J. Mt. Sci. (2015) 12(4): 854-863 e-mail: jms@imde.ac.cn http://jms.imde.ac.cn
DOI: 10.1007/s11629-015-3457-2

Benefitting from Geoinformatics: Estimating Floristic Diversity of Warwan Valley in Northwestern Himalaya, India

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Citation: Malik AH, Rashid I, Ganie AH, et al. (2015) Benefitting from Geoinformatics: Estimating Floristic Diversity of Warwan Valley in Northwestern Himalaya, India. Journal of Mountain Science 12(4). DOI: 10.1007/s11629-015-3457-2

Abstract: The Himalaya harbor rich floristic diversity which is of immense scientific interest and socio-economic importance. In this study, floristic diversity of a remote alpine valley has been studied based on information extracted from remotely sensed satellite data along with field surveys undertaken during 2008-2014. Analysis of vegetation information from satellite data revealed that ~75% of the area is covered with natural vegetation which comprises lush green coniferous forests, alpine pastures and alpine scrub lands. With inputs from vegetation information extracted from satellite data, comprehensive field surveys were planned to document the floristic diversity of the region. Analysis of species composition showed a total of 285 plant species, belonging to 191 genera in 60 families. Of these, 250 species are herbs, 14 shrubs, 2 sub-shrubs and 19 trees. The dicotyledons are represented by 240 species, monocotyledons 30, gymnosperms 04, and pteriodophytes 11 species. Asteraceae is the largest family with 35 species. During the present study, 5 species (*Corydalis cashmeriana*, *Hippophae rhamnoides*, *Primula minutissima, Saussurea sacra* and *Inula orientalis*) have been recorded for the first time from this Himalayan region. The study demonstrates the benefits of geo-informatics in floristic studies, particularly the robustness of remotely sensed data in identifying areas with potentially high species richness, which would be otherwise difficult in a complex mountainous terrain using traditional floristic surveys alone. The present study is expected to provide baseline scientific data for cutting edge studies relating to long term ecological research, bioprospecting, possible impacts of changing climate on vegetation and sustainable use of plant resources in this Himalayan region.

Keywords: Floristic diversity; Northwestern Himalaya; Remote sensing; GIS; Vegetation sampling

Received: 22 January 2015
Accepted: 9 June 2015

Introduction

Of the various ecological problems faced in modern times, the loss of biodiversity is one of the most serious global concerns. The unprecedented rate of species extinction, mainly driven by unbridled human activities, is fraught with grave economic and ecological consequences. The global diversity of biota on the planet is, however, so vast that only 1.7 % of it is scientifically known (Dar and Farooq 1997; Dar et al. 2014). This poses problems in assessing the taxa that are lost. Given such a perilous state of affairs, taxonomic inventory of biodiversity has gained much urgency worldwide (Khuroo et al. 2008). Globally, there is a scientific consensus that taxonomic documentation is the first step in assessment, conservation and sustainable use of biodiversity (Khuroo et al. 2007; Dar et al. 2001).

The floristic and vegetation studies are of prime importance in the present biodiversity-conscious world. In particular, the floristic studies and spatial distribution patterns of natural vegetation in a mountainous region can provide important inputs for conservation and bio-prospecting of biodiversity. During the past two decades, geoinformatic tools have been increasingly used for generating spatial data on vegetation types and land use patterns (Kokaly et al. 2003; Zhang et al. 2003; Joshi et al. 2005). In practice, the applications of geoinformatics have been widely demonstrated in the fields of ecology, biodiversity conservation, and biogeochemical cycling (Romshoo 2004; Wang et al. 2010). Spatial database on vegetation types and status have been used in GIS environment for landscape and habitat analysis (Pauli et al. 2003; Rashid et al. 2010). Vegetation characterization using remotely-sensed data hence provides vital inputs in prioritizing areas for biodiversity conservation (Roy and Tomar 2000; Gairola et al. 2013; Rashid et al. 2013). Geoinformatics has, thus, opened up new frontiers in understanding distribution patterns of biodiversity and the disturbance regimes affecting it (McMahon et al. 2011).

The Himalaya, recognized as a global biodiversity hotspot (Mittermeier et al. 2005), vital taxonomic information about flora of its many regions is still not available. Jammu and Kashmir (J&K) in the Western Himalaya is one such region which has been recognized as floristically under-explored (Dar et al. 2001; Dar et al 2014). Biogeographically, J&K comprises three distinct provinces: the subtropical Jammu, the predominantly temperate Kashmir and the cold-arid Ladakh. Owing to great variety of habitats all along these provinces, the region is very rich in floristic diversity. During the last two centuries, its flora has attracted the attention of many foreign and local botanists. Many of its plants are cited in the illustrious works of Hooker (1872-97) and Stewart (1972). In J&K, Jammu province possesses the greatest floristic richness. Several taxonomic studies dealing with floristic diversity of this province have been carried out over the last three decades. Sharma and Kachroo (1981) first of all published the Flora of Jammu and adjacent areas. Kapur and Sarin (1990) dealt with the flora of Trikuta hills, presenting a floristic account of the plants inhabiting these hills and the surroundings. Swami and Gupta (1998) published the Flora of Udhampur district, which is a useful treatise on the higher plants of this region. Bhellum and Magotra (2012) catalogued the flowering plants of Doda, Kishtwar and Ramban districts, dealing with floristic richness of these three adjacent districts in the Chenab Valley.

In India, the Himalayan state of J&K is recognized as one of regional hotspots of biodiversity. It has been rightly referred to as a '*Terrestrial Paradise*' on the Earth (Vigne 1842). Being located at the intersection of Holarctic and Paleotropical Floristic Realms, and falling within the bio-region of Northwestern Himalaya, the region has varied topography along elevation range which offers great habitat heterogeneity and as such is gifted with teeming treasure-troves of plant diversity. The scientific studies on the floristic diversity of J&K started about two centuries ago. Many workers have contributed to floristic studies in various areas and on various groups of plants throughout this region (Stewart 1972, 1979; Sharma and Kachroo 1981-82; Kapur and Sarin 1990; Swami and Gupta 1998; Dar et al. 2002, 2014; Malik et al. 2010, 2011; Bhellum and Magotra 2012).

The Warwan Valley, a remote region located in the Jammu province of J&K has, however, been left floristically unexplored due to its isolation, difficult terrain and inaccessibility with scanty and scattered information available on its flora (Stewart 1972; Sharma and Kachroo 1981; Vir Jee et al. 1984; Malik et al. 2010, 2011). At the present stage of investigation, to best of our knowledge, an inventory of plants occurring in this region is still unavailable. It is in this backdrop that the present study was carried out to document the floristic diversity of this region for the first time based on comprehensive field surveys conducted during 2008-2014. The present floristic study benefited a lot from geoinformatics by utilizing prior knowledge of the existing landscape conditions pertaining to broad vegetation types, elevation and slope extracted from remotely sensed data in a GIS environment. Thus, the study is an effort to generate a comprehensive floristic inventory and up-to-date spatial data about the vegetation and land use pattern in the study area. The data, so generated, has tremendous utility in framing the conservation strategies in this topographically challenging mountainous region of the Indian Himalaya.

Specifically, the paper provides detailed taxonomic inventory of plant diversity and high resolution vegetation information in the region. In addition, the paper presents information about the threatened and medicinal plants of the study area.

1 Study Area

Warwan Valley, the area of present study, is located in the southeastern part of J&K between 33°39'-33°55'N and 75°28'-75°41'E. Covering a total area of 305 km², its altitude ranges from 2116-4760 m, with most part falling in the alpine zone having elevation of > 3000 m (Figure 1). Warwan stream, a tributary of river Chenab, flows throughout the Warwan Valley and forms the main source of its irrigation and drinking water. The area exhibits complex topography with wide range in altitude and climatic conditions, resulting in diverse habitats in the form of forest lands, sub-alpine and alpine pastures, mountain slopes, glaciers and alpine lakes, etc. The climate is predominantly temperate, with wet and cold winters and relatively dry-mild summers. It is marked by well-defined seasonality, with four seasons a year-winter (December-February), spring (March-May), summer (June-August) and autumn (September-November).

2 Materials and Methods

2.1 Vegetation mapping

Using on-screen image interpretation of multispectral satellite data of LandSat TM (Spatial resolution: 30m, Path/Row: 148/37; Acquisition date: 23 October 2009) at 1:50000 scale, vegetation types were delineated in a GIS environment. In order to delineate vegetation types of the area Standard False Colour Composite band combination was used (Xiuwan 2002). An extensive ground validation was followed in order to enhance the accuracy of the delineated vegetation map. As all the vegetation types in the study area had different spatial extents, sampling was done with highest number of the samples being taken for the most dominant vegetation types

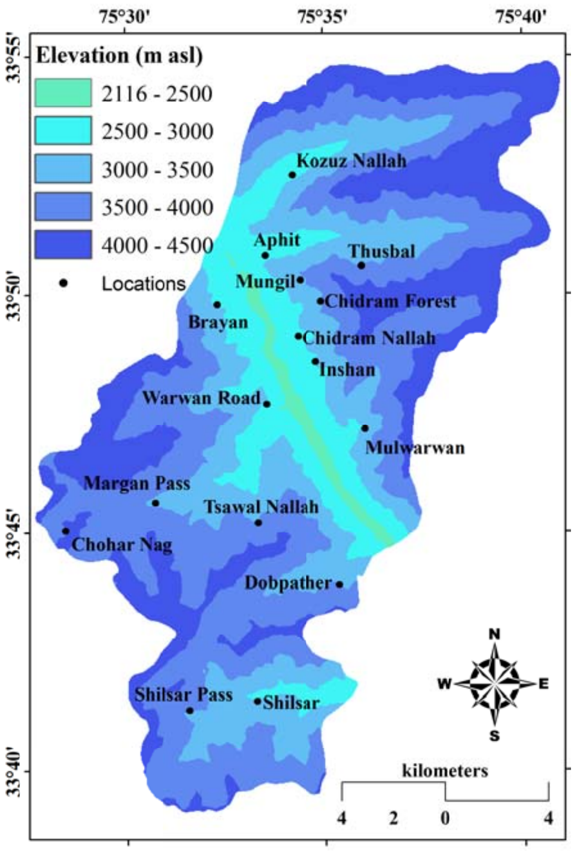

Figure 1 Location of study area (Warwan Valley) in Jammu and Kashmir.

followed by others. Stratified random sampling approach, involving sampling of different vegetation types (Cottam and Curtis 1956) based on their spatial extents, was adopted to carry out the validation of delineated vegetation types. Although it would have been ideal to sample the vegetation types based on their spatial extents, complex topography of the region did not allow it. The overall accuracy (Foody 2002) of the vegetation type map was calculated using the following formula:

$$\rho = (n / N) \times 100$$

where ρ is classification accuracy; n is number of points correctly classified on image, and N is number of points checked in the field. The vegetation types were validated with the help on an extensive GPS-aided field survey for 309 locations.

2.2 Floristic diversity

The field data were collected in several surveys and exploration trips during 2008-2014 in the company of one or more local helpers. Topographic setting along with land cover information formed the basis for sampling the region to determine the species composition. Stratified random sampling was adopted for analyzing composition of all vegetation types in the area. The exploration trips were undertaken throughout the study area; those to distant places being of longer duration (5-7 days), and to nearer places of shorter duration (2-3 days). In the first year, bulk plant collections were made, while in the subsequent years only the remnant specimens were collected. The time of sampling corresponded with the peak of vegetation season, which lasts from late May to late August in the Valley, because the area remains covered with snow throughout winter and the growth of plants starts during the months of May to August, most of the vegetation shows senescence at the end of September. Elevation above sea level was noted using a Trimble Juno SB GPS with an error of ±6 m.

Determining the sample locations for documentation of floristic richness is an intricate task in biodiversity studies. Remote sensing-derived vegetation map, used in conjunction with elevation and slope map of the area, provide vital inputs for locating the areas which need to be sampled in order to accomplish the task in time and cost-efficient manner. A digital elevation model from GTOPO, with a spatial resolution of ~860m, was used to divide the area into 403 grids of 860 m × 860 m. As the terrain is very complex and inaccessible because of sharp changes in elevation and slopes, sampling was restricted to 155 representative grids for documenting floristic richness in the region. A total of 286 locations were sampled (Figure 2) in 155 representative grids for their vegetation diversity (Degraded Forest: 11;

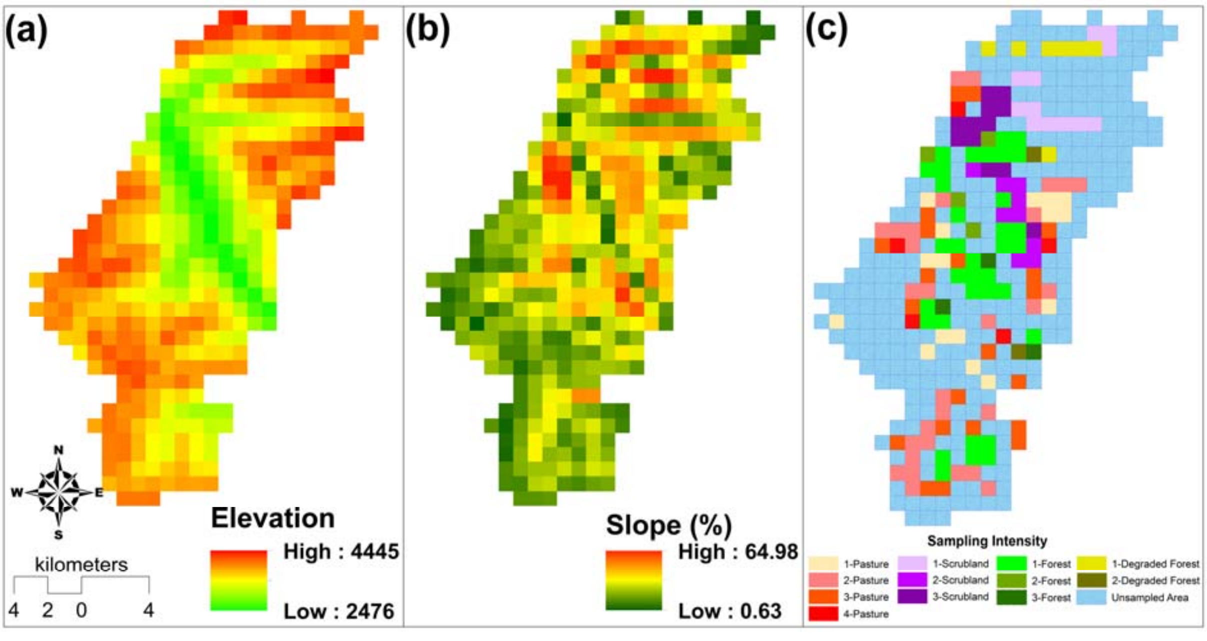

Figure 2 Variations in (a) Elevation (b) Slope and (c) Sampling intensity pertaining to broad vegetation types in the topographically complex Warwan Valley.

Dense Forest: 52; Scrubland: 66; Pastures: 157) depending on topographical accessibility. Quadrat approach (Fridley et al 2006) was utilized to estimate the floristic diversity. This involved 1 hectare plots for trees, 5 m × 5 m for shrubs and 1 m×1m for herbs. During these surveys, plants were collected from diverse habitats in different parts of the study area. The number of samples taken in an individual grid varied from 1-4 as shown in Figure 2c.

During collection, detailed field observations, including notes on life forms, flowering period and altitude of each species were recorded in the field notebook. Nomenclature of taxa was corrected/ updated using relevant taxonomic literature (Hooker 1872-97; Stewart 1972; Sharma and Kachroo 1981-82) and online resources, such as Flora of Pakistan, Flora of China and USDA-GRIN. The collected plant specimens were processed following standard herbarium techniques, and identified at the Centre for Biodiversity and Taxonomy, University of Kashmir, using relevant taxonomic literature. The identifications in some cases were verified from the already identified herbarium specimens at University of Kashmir Herbarium (KASH). The exsiccate of all the plant species included in this paper are deposited in KASH. Vegetation of the area was delineated into three zones along the altitudinal gradient: temperate (2100-2600 m), sub-alpine (2600-3200 m), and alpine zones (3200 -3500 m).

3 Results

3.1 Vegetation profile

Nine land use land cover classes were delineated in the present study: Cropland, Degraded forest, Dense forest, Scrub land, Exposed rock, Pasture, River, Settlement and Snow (Figure 3, Table 1). Pastures are the dominant class covering 46.87% of the area, followed by Dense forest (13.11%) and Scrub land (11.79%), while settlements are very sparse (0.09%). Cropland was dominated by maize, and usually found in low-lying areas or flatlands of the region. Human habitations have been classified as settlements. A substantial portion (7.84%) of the area is covered by perennial snow and glacier resources, which provide drinking and irrigational water to the populace of the catchment. The overall accuracy of delineated vegetation types is 90.61%. Class-wise accuracy of different land cover types is given in Table 1.

3.2 Taxonomic inventory

An important aspect of the study was floristic inventorying of Warwan Valley. Unlike traditional

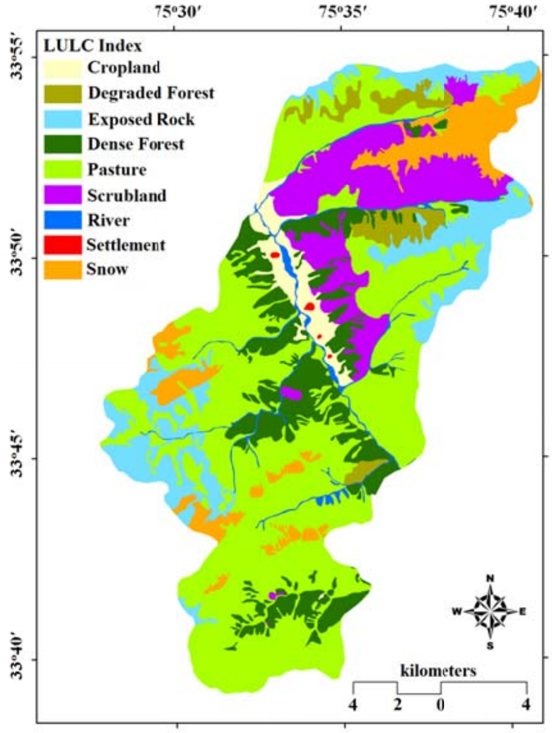

Figure 3 Land Use Land Cover / Vegetation types as delineated from LandSat satellite data.

Table 1 Spatial distribution of land use, and class-wise accuracy delineation in Warwan Valley

Class name	Area (km²/%)	GVP (N)	CC (n)	ρ
Cropland	10.18/3.32	11	10	90.91
Degraded forest	10.55/3.44	17	15	88.24
Exposed rock	35.24/11.51	6	6	100.00
Dense forest	40.13/13.11	59	51	86.44
Pasture	143.51/46.87	146	136	93.15
Scrub land	36.11/11.79	52	44	84.62
River	6.20/2.02	10	10	100.00
Settlement	0.26/0.09	4	4	100.00
Snow	24.00/7.84	4	4	100.00
Total	306.16/100	309	280	90.61

Notes: GVP = Ground Validation Points; CC = Correctly Classified; ρ = Accuracy.

floristic surveys which usually take longer time periods and are less efficient, the approach here was to utilize the benefits of information extracted from remotely sensed data so as to sample all the representative landscapes of the Valley (Rashid et al 2010). In this regard, a vegetation map as delineated from satellite data served as base map and was used along with topographic information (Figure 2) to aid in field surveys. This allowed for precise prior identification of landscapes which need to be sampled. Not only did it prove to be time saving but also efficient in the sense that critical habitats to be sampled were mapped/identified using information extracted from satellite data (Nagendra et al 2013). In all, 285 species of vascular plants were recorded during the present study. These species belong to 191 genera in 60 families; 154 genera belong to dicotyledons, 26 to monocotyledons, 4 to gymnosperms, while 7 genera belong to pteriodophytes (Table 2; Appendix 1). Among the dicotyledons, Asteraceae is the largest family, contributing 35 species, followed by Rosaceae with 21 species. Among the monocotyledons, Poaceae is the largest family, contributing 18 species, followed by Liliaceae with 6 species (Figure 4). In gymnosperms, Pinaceae is the largest family, with 3 species; while in pteriodophytes, Pteridaceae with 8 species is the dominant family (Appendix 1). The largest number of species grows in the temperate vegetation zone with 115 species followed by sub-alpine region with 100 and alpine with 70 species. Of all the plant species, 250 species are herbs, 14 shrubs, 2 sub-shrubs, and 19 species are trees.

3.3 Flowering phenology, threatened and medicinally important species

The peak flowering period in the Warwan Valley is June to July, when majority of the flora was observed in bloom: 123 species, out of total 285 species (Figure 5). Of the total plant species documented, 26 species have been categorized as threatened by previous workers in J&K (Table 3). The region is rich in medicinal plants which are used by the local people in treating different ailments (Appendix 1). The compilation of traditional knowledge about these medicinal plants in this region will serve as base line data in their commercial use for purposes of regional development (Malik et al. 2011). It has been found that 5 species (*Corydalis cashmeriana*, *Hippophae rhamnoides*, *Primula minutissima, Saussurea sacra* and *Inula orientalis*) have no past report of their occurrence anywhere in this topographically complex Himalayan region. As such, these are new records for this region (Table 4). Of these five species, the first four are endemic to this Himalayan region.

Table 2 **Numerical summary of taxa belonging to various plant groups in the flora of Warwan Valley**

Plant group	Families	Genera	Species
Dicotyledons	49	154	240
Monocotyledons	06	26	30
Gymnosperms	02	04	04
Pteriodophytes	3	7	11
Total	60	191	285

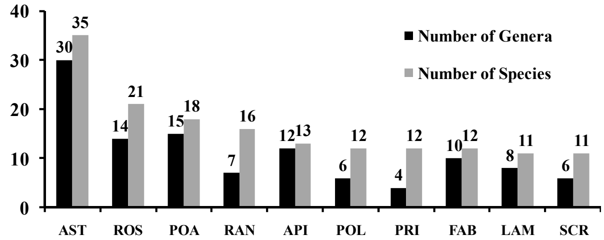

Figure 4 First ten largest plant families and the number of species therein of Warwan valley. (AST: Asteraceae, ROS: Rosaceae, POA: Poaceae, RAN: Ranunculaceae, API: Apiaceae, POL: Polygonaceae, PRI: Primulaceae, FAB: Fabaceae, LAM: Lamiaceae, SCR: Scrophulariaceae).

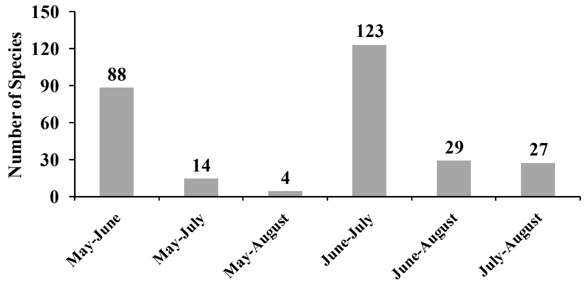

Figure 5 Duration of flowering period in terms of number of months and species in the flora of Warwan valley.

4 Discussion

Vegetation type map of the study area delineated from satellite data was very pivotal in

Table 3 Threatened plants of Kashmir Himalaya occurring in Warwan Valley

S. No	Plant species	Threat status	Source
1	*Aconitum violaceum* Jacquem. ex Stapf	Critically endangered	Kala 2005
2	*Aconitum heterophyllum* Wall.ex Royle	Critically endangered	Kala 2005
3	*Aquilegia nivalis* (Baker) Falc.ex B.D.Jacks.	Endangered	Tali et al. 2014
4	*Arnebia benthamii* I. M. Johnston	Critically endangered	Kala 2005
5	*Berberis lycium* Royle	Endangered	Kala 2005
6	*Bergenia ciliata* (Haw.) Sternb.	Vulnerable	Kala 2005
7	*Bergenia stracheyi* (Hook.f. & Thomson) Engl.	Vulnerable	Frlht 2010
8	*Betula utilis* D.Don	Critically endangered	Frlht 2010
9	*Colchicum luteum* Baker	Vulnerable	Frlht 2010
10	*Corydalis cashmeriana* Royle	Endangered	Tali et al. 2014
11	*Fritillaria cirrhosa* D.Don	Critically endangered/ Endangered	Kala 2005/Tali et al. 2014
12	*Heracleum candicans* Wall. ex DC	Endangered	Kala 2005
13	*Hippophae rhamnoides* L	Vulnerable	Kala 2005
14	*Hyoscyamus niger* L.	Vulnerable	FRLHT 2010
15	*Hypericum perforatum* L.	Vulnerable	FRLHT 2010
16	*Inula racemosa* Hook. f.	Critically endangered	Kala 2005
17	*Lagotis cashmeriana* Rupr	Vulnerable	Tali et al. 2014
18	*Lavatera kashmiriana* Cambess.	Endangered	Kala 2005
19	*Meconopsis aculeata* Royle	Critically Endangered	Kala 2005
20	*Paeonia emodi* Royle	Vulnerable	Kala 2005
21	*Picrorhiza kurroa* Royle ex Benth.	Endangered	Kala 2005
22	*Rheum webbianum* Royle	Vulnerable	Tali et al. 2014
23	*Rhododendron anthopogon* D. Don	Vulnerable	Kala 2005
24	*Rhododendron campanulatum* D. Don	Vulnerable	FRLHT 2010
25	*Saussurea sacra* Edgew.	Endangered	FRLHT 2010
26	*Saussurea costus* (Falc.) Lipsch.	Critically Endangered	Kala 2005

Table 4 New plant records to the Jammu province reported from Warwan Valley

Plant species	Altitude(m)	Threat status	Source
Corydalis cashmeriana Royle	2950-4000	Endangered	Tali et al. 2014
Hippophae rhamnoides L	2500-3100	Vulnerable	FRLHT 2010
Inula orientalis Lam.	2800-3400	NA	NA
Primula minutissima Jacquem. ex Duby	3100-3600	NA	NA
Saussurea sacra Edgew.	3650-4500	Endangered	Kala 2005

Note: NA = Not available.

helping us to carry out field surveys (Jetz et al. 2012; Powers et al. 2013). Although many taxonomic inventories exist for Kashmir Himalaya but Warwan valley is still unexplored. In this context, the present work serves as base line information regarding spatial distribution patterns of the plant wealth of this mountainous region and can provide vital responses for conservation and bioprospecting. It is a well-established fact that floristic documentation is the first step in assessment, conservation and sustainable use of biodiversity (Khuroo et al. 2007; Dar et al. 2012). As many as 26 plant taxa are found to be threatened in this region (Table 3), and need immediate conservation measures. The identification of threatened taxa will prove valuable by drawing scientific focus and public support to conserve these taxa (Ferrar 1989; Possingham et al. 2002). The documentation of threatened species, an indicator for biodiversity conservation, provides clues regarding comparative framework for conservation planning (Butchart et al. 2012; Le Saout et al. 2013) and is considered to be one of the most important steps in biodiversity conservation (Cheng and Zang 2004).

During the present study flowering phenology of all the plant species have been recorded. Any subtle changes in environmental conditions directly affect phenology (Parmesan 2007). Phenological datasets have been critical to document impacts of climate change on biological systems at both national (Karl et al. 2009) and global levels (Rosenzweig et al. 2007).

In the Warwan Valley, the temperate forests occur between 2100-2600 m asl and comprise usually the conifers, such as Blue Pine (*Pinus wallichiana*), Silver fir (*Abies pindrow*) and Spruce (*Picea smithiana*), with some associated broad-leaved trees such as Himalayan Bird Cherry tree (*Padus cornuta*), *Acer caesium* and some shrubs. In the sub-alpine forests (2600-3200 m asl), the Silver fir assumes dominance in the lower reaches, while natural stands of Birch (*Betula utilis*) occur above 3200 m asl, forming the treeline in this Himalaya region. Beyond the treeline, alpine scrub vegetation - comprising mainly the species of *Juniperus, Rhododendron, Salix, Lonicera* and *Cotoneaster,* are quite common. The mountains at sub-alpine and alpine altitudes are spotted with lush green meadows (locally known as 'Bahaks') with characteristic herbaceous elements, such as species of *Aconitum*, *Aquilegia*, *Gentiana*, *Iris, Pedicularis*, *Potentilla Primula*, *Ranunculus*, and *Saussurea*. Major tree species present in the forests belong to Pinaceae and include: *Pinus wallichiana*, *Picea smithiana* and *Abies pindrow* (Dar et al. 2001; Rashid et al. 2010); the associated deciduous trees are *Acer caesium*, *Populus alba, Pardus cornuta* and *Betula utilis*, etc (Dar et al. 2001). The scrublands are dominated by *Viburnum grandiflorum*, *Rhododendron campanulatum*, *R. anthopogon,* and *Juniperus squamata* (Champion and Seth 1968; Dar et al. 2001); while grasslands are dominated by *Cyanodon dactylon* and *Stipa sibirica* (Shaheen et al. 2011). The ferns cover the ground in association with alpine shrubs and dwarf flowering herbs. Similar studies have been carried out in Caucasus (Rafiqpoor et al. 2005), Mediterranean regions (Greuter 1991), Swiss Alps (Wohlegemuth 2002), Trans Himalayan- Nepal (Shrestha et al. 2006), Central Himalaya (Ram and Arya 1991) and Western Himalaya (Chawla et al. 2012). A comparison of these studies with present research work is provided in Table 5. It is evident that the species density in Warwan valley is higher when compared with similar mountainous regions of the world.

5 Conclusions

The present study has used an integrated approach wherein data from floristic studies have hugely benefited from the geoinformatics tools. The integration of data generated from field surveys, traditional knowledge and remote sensing was analyzed in a GIS environment to provide floristic diversity and vegetation mapping of topographically challenging mountainous terrain of Warwan Valley. A total of 285 plant species, belonging to 191 genera in 60 families has been recorded from this remote Himalayan valley, which had remained floristically unexplored till now. The Warwan valley, being isolated and inaccessible, most likely serves as the refuge for several plant species which are already recognized as threatened species in the Himalayas. The satellite data, extensively validated by ground truthing, revealed that ~75% of the study area is still covered with natural vegetation, which need to be conserved from the ill impacts of unsustainable developmental activities in mountainous landscapes. The study demonstrates the robustness of remotely sensed data in supplementing the

Table 5 Comparison of floristic diversity of Warwan valley with similar mountainous regions of the world

Mountain region	Authors	Number of species	Species density
Caucasas	Rafiqpoor et al. 2005	6000	0.04
Mediterranean	Greuter 1991	24000	0.25
Swiss Alps	Wohlgemuth 2002	1295	0.13
Trans-Himalayan Nepal	Shrestha et al. 2006	312	0.04
Rudranath (Central Himalaya)	Ram and Arya 1991	142	4.44
Kinnaur (Western Himalaya)	Chawla et al. 2012	881	0.14
Wadwan Valley (Western Himalaya)	Present Study	285	0.93

Note: Species Density values represent number of species per square kilometer traditional surveys for assessment of plant diversity in remote mountainous terrains. Hopefully, the results generated during the present study will provide baseline scientific data for advanced research studies relating to long-term mountain sites, bioprospecting, possible impacts of changing climate on vegetation and sustainable use of plant resources in this Himalayan valley.

Acknowledgements

Profound thanks are due to Dr. A. R. Naqshi for his help in identification of some plant species. AHM, AHG and AAK greatly acknowledge the Head, Department of Botany, University of Kashmir, Srialnagar for facilitating this work. We also thankfully acknowledge the satellite data provided by USGS for accomplishing the study. The authors also thank anonymous reviewers for suggesting comments which greatly improved the quality of the manuscript.

Electronic Supplementary Material: Supplementary materials (Appendix 1) are available in the online version of this article at http://dx.doi.org./10.1007/s11629-015-3457-2

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