Wetlands of India: inventory and assessment at 1 : 50,000 scale using geospatial techniques

Sushma Panigrahy, T. V. R. Murthy, J. G. Patel and T. S. Singh*

Conservation and wise use of wetlands has been given priority world over. India harbours diverse types of wetlands. This study highlights the findings of the national-level inventory and assessment of wetlands carried out using RESOURCESAT-1 LISS-III data of 2006–07 at 1 : 50,000 scale. A hierarchical system comprising 19 classes based on Ramsar definition has been used to classify the wetlands of India. The extent of wetlands has been estimated to be 15.26 m ha. Inland wetlands account for 69.22% (10.564 m ha), whereas the coastal wetlands account for 27.13% (4.14 m ha). The high-altitude wetlands (situated > 3000 m asl) in the Himalayan states were also mapped, comprising 126,249 ha of areal extent. The status of wetlands in terms of water spread, turbidity of open water and aquatic vegetation has shown significant variation during pre- and post-monsoon seasons. This article highlights the detailed results at state level and the status of wetlands in terms of water spread, aquatic vegetation and turbidity of open water in the wetlands in the pre- and post-monsoon seasons.

Keywords: Inventory and assessment, remote sensing, spectral indices, wetlands.

WETLANDS, which include rivers, lakes, reservoirs, etc. are the most precious life-sustaining water resources. Besides playing a crucial role in the hydrological cycle, wetlands are the most productive ecosystems of the world and a potential source of carbon sequestration, although they account only for about 4% of the earth's ice-free land surface[1]. Irrespective of their obvious positive contributions, wetlands are the first among the victims of modern development and degrading with time. In recent years, there has been a concerted effort world over to conserve and preserve these natural resources. India harbours a wide variety of wetlands and the first step towards planning the conservation and sustainable management of wetland resources is to have an accurate and updated database. Geographic Information System (GIS) and satellite remote sensing are the best available technologies for such a purpose. The first scientific national inventory of wetlands in the India carried out on a 1 : 250,000 scale using satellite remote sensing data (1992–93), estimated the total wetland extent to be about 8.26 m ha. Wetlands being dynamic and influenced by both natural and man-made activities, need frequent monitoring. Regular updation of the status of the wetlands is all the more significant in view of the accelerating pressure on the very existence of these resources due to developmental activities and population pressure being witnessed currently. With this objective, a national project entitled 'National Wetland Inventory and Assessment' was taken up by the Space Applications Centre (ISRO), Ahmedabad funded by the Ministry of Environment and Forests, Government of India during 2007–2011. This article highlights the results of the study, which is the current national wetland statistics of India.

Study area and data used

The entire country, including the mainland and island territories has been considered for inventory and assessment of wetlands. Resourcesat-1 LISS III data of 23.5 m spatial resolution with four spectral bands (green, red, NIR and SWIR) were used. India is covered in 365 LISS III scenes. Two-date datasets, one acquired during March–May and another during October–December, were used to capture the hydrological variability of the wetlands during the pre- and post-monsoon season respectively.

Field data in terms of location (latitude/longitude), status of the wetlands in terms of quality of open water and aquatic vegetation was collected on sample basis in each state, which was used to finalize the classification of satellite data and validation of accuracy. The other ancillary data included the administrative boundary (state/district), road/rail network, major towns/settlements, drainage network, etc. which were used from other national projects.

The authors are in the Space Applications Centre (ISRO), Ahmedabad 380 015, India.
*For correspondence. (e-mail: murthytvr@sac.isro.gov.in)

Methodology

Classification system

In the present study, 19 wetland classes were organized under a level-three hierarchical system. Level one has two wetland classes: inland and coastal; these are further bifurcated into two categories: natural and man-made under which the 19 wetland classes are suitably placed. Small wetlands of below 2.25 ha were mapped as point features.

Identification and mapping

In this project eight wetland theme layers were prepared as given below:

- Wetland extent: (layer 1) It is the wetland boundary.
- Water spread: There are two layers (layers 2 and 3) representing post-monsoon and pre-monsoon water spread during the year of data acquisition.
- Aquatic vegetation spread: Layer (layers 4 and 5) pertaining to the presence of vegetation (floating and emergent) is generated, as manifested on the pre-monsoon and post-monsoon imageries.
- Turbidity ratings of open water: A layer (layers 6 and 7) pertaining to a qualitative turbidity of the open water in the wetlands rated as low, medium and high is generated for the pre- and post-monsoon seasons.
- Small wetlands (< 2.25 ha) (layer 8) are mapped as point features.

Identification of thematic classes using remote sensing data is based on unique spectral signature of the study class in the spectral bands used[2]. In the present study, all the four spectral bands were used to identify the wetlands. Five spectral indices which are well established for their role to enhance various wetland structural components were used. These indices are: NDWI – Normalized Difference Water Index[3], MNDWI – Modified Normalized Difference Water Index[4], NDVI – Normalized Difference Vegetation Index[5], and NDPI – Normalized Difference Pond Index and NDTI – Normalized Difference Turbidity Index[6]. Depending upon the class to be interpreted, a combination of indices was used. The ground truth data thus collected were used to develop the optimal indices combination and interpretation key.

Database design

To generate maps at the 1 : 50,000 scale and create the digital database, the National Spatial Framework (NSF) and the National Natural Resources Management System (NNRMS) standard has been used[7]. Feature codification scheme for every input element has been worked out keeping in view the nationwide administrative as well as natural hierarchy (State–district within the feature class for each wetland category). Each wetland was given a unique 16-digit numerical code, which is self-explanatory. Work was carried out using ERDAS Imagine, Arc/Info and ArcGIS software.

Results

Extent under wetlands

Total wetland area was estimated to be 15.260 m ha using 2006–07 LISS-III data, which is around 4.63% of the geographical area of the country. This includes 555,557 ha area under small wetlands (point features which were allotted a nominal 1 ha area for the purpose of area computation). Excluding the wetland type under river/stream, the areal extent of wetlands stands at 10.0 m ha (Table 1).

Type-wise statistics of wetlands

The inland–natural wetlands accounted for around 43.4% of the total area, while the coastal–natural wetlands accounted for 24.3%. Among the 19 wetland types, river/stream is the dominant one, occupying 5.26 m ha area (Table 1). Among the other wetland types, reservoir/barrage leads the list with 2.48 m ha, followed by Intertidal mudflat (2.41 m ha), tank/pond (1.31 m ha) and lake/pond (0.73 m ha). India also harbours three unique wetland types. The two coastal/marine wetland categories, namely coral reefs and mangroves occupy 142,003 and 471,407 ha respectively. Owing to its importance, the high-altitude wetlands (HAWs) class was introduced for the first time. For this, elevation contour generated using satellite-derived digital elevation model (DEM) was used and all wetlands above 3000 m were classified as HAWs. A total of 4703 HAWs were mapped including 1996 small ones (< 2.25 ha), with a total area of 126,253 ha (0.81% of the total wetlands).

Small wetlands

Village tanks/ponds which are smaller than 2.25 ha form important wetlands. These are not mappable at the 1 : 50,000 scale. However, such features are clearly seen in satellite data and thus detected and mapped as point features. There are 555,557 such small wetlands in the country. West Bengal has highest number of small wetlands (138,707), followed by Uttar Pradesh, Odisha, Madhya Pradesh and Rajasthan. The distribution of wetlands in India is shown in Figure 1.

State/Union Territory-wise wetland distribution in India

State-wise distribution of wetlands in terms of percentage share reveals that Gujarat ranks first with 3.47 m ha

Table 1. Type-wise area statistics of wetlands in India

Wetland category	Wetland area (ha)	Percentage of wetland area	Open water (ha)			Aquatic vegetation (ha)		
			Post-Monsoon	Pre-Monsoon	Change (%)	Post-Monsoon	Pre-Monsoon	Change (%)
Inland: natural								
Lakes/ponds	729,532	4.78	454,416	198,054	–56.42	253,650	456,867	80.12
Ox-bow lakes/cut-off meanders	104,124	0.68	57,576	37,818	–34.32	42,292	33,387	–21.06
High-altitude wetlands	124,253	0.81	116,615	109,277	–6.29	–	427	
Riverine wetlands	91,682	0.60	48,918	29,739	–39.21	41,722	31,777	–23.84
Waterlogged	315,091	2.06	197,003	112,631	–42.83	97,974	91,578	–6.53
River/stream	5,258,385	34.46	3,226,238	2,628,182	–18.54	11,721	13,487	15.07
Sub-total	6,623,067	43.40	4,100,766	3,115,701	–24.02	447,359	627,523	40.27
Inland: man-made								
Reservoirs/barrages	2,481,987	16.26	2,260,574	1,268,237	–43.90	119,711	492,237	311.19
Tanks/ponds	1,310,443	8.59	916,020	349,512	–61.84	228,081	426,617	87.05
Waterlogged	135,704	0.89	85,715	33,822	–60.54	42,580	20,974	–50.74
Salt pans	13,698	0.09	5,293	2,599	–50.90	–	–	
Sub-total	3,941,832	25.83	3,267,602	1,654,170	–49.38	390,372	939,828	140.75
Total inland	10,564,899	69.23	7,368,368	4,769,871	–35.27	837,731	1,567,351	87.09
Coastal: natural								
Lagoons	246,044	1.61	208,915	191,301	–8.43	35,398	44,170	24.78
Creeks	206,698	1.35	199,743	189,489	–5.13	32	56	75.00
Sand/beach	63,033	0.41	–	–		–	–	
Intertidal mud flats	2,413,642	15.82	516,636	366,953	–28.97	1,426	2,980	108.98
Salt marsh	161,144	1.06	5,369	2,596	–51.65	3,068	6,023	96.32
Mangroves	471,407	3.09	–	–		441,732	441,368	–0.08
Coral reefs	142,003	0.93	–	–		–	–	
Sub-total	3,703,971	24.27	930,663	750,339	–19.38	481,656	494,597	2.69
Coastal: man-made								
Salt pans	148,913	0.98	105,253	94,047	–10.65	1,213	705	–41.88
Aquaculture ponds	287,232	1.88	196,514	186,963	–4.86	2,237	2,443	9.21
Sub-total	436,145	2.86	301,767	281,010	–6.88	3,450	3,148	–8.75
Total coastal	4,140,116	27.13	1,232,430	1,031,349	–16.32	485,106	497,745	2.61
Wetlands (< 2.25 ha)	555,557	3.64	–	–		–	–	
Total	15,260,572	100.00	8,600,798	5,801,220	–32.55	1,322,837	2,065,096	56.11

(22.77%), mainly due to vast stretches of intertidal mudflats and salt pans. Gujarat is followed by Andhra Pradesh (1.45 m ha), Uttar Pradesh (1.24 m ha), West Bengal (1.11 m ha) and Maharashtra (1.01 m ha). In terms of percentage extent of geographical area, Lakshadweep ranks first (96.12), mainly due to the presence of coral and mangrove. The other major states/Union Territories (UTs) having more than 10% area are: Andaman and Nicobar Islands (18.52), Daman–Diu (18.46), Gujarat (17.56), Puducherry (12.88) and West Bengal (12.48). State/UT-wise distribution of wetlands is graphically shown in Figure 2. Tamil Nadu has highest number of lakes (4369) followed by Uttar Pradesh (3684) and West Bengal (1327). Ox-bow lakes/cut-off meanders are observed in Uttar Pradesh, West Bengal, Bihar, Assam and Odisha. A large number of riverine wetlands exist in Uttar Pradesh, West Bengal, Bihar, Assam and Jammu and Kashmir. West Bengal has the highest area under mangrove (209,330 ha) followed by Gujarat (90,475 ha) and Andaman and Nicobar Islands (66,101 ha). Coral reefs are observed in Lakshdweep (55,179 ha), Andaman and Nicobar Islands (49,378 ha), Gujarat (33,547 ha) and Tamil Nadu (3899 ha). Gujarat has a large area under intertidal mud flats (2,260,365 ha) followed by Tamil Nadu (33,164 ha) and Andhra Pradesh (31,767 ha). Jammu and Kashmir has the highest share of HAWs accounting for 87.24% area with 2104 lakes, followed by Arunachal Pradesh with 1672 lakes contributing 9.4% of the area.

Status of wetlands

Significant change in the water spread, turbidity of open water, and spread of aquatic vegetation in the wetlands was observed during pre- and post-monsoon seasons. Table 1 shows the details of type-wise statistics of wetlands and their seasonal changes. The water spread of

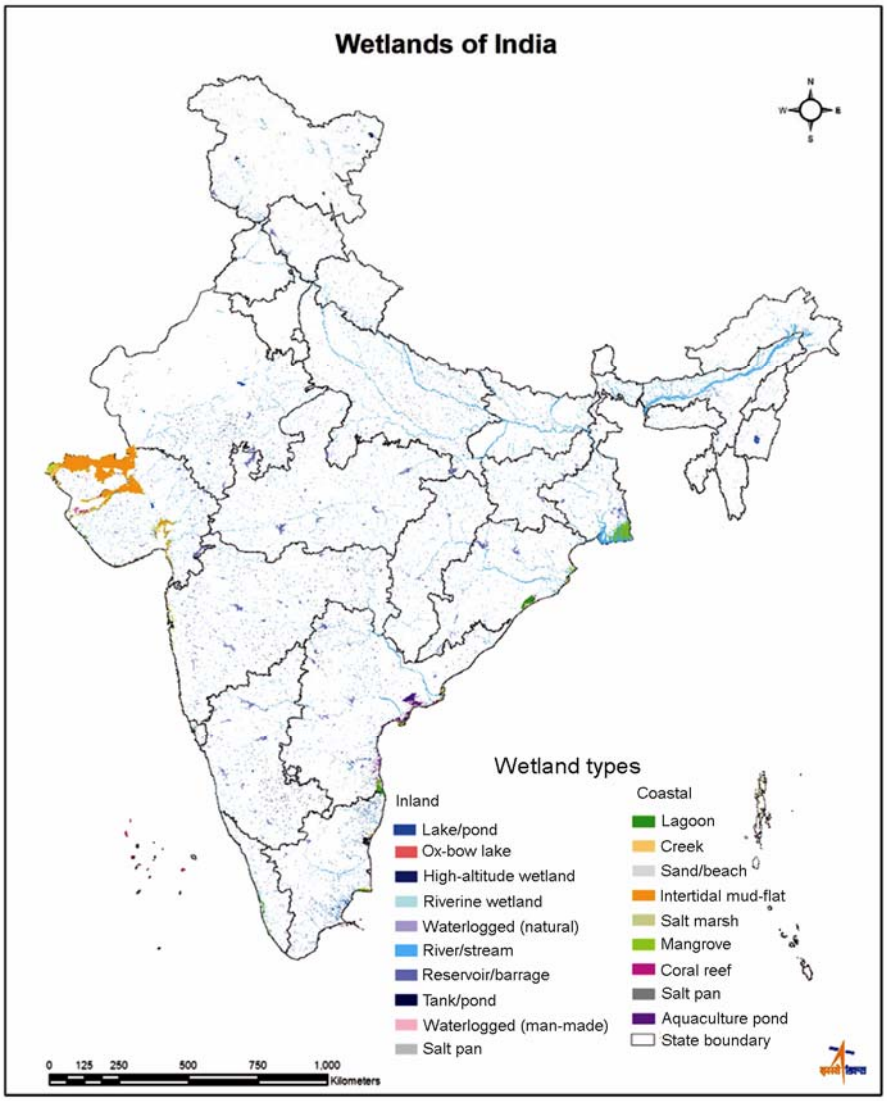

Figure 1. Map showing distribution of various types of wetlands in India derived using LISS III data (2006–2007) on a 1 : 50,000 scale.

wetlands showed significant reduction from post-monsoon (77.2%) to pre-monsoon (39.5%), indicating the strong influence of monsoon in the hydrology of wetlands in India. Inland–man-made wetlands show higher seasonal variability (–49.38%) in terms of open water compared to inland–natural wetlands (–24.02%). Tanks/ponds category showed highest reduction (–61.84%) in open water from post-monsoon to pre-monsoon, followed by waterlogged (man-made) wetlands (–60.54%). Overall, the inland wetlands have greater reduction (–35.27%) in the extent of open water compared to coastal wetlands (–16.32%). The reduction exhibited by the HAWs (–6.29%) is due to freezing during the post-monsoon months and not the actual reduction in open water.

The turbidity of the open water is in general medium to low in both seasons. Out of the 8.60 m ha of open-water area in the post-monsoon season, 48.47% and 37.28% area was under moderate and low turbidity respectively. During pre-monsoon, around 51.15% and 32.55% area was under moderate and low turbidity respectively. River/stream category contributes maximum to the moderate turbidity during both post-monsoon (24.78%) as well as pre-monsoon (31.27%) season. High turbidity of open water was observed in case of some reservoirs and tanks.

Aquatic vegetation (floating and emergent) was observed in lake/pond, riverine wetland, ox-bow lake, tank/pond and reservoir categories. The aquatic vegetation in wetlands showed higher extent during pre-monsoon (14%) compared to post-monsoon (9%). Estimation of the extent under wetland vegetation was restricted mostly to emergent macrophytes and at certain places floating macrophytes. Seasonal dynamics in wetland vegetation shows that there is an overall increase of about 56% in

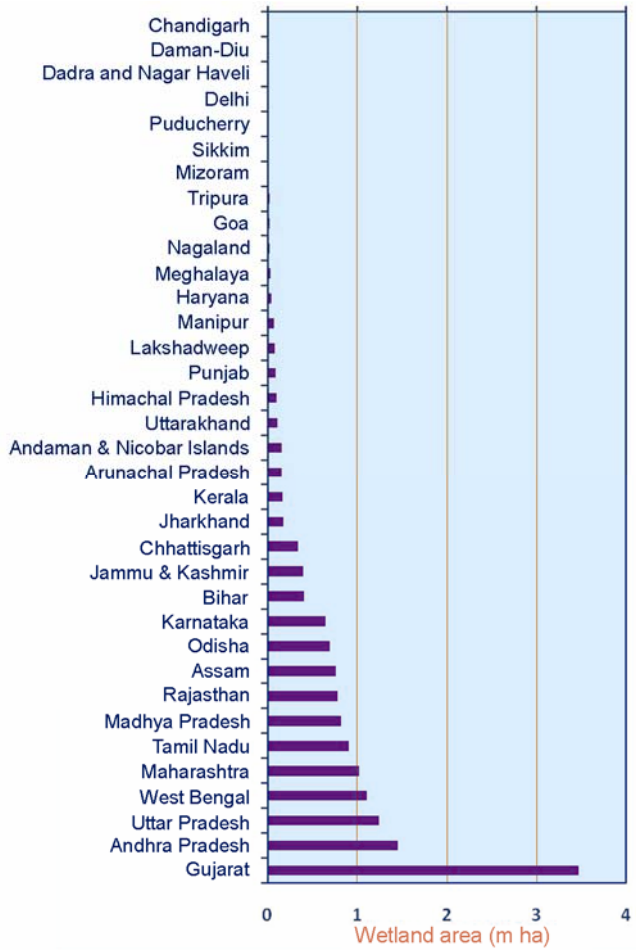

Figure 2. Graphical representation of area under wetlands in various states/Union Territories in India.

the extent from post-monsoon to pre-monsoon. The increase in the wetland vegetation in pre-monsoon is pronounced in reservoir/barrage, which is four times compared to post-monsoon followed by tanks/ponds and lakes/ponds. In the case of coastal wetlands, a marginal seasonal change in vegetation (2.6%) was observed.

Conclusion

India harbours diverse types of wetlands from high-altitude lakes situated at 5000 m elevation in the Himalayas to the marine systems of mangrove and coral. Updating the database of these wetlands is essential to monitor the status of these resources, and for scientific management planning. Thus, a wetland database showing location, extent and type at 1 : 50,000 scale has been created at the district, state and topographic map sheet level covering the entire country. This inventory estimated the total wetland area as 15.26 m ha. River/stream is the largest type wetland accounting for 5.26 m ha. This study has designed a level-three hierarchical system with 19 classes covering the entire spectrum of wetlands found in India, which are amenable from satellite remote sensing data with desirable accuracy. Thus, this will support future monitoring studies.

1. Prigent, C., Matthews, E., Aires, F. and Rossow, W. B., Remote sensing of global wetland dynamics with multiple satellite datasets. *Geophys. Res. Lett.*, 2001, **28**, 4631–4634.
2. Lillesand, T. M. and Keifer, R. W., *Remote Sensing and Image Interpretation*, Wliey and Sons, New York, 1987.
3. McFeeters, S. K., The use of normalised difference water index (NDWI) in the delineation of open-water features. *Int. J. Remote Sensing*, 1996, **17**, 1425–1432.
4. Hanqiu, X., Modification of normalised difference water index (NDWI) to enhance open-water features in remotely sensed imagery. *Int. J. Remote Sensing*, 2006, **27**, 3025–3033.
5. Townshend, J. R. and Justice, C. O., Analysis of dynamics of African vegetation using the normalised difference vegetation index. *Inter. J. Remote Sensing*, 1986, **7**, 1435–1445.
6. Lacaux, J. P., Tourre, Y. M., Vignolles, C., Ndione, J. A. and Lafaye, M., Classification of ponds from high-spatial resolution remote sensing: application to Rift valley fever epidemics in Senegal. *Remote Sensing Environ.*, 2007, **106**, 66–74.
7. Anon, NNRMS Standards. A National Standards for EO images, thematic and cartographic maps, GIS databases and spatial outputs. ISRO: NNRMS: TR: 112:2005. A Committee Report, National Natural Resources Management System, Bangalore, 2005.

ACKNOWLEDGEMENTS. We thank Dr R. R. Navalgund, Director, and Dr J. S. Parihar, Dy. Director, Space Applications Centre, Ahmedabad for their technical guidance and support. The project has been carried out in collaboration with a number of institutions in the country and we acknowledge their contribution in the creation of the database. Financial assistance provided by the Ministry of Environment and Forests, Government of India is also acknowledged.

Received 24 November 2011; accepted 24 January 2012