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ASSESSMENT ON SEASONAL VARIATIONS IN WATERLOGGING USING REMOTE SENSING AND GIS TECHNIQUES IN SATKHIRA DISTRICT IN BANGLADESH

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Abstract

Waterlogging, one of the most serious environmental hazards in Satkhira district of south-west Bangladesh, is adversely affecting the socio-economic development of this region. Remote Sensing (RS) combined with Geographical Information Systems (GIS) offers an admirable alternative to traditional techniques in mapping of surface waterlogged areas. Normalized Difference Water Index (NDWI) is used to delineate pre-monsoon and post-monsoon waterlogged areas of Satkhira district in 2014 and 2015. Seasonal variations of waterlogging are identified by overlapping the waterlogged areas derived from both the pre- and post-monsoon seasons under GIS environment. Results show that waterlogged areas for pre- and post-monsoon seasons in 2014 are 830.09 km^2 and 1,355 km^2, respectively, whereas 861.14 km^2 and 1,386.54 km^2 in 2015. Hence, the seasonal variations in waterlogged areas in 2014 and 2015 are 524.91 km^2 and 525.40 km^2, respectively. This study also reveals that the tendency of waterlogging is location-specific with high seasonal variations that depend not only on the amount of rainfall but also on local geologic settings and drainage pattern, mismanagement and climate change.

Keywords: Waterlogging, Remote Sensing, GIS, Satkhira, Bangladesh

Introduction

The south-west coastal area of Bangladesh, part of the greater Ganges floodplain, an exceptionally complex and delicate hydraulic system, is flat and low-lying, hardly one

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meter above mean sea level and below high tide level (UNDP, 2011; Adhikary et al., 2012). This plain is crisscrossed by numerous tidal creeks and channels and has high drainage density. This hydraulic system relies on a sensitive balance between flows of water from two directions; downward flows from the Ganges (Padma) river, and its distributaries, as well as sediment-laden tides from the Bay of Bengal. The delicate equilibrium of this system has been cruelly disrupted by various human actions in the last 50 or so years, the complete consequences of which are now being sensed.

Satkhira district, located in south-west Bangladesh, has been experiencing problems of waterlogging since the early 1980s (ADB, 2007; FAO, 2015; Oxfam, 2011 and UNDP, 2011). Associated with the annual monsoon season, arises the chronic waterlogging problem that inundates homes, agricultural fields, schools, ponds and roads, orchards and gardens and so on (Mirza et al., 2005; FSC, 2014). This covers tens of thousands of hectare resulting in devastating effect on livelihoods, agriculture, health and sanitation, essential services (such as water and food), and infrastructure etc. (Rahman, 1995; FAO, 2015). It is a long-lasting event often takes up to seven months to recede (FSC, 2014).

The construction of Farakka Dam across the Ganges in India, as an example of some major hydraulic adjustments to the Ganges (Padma) river, severely deteriorated the downward flows of water through distributaries (UNDP, 2011; FSC, 2014). After being cut-off from upstream, lower streams had been subject to tidal domination, associated with increasing sedimentation through tidal pumping from the Bay. Moreover, during 1960s a series of polders was built in the southwestern part of Bangladesh intending to increase agricultural productivity by protecting cultivable land from tidal flooding and saline intrusion (Oxfam, 2011; UNDP, 2011). These embankments altered the normal flow and drainage movements in the floodplains eventually resulting in successive siltation in the upstream and downstream (Unnayan Onneshan, 2006; Die, 2013). In addition, excessive monsoon rains, unplanned and unauthorized structural interventions and constructions, impact of climate change in the form of rising sea level lead to the onset of waterlogging in the south-west Bangladesh (Awal, 2014; Minar et al., 2013; Sahu, 2014a).

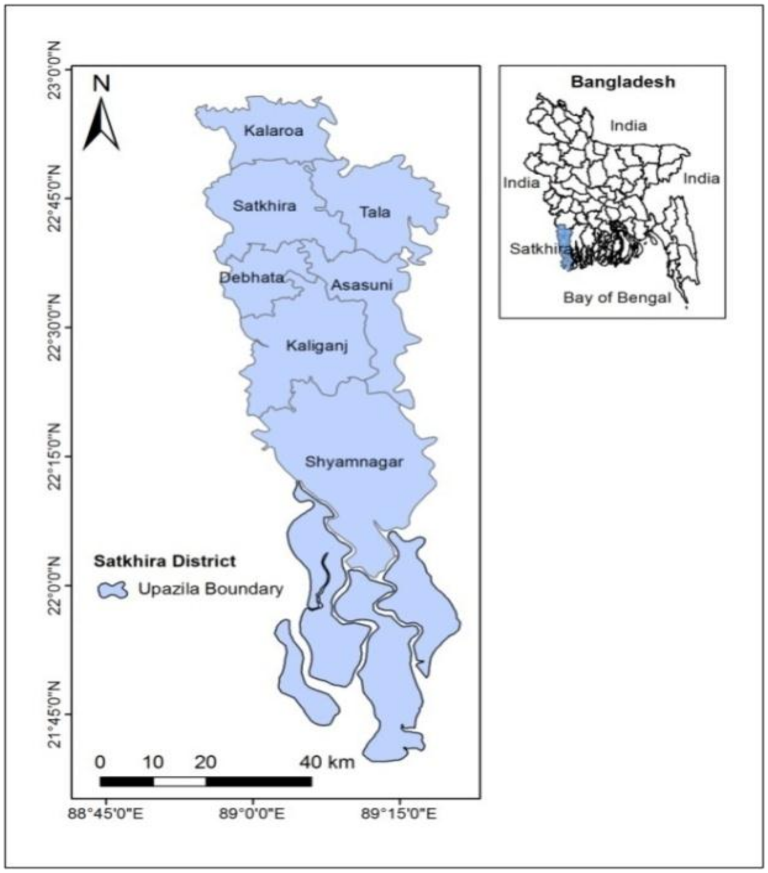


Fig. 1. Location map of study area.

The saturation of near surface soil with water is simply referred as waterlogging. When the groundwater table is too high, it starts affecting the normal air circulation in the root zones of most plants and results waterlogging (Sujatha et al., 2000). It occurs when the rate of accumulation of water through rainfall or some other means exceed the joint rate of drainage, infiltration and evapotranspiration of a catchment or when flood water submerges an area (Mancuso and Shabala, 2010). However, in Bangladesh, a situation when a river has been completely blocked by siltation such that any water above the blockage has no way of draining out or when annual monsoonal rains fall, water gets restricted by a boundary (polder) having no place to go, resulting in static flooding referred to as 'water logging', albeit a slightly misleading term in that it is technically a form of flooding, not waterlogging as such (FSC, 2014). To maintain the consistency with the language used by development and other actors in Bangladesh, the term waterlogging will be used in this paper.

Waterlogging may be seasonal which exhibits waterlogging only in one season or permanent, where it persists throughout the year (Sharma et al., 2009). One of the problems with waterlogging is to define the limits of water logging - a seasonal drainage problem – as distinct from permanent water bodies in south-west Bangladesh (FAO, 2015). Generally, mapping of waterlogged areas have been performed using conventional technique such as ground survey, but for regional studies, these techniques are neither cost effective nor time efficient. The RS combined with GIS offer an excellent alternative to traditional techniques in monitoring and assessing the extent of temporal and spatial variations in waterlogged areas (Chowdary et al., 2008). In the past, several studies have revealed the usefulness of RS and GIS techniques in detecting and monitoring waterlogged areas (Bouwer et al., 1990; Dwivedi, 1994; Choubey, 1996; Choubey, 1998; Lohani et al., 1999; Dwivedi et al., 2001; Dwivedi and Sreenivas, 2002; Chatterjee et al., 2003; Sahu, 2014b). Although some works have been conducted in south-west Bangladesh to delineate waterlogged areas using RS and GIS techniques, studies distinguishing permanent waterlogged areas from seasonal waterlogged areas are still lacking (FAO, 2015; Hasan and Sayed, 2014). In the present study, an attempt has been made to identify waterlogged areas for both pre-monsoon and post-monsoon seasons in Satkhira district in 2014 and 2015 and, therefore, to identify the seasonal variations in waterlogging by integrating waterlogged areas derived from both the pre- and post-monsoon seasons under GIS environment.

Study Area

Satkhira, a district in southwestern Bangladesh, is part of Khulna Division (Fig. 1). It has an area of 3,817.29 km^2 having 2,079,884 population. Satkhira district is bounded on the north by Jessore district, on the east by Khulna district, on the south by Bay of Bengal and on the west by India. It falls between $21^o36'$ and $22^o54'$ north latitudes and between $88^o54'$ and $89^o20'$ east longitudes. The district consists of seven upazilas (upazila is a smaller administrative unit of Bangladesh), namely Satkhira Sadar, Assasuni, Debhata, Tala, Kalaroa, Kaliganj and Shyamnagar Upazila. The study area shows flat topography where most of the region lie within 1m from sea level (Adhikary et al., 2012). The study area is characterized by grey, slightly calcareous, loamy soils on river banks and grey or dark grey, noncalcareous, heavy silty clays in the extensive basins (Huq and Shoaib, 2013). Climate data for Satkhira for the last 30 years (1985-2015) is given in Table 1.

Materials and Methods

Extensive literature review was conducted at every stages of this research work. The study area was recognized using the information from different peer reviewed scientific articles, conference proceedings, reports and gray literature such as media reports as well as considering hydro-meteorological parameters. The Landsat 8 satellite images of 2014 and 2015 were collected from USGS GLOVIS website. The satellite images, dated March and November, representing pre-and post-monsoon seasons respectively, were processed using ERDAS Imagine 9.3 software for delineation of surface waterlogged area. The analysis and visualization of the waterlogged areas were performed using ArcGIS10.1 software. The rainfall data were collected from *Weatherbase* and *Climate Change Tropical Portals* of World Bank to observe the rainfall pattern of the study area.

In general, the waterlogged areas exhibit sharp contrast with the adjacent areas on the satellite images and these spectral properties of waterlogged areas can be easily picked by visible and infrared domain of optical sensors. The standing water areas appear as dark blue to black in colour/tone depending upon the depth of water, while the wet areas appear as dark grey to light grey on the imagery (Chowdhury et al., 2008). Often, the land/water demarcation is confusing in a single near infrared (NIR) band, and hence, two band data such as green and NIR bands can be used in such situations. Thus, rationing of the two band data takes advantage of the difference in the reflectance of different wavelengths in enhancing a particular feature from the satellite data. So, in the present study, the Normalized Difference Water Index (NDWI) developed by McFeeters (1996) was used for delineation of waterlogged areas by enhance their presence in remotely sensed digital imagery, while simultaneously suppressing terrestrial vegetation features. Perennial waterlogged and seasonal waterlogged areas were identified for the study area by integrating the waterlogged areas derived for both the pre-monsoon and post-monsoon seasons. This index is calculated as follows:

$$NDWI = \frac{\rho\text{G} - \rho\text{NIR}}{\rho\text{G} + \rho\text{NIR}}$$

where, ρG is spectral reflectance in G band and ρNIR is spectral reflectance in NIR band. The NDWI value ranges from -1 to +1, in which, positive and negative NDWI values indicate water and vegetation features respectively (McFeeters, 1996). Water bodies show positive value due to higher reflectance of NIR band than G Band (McFeeters, 1996). The threshold NDWI value is likely to change with different overpass dates, and needs to be fixed for each data independently. In the current study, threshold NDWI value was fixed for each satellite image based on the visual interpretation of raw data (Table 2). At last, Google Earth verification was conducted to observe the waterlogged areas in the study areas and its seasonal variations.

Table 1. Climate data for Satkhira (monthly average for the years 1985 to 2015)*.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high Temp. (°C)	25	28	33	34	34	33	31	31	32	31	29	26	30
Average low Temp. (°C)	12	15	20	24	25	26	26	25	25	23	18	13	21
Average precipitation (mm)	8	23	30	71	145	295	353	325	267	142	30	8	1,689

*(Data Source: https://datahub.io)

Results and Discussion

The pre-monsoon and post-monsoon surface waterlogged areas in the study area for the year 2014 and 2015 are delineated practicing RS and GIS techniques. Permanent waterlogged areas are those where land remains waterlogged throughout the year. Water bodies on satellite images during March/April (peak of the dry season) may be considered as permanent waterlogged areas after subtracting the areas under ponds and rivers. On the other hand, seasonal inundation occurs due to intensive rainfall throughout the monsoon season. So water bodies on the satellite images during November/December (just after the monsoon season) may be considered as seasonal waterlogged areas.

Table 2. Threshold values for spatially and temporally different satellite images.

Year and Seasons	NDWI Threshold Value
2014 Pre-monsoon	≥ 0.05
2014 Post-monsoon	≥ 0.04
2015 Pre-monsoon	≥ 0.06
2015 Post-monsoon	≥ 0.03

It is clear from the map in Fig. 2(a) that the central part of the Satkhira district in 2014, mainly Debhata, Assasuni and Kaliganj Upazilas held water permanently, whereas Fig. 2(b) shows the northward extension of waterlogged areas after monsoon rainfall. After incorporating pre- and post-monsoon waterlogged areas in Fig. 2(c), it is noticeable that mostly the northern part of Satkhira district covering Satkhira Sadar, Tala, and Kolaroa Upazil as become inundated after the monsoon season and, thus, this part can be considered as seasonally waterlogged areas. The same scenario has been observed in Satkhira in 2015 with slight enhancement in estimated values (Fig. 3).

Based on the analysis in GIS environment, waterlogged areas in Satkhira district along with temporal variations have been estimated (Table. 3). It is observed that waterlogged areas in Satkhira in 2014 for pre- and post-monsoon seasons are 830.09 km^2 and 1,355 km^2, respectively, where their area coverage enhances 524.91 km^2 due to monsoon rainfall. The percentage of waterlogged area changes from 21.74% in pre-monsoon to 35.50% in post-monsoon and the seasonal variation is 13.75 percent. Similarly, in 2015, the corresponding waterlogged areas for pre- and post-monsoon seasons are 861.14 and 1386.54 km^2 and the seasonal variation is 525.40 km^2. The percentage of area coverage jumps up to 36.32 percent from 22.56 percent with the deviation of 13.76 percent due to monsoon rainfall.

It is reported that only 152.81 km^2 area was inundated in Satkhira in 2006, but it doubled only after three years in 2009 as 343.66 km^2 (FAO, 2015). According to the present study, even the seasonal waterlogged areas for the consecutive years 2014 and 2015 are 524.92 km^2 and 525.40 km^2 respectively. Comparative analysis of our results with various preceding research findings reveals that waterlogged areas in Satkhira district are increasing significantly even though the dimension of waterlogging problem was little in the initial stage. It started compounding from 2006 and a maximum disaster was observed during the downpour of 2011 monsoon (Oxfam, 2011). The waterlogging during 2011 monsoon was so intense that 556,365 people and over 70,000 houses (completely and partially) were affected in Satkhira district alone (Oxfam, 2011; FAO, 2015). The situation is expected to worsen more to the days to come.

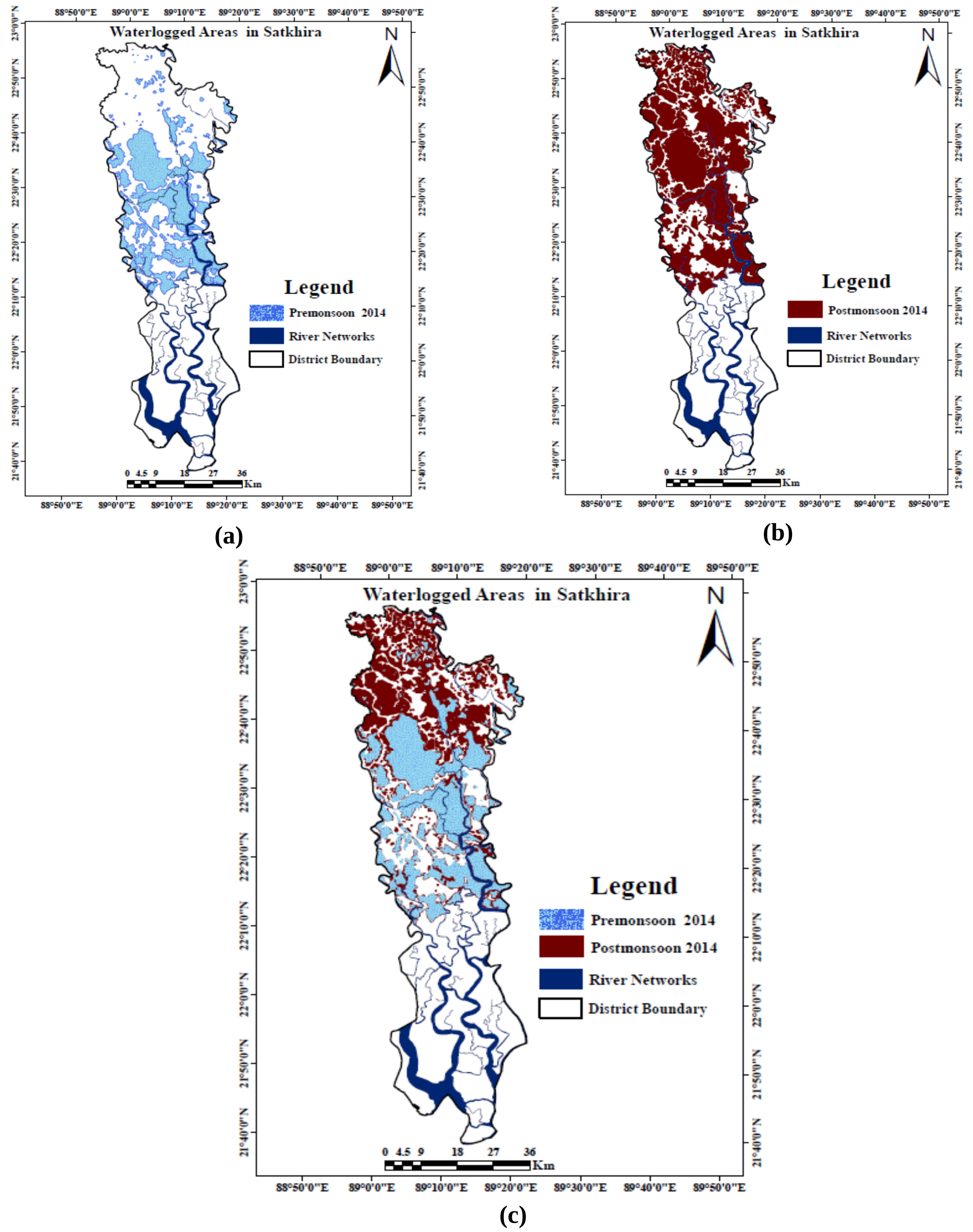
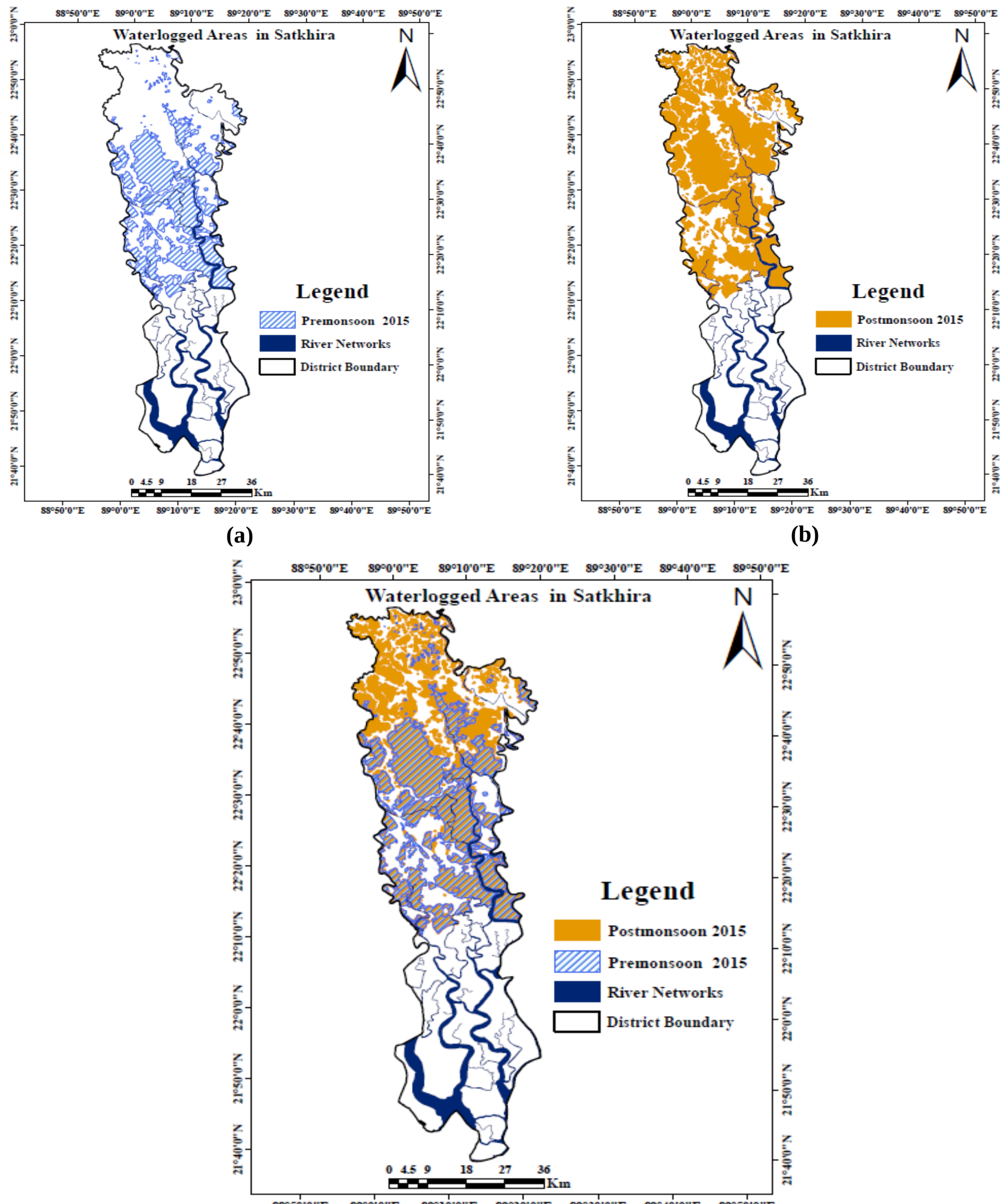


Fig. 2. (a) Maps displaying waterlogged areas in Satkhira during pre-monsoon, and (b) post-monsoon seasons in 2014, and (c) integrated map showing waterlogged areas for both pre-monsoon and post-monsoon seasons of the same year.



(c)

Fig. 3. (a) Maps displaying waterlogged areas in Satkhira during pre-monsoon, and (b) post-monsoon seasons in 2015, and (c) integrated map showing waterlogged areas for both pre-monsoon and post-monsoon seasons of the same year.

Table 3. Variations in waterlogged areas between pre-monsoon and post-monsoon seasons for the year 2014 and 2015 in Satkhira district.

	Pre-monsoon		Post-monsoon		Seasonal Variations	
Year	km^2	%	km^2	%	km^2	%
2014	830.09	21.74	1,355	35.50	524.91	13.75
2015	861.14	22.56	1,386.54	36.32	525.40	13.76

Rainfall is not solely responsible for waterlogging in southwest Bangladesh as it is clear from monthly average rainfall distribution of Satkhira district as compared to national monthly average that the monthly average rainfall of the former is remarkably lower than that of the later (Fig. 4). However, Mondal et al. (2013) found that, through the examination of rainfall data for a period of 63 years (1948–2010) at Khulna region, the number of rainy days in a year and the maximum number of consecutive rainy days is increasing. These suggest that water congestion would be prolonged in the locality, short after the end of monsoon in the coming days.

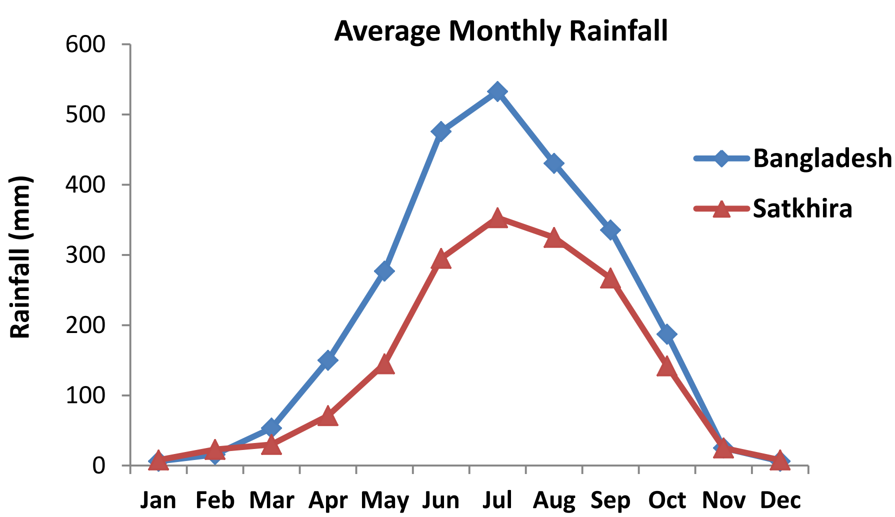


Fig. 4. Comparison of monthly average rainfall in Satkhira to that of Bangladesh for the last 30 years (1985-2015). (Data source: https://datahub.io and https://sdwebx.worldbank.org)

In addition to monsoon rainfall, rising of riverbed due to siltation as stimulated by retardation of upstream river flow by human intervention, polderization, encroachment of river banks, poorly executed infrastructure, unplanned aquaculture and climate change can be explained as the cause for waterlogging in the southwest of Bangladesh (Adri, and Islam, 2012; Awal, 2014; FAO, 2015; Ahmed, 2006; Hasan and Sayed, 2014).

Conclusion

Southwestern part of Bangladesh especially Satkhira is prone to waterlogging because of monsoon rainfall, local geologic settings, mismanagement and climate change. Reliable assessment of waterlogged areas forms a vital element in planning and implementing corrective measures for optimal utilization of available land and water resources for sustainable development in irrigation and other sectors. In this study, satellite images were successfully employed for the assessment of temporally and spatially distributed waterlogged areas aimed to evaluate the seasonal variations. However, this analysis can be carried out using considerably more time series data in order to draw a pattern in growth and seasonal variations in waterlogging. Extensive field survey could facilitate subtracting ponds from NDWI generated map to get a more accurate assessment. As suggested from the study that waterlogging areas are increasing, it is likely to be aggravated under climate change. Further, such study enables the administrators and planners in planning and implementing remedial and defensive measures for optimal utilization of available land and water resources for sustainable development. Therefore, comprehensive research is required to evaluate the impacts of waterlogging on agricultural productivity, soil fertility, biodiversity and water and sanitation system in the southwestern coastal areas of Bangladesh to find out the possible mitigation options. Furthermore, base rising and elevating the local habitats and physical infrastructures, excavating silted-up rivers and cannels can be considered as immediate and short-term measures to mitigate waterlogging problem, whereas operation of Tidal River Management (TRM) might be considered for long-term or permanent solution.

References

ADB. 2007. Bangladesh: Khulna-Jessore Drainage Rehabilitation Project. Performance Evaluation Report. Operations Evaluation Department, Asian Development Bank. 81pp.

Adhikary, S. K., A. D. Gupta, M. S. Babel, S. R. Perretand R. S. Celemente. 2012. Simulating river-aquifer dynamic interaction in the regional unconfined aquifer of southwestern Bangladesh. *Journal of Engineering Science.* **3**:147-160.

Adri, N. and I. Islam. 2012. Vulnerability and coping strategies in waterlogged area: a case study from Keshabpur, Bangladesh. *International Journal of Environment.* **2**:48-56.

Ahmed, A. U. 2006. Bangladesh: climate change impacts and vulnerability. A synthesis Climate Change Cell. Department of Environment. Comprehensive Disaster Management Programme (CDMP). 50pp.

Awal, M. A. 2014. Water logging in the southwestern costal region of Bangladesh: local adaptations and policy options. *Science postprint*. **1**:1-13.

Bouwer, H., A. R. Dedricand D. B. Jaynes. 1990. Irrigation management for ground water quality protection. *Irrigation Drainage System*. **4**:375-383.

Chatterjee, C., R. Kumar and P. Mani. 2003. Delineation of surface waterlogged areas in parts of Bihar using IRS-1C LISS-III data. *Journal of Indian Society of Remote Sensing*. **31**:57-65.

Choubey, V. K. 1996. Assessment of waterlogging in Tawa command area by remote sensing techniques. *Asian-Pacific Remote Sensing and GIS Journal*. **9**:31-38.

Choubey, V. K. 1998. Assessment of waterlogging in Sriram Sagar command area, India, by remote sensing. *Water Resource Management.* **12**:343-357.

Chowdary, V. M., R. Vinu Chandran, N. Neeti, R. V. Bothale, Y. K. Srivastava, P. Ingle, D. Ramakrishnan, D. Dutta, A. Jeyaram, J. R. Sharma and R. Singh. 2008. Assessment of surface and sub-surface waterlogged areas in irrigation command areas of Bihar state using remote sensing and GIS. *Agricultural Water Management*. **95**:754-766.

Die, L. 2013. Tidal Rive Management: temporary depoldering to mitigate drainage congestion in the southwest delta of Bangladesh. (Unpublished M. Sc. thesis), Water Resources Management Group, Wageningen University, The Netherlands. 130pp.

Dwivedi, R. S. 1994. Study of salinity and waterlogging in Uttar Pradesh (India) using remote sensing data. *Land Degradation and Rehabilitation*. **5**:191-199.

Dwivedi, R. S., K. V. Ramana, S. S. Thammappa and A. N. Singh. 2001. The utility of IRS-1C and LISS-III and PAN-Merged data for mapping salt-affected soils. *Photogrammetric Engineering Remote Sensing.* **67**:1167-1175.

Dwivedi, R. S. and K. Sreenivas. 2002. The vegetation and waterlogging dynamics as derived from space borne multispectral and multitemporal data. *International Journal of Remote Sensing*. **23**:2729-2740.

FAO. 2015. Mapping exercise on waterlogging in south west of Bangladesh. Draft for consultation. 160pp.

FSC and Partners. 2014. Measuring the impact of waterlogging on household economies, Satkhira, Bangladesh. HEA report. 34pp.

Hasan, M. S. and M. Syed. 2014. Detection of water-logging areas based on passive remote sensing data in Jessore district of Khulna division, Bangladesh. *International Journal of Scientific and Research Publication*. **4**:1-7.

Huq, S. M. I and J. U. M. Shoaib. 2013. The soils of Bangladesh. Springer. 165pp.

Lohani A. K., R. K. Jaiswal and R. Jha. 1999. Waterlogged area mapping of Mokama group of Tals using remote sensing and GIS. *Journal of the Institute of Engineers (India).* **80**:133-137.

Mancuso, S and S. Shabala. 2010. Waterlogging signalling and tolerance in plants. Heidelberg, Berlin: Springer Berlin Heidelberg. 294pp.

McFeeters, S. K. 1996. The use of Normalised Difference Water Index (NDWI) in the delineation of open water features. *International Journal of Remote Sensing*. **17**:1425-1432.

Minar, M. H., M. B. Hossain and M. D. Shamsuddin. 2013. Climate change and coastal zone of Bangladesh: vulnerability, resilience and adaptability. *Middle-East Journal of Scientific Research*. **3**:114–120.

Mirza, M. M. Q and Q. K. Ahmad. 2005. Climate Change and Water Resources in South Asia. CRC Press. 352pp.

Mondal, M. S., M. R. Jalal, M. S. A. Khan, U. Kumar, R. Rahman and H. Huq. 2013. Hydro-meteorological trends in southwest coastal Bangladesh: perspectives of climate change and human interventions. *American Journal of Climate Change.* **2**:62-70.

Oxfam. 2011. Monsoon floods and water logging in Bangladesh. Situation report 01. 4pp.

Rahman, A. 1995. Beel Dakatia: the environmental consequences of a development disaster. University Press Limited, Dhaka. 55pp.

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*. 9pp.

Sahu, A. S. 2014b.Identification and mapping of the water-logged areas in Purba Madanipur part of Khelaghai River Basin, India: GIS and RS methods. *International Journal of Advanced Geosciences.* **2**:59-65.

Sharma, J. R., D. Dutta and Y. Paithankar. 2009. Assessment of water logging and salt and/or alkaline affected soils in the commands of all major and medium irrigation projects in the country using satellite remote sensing. Country report, India. 21pp.

Sujatha, G., R.S. Dived, K. Sreenivas and L. Venkataratnam. 2000. Mapping and monitoring of degraded lands in part of Jaipur district of Uttar Pradesh using temporal spaceborne multispectral data. *International Journal of Remote Sensing*. **21**:519-531

UNDP. 2011. Water Logging in Satkhira District: An Analysis of Gaps between Needs and Response. Early Recovery Facility, UNDP Bangladesh. 25pp.

Unnayan Onneshan. 2006. The development disaster: waterlogging in the southwest region of Bangladesh. *IFI Watch Bangladesh.* **3**:1-9.

https://glovis.usgs.gov

https://datahub.io

https://sdwebx.worldbank.org