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Research Article

A multi-scale geospatial study of wetlands distribution and agricultural zones, and the case of India.

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Abstract
This paper highlights the global and the regional scale representation of wetlands ecosystems using geospatial tools and multiple data sets. At global scale, the Ramsar database is investigated for representation of the wetlands sites of international importance against the "global agricultural zones" derived from the thematic aggregation of Global Irrigated Area Map databases. The analysis of "Ramsar sites" under cultivation reflects the present trend in wetlands use for agriculture. The scenario is also compared with the historical pattern derived from Vavilov's food zones of 1926. Observed is an aggregate increase in cropped wetlands area from 25% (1926) to 43% (2006). The second component develops a regional partnership with Salim Ali Centre for Ornithology and Natural History in India. The partnership reviews the thematic national database of inland wetlands and "priority wetlands habitats" (PWH) in comparison with the bio-geographic and agro-ecological factors (regions/sub-regions) and by means of geographical information system (GIS) tools. We elaborate the strength of spatial tools to better understand the relationship between wetlands distribution and agricultural zones, both historically and at the present time. The disseminated message states, though from a technical perspective, the understanding of scale and resolution in combining information from diverse sources is essential; the effective implementation of spatial analysis requires a true cross-disciplinary approach. Complementing that, relevant policy support and appropriate institutional arrangements are fundamental to advance the management work required for unification of wetlands conservation with the existing challenges of food and livelihood security.

Keywords: Ramsar sites, global, wetlands, India, geospatial

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Introduction

Wetlands are ecological systems where the recent attention has shifted from "conversion and conservation" to "wise use and sustainable management." Globally, the non-availability of adequate and up-to-date information about wetlands is one of the main limitations for their sustainable management. The situation is of particularly high concern in Asia and the Neotropics [1]. The Ramsar Convention (www.**ramsar**.org) has played a key role in documenting the available information on wetlands from different geo-political regions and in promoting the culture of defining wetlands of international importance, commonly referred as "Ramsar sites" [2]. Traditionally, wetlands management received limited attention, and primarily for bird habitat [3, 4]. In alignment with the Ramsar vision to create sustainable wetlands systems, the Millennium Ecosystem Assessment [5] emphasized the role of wetlands for the provision of fresh water and food [6].

The International Water Management Institute (IWMI) initiated a Global Wetlands Inventory and Mapping (GWIM) project with an overarching goal to derive global wetlands maps, classify wetlands types, study their characteristics through local and regional partnerships, and support their management planning process and policy action [7]. We discuss a multiple-level (scale) GIS analysis to explain the relevance of wetlands for humans and their relationship with agricultural systems and biodiversity both at global and regional scales.

At a global scale the distribution of Ramsar sites was examined with a broad focus on the "representation" of wetlands primarily used for crop production. The regional (national for India) analysis adeptly captured the representation both for Ramsar sites and priority wetlands habitats (PWH). The partnership with SACON, an organization in India involved in wetlands conservation and management, and which participated in the creation of an inland wetlands spatial database at regional scale in 2004 under a UNDP project [8], was critical to integrate the perspective of a national-level stakeholder.

Wetlands management in India has long focused on water birds. Evidence of this can be traced to 1898, when India's first sanctuary for "waterfowl" was established in Tamil Nadu. Continuing with this trend, the National Wildlife Information System (NWIS) in India declared 611 protected areas, including 96 national parks, 510 wildlife sanctuaries, 3 conservation reserves, and 2 community reserves, covering a total of 156,728.52 km^2 (about 5%) of the country's geographical area (http://www.wii.gov.in/nwdc/). This territory is partially wetlands. India signed the Ramsar Convention in 1981 and has declared 25 Ramsar sites to date. In line with obligations under the Convention, the recent compilation of an inland wetlands inventory by SACON provides multi-thematic information on prospective sites requiring prioritization, referred to as "Priority Wetlands Habitats" (PWHs) [8].

From the Indian context, the national report submitted to the Ramsar Convention by SACON acknowledged 199 wetlands (PWHs) defined during the inland wetlands inventory and assessment project. These fulfill more than one criterion for inclusion as a site of international importance, even though the MoEF (Ministry of Environment and Forest-Government of India, the regulatory body for wetlands management) did not confer with the provincial authorities with any appropriate degree of seriousness on the subject. India's wetlands suffer more than other ecosystems [9].

Given the threatened status of many wetlands sites, and the increasing pressure for food production due to increased global population, it would seem that a critical information base for decision-making must include estimates of changes in wetlands, derived by combining multiple data on wetlands, agricultural land use, historical agricultural development, and biodiversity. We hypothesized that integration of multi-thematic information in a geospatial medium facilitates understanding of historical trends and the current situation in the context of decision-making for resource-management. In addition, GIS helps

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identify and fill gaps in the existing management frameworks that traditionally are based on field surveys, and do not necessarily cover or represent the entire region. In addition, limitations in the geospatial analysis in terms of nature, quality, scale, and resolution of the data, and the interpretation and its implications, are also discussed.

Methods

Data Overview

The present analysis primarily relies on the combination of multiple spatial data types (polygons, points, etc.), at differing scales, digitized/derived/created from different sources, while the methodology comprises simple data over-layering in the GIS (Arc-GIS) medium. In this section, we discuss the data sources and the challenges that may arise while combining data with inherent incompatibilities, as well as how we addressed these problems and what possible effect this may have had on the derived information.

In terms of the data availability at global scale, the geographical point database for the global network of Ramsar sites was publicly accessible and represented layered coverage of global wetlands (1675 wetlands, 155 member countries, and 150.2 million hectares as of August, 2007). To examine the past global scenario, Ramsar sites are evaluated in relation to the global food production zones defined by Vavilov in 1926 [10] and the global biological diversity regions [11]. Additionally, GIAM (aggregated raster maps at 10km-1km-500m) [12] and the Ramsar sites database were integrated to synthesize thematic spatial layers for the global irrigated and rain-fed agricultural regions. Regional analysis looked into representation of Ramsar sites and PWHs in the bio-geographic [13] and agro-ecological regions/sub-regions [14] of India. The data details are listed in Appendix 1.

I) The Ramsar Sites Database (RSDB) contains information on wetlands designated as internationally important or as Ramsar sites under the Wetlands Convention (The Ramsar Convention, 1971). It's a searchable database, fully accessible through the Internet, with an unprotected reporting system for public use, including information on wetlands types, land uses, threats, and hydrological values. The geographical coordinates in the database were used to create a point vector layer, in the absence of information on extent. The Ramsar sites' global vector layer (point data coverage) was projected on the global boundary layer from the Global Administrative Unit Layers (GAUL). Metadata information from the database is available at http://ramsar.wetlands.org/. The detail of Ramsar sites from India is listed in Appendix 2.

II) Vavilov's food centers describe the origin of cultivated plants, reflecting the theory on genesis of crops and the primary "center of diversity" or "center of origin" in 1926. Eight such zones are recognized primarily as regions where major crops were domesticated: (1) China; (2) India; (3) Turkey /Iran; (4) Southeast Asia; (5) Near East, Mediterranean Sea, and adjacent regions; (6) Ethiopia; (7) Southern Mexico and Central America; (8) Northeastern South America, Bolivia, Ecuador, and Peru (zones characterized by high genetic diversity). The historical information was digitized, scaled, and geo-referenced to align with the GIS analysis.

III) Biological Richness Centers refers to the mega-diversity countries and hot spots of biodiversity at a global scale as defined by Mittermeier (1988). Commonly referred as "zones of global biodiversity," these include (1) hot spots; (2) conservation priority areas; (3) mega-diversity countries; (4) mega-diversity countries with conservation prioritization, and (5) other areas. The historical information (printed map) was scanned, digitized, and converted to a thematic vector layer with a UTM projection and scaled at 1: 50,000.

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IV) The Global Irrigated Area Mapping (GIAM-www.iwmigiam.org) project by IWMI generated a set of aggregated (reclassified or grouped) and disaggregated (non-grouped) raster products with focus on the global distribution of irrigated/rain-fed areas (raster format), originally delineated at 10 km resolution. The data was re-clustered to eight wetlands-based agriculture zones, in order to extract spatial information on cultivated wetlands (irrigated and rain-fed) at the global level. The intermediary product from GIAM, such as the Global Map of Rain-Fed Cropland Areas (GMRCA) and the Global Map of Land Use Land Cover (GMLULC), each with resolution of 10 km, was available to complement the information on extracted wetlands agriculture zones (Table 1).

Table 1. Wetlands- based agriculture zones derived using thematic information from GIAM.

Agricultural zone	Majors crops	Other remarks
Purely rain-fed croplands	Rice, wheat, corn, soybeans, and cotton	Formed by merging three main categories, i.e., rice and wheat dominant, rice, wheat and corn dominant, and regions with rice, wheat, soybean, cotton, and corn.
Rain-fed croplands mixed with natural vegetation	Different crops including above interspersed with natural vegetation types (mixed pixels)	This zone was derived by merging the rain-fed cropland layer along with woodlands, fallow land, grasslands, mixed savannas, forests, and wetlands.
Irrigated croplands	Rice, wheat, corn, cotton, sugar cane, soybeans, pasture, plantations	Area covered under all types of irrigation: surface water, groundwater, conjunctive and multiple cropping patterns such as single, double, and continuous crop.
Other areas	Non-cultivated	Natural vegetation, forests.

V) Agro-ecological regions/sub-regions of India: The National Agricultural Research Project (NARP) in 1992, along with the National Bureau of Soil Survey and Land use Planning (NBSS LUP), defined these zones at the national level, taking into account physiographic, climate (rainfall and potential water surplus/deficit), soils, and agricultural factors. Sub-regional information on different lengths of growing periods (LGP) was integrated with soil criteria (depth, texture, and average water content), bio-climate and cropping patterns, and the moisture adequacy index (IMA). The country includes 20 agro-ecological regions (AERs) and 60 sub-regions (AESRs), largely based on development and sustainable use of natural resources. For use in the present study, a hard-copy map print (scale: 1: 50,000) was procured from the Soil Bureau in India, scanned, digitized, and projected to UTM.

VI) SACON's national inland wetlands database is part of its Environmental Information System (ENVIS) program on wetlands ecosystems. The spatial database (combination of raster and vector layers for different administrative scales) is created using a spectrum of earth observation data (Landsat and IRS LISS series) and largely prepared at district level (an administrative division directly below the state/provincial level), spanning a few hundred to a few thousand sq km. Along with raster attributes, information such as avifaunal diversity, wetlands size, ecosystems service profile, and socioeconomic data defined the vector attributes for 199 PWHs. The vector coverage from SACON was re-projected to

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UTM and scaled at 1: 50,000 for superimposition with other vector layers. The theory behind data preparation and defining PWHs is accessible at www.wetlandsofindia.org.

VII) Bio-geographic regions of India [13] are derived based on attributes such as natural ecological demarcation, physiography, geographical location, vegetative cover, geological features, and soil characteristics. The 10 regions are: (1)Trans-Himalaya, (2) Deccan Peninsula, (3) Semi-arid, (4) Gangetic plain, (5) Desert, (6) Himalaya, (7) Western Ghats, (8) Northeast India, (9) Coasts, and (10) Islands. The vector layer was procured from the Wildlife Institute of India and was scaled and re-projected for geospatial synchronization.

For global analysis, the wetlands representation at the early stages of the cultivation era was illustrated using Vavilov's historical data set, while the biodiversity study used Mittermeier's zones. At the regional level, Ramsar sites were investigated in comparison with the environmental zones (bio-geographic and agro-ecological) defined at the national level for conservation, planning, and development. A similar approach was adopted to determine the representation of PWHs.

It is important to note here that GIAM datasets were originally not derived for wetlands-related analysis; however, the derived outputs reflected the potential for wetlands study. Using spatial attributes from the Global Map of Rain-Fed Cropland Areas (GMRCA) and the Global Irrigated Area Map (GIAM), comprehensive thematic information for global cultivated wetlands (mainly the rice-predominant areas) was delineated. Reclassification, vectorization, and subsequent collation of information both from GIAM and GMRCA helped derive a thematic layer of interest, i.e., "global wetlands agricultural zones" defined in four classes: (1) irrigated croplands, (2) purely rain-fed croplands, (3) rain-fed croplands mixed with natural vegetation, and (4) other areas, as explained in Table 1.

Results

Global analysis

With re-configured GIAM and GMRCA layers as a backdrop, the study shows potential to illustrate the representation of cultivated wetlands in recent times. Of the sites, 57% fall under non-cultivated wetlands (water bodies such as lakes, swamps, and marshes), while 37% of the cultivated wetlands sites are characterized as rain-fed croplands mixed with natural vegetation and markedly reflecting the seasonal use of wetlands for cultivation. A smaller fraction, 6%, is perpetual agricultural lands (Appendix 3 and Table 2). Synoptically, nearly 43% of the Ramsar sites contribute to agriculture production; explaining the contribution of these systems towards the food production statistics.

Table 2B describes about 25% of Ramsar sites overlaid with Vavilov's food centers. The Mediterranean represents 155 sites (10%), and Central America, the Andes, and China add other 10%. This presumably indicates a contribution of wetlands ecosystems for crop production in past years, considering Ramsar sites as a proxy indicator of major wetlands areas worldwide. Surprisingly, Southeast Asia, India, Ethiopia, and Turkey represent a minor fraction (Appendix 4). Similarly, the role of wetlands as a biodiversity-rich area is illustrated by 13% overlap with mega-diversity countries (South and Southeast Asia, Central America, Australia, and part of Central Africa), while 28 sites are represented as biodiversity hot spots (Table 2 and Appendix 5).

While the above analysis is based on historical records translated to fit the GIS frame, the GIAM analysis reflects the present scenario. For GIAM layers, the information is derived to scale and projection. These layers are often used as "reference" data to fix the scale and projection of other raster and vector data sets. The challenging task was to achieve reasonable synchrony among data sets derived from varied sources and joined to a common objective.

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Table 2. Distribution of Ramsar sites in irrigated and rain-fed agricultural zones

Regions	Number of Ramsar sites	Percent
(A) Agricultural Zones from GIAM		
Irrigated croplands	100	6
Purely rain-fed croplands	6	0.4
Rain-fed croplands mixed with natural vegetation	608	36.5
Other areas (non-cultivated)	950	57.1
(B) Vavilov's centers of crop origin		
Andes/Brazil/Paraguay	42	2.5
China	42	2.5
Ethiopia	1	0.1
India	18	1.1
Mediterranean	155	9.3
Mexico/Central America	89	5.4
Southeast Asia	26	1.6
Turkey/Iran	28	1.7
Outside Vavilov's centers	1262	75.9
(C) Biological richness areas		
Conservation priority areas	4	0.2
Hot spots	28	1.7
Mega-diversity countries	182	10.9
Mega-diversity countries and conservation priorities	3	0.2
Other areas	1446	87

Regional Analysis

Analysis of Ramsar wetlands depicts 64% representation from freshwater inland systems that include lakes, springs, reservoirs, and river catchments, while the coastal/marine sites represent another 36%. We also note that nearly 64% of the Ramsar sites in India are under national protection in such zones as national parks, wetlands reserves, and bird sanctuaries. The remaining sites are unattended or managed by the local/provincial authorities (Appendix 2).

It is observed that the "semi-arid" bio-geographic zone contributes 7 (about 30%) of the total 25 Ramsar sites (Table 3). Two zones – deserts and islands – have no representation in the Ramsar list. The "Himalayan" region adds four sites, primarily high-altitude, freshwater wetlands, while "coastal" zones add another five sites. Thus nearly 65% of the list comes from three of the 10 bio-geographic regions. The other regions – for example the Northeast, Gangetic plains, Western Ghats, Deccan peninsula, and the Trans-Himalayas – contribute profoundly to local agriculture and biological diversity, yet are thinly represented in the international list (Appendix 6).

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At the national level, of the total 28 administrative (provincial) states and seven union territories in India, 14 of them contain at least one Ramsar site. The agro-ecological representation further exemplifies this observation. Ramsar wetlands overlaid on the AER reflect the wetlands-agriculture interaction in the northern plains, western Himalayas, and the eastern and western coastal plains, which together contribute 15 (60%) of the sites (Appendix 6 and Table 3). The Karnataka plateau, central highlands, eastern Himalayas, and the Andaman and Nicobar islands are represented only inconspicuously. It was observed that the western Himalayas, with five sub-agro-ecological regions, contribute six Ramsar sites, significantly capturing the agricultural and ecological diversity in the region.

Table 3. Wetlands representation in bio-geographic regions at regional/national scale. Ramsar sites and the prioritized wetlands habitat of India are represented in the bio-geographic regions.

Bio-geographic region	Region Description	Area (Million Hectare)	Area (%)	No. of Ramsar sites	PWHs (Priority Wetlands Habitats)
Deccan Peninsula	Covers the Aravalli hills and the deciduous zones in Madhya Pradesh, Orissa and Maharashtra	138.50	41.9	1	55
Semi-arid	Close to the desert ecosystem in the west	54.36	16.4	7	38
Gangetic plain	Ganges basin known for its flood plains, wetlands, and marshes	34.76	10.5	1	37
Desert	Arid region west of Aravalli hills	22.07	6.7	0	2
Himalaya	Spreads west to east India covering diverse cold biomes and habitat	21.34	6.5	4	17
Trans-Himalaya	Cold desert area with many high altitude lakes; includes the Tibetan plateau	18.61	5.6	2	2
North-East	One of the hot spots for floral and faunal diversity	17.60	5.3	3	34
Western Ghats	Extends along the west coast covering two hot spots of biodiversity	13.31	4.0	2	5
Coasts	Coastal units and the associated landscape	8.18	2.5	5	9
Islands	Includes the Andaman and Nicobar group with their rich tropical vegetation	2.11	0.6	0	0
Total		**330.84**		**25**	**199**

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In terms of representation analysis for PWHs, we observed that four bio-geographic zones – the Deccan peninsula, Semi-arid region, Gangetic plain, and the Northeast region – represent 82% of the total PWH sites. PWHs are defined with reference to their ecological and socio-economic benefits at the national level, and are also significantly relevant for conservation and the planning process. In all, the distribution of PWHs in the bio-geographic zones appears somewhat fragmented. The Himalayan region is moderately represented with 17 (9%) sites, and the Western Ghats and Coasts are represented feebly (7%). Deserts and islands have little or no representation as priority wetlands habitats. In short, the heterogeneity in the wetlands systems across the sub-continent is captured convincingly, yet gaps exist in representation of significant regions such as desert and islands.

The distribution of PWHs in AERs and AESRs looked reasonable and uniform. Regions such as the Northeastern zone of Assam and Bengal, Northern plains, Deccan plateau, and Eastern Ghats are well represented. On the contrary, the cold-arid zone of the western Himalayas, Karnataka plateau, Western Ghats, Eastern coast and plains, and the islands are thinly represented (5%). Each agro-ecological zone is broadly classified into sub-regions based on diversity in ecological and agrarian variables; however, it is interesting to note that the AERs with defined sub-regions have a good representation of PWHs, while the homogenous regions display the reverse (Table 4).

Table 4: Wetlands representation in the agro-ecological regions at regional/national scale [*Ramsar sites and Priority Wetlands Habitats across the agro-ecological regions of India].*

Agro Ecological regions	Number of sub-regions	No. of Ramsar sites	Priority Wetlands Habitats
Western Himalayas/ cold arid	2	1	1
Western plain	4	1	9
Karnataka plateau	1	-	-
Northern plain	4	3	18
Central highlands	3	-	18
Deccan plateau	4		15
Deccan plateau and Eastern Ghats	3	1	15
Eastern Ghats	3	-	19
Northern plain	2	2	15
Central highlands	3	1	4
Chhattisgarh/ Mahanadi basin	1	-	1
Eastern plateau	3	-	7
Eastern plain	2	-	2
Western Himalayas/ warm sub-humid	5	6	9
Assam and Bengal plain	4	2	36
Eastern Himalayas	3	-	11
North-Eastern hills	2	2	12
Eastern coastal plain	5	3	4
Western Ghats and coastal plain	3	3	2
Islands	2	-	-
Total number of agro-ecological regions : 20	60	**25**	**199**

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Discussion

This study clearly reflects the usefulness of GIS tools to study the distribution, extent, and status of wetlands based on strings of information from varied sources, both from historic and present times. With the objective of understanding multi-scale representation of wetlands, we conclude that updated information on state-of-the-art wetlands inventory and assessment, and appropriately defined criteria for local and regional prioritization, are pertinent to prevailing concerns about the future of wetlands ecosystems.

Ramsar sites analyzed with respect to Vavilov's food centers present an overview of wetlands system use for crop production since the 1920s, while overlaying with biological richness zones reflects their significance for biodiversity. The global analysis of the Ramsar sites with rain-fed and irrigated agriculture layers shows 714 sites (equal to 43% of the total) characterized as under the cultivated zone, while 36.5% of wetlands sites are represented under the mixed-cropland zone. In summary, we conclude that in the past the wetlands ecosystems represented well both the agriculture and the biodiversity sectors. The expansion of the agrarian system to meet the food demands of the burgeoning global population has impacted on wetlands with many being converted to agricultural production and assumedly increasing the contribution of wetlands ecosystems to overall food production and livelihood dependence.

To complement options for wetlands restoration programs at the national level, the regional analysis identifies the gaps in representation of PWHs by calibrating the geospatial environment. The overall analysis adds to the understanding of the gaps in representation and the status of conservation of wetlands ecosystems, while illustrating the potential and constraints of scaling the use of wetlands systems for enhanced food (agriculture/aquaculture) production. (Our focus, however, was on crop, primarily rice, production.)

We acknowledge that the study is based on certain assumptions and proxy indicators. We had to consider the unavailability of reference data on development trends in traditionally neglected resource systems such as wetlands, especially for the global-scale analysis; therefore, we relied on the estimates derived from available data on wetlands, agricultural land use, historical agricultural development, and biodiversity, and the use of simple digitization and overlay techniques. The geographical information embedded in Ramsar data and ENVIS wetlands maps are comprehensive in their identification of wetlands size, location, and distribution. In both case we took the thematic information as point location to analyze the aforementioned (Vavilov's food zones [10] and Mittermeier's biodiversity regions [11]) wetlands attributes, both in actual and in historical times. The multiple spatial data types (polygons, points, etc.) were originally collected from differing sources, digitized, and scaled by the authors to fit the frame of the research objective. The issue of inconsistencies was a challenge faced by the researchers during the course of the study, and this may have had an impact on the results in terms of "near" estimation rather than "real" estimation.

The study is relevant to bettering global understanding of wetlands uses and services. For national policy on wetlands conversion or conservation, evaluation of the Ramsar sites and PWHs in India depicts the strengths and gaps in that country's existing wetlands representation. This could also be a starting point for addressing local issues within international interests (relative to the Ramsar Convention) and for propagating the Convention's "wise use" theory. The conclusion points toward the need of detailed understanding of the "inter-reliance" between various resource systems (forests-wetlands-cultivated zones) promoted through inter-disciplinary assignments. While it is likely that similar exercises are broadly replicable for other resource systems such as forests and water bodies, the data requirements for the representation analysis can be expected to vary.

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Implications for conservation

The study provides pertinent information to enlarge the information base on the status and trends in multiple use of wetlands at global and regional scales. The geospatial analysis facilitates understanding of wetlands in a broader perspective and explains the contribution and representation of wetlands in the agro-biological spectrum. The importance of ecosystem services and benefits for livelihood support systems (croplands) for millions of poor and marginalized people is evident from many recent studies [5]. Conversely, the trade-offs between conservation and development interventions in wetlands systems have not been sufficiently investigated [15].

To fill that gap, it is important to attain up-to-date and reliable information; geospatial tools can be an important part of this effort. The geospatial information can aid decision-makers to more effectively manage wetlands ecosystems in terms of use, conservation, and restoration; it can also improve their ability to accurately assess trends in wetlands-based ecological services and benefits over time [16]. The estimated increase of the wetlands area under cultivation from 25% in 1926 to 43% in 2006 points to an indisputable concern. Do we re-investigate agriculture activities as a future threat to the identity of wetlands ecosystems? Or do we try to balance the crop production potential (productivity) of the system while conserving the ecological and hydrological characteristics of wetlands ecosystems?

The "wise use" framework promulgated by the Ramsar Convention [2] seems a promising theoretical direction, but in practice it has generated very few case studies. The representation of the wetlands in the agro-ecological and bio-geographic zones, using PWHs as a surrogate of important wetlands ecosystems in India, captures the gaps that are commonly encountered while managing complex and heterogeneous wetlands systems. A significant point is that, while defining PWHs as a common practice followed in many regions worldwide, the emphasis usually is on habitat value, biodiversity, and avifaunal diversity; the incorporation of socio-economic parameters that are reflective of livelihood dependence has been somewhat limited [17].

The two-point message of the paper is, first, to highlight the value of anecdotal records and survey maps as important material for studying the dynamics of resource use. The paper's second goal is to broaden understanding of geospatial applications and generate relevant information in order to permit decision-making with greater detail and accuracy. Combined, these two activities can provide conservation and development practitioners with relevant information on "wise use." Lastly, we conclude that in designing conservation strategies for resources systems, it is critical to answer the needs of social communities, so as to successfully deal with the challenge of sustainable development.

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Appendix 1: Data used for global /national (India) analysis

Data Sheet					
Data source	**Data set**	**Scale**	**Data Model**	**Resolution**	**Sensor/ Source**
GIAM data (source: www.iwmigiam.org	GIAM Aggregated 8 classes	Global	Raster	10 km	NOAA AVHRR SPOT VGT
	GIAM Disaggregated 28 classes	Global	Raster	10 km	NOAA AVHRR SPOT VGT
	GIAM Disaggregated 427 classes	India	Raster	500 m	MODIS
	GMLULC Aggregated 17 classes	Global	Raster	10 km	NOAA AVHRR SPOT VGT
	GMLULC Disaggregated 75 classes	Global	Raster	10 km	NOAA AVHRR SPOT VGT
	GMRCA Aggregated 22 classes	Global	Raster	10 km	NOAA AVHRR SPOT VGT
	GMRCA Disaggregated 273 classes	Global	Raster	10 km	NOAA AVHRR SPOT VGT
	Generic-IWMI 951 classes	Global	Raster	10 km	NOAA AVHRR SPOT VGT
SACON	State boundaries and Wetland – polygons Priority wetland Habitats (PWH's)	National National	Vector Vector	Polygon layer (Point layer)	Available at http://envfor.nic.in/envis
Ramsar database	Geographical location of the wetlands of international importance	Global	Vector	(Point layer)	Available at ramsar.wetlands.org
Vavilov's food centres	Historical information in a non-spatial format	Global	Digitised and referenced to a vector		Publication and Historical records Polygon layer
Biological richness zones	Historical information in a non-spatial format	Global	Digitised and referenced to a vector	Polygon layer	Publication and Historical records Polygon layer
Agro ecological regions/sub-regions of India	Hard copy map at the scale 1: 50,000 and with geo-coordinates	National		Polygon layer	National Bureau of Soil Survey and Land use Planning http://nbsslup.nic.in
Bio-geographic regions of India	Hard copy map at the scale 1: 50,000 and with geo-coordinates	National		Polygon layer	National Wildlife Database at Wildlife Institute of India www.wii.gov.in/nwdc/

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Appendix 2 : Descriptive analyses of Ramsar sites in India, the matrix is synthesised using the scattered information with different management authorities and the anecdotal records

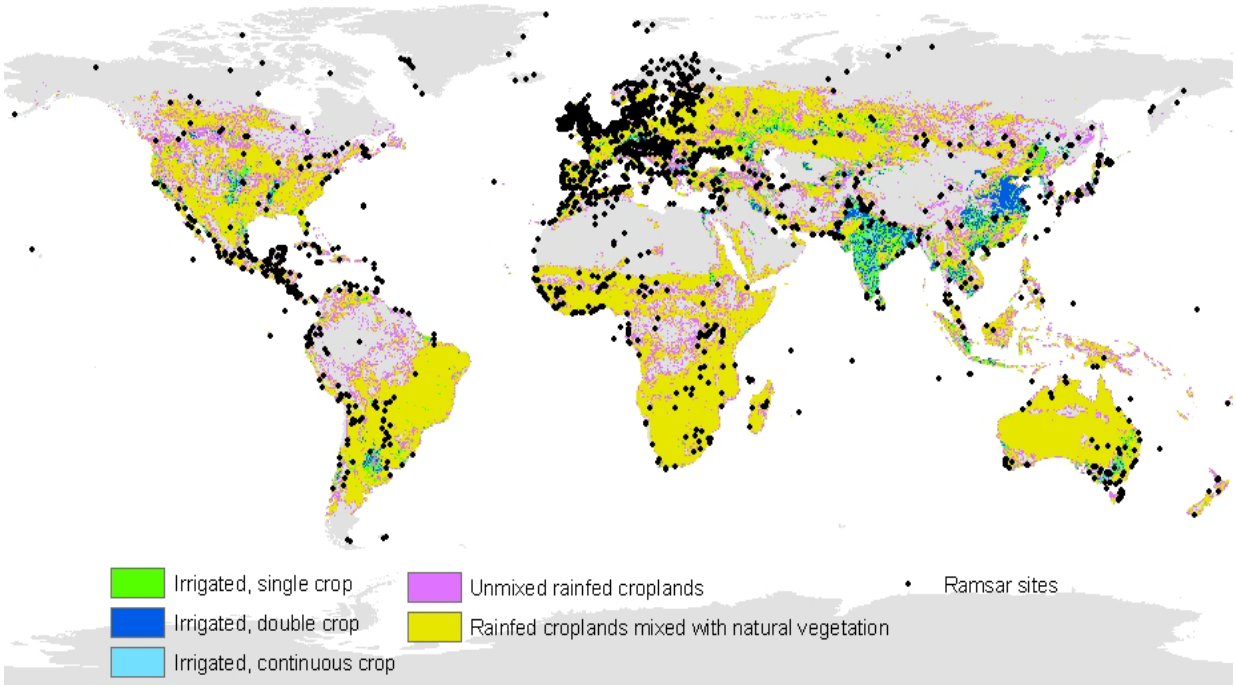
Site Name	*Ramsar Category	Agro ecological zone	Wetland /Type	Total area (hectare)	Administrative region (state)	Year Designated	**National conservation designation
Chilika	MCW	Eastern plateau	Brackish Lake	1,16,500	Orissa	1982	No
Keoladeo National Park	MCW	Western Plain	Seasonal Lagoon	2,873	Rajasthan	1981	NP , BS
Wular	IW	Western Himalayas	Fresh water lake	1,8900	Jammu & Kashmir	1990	No
Harike	IW	Northern Plains	Fresh water reservoir	4,100	Punjab	1990	BS,WLS
Loktak	IW	North Eastern Hills	Fresh water lake	2,660,0	Manipur and Bishanpur	1990	NP
Sambhar	MCW	Western Plain	Saline Lake	2,4000	Rajasthan	1990	No
Kanjli	IW	Northern Plain	Fresh water lake	183	Punjab	2002	No
Ropar	IW	Northern Plain	Man made lake	1,365	Punjab	2002	No
Ashtamudi	MCW	Western Ghats	Estuarine System	6,1400	Kerala	2002	No
Bhitarkanika	MCW	Eastern Plateau	Mangrove Forest	6,500,0	Orissa	2002	WLS
Bhoj	IW	Central highlands	Fresh water lake	3,201	Madhya Pradesh	2002	PA
Deepor Beel	IW	Assam and Bengal plains	Fresh water lake	4,000	Assam	2002	WLS
East Calcutta Wetlands	IW	Assam and Bengal plains	Ponds for water treatment	12,500	West Bengal	2002	PA
Kolleru	IW	Eastern Plateau	Fresh water to brackish lake	90,100	Andhra Pradesh	2002	WLS
Point Calimere	MCW	Eastern Ghats	Sandy coast	38,500	Tamil Nadu	2002	WLS, BS
Pong Dam	MCW	Northern Plain	Reservoir	15,662	Himachal Pradesh	2002	WLS
Sasthamkotta	IW	Eastern Ghats	Fresh water lake	373	Kerala	2002	No
Tsomoriri	IW	Chhattisgarh Mahanadi Basin	Fresh water to brackish lake	1,2000	Jammu & Kashmir	2002	WR
Vembanad-Kol	MCW	Western Ghats	Estuarine System	1,512,50	Kerala	2002	No
Chandertal Wetland	MCW	Western Himalayas	High altitude lake	49	Himachal Pradesh	2005	NIW
Hokera Wetland	IW	Western Himalayas	High altitude perennial	1,375	Jammu, Kashmir	2005	PA
Renuka Wetland	IW	Western Himalayas	Fresh water spring and krast	20	Himachal Pradesh	2005	WLS, RF
Rudrasagar	IW	North Eastern Hills	Fresh water reservoir	240	Tripura	2005	No
Surinsar-Mansar	IW	Western Himalayas	Fresh water lake	350	Jammu &Kashmir	2005	WLS, SG
Upper Ganga	IW	Western Himalayas	River	2,65.90	Uttar Pradesh	2005	SR

*MCW- Marine and coastal wetland; IW- Inland wetland

**NP: National Park; BS: Bird Sanctuary; NP-National Park; PA-protected Area; WR-Wetland Reserve; NIW: Nationally important wetland; RF-Reserve forest; SR -Sacred river ; WLS: Wildlife sanctuary,

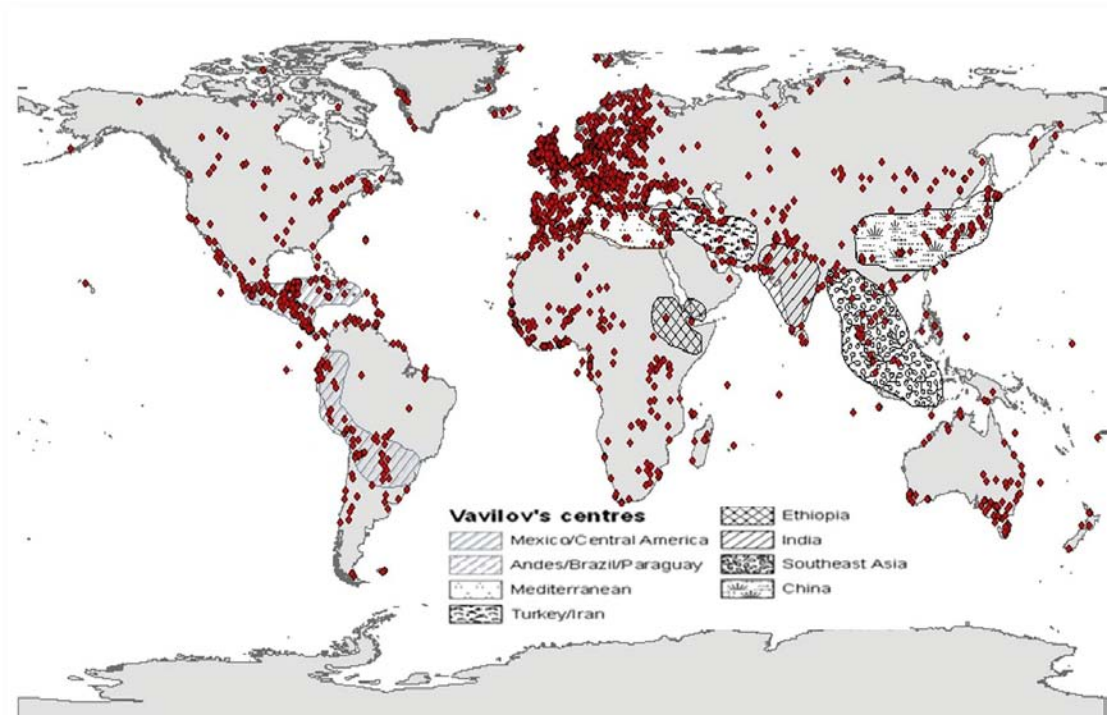
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Appendix 3: Ramsar site distribution; across the agricultural (irrigated/rain fed) zones (the grey colour is global land mass included in the base boundary layer , that is used to overlay the wetland coordinates) *Data Source:* Boundary: Global Administrative Unit Layers (GAUL); Ramsar site coordinates :(*ramsar.wetlands.org);* Agriculture zones: Global Irrigated Area Mapping (GIAM- www.iwmigiam.org)



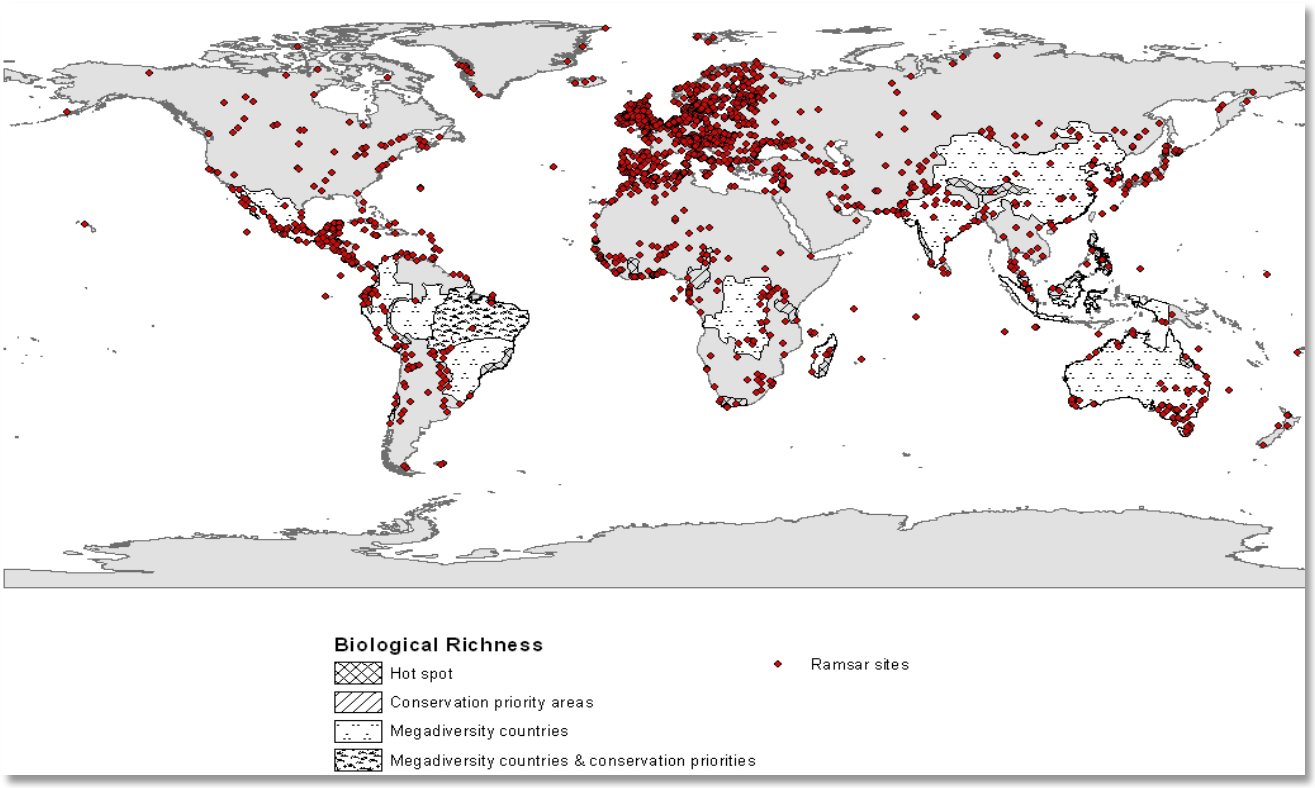
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Appendix 4: Ramsar site distribution across the Vavilov's food centre's (the grey colour is global land mass included in the base boundary layer). Data Source: Boundary: Global Administrative Unit Layers (GAUL); Ramsar site coordinates (ramsar.wetlands.org); Crop Centers [10]



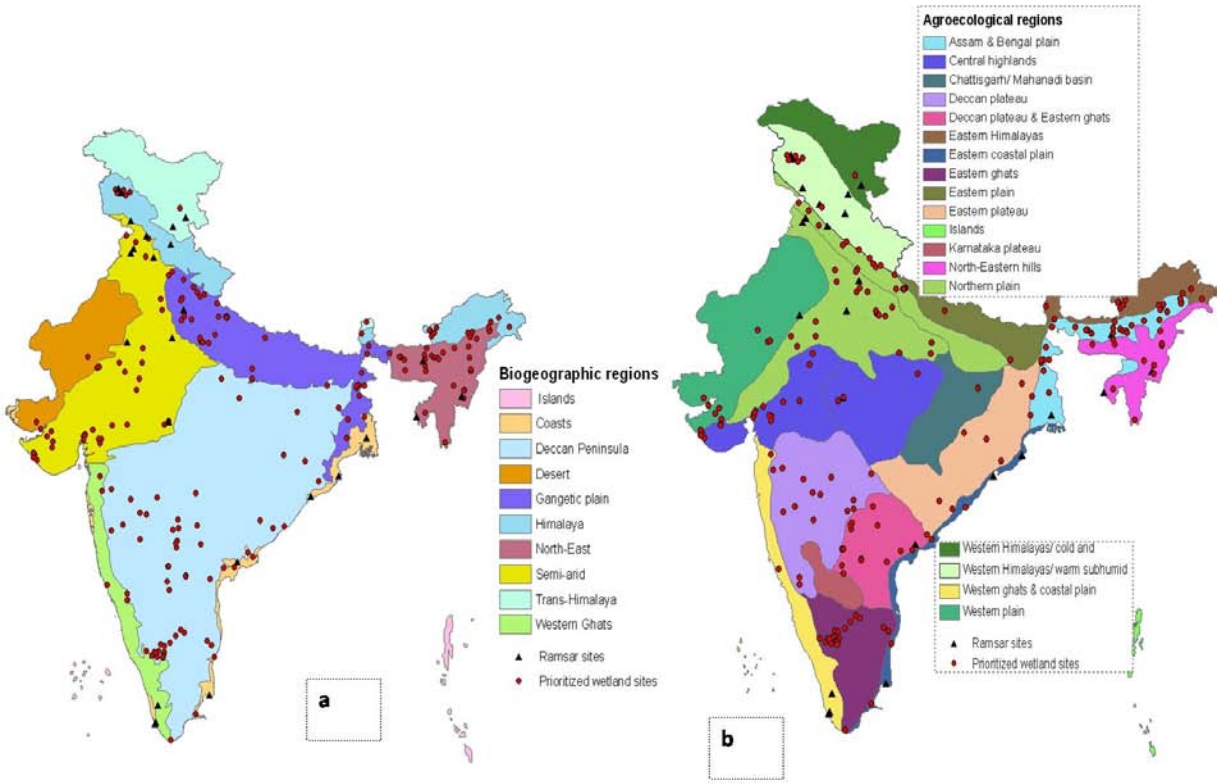
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Appendix 5: Point coordinates of the Ramsar wetland sites superimposed on the biologically rich regions of the world (the grey colour is global land mass included in the base boundary layer). Data Source: Boundary: Global Administrative Unit Layers (GAUL); Ramsar site coordinates (ramsar.wetlands.org); Biological Richness Centers [11].



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Appendix 6 : Distribution of 'Ramsar sites' and the 'priority wetland habitats' across the bio- geographical zones (a); and the agro-ecological zones (b) in India. Data Source: SACON (priority wetland habitats coordinates), India; Wildlife Institute of India (biogeography); National Bureau of Soil Survey and Land use Planning (agro- ecology); Ramsar site coordinates (*ramsar.wetlands.org)*



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