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PREFACE

Management of excess water in agriculture is a major challenge globally as well as in India, where about 11.6 million ha area is waterlogged. This is mainly due to (1) over irrigation, (2) run-off congestion, (3) unscientific *in-situ* water management, (4) imbalance in inflow and outflow water in irrigated lands and (5) obstruction of natural drainage networks. Even though availability of adequate water is essential for higher productivity, the excess water situation in agricultural field is a serious challenge to agricultural productivity in addition to negative ecological implications like greenhouse gas emission from waterlogged and marshy lands. Agriculture activity in this sub-productive waterlogged ecosystem always remains a challenge due to the changing physico-chemical and micro-biological soil properties.

Therefore, delineation of waterlogged areas which are normally designated as degraded land to bring under commercial agriculture to increase the land and water productivity is of paramount importance. These areas can be brought under conventional or non-conventional cultivation practices depending on the extent of waterlogging. Intensive cultivation in waterlogged areas has the potential in providing ecological services maintaining nutrient balance between soil and the water for sustainable agro-ecological conditions. Even under such limitation, cultivation of water chestnut (*Trapa bispinosa*) or other aquatic food crops, integrated with aquaculture play an important role in sustaining livelihood and makes the system economically secure.

Keeping this in view, attempts were made at ICAR-IIWM to identify critical intervening areas suitable for fitting in ideal crops and to develop their integrated package of practices based on the extent of waterlogging for improving land and water productivity. We sincerely hope that our effort in bringing out this research bulletin based on delineating waterlogged areas using Indian remote sensing satellite data and on-farm field trial will be helpful for all those engaged in integrated fish-aquatic crop farming and its management. This will also serve as a source of information to farmers, policy makers, entrepreneurs, researchers and extension workers as training guide.

Authors

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Introduction

Agricultural intervention in waterlogged areas is challenging. It is a major researchable issue as waterlogging causes land degradation making it unproductive. Excess water changes the physical, chemical and microbiological properties of waterlogged soils. India has approximately 11.6 M ha *i.e.* 8.3% of its net sown area under waterlogged condition (Planning Commission 2011) out of which more than 20 % falls in the eastern region where surface waterlogging is a major cause rendering the area unproductive. Eastern India, especially the 15 eastern districts of Uttar Pradesh and the entire states of Bihar, West Bengal and parts of Odisha constitute a significant chunk of the Ganga-Meghna-Brahmaputra (GMB) basin is home to 500 million of the world's poorest people (Saxena NC, Planning Commission). The population pressure (persons/km^2) in the region, comprising Eastern UP, Bihar (1102), West Bengal (1029), Assam (397) and Odisha (269) is also very intense. According to 2011 census, against national population density of 382 persons/km^2 area, in eastern India it is 625 persons/km^2. High dependence of its predominantly rural population on agriculture, especially 'smallholder agriculture' and wage labor often makes farming challenging. Therefore, improving water productivity of challenged ecosystems like waterlogged area is one of the major goal of ICAR-Indian Institute of Water Management (Ambast 2015). Because of its vulnerability to submergence, flood or unpredictable water regime, entire waterlogged area suffers from uncertainties of productivity. Therefore, delineation of waterlogged areas in Eastern Indian states and identification of resilient production system in waterlogged area warrants attention. In addition, assessment of their economic impact on livelihood improvement of the stakeholders is extremely important for attaining sustained growth in eastern region in general and in the unproductive waterlogged area in particular. Remote sensing tools alongwith Geographical Information Systems (GIS) provides a powerful alternative to conventional mapping techniques in assessment and mapping of surface waterlogged areas.

Along with irrigation, drainage *i.e.* removal of excess water from agricultural field is a major challenge in agricultural water management research. Such a vast area affected by waterlogging have two conflicting scenarios, *viz.* abundance of water and at the same time low agricultural productivity. Drainage of excess water from such vast areas is difficult as well as expensive. Therefore, as an easier option, cultivation of economically important plants, which have natural adaptation under such condition can be promoted. If the plants are of shorter duration they can be used for short-term cultivation. Some of these plants are profuse water users and transpire abundantly. These plants can also be used to remove excess water from recharge zone or to lower the water table in waterlogged areas. And more over as majority of this vast area is under low lying situation, integration of aquaculture helps in increasing productivity of both the land and water.

Eventhough, several studies have been carried out for delineation of waterlogged areas in India, information are lacking about the characterization of waterlogging especially in high rainfall areas like Eastern India, where proportion of areas with surface and subsurface waterlogging is different from the areas with lesser rainfall. The characterization of waterlogged area in Eastern India is critical for adopting any crop management strategy which otherwise remains fallow or has poor productivity. Lack of adequate drainage gradient and heavy rain in short spell keep vast area waterlogged. Therefore agricultural diversification in such delineated waterlogged areas has potential for increasing productivity of both land as well as water in eastern India (Kumar *et al*. 2007, Kar *et al*. 2011). Isolated technological solutions do not provide comprehensive package to keep such waterlogged areas agriculturally productive. This publication would attempt to fit in suitable technologies customized for delineated waterlogged areas to keep the areas productive throughout the year.

What is waterlogging?

Excess soil water leading to waterlogging is one of the major problems of land degradation in India making the land agriculturally sub-productive. Several factors ranging from unscientific management of water in agricultural field, imbalance of inflow and outflow of water in irrigated lands and obstruction of natural drainage systems by various developmental activities are responsible for disrupting the balance leading to waterlogging. While irrigated area over the years has increased several folds, resultant problem of inadequate drainage has increased the problems of waterlogging of agricultural lands. In addition, the excess monsoon rain also brings waterlogging in low lying areas and is generally seasonal in nature. Soil profile is considered to be waterlogged when the surplus water stagnates due to poor drainage or when the shallow water table rises to an extent that soil pores in the root zone of a crop become saturated, resulting in restriction of the normal circulation of the air, decline in the level of oxygen and increase in the level of carbon dioxide. Unlike free diffusion in air, movement of gases in aqueous solution is 10,000 times slower (Armstrong 1979) and hinders diffusion of oxygen and carbon-dioxide in waterlogged soil affecting root growth and finally overall growth and yield performance of crops. The actual depth of water table, when it starts affecting the yield of the crops adversely, may vary over a wide range from zero for rice to about 1.5 meters for other crops. A Working Group constituted by the Ministry of Water Resources to identify the problem areas affected by waterlogging/ salinity/ alkalinity in existing irrigation projects in the country and to suggest suitable remedial measures for their reclamation adopted in 1991 laid down following norms for identification of water logged areas (http://wrmin.nic.in/ printmain3.asp? sslid= 345 & subsublinkid =354&langid=1):

1. The water table is within 2 meters of the land surface and the area is defined as waterlogged area due to rise in water table.
2. The water table is between 2 to 3 meters below land surface and the area is defined as potential areas for waterlogging
3. The water table below 3 meters of land surface and the area is considered safe from waterlogging.

Generally when excess water remains below soil surface, the condition is known as 'subsurface waterlogging' where as when excess water is seen above soil surface, the situation is called ‘surface waterlogging'. However, some states have adopted different norms for defining waterlogged areas in their states according to their own conditions and perceptions. However, subsidies are available both for 'surface' as well as 'subsurface drainage' intervention from central government. The National Commission on Agriculture assessed that an area of about 6.0 million hectare was waterlogged in the country. Out of this, an area of 3.4 million hectare is affected due to surface water stagnation and 2.6 million hectare due to rise in water table. The Ministry of Agriculture estimated that an area of 11.6 million hectare was suffering from the problem of waterlogging. The Working Group of MOWR (1991) estimated that about 2.46 million hectare area in the country was affected by waterlogging in various irrigation commands. The extent of waterlogging is on rise in eastern part of India. The seasonally waterlogged area in the four doabs in Odisha (Mahanadi-Kathjhori-Debi, Mahanadi-Chitrotpala-Luna-Birupa-Brahmani, Luna-Chitrotpala and area to the East of high level canal) increased to 38998 ha during 1998-99 from 29330 ha in 1988-89 has (30% increase) and is still increasing. An area of 12318 ha in Jagatsinghpur district and 30291 ha Kendrapara districts and land area have been affected by slight and moderate soil salinity, respectively. The total irrigation efficiency for the area is about 34.7% (Pati *et al.* 2012). As the pre- and post-monsoon water table in the area is very shallow, the seasonal fluctuation is quite less. Similarly in Bihar, spread over 132 command areas, 10.57% of command area (5939 x10^3 ha) suffers from surface waterlogged condition and 2.95% of the waterlogged area in all the command areas has perennial surface inundated condition. Gandak command has maximum waterlogged area (212 x 10^3 ha) followed by Eastern Kosi irrigation scheme (116 x 10^3 ha) and Sone modernization scheme (82 x 10^3 ha; Chowdary *et al.* 2008).

In fact, the physical, chemical and microbiological properties of soils undergoes significant change due to submergence and differ markedly from those of uplands. The major changes that occur in the soil environment due to submergence of soil is cutting of its oxygen supply. Water fills all the pore space of soil and replaces the air. The oxygen diffusion in the water layer above the soil is very slow and the rate of O_2 consumption in reduced soil is high. Because of this high demand of oxygen in flooded soil and slow oxygen supply through water, the soil practically turns devoid of oxygen. This rapid depletion of oxygen takes place within a day or so of flooding the warm soils of tropics. Some oxygen trapped in blocked pore-space is rapidly utilized by facultative anaerobic organisms. The redox systems in flooded soils cover such a wide potential range from the oxygen system to the hydrogen system, that their identification and characterization is difficult due to chemical changes (Poonamperuma 1972).

Material and Methods

Land use land cover (LULC) data at 1:50,000 scale based on LISS-III (Linear Imaging Self Scanning Sensor) for the year 2005-06 were collected from Odisha Space Applications Centre (ORSAC), Bhubaneswar for classification of water bodies. District wise thematic maps of Odisha showing different waterbodies/waterlogged areas were prepared for waterlogging prone districts like Ganjam, Balasore, Bhadrak, Kendrapara, Cuttack, Jagatsinghpur, Puri, Sambalpur and less waterlogging prone districts Khurda and Koraput. Among seventeen different types of waterlogged areas, mainly three types of waterbodies *viz*. inland natural wet lands, coastal natural wet lands and manmade wetlands categories were found suitable for fitting in integrated water chestnut-aquaculture cultivation intervention mainly because of suitable water regime.

Use of GIS for delineation of areas suitable for water chestnut and *Typha* cultivation

United States Geological Survey (USGS) Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) imagery dated 07.09.2015 was collected from USGS and it was updated and georeferenced with the help of surveyed GPS data. As the digital number (DN) values of each band of the satellite data of USGS Earth Resources Observation and Science (EROS) Center, does not provide the reflectance values of each band, these were converted to Top of Atmosphere (TOA) spectral Reflectance and then were corrected to TOA reflectance through radiometric calibration techniques. Image processing and

GIS analysis works were carried out using Arc GIS 10.1 and ERDAS Imagine 8.7 software. Universal Transverse Mercator (UTM – Zone 45) projection type and WGS 1984 datum was used in the present study. For mapping the water chestnut plantation areas, visual image interpretation and automated mapping and manual digitization techniques were used. The surveyed points were plotted on the image to find out and mark the water chestnut areas along with the signatures in near infrared (NIR) band. As NIR Spectral band operates in the best spectral region to distinguish vegetation varieties and conditions, the same signatures in NIR band were collected over the surveyed areas. The range of reflected values of NIR region of those areas were thresholded using 0.35 to 0.45. Using this range the other areas were extracted through visual image interpretation techniques to mark out the water chestnut areas. It was found that, the water chestnut plantation area was majorly observed in the shallow depressed waterlogged areas along the railway track.

Similarly, *Typha* growing areas were also found confined to topographical depressions and tidal waterlogged areas along the both banks of Rupnarayan river till it opens in Bay of Bengal by using the imagery of dated 08.05.2014.

The NDWI (Normalized Difference Water Index; McFeeters 1996) was considered as representation of waterlogged areaand was used for delineation of waterlogged areas. The NDWI products shown here were derived using the NDWI formula (McFeeters 1996). The McFeeters' NDWI was computed as follows: [$NDWI = (X_{green} – X_{nir})/(X_{green} + X_{nir})$], where X_{green} refers to the green band reflectance and X_{nir} refers to the NIR band reflectance. This formulation of NDWI produces an image in which the '0' and positive data values are typically open water areas; while the negative values are typically non-water features (i.e. terrestrial vegetation and bare soil dominated cover types). In the study area the NDWI ranges from -0.64 to 0.42. The values 0 and above were marked as water features.

Mapping of *Typha* growing areas in West Bengal

For mapping the *Typha* plantation areas, the same signatures in NIR band is collected over the surveyed areas. After that the range of reflected values of NIR region of those areas are thresholded using the range 0.15 to 0.42 in reflectance of NIR region. The NIR spectral band operates in the best spectral region to distinguish vegetation varieties and conditions. Because water is a strong absorber of near infrared, this band has delineated water bodies (lakes and sink holes), distinguished between dry and moist soils (barren land and crop lands). So, in this way using the NDWI and NIR reflectance value the waterlogged areas and *Typha* plantation areas were delineated from 286100 ha area in Purba Medinipur and adjoining Howrah district and also validated using National Remote Sensing Centre (NRSC) land use and land cover data.

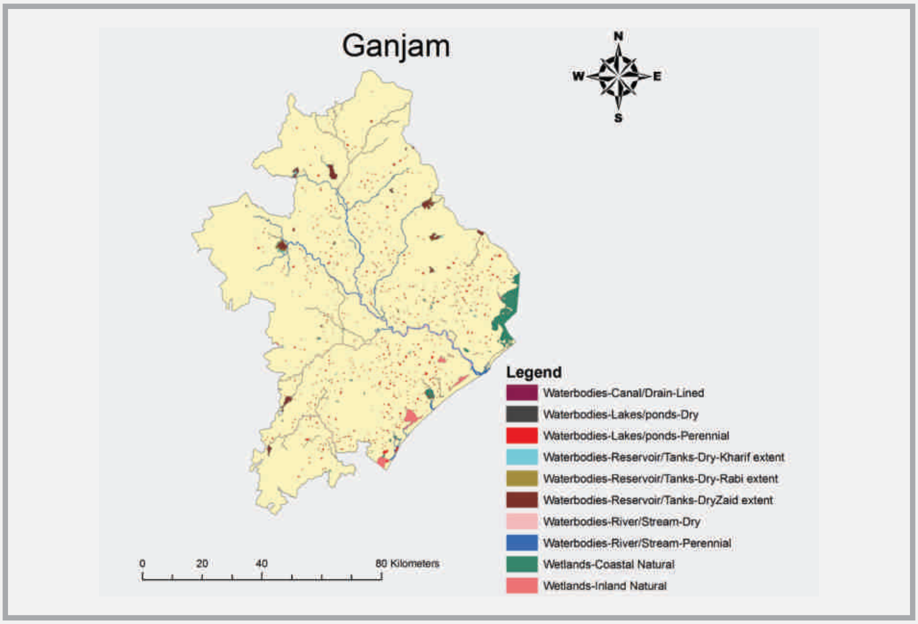
Mapping of aquaculture-water chestnut cultivable areas in Odisha

Similarly the NDWI and NIR reflectance value of the waterlogged areas and water chestnut cultivation areas were delineated for suitability of intervention with integrated aquaculture-water chestnut cultivation from 92452.61 ha study area in Balasore district of Odisha.

Results and discussion

Waterlogged districts of Odisha

The LISS III data (1:50,000 scale) for the period 2005-2006 collected from ORSAC, Bhubaneswar of three seasons, kharif, rabi and zaid (summer) showed 17 different types of water bodies and waterlogged areas in Odisha. Out of four waterlogged prone districts of Odisha, Jagatsinghpur district had 10884.42 ha perennially under rivers and streams, and 548.98 ha under lakes and ponds with a total of 11433.4 ha perennially under water bodies. This was followed by Kendrapara district where 11229.41 ha area was perennially under rivers and streams and 162.34 ha were perennially under lakes and ponds with a total perennial water bodies area of 11391.75 ha. The Balasore district had perennially 6350.86 ha area under rivers and streams and 253.53 ha area under lakes and ponds and 91.76 ha under tanks with total 6696.15 ha as perennial water bodies. In Bhadrak district 4747.67 ha area was perennially under rivers and streams and 286.24 ha was under lakes and ponds with total 5033.91 ha of perennial water bodies. The Ganjam district showed maximum 8,348.11 ha area perennially under lakes, ponds, reservoir and tanks followed by Bolangir district with 5,449.95 ha area. The Balasore and Kendrapara district showed 569.98 and 169.97 ha man-made waterlogged area of respectively. Therefore among the districts, Kendrapara district had highest area under rivers and streams, followed by Jagatsinghpur district, suggesting the proneness of these two districts for waterlogging scenarios especially seasonal waterlogged situation mainly due to rainfall. Puri had 6237.13 ha perennially under rivers and streams, and 204.92 ha under lakes and ponds. The Ganjam district had perennially 4075.77 ha area under rivers and streams and 4530.07 ha area under lakes and ponds and 3818.04 ha under reservoir and tanks with total 12423.88 ha as perennial water bodies. In Sambalpur district which is dominated by Mahanadi river basin and Hirakud command the 9563.29 ha area was perennially under rivers and streams, lakes and ponds and reservoir and tanks as perennial water bodies. Koraput district had perennially 4832.63 ha area under rivers and streams and 266.56 ha area under lakes and ponds and 117.05 ha under reservoir and tanks with total 5216.24 ha as perennial water bodies. The Khurda district showed 1729.07 ha area under perennial water bodies. (Fig.1, 2).


Ganjam
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W
E
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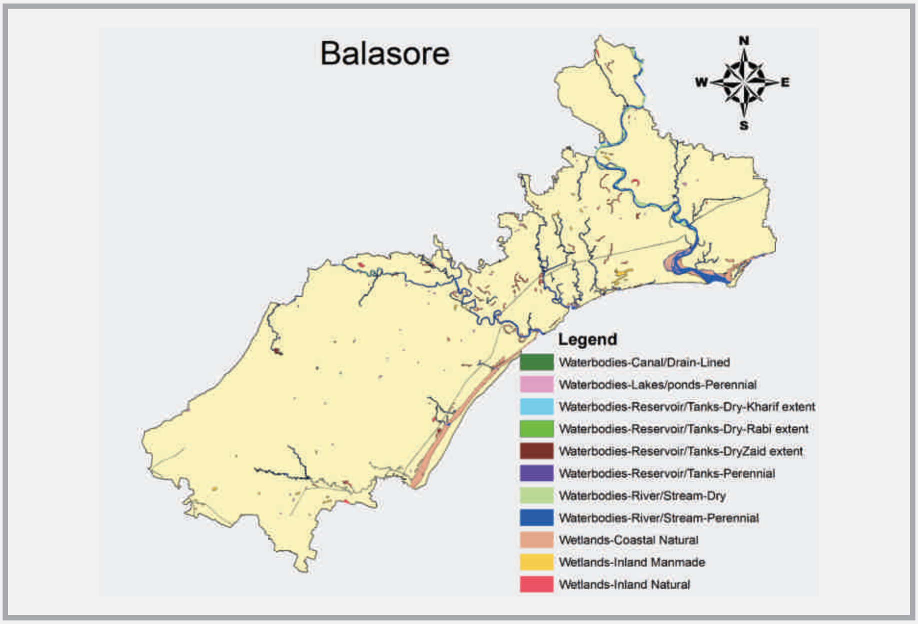
Legend
Waterbodies-Canal/Drain-Lined
Waterbodies-Lakes/ponds-Dry
Waterbodies-Lakes/ponds-Perennial
Waterbodies-Reservoir/Tanks-Dry-Kharif extent
Waterbodies-Reservoir/Tanks-Dry-Rabi extent
Waterbodies-Reservoir/Tanks-DryZaid extent
Waterbodies-River/Stream-Dry
Waterbodies-River/Stream-Perennial
Wetlands-Coastal Natural
Wetlands-Inland Natural
0 20 40 80 Kilometers


Balasore
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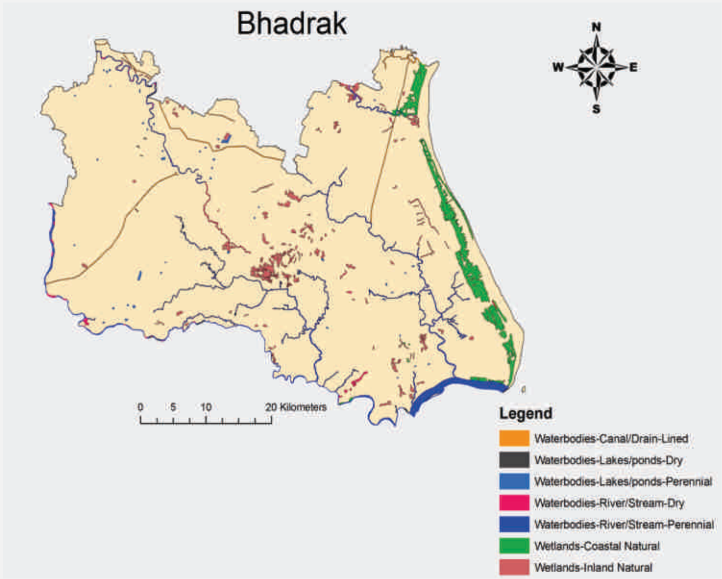
S
Legend
Waterbodies-Canal/Drain-Lined
Waterbodies-Lakes/ponds-Perennial
Waterbodies-Reservoir/Tanks-Dry-Kharif extent
Waterbodies-Reservoir/Tanks-Dry-Rabi extent
Waterbodies-Reservoir/Tanks-DryZaid extent
Waterbodies-Reservoir/Tanks-Perennial
Waterbodies-River/Stream-Dry
Waterbodies-River/Stream-Perennial
Wetlands-Coastal Natural
Wetlands-Inland Manmade
Wetlands-Inland Natural


Bhadrak
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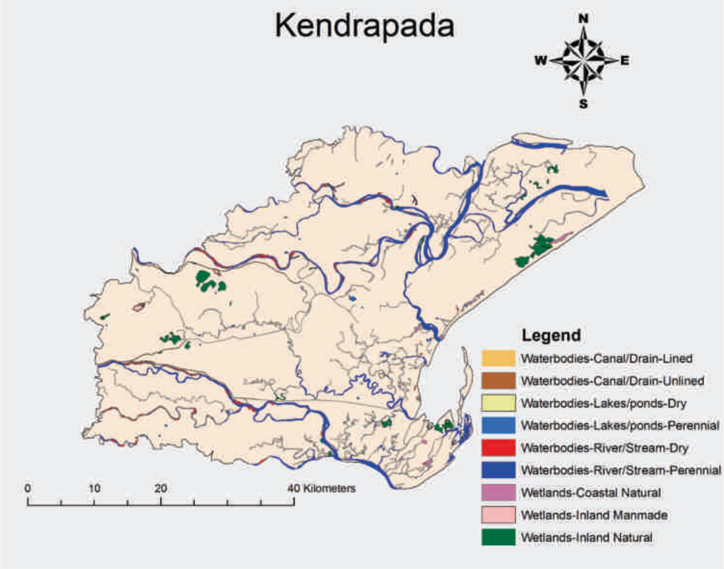
Legend
Waterbodies-Canal/Drain-Lined
Waterbodies-Lakes/ponds-Dry
Waterbodies-Lakes/ponds-Perennial
Waterbodies-River/Stream-Dry
Waterbodies-River/Stream-Perennial
Wetlands-Coastal Natural
Wetlands-Inland Natural


Kendrapada
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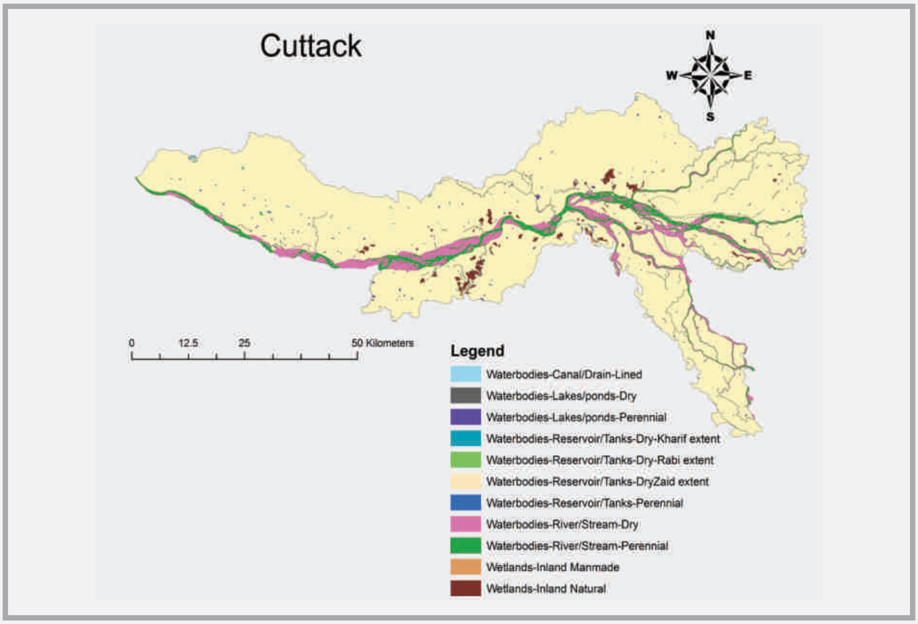
0 10 20 40 Kilometers
Legend
Waterbodies-Canal/Drain-Lined
Waterbodies-Canal/Drain-Unlined
Waterbodies-Lakes/ponds-Dry
Waterbodies-Lakes/ponds-Perennial
Waterbodies-River/Stream-Dry
Waterbodies-River/Stream-Perennial
Wetlands-Coastal Natural
Wetlands-Inland Manmade
Wetlands-Inland Natural


Cuttack
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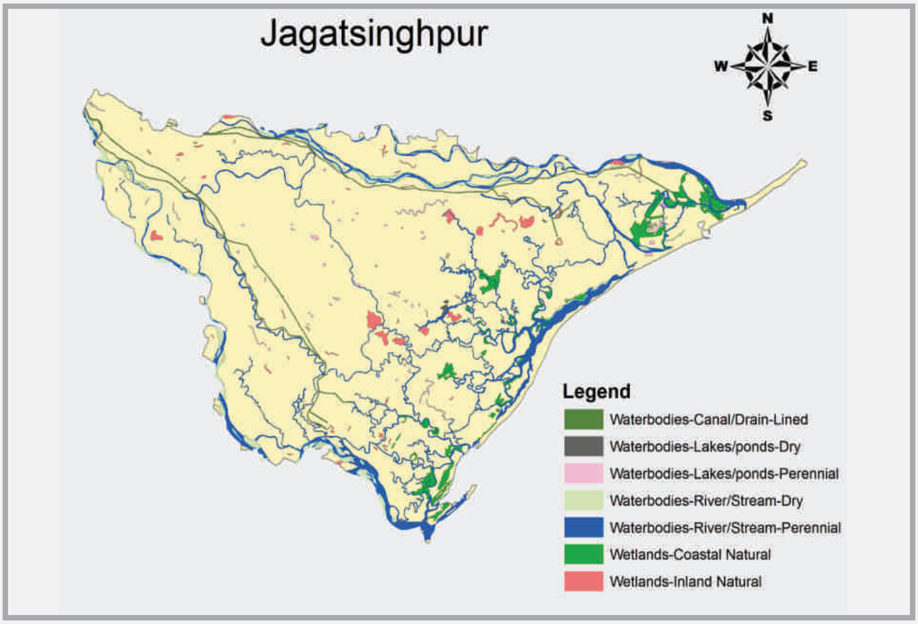
12.5
25
50 Kilometers
Legend
Waterbodies-Canal/Drain-Lined
Waterbodies-Lakes/ponds-Dry
Waterbodies-Lakes/ponds-Perennial
Waterbodies-Reservoir/Tanks-Dry-Kharif extent
Waterbodies-Reservoir/Tanks-Dry-Rabi extent
Waterbodies-Reservoir/Tanks-DryZaid extent
Waterbodies-Reservoir/Tanks-Perennial
Waterbodies-River/Stream-Dry
Waterbodies-River/Stream-Perennial
Wetlands-Inland Manmade
Wetlands-Inland Natural


Jagatsinghpur
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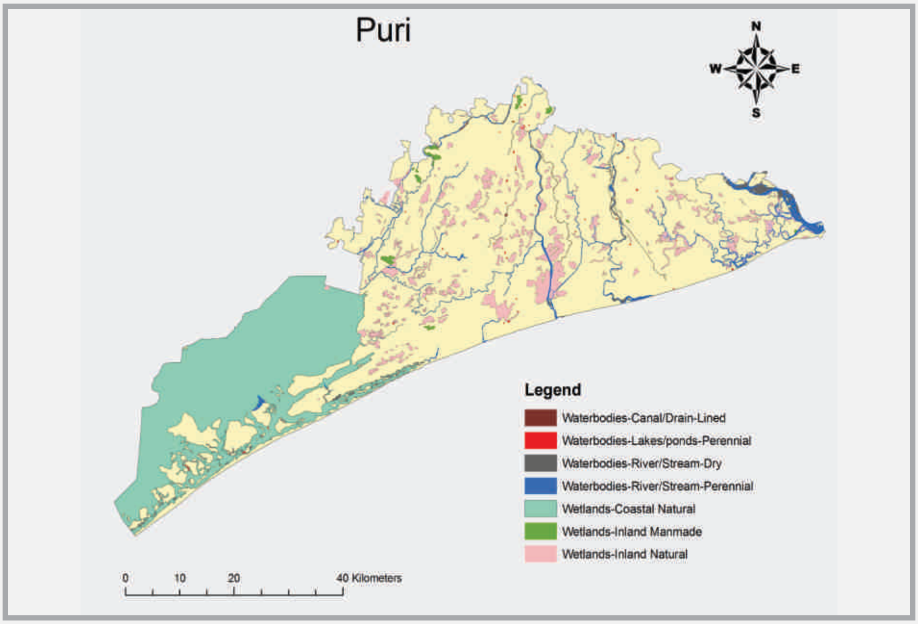
Legend
Waterbodies-Canal/Drain-Lined
Waterbodies-Lakes/ponds-Dry
Waterbodies-Lakes/ponds-Perennial
Waterbodies-River/Stream-Dry
Waterbodies-River/Stream-Perennial
Wetlands-Coastal Natural
Wetlands-Inland Natural



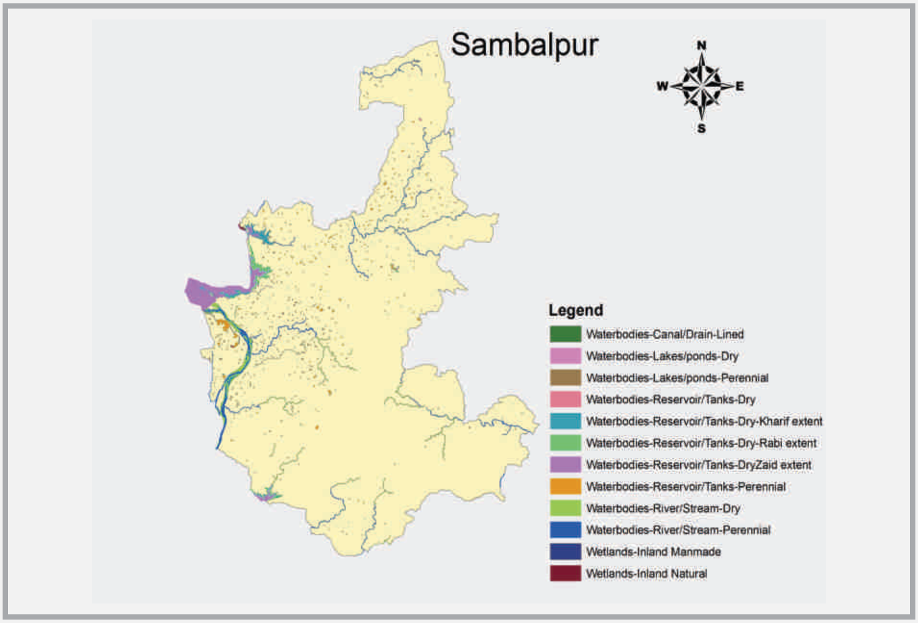
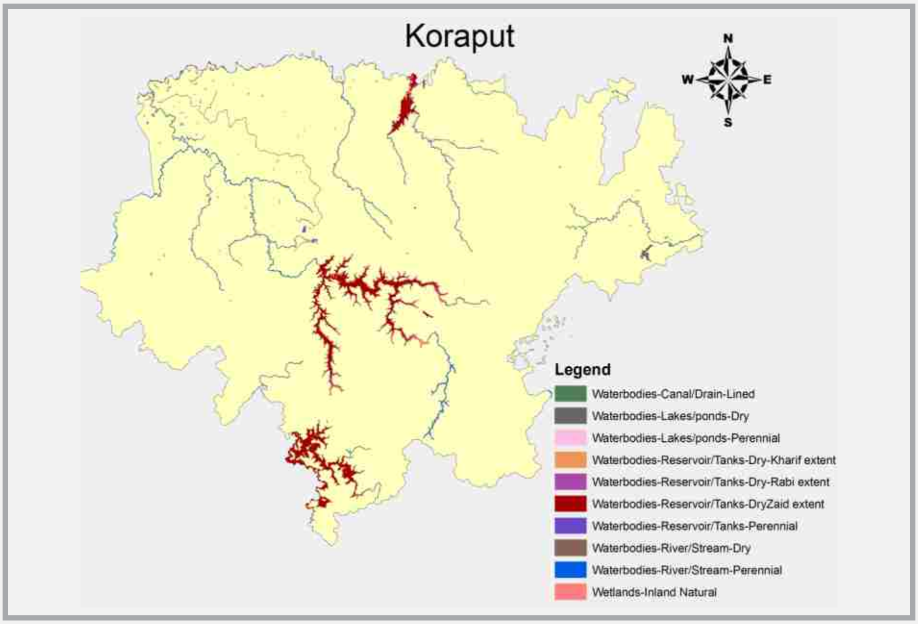


Fig.1. Thematic maps of waterlogged prone Ganjam, Balasore, Bhadrak, Kendrapara, Cuttack, Jagatsinghpur, Puri, Sambalpur districts in Odisha showing different types of waterlogged areas.



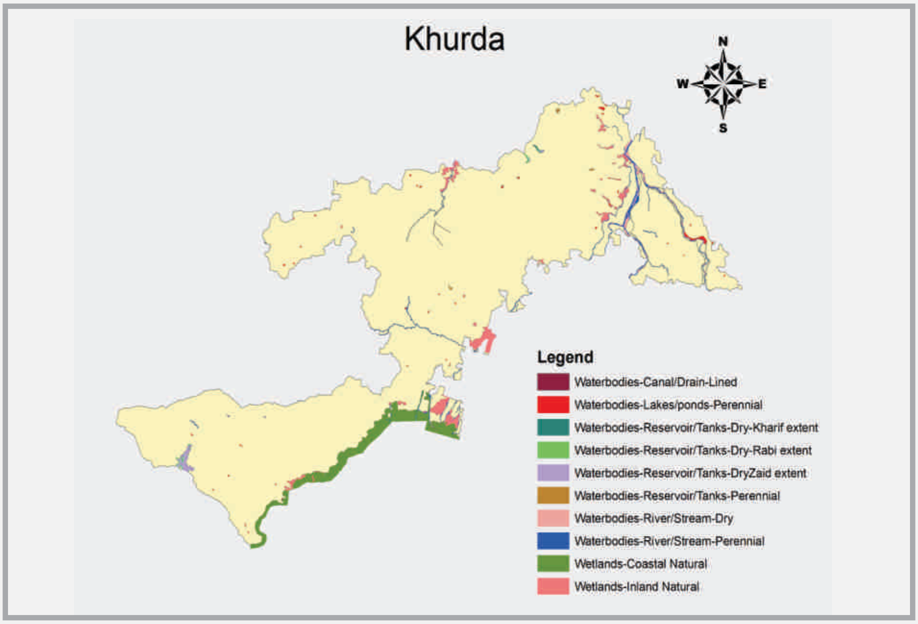


Fig.2. Thematic maps of less waterlogging prone Khurda and Koraput districts of Odisha showing different types of waterlogged areas.

Waterlogged districts of West Bengal

The LISS III data (1:50,000 scale) for the period 2005-2006 was collected from NRSC's 'Bhuvan' website for assessment of waterlogged area in West Bengal. In general, there are four major categories of waterlogged affected areas *viz*,(a) wetlands/water Bodies, River/Stream/canals, (b) Wetlands/Water Bodies or Inland Wetland, (c) Wetlands/Water Bodies, Reservoir/Lakes/Ponds and (d) Wetlands/Water Bodies, Coastal Wetland, Medinipur district had total of 66,907 ha of waterlogged area under different categories like inland and coastal wetlands/water bodies including river/stream/canals, reservoir/lakes/ponds; out of the total waterlogged area, the share of East Medinipur district was more. In North Bengal, among different districts, Jalpaiguri and Cooch Behar districts had maximum waterlogged areas under different categories.

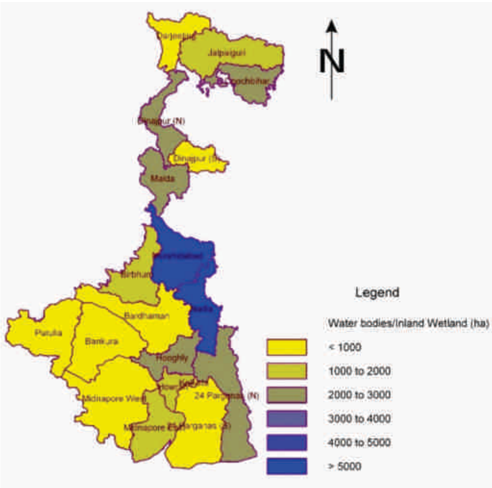


Fig.3

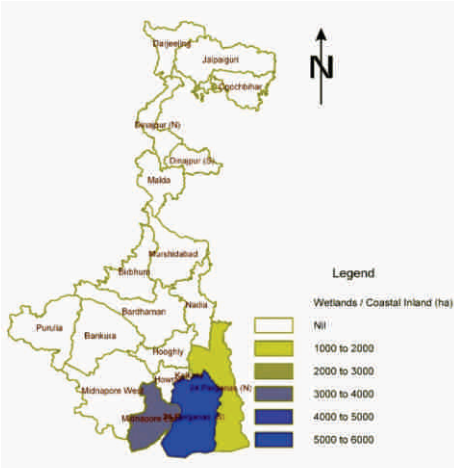


Fig.4

Fig. 3 and 4. District-wise consolidated area (ha) under water bodies/inland wetland (fig.3) and waterlogged areas under wetlands/coastal inland (fig.4) categories of West Bengal.

The two districts of 24 Pargana have total 2,90,667 ha under water bodies and waterlogged area category. Among four main categories of waterlogged areas, the district has total 1, 95,608 ha under wetlands/ water bodies, river/ stream/ canals. About 933 ha area in the district is under permanent waterlogging under wetlands/ water bodies, reservoir/ Lakes/ ponds. In Bardhaman district, among four main categories, under wetlands/water bodies, river/stream/canals, the district has total 227300 ha. About 16277 ha area in the district is under waterlogging under rivers/streams and canals and 961 ha is under wetland. The Howrah district has 5530 ha area under rivers/streams and canals and 1723 ha is under inland wetland. The Hooghly district has 6292 ha area under rivers/streams and canals and 2482 ha is under inland wetland. In North Bengal, among different districts, Jalpaiguri district has highest 58291 ha followed by Cooch Behar 29477 ha under different categories of waterlogging and water bodies. District-wise consolidated waterlogged areas (in ha) under inland wet land and under wet lands/coastal inland categories of West Bengal are given in Figure 3 and Figure 4.

Waterlogged districts of Assam

In Assam, Sonitpur district has highest total 83505 ha area under waterlogging including wetlands, inland wetlands, reservoirs, water bodies, rivers, streams canals, lakes and ponds followed by Dibrugarh district with 78477 ha, Dhemaji district (71011 ha) and Barpeta (68448 ha; Fig.5; LULC 2005-06, http://bhuvan.nrsc.gov.in/gis/thematic/index.php). Dhemaji (22621 ha) showed highest area under inland wetlands followed by Cachar (17478 ha), Kamrup (16166 ha) and Nagaon district (14179 ha; Fig.6). North Cachar district showed highest area under reservoir/lakes and ponds (2301 ha), followed by Kamrup (878 ha), Dhuburi (789 ha) and Karbi Anglong (734 ha).

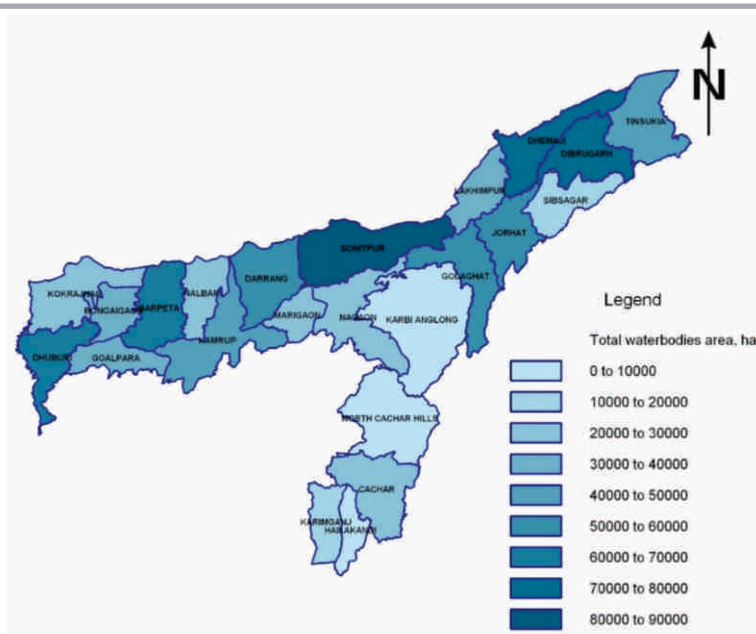


Fig. 5. District-wise consolidated area (ha) of waterlogged areas under total water bodies in Assam.

Waterlogged districts of Bihar

In order to assess the waterlogged area in Bihar, the LISS III data (1:50,000 scale) for the period 2005-2006, three main categories of waterlogged affected areas *viz*, wetlands/water bodies under river/stream/canals, under inland wetland and under reservoir/lakes/ponds were observed. Saran district has

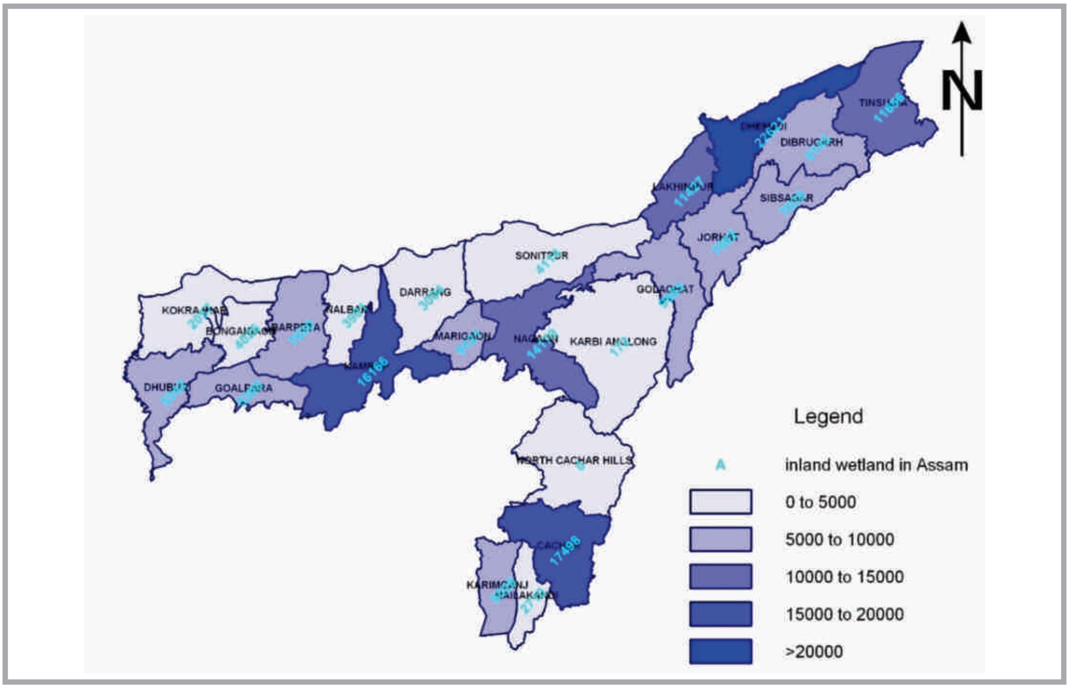


Fig. 6. District-wise consolidated area (ha) of inland wetlands under waterlogged areas in Assam.

the highest total of 37489 ha waterlogged area including inland wetlands, rivers/ streams/ canals, reservoirs/ lakes/ ponds, followed by Vaishali, Paschim Champaran, Supaul Bhagalpur and Kathihar with 37198, 32968, 32307, 30543 and 23556 ha, respectively. Vaishali (21401 ha) has highest area under inland wetlands followed by Purnea (19153 ha), Siwan (16264) and Purba Champaran district (15792 ha). Banka district has highest area under reservoir/lakes and ponds (3317 ha), followed by Jamui (1665 ha), Darbhanga (1595 ha), Madhubani (931 ha), Purba Champaran (917 ha) and Mujaffarpur district (833 ha; LULC 2005-06, http://bhuvan.nrsc.gov.in/ gis/ thematic/index.php). District-wise consolidated area (in ha) under different categories of waterlogged areas of Bihar (Fig.7) as well as district-wise consolidated area (in ha) of inland wetlands in waterlogged areas of Bihar were also estimated and thematic maps were prepared (Fig.8).

The survey and ground truthing of Bhagalpur and Katihar districts were completed alongwith adjoining Purnea district. The georeferenced satellite IRS P6- LISS-III imagery (path 106 and row 54) for both pre- and post-monsoon period was processed with the help of ground truthing data and toposheet maps procured from Survey of India, Dehradun for classification of waterlogged area. Thematic maps were prepared for pre-monsoon and post-monsoon period

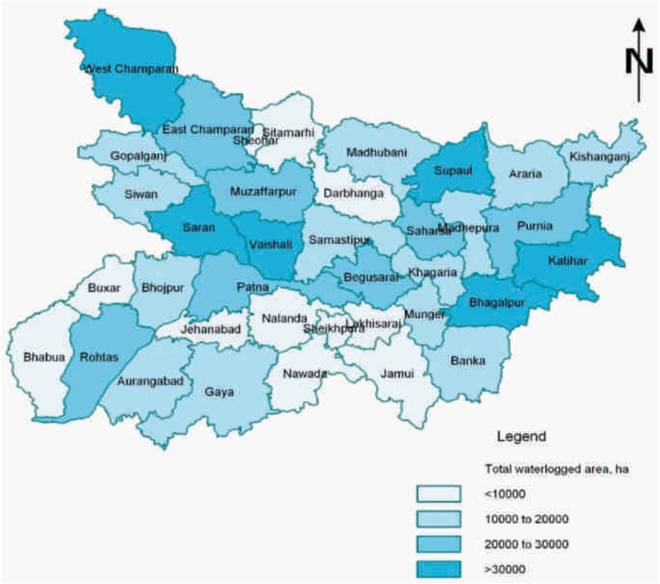


Fig. 7. District-wise consolidated area (ha) of waterlogged areas under total water bodies in Bihar.

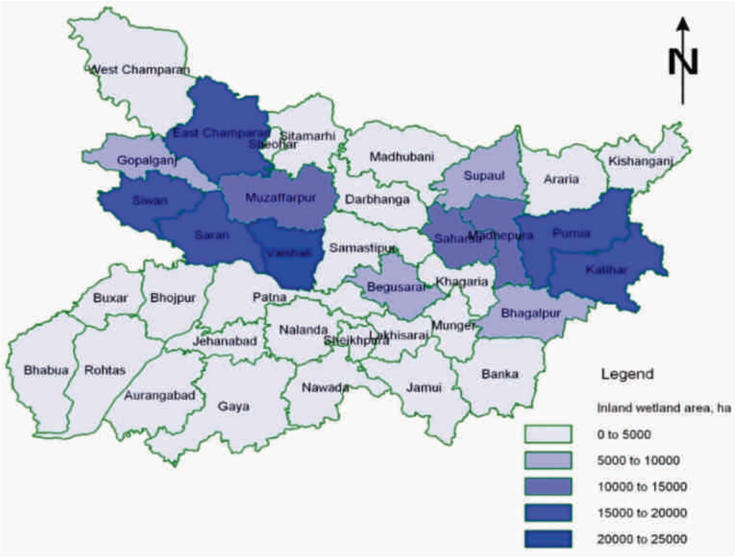


Fig. 8. District-wise consolidated area (ha) of inland wetlands under waterlogged areas in Bihar.

(Fig.9) for Bhagalpur district. The supervised classification of images was done for fitting in different crops and cropping system in the study area.

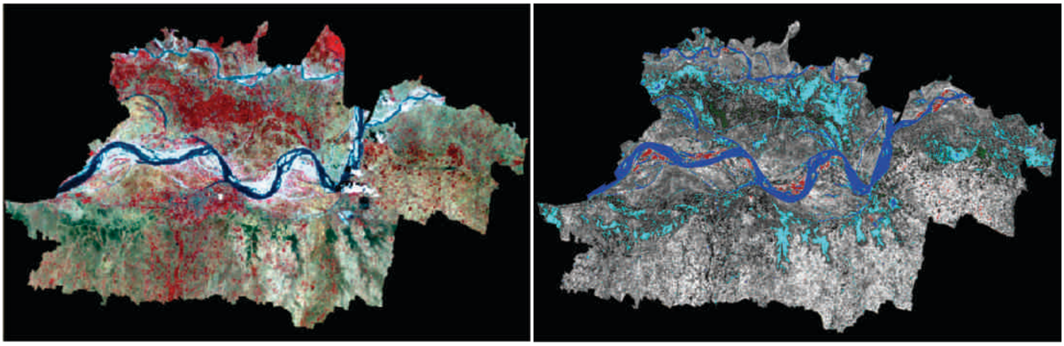


Fig. 9. The changes on waterlogging scenarios in pre-monsoon (left; 15.5.2014) and post- monsoon (right; 23.11.2014) period in Bhagalpur district. The shaded area ( ) is waterlogged areas delineated after monsoon.

Identification of critical intervening areas suitable for fitting in ideal crops and their package of practices based on extent of waterlogging

- **Odisha**

The characterization of waterlogged areas showed seventeen different types of water bodies and waterlogged areas in Odisha *viz*. 1. Canal drained lined, 2. Canal drain- unlined, 3. Lakes/ponds dry, 4. Lakes/ponds dry rabi-extent, 5. Lakes/ponds dry kharif-extent, 6.Lakes/ponds dry zaid-extent, 7. Lakes/ponds perennial, 8. Reservoir/tanks dry, 9. Reservoir / tanks dry rabi-extent, 10. Reservoir/tanks dry kharif-extent, 11. Reservoir/tanks dry zaid - extent, 12. Reservoir/ tanks perennial, 13. River stream dry, 14. River stream perennial, 15. Wetland coastal natural, 16. Wetland inland manmade, and 17. Wetland inland natural. The intense net work of rivers and streams of Kendrapara and Jagatsinghpur districts made them prone to waterlogging due to coastal location and lack of adequate slope for drainage. However among seventeen types of waterlogged areas mainly three types of water bodies *viz*. inland natural wetlands, coastal natural wetlands and manmade wetlands categories were found suitable for fitting in integrated water chestnut-aquaculture cultivation for suitable water regime (Fig.10 and 11). Maximum manmade waterlogged areas were found in Balasore district (569.98 ha).

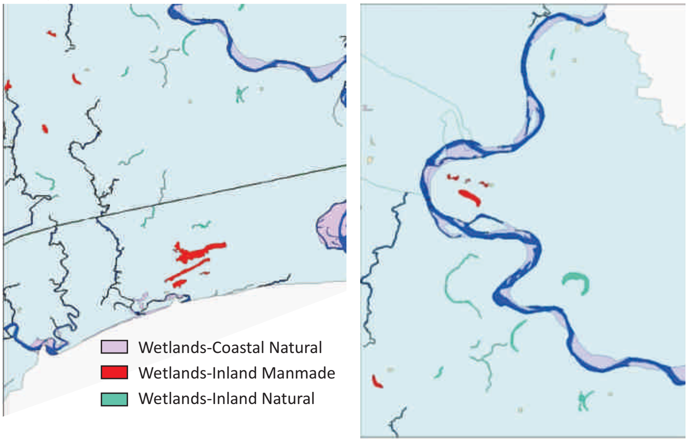


Fig. 10. Three different types of water bodies in Balasore district suitable for fitting in integrated water chestnut - aquaculture cultivation.

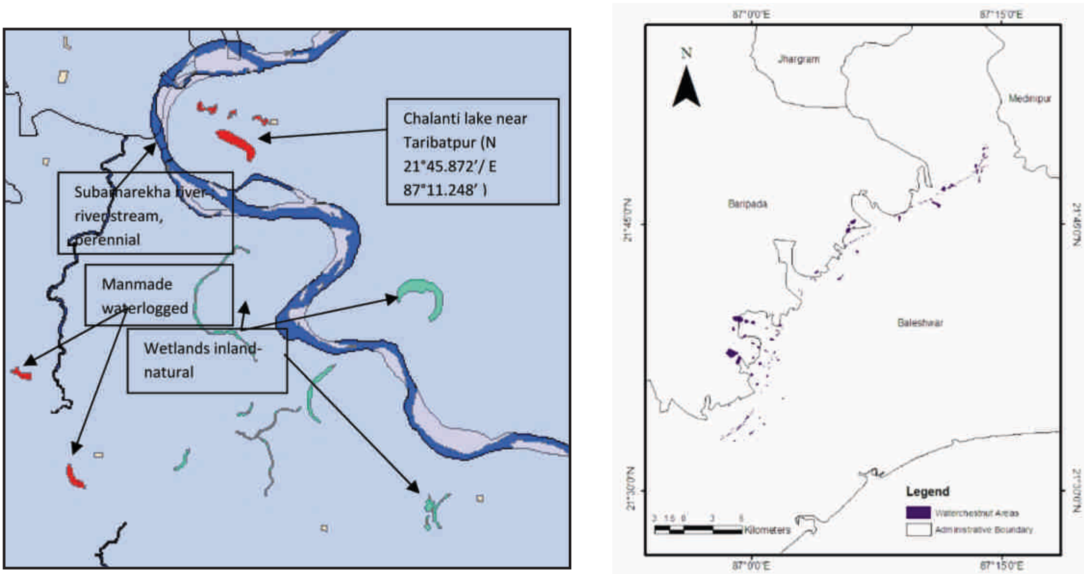


Fig. 11. (Left) Different types of water bodies in Balasore district suitable for fitting in integrated water chestnut-aquaculture cultivation. (Right; ▬)Integrated aquaculture-water chestnut cultivation area in Balasore district.

Package of practices for integrated water chestnut-aquaculture in shallow waterlogged areas

The identified waterlogged area having at least 0.5m depth of water above the surface at least for ten month period, over entire year was considered suitable for this practice. The area was cleaned and ploughed during last week of May to 1st week of June, before onset of monsoon. The organic manure mainly cow dung is incorporated @ 8 t/ha before planting during field preparation. Before planting, seedlings from nursery was given a combined treatment of fungicide and insecticide *i.e.* carbendazim @0.1% with chloropyriphos @0.2% by dipping the planting materials overnight (12 hour). Planting of water chestnut was completed in second week of June. The young sprouting seedlings up to 0.5 - 1.0 meter length were planted depending on depth of water throughout the field. Three to four young seedlings were loosely tied at the bottom in a knot. The knot was pressed gently against the mud bottom of the water body with toe. A spacing of 1.5m x 1.5m was maintained between planting spots. About 4400 bundles of seedlings (each containing 3-4 seedlings) are generally required to cover an area of one hectare. The vegetative growth continued for three months *i.e.* from mid June to mid September and crop covered entire surface of the water body within September. The N:P:K fertilizer @ 40:60:40 were applied in three splits. The one third of N as urea and K as muriate of potash (KCl) with full P as single super phosphate was applied as basal application. The rest 2/3 N and K was applied in two splits at two and four months after planting.

Air breathing fish (cat fish; *Clarius batrachus*) was released during mid-August when water chestnut crop establishes reasonable canopy growth. Release of fish at the time of planting and establishment may dislodge the knot from mud bottom and might affect the crop stand. The cat fish of 15 g mean body weight (MBW) was released with 5000/ha stocking density during 1st week of August. Fish feed (soya meal + wheat or rice bran + fish meal: 30:55:15) was given @3% of mean body weight, twice a day. Fish was harvested in the month of February to April after harvest of water chestnut.

Package of practices for *Typha* cultivation in topographical depression and tidal waterlogged areas

For cultivation of *Typha,* land was prepared with basal application of 2.5 t/ha cow dung manure with 30kg P. In tidal waterlogged areas, the main growing areas of *Typha*, basal application of urea N @ 90kg/ha is recommended. The K was given in two spilt, one and two months after planting. Young cat tail seedlings of 5-6 leaved stage were planted at a spacing of 60 x 60 cm. Planting can be done in two seasons depending upon the extent of waterlogging, either in January-February or in May-June before onset of monsoon. The crop was harvested as leaves, 18 months after planting.

Package of practices for swamp taro cultivation in swampy marsh areas

In cultivation of swamp taro, land is prepared with farm yard manure @ 8 t/ha was added at the time of field preparation. Defoliated petiole with root stock were planted at a spacing of 60 x 75 cm in the month of January in marshy waterlogged condition. The recommended N:P:K fertilizers are @ 52:60:63 kg / ha was applied in three doses at second, fifth and eighth month after planting of the crop. Hand weeding were done each time before application of fertilizers. The runner, the edible part of the plant starts sprouting from 3-4 month stage after planting and are periodically harvested from 4-5 month stage after planting depending on the growth of the crop and marshy condition.

Package of practices for cultivation of overaged rice seedlings in low lying areas

Technology for use of older seedlings was developed to enhance productivity of waterlogged areas. In low lying areas, paddy crop is often affected by submergence due to waterlogging. Under such unfavourable ecology, use of taller and over aged 60 days old seedlings avoid risk of submergence and has been found suitable for cultivation in submergence prone low lying areas. The spacing was maintained at 20x20 cm and P, K fertilizers was applied @ 40:40 kg /ha. The entire dosage of P and K was applied at planting time. The application of N through mud ball was done in split in three stages, *i.e.* 7 days after planting, at maximum tillering stage (58 days after transplanting) and at panicle initiation stage (93 days after transplanting) @ 20:10:10 kg/ha. Therefore cultivation of 60 days old rice seedlings with 40 kg/ha N through mud ball can be recommended for cultivation in low lying, submergence prone areas to avoid risk of crop failure due to submergence as well as to achieve better productivity.

- **West Bengal**

Between Purba and Paschim Medinipur district out of the total waterlogged area, Purba Medinipur has more waterlogged area. In Howrah district, large part of the wetland in Bagnan, Uluberia and Sankrail blocks are utilized for water chestnut, lotus with aquaculture or cat tail (*Typha* sp.) cultivation. The 365 ha area is under reservoir/lakes/ponds in the district is mainly suitable for aquaculture and lotus, water chestnut cultivation with integrated aquaculture. A large part the wetland in Bagnan, Birshivpur, Sankrail blocks,is utilized for *Typha* cultivation. The leaves of cat tail is used for making thatching material. Between two districts of north- and south 24 Paragana, latter has more area under water bodies and waterlogged area. Particularly the areas occupied by lakes and ponds can be utilized for fitting different aquatic crops and aquaculture intervention. In Bardhaman district, water chestnut and lotus are main aquatic crops in the district in seasonal /perennial waterlogged areas. The part of 1723 ha of inland wetland in Howrah district and 1132 ha area is under reservoir/lakes/ponds Hooghly district mainly under lakes and ponds are suitable for aquaculture and also for lotus and water chestnut cultivation due to market demand in adjoining Kolkata market. In North Bengal, thematic maps of pre- and post-monsoon scenarios of Malda, and Uttar Dinajpur district are given in figure 12 and 13. Reservoir/lakes, ponds and adjoining marshy areas of 2403 and 1208 ha in Malda and Uttar Dinajpur district respectively, provide scope for integrated water chestnut-aquaculture intervention or swamp taro cultivation utilizing these non-arable areas.

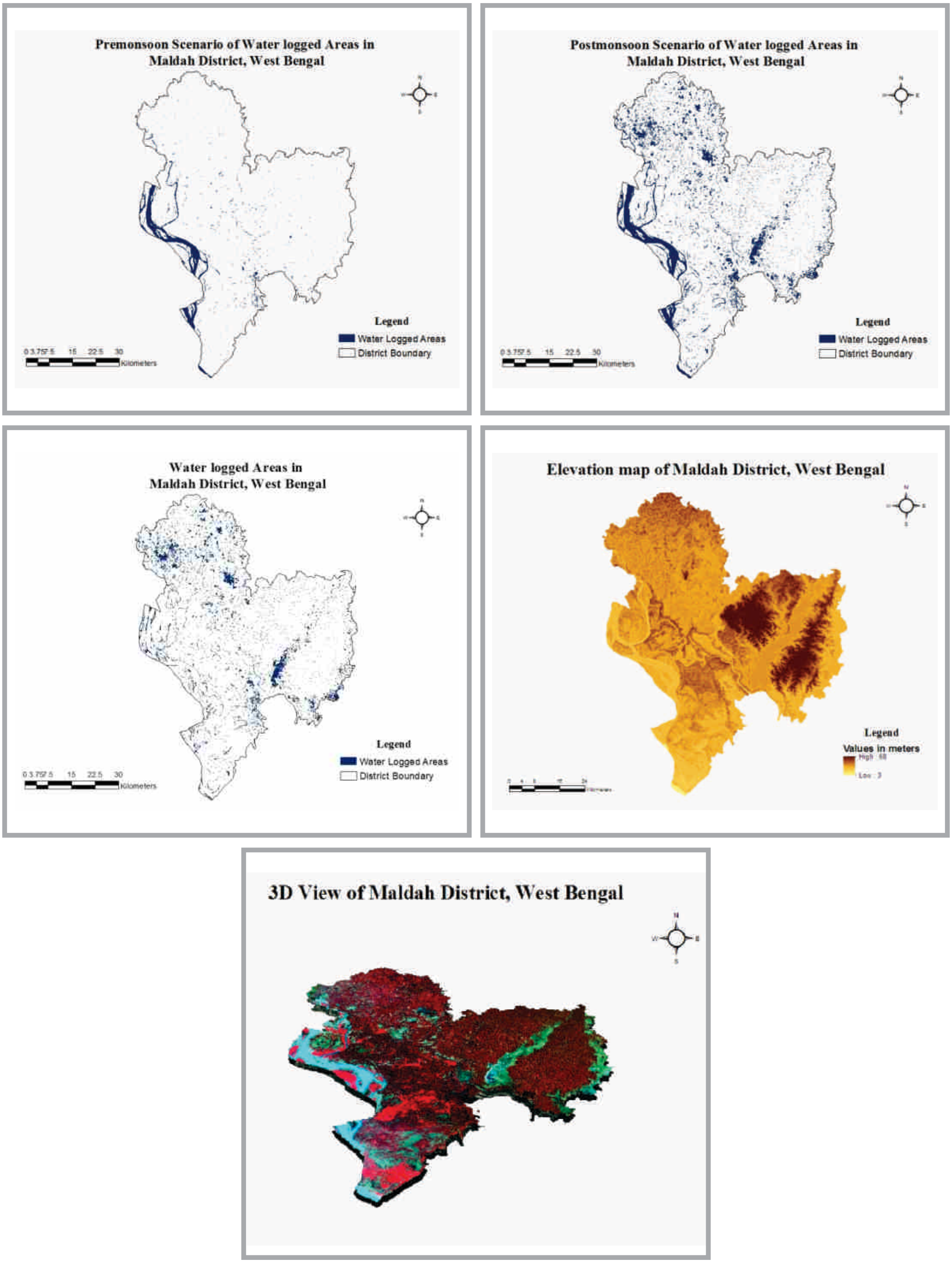


Fig. 12. Thematic maps of pre- and post-monsoon period showing delineated waterlogged area with district elevation maps and 3D view of Malda district of West Bengal.

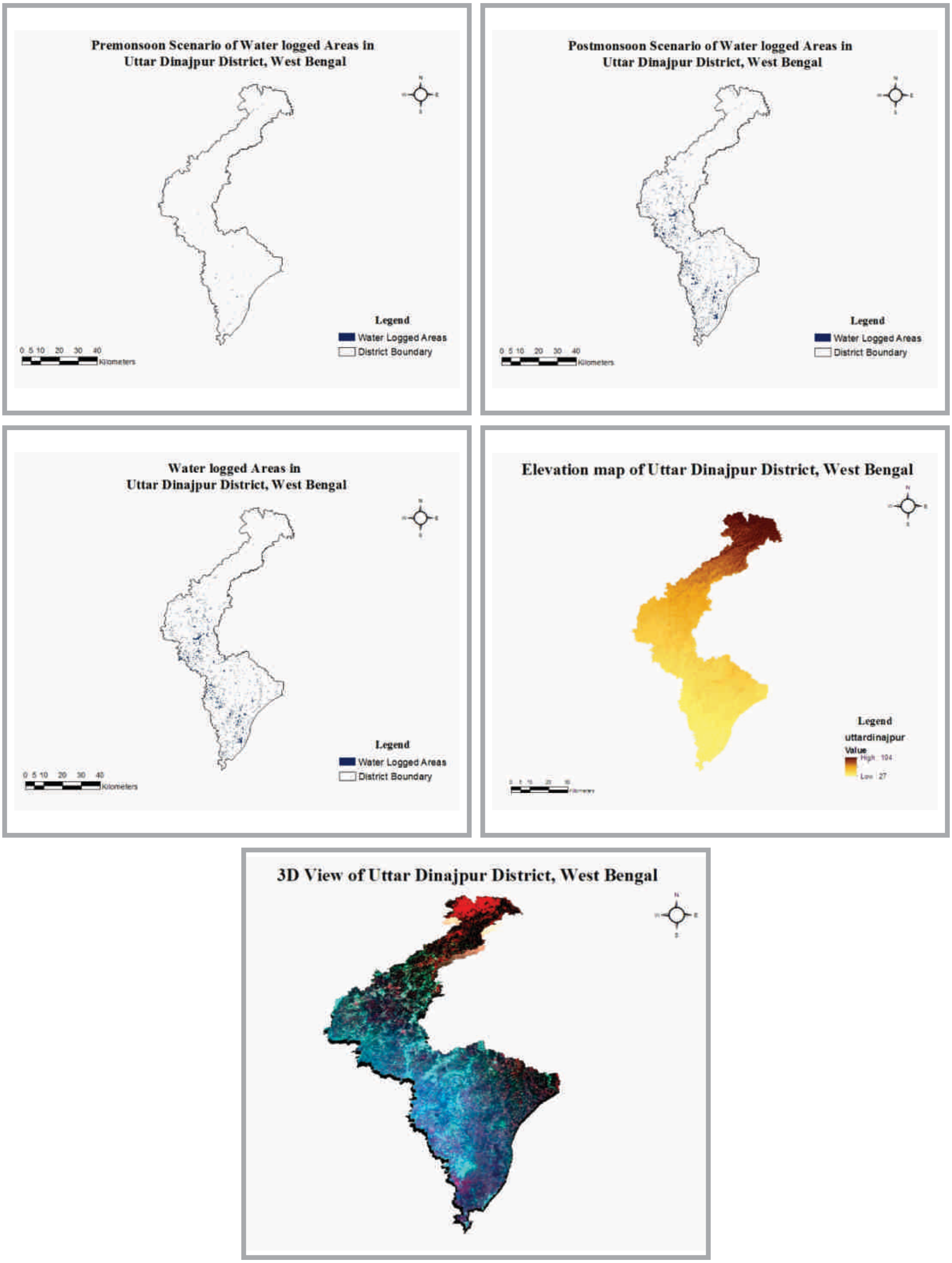


Fig. 13. Thematic maps of pre- and post-monsoon period showing delineated waterlogged area with district elevation maps and 3D view of Uttar Dinajpur district of West Bengal.

- **Assam**

In the Dibrugarh district (with 78477 ha total waterlogged area) in flood prone areas, wet seeding of sprouted seeds (@75-80 kg/ha) of short to medium duration varieties like Disang, Luit, (100 days), Kapili, Kolong (120 days), or 50-60 days old over aged seedlings of cultivars like Gitesh, Prafulla is suitable. Large inland wetlands in Dhemaji, Cachar, Kamrup and Nagaon districts have opportunity for cultivation of wetland crops like water chestnut and lotus apart from *Calamus*, a commercially important crop. North Cachar district with highest area under reservoir/lakes and ponds could be ideal for aquaculture interventions Cahar district due to its topography showed early appearance of flood water alongwith Kamrup district. As a strategic intervention cultivation of swarna sub-1 could be a crop management measure in flash flood affected or flash prone areas. The cultivation of mixture of 'Ahu' and 'Bao' in low lying areas is another cropping strategy against flood damage. In this mixed cultivation method, the 'Ahu' crop is expected to give yield in non-flood scenario. In the event of arrival of early flood even if 'Ahu' yield is affected, the 'Bao' crop gives some yield. Therefore, total crop failure due to flood is avoided. Strengthening of field dykes in low lying flood prone areas, disinfecting water bodies with lime or potassium permanganate is essential for sole aquaculture. Rice-fish integration is another scope for submergence prone bunded waterlogged areas in different districts where arrival of flood water is slow and spread of waterlogged areas is relatively slower without causing damage to the water bodies with aquaculture except water level rise.

- **Bihar**

The georeferenced satellite IRS P6- LISS-III imagery (path 106 and row 54) for both pre and post monsoon period was processed with ground truthing data and toposheet maps of Survey of India, Dehradun for classification of waterlogged area. Thematic maps were prepared for waterlogged areas during pre- and post-monsoon period for Bhagalpur, Katihar, Purnea, Kishanganj, Sahibganj, Godda, Banka, Madhepura and Munger districts. Finally the waterlogged areas except rivers surface areas were worked out (table 1). District-wise waterlogged areas, elevation maps and 3d maps prepared (fig.14-21). Except Kishanganj district, the slope of the district topography (difference between maximum and minimum elevation in DEM of the district) was found critical in determining extent of waterlogged areas in the districts ($Y = -24.99x+1642$, R^2 0.57, n = 11) suggesting that mainly lack of gradient is the main reason for extent of waterlogging in the district.

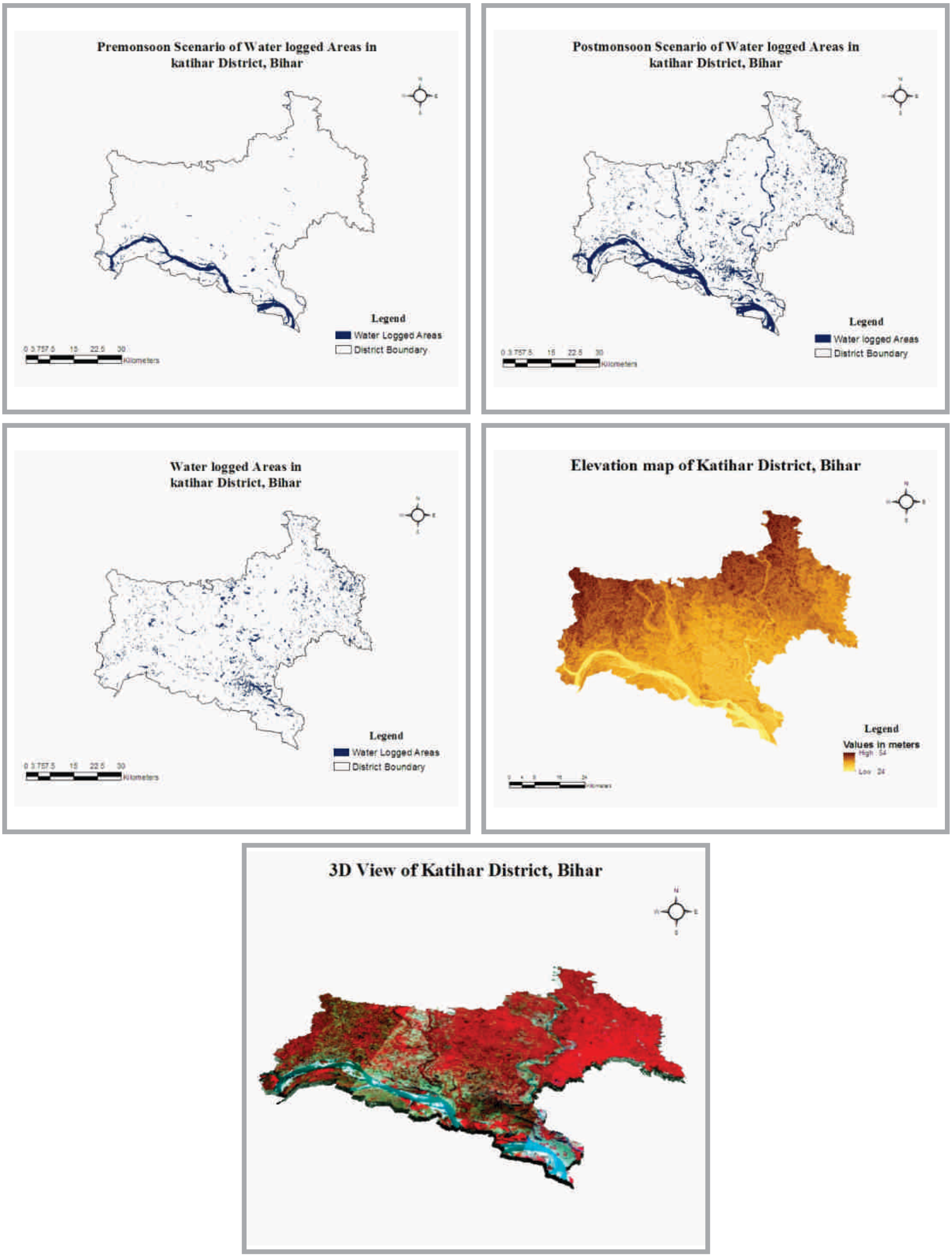


Fig. 14. Thematic maps of pre- and post-monsoon period showing delineated waterlogged area with district elevation maps and 3D view of Katihar district of Bihar.

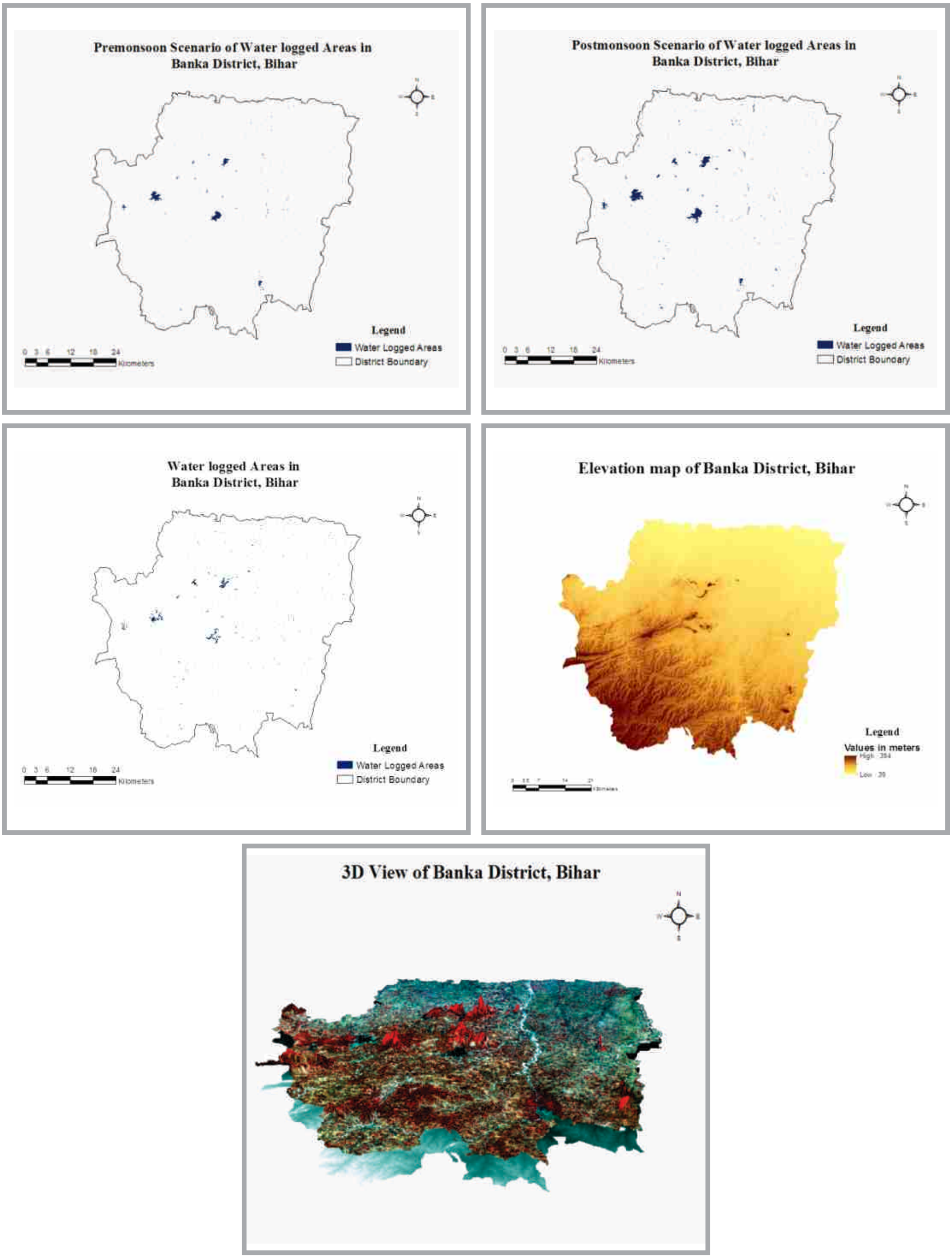


Fig. 15. Thematic maps of pre- and post-monsoon period showing delineated waterlogged area with district elevation maps and 3D view of Banka district of Bihar.

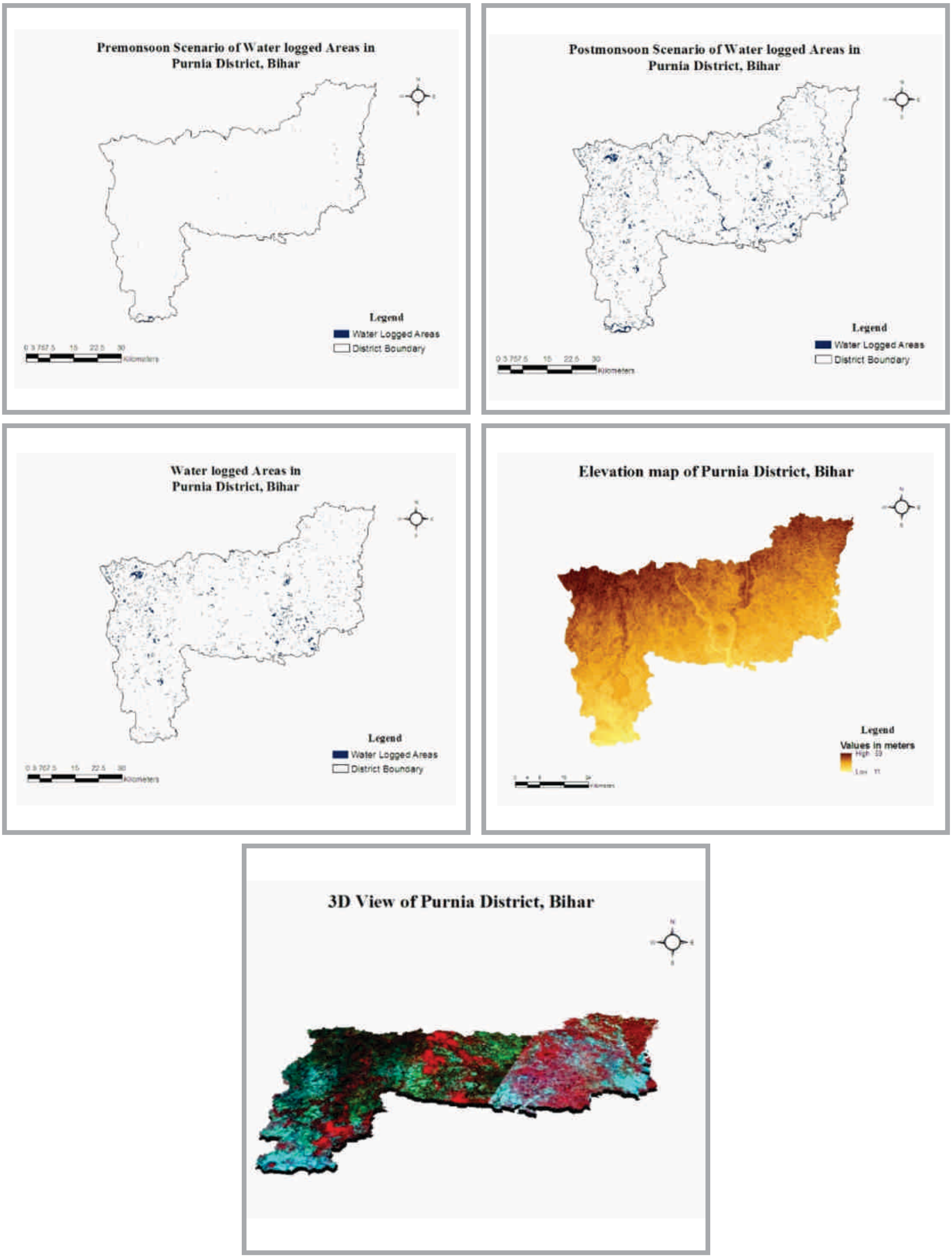


Fig. 16. Thematic maps of pre- and post-monsoon period showing delineated waterlogged area with district elevation maps and 3D view of Purnea district of Bihar.

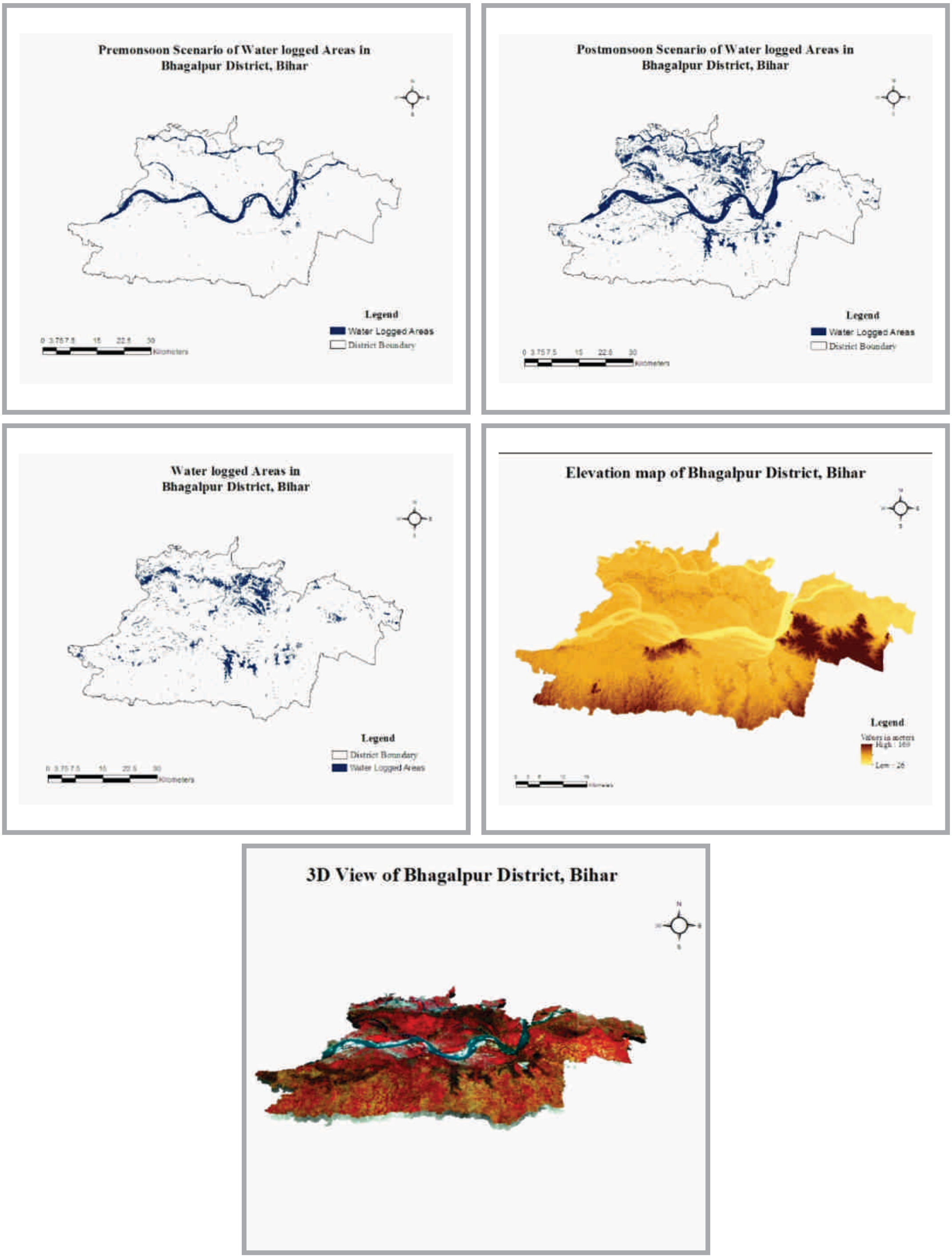


Fig. 17. Thematic maps of pre- and post-monsoon period showing delineated waterlogged area with district elevation maps and 3D view of Bhagalpur district of Bihar.

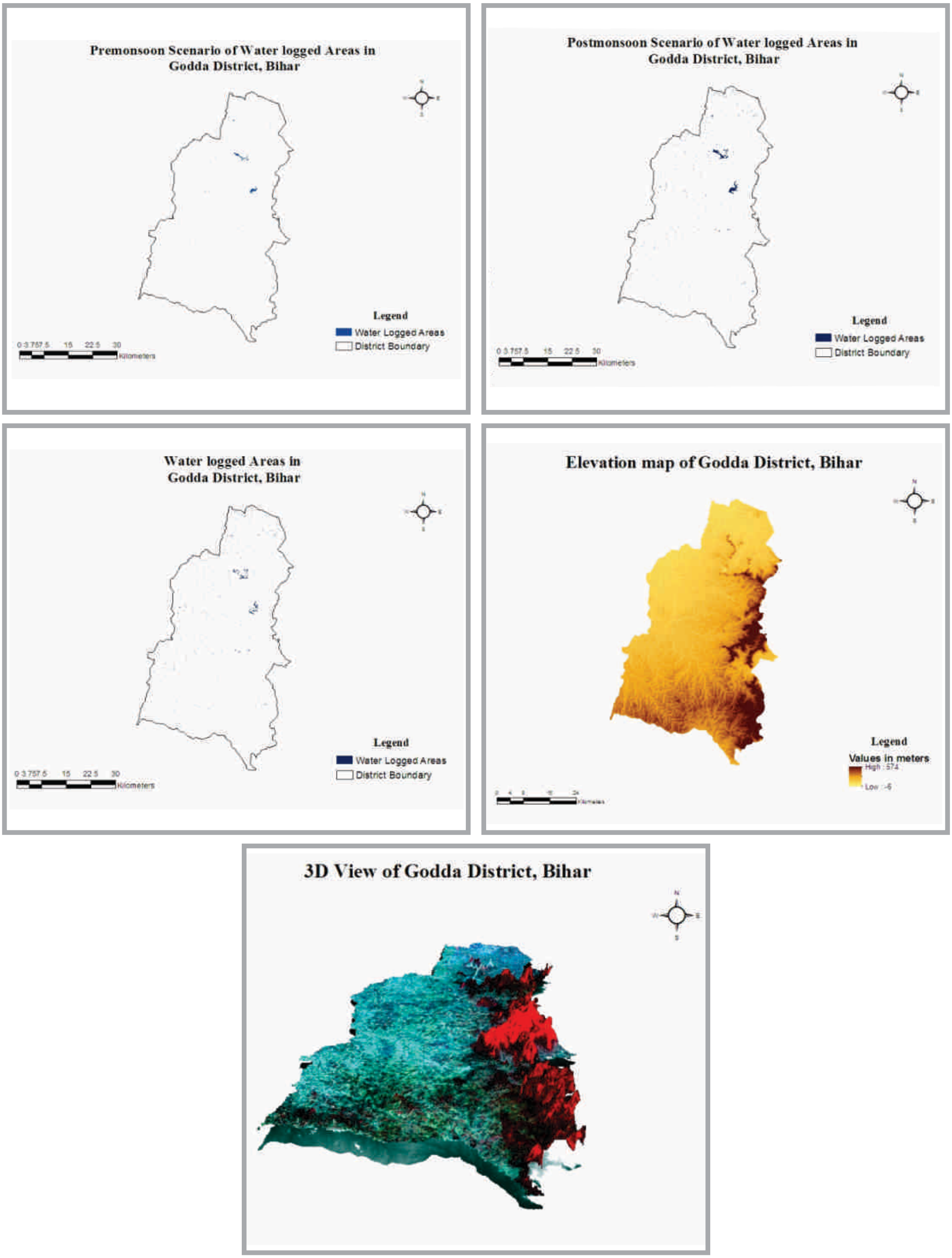


Fig. 18. Thematic maps of pre- and post-monsoon period showing delineated waterlogged area with district elevation maps and 3D view of Godda district of Bihar.

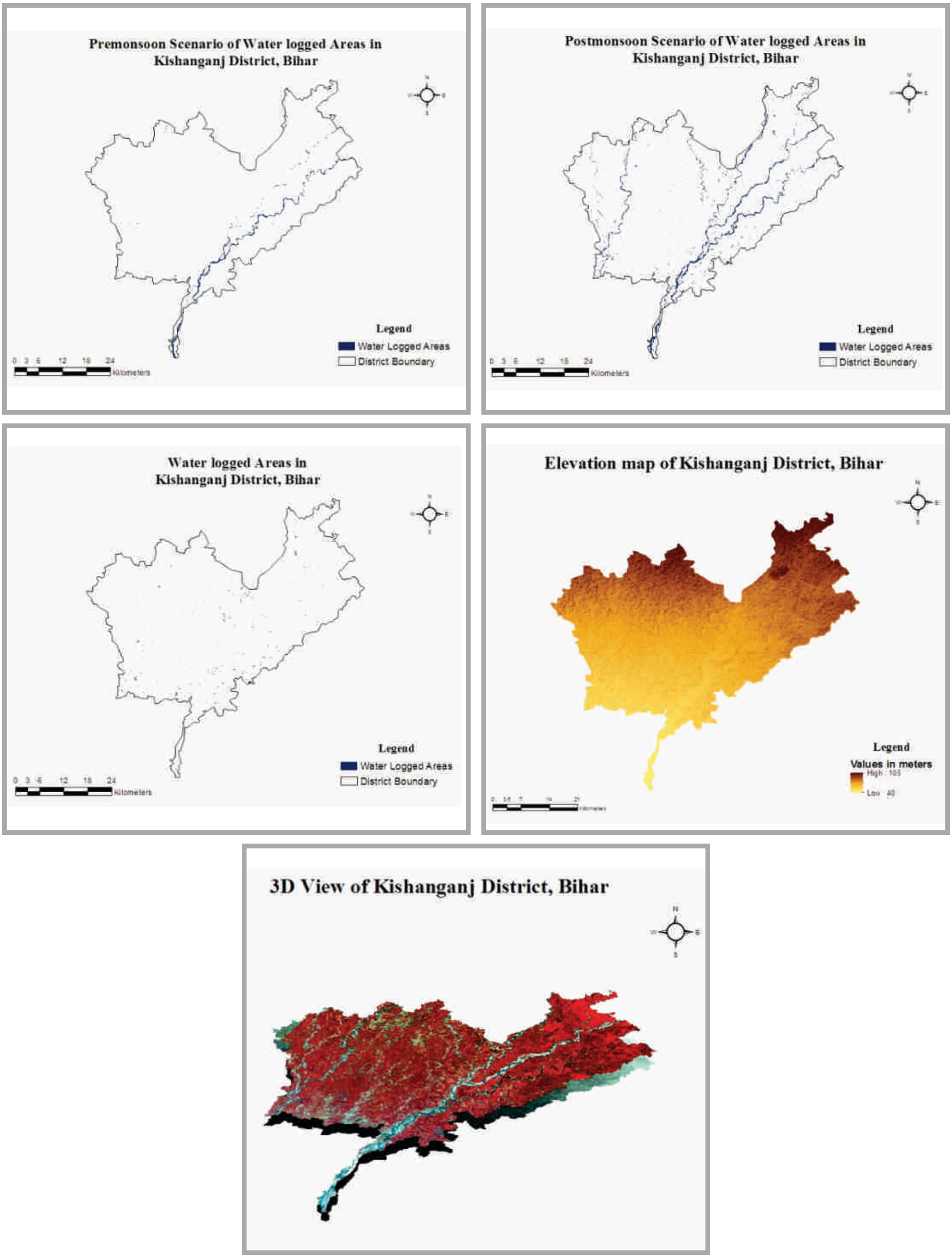


Fig. 19. Thematic maps of pre- and post-monsoon period showing delineated waterlogged area with district elevation maps and 3D view of Kishanganj district of Bihar.

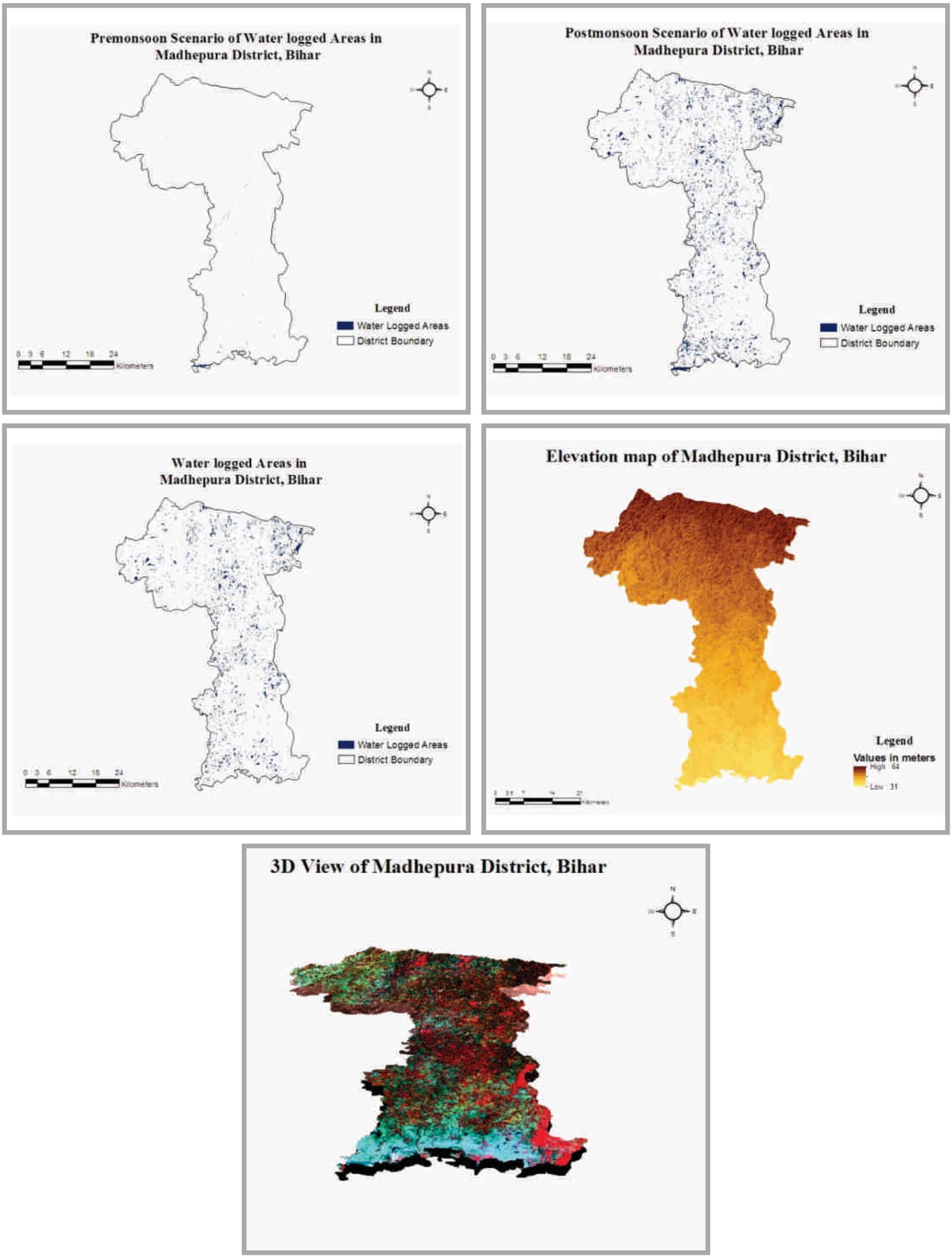


Fig. 20. Thematic maps of pre- and post-monsoon period showing delineated waterlogged area with district elevation maps and 3D view of Madhepura district of Bihar.

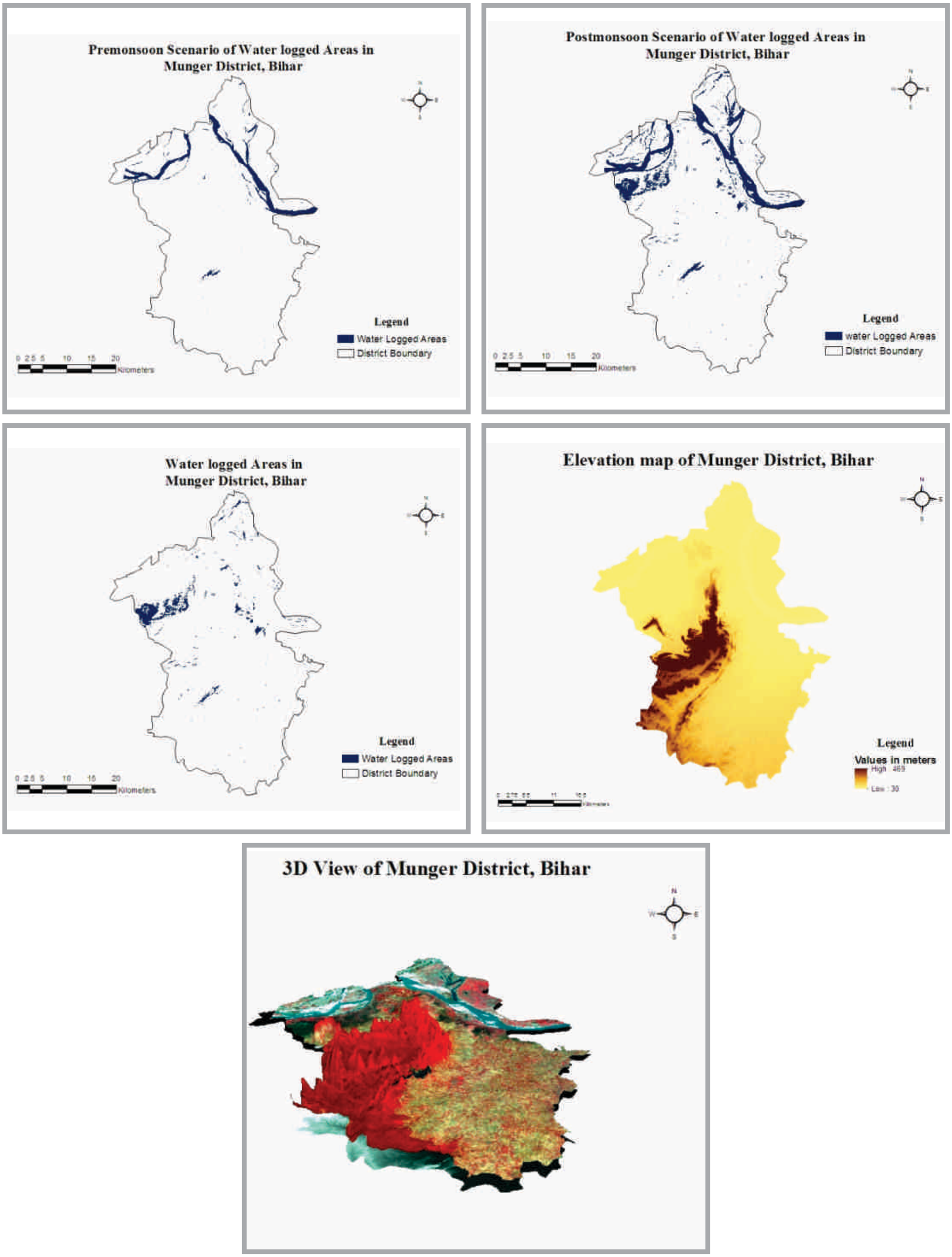


Fig. 21. Thematic maps of pre- and post-monsoon period showing delineated waterlogged area with district elevation maps and 3D view of Munger district of Bihar.

Table 1: The extent of waterlogging based on pre- and post-monsoon scenario in Bihar, West Bengal and Jharkhand.

Sl. No.	District	State	Pre-monsoon waterlogged area (ha)	Post-monsoon waterlogged area (ha)	Waterlogged area excluding perennial water bodies (ha)
1	Bhagalpur	Bihar	12967.31	35721.82	17081.24
2	Katihar	Bihar	10671.45	33258.38	15786.31
3	Purnia	Bihar	767.61	15619.84	11118.12
4	Kisganganj	Bihar	1991.09	5225.89	773.61
5	Sahibganj	Bihar	7432.9	18777.36	8680.2
6	Godda	Bihar	478.38	1307.04	954.77
7	Banka	Bihar	1312.51	2793.83	1474.92
8	Madhepura	Bihar	332.66	11177.08	9328.32
9	Munger	Bihar	5628.15	12547.4	3960.99
10	Maldah	West Bengal	13984.76	44045.71	24634.95
11	Uttar Dinajpur	West Bengal	1345.95	16145.09	14197.07
12	Pakur	Jharkhand	564.64	5000.02	4092.05

Diversification and intensification of agriculture with integrated aquaculture for improved productivity.

- **Odisha**

The poor productivity of waterlogged areas in Odisha is mostly due to unfavorable conditions for crop survival and growth. The unpredictability of extent of waterlogging makes situation more vulnerable. In case of manmade waterlogged areas, the extent of waterlogging is predictable hence allows for strategic crop planning for augmenting the land and water productivity.

In Balasore district from a study area of 92452.61 ha, 607.87 ha was found suitable for cultivation of integrated aquaculture with water chestnut. Three delineated areas under man made waterlogged area category was identified for agricultural intervention in the year 2013-14 in Balasore district. They were in Haldipada block in Balasore district, Taribatpur village (21°45.87'N, 87°11.24'E) of Jaleswar block of Balasore district and Jambhirai village (located at 21°33.12'N, 87°11.10'E) in Baliapal block . The quality of water was analyzed and was found suitable for aquaculture practices (Table 2). The agricultural intervention at Haldipada block in Balasore district yielded 8.6 t/ha water chestnut alongwith fish yield of 1.4 t/ha. Cultivation of medicinal plants like *Coleus forskholii, Eclipta alba* was also found profitable for cultivation in seasonal waterlogged areas in post waterlogged scenario as a rabi crop in rice based cropping system (Brahmanand *et al* 2011).

Table 2. Pond water quality parameters at farmer's site, Taribatpur village (Farmer Name: Narayan Dhal)

Water pH	7.66 ± 0.12
Dissolved Oxygen (ppm)	5.9 ± 0.6
Temperature (°C)	29.8 ± 0.3
Total alkalinity (ppm)	111 ± 9
Dissolved Organic Matter (ppm)	5.1 ± 0.2
Total Suspended Solids (ppm)	192 ± 11
NH_4^+ water (ppm)	0.6 ± 0.01
Total plankton (nos l^{-1})	$6.8x10^4 \pm 1.3x10^3$
Nitrite – N (ppm)	0.04 ± 0.01
Nitrate – N (ppm)	0.33 ± 0.05
Phosphate – P (ppm)	0.21 ± 0.02

All values are mean ± SD.

In addition to brinjal (yield 12.2 t/ha) and potato (yield 14.4 t/ha) near Chalanti of Jaleswar block, aquaculture activity of indian major carps showed yield of 2.6 t/ha whereas at Jambhirai village (located at 21°33.12'N, 87°11.10'E) in Baliapal block in Balasore district water chestnut yield of 8.4 t/ha was obtained. From another delineated area of 1.5 ha size, integrated water-chestnut and aquaculture cultivation gave net profit of Rs.117,000/- per ha with net economic water productivity of Rs.7.31/m^3 of water in the year 2015-16 (Farmer Name : Shankar Behera).

- **West Bengal**

Among all the districts of West Bengal, West Medinipur leads in cultivated area of rice (655684 ha) followed by Burdwan (592801 ha) and East Medinipur (399722 ha). Wheat occupies about 0.315 M ha area which is 3.46% of the gross cropped area. Murshidabad leads in total cultivated area of wheat (97146 ha) followed by Malda (43517) and Dinajpur (North) (36936 ha).The cereals all together occupy about 5.85 M ha area which is 64.3% of the total gross cropped area of West Bengal. Similarly, the pulse cultivated area was about 0.199 M ha (2.2%) and the total food grains constitute an area of 6.06 M ha (66.5%).

Both East and West Medinipur districts are suitable for fitting of different crops and aquaculture intervention because of seasonal nature of waterlogged regime. The cultivation of aquatic crops like water chestnut (*Trapa bispinosa*) and lotus (*Nelumbium speciosum*) in kharif season can be taken up whereas adjoining upland area can be utilized for paddy cultivation (Photo 1, at Kolaghat block 22° 26′ N, 87° 53′ E in Purba Medinipur district). Rice is cultivated after harvest of water chestnut and lotus during rabi season in low lying areas (Photo1, right).The model is applicable in other low lying areas, where other than rice cultivation, large area is kept fallow due to unfavourable water regime. In tidal waterlogged areas and near coastal wetlands cat tails (*Typha elephantina, T. domingensis*) can be grown as economically important crops (Photo 2).

Photo 1. Year-round cropping by growing of water chestnut and lotus during kharif season (left), and rice after harvest of water chestnut during rabi season (right) in low lying areas under Kolaghat block (22° 28′ N, 87° 53′ E) of East Medinipur district of West Bengal.

A large part of the wetland in Bagnan, Uluberia and Sankrail blocks in Howrah district is utilized for water chestnut, lotus with aquaculture or cat tail (*Typha* sp.) cultivation. The 365 ha area is under reservoir/Lakes/Ponds mainly suitable for aquaculture and lotus, water chestnut cultivation. The leaves of cat tail are used for making thatching material. A large part of the wetland is utilized for *Typha* cultivation mainly in Bagnan, Birshivpur, Sankrail blocks. From an study area of 286100 ha in East Medinipur and adjoining Howrah district, 2715 ha areas was suitable for *Typha* cultivation out of which in about 928 ha area has been occupied by *Typha* cultivation (Photo 2, Fig.22) .

Photo 2. (Left) Typha cultivation on the bank of Rupnarayan River, Panskura 2 block, East Medinipur district. (Right) Farmers engaged in harvest of *Typha* leaves.

Along with marshy waterlogged areas in Nadia and South 24 Pargana district, swamp taro (*Colocasia esculenta*) is grown (Fig.23 and 32) mainly as vegetable. Wet land plant 'shola' (*Aschynomene aspera*) grown in wet regions like Bonga, Habra, Boshirhat, Kalyani in South 24 Pargana district produce superior quality shola. The product is used in religious ceremony festivals and for other ornamental purpose (Fig.24). A large part of the wetland in the Hooghly district is utilized for seasonal water chestnut cultivation at Kamarkundu (22° 49.23'N, 88° 12.31'E) in Singur block. About 1132 ha area is under reservoir / Lakes / Ponds out of which the area occupied by lakes and ponds are suitable for aquaculture and also for lotus and water chestnut cultivation due to market demand in adjoining Kolkata market.

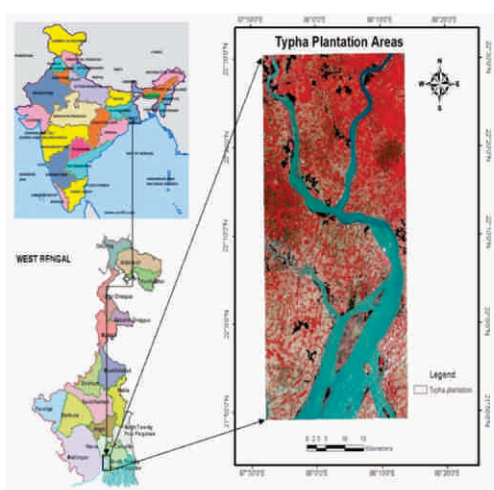


Fig. 22. *Typha* growing areas (■)in East Medinipur and adjoining Howrah district.

In Bardhaman district, a part of 5492 ha area occupied under reservoir/ Lakes/ Ponds, mainly the areas under lakes/ponds can be utilized for aquatic crops cultivation and aquaculture in the district. Water chestnut and lotus are main aquatic commercial crops in the Burdwan and Hooghly district. Apart from aquaculture and aquatic crops cultivation, part of low lying wet land/waterlogged areas of few blocks of Cooch Behar district, *i.e.* Cooch Behar I and II and Mathabhanga I and II, Dinhata is suitable for cultivation of *Clinogyne dichotoma* and the produce is utilized for knitting premium quality mats 'sital pati' (Fig. 30). The ordinary mat grass (*Cyperus tegetum*) from the area is also used for preparation of coarse quality mats (Fig. 34). Another aquatic food crop, Makhana (*Euryle ferox*) is also grown in Malda and Nadia district. Some of these districts also have potential for cultivation of biodrainage trees, *Casuarina, Eucalyptus* and *Populus* sp. or poplar in marshy waterlogged areas for reclamation and crop cultivation (Fig 25 - 28 and 33).

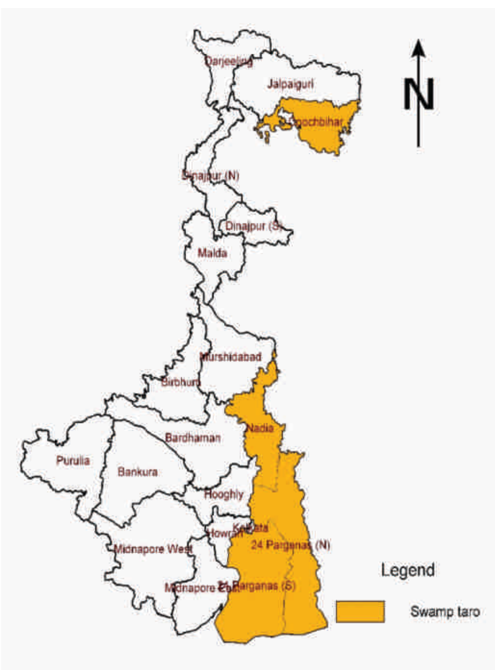


Fig.23

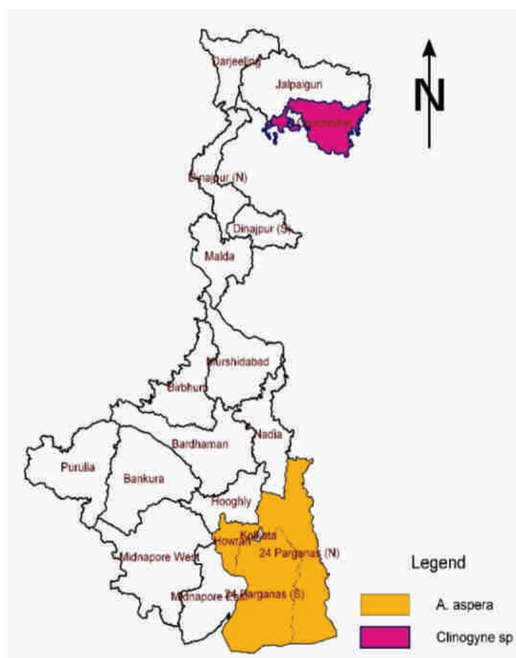


Fig.24

Fig. 23-24. District-wise scope for fitting in swamp taro, *A. aspera* and *Clinogyne sp.* in waterlogged areas of West Bengal.

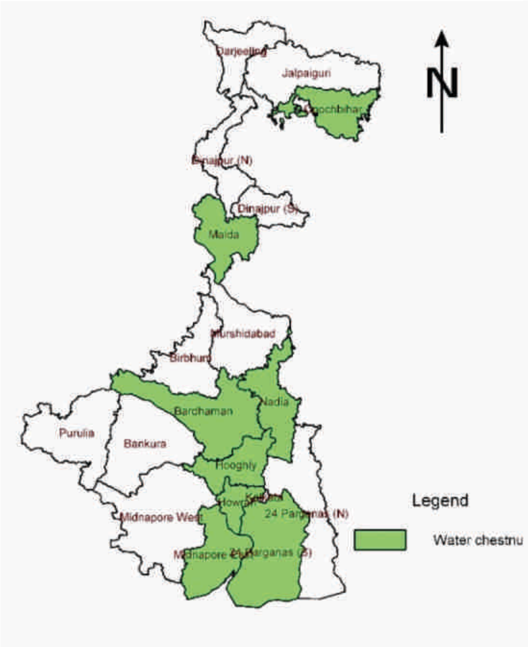


Fig.25

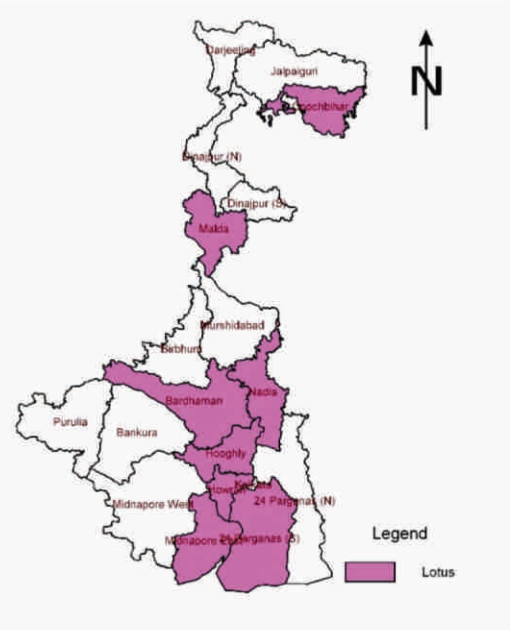


Fig.26

Fig. 25-26. District-wise scope for fitting in water chestnut and lotus in waterlogged areas of West Bengal.

Fig.27

Fig.28

Fig. 27-28. District-wise scope for fitting in cat tail and makhana in waterlogged areas of West Bengal.

➢ Assam

The cereals all together occupy about 2.64 Mha area which is 63.5% of the total gross cropped area of Assam. Similarly, the pulse cultivated area is about 0.126 Mha (3.03%). Oilseeds and fibres constitute about 0.297 Mha (7.14%) and 0.0837 m ha (2.01%), respectively. Among all the districts of Assam, Nagaon district leads in cultivated area of rice (186251 ha) followed by Sonitpur (170586 ha) and Barpeta (167523 ha). Wheat occupies about 0.0447 Mha area which is 1.07% of the gross cropped area. Barpeta district leads in total cultivated area of wheat (6654 ha) followed by Bongaigaon (5555). Maize occupies about 0.0197 Mha area which is 0.47% of the gross cropped area. Karbi-Anglong district leads in total cultivated area of maize (10230 ha) followed by Darrang (1745). In the Dibrugarh district (with 78477 ha total waterlogged area) in flood prone areas wet seeding of sprouted seeds (@75-80 kg/ha) of short to medium duration varieties like Disang, Luit, (100 days), Kapili, Kolong (120 days), or transplanting of 50-60 days old over aged seedlings of cultivars like Gitesh, Prafulla is suitable. Mixed cultivation of 'Ahu' and 'Bao' in low lying areas is a suitable flood resilient measure where Ahu can give produce in non-flood scenario. Even early flood affects Ahu yield, the 'Bao' crop gives produce avoiding total crop loss due to waterlogging and flood. Strengthening of bunds in low lying flood prone areas, disinfecting water bodies with lime or potassium permanganate is essential for sole aquaculture. Rice-fish integration is another scope for submergence prone bunded waterlogged areas in different districts.

➢ Bihar

Bhagalpur district of Bihar is under Middle Gangetic Plain region (Agro-climatic region no. IV) of India which receives an annual rainfall of 1208 mm. It has cultivable area of 1,53,600 ha with 30% area under fine sandy loam soils and 23.4% area under clayey soils. Rice and maize are predominant crops during *kharif* season and wheat, maize, lentil, mustard and potato are predominant crops in *rabi* season in this district. Out of the total net sown area 11.74% area and 14.59% of Bhagalpur and Katihar district showed waterlogged condition, respectively. The existing cropping intensity is only 125% which can be enhanced significantly through utilization of waterlogged areas and development of alternate cropping pattern. The area under maize can be further enhanced by about 8-10% and area under arhar, pearlmillet and sunflower can be enhanced by about 15-20% from the present level.

Katihar district of Bihar is also under Middle Gangetic Plain region (Agro-climatic region no. IV) of India which receives an annual rainfall of 1298 mm. It has cultivable area of 1,46,927 ha and cropping intensity of 169%. Rice, maize, jute and lentil are predominant crops during *kharif* season and wheat, mustard and potato are predominant crops in Rabi season in this district. The area under maize can be further enhanced by about 10-15% and area under arhar and pearl millet can be enhanced by about 20% from the present level. In rice dominated areas in both these districts, integrated rice-fish farming without-field refuge and growing overaged rice seedlings of about 45-60 days duration, implementing Kharuhan (double transplanting) method and cultivation of flash flood tolerant rice varieties such as swarna sub-1 would be quite useful in enhancing the grain productivity. Integrated aquaculture with aquatic crops like water chestnut and makhana is a profitable option in waterlogged area affected districts (Fig. 29, 31 and 32).

The water quality parameters in waterlogged areas observed in surveyed districts in Bihar (Bhagalpur, Katihar and Purnea) in integrated cultivation set up were analyzed for identifying suitability of integrated aquaculture intervention. The parameters in these water bodies were found within permissible limits suitable for aquaculture operation (Table 3). In all these three districts integrated cultivation of water chestnut, makhana and aquaculture both with cat fish as well as with Indian major carps has scope for introduction in perennial as well as seasonal waterlogged areas with stagnation of water for at least eight to nine months period from June to February.

Table 3. *In-situ* water quality in waterlogged areas under fish, water chestnut and makhana cultivation in three districts of Bihar

Parameters	Bhagalpur (Fish)	Katihar (water chestnut)	Purnea (Makhana)
Water pH	7.16	7.42	7.24
Dissolved Oxygen (ppm)	5.6	4.2	4.9
Temperature (^{0}C)	27.2	28.1	28.9
Total alkalinity (ppm)	88	76	101
Dissolved Organic Matter (ppm)	3.9	4.0	5.1
Total Suspended Solids (ppm)	266	338	305
Nitrite – N (ppm)	0.04	0.03	0.04
Nitrate – N (ppm)	0.37	0.41	0.46
Phosphate – P (ppm)	0.21	0.2	0.25

Crop-weed interaction in waterlogged ecosystem

The survival ability of crops in waterlogged ecosystem is influenced by weed composition and population. The naturally well adapted plant species gain advantage in submerged environment and dominate over the weeds.

Dicotyledonous weeds such as *Argemone mexicana* show higher susceptibility in waterlogged environment. The emergence of annual grasses like *Echinocloa colona, Echinocloa crusgulli, Sacharum spontaneum*, perennial grasses like *Panicum repens*, annual sledges like *Cyperus difformis* and broadleaf weeds like *Monochoria vaginalis* was observed in such situation. In general, the weed species belong to the families of Cyperaceae (*Cyperus rotundus, C iria, C difformis*) and Poaceae dominated the waterlogged crop fields of Odisha. In water chestnut cultivation areas, the crop smothered the weeds successfully except floating weeds like *Pistia, Azolla* etc.which needs periodic removal. The weeds like *Aschynomene aspera* add nitrogen to the soil through biological nitrogen fixation. Hence soil incorporation of the same after harvest of economically important pith (shola) is recommended in post flood environment for obtaining higher crop productivity.

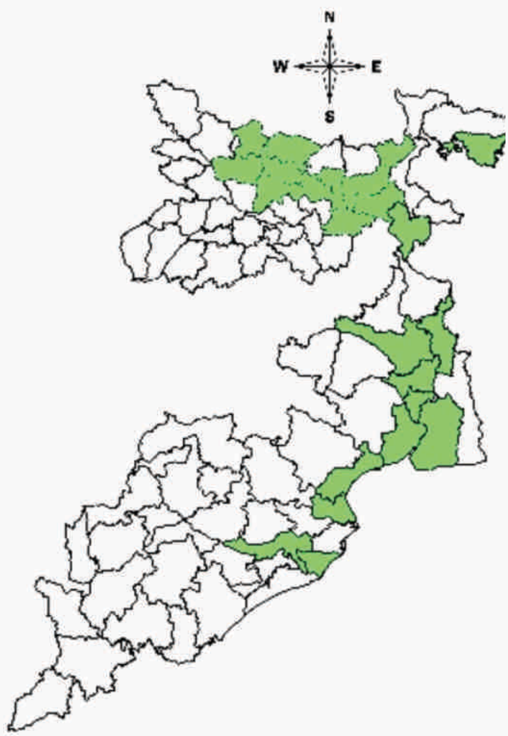


Fig. 29. Major water chestnut-fish cultivation adoptable districts of Orissa, West Bengal and Bihar

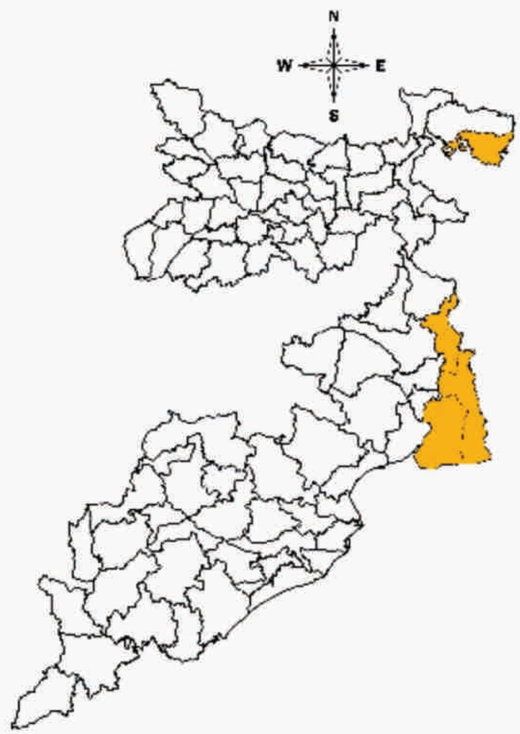


Fig. 30. Major sital pati cultivation adoptable districts of West Bengal

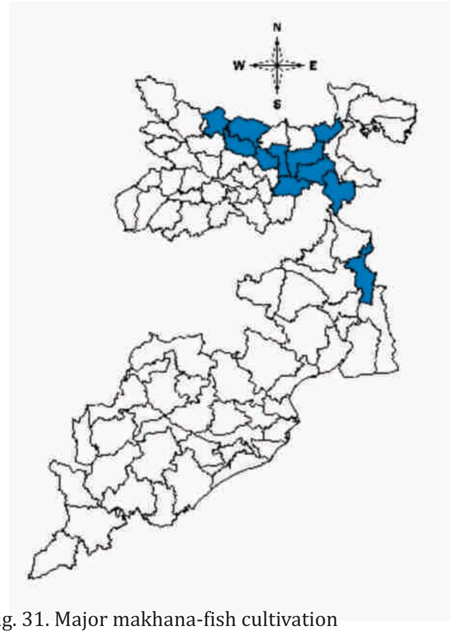


Fig. 31. Major makhana-fish cultivation adoptable districts of West Bengal and Bihar

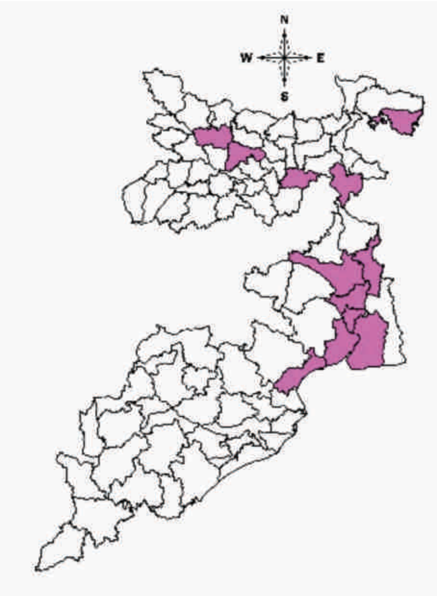


Fig. 32. Major swamp taro cultivation adoptable districts of Orissa, West Bengal and Bihar

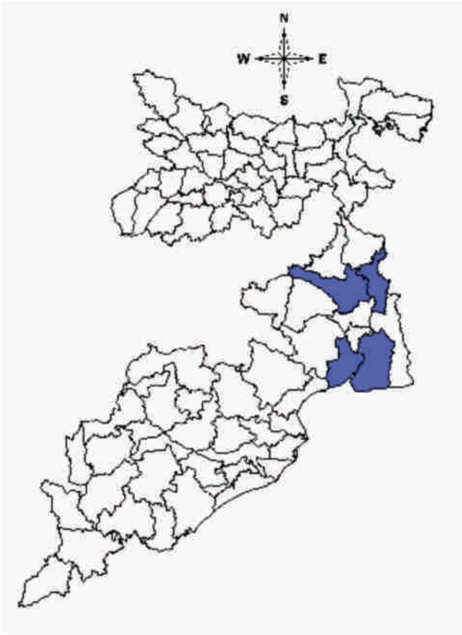


Fig. 33. Major biodrainage adopting districts of Odisha and West Bengal

Fig. 34. Major cat tail and mat stick cultivation districts of West Bengal

Intervention in cyclone affected waterlogged areas

In case of manmade waterlogged areas, the extent of waterlogging is predictable, hence provides scope for implementing strategic crop planning for augmenting the land and water productivity. Chalanti (Jaleswar block, Balasore district, N 21°45.872'/ E 87°11.248') comes under such scenario where waterlogging has been a common feature since long and farmers have been practicing rice cultivation in kharif season and potato and greengram, groundnut, brinjal and other vegetables in rabi season. Ten days advanced sowing time to first week of November in greengram resulted in 16% higher pod yield to 835 kg/ha. Similarly, ridge and furrow system has bettered the fruit yield of brinjal and tuber yield of potato significantly compared to the flat bed system.

In cyclone 'Phailin' (October, 2014) affected areas, in Bhadrak and Jajpur district, the farmers mainly cultivated groundnut and mustard either as sole crop or as intercrop in post-cyclone period. The pod yield of groundnut was 1165 kg/ha and seed yield of mustard was 980 kg/ha. The pod number per plant and seed number per pod of mustard were 286 and 11.7, respectively, contributing to higher pod yield and suggested better resilience of this crop to survive under post flood scenario. Some farmers have grown cucurbits such as pumpkin and ridge gourd. In relatively low lying areas, the Colocasia esculenta var. antiquorumis preferred for cultivation. In Phailin affected areas after the harvest of groundnut and mustard, about 20% of the farmers have cultivated the crops such as watermelon, cucumber and pumpkin. *Acacia, Eucalyptus*, *Casuarina* plantation in low lying areas were also undertaken as a component of economically profitable agroforestry intervention either on dykes or raised bed or in fields.

Conclusions

Delineation of waterlogged areas which are normally designated as degraded land to bring under commercial agriculture for increased land and water productivity is of paramount importance. The seasonal waterlogged areas were estimated in twelve different districts of Bihar, West Bengal and Jharkhand from the georeferenced IRS P6- LISS-III imagery (path 106 and row 54) from pre- and post-monsoon scenarios with the help of ground truth visit data and toposheet maps of Survey of India, Dehradun. District-wise different types of waterlogged areas was thematically mapped for clustering the affected areas under types of waterlogging in order to strategize interventions depending on nature of waterlogging. The findings of the project have suggested that in these eastern states studied (Assam, Bihar, Odisha, and West Bengal), a sizable areas exist under different categories of waterlogging. Among these, the man made waterlogged areas, part of inland waterlogged areas under perennial waterlogging and areas under influence of seasonal waterlogging can be brought under cultivation which otherwise remain unutilized as degraded land due to waterlogging. These areas can be brought under conventional or non-conventional cultivation practices depending on extent of waterlogging. The package of practices of sole water chestnut, integrated water chestnut-aquaculture, and swamp taro cultivation are available for agricultural intervention in these waterlogged areas. Use of over aged seedlings, flash flood tolerant swarna sub-1, deep water paddy cultivars (Hanseswari, Saraswati), pond based integrated farming systems, rotational water chestnut/ lotus/ paddy are among new interventions suggested for adoption in delineated waterlogged areas. Cultivation of *Typha* in tidal waterlogged areas along river banks is also suggested for remunerative agriculture as well as to prevent soil erosion and downstream eutrophication maintaining health of the water bodies. Therefore, intensive cultivation in waterlogged areas has potential not only to bring the uncultivated areas under agricultural intervention, but also in providing ecological services maintaining nutrient balance between soil and the water bodies for sustainable agro-ecological conditions.

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