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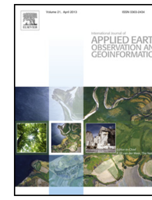

New vegetation type map of India prepared using satellite remote sensing: Comparison with global vegetation maps and utilities

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ABSTRACT

A seamless vegetation type map of India (scale 1: 50,000) prepared using medium-resolution IRS LISS-III images is presented. The map was created using an on-screen visual interpretation technique and has an accuracy of 90%, as assessed using 15,565 ground control points. India has hitherto been using potential vegetation/forest type map prepared by Champion and Seth in 1968. We characterized and mapped further the vegetation type distribution in the country in terms of occurrence and distribution, area occupancy, percentage of protected area (PA) covered by each vegetation type, range of elevation, mean annual temperature and precipitation over the past 100 years. A remote sensing-amenable hierarchical classification scheme that accommodates natural and semi-natural systems was conceptualized, and the natural vegetation was classified into forests, scrub/shrub lands and grasslands on the basis of extent of vegetation cover. We discuss the distribution and potential utility of the vegetation type map in a broad range of ecological, climatic and conservation applications from global, national and local perspectives. We used 15,565 ground control points to assess the accuracy of products available globally (*i.e.*, GlobCover, Holdridge's life zone map and potential natural vegetation (PNV) maps). Hence we recommend that the map prepared herein be used widely. This vegetation type map is the most comprehensive one developed for India so far. It was prepared using 23.5 m seasonal satellite remote sensing data, field samples and information relating to the biogeography, climate and soil. The digital map is now available through a web portal (http://bis.iirs.gov.in).

1. Introduction

Vegetation, 'the green blanket of the earth' is an attribute of the land. It is classified into natural, semi-natural and cultural categories, depending on the degree of human influence. The vegetation is the main component of an ecosystem. It displays the effects of environmental conditions in an obvious and easily measurable manner. Information on the vegetation type is a key input in characterizing landscape structurally and functionally. Classifying and mapping vegetation types is important for managing natural resources as the vegetation affects all living beings and influences the global climate and terrestrial carbon cycle significantly (Sala et al., 2000; Xiao et al., 2004). Vegetation type mapping also provides valuable information for understanding the distribution of natural and man-made systems by quantifying the vegetation cover from local to global scales at a given point of time continuously. Information on the distribution of vegetation types is a key input in planning at the national level for food security, wildlife habitats, sustainable natural resource management, agroforestry and biodiversity conservation in hotspot areas (Myers et al., 2000; Roy et al., 2012). It is also useful in planning protected areas and developing forest corridors. And accurate assessment of the current status of the vegetation cover is critical for initiating vegetation protection and restoration programs (Egbert et al., 2002; He et al., 2005). Forest vegetation is particularly sensitive to climate change because the long life-span of trees does not allow rapid adaptation.

The Himalayan orography has a profound impact on the precipitation pattern of India, including the monsoonal rainfall. Nearly 65% of the area of the country falls in the biotic region of tropical deciduous forests and tropical scrub. Tropical rain (evergreen/semi-evergreen) forests are confined to narrow strips in the Western Ghats, northeast India and the Andaman and Nicobar Islands. Subtropical, temperate and alpine forms of vegetation occur in the Himalaya by virtue of their being the altitudinal mirror of latitude. Southwest and northeast India, with heavy annual precipitation, provide favorable conditions for evergreen and moist deciduous forests, whereas the western and northwestern regions, with low annual precipitation, support desert (Thar) and semi-arid ecosystems. The climatic classification developed by Thornthwaite (1948) made use of the average monthly temperature and precipitation to classify vegetation. Champion and Seth (1968) attempted a forest type classification of India based on broad climatic, physiographic, edaphic and local conditions, with five major types, 16 type groups, 46 sub-types and 221 ecologically stable formations in different geographic zones. This classification of forest types is based on broad observations, and their type map is approximate: no systematic survey was conducted, and division of areas into different forest types was done arbitrarily. The moist mixed deciduous forests occurring the south of the Brahmaputra River, in northeast India, which have sal (*Shorea* spp.) to an extent of more than 15%, were not covered by any of the types and sub-types in this classification. Roy et al. (2006) identified 22 vegetation cover types, including 14 forest cover types, at a 1:500,000 scale using coarse resolution WiFS images, finding that forests occupy 18.39% of the country's total geographical area. However, the utility of a coarse resolution dataset at a regional level is limited, and a reliable and comprehensive vegetation type map of India at a 1:50,000 scale has been unavailable.

The vegetation types of the northern frontier of India (*i.e.*, the state of Jammu and Kashmir) include alpine pasture, scrub and temperate/sub-tropical scrub (Champion and Seth, 1968). Pascal and Pelissier (1996) prepared a 1:250,000 vegetation type map of the entire Western Ghats region using satellite data, ground-based phytosociological surveys and bio-climatic data. The Andaman and Nicobar Islands, constituting 0.03% of the country's landmass, has about 86% of its total geographical area under very fragile tropical rain forest (Rao, 1989). The vegetation of the Lakshadweep Islands is classified as littoral vegetation (Champion and Seth, 1968), with man-made vegetation (plantations) covering the major part of the islands.

Satellite remote sensing, with its synoptic coverage, provides a rapid and economic means for mapping vegetation types and changes (Navalgund et al., 2007). Reliable, geo-referenced vegetation type data at global, continental and regional scales are essential for global change research and modelling the earth system. Only satellite sensor data provide a truly synoptic view of the earth. They potentially increase the quality, internal consistency and reproducibility of global land and vegetation cover information and allow the earth to be studied as an integrated system (Yang et al., 2013). Remote sensing has contributed significantly to vegetation mapping and to our understanding of the functioning of terrestrials, primarily through the relationships between reflectance and vegetation structure (Roy et al., 1985; Lillesand et al., 2008). India is emerging as an important participant and contributor to global change research and monitoring programs by developing a comprehensive geospatial database on vegetation geography and diversity (Roy et al., 2013). In global climate change scenarios, national-level vegetation data are often considered the best surrogate for conservation and management.

Although various vegetation map products have been created at the global level (DeFries and Townshend, 1994; Hansen et al., 2000; Loveland et al., 2000), only a few of them (*viz.*, International Geosphere Biosphere Programme's DISCover product (Loveland et al., 2000)), the GlobCover product of the European Space Agency (ESA) and Moderate Resolution Imaging Spectroradiometer (MODIS) tree canopy cover data have been validated. In addition to the ground truth information, these efforts rely on regional experts' efforts to interpret remote sensing-based data. Some of the difficulties associated with validation of such data are (a) the availability of only small numbers of ground truth validation points and (b) the limited use of these data at a regional or local level (Scepan et al., 1999). The use of precise *in situ* data results in a better validation data test bed (Cohen and Justice, 1999; Hansen et al., 2002), and the validation is done by establishing a link between classified outputs and true information classes (Behera et al., 2000) for sub-sets of precisely located pixels representing these classes in the real world. Classification accuracy has been traditionally evaluated either using photo-interpretation or through field verification. In recent years, global positioning system (GPS) technology has gained much recognition for its use of ground collection of object information due to its applicability in traditional as well as modern survey methods (Sigrist et al., 1999; Behera et al., 2000). GPS systems are based on electromagnetic energy emitted by satellites and received by receivers in automobiles, airplanes and users' hand (Bettinger and Fei, 2010). However, the accuracy and precision of these devices vary according to the location, availability of satellites, environmental factors and GPS device quality. Thus, accuracy assessment is obligatory for evaluating the utility of a thematic map for the intended applications.

1.1. GlobCover data

The vegetation data of GlobCover were compiled by the ESA under the GlobCover 2005 project, carried out by an international consortium. This project was started in April 2005 in partnership with JRC, EEA, FAO, UNEP, GOFC-GOLD and IGBP. The land cover map was prepared at the global level with a 300 m resolution using the MERIS sensor onboard the ENVISAT satellite. Land cover maps are available for two time periods: December 2004–June 2006 and January 2009–December 2009 (Bontemps et al., 2009). This product incorporates 22 land cover classes defined by the United Nations (UN) land cover classification system (LCCS). The processing principle of the product includes two modules: (1) a pre-processing module, which produces global mosaics of land surface reflectance at a 300 m resolution (*i.e.*, geometric corrections, atmospheric correction, cloud screening, *etc.*) and (2) a classification module that produces a final land cover map at a 300 m resolution. The classification module stratifies the world into equal reasoning areas on the basis of ecological and remote sensing points of view. Then various classification algorithms (*i.e.*, supervised and unsupervised) that operate at pixel and cluster levels are used to classify the regions (for more details, refer to Bontemps et al., 2009).

1.2. Potential natural vegetation data (PNV)

PNV data at the global level were derived at a resolution of 0.5° by synthesizing the 1 km land cover dataset of Ramankutty and Foley (1999); NDVI composites from the advanced very high resolution radiometer (AVHRR) sensor of Loveland et al. (2000) and the Haxeltine and Prentice (1996) data set (refer to Ramankutty and Foley (2010) for details). PNV data classify the world into 16 major classes including 'water body' and 'desert'.

1.3. Holdridge's life zone data

Holdridge's life zone data, available from the International Institute for Applied Systems Analyses (IIASA), in Laxemburg, Austria, shows the Holdridge life zones of the world on the basis of a combination of climate and vegetation types. We used the present data under normal conditions for visual comparison with the Indian vegetation type map. These data have a spatial resolution of 1.5° and include a total of 38 life zone classes (for more details, refer to Leemans (1990)).

Here, we present a seamless vegetation type map of India, prepared from medium-resolution IRS LISS-III images using the on-screen visual interpretation technique at a 1:50,000 scale. The accuracy was assessed using 15,565 ground-visited reference points. This assessment involved a collaborative effort in which 21 institutes and 61 scientists participated. It spanned a period of one and a half decades between 1997 and 2012. Further, we characterized the vegetation type distribution in terms of their occurrence and distribution, area occupancy, percentage of protected area (PA) covered by each vegetation type, range of elevation, mean annual average temperature and precipitation with respect to the past 100 years, and three dominant plant species of each vegetation type (Table 1). The ecological significance of the vegetation type

Table 1
Vegetation type characteristics: The area covered, percentage of protected area (PA) in each vegetation type, the range of elevation, mean annual average temperature and precipitation with respect to past 100-years, and three dominant plant species per each vegetation type is shown.

Sl. no.	Vegetation type	Area covered (Km^2)	% PA	Elevation range (m)	Temperature range (°C)	Precipitation range (mm)	Three dominant plant species
1	Tropical evergreen	14989.7	27	21–2300	13.71–29.27	800–7000	*Dendrocalamus hamiltonii*, *Olea dioica*, *Melocanna bambusoides*
2	Andaman tropical evergreen	2772.73	22	23–732	22.55–30.53	2000–3000	*Leea indica*, *Oplismenus compositus*, *Myristica andamanica*
3	Southern hilltop tropical evergreen	63.18	37	22–732	22.10–29.40	2000–3000	*Striga asiatica*, *Artocarpus lakoocha*, *Bouea oppositifolia*
4	Secondary tropical evergreen	297.69	23	19–565	22.00–30.62	2000–3000	*Oplismenus compositus*, *Polyalthia jenkensii*, *Myristica andamanica*
5	Sub-tropical broadleaved evergreen	30221.53	9.2	650–2566	5.60–25.73	800–11000	*Capillipedium assimile*, *Arundinaria maling*, *Calamus floribundus*
6	Sub-tropical dry evergreen	155.83	21	65–732	16.83–36.50	800–1500	*Albizia odoratissima*, *Chloroxylon swietenia*, *Aristida setacea*
7	Montane wet temperate	1955.99	34	1400–3900	−19.03	600–4000	*Arundinaria maling*, *Abies densa*, *Ainsliaea aptera*
8	Himalayan moist temperate	32631.9	10	1400–3700	0.26–21.98	600–3000	*Castanopsis hystrix*, *Symplocos lucida*, *Cedrus deodara*
9	Sub-alpine	1161.39	20	2800–4200	0.26–21.99	600–2000	*Abies densa*, *Woodfordia fruticosa*, *Rhododendron thomsonii*
10	Tropical semi-evergreen	29614.89	15	65–1500	14.69–32.18	600–7000	*Melocanna bambusoides*, *Chromolaena odorata*, *Hemidesmus indicus*
11	Tropical moist deciduous	117865.11	12	23–1500	7.94–29.77	600–5000	*Quercus dealbata*, *Shorea robusta*, *Tectona grandis*
12	Tropical sal mixed moist deciduous	27297.75	18	21–1050	10.75–37.37	600–3000	*Shorea robusta*, *Prosopis juliflora*, *Cynodon dactylon*
13	Tropical teak mixed moist deciduous	34172.14	14	55–1100	10.18–38.34	600–4000	*Shorea robusta*, *Tectona grandis*, *Oplismenus burmannii*
14	Tropical dry deciduous	127424.71	20	59–990	12.29–38.43	400–3000	*Cassia tora*, *Hyptis suaveolens*, *Tectona grandis*
15	Tropical sal mixed dry deciduous	16178.46	16	34–1150	11.26–37.94	800–2000	*Shorea robusta*, *Hemidesmus indicus*, *Diospyros melanoxylon*
16	Tropical teak mixed dry deciduous	8756.18	26	140–980	12.85–40.54	600–2000	*Tectona grandis*, *Hyptis suaveolens*, *Butea monosperma*
17	Tropical thorn	9050.45	9.1	60–980	9.74–38.78	100–1500	*Prosopis juliflora*, *Balanites aegyptiaca*, *Cassia tora*
18	Dry tropical bamboo mixed	4122.79	19	230–1700	13.65–38.22	600–2000	*Dendrocalamus strictus*, *Tectona grandis*, *Albizia amara*
19	Temperate coniferous	21167.88	12	2200–3900	−24.52	200–3000	*Pinus wallichiana*, *Cedrus deodara*, *Fragaria nubicola*
20	Sub-tropical pine mixed	2296.86	2.7	400–2300	5.00–33.42	1000–3000	*Pinus roxburghii, Lantana camara, Chrysopogon polyphyllus*
21	Sal (*Shorea* sp.)	33953.5	16	24–1700	9.74–37.50	800–4000	*Shorea robusta*, *Diospyros melanoxylon*, *Oplismenus burmannii*
22	Teak (*Tectona* sp.)	7460.07	19	20–1150	12.55–40.09	600–4000	*Tectona grandis*, *Oplismenus burmannii*, *Hyptis suaveolens*
23	*Dipterocarpus* sp.	982.42	2.1	70–1650	6.25–26.50	1500–4000	*Dipterocarpus retusus*, *Mesua ferrea*, *Vatica lanceaefolia*
24	Bamboo	17163.55	11	19–3500	11.11–34.36	600–11000	*Melocanna bambusoides*, *Dendrocalamus hamiltonii*, *Oplismenus burmannii*
25	Pine (*Pinus* sp.)	15036.11	3.1	880–3700	2.83–27.81	600–7000	*Cynodon dactylon*, *Pinus insularis*, *Quercus dealbata*
26	Fir (*Abies* sp.)	885.59	4.6	2800–4200	−26.32	400–2000	*Abies pindrow, Viburnum cylindricum, Rosa webbiana*
27	Oak (*Quercus* sp.)	1747.7	8.4	900–3560	1.00–27.25	600–2000	*Quercus leucotrichophora, Trifolium repens, Viola hamiltoniana*
28	Deodar (*Cedrus* sp.)	2642.43	5.7	2300–3600	−23.84	400–2000	*Cedrus deodara, Medicago polymorpha, Fragaria nubicola*
29	*Hardwickia* sp.	307.52	0.3	230–1050	14.13–37.13	400–1500	*Hardwickia binata*, *Apluda mutica*, *Enicostemma axillare*
30	Red sanders	93.44	48	230–1150	16.33–36.33	600–1000	*Sida acuta*, *Pupalia lappacea*, *Polygala erioptera*
31	*Cleistanthus* sp.	69.26	27	200–560	12.44–41.44	1000–2000	*Cleistanthus collinus*, *Oplismenus burmannii*, *Sida cordifolia*
32	*Boswellia sp.*	1818.99	5	140–650	8.53–40.53	600–1500	*Apluda mutica*, *Boswellia serrata*, *Shorea robusta*
33	*Acacia catechu*	1419.24	22	60–800	6.76–39.11	600–2000	*Acacia catechu*, *Lantana camara*, *Heteropogon contortus*
34	*Anogeissus pendula*	2806.24	40	150–730	7.44–40.43	400–1500	*Anogeissus pendula*, *Lantana camara*, *Acacia catechu*
35	*Acacia senegal*	220.29	12	50–900	−18.5	200–1000	*Aristida adscensionis*, *Azadirachta indica*, *Boerhavia erecta*
36	*Rhododendron sp.*	1.94	84	2650–3230	−26.49	800–2000	*Carex fusiformis*, *Arundinaria maling*, *Cyperus cyperoides*

Table 1 (*Continued*)

Sl. no.	Vegetation type	Area covered (Km^2)	% PA	Elevation range (m)	Temperature range (°C)	Precipitation range (mm)	Three dominant plant species
37	*Juniperus* sp.	310.6	5	2800–3650	17.84–33.27	400–1500	*Berberis asiatica*, *Rosa webbiana*, *Indigofera hirsuta*
38	Mangrove	3313.67	62	30–480	16.07–32.69	200–4000	*Gigantochloa nigro-ciliatia*, *Suaeda maritima*, *Excoecaria agallocha*
39	*Avicennia* sp.	265.37	72	30–60	22.00–32.00	1000–4000	*Avicennia alba*, *Suaeda maritima*, *Porteresia coarctata*
40	*Lumnitzera* sp.	34.38	49	21–75	16.00–33.14	2000–4000	*Ceriops tagal*, *Excoecaria agallocha*
41	Mangrove scrub	267.33	40	20–60	14.40–33.10	200–2000	*Apluda mutica*, *Anogeissus pendula*, *Aristida funiculata*
42	*Phoenix* sp.	580.27	98	20–145	22.11–31.36	1500–4000	*Phoenix paludosa*, *Excoecaria agallocha*, *Suaeda maritima*
43	*Rhizophora* sp.	289.77	34	20–190	22.00–30.00	2000–4000	*Oplismenus compositus*, *Calamus andamanicus*, *Calamus pseudorivalis*
44	*Xylocarpus* sp.	3.43	13	20–60	22.13–31.77	2000–4000	*Xylocarpus granatum*, *Rhizophora apiculata*, *Ceriops tagal*
45	Littoral forest	106.44	20	20–190	8.00–29.00	2000–4000	*Calophyllum inophyllum*, *Terminalia catappa*, *Manilkara littoralis*
46	Fresh water swamp	225.24	7.6	730–1150	9.87–37.00	1500–2000	*Quercus dealbata*, *Pinus insularis*, *Wendlandia pendula*
47	Lowland swamp	635.49	43	20–230	22.00–32.00	1000–3000	*Cynodon dactylon*, *Acacia nilotica*, *Prosopis juliflora*
48	*Syzigium* swamp	14.48	0	20–145	10.78–25.33	2000–3000	*Pandanus tectorius*, *Syzygium samarangense*, *Pinanga coronata*
49	Sholas	332.26	30	145–2400	12.87–36.84	800–5000	*Panicum trypheron*, *Isachne miliacea*, *Vateria indica*
50	Riverine	3484.82	19	20–1560	11.29–40.00	400–4000	*Saccharum spontaneum*, *Saccharum bengalense*, *Oplismenus burmannii*
51	Ravine	466.1	3.7	20–310	11.50–27.75	400–1500	*Holarrhena pubescens*, *Terminalia alata*, *Tectona grandis*
52	Sacred groves	277.13	9.8	20–2100	9.21–35.64	1000–4000	*Quercus serrata*, *Quercus dealbata*, *Melastoma malabathricum*
53	Trop seasonal swamp	68.18	84	20–230	15.33–31.83	1000–2000	*Calamus tenuis*, *Syzygium cumini*, *Mallotus phillippensis*
54	Kans	140.58	2.9	480–900	6.69–39.87	1000–3000	*Terminalia paniculata*, *Terminalia alata*, *Dillenia pentagyna*
55	Forest plantations	3662.22	13	40–1650	8.14–37.82	300–1500	*Prosopis juliflora*, *Desmostachya bipinnata*, *Achyranthes aspera*
56	*Acacia* sp.	601.61	5.6	60–150	8.00–38.00	400–1500	*Acacia auriculiformis*, *Syzygium caryophyllatum*, *Chromolaena odorata*
57	*Eucalyptus* sp.	0.03	0	60–150	12.84–36.53	600–1000	*Eucalyptus teriticornis, Achyranthes aspera, Brachiaria reptans*
58	*Casuriana* sp.	377.73	26	60–150	15.67–33.50	800–1000	*Casuarina equisetifolia, Tectona grandis, Prosopis juliflora*
59	Alnus sp.	2.11	0	60–140	22.25–30.25	800–1000	*Alnus nepalensis, Persicaria chinensis, Oplismenus compositus*
60	Mixed plantation	5905.79	5	140–1650	6.00–23.29	600–1000	*Shorea robusta, Mallotus philippensis, Clerodendrum viscosum*
61	*Gliricidia* sp.	74.67	11	60–1150	10.62–37.43	600–1000	*Gliricidia sepium, Apluda mutica, Iseilema laxum*
62	Degraded forest	43583.98	9	60–140	12.67–38.33	600–800	*Cassia tora, Tectona grandis, Terminalia alata*
63	Shifting cultivation	752.96	4.4	60–1400	10.14–36.02	1000–2000	*Xylia xylocarpa, Ardisia solanacea, Cleistanthus collinus*
64	Abandoned Jhum	0.05	0	560–1560	14.36–35.36	1000–3000	*Quercus dealbata, Melocanna bambusoides, Quercus serrata*
65	Current Jhum	11005.23	1.6	20–2700	9.29–27.76	1000–4000	*Melocanna bambusoides, Quercus dealbata, Quercus serrata*
66	Woodland	178.46	5.7	145–1400	15.00–34.00	600–3000	*Tarenna asiatica, Flueggea leucopyrus, Cardiospermum halicacabum*
67	Tree savannah	10988.02	14	20–1650	11.95–39.05	400–4000	*Aristida funiculata, Aristida adscensionis, Heteropogon contortus*
68	Shrub savannah	2990.28	8.3	140–1050	12.80–39.60	200–3000	*Apluda mutica, Aristida funiculata, Dichanthium annulatum*
69	Dense scrub	106109.57	7.5	20–3500	11.91–63.06	200–7000	*Shorea robusta, Sporobolus diandrus, Heteropogon contortus*
70	Open scrub	16831.84	7.9	20–3500	7.81–35.06	200–7000	*Shorea robusta, Cynodon dactylon, Bothriochloa ischaemum*
71	Dry evergreen scrub	363.16	4.8	100–2700	16.92–37.50	600–3000	*Grewia tiliaefolia, Hybanthus enneaspermus, Pinus roxburghii*
72	Dry deciduous scrub	24982.32	12	60–3300	9.54–38.85	400–3000	*Dendrocalamus strictus, Cynodon dactylon, Indigofera cordifolia*
73	*Ziziphus* sp.	653.96	4.7	60–1200	7.94–41.12	600–2000	*Ziziphus mauritiana, Aristida redacta, Aristida funiculata*
74	*Euphorbia* scrub	204.63	1.7	60–730	17.00–40.00	200–800	*Euphorbia sp., Globba marantina, Polygala elongata*
75	Moist alpine scrub	8405.18	19	2800–4700	−29.15	100–3000	*Phleum alpinum, Cirsium arvense, Poa annua*
76	Dry alpine scrub	7550.04	17	2600–4800	−25.76	25–2000	*Melilotus alba, Hippophae rhamnoides, Bromus japonicus*
77	*Prosopis juliflora*	5435.2	18	21–800	9.12–39.61	200–3000	*Prosopis juliflora , Aristida hystirx, Isachne globosa*

Table 1 (*Continued*)

Sl. no.	Vegetation type	Area covered (Km^2)	% PA	Elevation range (m)	Temperature range (°C)	Precipitation range (mm)	Three dominant plant species
78	*Lantana* scrub	4985.24	11	20–980	7.41–39.62	100–1000	*Lantana camara, Prosopis juliflora, Capparis zeylanica L.*
79	Desert dune scrub	14565.64	1.8	20–560	7.53–41.18	50–600	*Prosopis cineraria, Acacia senegal, Tecomella undulata*
80	Thorn scrub	3575.8	4.6	20–1300	12.17–36.17	600–5000	*Carissa carandas, Pterocarpus marsupium, Gmelina arborea*
81	*Prosopis cineraria*	74.7	0	140–400	7.00–39.00	200–800	*Prosopis cineraria, Holoptelea integrifolia, Anogeissus pendula*
82	Grassland	25224.92	11	20–3800	10.50–30.13	400–8000	*Heteropogon contortus, Pinus insularis, Oplismenus burmannii*
83	Wet grassland	1784.65	8.1	300–3400	4.67–30.33	800–3000	*Chrysopogon aciculatus, Cynodon dactylon, Pinus roxburghii*
84	Riverine	2090.04	8.8	19–1400	8.47–37.95	600–4000	*Saccharum bengalense, Tiliacora acuminata, Themeda arundinacea*
85	Moist alpine pasture	17171.96	16	2700–6000	−29.7	50–2000	*Bromus japonicus, Cynodon dactylon, Poa annua*
86	Dry alpine pasture	32571.82	28	2750–6500	−27.26	25–1500	*Digitaria stewartiana, Phleum alpinum, Bromus japonicus*
87	Dry grassland	1666.71	9.7	20–4000	10.52–38.69	50–2000	*Eragrostis tenella, Heteropogon contortus, Carissa spinarum*
88	Swampy grassland	1085.16	60	20–4000	−31.16	50–4000	*Setaria viridis, Carex stenophylla, Digitaria stewartiana*
89	*Lasiurus-Panicum* grassland	3732.7	15	20–400	6.89–41.24	50–1500	*Lasiurus scindicus, Panicum turgidum , Aerva persica*
90	*Cenchrus-Dactyloctenium* grassland	5634.18	2.2	20–980	7.15–40.80	100–1000	*Cenchrus biflorus, Dactyloctenium aegyptium, Aerva persica*
91	*Sehima-Dichanthium* grassland	676.6	10	145–1060	8.36–37.73	200–1000	*Sehima nervosum, Dichanthium annulatum, Aristida adscensionis*
92	Costal swampy grassland	294.47	40	230–730	7.00–40.19	400–1000	*Ochthochloa compressa, Sporobolus virginicus, Anogeissus pendula*
93	Orchard	49723.1	3.2				*Clerodendrum viscosum, Butea monosperma, Colebrookea oppositifolia*
94	Tea	1331.58	1				*Coffea benghalensis, Shorea robusta, Cycas pectinata, Mallotus phillippensis*
95	Arecanut	155.08	2.8				*Areca triandra, Psychotria curviflora, Actinodaphne bourdillonii*
96	Coconut	158.59	0.7				*Cocos nucifera, Thespesia populnea, Calophyllum inophyllum*
97	Mango	777.51	0.2				*Mangifera indica, Bauhinia racemosa, Bombax ceiba*
98	Saffron	50.22	0.1				*Crocus sativus*
99	*Cryptomeria* sp.	32.73	13				*Cryptomeria japonica, Oplismenus compositus, Trifolium repens*
100	*Padauk* sp.	0.08	9.1				*Pterocarpus dalbergioides, Oplismenus compositus, Phrynium pubinerve*

classification scheme adopted here has been discussed. The regional distribution of the vegetation types and the potential utility of the vegetation type map in a broad range of ecological, climatic and conservation applications from global, national, regional and local perspectives are also discussed. We also used above 15,565 ground control points as references to assess the accuracy of a few available global products (*i.e.*, GlobCover, Holdridge's life zone map and potential natural vegetation (PNV) maps) and promote their use. The vegetation type map is also projected as a replacement of the existing classic forest type classification of Champion and Seth (1968), which is now available through a web portal.

2. Study area

India has a total geographic area of about 3,287,263 km^2 and lies between latitudes 6° 44′ N and 35° 30′ N and longitudes 68° 7′ E and 97° 25′ E. The country has the largest peninsula in Asia and measures 3219 km from north to south and about 2977 km from east to west. The northern and northeastern parts of India are bounded by the Himalaya, geologically new fold mountains, and share terrestrial boundaries with China, Nepal and Bhutan in the north; Burma and Bangladesh in the east; and Pakistan to the west. The southern part is bounded by the Indian Ocean, the southwest part by the Arabian Sea and the southeast part by the Bay of Bengal. The coastline is about 7516.6 km long (EIU, 1996). India's Andaman and Nicobar Islands share a maritime border with Thailand and Indonesia. India is one of the 12 mega biodiversity countries of the world (Chitale et al., 2014). The average rainfall in India is about 125 cm, but the variation is high (from >600 cm in the northeast and Western Ghats to <50 cm in parts of Rajasthan, Tamil Nadu, Andhra Pradesh and Ladakh). In summer (April–July), the temperature ranges between 32 °C and 40 °C, and in winter (December–April), it ranges between 10 °C and 15 °C. The Indian climate is strongly influenced by the Himalayas and the Thar Desert. The Himalayas prevent cold Central Asian katabatic winds from blowing in, keeping the bulk of the Indian sub-continent warmer than most locations at similar latitudes. The Thar Desert plays a crucial role in attracting the moisture-laden southwest monsoon winds of summer, which provide most of India's rainfall. Four major climatic groups determine India's vegetation, namely tropical wet, tropical dry, sub-tropical humid and montane.

3. Methodology

3.1. Type mapping

Satellite remote sensing was used to classify vegetation and land cover units using an on-screen visual interpretation technique at the 1:50,000 scale. The GPS was used for locating field sample plots, gathering location attributes of plant species and providing field-points for assessing the classification accuracy of the vegetation type map. Cloud-free images from IRS 1C, IRS 1D and P6 LISS-III satellite data (spatial resolution 23.5 m) were used for vegetation type mapping. Three seasons' (time windows of November–early January, February–early April and late April–May) images from IRS, LISS-III and Landsat (wherever LISS-III data were not available) were used. Besides satellite images, biogeographic maps (Rodgers and Panwar, 1988), a digital elevation model (SRTM-DEM), topographical maps (scale 1:50,000) and a stratified random distribution of geo-located sample points were used for vegetation mapping and accuracy assessment. A remote sensing-amenable hierarchical classification scheme was prepared using a climatologically driven distribution of forest ecosystems adapted from Champion and Seth (1968) (Table S1). These type groups are further divided into subgroups on the basis of the dominant compositional patterns and location-specific formations, which are controlled by edaphic and disturbance conditions. An on-screen visual interpretation technique was utilized for vegetation type mapping (Fig. 1).

State-level vegetation type maps were edge matched, and a mosaic was created to generate a seamless national-level map (Fig. 2). A vegetation classification scheme was framed, and natural and semi-natural systems were classified into forests, scrub/shrub lands and grasslands on the basis of the extent of green cover (Table S1). Cultivated and managed systems were classified into orchards, croplands, long fallow/barren lands and water bodies. The forest class was subdivided into mixed forest formations, gregarious formations, locale-specific formations, degraded/succession types and plantations (Fig. 2). The classes that were not amenable to delineation directly using remote sensing were retained at their broad class levels (Table S1; Fig. 2). The original map was modified by merging some of the related classes to produce a more concise and robust vegetation type map (Roy et al., 2012). The derived vegetation map contained 100 classes within nine broad categories (Fig. 2). The merging was based on two criteria: (1) The first criterion was the area occupied by the individual classes. Classes occupying area ≦10 pixels (9000 m^2) were merged into a broader category. For example, apple, cashew nut, coffee, *etc.* were merged into 'orchard', and Terai swampy grasslands were merged into 'swampy grassland'. (2) The second criterion was the availability of field-laid reference GPS points. Classes that did not have these were merged to the most suitable broader classes. Here, we added one broader category, 'managed ecosystem', which included eight classes managed by humans, such as tea and saffron (Fig. 2).

Temperature and precipitation data available from the Climate Research Unit (CRU) were used to derive the distribution ranges of vegetation classes. Vegetation class-wise elevation distribution ranges were evaluated from a digital elevation model (DEM) obtained from the Shuttle Radar Topographic Mission (SRTM). It was determined whether the classes were included within PAs (Table 1).

3.2. Field survey

Field sampling was carried out to collect information on the composition of vegetation types/classes. A random distribution of sample points was chosen in the vegetation type strata to determine the type-specific relative species composition. A minimum sampling intensity of 0.001–0.002% was selected on the basis of the remote sensing-based vegetation type strata along with the physiography and climatic zones. This sampling intensity was selected so as to optimize the available resources and time, given the forest vegetation cover and other characteristics of the eco-regions in India. The species composition was determined through 15,565 GPS points, which were selected on the basis of stratified random sampling (Behera et al., 2000; Roy et al., 2012). During the field survey, all the vegetation types were verified and recorded along traverses and across ridges and valleys. The dominant vegetation types were marked on satellite images using the image characteristics (tone and texture). The image characteristics, climate, elevation, soil information, *etc.* helped develop an interpretation key for on-screen visual interpretation. A survey of the published literature was carried out, and several interactions were held with forest departments and educational/local institutions to gather information on the vegetation type distribution. The information available in the forest working plans and published records was also considered. A reconnaissance survey helped understand the prevailing phenological, gregarious, locale-specific vegetation types.

3.3. Accuracy assessment

The quality of vegetation maps derived from remote sensing data are often judged by evaluating the derived data against some reference data and interpreting the disagreement between the two as errors (Table 2). To compensate for the spatial differences between the map and locations, the scoring of the map cover was done at two levels: (1) at the individual pixel point level and (2) at the 600 m buffer zone (since the GlobCover data are available at a 300 m resolution (Table 3a). We used 15,565 field-laid geotagged vegetation plots as references to assess the accuracy of the vegetation map of India and the GlobCover vegetation data in ERDAS IMAGINE (Fig. 3). We first measured the distances of the omitted vegetation points from the actual class, and the average error distance was calculated here to be 150 m. Thus, any maximum positional error can be within a 300 m circumference or buffer range >300 m. Since we wanted to compare our data with the GlobCover data, we used a buffer of 600 m (multiple of 300 m) to check the accuracy with one surrounding pixel. The GlobCover data have fewer broad classes (22) compared with the Indian vegetation type classes (Fig. 3). We merged the appropriate classes among the 22 broad classes and 100 Indian vegetation type classes to eight categories, which brought about an appropriate translation between the two map sources (Table S2). Accordingly, in many places the density-level gradations were merged to their respective type class. Further, we assessed the accuracy of the GlobCover map by comparing it with our 15,565 field points (Table 3a). Comparison of the vegetation type map of India with Holdridge's life zone map and a potential natural vegetation (PNV) map was also performed using 21 randomly distributed GPS-gathered field points (references) with respect to broad vegetation classes (Table 3a and Fig. 3).

4. Results

The vegetation type map (developed through a collaborative effort involving 21 institutes and 61 scientists) provides spatial information on 100 vegetation types consisting of natural, semi-natural and managed formations clubbed under 10 broad categories (Fig. 2). The tree- dominant systems include mixed, gregarious, locale-specific, degraded formations, plantations and woodlands, followed by scrublands, grasslands and managed ecosystems (Fig. 2). We classified 11 evergreen and nine deciduous forests including semi-evergreen classes under mixed natural and semi-natural formations from tropical to sub-alpine ranges. The

Table 2
Estimates of classification accuracy (producer's and user's accuracy) of Indian vegetation type map using 15,565 GPS-gathered field points at individual pixel level, and 600 m buffer zone (in brackets).

Vegetation	Code	Reference total	Classified total	Correct classification	Producer's accuracy	User's accuracy
Tropical Evergreen	11	296	281 (286)	281 (286)	95 (97)	100 (100)
Andaman tropical evergreen	12	118	114 (119)	112 (118)	95 (100)	98 (99)
Southern hilltop tropical evergreen	14	9	9 (9)	9 (9)	100 (100)	100 (100)
Secondary tropical evergreen	15	13	13 (13)	12 (13)	92 (100)	92 (100)
Sub-tropical broadleaved evergreen	16	164	161 (165)	159 (164)	97 (100)	99 (99)
Sub-tropical dry evergreen	17	5	5 (5)	5 (5)	100 (100)	100 (100)
Montane wet temperate	18	99	99 (98)	97 (98)	98 (99)	98 (100)
Himalayan moist temperate	19	199	185 (195)	183 (195)	92 (98)	99 (100)
Sub alpine	21	6	6 (6)	6 (6)	100 (100)	100 (100)
Tropical semi-evergreen	22	601	582 (593)	580 (592)	97 (99)	100 (100)
Tropical moist deciduous	23	1959	1757 (1876)	1754 (1876)	90 (96)	100 (100)
Tropical sal mixed moist deciduous	24	795	740 (780)	738 (780)	93 (98)	100 (100)
Tropical teak mixed moist deciduous	25	544	487 (520)	485 (519)	89 (95)	100 (100)
Tropical dry deciduous	26	2754	2661 (2712)	2652 (2708)	96 (98)	100 (100)
Tropical sal mixed dry deciduous	27	391	355 (378)	353 (378)	90 (97)	99 (100)
Tropical teak mixed dry deciduous	28	327	289 (315)	288 (315)	88 (96)	100 (100)
Tropical thorn forest	29	184	169 (177)	166 (176)	90 (96)	98 (99)
Bamboo mixed	30	129	124 (129)	123 (129)	95 (100)	99 (100)
Temperate coniferous	31	225	210 (222)	206 (221)	92 (98)	98 (100)
Sub-tropical pine mixed	32	36	29 (34)	28 (33)	78 (92)	97 (97)
Shorea sp.	36	650	530 (591)	527 (591)	81 (91)	99 (100)
Tectona sp.	37	200	180 (189)	178 (189)	89 (95)	99 (100)
Dipterocarpus sp.	38	4	4 (4)	4 (4)	100 (100)	100 (100)
Bamboo sp.	40	169	156 (166)	154 (166)	91 (98)	99 (100)
Pinus sp.	41	206	185 (197)	174 (193)	84 (94)	94 (98)
Abies sp.	42	22	21 (22)	21 (22)	95 (100)	100 (100)
Quercus sp.	44	6	6 (6)	6 (6)	100 (100)	100 (100)
Cedrus sp.	45	30	30 (32)	28 (30)	93 (100)	93 (94)
Hardwickia sp.	46	8	8 (8)	8 (8)	100 (100)	100 (100)
Red sanders	47	7	7 (7)	7 (7)	100 (100)	100 (100)
Cleistanthus sp.	48	11	11 (11)	11 (11)	100 (100)	100 (100)
Boswellia sp.	49	24	24 (24)	23 (24)	96 (100)	96 (100)
Acacia catechu	53	28	26 (28)	24 (27)	86 (96)	92 (96)
Anogeissus pendula	54	111	109 (109)	106 (109)	95 (98)	97 (100)
Acacia senegal	55	1	1 (1)	1 (1)	100 (100)	100 (100)
Rhododendron sp.	58	1	1 (1)	1 (1)	100 (100)	100 (100)
Juniperus sp.	63	12	12 (12)	12 (12)	100 (100)	100 (100)
Mangrove forest	66	103	87 (94)	86 (94)	83 (91)	99 (100)
Avicennia sp.	67	31	31 (31)	30 (31)	97 (100)	97 (100)
Lumnitzera sp.	71	1	1 (1)	1 (1)	100 (100)	100 (100)
Mangrove scrub	72	13	13 (14)	12 (13)	92 (100)	92 (93)
Phoenix sp.	73	20	18 (20)	17 (20)	85 (100)	94 (100)
Rhizophora sp.	74	42	40 (42)	40 (42)	95 (100)	100 (100)
Xylocarpus sp.	75	2	2 (2)	2 (2)	100 (100)	100 (100)
Littoral forest	76	32	27 (29)	27 (29)	84 (91)	100 (100)
Fresh water swamp forest	77	13	11 (13)	11 (13)	85 (100)	100 (100)
Lowland swamp forest	78	10	10 (10)	10 (10)	100 (100)	100 (100)
Syzigium sp. swamp	80	1	1 (1)	1 (1)	100 (100)	100 (100)
Sholas	81	12	12 (12)	12 (12)	100 (100)	100 (100)
Riverine	82	88	73 (82)	72 (82)	82 (93)	99 (100)
Ravine	84	7	7 (7)	7 (7)	100 (100)	100 (100)
Sacred groves	85	4	4 (4)	4 (4)	100 (100)	100 (100)
Tropical seasonal swamp forest	86	17	13 (15)	13 (15)	76 (88)	100 (100)
Kans	87	5	5 (5)	5 (5)	100 (100)	100 (100)
Forest plantations	90	80	71 (77)	69 (76)	86 (95)	97 (99)
Acacia sp.	94	13	12 (13)	12 (13)	92 (100)	100 (100)
Eucalyptus sp.	95	49	40 (46)	40 (46)	82 (94)	100 (100)
Casuriana sp.	96	5	5 (5)	5 (5)	100 (100)	100 (100)
Alnus sp.	101	11	10 (11)	10 (11)	91 (100)	100 (100)
Mixed plantation	102	137	118 (122)	114 (120)	83 (88)	97 (98)
Gliricidia sp.	103	4	4 (4)	4 (4)	100 (100)	100 (100)
Degraded forest	106	521	509 (516)	507 (516)	97 (99)	100 (100)
Shifting cultivation	107	13	12 (13)	12 (13)	92 (100)	100 (100)
Abandoned jhum	108	182	156 (174)	153 (172)	84 (95)	98 (99)
Current jhum	109	123	110 (120)	109 (120)	89 (98)	99 (100)
Woodland	115	3	3 (3)	3 (3)	100 (100)	100 (100)
Tree savannah	116	158	142 (152)	141 (152)	89 (96)	99 (100)
Shrub savannah	117	23	19 (23)	19 (23)	83 (100)	100 (100)
Dense Scrub	120	959	914 (943)	913 (943)	95 (98)	100 (100)
Open scrub	121	125	103 (117)	103 (117)	82 (94)	100 (100)
Dry evergreen scrub	122	9	9 (9)	9 (9)	100 (100)	100 (100)
Dry deciduous scrub	123	550	467 (529)	465 (528)	85 (96)	100 (100)
Ziziphus sp.	124	16	15 (16)	15 (16)	94 (100)	100 (100)

Table 2 (*Continued*)

Vegetation	Code	Reference total	Classified total	Correct classification	Producer's accuracy	User's accuracy
Euphorbia scrub	125	1	1 (1)	1 (1)	100 (100)	100 (100)
Moist alpine scrub	126	118	111 (118)	111 (118)	94 (100)	100 (100)
Dry alpine scrub	127	67	56 (65)	56 (65)	84 (97)	100 (100)
Prosopis juliflora	128	71	53 (67)	53 (67)	75 (94)	100 (100)
Lantana sp. scrub	129	97	79 (93)	79 (93)	81 (96)	100 (100)
Desert dune scrub	131	156	125 (148)	124 (148)	79 (95)	99 (100)
Thorn scrub	132	11	10 (11)	10 (11)	91 (100)	100 (100)
Prosopis cineraria	133	2	2 (2)	2 (2)	100 (100)	100 (100)
Grassland	135	217	203 (213)	199 (213)	92 (98)	98 (100)
Wet grasslands	136	11	8 (11)	8 (11)	73 (100)	100 (100)
Riverine grasslands	137	32	26 (32)	26 (32)	81 (100)	100 (100)
Moist alpine pasture	138	109	97 (106)	97 (106)	89 (97)	100 (100)
Dry alpine pasture	139	356	301 (337)	297 (335)	83 (94)	99 (99)
Dry grassland	141	30	29 (28)	28 (28)	93 (93)	97 (100)
Swampy grassland	143	42	34 (40)	34 (40)	81 (95)	100 (100)
Lasiurus-Panicum grassland	144	44	38 (41)	37 (41)	84 (93)	97 (100)
Cenchrus-Dactyloctenium grassland	145	172	129 (156)	128 (155)	74 (90)	99 (99)
Sehima-Dichanthium sp. grassland	147	14	11 (14)	11 (14)	79 (100)	100 (100)
Costal swampy grassland	148	9	9 (9)	9 (9)	100 (100)	100 (100)
Orchard	150	223	178 (209)	177 (209)	79 (94)	99 (100)
Tea	151	16	13 (16)	13 (16)	81 (100)	100 (100)
Arecanut	153	1	1 (1)	1 (1)	100 (100)	100 (100)
Coconut	154	13	13 (13)	13 (13)	100 (100)	100 (100)
Mango	157	1	1 (1)	1 (1)	100 (100)	100 (100)
Saffron	158	1	1 (1)	1 (1)	100 (100)	100 (100)
Cryptomeria	160	19	18 (19)	17 (19)	89 (100)	94 (100)
Padauk	163	6	6 (6)	6 (6)	100 (100)	100 (100)
Total		15,565	14,214 (15,073)	14,114 15,045		
Non vegetation		–	1351 (492)	–		

three temperate forest classes and one sub-alpine forest class were found to be present in the Himalaya. The dominant genera in both the gregarious and locale-specific formations could be recognized by the satellite sensor and classified due to their large spatial extent. In mangrove formations, five dominant genera (*Avicennia*, *Lumnizera*, *Phoenix*, *Rhizophora* and *Xylocarpus*) could be classified and delineated as a separate class, whereas others were retained under the broad 'mangrove' class. Similarly, in grassland formations, five

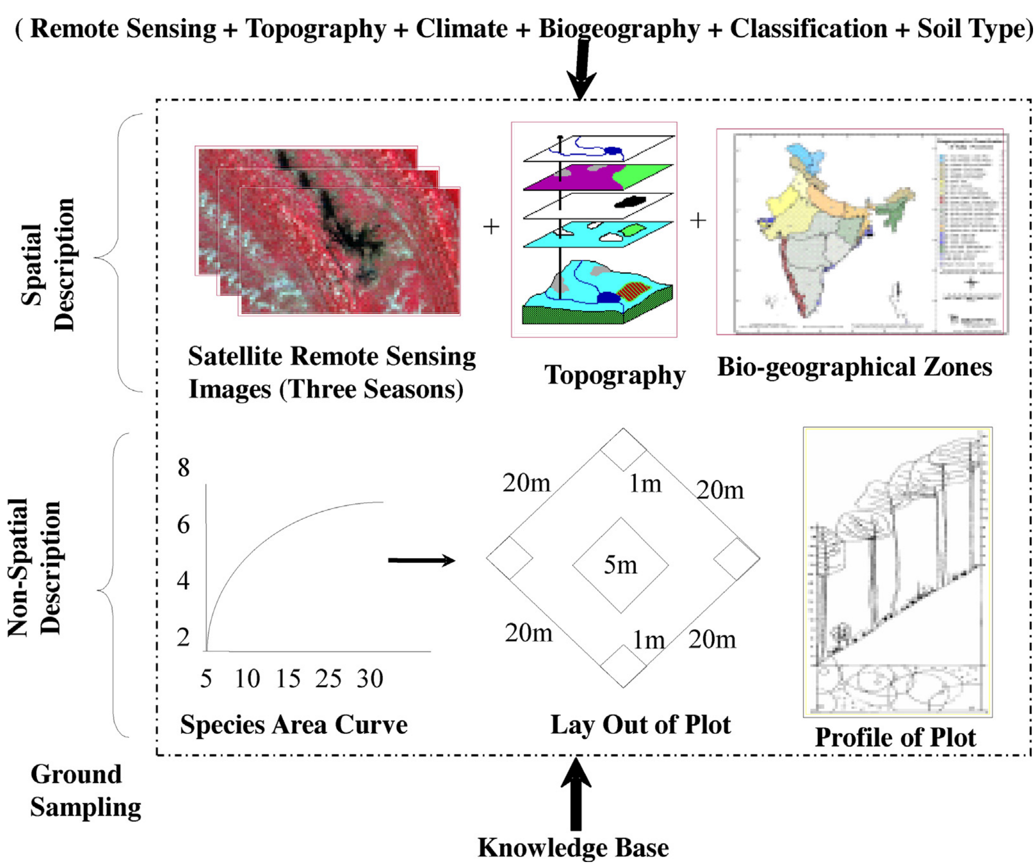

Fig. 1. Showing methodology of vegetation type mapping.

Source adapted from Anon (2008).

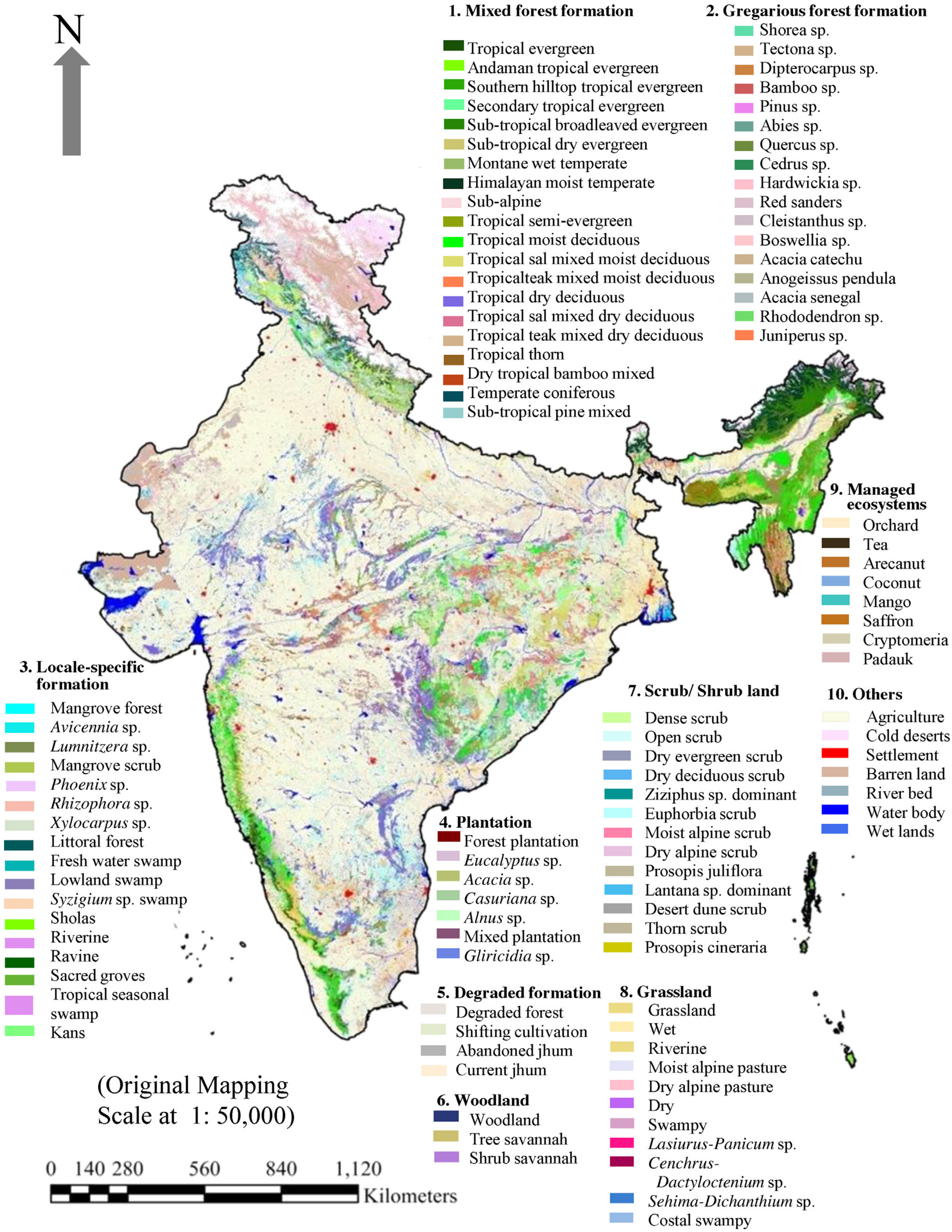

Fig. 2. Vegetation type map of India.

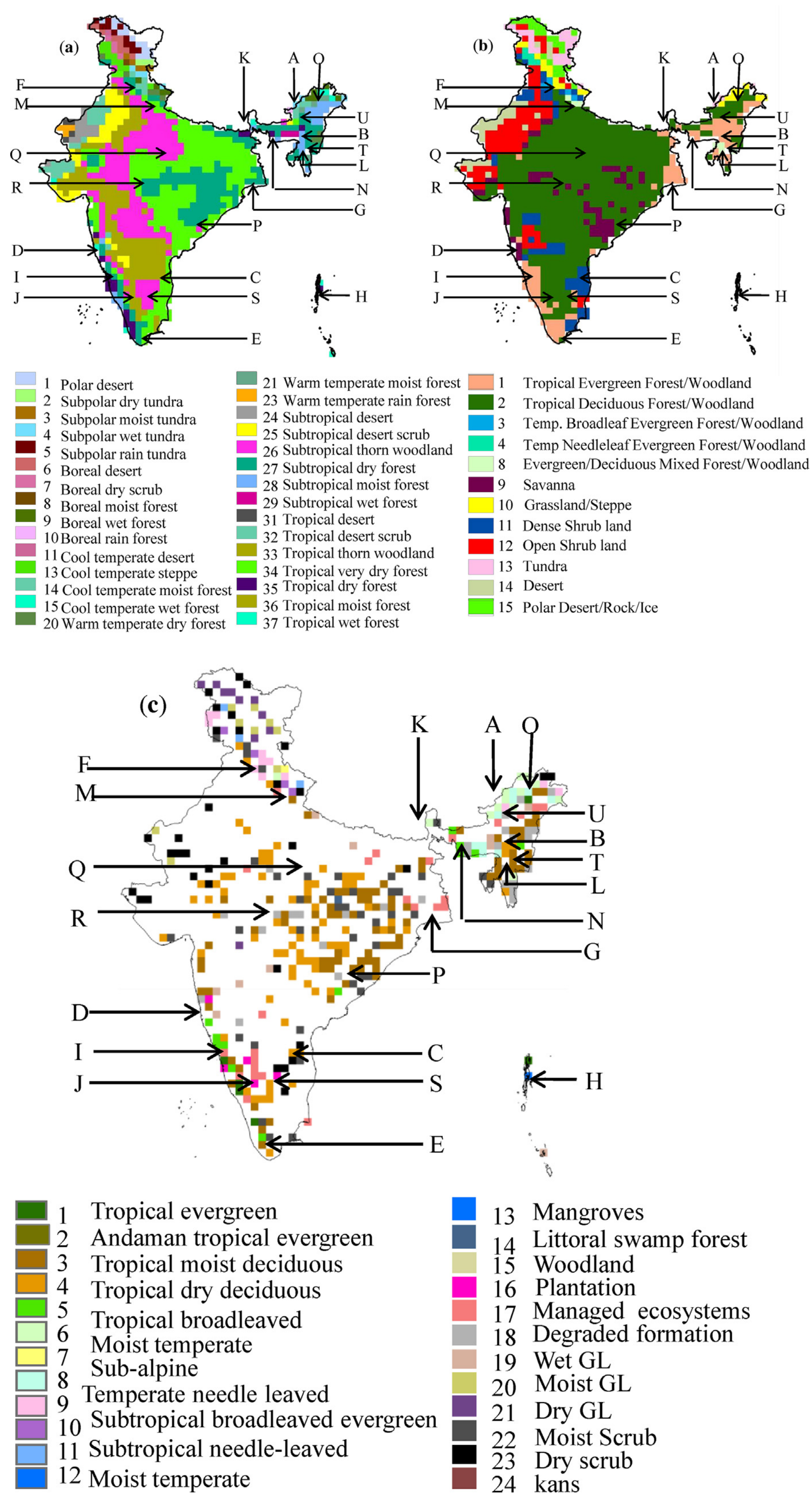

Fig. 3. Accuracy assessment of (a) Holdridge's life zone map, and (b) Potential natural vegetation (PNV) map with respect to (c) vegetation type map of India (Please refer Table 3b for descriptions on A–U).

Table 3a
Estimates of classification accuracy (producer's and user's accuracy) of Globcover map using 15,565 GPS-gathered field points at 1-pixel level, and 600 m buffer level.

Reference points	Classified pixels	Correctly classified		Producer's accuracy		User's accuracy	
		1-Pixel	600 m	1-Pixel	600 m	1-Pixel	600 m
1211	1080	454	804	37.49	66.4	42.04	74.4
2987	2757	2126	2714	71.18	90.9	77.11	98.4
6266	5805	5221	5748	83.32	91.7	89.94	99.0
537	493	223	310	41.53	57.7	45.23	62.9
181	161	59	159	32.60	87.8	36.65	98.8
3116	2831	1846	1878	59.24	60.3	65.21	66.3
1036	885	625	867	60.33	83.7	70.62	98.0
231	202	161	202	69.70	87.4	79.70	100.0
15,565	14,214	10,715	12,682				

genera forming three dominant associations (*Lasiurus–Panicum*, *Cenchrus–Dactyloctenium* and *Sehima–Dichanthium*) could be identified and delineated as separate classes, whereas others were retained under the broad 'grassland' class. The riverine class was categorized under 'locale-specific' or 'grassland' on the basis of the distribution of trees or herbs, respectively (Fig. 2).

Tropical evergreen forests are distributed mainly in the Western Ghats, northeast region and Andaman and Nicobar Islands, whereas tropical semi-evergreen forests occur as a transition zone between evergreen and moist deciduous forests. Tropical moist deciduous forests are distributed in strips along the foothills of the Himalaya, along the eastern side of the Western Ghats and in Chota Nagpur Plateau and the northwestern hills. Tropical dry deciduous forests, concentrated on both sides of the Tropic of Cancer, predominantly consist of teak (*Tectona grandis*) and sal (*Shorea robusta*). Tropical thorn forests found in western India are often composed of short trees, generally belonging to thorny leguminous species. Sub-tropical forests include both broad-leaved hill forests and dry evergreen forests and could be mapped in both the eastern and western Himalaya. Temperate broad-leaved forests are found between 1500 m and 3000 m elevation in the eastern Himalaya and the upper reaches of the Western Ghats, specifically, the Nilgiris. Temperate mixed forests, consisting of both coniferous and broad-leaved species, are distributed primarily in the western and eastern Himalaya (Fig. 2). Sub-alpine forests extend up to the tree line throughout the Himalaya and are succeeded by alpine meadows (moist and dry). Mangroves are mainly evergreen vegetation distributed in the river deltas along the coasts, including the Sunderbans. Scrub/shrub areas, making up less than 10% of the forest cover, and small saplings and trees are found in northern India, the central highlands and areas of southern India. Grasslands are found as both primary and secondary formations in the plains, along the coasts of western India, along the slopes in the Himalaya and in abandoned shifting cultivation lands. Patchiness indicates extreme conditions such as salinity. Thus, all kinds of geo-morphological forms depicted in the vegetation map reveal the dependence of the vegetation on the soil, hydrological or climatological factors that are correlated with such geo-morphological forms (Fig. 2).

The forest and tree cover in India (including orchards) is 69.26 Mha and constitutes 21.05% of the total geographic area (TGA) of the country (Table 1). Natural vegetation covers about 19.51% of the TGA in India. Mixed natural formations occupy the greatest area among the forest covers (14.25%), followed by gregarious formations (2.60%), and the rest, which include locale-specific formations, forest plantations, degraded formations and woodlands, occupy 5.26% of the TGA. Scrub and grassland occupy about 2.81% and 5.83% of the TGA, respectively. Agriculture and other managed ecosystems occupy 59.15% of the TGA. The other land cover classes are barren/long fallow land (4.47%), wetlands and water bodies (3.22%), snow cover (2.55%) and settlements (1.69%).

Seven distinct vegetation types could be differentiated among the tropical forest on the basis of tonal and contextual differentiation from satellite data. These are evergreen, semi-evergreen, moist deciduous, dry deciduous, dry evergreen forest, thorn forest, littoral forest and swamp forest (Fig. 2). The altitudinal ranges for the above vegetation types were 21–2300 m, 65–1500 m, 23–1500 m, 59–990 m, 150–980 m, 60–980 m, 20–190 m and 20–1150 m, respectively, and the precipitation ranges were 400–8000 mm, 600–11,000 mm, 600–8000 mm, 400–6000 mm, 800–2000 mm, 100–1500 mm, 2000–4000 mm and 1500–3000 mm, respectively (Table 1). Tidal swamp forests were mapped under mangroves (*Avicennia*, *Bruguiera*, *Heriteria*, *Lumnitzera*, *Phoenix*, *Rhizophora*) and mangrove scrub (Fig. 2). They fall in the altitudinal range of 20–480 m, and the precipitation range is 200–4000 mm (Table 1).

Montane sub-tropical forests are characteristic of hilly tracts and are transition zones between tropical forests and montane temperate forests. Three sub-groups of montane sub-tropical forests have been mapped, *i.e.*, sub-tropical broad-leaved hill forests, sub-tropical pine forests and secondary evergreen forests. Sub-tropical broad-leaved hill forests are present in the eastern Himalaya, in the Western Ghats and in south Indian hills. The altitudinal range of these forests is 650–2566 m, and the annual average precipitation they receive is up to 11,000 mm. Sub-tropical pine forests were observed in the western and central Himalaya, eastern Himalaya, Assam hills and Meghalaya. *Pinus wallichiana* is found at 880–3700 m elevation, with precipitation up to 7000 mm. Secondary evergreen forests occur in the plains at low elevations (19–565 m) in northwest India where the precipitation is up to 3000 mm.

A total of five classes could be mapped in the montane temperate forests, *viz.*, montane wet temperate, Himalayan moist temperate, Himalayan dry temperate, *Cedrus* spp. and *Quercus* spp. (Fig. 2). Montane wet temperate forests occur in the high altitudes of southern India as well as in northern parts of India (eastern Himalaya and northeast India). These forests are found in the elevation range between 1400 and 3900 m, where the precipitation is up to 4000 mm, and are dominated by *Ilex* and *Quercus* spp. Himalayan moist temperate forests are found across the length of the Himalaya between 1400 m and 3700 m altitude and receive average annual precipitation up to 4000 mm and are dominated by *Quercus* spp., *Cedrus* spp., *P. wallichiana*, *Abies* spp., spruce and other temperate deciduous forest species (Table 1). Himalayan dry temperate forests are basically conifer-dominated forests, having xerophytic characters. They are distributed in the higher altitudes of the Himalaya, where the average annual precipitation ranges from 400 mm to 2000 mm (Table 1). The dominating species are *Pinus gerardiana*, *Cedrus deodara*, high- altitude oak, and *Rhododendron*, *etc.*, which could be mapped separately (Fig. 2).

Sub-alpine forests are dominated by *Abeis* spp., *Picea* sp., *Betula* spp. and *Rhododendron*. The forests are evergreen but also have some broad-leaf deciduous species. These forests exist in the 2800–4200 m altitudinal range and receive average annual precipitation of up to 2000 mm (Table 1). The other associated species, *e.g.*, *Abeis* spp. and *Picea* spp., that could be mapped separately range from 2800 m to 4200 m and 2650 m to 3400 m, respectively, and receive average annual precipitation of 400–2000 mm and 1000–2000 mm, respectively (Table 1). These forests receive the maximum snowfall in winter, and snow cover exists up to June sometimes. The mapped alpine scrub was divided into two classes, *i.e.*, moist alpine scrub and dry alpine scrub, according to the precipitation range. The altitudinal range of moist and dry alpine scrub is 2700–5500 m, but the precipitation received ranges up to 3000 mm and 2000 mm, respectively (Fig. 2). Junipers are the major dominating species in this forest. They are found between 2800 m and 3650 m and receive average annual precipitation of up to 1500 mm. High altitude grasslands were mapped under moist and dry alpine pasture (Fig. 2). The altitudinal ranges of the two pasture classes are 2700–5600 m and 2750–5600 m, and they receive average annual precipitation of up to 3000 mm and 2000 mm, respectively.

One of the important observations was that the distribution of the various socio-economic and traditional disturbance regimes such as shifting cultivation was concentrated mostly in northeast India, the Deccan Peninsula and the tribal dominated districts of the Eastern Ghats of India. Similarly, most of the sacred groves of considerable area that could be mapped using remote sensing data were observed in the northeast, Western Ghats and Eastern Ghats. Abandoned shifting cultivation lands were mapped under one class; however, fresh shifting cultivation/denuded areas were mapped separately (Fig. 2). Some major habitations and settlements were delineated separately using a knowledge-based approach (Behera et al., 2001). Dark hill shadows and partial shadows in hilly regions were dealt with carefully using a visual interpretation technique. Permanent snow cover and cloud, though classified separately, were later placed in one category.

The Andaman and Nicobar Islands support tropical rain forests, which are a rich storehouse of biodiversity and change across environmental gradients such as latitude, altitude and aridity. The semi-evergreen forests of the Andamans have taken over the evergreen formations with the passage of time, while in the Nicobar Islands coconut plantations have significantly increased in extent (Fig. 2). *Pterocarpus dalbergioides*, the pride of the Andaman Islands and an endemic species, was found to be a component of both semi-evergreen and moist deciduous formations. Nine major vegetation types occur in the Andaman Islands and seven occur in the Nicobar Islands. Giant evergreen, semi-evergreen and southern hilltop evergreen forests are the unique vegetation types of the Andaman Islands, whereas mixed evergreen, lowland swamp and *Syzygium* swamp forests and grasslands are unique to the Nicobar Islands (Fig. 2). The vegetation of the Lakshadweep Islands exhibits little variation despite their being situated in the tropics and being surrounded by the sea, with flat coral sand beaches. The natural flora consists of littoral or strand vegetation (Fig. 2). Strand coral vegetation consists of three aquatic angiosperms namely, *Thalassia hemprichii*, *Syringodium isoetifolium* and *Cymodocea isoetifolia*.

Four major phenological forest types, namely evergreen, semi-evergreen, moist deciduous and dry deciduous forests, together are found in the Western Ghats (Fig. 2). The locale-specific vegetation types such as sholas (a local name for patches of stunted tropical montane forest found in valleys amid rolling grassland in the higher montane regions of south India), dry evergreen forests and kan forests (which are most often climax evergreen forests preserved through generations by village communities as sacred forests/groves), the distribution patterns of various gregarious species (*Tectona* sp., bamboo, *etc.*), grasslands, plantations, *etc.* were delineated in the Western Ghats region using satellite data. Similarly, four major phenological forest types, namely mixed conifer, *Pinus roxburghii*, dry deciduous and moist forests were mapped in the western Himalaya. Vegetated areas in the northern tip of India (Jammu and Kashmir) showed prominence predominance of dry alpine pasture, moist alpine pasture, agriculture and open scrub. Western mixed coniferous forests, Himalayan *P. roxburghii* forests (mixed with broad-leaved forests) and *C. deodara* forests are the representative temperate forest cover of the key region of the Kashmir valley (Fig. 2). Dry alpine scrub, characteristic of upslope and distant habitats with respect to moister regimes, which is the mesic counterpart of the drier type, was found to prevail. In the gregarious formation category, *P. wallichiana*, *C. deodara*, *Abies*, *Quercus* (0.2%) and *P. gerardiana* were mapped. Vegetation classes such as sub-alpine forests, *Betula* stands, moist deciduous forests and sub-tropical dry evergreen forests were found to be sparsely distributed.

Mangroves are found located along the eastern and western Indian coasts at river estuaries, including the pristine ecosystem of the Sunderbans, and the dominant species and community classes could be mapped (Fig. 2). In the Deccan Plateau Peninsula, dry deciduous and teak mixed dry deciduous forests occur in gregarious formations dominated by teak, while the degraded forests mostly comprise scrub and temporary grasslands (Fig. 2). In the northern plains, more than 86% of the area was mapped under three classes, *i.e.*, agriculture, agro-forestry and orchards (Fig. 2). Since this region has one of the highest population densities in the world, the extent of the natural areas in this region is <5%, including forests (mixed formations), gregarious forest formations, locale-specific forests, forest plantations, degradation formations, woodlands, shrub/scrubland and grasslands (Fig. 2). The region has one of the most productive lands with the alluvium from the major rivers having a depth of >2 km.

The accuracy of the Indian vegetation data was assessed at 90% and 96% for the individual pixel level and the 600 m buffer range, respectively (Table 2). However, the accuracy of the GlobCover data was found to be less, only 68% and 81% for the two levels, respectively (Table 3a). The kappa coefficient of the Indian vegetation data was enhanced from 90% to 96% for the 600 m buffer; on the other hand it was enhanced from 68% to 76% for the GlobCover data (Tables 2 and 3a). It is clear from the map that the vegetation cover type misclassification was not uniform. Problems usually involved confusion between similar and adjacent classes. It is apparent from Tables 2 and 3a that most of the classes were identified as non-vegetation classes, *i.e.*, agriculture, water bodies, settlements, *etc.* The confusion of these adjacent classes was mostly in the tropical region, where the greatest number of points was omitted to non-vegetation classes (Fig. 3). Temperate and alpine forests also showed omission to adjacent classes. Analyses showed that the GPS error was a little higher in tropical forests compared with temperate forests as a larger number of points was categorized in other classes.

The greatest mismatch of classes was observed for tropical semi-evergreen forests, tropical moist deciduous forests, tropical dry deciduous forests, sal and teak mixed dry deciduous forests, orchards, sal and teak mixed moist deciduous forests, sal, teak, thorn forests, mangrove forests, pine forests and moist Himalayan temperate forests (Fig. 3). The results showed that all the omission points are well interspersed with agricultural land. Additionally, the classes in the coastal areas also showed an omission of GPS points to water bodies, *e.g.*, Andaman evergreen forests. Apart from these classes, a few classes in northeast India, *i.e.*, jhum cultivation and degraded forests, were also interspersed with agricultural land (Fig. 3). These positional inaccuracies can be attributed to (1) the dense canopy cover in tropical forests, (2) the elevations and slope gradients in temperate forests and alpine pastures, (3) environmental factors and (4) the quality of the hand-held GPS receivers.

In general, it was observed that the number of satellites available to a GPS can be affected by physical obstructions between the GPS holder and the satellites. The precision and accuracy of the data collected using GPS receivers decrease in forested landscapes (Rodriguez-Perez et al., 2006; Danskin et al., 2009). The GPS uses microwave signals, and forest vegetation and the topography might interfere with the satellite signals (Veal et al., 2001). Moreover, in landscapes with less rugged topography, the positional accuracy is probably more affected by the vegetative cover (Dussault et al., 1999; Sager-Fradkin et al., 2007). Applying this inference to our results, we explain that the positional error in tropical forests might be due to the dense vegetation cover, which obstructs signals under the canopy. Moreover, GPS occultation events are not strictly uniformly distributed and depend on the orbital configuration of the GPS satellites. Thus, there are more occultation events in the mid-latitude area than in the tropical and polar regions (Ge, 2006). In addition, water vapor is abundant in the atmosphere in tropical regions, which induces a very strong refractivity gradient, leading to noisier signals than in dry air. On the other hand, the positional error in alpine pastures and temperate forests might be due to steeper topography and the very dense canopy cover of coniferous forests. Physical features such as the percentage of horizon available and slope can partially block or reduce the view of satellites from the receiver. Gamo et al. (2000) discussed the influence of forest structure and topography on the GPS and observed a decreasing probability of obtaining 3D locations with dense vegetation as well as steeper topography. Apart from these, positional error could be due to the quality of the GPS system used. Since the project was undertaken for national-level assessment, over the 15 years' duration of the project, the measurements in the field might have been influenced by time, season and GPS variety. According to Ucar et al. (2014), GPS receivers are categorized in three grades: (1) survey grade, (2) mapping grade and (c) consumer grade (or recreational grade). The accuracy of these systems varies from 1 cm to 100 m (Bettinger and Fei, 2010; Wing, 2011).

The clear enhancement of accuracy of the India vegetation type map at the 600 m buffer zone shows the significant contribution of the GPS position to the error. However, the accuracy of the GlobCover data did not reached the acceptable level of 85%, which shows that there was misclassification of pixels at the global level (Table 3a). This misclassification might be due to (1) an inadequate number of validation points as the GlobCover data classification methodology is constrained by the quality and number of reference data points and (2) the classification algorithm, with the interpretation and classification of a few classes proving to be difficult because pastures were regarded as semi-natural vegetation (However, in a few instances these were interpreted as meadows). A major issue might arise from the classes addressed here. In the GlobCover data, only 22 classes are addressed; however, the real world is more heterogeneous (Table 3a). Additionally, the classification algorithm classifies an area of 300 m^2 pixel to a single class, which might introduce error, when the actual area is less. The non-availability of dense validation points at the global level (limited to 4258 sample data points) also places a constraint, with the density of our data being much larger (15,565 sample data points representing India alone). It is worth addressing the error in broad classes, where misclassification of a single pixel may lead to an error of nearly 50 km^2 and might generate a wrong output when used in global models.

We did not carry out accuracy assessment for the PNV and Holdridge vegetation data against the Indian data; however, the visual interpretation technique was used to compare the vegetation class pixels, and we resampled the Indian data at a 0.5° resolution (Table 3b). We observed that most of the pixels were misclassified (Fig. 3). The classes marked with a single star (*) need the most critical consideration with respect to their classification. On the other hand, the classes marked with a double star (**) need less critical, but still significant, consideration of their classification (Table 3b). We observed most of the mismatches in pixels were with the tropical moist deciduous type in comparison with Holdridge's life zone map (Fig. 3a). However, a few pixels in the PNV map were misclassified as tropical deciduous forests, but actually represented temperate forests (Roy et al., 2012; Fig. 3b). Most of the tropical moist and dry deciduous forests are classified as sub-tropical thorn forests in Holdridge's map.

The satellite-based mapping has succeeded in overcoming many drawbacks of Champion and Seth's classification because it was based on the spectral characteristics of the vegetation and was supplemented by a field survey (Fig. 2). The present mapping has provided the exact extent and distribution of various forest vegetation types with reasonable accuracy. The moist mixed deciduous forest to the south of the Brahamputra River (northeast India) with

Table 3b
Comparison of vegetation type map of India with Holdridge's life zone map and potential natural vegetation (PNV) map using 21 randomly distributed GPS-gathered field points (reference) with respect to broad vegetation classes.

Reference point	Vegetation type map India	Holdridge's life zone map	Potential natural vegetation (PNV)
A	Moist temperate	Cool temperate moist forest	Grassland steppe/tundra[b]
B	Tropical moist deciduous	Subtropical dry forest and[b]	Tropical evergreen forest/woodland[b]
C	Tropical dry deciduous/dry scrub and moist scrub	Tropical thorn woodland	Tropical deciduous forest/dense shrub land
D	Tropical moist deciduous forest	Subtropical thorn wood land/tropical very dry forest/tropical dry forest	Tropical deciduous/woodland
E	Tropical moist deciduous forest and tropical broadleaved	Subtropical dry forest/tropical very dry forest	Tropical evergreen/woodland
F	Temperate needle leaved	Sub polar wet tundra/boreal wet forest[b]	Grassland steppe/polar desert rock/ice[b]
G	Managed ecosystem	Subtropical dry forest[a]	Tropical evergreen forest/woodland[b]
H	Tropical evergreen/mangroves/wet grassland	Tropical wet forest/tropical dry forest	
I	Tropical broadleaved	Subtropical dry forest[b]	Tropical evergreen forest/woodland
J	Managed ecosystem	Subtropical/tropical thorn woodland[b]	Tropical deciduous/woodland
k	Moist temperate	Cool temperate moist forest	polar desert rock/ice/tropical deciduous[a]
L	Tropical moist deciduous, tropical dry deciduous, tropical broadleaved	Subtropical dry forest, subtropical moist forest[b]	Tropical evergreen forest/woodland
M	Subtropical needle leaved	Warm temperate dry/subtropical dry[b]	Temperate broadleaved evergreen/woodland[b]
N	Moist temperate	Tropical deciduous forest[a]	Subtropical wet forest[a]
O	Moist temperate	Cool temperate wet forest	Tropical deciduous forest[a]
P	Tropical moist deciduous	Subtropical dry forest[a]	Tropical deciduous/woodland
Q	Tropical dry deciduous	Subtropical thorn wood land[a]	Tropical deciduous/woodland
R	Tropical moist/dry deciduous	Subtropical thorn wood land[a]	Tropical deciduous/woodland
S	Tropical dry deciduous	Subtropical thorn wood land[a]	Tropical deciduous/woodland
T	Tropical moist deciduous	Warm temperate dry[a]	Tropical deciduous/woodland
U	Moist temperate	Sub tropical moist forest[a]	Tropical deciduous/woodland[a]

[a] Indicates that the misclassification needs critical consideration.
[b] Indicates less critical but noteworthy consideration.

>15% sal forest could be mapped (Fig. 2). This is due to variations in temperature, rainfall, soil conditions, microclimate and topography (slope, aspect and altitude). Semi-evergreen formations were observed in the sub-tropical zone in Dibang valley, of eastern Arunachal Pradesh, which was primarily dominated by species such as *Altingia exelsa*, *Bischofia javanica*, *Ficus* sp., *Lagerstroemia speciosa*, *Quercus lamellosa*, *Quercus semiserrata* and *Albizia lebbeck*. Various associated/secondary forest vegetation types (abandoned jhum and degraded forests) that are very important for understanding the land cover dynamics were mapped (Fig. 2). Orchards, including tea gardens, were mapped as a separate vegetation class, which has an economic incentive tag attached to it. The state-wise forest vegetation cover was tallied with the classification of Champion and Seth (1968), which showed considerable similarity at the broad type level (Table S1).

The spectral separability of vegetation classes proved to be a useful tool in establishing relationships between ground and spectral classes, although it has generally been used to subjectively map forest vegetation classes (Roy et al., 1985; Behera et al., 2001). This close linking of the ground cover and spectral classifications demonstrates that sound image analysis and accepted ecological methods can be successfully combined to gain a better understanding of the functioning of ecosystems. This study also provides more consistent and accurate baseline information than does any conventional or satellite-based study carried out so far for India. This study has also proved that space technology provides this up-to-date information in a time-bound manner and has replaced time-consuming and imprecise land-based surveys.

5. Discussion

Detailed information about vegetation cover types is important for biodiversity conservation planning and developing future management strategies. The databases available presently in the country only provide information about the forest cover with two broad density classes (FSI, 2013). The spatial database generated in the present effort is location-specific, with a detailed inventory. The database, created in a geospatial platform, may be updated and used with future inventory programs. The outcomes of the study can also help conserve threatened species in terms of providing information on the extent of occurrence, area of occupancy and habitat fragmentation (Roy et al., 2013; Rupprecht et al., 2011; Ferraz et al., 2007). The spatial information generated on vegetation types and disturbance regimes stands as baseline data for habitat suitability assessment, prioritization for micro scale habitat studies, corridor connectivity and landscape planning (Roy, 2011). This database can be used to improve the various climate models and their outputs because the use of a coarse-resolution vegetation database for calibrating the various climate forcings in climate change studies sometimes gives erroneous results, especially in the Indian region, due to various local factors such as the orography (Renssena and Lautenschlagerc, 2000).

5.1. Cane distribution in Andamans and Nicobar Islands

Remote sensing was used to assess rattan resources, which have in recent times played an important role in the economic upliftment of local dwellers. Rattan products are categorized as non-timber forest products (NTFPs). The habitat of the cane in natural forests needs to be identified as it lies scattered in isolated patches in different types of vegetation. Information on the distribution of the cane could be obtained through ground surveys and thus a correlation was established between the understory and overstory vegetation. The ground inventory and the primary data collected showed that *Calamus* sp. is an important component of evergreen and semi-evergreen vegetation though it was observed growing along with deciduous species also. A study of the habitat parameters favoring the growth of the ecologically important plant is necessary for meeting the requirements of small-scale cane Industries and for the upliftment of the economy.

5.2. Shifting cultivation and deforestation in northeast India

Shifting cultivation was identified as the primary cause of deforestation in northeast India and seemed to be one of the major causes of forest conversion. Because the people living in or near the forest practice shifting cultivation, it continues to have a constant impact on the neighboring forests. This study has assessed precisely the extent of shifting cultivation and its role as a factor in the degradation and loss of the neighboring forests. This information can be used to derive a system of management for conserving or rehabilitating these forests. A landscape dynamics study can also elucidate the rationale behind land use decisions made by shifting cultivators. It would allow the effects of those decisions on the landscape and the constraints on future land use decisions to be predicted. The forests and forest ecosystems of northeast India are under severe pressure, from both biotic and abiotic factors – the population explosion, encroachments into forest lands, loss of forest cover to non-forest uses, shifting cultivation and degradation caused by illicit felling, lopping for fuel wood and fodder, removal of forest cover for litter, forest fires, *etc.* Given the rich biodiversity of this region, conserving it has become a major challenge. The details of the biodiversity of this region that are required include the kind, extent, quality, variety, location, status, life cycle, valuable products derived, as well as those that may be derived, accessibility, present demands and future prospects.

Vegetation data are always of importance in ecological studies. Thus accuracy and significance of data at a finer scale might permit it to be used at the global level. The current study aimed to assess the accuracy of Indian landscape-level vegetation data at two levels and emphasize the robustness of the data with respect to the global datasets that are mostly used in global-level studies. On the basis of our results and analyses, we recommend that the vegetation type map be used by the global community. Accurate representation of broad vegetation classes will lead to generation of correct outputs in dynamic global vegetation models (DGVMs) since different phenological traits (leaf area index, specific leaf area, *etc.*), and climate tolerance parameters (average temperature and precipitation) are specified for different groups. National-level data obtained from regional or landscape-level assessments could serve as a surrogate for evaluating and improving coarse-resolution land cover products.

6. Utility

India is emerging as an important player in short- and long-term ecological research on vegetation. This database will fulfil a long-standing gap in the information relating to the distribution of vegetation cover at the 1:50,000 scale and species richness that is appropriate as input for various vegetation dynamics models. The database of the vegetation type map will have potential application in ecological conservation and climate change-induced adaptation and mitigation measures such as the following.

a) Green cover: The targeted 33% forest cover of the Green India Mission requires an additional 30.11 Mha to bring in by prioritization of different forest gap areas, degraded formations and deforested barren lands adjoining forest boundaries (Ravindranath and Murthy, 2010).

b) Protected areas: The targeted 11% of the nation's land cover under PAs requires additional areas to be brought in, preferably from the natural and semi- natural forests of mixed, gregarious and locale-specific formations and scrub, grasslands and other suitable areas adjoining forest vegetation, considering the land ownership issue (AICHI Target, 2010).
c) Ecosystem resilience: In the face of rapid climate change and forest fragmentation, the resilience to fire and invasions of species can be evaluated considering climate, environmental and anthropogenic variables and the occurrence of endemic and RET species of ecosystems/niches for conservation prioritization (De Dios et al., 2007). The vegetation database integrated in Indian Forest Fire Response and Assessment (INFFRAS), which is used by different stakeholders, can also be used to develop forest cover change scenario as a function of these disturbance factors.
d) Mono-species-dominated systems: Dominant and economically important gregarious species such as *S. robusta* (sal), *T. grandis* (teak), *Pinus* spp. (pine) can be studied to understand their ecological (seed germination and regeneration, weed infestation, resource partitioning, *etc.*) and climatic responses for policy-planning (Thompson et al., 2009).
e) Participatory management and ecosystem goods: India's rural population of >10 million depends on forest produce, and hence viable rural participatory management systems contribute to reduction in deforestation and degradation (REDD) as an adaptation strategy. The geospatial database has been utilized in identification, prioritization and development of action plans and monitoring and evaluation of areas under joint forest management activities. Utilizing the vegetation database, an Indian state, namely Andhra Pradesh, has registered a joint forest management (JFM) program under the United Nations Framework Convention on Climate Change (UNFCCC) (22) in collaboration with International Training Centre (ITC), in which 128 integrated tribal development areas consisting of 0.2 M villages with a tribal population of 4 million and spread across nine states have been prioritized.
f) Spatial carbon accounting: The database has the potential to contribute to vegetation class-wise precise carbon estimation because of its distinctive division into homogeneous categories. There by it has implications in REDD and REDD+ studies. Enhancing vegetation carbon sequestration under the Clean Development Mechanism (CDM) using the database is planned.
g) Plant functional types (PFTs): The classification logic for vegetation type mapping holds the key to deriving various PFTs (groups of plant species responding in a comparable manner to environmental conditions) such as life-forms, phenology, bioclimatic tolerance, moisture regime, species content and characteristics of the vegetation classes that are required as inputs to vegetation models.
h) International protocols: Many goals of the Convention on Biological Diversity (CBD) for 2012 can be realized by evaluating the indicative trends in the extent of selected biomes, ecosystems and habitats, trends in the abundance and distribution of selected species and the connectivity and fragmentation of ecosystems using the geospatial database of vegetation types.
i) Modelling and validation: The database at the 1:50,000 scale will be very useful for regional-scale vegetation and climate modelling and habitat niche and species distribution modelling with appropriate up-scaling (Bellard et al., 2012).
j) Comprehensive biodiversity study: The database will be useful for comprehensive biodiversity studies if attributes of other groups such as mammals, birds, reptiles and fishes are integrated with their habitats using GIS tools (Rutter, 2007).
k) Indian national forest cover estimates: A similar comprehensive study on the distribution and characterization of vegetation using medium-resolution satellite imagery will clear any confusion regarding the national forest cover assessment (by Forest Survey of India (FSI)) and estimated area of plantations through the detailed classification of natural, semi-natural and managed classes.

6.1. Enabling data utilisation and awareness

The spatial and non-spatial data are all organized in webGIS (http://bis.iirs.gov.in) for open dissemination and online sharing. This allows gap areas and species/habitat relationships to be identified and helps biodiversity conservation planning by setting priority areas. The information services implemented using OGCWMS (Open Geospatial Consortium—Web Monitoring Service) services may be accessed freely by users, and the digital spatial data are available for scientific studies and implementation of conservation efforts. It is proposed to introduce this vegetation type map in school-level studies and vegetation–climate change campaigns.

The methodology presented here in relation to habitat conservation helps rapid biodiversity assessment and ecological inventory. It allows one in deciding 'what to look where' and helps protect biodiversity with limited funds available for conservation and little time to lose. It will be of great value to the scientific community, bio-resource managers and research groups for biodiversity conservation and monitoring. It will serve as baseline data for various assessments of biodiversity for addressing CBD 2020 targets (See Supplementary information).

7. Conclusions

A comprehensive high-quality vegetation type map of India has now been constructed at almost the continental scale (seeing India as a continent) on the basis of IRS LISS-III images, and interesting inferences can be drawn from it. The satellite based study, supported with adequate ground observation, has revealed the potential of identifying ecosystem distribution. Here, we have demonstrated a vegetation type mapping methodology that relates the reflectance information contained in multispectral imagery to traditionally accepted ecological classifications. This study provides more consistent and accurate baseline information than does any conventional or satellite-based study carried out so far for India.

A remote sensing-amenable hierarchical classification scheme prepared using a climatologically driven distribution of forest ecosystems, adapted from Champion and Seth (1968), was able to handle the medium-resolution LISS-III data well at a 1:50,000 scale for vegetation mapping. The vegetation classification scheme was framed with several rounds of brainstorming and is very comprehensive. Natural and semi-natural systems were classified into forests, scrub/shrub lands and grasslands on the basis of the extent of green cover. Cultivated and managed systems were classified into orchards, croplands, long fallow/barren lands and water bodies. The forest class was further sub-divided into mixed forest formations, gregarious formations, locale-specific formations, degraded/succession types and plantations (Fig. 2). The classes that were not amenable to delineation directly using remote sensing data were retained at their broad class levels. The on-screen visual interpretation technique provided good control over the regional maps, and perfect edge matching and mosaicking could be achieved to generate a seamless national-level vegetation map.

The present mapping provided the exact extent and distribution of various forest vegetation types. The vegetation type map has succeeded in overcoming many drawbacks of Champion and Seth's classification because it was based on the spectral characteristics of vegetation and supplemented by a comprehensive field survey. Higher-resolution satellite data may help community-level classification and mapping. This vegetation type map will serve as a baseline map for change detection studies in a warming world in the future.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.jag.2015.03.003.

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