Protocols for riverine wetland mapping and classification using remote sensing and GIS

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Wetlands are one of the most important ecological environments that also have high socio-economic importance. India hosts a large number of wetlands, among which most are in the Indo-Gangetic Plains formed by riverine processes. In order to understand the extensive system of riverine wetlands and their distinction from other floodplain water bodies, mainly the waterlogged areas, a mapping and classification system has been proposed and applied for wetlands in the Begusarai district of north Bihar plains, India. The proposed hydro-geomorphic classification system is hierarchical, simple, and robust, and can be implemented through quick processing of satellite images integrated with minimal ancillary data.

Keywords: Hydro-geomorphology, mapping and classification, waterlogging, wetlands.

WETLANDS are permanently or seasonally water-saturated land areas and are a fundamental hydrologic landscape unit[1] that usually form on shallow slopes (flat areas) where 'perennial water lies at or near the land surface, either above or below'[2]. Wetlands are often known as 'nature's kidneys'[3] as they cleanse the environment, and 'biological supermarkets'[4], because they support an extensive food chain and rich biodiversity.

Ramsar, an international organization for wetland conservation, defines the wetlands broadly as 'areas of marsh, fen, peatland, or water, whether natural or artificial, permanent or temporary with water, i.e. static or flowing, fresh, brackish, or salt including areas of marine water, the depth of which at low tide does not exceed six metres'. More precisely, wetlands have been defined as 'areas where wet soils are prevalent, having a water table near or above the mineral soil for most of the thawed season, supporting a hydrophilic vegetation'[5], and with open water less than 2 m deep. It is important to note here that this definition does not include those areas as wetlands which are flooded temporally but drain well during most parts of the growing season.

In order to manage, monitor and study the wetland systems, two factors are of utmost importance – their mapping and classification. During the last few decades, remote sensing has been used as the most efficient tool to map, make inventories, apply management practices and monitor wetlands[6–8]. Satellite remote sensing, with the advantages of cost-effectiveness, multi-temporal coverage and multi-spectral data, provides a way to analyse the usually otherwise inaccessible wetland environment[6]. It is also the most viable option when little or no prior information about the wetland is available[7].

Traditionally, wetland classification has been based on physical, genetic, biological, chemical, or biochemical criteria, especially for European wetlands and thus do not always characterize wetland in other parts of the world[9]. Broadly, all classification schemes fall in two categories: (a) geographical, defined by ecological units and eco-regions, and (b) environmental, defined by either individual or clumped watershed characteristics, viz. hydro-geomorphology, land use/land cover and vegetation type[10]. The hydro-geomorphic (HGM) classification[11] is a better way to identify the dominant landscape and hydrologic factors in order to understand the wetland forms and functions[2], because the 'functional aspects of seemingly dissimilar wetland types could be seen to be similar when classified by geomorphic setting and water source'[12].

The Indian wetlands despite their diversity are not as much studied as their North American[11,13,14], European[15], and Australian[9,16] counterparts. There was no account of any systematic classification scheme for the Indian wetlands until Gopal and Krishnamurthy[17] proposed an ecological classification based on hydrological factors and associated vegetation type for this region. The National Wetland Inventory and Assessment (NWIA), based on the mapping done by Indian Space Research Organization has also provided a methodology to map the wetlands using remote-sensing data and presented a wetland classification system known as 'Modified National Wetland Classification System'[18]. On 24 July 2016, the National Green Tribunal (NGT) directed the Central Wetlands Regulatory Authority to hold monthly meetings with the States and Union Territories so as to identify and notify all the wetlands in the country. This has further emphasized the need for a robust and simple wetland mapping and classification scheme.

As the inland wetlands in India are mainly riverine, spanning the vast Indo-Gangetic Plains (IGP), the present study is focused on distinguishing the floodplain water bodies and providing a simple riverine wetland classification scheme. The proposed classification scheme is

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derived from the NWIA classification for riverine wetlands, but with important modifications. For instance, the waterlogged areas (natural or anthropogenic) are not considered as wetlands in our scheme. While wetlands are of high ecological importance, and evolve over long timescales, waterlogging is an undesirable phenomenon, and rather than supporting any ecosystem, it destroys them. Further, we have also distinguished natural and artificial wetlands such as aquaculture ponds and paddy fields, as also advocated by previous workers[17]. Finally, we have demonstrated the integrated use of remote sensing images, digital elevation models and other ancillary data in a GIS environment for mapping and classification of the wetlands.

The proposed protocol has been applied to the wetlands of the Begusarai district, north Bihar plains, India. The study area includes the Kaabar Tal, the largest wetland of the region, which is also a potential Ramsar site. The mapped wetlands and other floodplain water bodies have been classified according to the proposed geomorphic-based hierarchical classification scheme.

Study area

The IGP host the largest wetland system of the country and most of these are riverine wetlands and Himalayan Terai wetland systems[19]. The Begusarai district (Figure 1), which lies in the eastern part of the IGP and hosts numerous riverine wetlands, has been selected to demonstrate the proposed protocol for wetland mapping and classification. This region is characterized by tropical monsoonal climate with medium to high rainfall (annual rainfall: 1200 mm) and variable temperature regime. While the winter (December to January) temperature ranges from 8°C to 25°C, the summer (April to June) temperature varies from 23°C and 38°C. The largest wetland of this region, the Kaabar Tal, spreads over an area of 51 sq. km and is located in the interfan region of the Kosi and Gandak rivers. The closest channel to this wetland is a plains-fed river, the Burhi Gandak[20]. The other wetlands are of variable size ranging from 0.03 to 43 sq. km.

Methodology for wetland delineation and mapping

The Landsat 8 (OLI-TIRS) imageries dated 4 April 2014 and 30 November 2014 (pre- and post-monsoon) were used as the primary data for mapping, while SRTM DEM data (spatial resolution 30 m) were used to evaluate depressions in the terrain, and for detailed interpretation of the broad units covered under the proposed classification.

The major steps in the creation of a wetland database included: (1) generation of spatial framework in GIS environment for database creation and organization; (2) identification of wetland classes through a series of enhanced and transformed satellite images, and mapping them through onscreen interpretation; (3) generation of feature layers (rail, road network, settlements, drainage, administrative boundaries) from satellite image and ancillary data for overlay and proximity analysis; (4) cross-checking the mapped features using evaluated depressions superimposed on NDWI values with appropriate threshold and wetness index image, and (5) preparation of maps and generation of statistics. Work was carried out using ERDAS Imagine and ArcGIS software. A flow chart depicting the work carried out is shown in Figure 2, drawing instances from Kaabar Tal.

In the raw images, the effect of each wavelength was manipulated using mathematical operators to emphasize some features. For instance, visualization quality was improved by nonlinear contrast stretching operators of square root (enhancing the low DN values) and histogram equalization (enhancing the overall contrast of the image); band ratios, combinations, colour composites and spectral indices were obtained using Spatial Modeller of ERDAS Imagine 9.1. These specific image processing techniques have been listed in Table 1, along with their advantages and significance.

Additional images were prepared to cross-check the feature being mapped, namely wetness index image and the evaluated depression image (Table 2). A major challenge was to separate the waterlogged areas and artificial wetlands, which are difficult to distinguish from natural wetlands using automated mapping techniques. Therefore, a semi-automated method using satellite imagery and DEM data has been devised. The processed images were superimposed with evaluated depressions and all classes of water bodies were delineated. For instance, NDWI with the threshold range of – 0.15 to 0 was superimposed with evaluated depressions to separate wetland signatures from waterlogging[8]. Since the wetlands have evolved over longer (pre-historic/geological) periods of time, the depressions pertaining to them would be less fragmented and more homogenized than those pertaining to waterlogged areas that have developed over much shorter (historical) timescales (Figure 3).

While mapping, the main objective was to identify the spectral signatures of water and water–vegetation mixed features. Various classes were distinguished from each other based on their distinct physical attributes. For instance, floodplain lakes are large bodies of standing water of considerable depth, occurring in natural depressions usually not much closer to a stream and fed by the groundwater table. These were identified as patches of deep shades of blue signifying larger depth than other types and located at a distance from nearby stream(s). One peculiar attribute of these lakes is that the lake boundary is surrounded by an area with little or no vegetation. Oxbows and scrolls were identified from their characteristic shapes around the traces of palaeo-channels or abandoned meanders. On false colour composite (FCC;

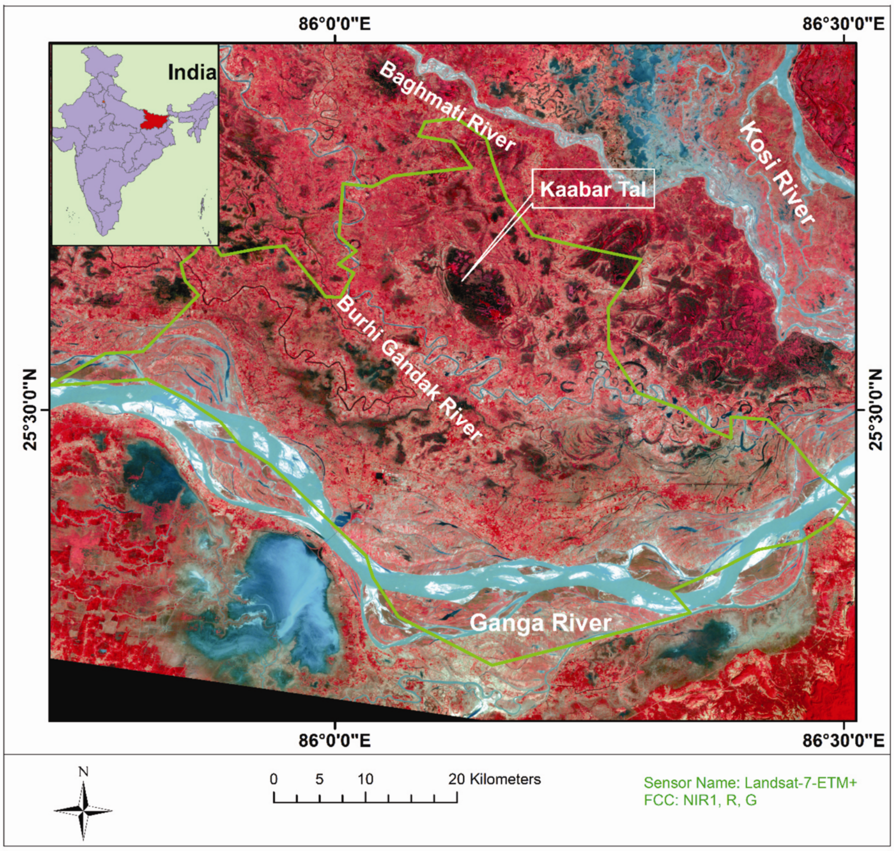

Figure 1. Landsat colour infrared map showing the study area and major hydrogeomorphic features. Begusarai district is marked by a green outline which includes the Kaabar Tal, the largest wetland in north Bihar plains, India.

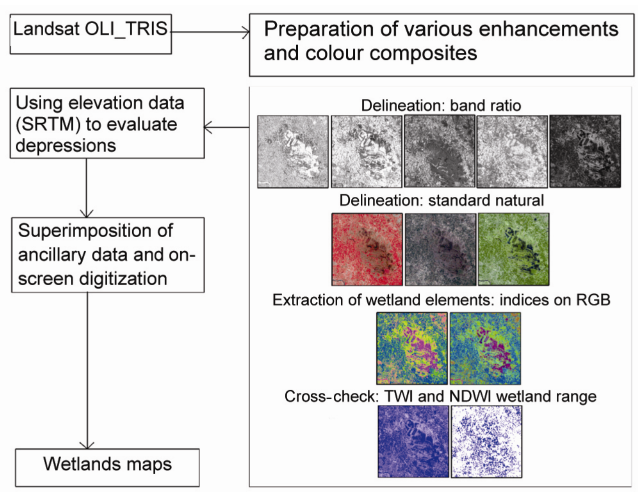

Figure 2. Flow chart depicting the sequence of operations followed in data processing and mapping of wetlands, waterlogging and other water bodies. The area covering the Kaabar Tal is used for illustration.

Landsat 8, band 764 on RGB), they appear in blue shades with greenish shades of vegetation near the boundaries. Marshes and swamps are generally found close to a stream, sometimes attached to it. On satellite images, they appear in grey–blue tone and smooth texture. Natural waterlogging is abundant, where there is a congestion of numerous streams in a small area, and/or in areas of small fragmented depressions. Post-monsoon increase in natural waterlogging is due to flooding of disconnected palaeo-channels. On satellite images, they appear as irregular and mixed signatures of vegetation and shallow water. During the monsoon period when surface water exists, waterlogged areas might appear similar to flood-plain lakes/ponds, and hence ancillary data are needed for distinguishing them. However, waterlogged areas dry up during summer and give the appearance of mud/salt flats (grey-bluish) on FCC (Landsat 8, band 764 on RGB).

Anthropogenic waterlogging was distinguished with the help of ancillary data. All waterlogged areas were first mapped without assigning anthropogenic or natural category. After proximity analysis from the ancillary data, especially urban settlements, rail–road congestions, lined canals as well as embankments of rivers, man-made waterlogged areas were separated from the naturally waterlogged areas (Figure 4). Rest of the area under waterlogging was assigned as naturally waterlogged after checking the sources of water in the proximity. Soil cover of the study area along with the digital elevation model

Table 1. Image enhancement techniques and colour composites used to identify wetland and surrounding features

Enhancement	Definition and significance
Contrast stretching	Increases the contrast between targets and their backgrounds using methods such as histogram equalization.
Band ratio	TM4/TM3: Vegetation, water and croplands are distinguished; this ratio uniquely defines the distribution of vegetation. The lighter the tone, greater the amount of vegetation present.
	TM5/TM7: Land and water separated uniquely as both band 5 and band 7 are sensitive to moisture content variation in soils and vegetation. Land appears as lighter tone and water appears as dark tone.
	TM4/TM5: Enhances the water body, vegetation and presence of moisture content in the croplands; useful for discriminating water bodies from land.
	TM5/TM4: Water body separated from forest, barren lands and vegetation.
	TM3/TM5: Enhances barren lands, highways, street patterns within urban areas and urban built-up or cemented areas. It is useful for observing differences in water turbidity, as it enhances turbid water.
Spectral indices	NDWI = {(green – NIR)/(green + NIR)} MNDWI = {(green – MIR)/(green + MIR)} NDVI = {(NIR – red)/(NIR + red)} NDPI = {(MIR – green/MIR + green)} NDTI = {(red – green)/(red + green)}
Band combinations	432 on RGB: 'False colour' composite; vegetation in shades of red, urban areas cyan blue, and soils dark to light brown.
	321 on RGB: 'Natural colour' composite; ground features appear in colours similar to their appearance to the human visual system.
	753 on RGB: 'Natural-like' appearance, penetrating atmospheric particles, smoke and haze; vegetation in shades of dark and light green.
	NDTI, NDPI, NDWI on RGB: Enhance aquatic vegetation cover of the wetland.
	NDVI, NDPI, MNDWI on RGB: Enhance turbidity within the wetland; help delineate the minimum actual water boundary.

Table 2. Indices generated from satellite images with their parameters and significance

Generated image	Definition and significance
Wetness index	TWI = ({B2} * 0.1509 + {B3} * 0.1973 + {B4} * 0.3279 + {B5} * 0.3406 + {B6}* 0.7112 + {B7} * – 0.4572) where B2–B7 are the digital number (DN) values of the respective bands of Landsat 8 data.
Depression feature map	This has been created from the SRTM DEM data, which further helps in comprehending the difference between wetlands and waterlogged areas.

were also used as ancillary data, but merely for interpretation and understanding the spatial distribution of water bodies.

Proposed wetland classification scheme

An exhaustive wetland classification can either be developed by 'detailed field survey and data analysis' or using 'general information' to clump similar features first before classifying them further through field surveys and other hydro-geomorphic data[17]. The latter approach is most suitable in the regions with limited prior wetland information. The existence of any wetland type is mainly dependent on two fundamental factors – water regime and landform. Soil type, climate or vegetation are secondary factors[21], and thus classification schemes like the HGM system which is based on these two fundamental factors, are the most suited[22]. Between the two factors, geomorphic setting and water source that constitute the HGM class[23], the latter cannot be established from remote sensing data alone. Thus, in order to develop a first-order remote sensing data-based classification system, geomorphic framework is most useful. However, one can always convert the proposed geomorphic classification scheme to a HGM system one by including the hydrodynamics of these water bodies. At this point it must be noted that remote sensing is not a substitute for actual field surveys, but it assists in and simplifies the field surveys. In the present study, several water bodies mapped from satellite images were confirmed through field visits.

We propose a two-level hierarchical system for classifying the waterbodies on floodplains (Table 3). Level one constitutes three major classes, namely 'riverine wetlands', 'waterlogged areas' and 'other waterbodies'. All the wetlands which have been carved by the action of rivers are considered as riverine wetlands. Our aim is to

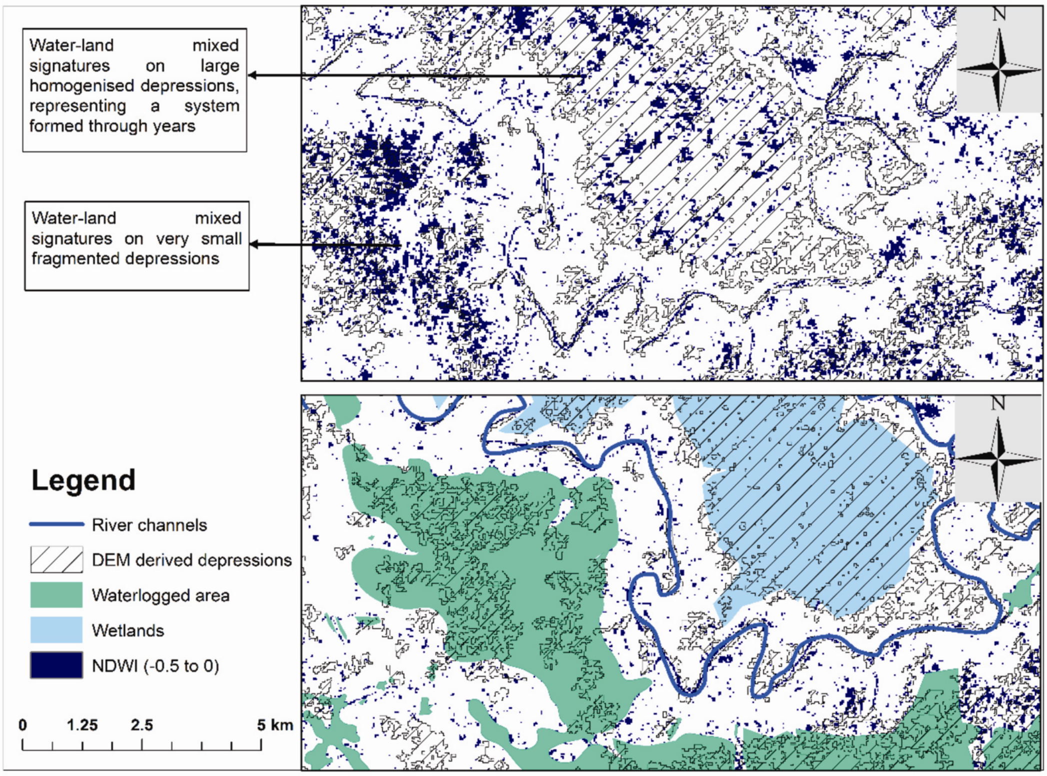

Figure 3. Protocols for separating wetlands from waterlogging. Water–land mixed signatures are extracted from NDWI using appropriate threshold, which is superimposed over the depressions evaluated from SRTM DEM data, to serve as the base image for interpretation.

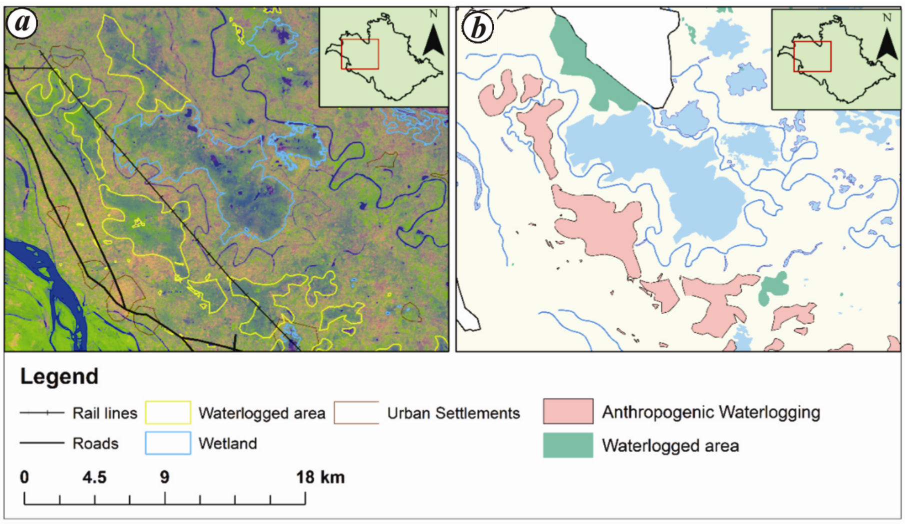

Figure 4. A section of Begusarai district depicting the following: ***a***, Use of ancillary data in identifying the anthropogenically induced waterlogging and inundation utilizing the FCC of MNDWI-NDPI-NDVI. ***b***, Extracted features with distinction among wetlands, anthropogenic and natural waterlogging.

delineate and classify the riverine wetlands which are natural wetlands, and therefore, the artificial wetlands are not included in the wetland sub-class, but in the 'other water bodies' class. Lakes are also put into the 'other water bodies' class. A relatively large water body is classified as a 'lake' rather than a 'wetland' if it is deeper than 2 m, and 10% or more of its area remains under permanent inundation[5,9]. The artificial wetlands are classified as 'other water bodies' and usually include large patches of paddy fields, aquaculture ponds, flood-control structures, water supply and irrigation structure[19]. Most of these artificial wetlands, especially paddy fields and

Table 3. Proposed classification of 'riverine wetlands', waterlogged areas and other water bodies

Level 1	Level 2
Riverine wetlands	Floodplain lakes: Large bodies of standing water of considerable depth, occurring in natural depressions, usually far from the active stream and fed by precipitation as well as groundwater table.
	Oxbows and scroll lakes: Fluvial geomorphic features left behind by the meandering river channels and filled with water; easily identifiable due to their signature shapes. Usually, the oxbows are deeper than the scroll lakes.
	Marshes and swamps: Along the length of rivers in plains, water accumulates to a very shallow depth (e.g. in crevasses), wherever there is a change in speed of running water, leading to formation of marshes and swamps.
Waterlogged areas	Natural waterlogged: These are seasonally-fed, inundated and generally low-lying areas in close proximity to rivers/streams.
	Anthropogenic waterlogging: These are areas under waterlogging caused by surface and sub-surface run-off blockage induced by anthropogenic activities.
Other water bodies	River/stream: All the rivers and streams comprise this category.
	Drainage/canals*: These are man-made canals lined or unlined, easily identifiable due to their perfect linear shape.
	Lakes*: Large water bodies with average depth greater than 2 m.
	Tanks, ponds and reservoirs: All constructed water bodies in urban as well as rural settlements, easily identifiable due to their sharp boundaries.
	Artificial wetlands*: Aquaculture ponds and paddy fields.

*Although these sub-classes are not present in the study area, they have been included to make a general classification scheme rather than one specific to the study area.

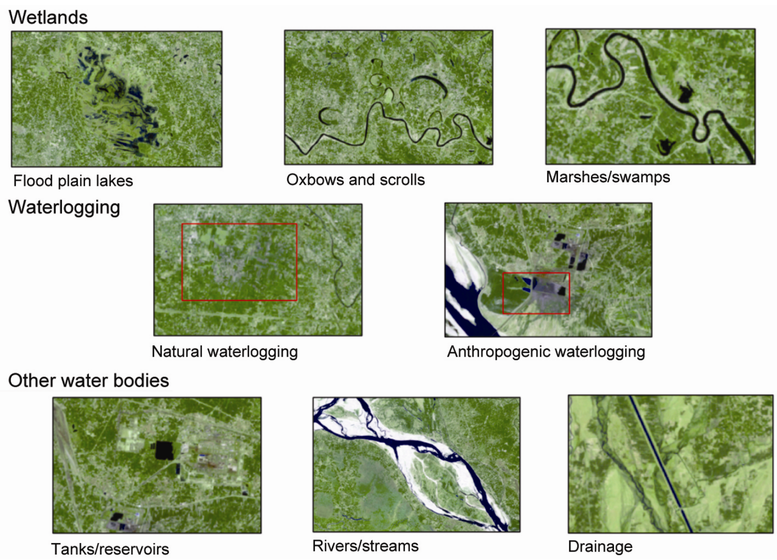

Figure 5. The proposed classification of water bodies illustrated with examples from the study area.

aquaculture ponds, are the result of the transformation of 'natural temporary wetlands'[24]. Figure 5 shows some examples of classified water bodies.

Discussion

Following the classification scheme outlined above, a map depicting different water bodies in the Begusarai district has been prepared for both pre- and post-monsoon periods (Figure 6). The map clearly shows the distinction among different riverine wetlands, waterlogged areas (anthropogenic and natural separately), and other water bodies such as rivers and ponds. As evident from Figure 6, the spatial distribution of natural water bodies, i.e. riverine wetlands and natural waterlogged areas follows the geomorphic setting of the district. Most of the

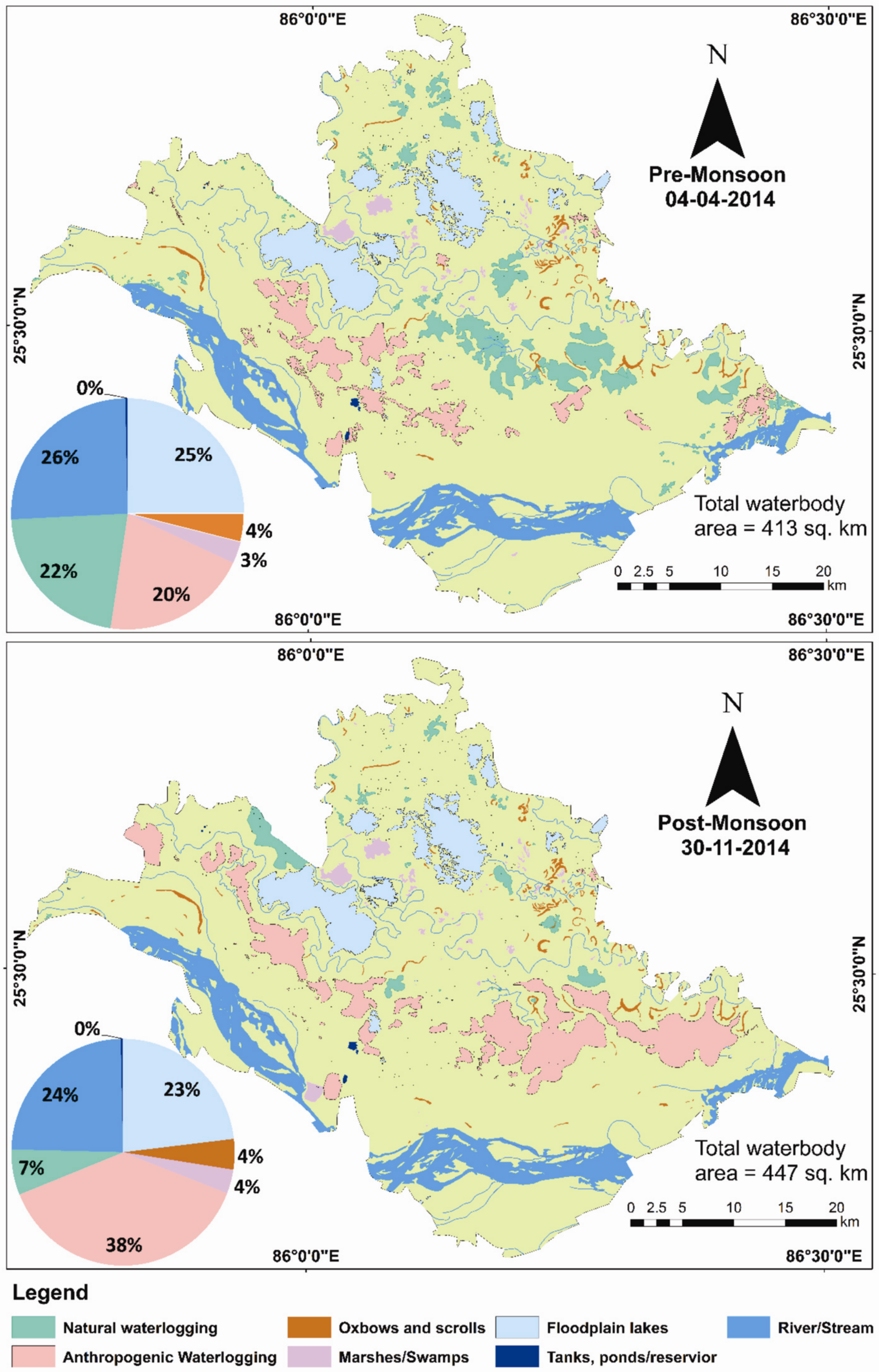

Figure 6. Map showing seasonal geospatial distribution of water bodies in Begusarai district. Oxbows and scrolls, floodplain lakes, and marshes/swamps constitute the natural wetland system in the area, they do not show any significant seasonal changes. The most remarkable change occurs in anthropogenic waterlogging, highlighting the severe drainage congestion in this region.

riverine wetlands are in the vicinity of the Burhi Gandak river with remarkably high sinuosity[20]. The waterlogged areas occur mostly in the interfluve region between the Ganga and Burhi Gandak rivers, mainly because both the rivers are embanked and drainage conditions are poor. The urban settlements and transport networks (rail and road) are also found to be associated with waterlogging. Tanks and ponds are distributed all over the district, except in areas close to the Ganga river. The most iconic wetland of the region, the Kaabar Tal, which has been classified as a floodplain lake, lies in the interfluve of the Burhi Gandak and Baghmati rivers.

Table 4. The pre- and post-monsoon areal extent of water-bodies in Begusarai district, north Bihar plains, India

Level-1	Level-2	Area (sq. km) pre-monsoon	Area (sq. km) post-monsoon
Riverine wetlands	Floodplain lakes	103.03	103.39
	Oxbows and scrolls	16.74	19.496
	Marshes/swamps	12.49	15.29
Waterlogging	Anthropogenic waterlogging	84.28	170.24
	Natural waterlogging	90.22	28.86
Other waterbodies	Rivers or streams	105.25	108.61
	Tanks, ponds and reservoirs	1.39	1.50
Total		413.41	447.38

In general, natural waterlogging covers greater area than anthropogenic waterlogging, but there is a remarkable seasonal difference in terms of total area covered by the water bodies (Table 4 and Figure 6). Total area covered by all water bodies in Begusarai district is 413 sq. km during pre-monsoon, which increases to 447 sq. km in the post-monsoon period. Interestingly, most of this seasonal increase happens in the waterlogged areas, suggesting severe drainage congestion in the region.

Our results demonstrate that remote sensing and GIS are viable tools to obtain the spatial and temporal distribution of wetlands, and to develop a fairly reliable wetland database and inventory. The proposed method is scale-independent, i.e. the same method can be applied to obtain maps at different resolutions. Further, the proposed methodology is not only capable of distinguishing between wetlands and waterlogged areas, it further identifies natural and anthropogenic waterlogging, thus making the management and mitigation task easier. This is important as the management practices for conservation of wetlands are entirely different from those of waterlogging mitigation.

The proposed geomorphic classification for riverine wetlands stands out because it is not only a simpler and robust classification scheme, but also clearly distinguishes waterlogged areas from wetlands. Further, it is based on remote sensing techniques with minimal data requirements, and thus provides an opportunity to classify and catalogue the wetlands with little or no prior information. For the same reason, this approach is widely applicable across different climatic regimes. The proposed two-level classification can be further enhanced to tertiary or more levels with additional hydrological data, vegetation, and/or soil data. Furthermore, the proposed scheme is reproducible, temporal and quick, the essential qualities of any classification scheme for developing a sustainable management strategy.

Concluding remarks

The utility of remote sensing and GIS in the mapping and classification of the water bodies in a river-dominated area has been successfully demonstrated. A simple geomorphic classification system for riverine wetlands has been devised and demonstrated for water bodies of Begusarai district. A significant portion of the district is currently covered by waterlogged areas that have often been mixed with wetlands in the existing maps. The exclusion of waterlogged areas from the category of wetlands in a classification scheme is important keeping in view that all wetlands have to be notified by the states according to the NGT guidelines. Our classification scheme provides the criteria for robust and quick mapping and assessment of wetlands, and therefore, has significant implications for wetland conservation and management.

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