Conservation of wetlands of India – a review

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Abstract: Wetlands of India, estimated to be 58.2 million hectares, are important repositories of aquatic biodiversity. The diverse ecoclimatic regimes extant in the country resulted in a variety of wetland systems ranging from high altitude cold desert wetlands to hot and humid wetlands in coastal zones with its diverse flora and fauna. The review deals with the status and distribution of wetlands and causes and consequences of wetland losses. It also provides an overview of the use of Remote Sensing and Geographic Information System (GIS) tools in flood zonation mapping, in monitoring irrigation and cropping patterns, water quality analysis and modelling, change analyses and in mapping of surface water bodies and wetlands. The review provides a methodology and an action plan for evolving a nationwide network of conservation preserves of wetlands. The major elements of this methodology involve use of IRS LISS III sensors for delineating turbidity, aquatic vegetation and major geomorphological classes of wetlands. An extensive fieldwork to generate attribute information on biodiversity and socioeconomic themes is a significant component of the suggested methodology. GIS tools to integrate habitat information with the field information are envisaged to be the final component in evolving a conservation network of wetlands for the entire country.

Resumen: Los humedales de la India, cuya superficie estimada es de 58.2 millones de hectáreas, son depósitos importantes de la biodiversidad acuática. Los diversos regímenes ecoclimáticos que existen en el país han dado por resultado una extensa gama de sistemas de humedales que abarca desde los humedales de desierto frío de alta altitud, hasta los humedales cálidos y húmedos de las zonas costeras con su flora y fauna diversas. La revisión versa sobre la condición y la distribución de los humedales, y las causas y consecuencias de su pérdida. También proporciona una visión de conjunto sobre el uso de herramientas de Percepción Remota y Sistemas de Información Geográfica (SIG) en la elaboración de mapas de la zonación de inundación, el monitoreo de patrones de irrigación y de cultivo, el análisis de calidad de agua y su modelado, el análisis de cambios y en la elaboración de mapas de cuerpos de agua superficial y de humedales. La revisión hace una sugerencia metodológica y ofrece un plan de acción para la creación de una red nacional de reservas para la conservación de humedales. Los principales elementos de esta metodología involucran el uso de sensores IRS LISS III para definir la turbidez, la vegetación acuática y las principales clases geomorfológicas de los humedales. Un componente significativo de la metodología sugerida es el trabajo extensivo de campo para generar la información tanto de atributos de biodiversidad como de temas socioeconómicos. Se prevé que las herramientas de SIG para integrar información de hábitat con información de campo serán el componente final en la conformación de una red de conservación de humedales en todo el país.

Resumo: As terras húmidas da Índia, que estão avaliadas em 58,2 milhões de hectares,

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são importantes repositórios de biodiversidade aquática. Os diferentes ecoclimas existentes no país caracterizam-se por uma variedade de sistemas húmidos oscilando dos desérticos frios de alta altitude aos quentes e húmidos das zonas húmidas costeiras com a sua flora e fauna diversificada. Este revisão trata do *status* e distribuição das zonas húmidas e causas e consequências da perda destes zonas. Ela proporciona, também, uma visão de conjunto do uso das ferramentas de Detecção Remota e do Sistema de Informação Geográfica (GIS) nos mapas de zonagem, monitorização da irrigação e dos padrões de cultura, análise da qualidade da água e modelação, análise das mudanças e mapeamento dos cursos de água e das terras húmidas. A revisão proporciona a sugestão de uma metodologia e um plano de acção para envolver uma rede nacional de conservação e preservação das terras húmidas. Os maiores elementos desta metodologia envolvem o uso dos sensores do IRS LISS III para delinear a turbidez, a vegetação aquática e as principais classes geomorfológicas das terras húmidas. Um trabalho de campo extensivo para gerar informação sobre os atributos da biodiversidade e temas sócio-económicos, é uma componente significativa da metodologia sugerida. A utilização das ferramentas do GIS para integrar a informação sobre o habitat com a informação de campo, é encarada como a componente final no envolvimento de uma rede de conservação das terras húmidas para todo o país.

Key words: Aquatic vegetation, avifauna, conservation, fishes, geographic information system (GIS), protected areas, remote sensing, tropical wetlands.

Introduction

Wetlands are defined as 'lands transitional between terrestrial and aquatic eco-systems where the water table is usually at or near the surface or the land is covered by shallow water (Mitsch & Gosselink 1986). The value of the world's wetlands are increasingly receiving due attention as they contribute to a healthy environment in many ways. They retain water during dry periods, thus keeping the water table high and relatively stable. During periods of flooding, they mitigate flood and to trap suspended solids and attached nutrients. Thus, streams flowing into lakes by way of wetland areas will transport fewer suspended solids and nutrients to the lakes than if they flow directly into the lakes. The removal of such wetland systems because of urbanization or other factors typically causes lake water quality to worsen. In addition, wetlands are important feeding and breeding areas for wildlife and provide a stopping place and refuge for waterfowl. As with any natural habitat, wetlands are important in supporting species diversity and have a complex of wetland values.

The present review is aimed at providing in a nutshell, the distribution of wetlands, the value of wetlands, the causes and consequences of the loss of wetlands. The review attempts to provide a glimpse of the use of modern spatial technology tools, viz. Remote Sensing / GIS for obtaining an assessment, description and monitoring of inland wetlands. The review also gives a methodology for an ongoing nationwide attempt on evolving a conservation area network or a protected area network of inland wetlands.

Distribution of wetlands in India

India, with its annual rainfall of over 130 cm, varied topography and climatic regimes support and sustain diverse and unique wetland habitats. Natural wetlands in India consists of the high-altitude Himalayan lakes, followed by wetlands situated in the flood plains of the major river systems, saline and temporary wetlands of the arid and semi-arid regions, coastal wetlands such as lagoons, backwaters and estuaries; mangrove swamps; coral reefs and marine wetlands, and so on. Infact with the exception of bogs, fens and typical salt marshes, Indian wetlands cover the whole range of the ecosystem types found. In addition to the various types of natural wetlands, a large number of man-made wetlands also contribute to the faunal and floral diversity. These man-made wetlands, which have resulted from the needs of

irrigation, water supply, electricity, fisheries and flood control, are substantial in number. The various reservoirs, shallow ponds and numerous tanks support wetland biodiversity and add to the countries wetland wealth. It is estimated that freshwater wetlands alone support 20 per cent of the known range of biodiversity in India (Deepa & Ramachandra 1999)

Wetlands in India occupy 58.2 million hectares, including areas under wet paddy cultivation (Directory of Indian Wetlands). Majority of the inland wetlands are directly or indirectly dependent on the major rivers like, Ganga, Bhramaputra, Narmada, Godavari, Krishna, Kaveri, Tapti. They occur in the hot arid regions of Gujarat and Rajasthan, the deltaic regions of the east and west coasts, highlands of central India, wet humid zones of south peninsular India and the Andaman and Nicobar & Lakshwadeep islands.

Indian wetlands are grouped as:

Himalayan wetlands

Ladakh and Zanskar	: Pangong Tso, Tso Morari, Chantau, Noorichan, Chushul and Hanlay marshes
Kashmir Valley	: Dal, Anchar, Wular, Haigam, Malgam, Haukersar and Kranchu lakes
Central Himalayas	: Nainital, Bhimtal and Naukuchital
Eastern Himalayas	: Numerous wetlands in Sikkim, Assam, Arunachal Pradesh, Meghalaya, Nagaland and Manipur, Beels in the Brahmaputra and Barak valley

Indo-Gangetic wetlands

The Indo-Gangetic flood plain is the largest wetland system in India, extending from the river Indus in the west to Brahmaputra in the east. This includes the wetlands of the Himalayan terai and the Indo-Gangetic plains.

Coastal wetlands

The vast intertidal areas, mangroves and lagoons along the 7500 kilometer long coastline in West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, Kerala, Karnataka, Goa, Maharashtra and Gujarat. Mangrove forests of the Sunderbans of West Bengal and the Andaman and Nicobar Islands. Offshore coral reefs of the Gulf of Kutch, Gulf of Mannar, Lakshwadeep and Andaman and Nicobar Islands.

Deccan

A few natural wetlands, but innumerable small and large reservoirs and several water storage tanks in almost every village in the region.

Wetland values

Wetlands provide many services and commodities to humanity. Regional wetlands are integral parts of larger landscapes, their functions and values to the people in these landscapes; depend on both their extent and their location. Each wetland thus is ecologically unique. Wetlands perform numerous valuable functions such as recycle nutrients, purify water, attenuate floods, maintain stream flow, recharge ground water, and also serve in providing drinking water, fish, fodder, fuel, wildlife habitat, control rate of runoff in urban area, buffer shorelines against erosion and recreation to the society. The interaction of man with wetlands during the last few decades has been of concern largely due to the rapid population growth - accompanied by intensified industrial, commercial and residential development further leading to pollution of wetlands by domestic, industrial sewage, and agricultural run-offs as fertilizers, insecticides and feedlot wastes. The fact that wetland values are overlooked has resulted in threat to the source of these benefits.

Wetlands are often described as "kidneys of the landscape" (Mitsch & Gosselink 1986). Hydrologic conditions can directly modify or change chemical and physical properties such as nutrient availability, degree of substrate anoxia, soil salinity, sediment properties and pH. These modifications of the physiochemical environment, in turn, have a direct impact on the biotic response in the wetland (Gosselink & Turner 1978). When hydrologic conditions in wetlands change even slightly, the biota may respond with massive changes in species composition and richness and in ecosystem productivity. Traditional limnological methods of assessment of water quality are time consuming and uneconomical, but using remote-sensing data assessment of water quality and productivity in surface impoundment is both cost effective and fast.

The indicators useful for such an assessment include suspended materials visible to the human eye, which include suspended inorganic material, phytoplankton, organic detritus and dyes.

Diversity of aquatic vegetation and avifauna

Aquatic biodiversity is dependent on hydrologic regime; geological conditions and efforts are being made to conserve the biodiversity found in wetlands, streams and rivers. The goal of this irreplaceable biodiversity is to minimize its loss through sustainable management and conservation practices. The first step in conservation of biodiversity is to assess the diversity of natural resources present and identify those, which are important and most irreplaceable (Groombridge & Jenkins 1998). Awareness of the unique nature of biodiversity, the plethora of factors contributing to decline in habitat quality and species populations has been growing in the past decade.

In India, lakes, rivers and other freshwaters support a large diversity of biota representing almost all taxonomic groups. Algae in open waters represent the floristic diversity and macrophytes dominate the wetlands. It is difficult to analyze the algal diversity in India with reference to different habitats, endemicity to India, as well as the changes that occur due to anthropogenic disturbances. From an ecological point of view, the diversity of species present in the wetlands is an indication of the relative importance of the aquatic biodiversity issue as a whole.

The total numbers of aquatic plant species exceed 1200 and a partial list of animal for aquatic and wetland system is given by Gopal (1995). Wetlands are also important as resting sites for migratory birds. Aquatic vegetation is a valuable source of food, especially for waterfowl. In the winter, migratory waterfowl search the sediment for nutritious seeds, roots and tubers. Resident waterfowl may feed on different species of aquatic vegetation year-round. Avifauna species found in India have been listed by Gopal (1995).

Diversity of fishes

The Indian fish fauna is divided into two classes, viz., Chondrichthyes and Osteichthyes. The Chondrichthyes are represented by 131 species under 67 genera, 28 families and 10 orders in the Indian region (Kar *et al.* 2000). The Indian Osteichthyes are represented by 2,415 species belonging to 902 genera, 226 families and 30 orders, of which, five families, notably the family Parapsilorhynchidae are endemic to India. These small hill stream fishes include a single genus, viz., Parapsilorhynchus that contains 3 species. They occur in the Western Ghats, Satpura mountains and the Bailadila range in Madhya Pradesh only. Further, the fishes of the family Psilorhynchidae with the only genus Psilorhynchus are also endemic to the Indian region. Other fishes endemic to India include the genus Olytra and species *Horaichthys setnai* belonging to the families Olyridae and Horaichthyidae respectively. The latter occur from the Gulf of Kutch to Trivandrum coast. The endemic fish families form 2.21 per cent of the total bony fish families of the Indian region. 223 endemic fish species are found in India, representing 8.75 per cent of the total fish species known from the Indian region and 128 monotypic genera of fishes found in India, representing 13.20 per cent of the genera of fishes known from the Indian region.

Wetland losses – a threat to ecological balance

Wetlands are one of the most threatened habitats of the world. Wetlands in India, as elsewhere are increasingly facing several anthropogenic pressures. Thus, the rapidly expanding human population, large scale changes in land use/landcover, burgeoning development projects and improper use of watersheds have all caused a substantial decline of wetland resources of the country. Significant losses have resulted from its conversion threats from industrial, agricultural and various urban developments. These have led to hydrological perturbations, pollution and their effects. Unsustainable levels of grazing and fishing activities have also resulted in degradation of wetlands.

The current loss rates in India can lead to serious consequences, where 74% of the human population is rural (Anon. 1994) and many of these people are resource dependent. Healthy wetlands are essential in India for sustainable food production and potable water availability for humans and livestock. They are also necessary for the continued existence of India's diverse populations of wildlife and plant species; a large number of endemic species are wetland dependent. Most problems pertaining to India's wetlands are related to human population. India contains 16% of the world's population, and yet constitutes only 2.42%

of the earth's surface. Indian landscape has contained fewer and fewer natural wetlands over time. Restoration of these converted wetlands is quite difficult once these sites are occupied for non-wetland uses. Hence, the demand for wetland products (e.g., water, fish, wood, fiber, medicinal plants etc.) will increase with increase in population. Wetland loss refers to physical loss in the spatial extent or loss in the wetland function. The loss of one km^2 of wetlands in India will have much greater impacts than the loss of one km^2 of wetlands in low population areas of abundant wetlands (Foote Lee *et al.* 1996). The wetland loss in India can be divided into two broad groups namely acute and chronic losses. The filling up of wet areas with soil constitutes acute loss whereas the gradual elimination of forest cover with subsequent erosion and sedimentation of the wetlands over many decades is termed as chronic loss.

Acute wetland losses

Agricultural conversion

In the Indian subcontinent due to rice culture, there has been a loss in the spatial extent of wetlands. Rice farming is a wetland dependent activity and is developed in riparian zones, river deltas and savannah areas. Due to captured precipitation for fishpond aquaculture in the catchment areas and rice-farms occupying areas that are not wetlands, water is deprived to the downstream natural wetlands. Around 1.6 million hectares of freshwater are covered by freshwater fishponds in India. Rice-fields and fishponds come under wetlands, but they rarely function like natural wetlands. Of the estimated 58.2 million hectares of wetlands in India, 40.9 million hectares are under rice cultivation (Anon. 1993).

Direct deforestation in wetlands

Mangrove vegetation are flood and salt tolerant and grow along the coasts and are valued for fish and shellfish, livestock fodder, fuel wood, building materials, local medicine, honey, bees wax and for extracting chemicals for tanning leather (Ahmad 1980). Alternative farming methods and fisheries production has replaced many mangrove areas and continues to pose threats. Eighty percent of India's 4240 km^2 of mangrove forests occur in the Sunderbans and the Andaman and Nicobar Islands (Anon. 1991). But most of the coastal mangroves are under severe pressure due to the economic demand on shrimps. Important ecosystem functions such as buffer zones against storm surges, nursery grounds and escape cover for commercially important fishery are lost. The shrimp farms also caused excessive withdrawal of freshwater and increased pollution load on water like increased lime, organic wastes, pesticides, chemicals and disease causing organisms. The greatest impacts were on the people directly dependent on the mangroves for natural materials, fish proteins and revenue. The ability of wetlands to trap sediments and slow water is reduced.

Hydrologic alteration

Alteration in the hydrology can change the character, functions, values and the appearance of wetlands. The changes in hydrology include either the removal of water from wetlands or raising the land-surface elevation, such that it no longer floods. Canal dredging operations have been conducted in India from 1800s due to which 3044 km^2 of irrigated land has increased to 4550 km^2 in 1990 (Anon. 1994). Initial increase in the crop productivity has given way for reduced fertility and salt accumulations in soil due to irrigated farming of arid soils. India has 32,000 ha of peat-land remaining and drainage of these lands will lead to rapid subsidence of soil surface.

Inundation by dammed reservoirs

Presently, there are more than 1550 large reservoirs covering more than 1.45 million ha and more than 100000 small and medium reservoirs covering 1.1 million ha in India (Gopal 1994). By impounding the water, the hydrology of an area is significantly altered and allows for harnessing moving water as a source of energy. While the benefits of energy are well recognized, it also alters the ecosystem.

Chronic wetland losses

Alteration of upper watersheds

Watershed conditions influence the wetlands. The condition of the land where precipitation falls, collects and runs-off into the soil will influence the character and hydrologic regime of the downstream wetlands. When agriculture, deforestation or overgrazing removes the water-holding capacity of the soil then soil erosion becomes more pronounced. Large areas of India's watershed area are being physically stripped of their vegetation for human use.

Degradation of water quality

Water quality is directly proportional to human population and its various activities. More than 50,000 small and large lakes are polluted to the point of being considered 'dead' (Chopra 1985). The major polluting factors are sewage, industrial pollution and agricultural runoff, which may contain pesticides, fertilisers and herbicides.

Ground water depletion

Draining of wetlands has depleted the ground water recharge. Recent estimate indicates that in rural India, about 6000 villages are without a source for drinking water due to the rapid depletion of ground water.

Introduced species and extinction of native biota

Wetlands in India support around 2400 species and subspecies of birds. But losses in habitat have threatened the diversity of these ecosystems (Mitchell & Gopal 1990). Introduction of exotic species like water hyacinth (*Eichornia crassipes*) and salvinia (*Salvinia molesta*) have threatened the wetlands and clogged the waterways competing with the native vegetation.

In a recent attempt at prioritization of wetlands for conservation, Samant (1999) noted that as many as 700 potential wetlands do not have any data to prioritize. Many of these wetlands are threatened.

Wetland management - current status

Wetlands are not delineated under any specific administrative jurisdiction. The primary responsibility for the management of these ecosystems is in the hands of the Ministry of Environment and Forests. Although some wetlands are protected after the formulation of the Wildlife Protection Act, the others are in grave danger of extinction. Effective coordination between the different ministries, energy, industry, fisheries revenue, agriculture, transport and water resources, is essential for the protection of these ecosystems.

Protection laws and government initiatives

Wetlands conservation in India is indirectly influenced by an array of policy and legislative measures (Parikh & Parikh 1999). Some of the key legislations are given below:
- The Indian Fisheries Act - 1857
- The Indian Forest Act - 1927

- Wildlife (Protection) Act - 1972
- Water (Prevention and Control of Pollution) Act - 1974
- Territorial Water, Continental Shelf, Exclusive Economic Zone and other Marine Zones Act - 1976
- Water (Prevention and Control of Pollution) Act - 1977
- Maritime Zone of India (Regulation and fishing by foreign vessels) Act - 1980
- Forest (Conservation act) – 1980
- Environmental (Protection) Act - 1986
- Coastal Zone Regulation Notification - 1991
- Wildlife (Protection) Amendment Act - 1991
- National Conservation Strategy and Policy Statement on Environment and Development – 1992
- National Policy And Macro level Action Strategy on Biodiversity-1999

India is an also signatory to the Ramsar Convention on Wetlands and the Convention of Biological Diversity. Apart from government regulation, development of better monitoring methods is needed to increase the knowledge of the physical and biological characteristics of each wetland resources, and to gain, from this knowledge, a better understanding of wetland dynamics and their controlling processes. India being one of the mega diverse nations of the world should strive to conserve the ecological character of these ecosystems along with the biodiversity of the flora and fauna associated with these ecosystems.

National wetland strategy

National wetland strategy should encompass (i) Conservation and collaborative management, (ii) Prevention of loss and restoration and (iii) Sustainable management. These include:

Protection

The primary necessity today is to protect the existing wetlands. Of the many wetlands in India only around 68 wetlands are protected. But there are thousands of other wetlands that are biologically and economically important but have no legal status.

Planning, managing and monitoring

Wetlands that come under the Protected area network have management plans but others do

not. It is important for various stakeholders along with the local community and corporate sector to come together for an effective management plan. Active monitoring of these wetland systems over a period of time is essential.

Comprehensive inventory

There has been no comprehensive inventory of all the Indian wetlands despite the efforts by the Ministry of Environment and Forests, Asian Wetland Bureau and World Wide Fund for Nature. The inventory should involve the flora, fauna, and biodiversity along with values. It should take into account the various stakeholders in the community too.

Legislation

Although several laws protect wetlands there is no special legislation pertaining specially to these ecosystems. Environment Impact Assessment needed for major development projects highlighting threats to wetlands need to be formulated.

Coordinated approach

Since wetlands are common property with multi-purpose utility, their protection and management also need to be a common responsibility. An appropriate forum for resolving the conflict on wetland issues has to be set up. It is important for the ministries to allocate sufficient funds towards the conservation of these ecosystems.

Research

There is a necessity for research in the formulation of national strategy to understand the dynamics of these ecosystems. This could be useful for the planners to formulate strategies for the mitigation of pollution. The scientific knowledge will help the planners in understanding the economic values and benefits, which in turn will help in setting priorities and focusing the planning process.

Building awareness

For achieving any sustainable success in the protection of these wetlands, awareness among the general public, educational and corporate institutions must be created. The policy makers, at various levels along with site managers need to be educated. As the country's wetlands are shared, the bi-lateral cooperation in the resource management needs to be enhanced.

Use of remote sensing and GIS in wetland management

Remote sensing data in combination with Geographic Information System (GIS) are effective tools for wetland conservation and management. The application encompasses water resource assessment, hydrologic modeling, flood management, reservoir capacity surveys, assessment and monitoring of the environmental impacts of water resources project and water quality mapping and monitoring (Jonna 1999).

Flood zonation mapping

Satellite data are used for interpretation and delineation of flood-inundated regions, flood-risk zones. Temporal data helps us to obtain correct ground information about the status of ongoing conservation projects. IRS 1C/D WIFS data having 180 km spatial resolution and high temporal repetitiveness has helped in delineating the zonation of flooding areas of large river bodies, thus helping in the preparation of state-wise and basin wise flood inventories.

Inventory and monitoring of irrigation and cropping pattern

Remote-sensing data paves way for economic methodology for inventorying, monitoring and management of water bodies due to improving spatial, spectral and temporal resolution. Satellite data in association with the geographical information systems provides a cost and time-effective tool for identification, mapping, inventorying and monitoring of cropping pattern, crop production and condition, monitoring irrigation status and in the diagnosis of poorly performing irrigation patterns. Indian IRS-1A and 1B satellites data has been used for inventorying irrigation systems, cropping pattern, water logging, tank irrigation, watershed delineation, silting during post monsoon, temporal changes in the water-spread and irrigated area. These inventorying data are used as inputs for formulation of conservation and management plans for development of land and water resources.

Water quality analysis and modeling

Remote sensing data is used for the analysis of water quality parameters and modeling. Water

quality studies have been done carried out using the relationship between reflectance, suspended solid concentration, and chlorophyll-a concentration. In the near infrared wavelength range, the amount of suspended solids content is directly proportional to the reflectance. Due to spatial and temporal resolution of satellite data information of the source of pollution and the point of discharge, inflow of sewage can be regularly monitored.

Using IRS LISS II data (Sasmal & Raju 1996) monitored the suspended load in estuarine waters of Hoogly, West Bengal in a GIS environment. In this study band 4 of the data set was found to show a wider range of digital classes indicating a better response with depth than rest of the bands. Landsat TM and IRS –1A data were used to estimate sediment load in Upper lake, Bhopal (Raju *et al.* 1993). This study showed high relationship between the satellite as well as ground truth radiometric data and total suspended solids. Different image processing algorithms are also used on Landsat MSS dataset to delineate sediment concentration in reservoirs (Jonna *et al.* 1989). Qualitative remote sensing methods have been used for real time monitoring of Inland Water quality (Gitelson *et al.* 1993) Airborne sensor has also been used to study the primary productivity and related parameters of coastal waters and large water bodies (Seshmani *et al.* 1994).

Mapping changes in the river course

Hazra & Bhattacharya (1999) studied the changes in the river course of Ganga - Padma River over space and time to delineate the vulnerable zones for environment management, using visual interpretation techniques to identify and delineate various geomorphological and geological features. The results indicate the river will shift along its course due to natural calamity and in some places due to anthropogenic interferences.

Delineation of extinct river course

Because of its sensitivity to moisture and penetration capabilities in arid regions, satellite remote sensing also helps in displaying anomalies in the terrain that are caused due to the pattern of vegetation/water bodies, sand-dunes, lithology, drainage courses, salt lakes, topography and slopes, natural breaks etc. which help in creating a conceptualized model of the extinct river-course. Hence it proves an effective tool for the study of

the course of ancient Saraswati (Sharma *et al.* 1999) more than any other method.

Water resource management

GIS and remote sensing was used for the development of water resources in Sai-Gad sub-watershed of Almora District, Uttar Pradesh (Mohan *et al.* 2000). Various thematic maps on the hydro-geomorphological characteristics, elevation, slope, drainage, surface water bodies and land-use have been generated and integrated for the action plan for Water Resources Development.

For the evaluation of hydro-geochemical conditions of Niva river basin, Chittoor district in Andhra Pradesh drainage maps of the basin were prepared and the imagery data were interpreted using standard interpretation keys such as colour, tone, texture and pattern of drainage, shape and topography. The results revealed that the underground potential of the basin is moderate to good (Rao 1997).

The drainage pattern of Jharia coalfield, Bihar, India as observed on IRS-1A LISS II image shows that the region is drained by 11 streams, which eventually drain into river Damodar (Srivastava 1997). It is thus helpful in conducting environmental impact assessment.

Use of satellite remote sensing data coupled with aerial photo-interpretation greatly aid in planning ground water exploration and help in locating the sources by identification of geomorphological units. Air-borne and space-borne data were used for the qualitative evaluation of ground water resources in Keonjhar district, Orissa (Das *et al.* 1997). The study revealed the importance of hydrogeomorphological mapping from remotely sensed data in groundwater targeting in the structurally complex terrain of the district. Resistivity soundings and exploratory digging further corroborated the study.

Remote sensing, geophysical, DBTM (Digital Basement Terrain Model) and GIS (Geographic Information System) were used for sustainable utilisation of water resources of Alaunja watershed, located in 'Chotanagpur' plateau of Bihar (Kumar 1999). The study helped in the prioritization of water resource development in the watershed i.e., delineation of the area suitable for groundwater/surface water utilisation.

With the development of highly precise remote sensing techniques in spatial resolution and GIS,

the modeling of watershed has become more physically based and distributed to enumerate interactive hydrological processes considering spatial heterogeneity. A distributed model with SCS curve number method called as Land Use Change (LUC) model was developed (Mohan & Shresta 2000) to assess the hydrological changes due to land use modification. The model developed was applied to Bagmati river catchment in Kathmandu valley basin, Nepal. The study clearly demonstrated that integration of remote sensing, GIS and spatially distributed model provides a powerful tool for assessment of the hydrological changes due to land-use modifications.

Habitat mapping using microwave remote sensing

Microwave remote sensing tools have an important role to play in applications relating to wetland monitoring and mapping. In optical remote sensing, the visible and infrared part of the electromagnetic spectrum is made use of to characterize objects of interest. However, during monsoon season, the suitable atmospheric windows for acquisition of optical data are limited to cloud free period. This is a major lacuna for wetland applications as wetlands are highly seasonal and dynamic systems compared to terrestrial ecosystems. The radar imaging system overcome many of these limitations by providing increased canopy penetrations and day and night acquisitions nearly independent of weather conditions (Ramsey 1995; Ramsey & Laine 1997). It is, therefore, imperative to use radar data for a better understanding of the dynamics of wetland ecosystems as also their assessment, monitoring and management. There are also several advantages using microwave data. Microwave sensors have unique sensitivity towards the moisture content of earth material. They are also highly sensitive to textural properties of vegetative cover. Therefore, they can be used to discriminate grasses, aquatic vegetation, forest and crop cover. In this way the surrounding people can use them to identify the encroachment inside a national park for agricultural activities.

Identification of different habitat is also an important activity for wetland monitoring and management. Studies indicate that Synthetic aperture Radar data is far superior to optical satellite data in delineation of open water, habitat and aquatic vegetation. Though radar remote sensing can play an important role in wetlands but so far very little work has been carried out and there is huge potential to explore and exploit the different capabilities of radar data for wetland research. High incidence angle radar data has been used to delineate the open water habitat with aquatic vegetation critical for waterfowl in wetlands The study of Keoladeo Ghana National park in Bharatpur has shown that radar data is 3 to 4 times better in delineating extent of open water, aquatic vegetation categories and also localities of high soil moisture content (Srivastava *et al.* 2001). This information will be of great significance in formulating Habitat Suitability Index (HSI) models for a variety of faunal species.

The interconnectivity of wetlands

The interconnectivity of wetlands and changes in it over a period of time were documented for large areas of Bangalore urban and rural districts by Deepa & Ramachandra (1999). From a landscape perspective, it is vital that studies on interconnectivity are given emphasis. The results are of crucial significance in designing conservation preserves of wetlands.

Wetland mapping – a status review

Wetlands play a vital role in maintaining the overall cultural, economic and ecological health of the ecosystem, their fast pace of disappearance from the landscape is of great concern. The Wildlife Protection Act protects few of the ecologically sensitive regions whereas several wetlands are becoming an easy target for anthropogenic exploitation. Survey of 147 major sites across various agro climatic zones identified the anthropogenic interference as the main cause of wetland degradation (The Directory of Indian Wetlands 1993). Current spatial spread of wetlands under various categories is shown. (Table 1) (Parikh & Parikh 1999).

The National wetland committee of the Ministry of Environment and Forests (MoEnF), Govt. of India has recommended a number of proactive steps. Accordingly, twenty-two sites were declared tentatively as wetlands of National and International significance for long term conservation. The committee recommended a nation wide inventory of wetlands to be undertaken under the guidance of National wetland committee with the support of

Table 1. Extent of wetlands in India (Parikh & Parikh 1999).

Wetlands in India	Area (million ha)
Area under wet paddy cultivation	40.9
Area suitable for fish culture	3.6
Area under capture fisheries	2.9
Mangroves	0.4
Estuaries	3.9
Backwaters	3.5
Impoundments	3.0
Total area	58.2

the Standing Committee on Bioresources (SC-B) of the National Natural Resource Management system (NNRMS) and MoEF. The Space Application Center (SAC) Ahmedabad, of the Indian Space Research Organization (ISRO) had undertaken, in collaboration with various state remote sensing application centers, a nation wide mapping of Inland wetlands. This was done on a reconnaissance scale and was completed in 1997. The study recommended mapping at larger spatial scale as wetlands below 56 ha in size could not be delineated.

The Space Application Center (SAC) has mapped the wetlands at 1:250000 scale in the mainland as well the islands using the visual interpretation of coarse resolution satellite data. The states of Sikkim, West Bengal, Goa Punjab, Haryana, Himachal Pradesh, Chandigarh, Delhi, Andaman, Nicobar, Lakshwadeep, Dadra and Nagerhaveli were mapped at 1:50000 scale. However, in the rest of the country, only wetlands of 56.25 ha and above in size could be mapped (Table 2). It is known that a vast majority of wetlands-often in number, extent and conservation importance is below 50 ha in size (For example, those in the Indo-gangetic plains and in the Deccan peninsula). Thus, the inventory covered only a small number of wetlands: more over, the conservation values are not known for those wetlands even whose inventory has now been obtained. The data merely indicates location of wetlands, the classification of wetlands on 1:250,000 scale is moreover, only geomorphologic in nature (such as Oxbow lakes, Playas, Lakes and Ponds etc.) and has no other factual biological conservation value. By itself, the information will only be partly useful for conservation of wetlands. This estimate is likely to be twice

if we include wetlands of size 50 ha or less (Das *et al*. 1994 for Etwah and Mainpuri districts of U.P.).

Requirement and information needs for wetland mapping

Past research on wetland conservation in the country has shown conclusively that micro wet-

Table 2. Extent of inland wetlands.

State	Wetland area (ha)
1:250,000 Scale	
Andhra Pradesh	366609
Bihar	177683
Gujarat	209206
Jammu & Kashmir	406780
Karnataka	254015
Kerala	34200
Madhya Pradesh	294118
Maharashtra	284942
Orissa	162774
Rajasthan	344964
Tamil Nadu	161521
Uttar Pradesh	328690
Pondicherry	59
1:50,000 Scale	
Arunachal Pradesh	56325
Assam	101232
Delhi	4717
Goa	2145
Haryana	27057
Himachal Pradesh	54766
Manipur	52959
Meghalaya	2222
Mizoram	152
Nagaland	918
Punjab & Chandigarh	71879
Sikkim	1985
Tripura	9896
West Bengal	143859
Andaman & Nicobar Islands	3204
Daman Diu & Nagar Haveli	38
Lakshadweep	918
Total	3558915

lands or satellite wetlands around a bigger wetland act as a constellation of habitat mosaic for resident and migratory waterfowl (Vijayan 1991). This is of special importance for inland wetland habitats in the flyways of migratory birds in the Indo-Gangetic plains and in Deccan peninsula. Often, the size of these micro wetlands is much smaller than 50 ha. Therefore, there is a great need to map wetlands of size smaller than 50 ha.

Thus, the objective is to develop an inland wetland inventory for the entire country. This will be carried out by means of available data and by also fresh data generation using modern spatial technologies. Thus by using digital remote sensing data for wetland mapping and analysis, information at any scale of all Wetlands will be available according to the management and conservation requirements. Realizing the importance of wetlands, the Ramsar convention in 1971 has urged the member countries to designate noted wetlands as Ramsar sites or wetlands of International Significance.

Many conservationists (e.g. Choudhury 2000) have recognized this and a wetland conservation strategy should therefore have an extensive bias of participatory process. A hierarchical watershed based approach will have a positive impact in not only reversing the chronic cases of wetland resource depletion but also help design a network of wetland conservation preserves. These preserves would strive to not only conserve precious aquatic biodiversity but also help serve as refuge for important economically useful wild plants and animal genetic resources.

Ongoing programme of wetland conservation

It is with this goal, the programme aims at developing:

a) a user friendly and cost effective process of wetland mapping from a biodiversity conservation perspective.

b) an inland wetland information system encompassing *inter alia* socioeconomic data on wetlands and ecological, ornithological and other biodiversity values and

c) establishment of a basis and framework for effective national, regional and sub-regional monitoring of wetlands using satellite data and other spatial information as well as ancillary data.

The programme output is expected to aid in evolving a National Inland Wetland Conservation Strategy. The strategy includes policy, administrative and monitoring measures.

Classification scheme of inland wetlands

Classification scheme proposed by Gopal (1994) on Inland wetlands in the Indian subcontinent is a mix of hydrological and biological (aquatic plants diversity) factors. However, from a practical conservation planning perspective, the immediate need of the hour is to produce a reasonably detailed classification based on a mix of habitats and aquatic vegetation. The merits of such a classification lies mainly in its utility to be used by both managers and academicians. Such a scheme is possible with extensive state of art spatial technologies and a carefully chosen field information and data. The current sensor resolution of course would permit aquatic vegetation classification at species assemblages level, if not at species level. However, for the reasons of wider usage and lower costs, it is nevertheless possible to use the 20 m resolution sensors of IRS series of Indian remote sensing satellites. Hence the modified classification system (Table 3) should be adopted for classification of inland wetlands using remote sensing data.

Table 3. Proposed classification of inland wetlands in the Indian subcontinent.

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1. Forest
   A. Dense
   B. Open
1. Arable
2. Wasteland
3. Wetland
   A. Ponds/Tanks/Lakes
   B. Reservoirs
   C. Waterlogged
   D. Oxbow lakes / Cutoff
      (a) Turbidity Low
      (b) Turbidity Medium
      (c) Turbidity High
          i. Aquatic vegetation poor coverage
          ii. Aquatic vegetation moderate coverage
          iii. Aquatic vegetation high coverage
4. Roads
5. Major Habitation

A proposed methodology

For classification of Inland wetlands using remote sensing techniques, Band 4 of IRS 1C LISS III image data is to be density sliced for the separation of water bodies. The threshold values for water mask are to be obtained interactively. A bit map is to be generated for the water bodies. This mask will be used for further classification of water bodies into turbidity pattern and aquatic vegetation. Although, the density slicing of band 4 provides acceptable results in most of the cases, it may sometime, lead to confusions with non-water classes. Major class of confusion is the shadow due to terrain. Such anomalies can be removed through stratified density slicing and through contextual refinements.

Normalized Difference Vegetation Index (NDVI) that minimizes effect of the shadow can also be used for separation of water bodies, as the wetland areas fall in lower NDVI zone, than terrestrial vegetation. However, NDVI may also exhibit confusing results as many other non-vegetated classes like snow, barren, land etc. may exhibit the NDVI values comparable to water body. However, an interactive integration of band 4 and NDVI will clearly separate water bodies.

Turbidity patterns

Turbidity patterns are best reflected by the band 1of IRS 1C, LISS III image data. Higher the DN value in band 1, higher is the turbidity. The turbidity classification is a subjective one as it is impractical to relate the quantitative values for turbidity (which are dynamic according to the season) with the reflectance. Thus, determination of the threshold for different turbidity levels needs to be carried out by examining the major (large sized) water bodies in the area.

Aquatic vegetation

Aquatic vegetation need to be classified within the water body mask that is generated using band 4 of IRS LISS III data. The Normalised Differential Vegetation Index (NDVI) {generated as: (IR-)/(IR+R) where, IR is DN value in Band 3 and R is DN value in band 2 of IRS 1C LISS III is to be obtained for water bodies. The NDVI values are subjectively divided into vegeta-tion levels i.e. nil, poor, moderate and high vegetation coverage.

After country wide mapping of inland wetlands, some selected wetlands of each state which are prioritized due to their biodiversity values are to be considered for detail mapping on 1:50,000 scale.

Conclusion

It is noteworthy that even a small country like UK could designate 161 wetlands as Ramsar sites, India being a mega-diversity country, so far managed to delineate a mere six sites till date. There is obviously much ground to be covered in our conservation efforts of wetlands. In addition, a paradigm shift in conservation ethic is also a strong need of the hour. This shift is necessary and perhaps mandatory due to the very nature of resource being conserved and 'protected'. Since wetlands are a common property resource, it is an uphill task to protect or conserve the ecosystems unless; the principal stakeholders are involved in the process. The dynamic nature of wetlands necessitates the widespread and consistent use of satellite based remote sensors and low cost, affordable GIS tools for effective management and monitoring.

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