi.org/10.1016/j.gloplacha.2015.12.018.

19. Mukherjee, K., & Pal, S. (2017). Channel migration zone mapping of the River Ganga in the Diara surrounding region of Eastern India. *Environment, Development and Sustainability*. https://doi.org/10.1007/s10668-017-9984-y.

20. Lambourn, G. E. (1918). *Bengal District Gazetteers: Malda*. Calcutta: The Bengal Secretariat Book Depot.

21. Mcfeeters, S. K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing, 17*(7), 1425–1432.

22. Cowardin, L. M., Carter, V., Goletm, F. C., & La Roe, E. T. (1979). Classification of wetlands and deepwater habitats of the United States. *U.S. Fish and Wildlife Service Report FWS/OBS-79/31*, Virginia, p. 131.

23. Gao, B. C. (1996). NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment, 58,* 257–266.

24. Cohen, J. (1960). Coefficient of agreement for nominal scales. *Educational and Psychological Measurement, 20*(1), 37–46.

25. Pettitt, A. N. (1979). A non-parametric approach to the change-point detection. *Applied Statistics, 28*(2), 126–135.

26. Agha, O. M. A. M., Bağçacı, S. Ç., & Şarlak, N. (2017). Homogeneity analysis of precipitation series in North Iraq. *IOSR Journal of Applied Geology and Geophysics, 5*(3-II), 57–63.

27. Xu, H. (2006). Modification of Normalised Difference Water Index (NDWI) to enhance open water features in remotely sensed imagery. *International Journal of Remote Sensing, 27,* 3025–3033.

28. Sarp, G., & Ozcelik, M. (2017). Water body extraction and change detection using time series: A case study of Lake Burdur, Turkey. *Journal of Taibah University for Science, 11*(3), 381–391. https://doi.org/10.1016/j.jtusci.2016.04.005.

29. Mazumder, S. K. (2004). Role of Farakka barrage on the disastrous 1998 Flood in Malda (West Bengal). In M. M. Q. Mirza (Ed.), *The ganges water diversion: Environmental effects and implications (Water Science and Technology Library)* (Vol. 49, pp. 39–48). Dordrecht: Springer.

30. Sankalpa. (1998). *Special report: Flood 1998! The deluge of the decade*. http://sankalpa.tripod.com/stop/s4flood98.html. Accessed June 20, 2017.

31. Ismail, M., & Mustaquim, M. (2013). Socio-economic status of population in flood prone areas of Chanchal sub-division in Malda district, West Bengal. *IMPACT: International Journal of Research in Applied, Natural and Social Sciences, 1*(3), 141–152.

32. IWD. (2014). *Annual flood report for the year 2014*. Irrigation and Waterways Directorate, Government of West Bengal, p. 14. http://wbiwd.gov.in/pdf/ANNUAL_FLOOD_REPORT_2014.pdf. Accessed on July 17, 2017.

33. Rudra, K. (2003). *The encroaching Ganga and social conflicts: The case of West Bengal, India*. Department of Geography, Habra S.C. Mahavidyalaya (College), West Bengal, India. http://gangawaterway.in/assets/02Rudra.pdf. Accessed October 10, 2016.

34. Mallik, B., & Bandyopadhyay, J. (2004). West Bengal: Reductionist engineering and conflicts. In V. Subba & K. Pradhan (Eds.), *Dispute over the Ganga. A look at the potential water-*

*related conflicts in South Asia* (pp. 55–90). Kathmandu (Nepal): Panos Institute South Asia.

35. The Hindu. (2009). *Fresh areas flooded in Bihar, Malda*. http://www.thehindu.com/todays-paper/tp-national/tp-otherstates/Fresh-areas-flooded-in-Bihar-Malda/article16540023.ece. Accessed June 20, 2017.

36. Times of India. (2010). *Malda: Flood claimed its first victim in Malda*. http://timesofindia.indiatimes.com/city/kolkata/Malda-Flood-claimed-its-first-victim-in-Malda/articleshow/6477338.cms. Accessed June 21, 2017.