Chapter 2
Land Cover Mapping and Its Spatial Pattern Analysis in Nepal

Guangbin Lei, Ainong Li, Xiaomin Cao, Wei Zhao, Jinhu Bian, Wei Deng and Hriday Lal Koirala

Abstract Nepal, located in a unique transition zone spanning from plains to mountains and then to the plateau, is characterized by diverse and complex land cover. Based on an object-oriented method and decision tree classifier, a land cover product covering the whole of Nepal in 2010 (hereinafter referred to as the NepalCover-2010) was produced using 30 m-resolution Landsat TM images, consisting of 8 classes at Level I and 31 classes at Level II. The accuracy of the NepalCover-2010 product at Level II was validated using samples collected from high-resolution Google Earth images. The result showed that the overall accuracy of the product was 87.17%, with a Kappa coefficient of 0.85, making it the most accurate product among similar land cover products. The product can accurately reflect the spatial patterns of land cover in Nepal. Forests are the main land cover classes, accounting for 41% of the land, followed by croplands covering about 25%. The areal proportion of paddy fields to dry farmlands was approximately two to three. Topographical and meteorological factors presented as the determining effects on the spatial patterns of land cover in Nepal. With elevation uplift from south to north, land cover classes showed a vertical zonality ordered thus: paddy fields, evergreen broadleaf forests, dry farmlands, evergreen broadleaf shrubs, evergreen needleleaf forests, grasslands, sparse vegetation, and permanent ice/snow. Land cover mapping in Nepal contributes significantly to the basic data collection in this country, and can also be of a benefit to China's international regional economic cooperation strategy entitled "the Belt and Road Initiative".

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2.1 Introduction

The Hindu–Kush–Himalayan (HKH) region has an area of approximately 4.3 million km^2, related to eight countries including Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan, which is also the major research object of the International Center for Integrated Mountain Development (ICIMOD). Diverse and complex land cover in the HKH region directly or indirectly affect the livelihoods of 1.3 billion downstream residents and maintains the stability of local ecosystems (Molden et al. 2013). Under the background of global climate change and rapid economic development, the land cover in the HKH region has witnessed tremendous changes over the past decades.

Nepal, as an essential part of the HKH region, is a typical, mountainous land-locked south Asian country (Bhattarai et al. 2009), and is located in a unique transition zone spanning from plains to mountains and then to the plateau. The temperature and precipitation of this country varies with the vertical terrain. The specific topographical, meteorological, and socio-economic conditions breed diverse and complex land cover in Nepal (Bhattarai et al. 2009). Currently, a large number of land cover products on various scales have been produced based on remote-sensing technologies, such as IGBP DISCover (Loveland et al. 2000), UMD land cover (Hansen et al. 2000), and GlobeLand30 (Chen et al. 2015) on a global scale, and Africover (Kalensky 1998) and ChinaCover (Wu et al. 2014) on the national scale. These land cover products were characterized by their different advantages due to their differences in data sources, classification systems, mapping methods, and application requirements. However, similar land cover mapping projects in Nepal have not been conducted since 1986, resulting in shortages of available land cover data for usage (Uddin et al. 2015).

Supported by an international cooperation key project of the Chinese Academy of Science (CAS), named "Comparison study on typical mountain ecosystems in China and Nepal based on remote sensing technologies (No. GJHZ201320)", land cover in 2010 over the whole of Nepal (NepalCover-2010) was produced by the Institute of Mountain Hazards and Environment (IMHE), CAS. This work not only reveals the detailed spatial patterns of land cover in Nepal, but also has a great scientific and practical significance for land resource management, ecosystem protection, and even sustainable economic and social development (Liu et al. 2014). Simultaneously, it is of benefit to the China's international regional economic cooperation strategy entitled "the Belt and Road Initiative" (Liu 2015).

This chapter comprehensively introduces the method of mapping used to generate the NepalCover-2010 product and also its validation scheme. The 2012 Statistical Yearbook data and an existing product named GlobeLand30-2010 (Chen et al. 2015) are further used to evaluate product quality. Finally, the relationship between topographical and meteorological factors and spatial patterns of typical land cover classes are analyzed and discussed.

2.2 Study Area

Nepal is located in the north of the Indian subcontinent and the south of the middle section of the Himalayas. It is bordered by China to the north and by India to the east, west, and south, and lies between latitudes 26°22′–30°27′ N, and longitudes 80°4′–88°12′ E (Fig. 2.1). Nepal exhibits a considerable variation in elevation from north to south, with the Himalayas at a maximum elevation of 8844 m standing to the north, numerous conspicuous mountains distributed in its middle section, and the Terai Plain with an average elevation below 400 m located in the south. This tremendous altitudinal gradient forms five ecological regions: Terai Plain, Siwalik, Middle Mountain, High Mountains, and High Himalaya. Temperature and precipitation in Nepal are obviously affected by its steep topography and the India Ocean southeast monsoon. The land cover in Nepal mainly includes broadleaf forests, needleleaf forests, mixed broadleaf and needleleaf forests, croplands, shrubs, grasslands, bare lands, as well as permanent ice/snow (Wang 2004).

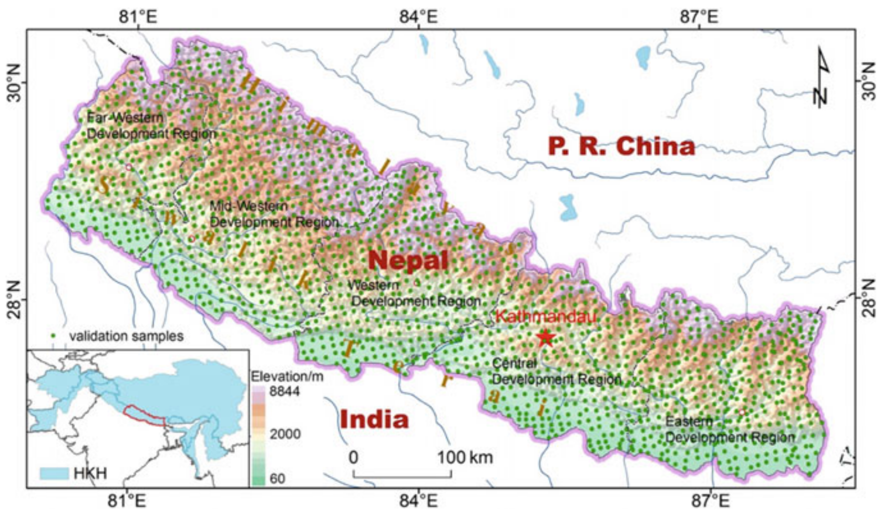

Fig. 2.1 Geographical location of Nepal and spatial distribution of the land cover validation samples

2.3 Data and Methods

2.3.1 Data

A total of 32 scenes of Landsat TM images with 30 m resolution were acquired to produce the NepalCover-2010 product (Fig. 2.2). These were downloaded from a scientific data-sharing platform of the US Geological Survey, USGS (http://glovis.usgs.gov/). To explore the potential of multi-temporal satellite images for land cover mapping, both growing and non-growing seasonal images were acquired in each satellite path/row (Fig. 2.2). For a path/row without high-quality satellite images (cloud coverage below 5%) in 2010, a number of high-quality satellite images in 2009 or 2011 were acquired. All acquired Landsat TM images were L1T products, which had been radiometrically and geometrically corrected. The LEDAPS pre-processing package (Wolfe et al. 2004) was further used for atmospheric correction on each image in this study.

Besides the remote-sensing images, topographical data including elevation, slope, and aspect, and meteorological data including temperature and precipitation, were used as auxiliary data in land cover mapping and subsequent analyses. The 30 m-resolution ASTER GDEM data was adopted. Slope and aspect were calculated from the GDEM data using ERDAS software. Temperature data at meteorological stations were downloaded from the US National Climatic Data Center (NCDC http://www.ncdc.noaa.gov/). Based on the acquired temperature data, the annual average temperature over the whole of Nepal was interpolated using ANUSPLIN software. Precipitation data used in this study were the monthly TRMM 3B43 products with a spatial resolution of 0.25° × 0.25° (ftp://disc2.nascom.nasa.gov/data/s4pa/TRMM_L3/TRMM_3B43/).

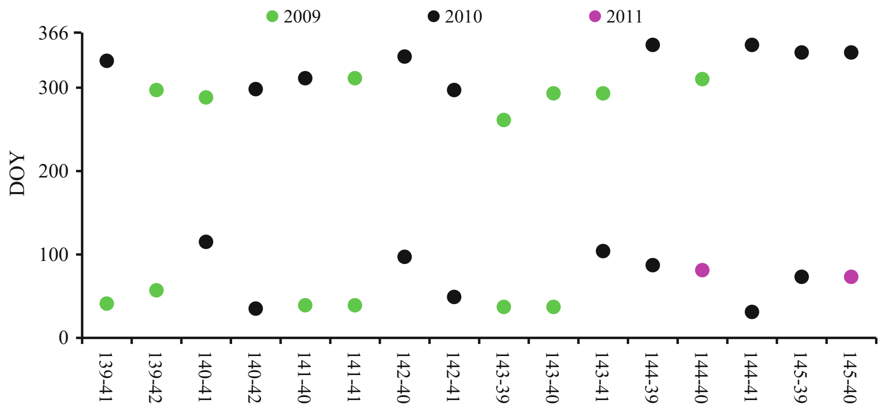

Fig. 2.2 The acquisition time of Landsat TM images used to produce the NepalCover-2010 product

2.3.2 Land Cover Mapping

2.3.2.1 Land Cover Classification System

The land cover classification system adopted by the NepalCover-2010 product was formed by taking into full consideration the existing classification systems (De Fries et al. 1998; Hansen et al. 2000; Zhang et al. 2014) and the actual land cover situation in Nepal. The classification system adopted consists of 8 classes at the first level (Level I) and 31 classes at the second level (Level II), which is detailed in Table 2.1.

2.3.2.2 Land Cover Classification Method

The object-oriented classification method was used to produce the NepalCover-2010 product, and its flowchart is shown in Fig. 2.3. The multi-temporal satellite images were firstly collected and pre-processed. After object-oriented, multi-resolution segmentation, a series of rules for each path/row were built by decision tree algorithm (See 5.0) and were then used to produce preliminary classification results. Finally, post-processing of classification was used to further improve the quality of the classification results. This chapter mainly introduces four critical steps: (1) image segmentation, (2) training sample collection, (3) automatic classification via a decision tree algorithm, and (4) error checking and revising. Details are given in Fig. 2.3 and the following text.

Image segmentation: Image segmentation represents the foundation of the object-oriented classification method. It groups homogenous neighboring pixels into meaningful objects based on the principles of homogeneity and heterogeneity (Benz et al. 2004). In this study, a widely used, multi-resolution segmentation algorithm (Benz et al. 2004; Zhang et al. 2014), embedded in the eCognition 8.7 platform, was adopted to segment satellite images. Scale, shape, and compactness are three critical parameters. The optimal values of these parameters are determined by trial-and-error along with visual assessment of the segmentation results. In this study, the scale parameter was set as 25, the shape parameter was set as 0.1, and compactness as 0.7.

Training samples collection: Training samples were collected from high-resolution Google Earth images. The sample size of each path/row was not less than 1000, and the sample size of each land cover class was at least 50.

Automatic classification with a **decision tree algorithm**: The total number of features used for classification was 28, including mean value and standard deviation of the reflectance value of each band, texture features, shape features, topographic features (including elevation, aspect, and slope), as well as the Normalized Difference Vegetation Index (NDVI), Modified Normalized Difference Water Index (MNDWI, Xu 2005), and Normalized Difference Building Index (NDBI, Chen et al. 2006).

Table 2.1 Land cover classification system adopted in the NepalCover-2010 product

Level I		Level II		Classification rules
Name	Code	Name	Code	
Forest	1	Evergreen broadleaf forest	11	Natural or semi-natural vegetation, evergreen, rounded tree canopy, C > 60%, H > 5 m
		Deciduous broadleaf forest	12	Natural or semi-natural vegetation, deciduous in winter, rounded tree canopy, C > 60%, H > 5 m
		Evergreen needleleaf forest	13	Natural or semi-natural vegetation, evergreen, needle leaf, C > 60%, H > 5 m
		Mixed broadleaf and needleleaf forest	14	Natural or semi-natural vegetation, C > 60%, H > 5 m, 25% < needleleaf broadleaf < 75%
		Tree garden	15	Artificial vegetation, around artificial surface, C > 60%, H > 5 m
Shrub	2	Evergreen broadleaf shrub	21	Natural or semi-natural vegetation, evergreen, rounded tree canopy, 20% < C<40%, 0.3 m < H<5 m
		Deciduous broadleaf shrub	22	Natural or semi-natural vegetation, deciduous in winter, rounded tree canopy, 20% < C<40%, 0.3 m < H<5 m
		Evergreen needleleaf shrub	23	Natural or semi-natural vegetation, evergreen, needleleaf, 20% < C<40%, 0.3 m < H<5 m
		Shrub garden	24	Artificial vegetation, around artificial surface, 20% < C<40%, 0.3 m < H<5 m
Grassland	3	Meadow	31	Natural or semi-natural vegetation, aquatic, C > 20%, 0.03 m < H<3 m
		Steppe	32	Natural or semi-natural vegetation, xerophyte or mesophyte, C > 20%, 0.03 m < H<3 m
		Tussock	33	Natural or semi-natural vegetation, C > 20%, 0.03 m < H<3 m
		Lawn	34	Artificial vegetation, around artificial surface, C > 20%, 0.03 m < H<3 m

(continued)

Table 2.1 (continued)

Level I		Level II		Classification rules
Name	Code	Name	Code	
Wetland	4	Herbaceous wetland	41	Natural or semi-natural vegetation, freshwater marsh with mainly seasonal floating plants, C > 20%, 0.03 m < H<3 m
		Lake	42	Natural water surface, still water, water conservation
		Reservoir/pond	43	Artificial water surface, still water, water conservation
		River	44	Natural water surface, linear flow
		Canal/channel	45	Artificial water surface, flowing, functions of water distribution, flood diversion, flood drainage and water supply
		Flood plain	46	Naturally formed, around rivers, inundated in flood season and emergent in dry season
Cropland	5	Paddy field	51	Artificial vegetation, disturbed soil, mainly aquatic plants and partly paddy-upland rotation, harvesting process
		Dry farmland	52	Artificial vegetation, disturbed soil, mainly xerophytes and drought-resistant crops, harvesting process
		Tree orchard	53	Artificial vegetation, economic benefit, C > 60%, H > 5 m
		Shrub orchard	54	Artificial vegetation, 20% < C<40%, 0.3 m < H<5 m
Artificial surface	6	Residential land	61	Hard artificial surface, residential buildings
		Industrial land	62	Hard artificial surface, manufacturing buildings
		Transportation land	63	Hard artificial surface, linear ground objects
		Mining field	64	Mining pits, stairs and outdoor man-made channels
Bare land	7	Sparse vegetation	71	Natural or semi-natural vegetation, 4% < C<20%, 0.03 m < H<3 m
		Bare rock	72	Naturally formed, bare hard surface, non-vegetative
		Bare soil	73	Naturally bare soil texture sheets, sparse vegetation
Permanent ice/snow	8	Permanent ice/snow	81	Naturally occurring, solid reservoir, at the covered surface

NOTE C is short for coverage/canopy density (%); *H* is short for vegetation height (m)

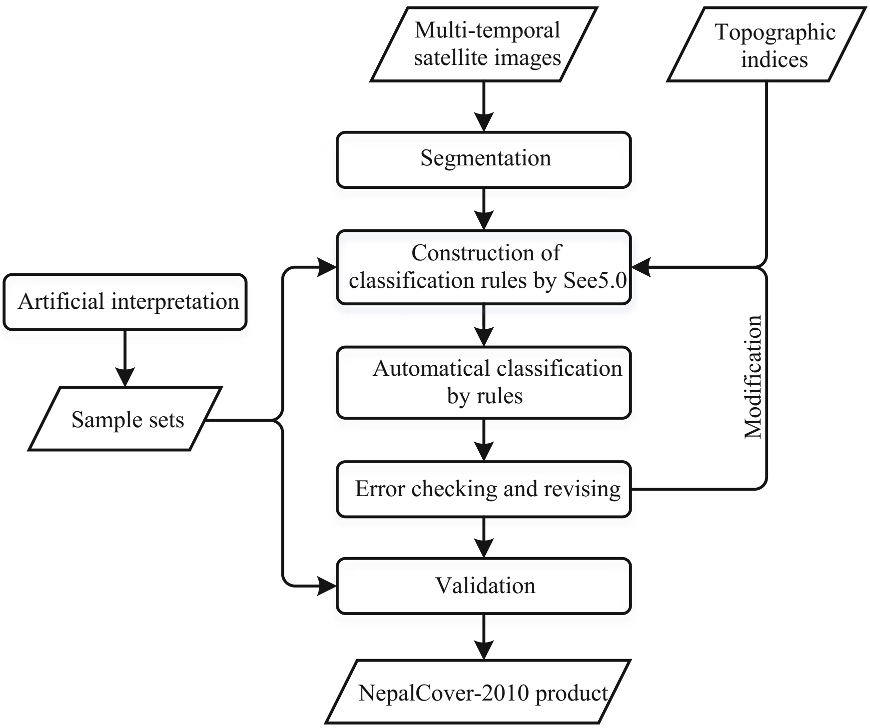

Fig. 2.3 The flowchart of the proposed object-oriented classification method

The essential part of classification using a decision tree algorithm is to establish the classification rules (Jia et al. 2011). This study used decision tree classifier See 5.0 (Friedl et al. 1999) to train collected samples and features, and then to form corresponding classification rules. Finally, the classification results were derived following these rules. Figure 2.4 shows a typical classification rule set used for the Terai Plain (path/row: 141/41, WRS2).

Generally, the differences in the NDVI, between vegetation and non-vegetation, are evident in the non-growing season. Therefore, the NDVI in the non-growing season was used to distinguish between them. The MNDWI, derived from the same season, was chosen to identify open water misclassified as vegetation, because it is very sensitive to water. Vegetation was subdivided into forests, shrubs, grasslands, croplands, and herbaceous wetlands, while non-vegetation was subdivided into artificial surfaces, bare lands, permanent ice/snow, and open waters. The T2_B2_Mean feature was used to identify croplands, grasslands, and forests with significant spectral differences among them during the non-growing season. Considering the "absorbing valley" of forests in the red band, the T1_B3_Mean feature was adopted to distinguish between forests and shrubs. The T2_NDVI_Mean feature was used to differentiate croplands from grasslands due to the difference in the NDVI in the non-growing season. Open waters had noteworthy

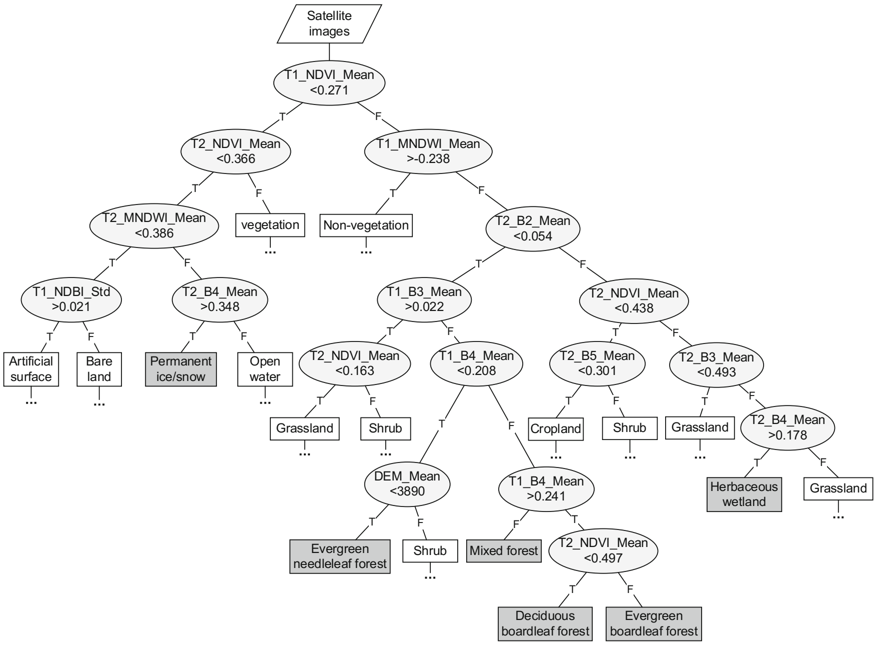

Fig. 2.4 Typical classification rules used for producing the land cover map of the Terai Plain (*path/row*: 141/41, WRS2). *T1* represents Landsat TM images in the growing season (2009-03-10), *T2* represents Landsat TM images in the non-growing season (2009-11-07), *Bx* represents the band *x* of the Landsat TM image, *Std* represents standard deviation, and the *ellipsis* represents a land cover class which needs to be further subdivided

absorption in the near-infrared band, therefore, the T2_B4_Mean feature was adopted to differentiate open waters, permanent ice/snow, as well as herbaceous wetlands. Artificial surfaces and bare lands were distinguished using the mean value of the NDBI. Finally, above land cover classes were further subdivided. Taking the forests subdivision as an example, broadleaf forests, needleleaf forests, and mixed broadleaf and needleleaf forests were distinguished using the near-infrared band (T1_B4_Mean feature) and the NDVI (T2_NDVI_Mean feature). Similar approaches were conducted for the subdivision of shrubs, grasslands, croplands, artificial surfaces, open waters, and bare lands.

Error checking and revising: Error checking and revising mainly deals with problems such as cloud and cloud shadow areas, spatial discontinuity phenomena of classification results, as well as certain regions and land cover classes with relatively low classification accuracy. Due to the limitations of the interpretation abilities of satellite images and classification methods, some linear land cover classes, like rivers and roads, were discontinuous in the automatic classification results, and some other land cover classes, like industrial lands and mining fields, were not easily classified automatically. To solve these problems, artificial modification was needed. The evergreen and deciduous characteristics of forests were

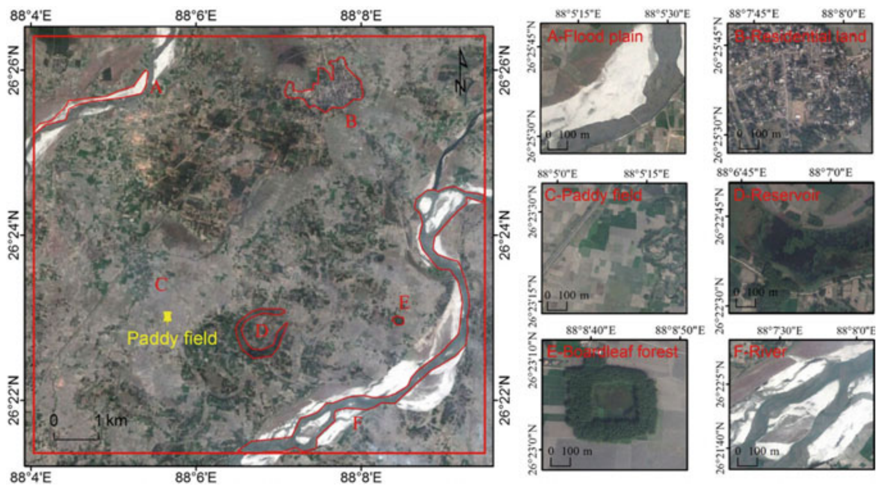

Fig. 2.5 A diagram depicting the method used for selecting validation samples from high-resolution Google Earth images. The red box represents a 10 km × 10 km grid

automatically distinguished using the differences in the NDVI between growing and non-growing season images (Lei et al. 2014). For cloud and cloud shadow regions, spatial autocorrelation[1] and multi-temporal satellite images were adopted to fill the gaps caused by clouds. The spatial discontinuity phenomena of land cover often occurs at the overlap regions of neighboring paths/rows, which are mainly caused by the differences in the acquisition phase of selected satellite images and the cognitive level of mappers. Therefore, spatial consistency verification (Lei et al. 2016) is indispensable when removing the spatial discontinuity phenomena which exists in the NepalCover-2010 product (Tobler 1970).

2.3.2.3 Accuracy Validation

Accuracy validation is an essential part of land cover mapping. An error matrix was calculated by comparing the classification results with the validation samples, which were collected from high-resolution Google Earth images – a method proved as successful by Chen et al. (2007). The study area was divided into a series of 10 km × 10 km grids. Land cover classes were visually interpreted in each grid, based on high-resolution Google Earth images. The land cover class with the largest area in each grid was selected as a validation sample. For an example, as shown in Fig. 2.5, the grid contains at least six land cover classes, and the area of paddy

[1]The First Law of Geography, according to Tobler (1970), is "everything is related to everything else, but near things are more related than distant things.", which is the foundation of the fundamental concepts of spatial dependence and spatial autocorrelation.

fields is much larger than that of the other land cover classes, therefore, a validation sample was collected from the geometric center of the polygon of paddy fields. In addition, validation samples of some land cover classes which did not occupy large areas, such as rivers, flood plains and residential land, were also collected.

2.4 Results and Analysis

2.4.1 The NepalCover-2010 Product and Its Accuracy

Described in the method above, the NepalCover-2010 product was generated, and its land cover map is shown in Fig. 2.6.

A total of 1528 validation samples were collected as shown in Fig. 2.1, and Table 2.2 lists the error matrix of the NepalCover-2010 product. The overall accuracy of Level I in the NepalCover-2010 product was 94.83%, with a Kappa coefficient of 0.94, whilst the overall accuracy of Level II reached 87.17%, with a Kappa coefficient of 0.85. The producer and user accuracy for most of the land cover classes exceeded the overall accuracy of Level II in the NepalCover-2010 product (87.17%), like deciduous broadleaf forests, paddy fields, dry farmlands, flood plains, residential lands, and permanent ice/snow.

Table 2.2 shows that paddy fields and dry farmlands are relatively easy to be misclassified, which frequently occurred in the Terai Plain and the mountainous valley areas. As a consequence of the fact that the tillage technologies at these areas are mainly paddy–upland rotation and mixed cropping, the boundaries between

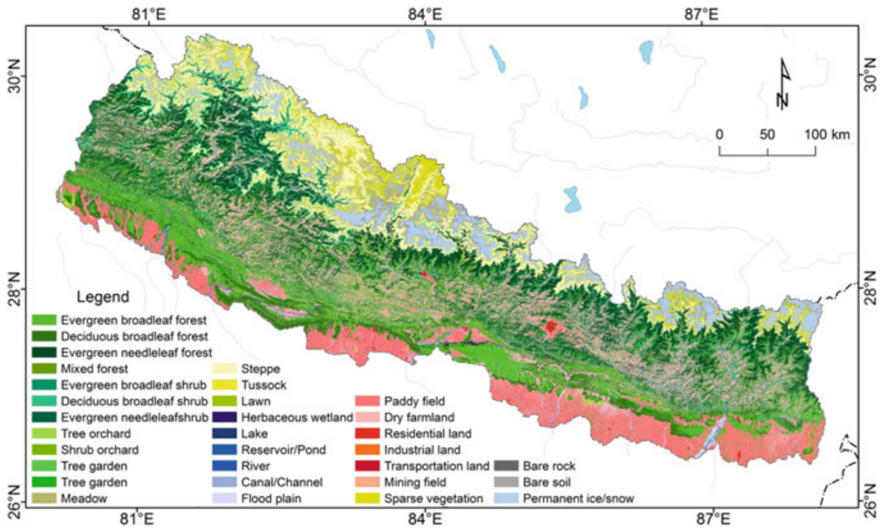

Fig. 2.6 The final NepalCover-2010 product

Table 2.2 Error matrix of the NepalCover-2010 product

		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Total	PA (%)
Classification results																			
Validation samples	A	188		8	3	4							1					204	92.16
	B		85	2	1	1												89	95.51
	C	27	1	163	3	1												195	83.59
	D	4		1	21								6					32	65.63
	E	2	6			33			2				3					46	71.74
	F					3	12	1	2									18	66.67
	G							11										11	100.00
	H								134				5		6		3	148	90.54
	I									13		2						15	86.67
	J										12							12	100.00
	K	3									1	142	14					160	88.75
	L	11	4	4		5		2	3	2		16	328					375	87.47
	M											1		26				27	96.30
	N							1	9						39		1	50	78.00
	O														3	16	4	23	69.57
	P			1		1	1	2	7						2		109	123	88.62
	Total	235	96	179	28	48	13	17	157	15	13	161	357	26	50	16	119	1528	
	UA (%)	80.00	88.54	91.06	75.00	68.75	92.31	64.71	85.35	86.67	92.31	88.20	91.88	100.00	78.00	100.00	93.16		

Total accuracy 87.17%, *Kappa coefficient* 0.85

Note A Evergreen broadleaf forest; *B* Deciduous broadleaf forest; *C* Evergreen needleleaf forest; *D* Evergreen broadleaf shrub; *E* Deciduous broadleaf shrub; *F* Evergreen needleleaf shrub; *G* Meadow; *H* Steppe; *I* River; *J* Flood plain; *K* Paddy field; *L* Dry farmland; *M* Residential land; *N* Sparse vegetation; *O* Bare soil; *P* Permanent ice/snow; *PA* Producer accuracy; and *UA* User accuracy paddy fields and dry farmlands on satellite images are often difficult to distinguish. Terrain shadows and cloud shadows are inevitable in mountain areas, which led to a few misclassifications between broadleaf forests and needleleaf forests. The accuracy of shrubs is the lowest among all Level I classes in the NepalCover-2010 product. The misclassification of shrubs comes about due to the fact that their growth is usually mixed within croplands and forests. Mixed pixel is especially prominent on the 30-m-resolution satellite images, which is a non-negligible factor for classification errors. Meanwhile, the background noise and differences in soil properties also affect NDVI values of vegetation, which might cause confusion among shrubs, croplands, and forests. In future research, the soil-adjusted vegetation index (SAVI) and an improved soil-adjusted vegetation index (Li et al. 2015) will be further used. Simultaneously, higher resolution remote sensing imagery will also be incorporated to reduce classification errors in regions with relatively low accuracy.

This study also conducted a comparative analysis to further evaluate the quality of the NepalCover-2010 product. The data used in the comparative analysis included 2012 Statistical Yearbook data and an existing product named GlobeLand30-2010 (Chen et al. 2015). The comparison result is shown in Fig. 2.7. The orders of areal ratios for each land cover class in the three products were consistent: forests > croplands > grasslands > shrubs > bare lands > permanent ice/snow > wetlands > artificial surfaces. However, in terms of a single land cover class, the areal ratios in each of the three products were different. Areal proportion of forests in the NepalCover-2010 product was almost in line with that of the GlobeLand30-2010 product, about 1% higher than that of the Statistical Yearbook data. For croplands, the areal ratio in the NepalCover-2010 product was about 2% lower compared to the other two products, but much closer to the report (32,510 km^2) published by Nepal's Central Bank website (http://www.NRB.org.NP/). For grassland, the areal ratio in the NepalCover-2010 product was almost identical to the data in the Statistical Yearbook, which was about 11%, while the areal ratio of grasslands in the GlobeLand30-2010 product reached 16%. In terms

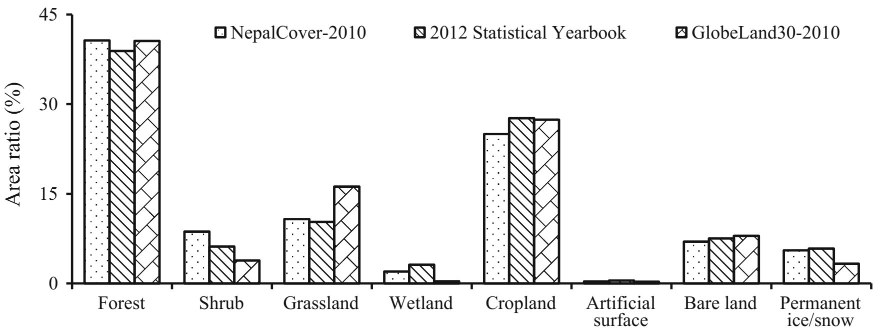

Fig. 2.7 The areal ratio of each land cover class for the NepalCover-2010 product, 2010 Statistical Yearbook of Nepal, and GlobeLand30-2010 product

of permanent ice/snow, the areal ratio in the NepalCover-2010 product was almost consistent with the data in the Statistical Yearbook, which was about 6%, and almost 3% higher than that of the GlobeLand30-2010 product. The difference in areal ratio of bare lands and artificial surfaces among these three products was quite small. According to the above comparison results, the NepalCover-2010 product was the most accurate in general.

Based on the 1528 validation samples, this study compared the accuracy of the NepalCover-2010 product with that of the GlobeLand30-2010 product. The comparison results showed that the overall accuracy of the NepalCover-2010 product at Level I was 14.72% higher than that of the GlobeLand30-2010 product. The producer accuracy of forests, shrubs, grasslands, wetlands, croplands, artificial surfaces, and permanent ice/snow in the NepalCover-2010 product was higher than that of the GlobeLand30-2010 product. For example, the producer accuracy of shrubs and wetlands was 40% higher, permanent ice/snow was about 26% higher,

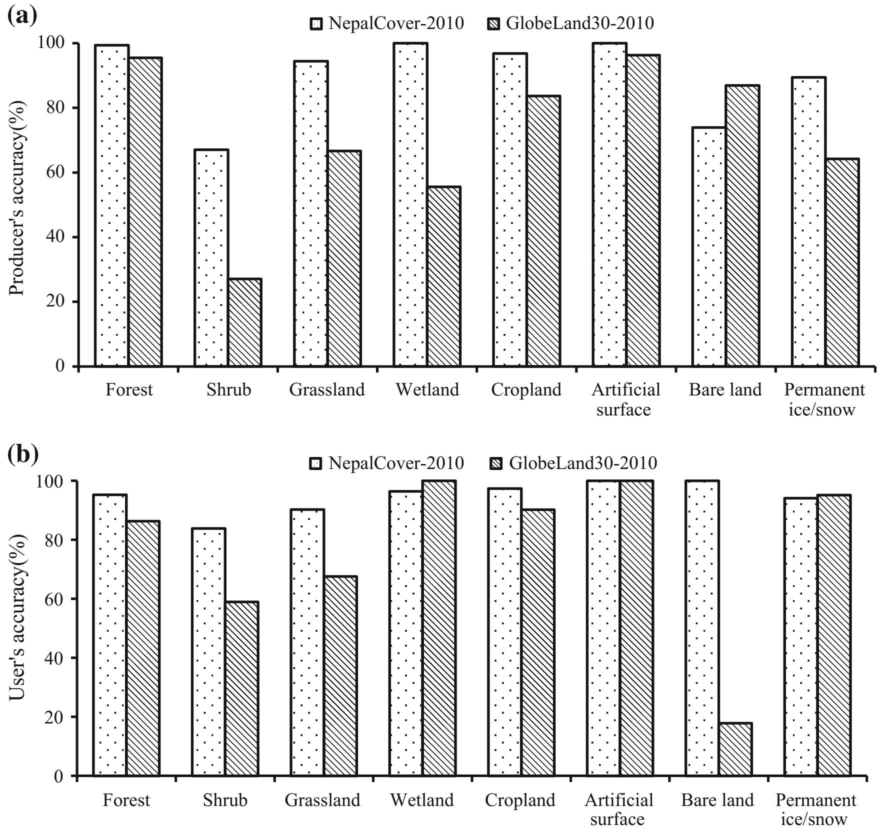

Fig. 2.8 Comparison of producer accuracy **a** and user accuracy **b** between the NepalCover-2010 product and the GlobeLand30-2010 product

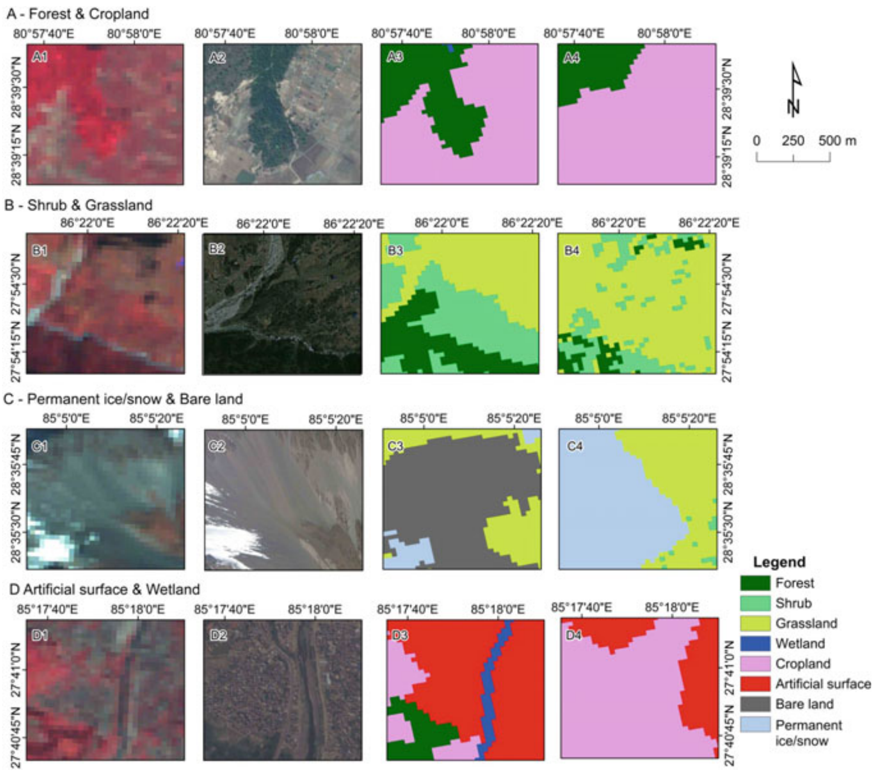

Fig. 2.9 Comparison of the NepalCover-2010 product with the GlobeLand30-2010 product over four typical regions: *A1*, *B1*, *C1*, and *D1* represent Landsat TM images; *A2*, *B2*, *C2*, and *D2* represent high-resolution Google Earth images; *A3*, *B3*, *C3*, and *D3* represent the NepalCover-2010 products; and *A4*, *B4*, *C4*, and *D4* represent the GlobeLand30-2010 product

farmlands was about 13% higher, forests and artificial surfaces was about 4% higher (Fig. 2.8a). The user accuracy of forests and croplands in the NepalCover-2010 product was about 8% greater than that of the GlobeLand30-2010 product, shrubs and grasslands was about 24% higher, and bare lands accuracy was about 80% higher (Fig. 2.8b).

Meanwhile, the NepalCover-2010 product better reflected spatial distribution patterns of land cover in the transition areas than did the GlobeLand30-2010 product (Fig. 2.9a, b). To precisely distinguish permanent ice/snow from bare lands in the NepalCover-2010 product (Fig. 2.9c), two satellite images—one in the growing/warm season and the other in the non-growing/cold season—were used in each path/row. In addition, the NDVI, MNDWI, and NDBI were also applied in order to generate the NepalCover-2010 product, which greatly eliminated the effects of vegetation and open waters on extraction of artificial surfaces (Fig. 2.9d). In conclusion, the overall quality of the NepalCover-2010 product was better than that of the GlobeLand30-2010 product, which can accurately reflect the spatial patterns of each land cover class in Nepal.

2.4.2 The Statistical Analysis of Land Cover in Nepal

Administratively, the whole land of Nepal is divided into five development regions, namely the Eastern, Central, Western, Mid-Western and Far-Western Development Regions (Fig. 2.1). The areal proportions in each development region are 19.34, 18.52, 19.98, 28.82, and 13.33%, respectively. The area and areal proportions of each land cover class in Nepal, according to the statistics of the NepalCover-2010 product, are listed in Table 2.3 and the areal proportions of each land cover class within the different development regions is presented in Fig. 2.10.

Forests were mainly distributed in the Terai Plain, Siwalik Mountains, and Mahabharata Mountains, covering 60,009.27 km^2, which accounted for 40.66% of the land. Among these, evergreen broadleaf forests and evergreen needleleaf forests were the main forest classes. The areal proportion of forests in the Central and Western Development Regions were larger than in other regions, due to the fact that there are three national forest parks (Rara National Park, Shey–Phoksundo National Park, and Royal Bardia National Park) and one hunting reserve (Dhorpatan Hunting Reserve) in these regions.

The area of croplands was 36,901.96 km^2, accounting for 25.01% of the land. They were mainly distributed in the Terai Plain, Kathmandu Valley, Pokhara Valley, Koshi River Basin, Gandaki River Basin, and Carl River Basin. The areal proportion of paddy fields and dry farmlands was approximately two to three. Almost three-quarters of paddy fields were located in the Terai Plain, and two-thirds of dry farmlands were situated in mountainous valleys. The areal ratio of croplands in the Eastern and Central Development Regions were the largest, covering 52.1% of the overall cropland area, which was closely related to those regions increasing populations, rapid development of agriculture, abundance of water resources, and appropriate growth environment for crops.

Shrubs were mainly distributed around croplands and at the high Himalayan region with an area of 12,811.13 km^2, which accounted for 8.68% of the land. The areal ratio of shrubs in the Eastern and Western Development Regions were the largest, accounting for 55.63% of the total shrub area. Native shrubs were mainly distributed in highland areas, while secondary shrubs grew in hill and mountain valleys, resulting from the damaging effects of human activities on native forests.

Grasslands were mainly located in the high Himalayan region with an extent of 15,898.78 km^2, which accounted for 10.77% of the land. Steppes were the main grassland classes, accounting for 87.3% of the total grassland area. The areal proportion of grasslands in the Mid-Western Development Region was the largest, nearly half of the total grassland area.

The area of permanent ice/snow was 8160.79 km^2, accounting for 5.53% of the land. It was mainly distributed in the high Himalayan areas where 8 of the 10

Table 2.3 The area and areal proportions of each land cover class in Nepal according to the statistics of the NepalCover-2010 product

Level I	Area (km^2)	Ratio (%)	Level II	Area (km^2)	Ratio (%)
Forest	60,009.27	40.66	Evergreen broadleaf forest	26,794.78	18.16
			Deciduous broadleaf forest	8965.31	6.08
			Evergreen needleleaf forest	23,803.30	16.13
			Mixed broadleaf and needleleaf forest	440.75	0.3
			Tree garden	5.14	0
Shrub	12,811.13	8.68	Evergreen broadleaf shrub	5271.21	3.57
			Deciduous broadleaf shrub	6224.20	4.22
			Evergreen needleleaf shrub	1314.64	0.89
			Shrub garden	1.07	0
Grassland	15,898.78	10.77	Meadow	1533.97	1.04
			Steppe	13,880.24	9.41
			Tussock	475.67	0.32
			Lawn	8.9	0.01
Wetland	2945.41	2	Herbaceous wetland	101.56	0.07
			Lake	71.77	0.05
			Reservoir/pond	42.08	0.03
			River	1057.57	0.72
			Canal/channel	17.05	0.01
			Flood plain	1655.37	1.12
Cropland	36,901.96	25.01	Paddy field	13,938.75	9.45
			Dry farmland	22,846.88	15.48
			Tree orchard	114.9	0.08
			Shrub orchard	1.43	0
Artificial surface	512.67	0.35	Residential land	427.35	0.29
			Industrial land	4.61	0
			Transportation land	79.07	0.05
			Mining field	1.65	0
Bare land	10,329.96	7	Sparse vegetation	6978.82	4.73
			Bare rock	373.14	0.25
			Bare soil	2978.01	2.02
Permanent ice/snow	8160.79	5.53	Permanent ice/snow	8160.79	5.53

highest peaks in the world, with elevations above 8000 m, are gathered, including Mount Everest, Kanchenjunga, Lhotse, Makalu, Cho Oyu, Dhaulagiri, Manaslu, and Annapurna peak. Bare lands, with an extent of 6978.82 km^2, are mainly

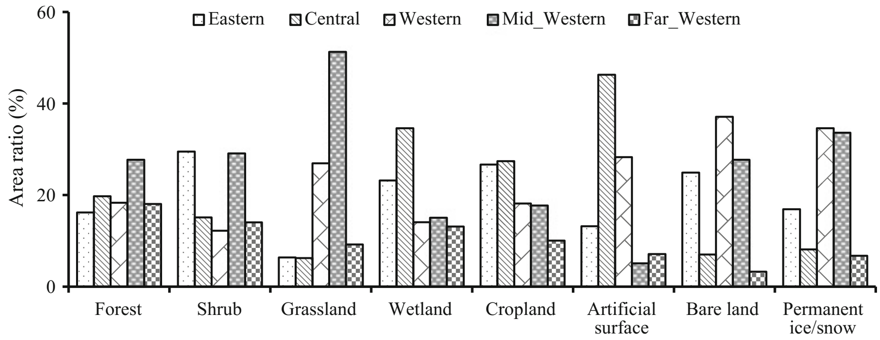

Fig. 2.10 The areal proportions of each land cover class in different development regions according to the statistics of the NepalCover-2010 product

distributed near permanent ice/snow, which accounts for 4.73% of the land. Both bare lands and permanent ice/snow are more widely distributed in the Western and Mid-Western Development Regions than in other regions. This is because nearly one-third of these regions are located in Himalayan mountainous areas—unsuitable conditions for the growth of plants at such high-altitudes with severe cold weather. Thus a spatial pattern of bare lands and permanent ice/snow has formed.

The extent of wetlands and artificial surfaces were relatively small compared to the rest of the land cover classes. Wetlands accounted for 2% of the land. Artificial surfaces were mainly distributed in agricultural areas, accounting for only 0.35% of the land.

2.4.3 Relationships Between Spatial Patterns of Typical Land Cover Classes and Topographical Factors

As shown in Fig. 2.11a, with an increase in elevation, land cover classes showed a distinctively vertical zonality ordered by paddy fields, evergreen broadleaf forests, dry farmlands, evergreen broadleaf shrubs, evergreen needleleaf forests, grasslands, sparse vegetation, and permanent ice/snow. Among these, almost all paddy fields were distributed in the Terai Plain, where the elevation is below 400 m, because such flat and rich (in terms of water resources) land is suitable for rice cultivation. Evergreen broadleaf forests, dry farmlands, and evergreen broadleaf shrubs were mainly distributed in river valleys and hilly areas with elevations below 3000 m. The areal proportions of evergreen broadleaf shrubs increased with elevation, and some of their distribution regions (secondary shrubs) overlapped with those of dry farmlands (Pandit 2011).

There are three types of pattern for spatial distributions of land cover classes and terrain slopes: Type I, areal proportion gradually decreases with increase of slope; Type II, "peak-valley" pattern; and Type III, "peak" pattern (Fig. 2.11b). The spatial

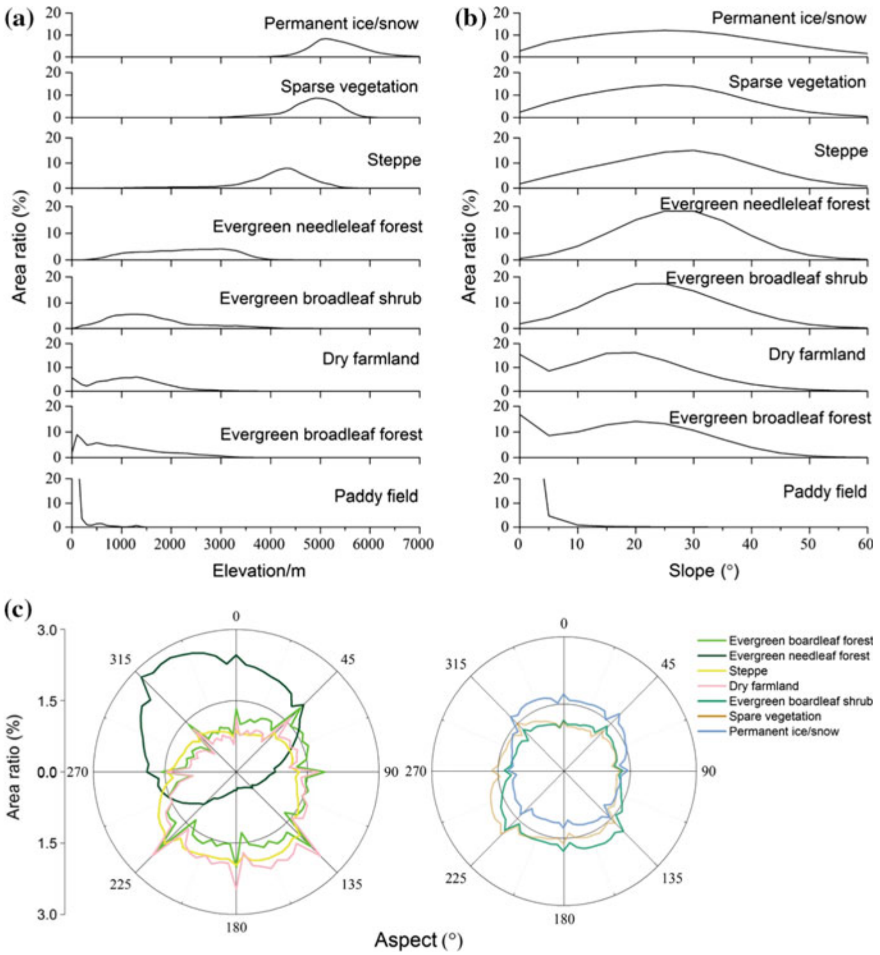

Fig. 2.11 Relationships between the spatial patterns of typical land cover classes and topographical factors, including **a** elevation, **b** slope, and **c** aspect

distribution of paddy fields belongs to Type I. Paddy fields are almost all distributed in areas where the slope is less than 10°, because irrigation facilities are not well developed in Nepal. The spatial distribution of evergreen broadleaf forests and dry farmlands belongs to Type II, with two inflection points appearing at 5 and 20°, respectively. The distribution pattern of the rest of the land cover classes belong to Type III, which are mainly distributed in areas where the slope was below 50°—steep slopes being unconducive to vegetation growth (Wang 2004; Higaki et al. 2005).

This study used two aspect diagrams to present the relationship between spatial patterns of typical land cover classes and aspect (Fig. 2.11c). The areal proportion of dry farmlands on sunny slopes was far greater than on shady slopes, because crops in Nepal are mainly corn, wheat, rapeseed, and other light-demanding crops.

The areal proportion of evergreen broadleaf forests, grasslands, sparse vegetation, and evergreen broadleaf shrubs was slightly larger in sunny and half-sunny slopes. The light in these areas is sufficient to meet the needs of vegetation growth. Evergreen needleleaf forests and permanent ice/snow were mainly distributed in shady and half-shady slopes. The temperature is relatively low in these areas, which is explains the distribution of permanent ice/snow. Light is relatively scarce in shady and half-shady slopes compared to sunny and half-sunny slopes, therefore, needleleaf forests find it easier to grow on shady slopes compared to the broadleaf forests which prefer sunny slopes (Wang 2004).

2.4.4 Relationships Between Spatial Patterns of Typical Land Cover Classes and Meteorological Elements

With an increase in annual average temperature, land cover classes appeared in the following order: grasslands, evergreen needleleaf forests, evergreen broadleaf shrubs, dry farmlands, evergreen broadleaf forests, and paddy fields (Fig. 2.12a). This is opposite to the order of vertical zonality determined by the elevation. The areal proportion of dry farmlands and evergreen broadleaf shrubs reached a maximum value with an annual average temperature of 21 °C, while the areal proportion of paddy fields and evergreen broadleaf forests reached a maximum value with an annual average temperature around 25 °C; this can be simply explained by recognizing that the growth of different vegetation types requires different amounts of energy (Xu et al. 2003).

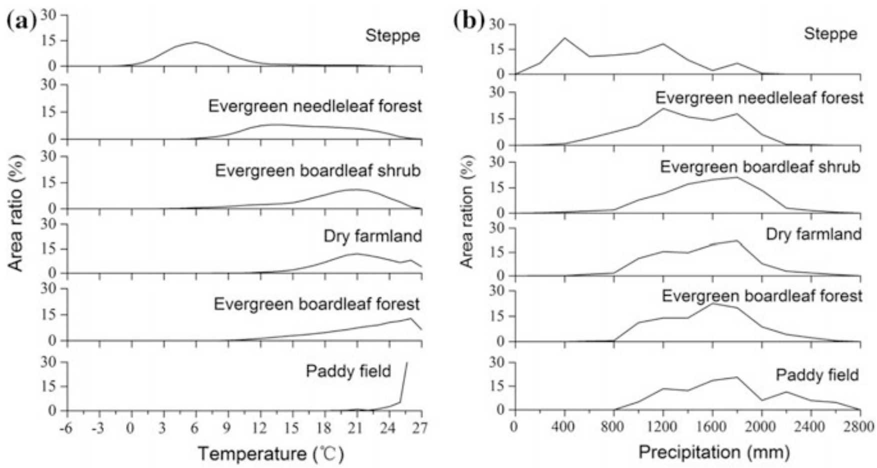

Fig. 2.12 Relationships between the spatial patterns of typical land cover classes and meteorological elements, including **a** annual average temperature and **b** annual precipitation

The spatial distribution of annual precipitation in Nepal is mainly affected by the towering Himalayas, which block the Indian Ocean's southeast monsoon generating significant monsoon rains. Therefore, the rainfall in Nepal is abundant but demonstrates an uneven spatial distribution (Wang 2004). The spatial distribution of typical land cover classes appeared as multiple peaks aligned to the increase of annual precipitation. The distribution ranges of these land cover classes partly overlapped. It was found that 1200 mm was the optimal precipitation for evergreen needleleaf forests, and 1800 mm was the optimal precipitation for paddy fields, dry farmlands, and evergreen broadleaf forests (Fig. 2.12b).

2.5 Conclusion

This chapter introduced the method used to produce the NepalCover-2010 product and its validation scheme. The NepalCover-2010 product, with 30 m resolution, consists of 8 classes at Level I and 31 classes at Level II. The classification accuracy of the NepalCover-2010 product at Level II reached 87.17%, with a Kappa coefficient of 0.85, which makes it the most accurate land cover product among similar products. It therefore accurately reflect the spatial patterns of land cover in Nepal. Forests were the major land cover classes in Nepal, accounting for 41% of the land, which is mainly distributed in mountainous areas and the nature reserves of the Eastern and Western Development Regions. Croplands covered 25% of the land, mainly distributed in the Eastern and Central Development Regions, where the population continues to grow and agriculture develops rapidly. The ratio of the areal proportion of paddy fields to dry farmlands was approximately two to three. This product will contribute significantly to basic data collection in Nepal, and also will be of benefit to China's international regional economic cooperation strategy of, known as "the Belt and Road Initiative".

Topographical and meteorological factors presented themselves as the determining effects on the spatial patterns of land cover in Nepal. With elevation uplift from south to north, land cover classes showed a vertical zonality ordered by paddy fields, evergreen broadleaf forests, dry farmlands, evergreen broadleaf shrubs, evergreen needleleaf forests, grasslands, sparse vegetation, and permanent ice/snow. These relationships provide a potential foundation for predicting the trends in land cover change whilst considering global climate change and increasing human activities.

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