Land use/ land cover changes in the central part of the Chitwan Annapurna Landscape, Nepal

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Background. Land use/land cover assessment and monitoring of the land cover dynamics are essential to know the ecological, physical and anthropogenic processes in the landscape. The studies have indicated changes in the landscape of mid-hills of Nepal in the past few decades. But there is a lack of study in the Chitwan Annapurna Landscape, hence, this study was carried out to fill in study gap that existed in the area.

Methods. This study evaluates land use/land cover dynamics between 2000 to 2020 in the central part of the Chitwan Annapurna Landscape, Nepal by using Landsat images. The Landsat images were classified into eight different classes using remote sensing and geographic information system (GIS). The accuracy assessment of classified images was evaluated by calculating actual accuracy, producer's accuracy, user's accuracy and kappa coefficient based on ground-truthing points for 2020 and Google Earth and topographic maps for images of 2010 and 2000.

Results. The results of land use/land cover analysis of Landsat image 2020 showed that the study area was composed of grassland (1.73%), barren area (1.76%), riverine forest (1.93%), water body (1.97%), developed area (4.13%), Sal dominated forest (15.4%), cropland (28.13%), and mixed forest (44.95%). The results of land cover change between 2000 to 2020 indicated an overall increase in Sal dominated forest (7.6%), developed area (31.34%), mixed forest (37.46%) and decrease in riverine forest (11.29%), barren area (20.03%), croplands (29.87%) and grasslands (49.71%). The classification of the images of 2000, 2010 and 2020 had 81%, 81.6% and 84.77% overall accuracy, respectively. This finding can be used as a baseline information for the development of a proper management plan to protect wildlife habitats and forecasting possible future changes, if needed.

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Abstract
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45 **Keywords** Accuracy assessment, Habitat change detection, Image classification, Landsat image,
46 Remote sensing
47
48
49 **Introduction**
50
51 Land use/land cover changes (LULCC) are widely evaluated in different parts of the world as a
52 result of increasing socio-economic necessities needed for ever increasing human population
53 (Hassan et al. 2016; Reis 2008; Zhu et al. 2021). The LULCC leads to change in vegetation
54 cover and other different components of biodiversity (Halmy et al. 2020; Petrou et al. 2015). It
55 is, thus, important to know the extent of LULCC to find out the drivers and their exact impacts
56 on ecological (e.g., forest cover) and anthropogenic processes (e.g, cropland and settlement
57 area). LULCC are the major sources of environmental changes such as change in biodiversity,
58 habitats, destructions, loss of soil resources, landslides, flood, global climate change and the
59 impact of invasive and alien plant species (MEA 2005; MoLRM 2015; Paudyal et al. 2019;
60 Rather et al. 2020; Rimal et al. 2019; Wu 2019). Hence, understanding about LULCC is
61 important issues in current scenario (Chamling & Bera 2020).
62
63 The landscape is spatially heterogeneous and composed of the visible features of a geographic
64 area (Crowley & Cardille 2020; Shao & Wu 2008) that is directly or indirectly affected by
65 ecological (e.g., biotic interactions, ecological successions), physical (e.g., natural disasters) and
66 anthropogenic (e.g., agricultural practices, livestock grazing) factors (Rather et al. 2020; Scheller
67 2020; Zhu et al. 2021). Land use relates to land cover patterns, and it affects to numerous
68 consequences (Siddique et al. 2020). Landscape patterns quantify the configuration and
69 composition of the landscape by using the number of matrices which are further used for the
70 distribution of the species (Haines-Young 1992; Raut et al. 2020). The studies revealed that
71 anthropogenic factors cause more change in land cover use than the environmental factors
72 (Rimal et al. 2019; Song et al. 2018).
73
74 The mid-hills of Nepal are human dominated and highly fragmented. In the past, the people lived
75 in rural area and performed agricultural activities. They cleared the forest for the expansion of
76 agriculture, hence, the forest was in decreasing trend (MoFE 2019) but now, the scenario has
77 been changed. About one third of agricultural land in the mid-hills of Nepal has already been
78 abandoned and the people migrate to the urban and semi-urban areas (Garrard et al. 2016; Paudel
79 et al. 2012). This migration process leads to increase the forest cover in the rural area and
80 population growth, unplanned expansion of settlements, increased demand of natural resources
81 in urban and semi-urban areas. The policy makers seek the information on the causes and main
82 effects of LULCC for developing the policies as well as a management plan for the conservation
83 of natural resources.
84
85 Studies related to the LULCC in Nepal have focused mainly on the urbanization patterns (Thapa
86 & Murayama 2009; Wang et al. 2020), glacier fluctuations and outburst, and landslides (Huggel
87 et al. 2002; Rimal et al. 2019; Sharma et al. 2019), land cover change in and around the
88 watershed and river systems (Lamsal et al. 2019; Paudyal et al. 2019; Rai et al. 2018) and land
89 use/land cover change in the protected areas (Chettri et al. 2013; Kafley et al. 2009; Thapa
90 2011). However, there are scattered information on the studies at landscape level and the studies

91 related to land cover change analysis are not adequate in number (Chhetri et al. 2017; WWF
92 2013a; Zomer et al. 2001). LULCC data sets provide detailed information about ecosystems and
93 processes needed for analysis and modeling (Rather et al. 2020; Rimal et al. 2019; Wang et al.
94 2020). Hence, this study classified the temporal and spatial pattern of LULCC in the central part
95 of the Chitwan Annapurna Landscape (CHAL), Nepal.
96

Materials & Methods

98
99 **Study area**
100
101 The CHAL in the central Nepal is drained by eight major rivers (Kali Gandaki, Seti, Madi,
102 Marshyandi, Daraudi, Budi Gandaki, Trishuli and Rapti) and their tributaries. This landscape
103 covers all or parts of six protected areas and 19 districts (WWF 2013a). We have chosen the
104 central part of CHAL this landscape that connects two biologically important protected areas, the
105 Chitwan National Park (CNP) in the south and the Annapurna Conservation Area (ACA) in the
106 north. This part of CHAL has given the highest priority corridor for landscape level connectivity
107 (WWF 2013b). The intensive study area covers Chitwan (around Barandabhar Corridor and
108 surrounding areas), Tanahun (Seti River basin), Kaski and some parts of Syanja and Parbat
109 districts (Panchase and part of Annapurna Conservation Area) with an area of 2749.48 km^2 (Fig.
110 1). The elevation ranges from 150m to 3300m. The lowland part has tropical and subtropical
111 types of climate, whereas mid-hills have the temperate type of climate and the upper mountain
112 region have subalpine type of climate.
113
114 This landscape is rich in biodiversity, including three Global 846 Ecoregions (Terai–duar
115 Savanna and Grasslands, Himalayan Subtropical Broadleaf Forests, Himalayan Sub-tropical pine
116 forest) (Dinerstein et al. 2017; Wikramanayake et al. 2002) and two Ramsar sites (Beeshazari
117 and associated lakes, Chitwan and Lake Clusters of Pokhara valley, Kaski) (NLCDC 2020). This
118 area is prime habitat for many important mammal species, birds, herpetofauna, fish and many
119 other micros and macroinvertebrates (Bhuju et al. 2007; WWF 2013b).
120
121
122 **Data sources**
123 Landsat images from 2000, 2010 and 2020 were used to detect the LULCC within the 10-year
124 time interval. The Landsat 7-ETM (Enhanced Thematic Mapper) for 2000, Landsat 5-TM
125 (Thematic Mapper) for 2010, and Landsat 8-OLI (Operational Land Imager) for 2020, images
126 with same 30m spatial resolution were downloaded from the United States Geological Survey
127 (USGS) (https://glovis.usgs.gov/app) geoportal. A total of six scenes of satellite images of two
128 from each year were downloaded (Table 1). The entire Landsat images consist of around 3-10%
129 of cloud cover, but this was less than 1% in our study area. We also used the topographic maps
130 with 1:25000 and 1:50000 scales developed by the Department of Survey, Government of Nepal.
131
132 In addition, the Google Earth and a classified map of 2010 developed by the International
133 Centre for Integrated Mountain Development (ICIMOD) (http://rds.icimod.org) used as a
134 reference for verification. The reference field data were collected using a Global Positioning
135 System (GPS) during the field study and used as ground-truthing points during classification of
136 images and accuracy assessments (Table 1).

137
138 **Image pre-processing**
139 Each band of Landsat image was checked using metadata and georeferenced to the WGS_84
140 datum and Universal Transverse Mercator (UTM) Zone 44 or 45 North coordinate system. The
141 details of bands and resolution are mentioned in Table S1. We only used the bands with 30m
142 resolution for further analysis. Landsat 5 TM images has seven bands, Landsat 7 ETM images
143 have eight spectral bands, and Landsat ETM has 8 bands in which 1 to 7 bands have 30m
144 resolution (Barsi et al. 2014). Similarly, Landsat 8 OLI images have 11 bands in which eight
145 bands 1 to 7 and 9 have 30m resolution. (https://www.usgs.gov) (Table S1). For the natural
146 color composite of Landsat 8 OLI images, band 4 (red), 3 (green) and blue (2) were combined
147 for the natural color, whereas bands 7, 6, 4 were used for false color (urban). Similarly, bands 5,
148 4, 3 for vegetation composition, bands 6, 5, 2 for agriculture, 5, 6, 4 for land and water (Acharya
149 & Yang 2015; Barsi et al. 2014).
150
151 The images were processed in ERDAS IMAGINE 9.2. Bands of each satellite image (2000, 2010
152 and 2020) were stacked within Raster main icon with layer stack function as a single layer. In
153 this study, we selected band 1 to 5 and 7 (blue, green, red, near infrared (NIR), shortwave
154 infrared I (SWIR1) and shortwave infrared II (SWIR2)) for Landsat 5 TM and Landsat 7 ETM;
155 band 1 to 7 (coastal, blue, green, red, NIR, SWIR1 and SWIR2) for Landsat 8 OLI in land use
156 and land cover classification. Band 8 to 11 of Landsat image 2020 are less used in LULCC (Yu
157 et al. 2019). The images of each scene were masked using the Area of Interest (AOI) of the study
158 area using mask function (Fig. 2).
159
160 **Ground-truthing points**
161 The field survey which was carried out from 2018 to 2020 provided a clear idea about the field,
162 forest types and land cover types. For ground-truthing, geographic coordinates were collected
163 during the sign survey of large mammals, including leopard and their prey using GPS (Garmin
164 eTrex 10). These geographic coordinates represented all land cover types along the landscape.
165 Each coordinate was taken from the central point of the land cover patches which was more than
166 30m radius. A total of 1350 coordinates were collected (259 from Sal dominated forest, 125 from
167 riverine forest, 299 from mixed forest, 125 from grasslands, 88 from barren areas, 135 from
168 developed areas, 92 from water bodies and 229 from cropland). Out of the total sampling
169 coordinates, half of the coordinates (667) were used for supervised classification and the
170 remaining coordinates (683) were used for accuracy assessment. In addition to this, we also used
171 printed versions of topographic maps to locate the different land cover types including changes
172 over there through participatory GIS (pGIS) techniques. pGIS studies consider that the local
173 people are familiar and experience with change to their surroundings and provide the greater
174 spatial information about the area (Brown 2012; Zolkafli et al. 2017). For this purpose, focus
175 group discussions were performed with members of community forests and elderly people who
176 inhabited for a long time in that area and easily felt the changes in their surroundings. Twenty
177 group discussions were arranged in different locations of the landscape (five discussions on
178 Barandabhar and associated area, ten on the Seti River basin of Tanahun, five on Panchase and
179 lower part of the ACA) where the local people felt more change in their surroundings.
180
181 **Image classification**
182

183   The consistency of the land cover classes at national, regional and international level is not same
184   (Chettri et al. 2013; MoLRM 2015; Uddin et al. 2015b; Wang et al. 2020). In the present study,
185   land cover classification was established with the help of published literature and maps (Khanal et
186   al. 2020; MoFE 2019; MoLRM 2015; Thapa 2011; Uddin et al. 2015b; Zomer et al. 2001). We
187   classified the land cover of the central part of CHAL into eight major classes, based on the
188   dominant plant species, human settlements, landscape and agriculture. We categorized the forest
189   types as Sal dominated forest, riverine forest and mixed forest (Table 2). The dominant plant
190   species composition in the mid-hills is of mixed type and difficult to separate into other
191   subcategory, hence, we classified such forest as mixed forest.
192
193   **Unsupervised classification**
194   In the beginning, the unsupervised classification of the multi-temporal Landsat images of 2000,
195   2010, 2020 was performed. This classification is based on the automatic identification and
196   assignment of image pixels to spectral grouping. It starts with a spectral plot of the whole image
197   and group the pixels with similar features. Two common algorithms are used for the creation of
198   the clusters in unsupervised classification (Duda & Canty 2002). They are k-means clustering and
199   Iterative Self-Organizing Data Analysis Technique (ISODATA) (Ragettli et al. 2018). In this
200   classification, we used k-means algorithm. The nearest likelihood with 10 iterations were used to
201   group the pixels having similar features. The images were classified into 40 classes with a
202   convergence threshold 0.90. Then, the similar classes were merged into eight different classes
203   using recoding of classes (Table 2 and Fig. 2). The unsupervised classification of images was used
204   for the planning of field data collection that provided the basic field knowledge. The unsupervised
205   classes were revised after the collection of ground-truthing points.
206
207   **Supervised classification**
208   The supervised classification was performed using the widely used parametric classification
209   algorithm namely Maximum Likelihood Classification (MLC) (Chamling & Bera 2020; Rai et al.
210   2018). The signature classes or training sets were prepared from ground-truthing points for 2020
211   and Google Earth map for 2000 and 2010 were used to prepare signature classes for supervised
212   classification. Two separately classified Landsat images were mosaicked to make a single image.
213   Finally, the images were filtered fixing the pixels 3×3 for smoothing the image and avoid the errors
214   of misclassification. The images were again recoded based on field knowledge to minimize the
215   errors of misclassification. We selected five sites, two from low land (Barandabhar and associate
216   area), two from mid hill (Seti River basin and Panchase area) and one from an upland area (lower
217   part of the ACA) for the separate analysis where the land use/land cover was changed drastically
218   within the land 20 years.
219
220   **Accuracy assessment**
221   Accuracy assessment increases the quality of the remotely sensed data on classified thematic
222   maps. It compares the classified image with ground truthing points (Congalton 2001; Rai et al.
223   2018; Siddique et al. 2020; Song et al. 2001; Thapa 2011). Another common method to assess
224   the accuracy of the classified map is to generate stratified random points as the classified class.
225   These random points compared with the Google Earth and topographic maps as reference for
226   verification (Crowley & Cardille 2020). The topographic maps of Nepal were used as reference
227   of settlements or developed area, water resources, croplands and forest area. In this study,
228   ground-truthing points (n = 683) were used as reference for the accuracy assessment of classified

229 images of 2020 (Fig. 3). For Landsat images of 2000 and 2010, 500 stratified random points
230 were generated and compared them with references such as Google Earth, topographic maps of
231 Nepal (for water bodies, settlements, urban or developed area and forest) and the classified maps
232 of ICIMOD (for the classification of forest and grassland). The evaluation was performed
233 computing confusion matrix or error matrix and Kappa Coefficient (Congalton 2001; Foody
234 2002). The user's accuracy, producer's accuracy, overall accuracy was obtained from the error
235 matrix. The user's accuracy provides the reliability that the classified pixels of the map match
236 with the ground-truthing points (Equation 2). Similarly, the producer's accuracy determines the
237 probability of correctly classified reference pixels (Equation 3). The overall accuracy was
238 calculated by dividing the correctly classified pixels by the total number of reference points
239 (Equation 1) (Congalton 2001; Foody 2002). Kappa Coefficient ($\hat{K}$) is used to measure the
240 agreements between model prediction and reality (Congalton 2001). It is the multivariate
241 analysis technique to evaluate the accuracy of the classified map statistically. The Kappa
242 Coefficient ($\hat{K}$) ranges from 0 to 1. If the value of $\hat{K}$ is 0, this reflects there is no agreements, 0-
243 0.2 signifies as slight, 0.21-0.40 as fair, 0.41-0.60 as moderate, 0.61-0.80 as satisfactory or good
244 and 0.81 to 1 as almost perfect agreements (Maingi et al. 2002). Statistically, the $\hat{K}$ was
245 calculated using equation 4.
246
247 Overall accuracy= $\dfrac{Total\ number\ of\ correctly\ classified\ pixels}{Total\ number\ of\ reference\ pixels} \times 100$ (1)
248
249 User's accuracy= $\dfrac{Number\ of\ correctly\ classified\ pixels\ in\ each\ category}{Total\ number\ of\ classified\ pixels\ that\ category\ (row\ total)} \times 100$ (2)
250
251 Producer accuracy= $\dfrac{Number\ of\ correctly\ classified\ pixels\ in\ each\ category}{Total\ number\ of\ classified\ pixels\ that\ category\ (column\ total)} \times 100$ (3)
252
253 Kappa coefficient ($\hat{K}$) = $\dfrac{N\left(\sum_{i=1}^{r} X_{ii}\right) - \sum_{i=1}^{r}(X_{1+} \times X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i+} \times X_{+i})}$ (4)

254 Where, r= Number of rows in the error matrix
255   Xii= number of observations in row i and column i (on the major diagonals)
256   Xi+ = Total number of observations in rows i
257   X+i= Total number of observations in column i
258   N= Total number of observations included in matrix
259

260 **Results**
261

262 **Land use/land cover classes and change**
263 Out of eight land cover classes of 2020, mixed forest was the most dominant (44.95%) followed
264 by croplands (28.3%), Sal dominated forest (15.4%) and developed area (4.13%) (Table 3, Fig.
265 4).
266 The results of LULCC from 2000 to 2010 indicated that there was a decrease in water bodies,
267 barren land, grassland, riverine forest and croplands by 0.9%, 7.7%, 6.2%, 13% and 16%,
268 respectively; build-up or developed area, Sal dominated forest and the mixed forest were
269 increased by 19.1%, 4.62% and 18.2%, respectively. Similarly, from 2010 to 2020, water bodies,
270 riverine forest, Sal dominated forest, developed area and mixed forest were increased by 2.54%,
271 2.09%, 3%, 10.3% and 16.3%, respectively. Barren area, cropland and grasslands were decreased

272   by 13.3%, 16.3% and 46.4% respectively (Table 4, Figs. 5-6). Overall, from 2000 to 2020, the
273   areas of grassland, riverine forest, cropland and barren area were drastically decreased, whereas
274   developed area, mixed forest and Sal dominated forest were increased (Table 4).
275
276   The separate analysis of LULCC between 2000 to 2020 in old Padampur and associated areas
277   (low land) clearly showed that more than 93% of the total cultivated land was changed into the
278   grassland and forest. Similarly, the barren area (flood plain of Rapti River) was reduced by
279   74.67%. However, grassland, riverine forest and mixed forest in the old Padampur and
280   associated areas were increased by 94.45%, 91.26% and 62.5%, respectively (Figs. 7 A1-A3, 8A,
281   Table S2). The trend of land cover change from 2000 to 2020 in new Padampur and associated
282   areas (low land) indicated that the riverine forest, Sal dominated forest and grassland were
283   drastically reduced by 61.21%, 54.14% and 64.88%, respectively, whereas the cropland and
284   developed areas were increased by 88.17% and 1433.33%, respectively (Figs. 7 B1-B3, 8B,
285   Table S2). Land cover change from 2000 to 2020 in Byas municipality of Tanahun district and
286   surrounding areas showed a significant reduction in the cropland by 40.86%, whereas there was a
287   significant increase in developed areas and mixed forest by 86.55% and 62.14%, respectively.
288   The trend of land cover change in Byas and surrounding areas was more between 2010 to 2020
289   than 2000 to 2010 (Figs. 7C1-C3, 8C, Table S2). The results of land cover change analysis of
290   Panchase Protected Forest and associate areas between 2000 to 2020 showed a reduction in
291   cropland by 51.92% and grassland by 43.22%, whereas an increase in mixed forest and Sal
292   dominated forest by 68.1% and 23.29%, respectively (Figs. 7D1-D3, 8D, Table S2).
293
294   The results of land cover change analysis of a part of the ACA between 2000 to 2020 clearly
295   showed an increase in mixed forest and developed area by 14.93% and 166.66%, respectively,
296   whereas a decrease in cropland, barren area and grassland were decreased by 40.97%, 24.09%
297   and 19.94%, respectively (Figs. 7E1-E3, 8E, Table S2).
298
299   **Accuracy assessment**
300   The overall accuracy of classified images of 2000, 2010 and 2020 was 81%, 81.6% and 84.77%,
301   respectively. The user's accuracy ranged from 73.33% to 87.09% in 2000, 73.68% to 83.33% in
302   2010 and 80.26% to 90.69% in 2020. The low range of user's accuracy in barren area in 2000
303   (73.33%), in a developed area in 2010 (73.68%) indicated confusion during land cover
304   classification (Tables 5). Riverine forest in 2000, mixed forest in 2010 and Sal dominated forest
305   in 2020 were more reliable with user accuracy of 87.09%, 83.77% and 90.69%, respectively
306   (Tables 5, supplementary tables S3-S5). The Kappa coefficient for the years 2000, 2010 and
307   2020 were 0.76, 0.79 and 0.82, respectively.
308
309   **Discussion**
310
311   The present study categorized eight land cover classes including four major forest types- Sal
312   dominated forest, riverine forest, mixed forest and grassland. Among the land cover classes, Sal
313   dominated forest was the most common in the Barandabhar Corridor Forest and some parts of
314   Tanahun and Kaski districts. The tropical and subtropical climate with high temperature and
315   precipitation support the Sal dominated forest (Adhikari et al. 2019; Reddy et al. 2018).
316   Similarly, the riverine forest was found in the flood plains of major river systems (Rapti,
317   Narayani, Marshyandi, Kaligandaki, Seti river basin). In the mid-hills, most of the area was

318   covered by mixed forest. LULCC analysis in the central part of the Chitwan Annapurna
319   Landscape showed that there were more than 62% of total land covered by forest area (mixed
320   forest, Sal dominated forest and riverine forest). Therefore, this area is regarded as priority
321   corridor for biodiversity conservation in CHAL. However, this landscape is human-dominated
322   and highly fragmented (WWF 2013a) due to the scattered human settlements and croplands. The
323   river systems (Rapti, Narayani, Seti, Madi, Modi, Kaligandaki, Marshyandi and other associates)
324   and lakes (two Ramsar sites Beeshhazari Lake and Lake clusters of Pokhara Valley) are crucial
325   for maintaining different ecosystems. Similar type of study based on the Google Earth map
326   analysis of 2018 by MoFE (2019) found 44.47% of the total area in Nepal was covered by forest.
327

328   The temporal patterns of the LULCC analysis showed the direction of land cover changes with
329   respect to the initial land cover (land cover of 2000) as a reference. Our classified images of the
330   central part of CHAL clearly showed a decrease in cropland (29.87%) and drastically an increase
331   in mixed forest (37.46%). This is due to the shifting of the people from the hilly area to the urban
332   area for a better life and employment opportunities, hence, the cropland left by them gradually
333   converted into the forest (Garrard et al. 2016). Such type of changes was observed in the studies;
334   Bhandari et al. (2022) in Bhanu Municipality, Ragettli et al. (2018) in Tanahun district and Kc &
335   Race (2019) in Lamjung district of Nepal. The results of increment of urban area from 2000 to
336   2020 (31.34% increment) also proved the migration of the people from rural to urban area as the
337   study by Kc & Race (2019). The rapid development of the roads, tracks, hydropower, industrial
338   areas, airports and settlements in urban areas have created major barriers for wildlife movements.
339   The settlement density was more in urban and plain areas than in the hilly areas (CBS 2012).
340   Similarly, the study of Ragettli et al. (2018) indicated the increase in the barren area in Tanahun
341   district between 2000 to 2019 but our study indicated the decrease in the barren and grassland
342   area within the landscape because the most of these areas were replaced by the forest. The
343   grasslands that were scattered inside the forest and the grassland in the mountain were used by
344   the local people as pasture land as reported in the study of Rai et al. (2018) in Gandaki River
345   basin and Chetri & Gurung (2004) in Upper Mustang in the central Nepal. The landslide was
346   very common in the mid-hills and high mountain (Budha et al. 2020; Petley et al. 2007). Besides,
347   rivers also deposited sands and gravels to their catchment areas, played a significant role in land
348   cover change.
349

350   The increase in the forest indicated that there are improvements in wildlife habitats, especially
351   for large mammals. Forest cover inside the protected areas (Chitwan National Park and
352   Annapurna Conservation Area) was also in increasing steadily as observed in the Old Padampur
353   area. After the shifting of Padampur village to another place to include an old village area inside
354   the Chitwan National Park, the crop land was transformed into the grassland and riverine forest.
355   The land cover change analysis showed that more than 94% grassland was increased from 2000
356   to 2020 in the Old Padampur area. The forest was cleared and the Padampur village was
357   relocated to the New Padampur area. Hence, the cropland and developed areas increased
358   drastically within the period of 20 years in newly settled areas. Similarly, the forest increased in
359   the mid-hills due to the implementation of effective community forestry program by the
360   government. Our findings were similar to the findings of other parts of Nepal such as in Nepal's
361   Kailash Scared Landscape (Uddin et al. 2015a), Koshi river basin (Rimal et al. 2019) and
362   Mechinagar and Buddhasanti landscape (Rijal et al. 2021b) but different than studies from
363   Bagmati River basin (Rijal et al. 2021a). Regeneration of the forest inside the ACA increased

364 during recent years. The people abandoned the marginal agriculture land due to low production,
365 shortage of labors for agricultural work and high human wildlife conflict, hence, these areas were
366 converted into the forests. Similar observations were found in the studies by Paudel et al. (2016)
367 in Nepal and Bhandari et al. (2022) in western Nepal. Our field observations also showed that
368 there was a similar type of trend in Panchase and surrounding areas, where the local people left
369 their productive land and migrated to the city. Population density increased vigorously hence
370 increased in the settlement (86.55%) within 20 years in the city area and Byas municipality,
371 Tanahun district as people migrated from nearby hills. Similarly, an increase in population was
372 observed in the Kathmandu valley (412% increased) within 1989 to 2016 (Ishtiaque et al. 2017)
373 and in the Pokhara valley (125.55% increased) from 1990 to 2013.
374
375
376 The classified images of Nepal clearly showed 48.6% of the forest area lost from 1930 to 2014
377 (Reddy et al. 2018). But this loss was very low from 2005 to 2014 (only 4 km^2 per year). From
378 2005 onwards the deforestation rate is decreased due to the effective implementation of
379 community forestry program by the government of Nepal (MoFSC 2016). The forest loss during
380 recent years is due to developmental projects and are comparatively more in the Terai region
381 (Reddy et al. 2018). However, the land use/land cover change analysis of the CHAL area
382 (landscape includes 19 districts from Terai to high mountains) between 1990-2010 showed an
383 increased in forest area by 0.3% while the grasslands decreased slightly (WWF 2013a). The
384 overall forest of mid-hills of CHAL area is increasing while cropland and grasslands are
385 decreasing. Land cover analysis in 2015 found that 48% of the mid-hills, 62.6% of high
386 mountain and 6.1% of the high Himalayan area were covered by forest (MoFSC 2015).
387 However, the forest area of the mid-hills and high mountains were increasing while the
388 croplands were decreasing (MoFSC 2015) similar to this study.
389

390 **Conclusions**
391
392 Land cover change/land use patterns determine the spatial patterns of land cover in the central
393 part of the Chitwan Annapurna Landscape. With an increase in elevation from south to north,
394 land cover classes in CHAL showed a change in composition of riverine forest, barren area,
395 croplands, developed areas, mixed forest, Sal dominated forest and grasslands. The land cover
396 change analysis of 2000, 2010 and 2020 showed the clear scenario of land cover changes, mainly
397 in human-dominated fragmented landscape. The results of the temporal and spatial analysis of
398 the land cover provide the baseline information for the conservation of wildlife habitats,
399 landscape management and sustainable development of the landscape.
400

407
408
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Figure 1

Map showing the intensive study areas which links two biodiversity significant areas: Chitwan National Park (CNP) and Annapurna Conservation Area
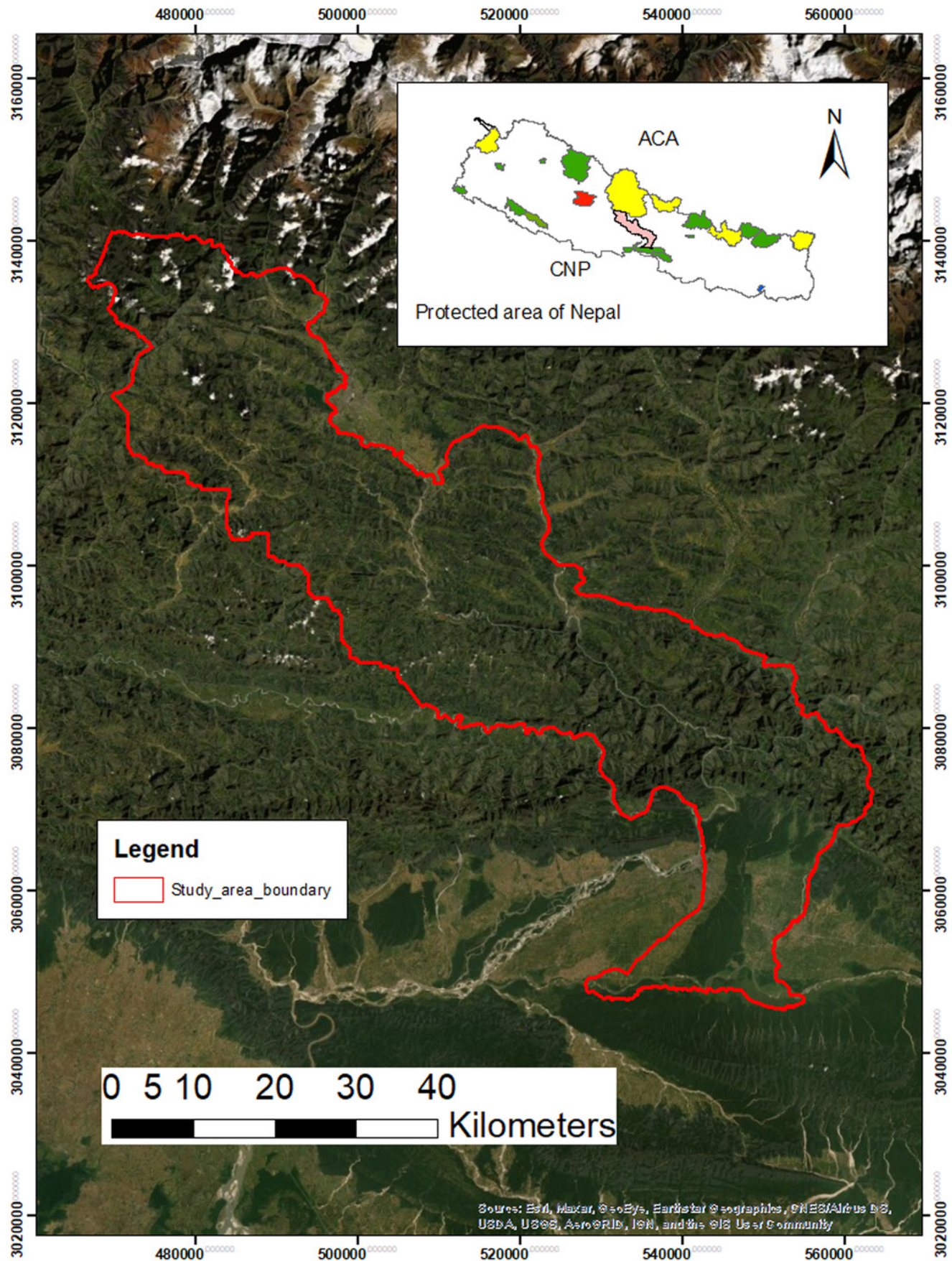
Figure 2

Flow chart of overall process of Landsat image classification
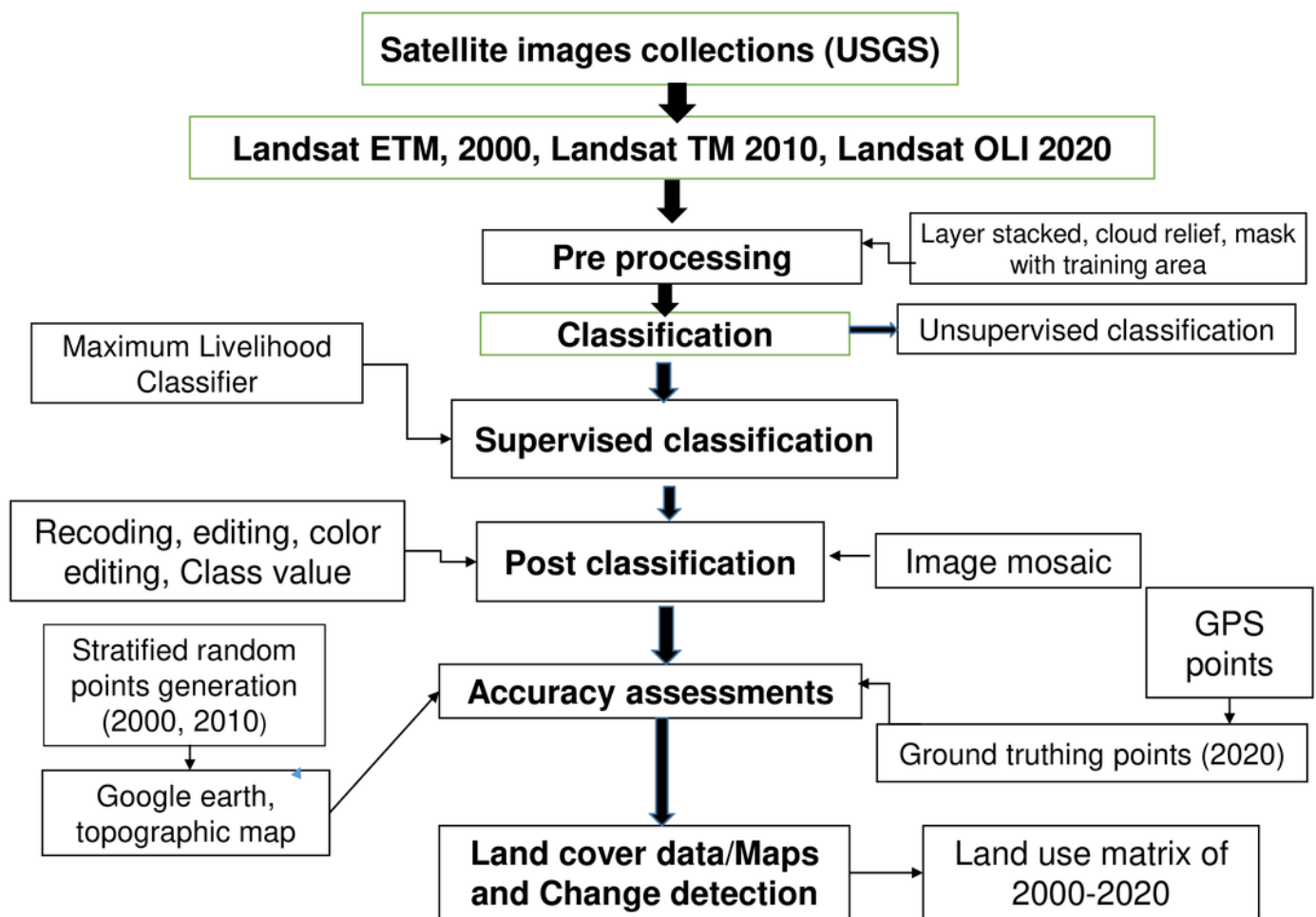
Figure 3

Map showing the ground-truthing points used for accuracy assessment of the classified
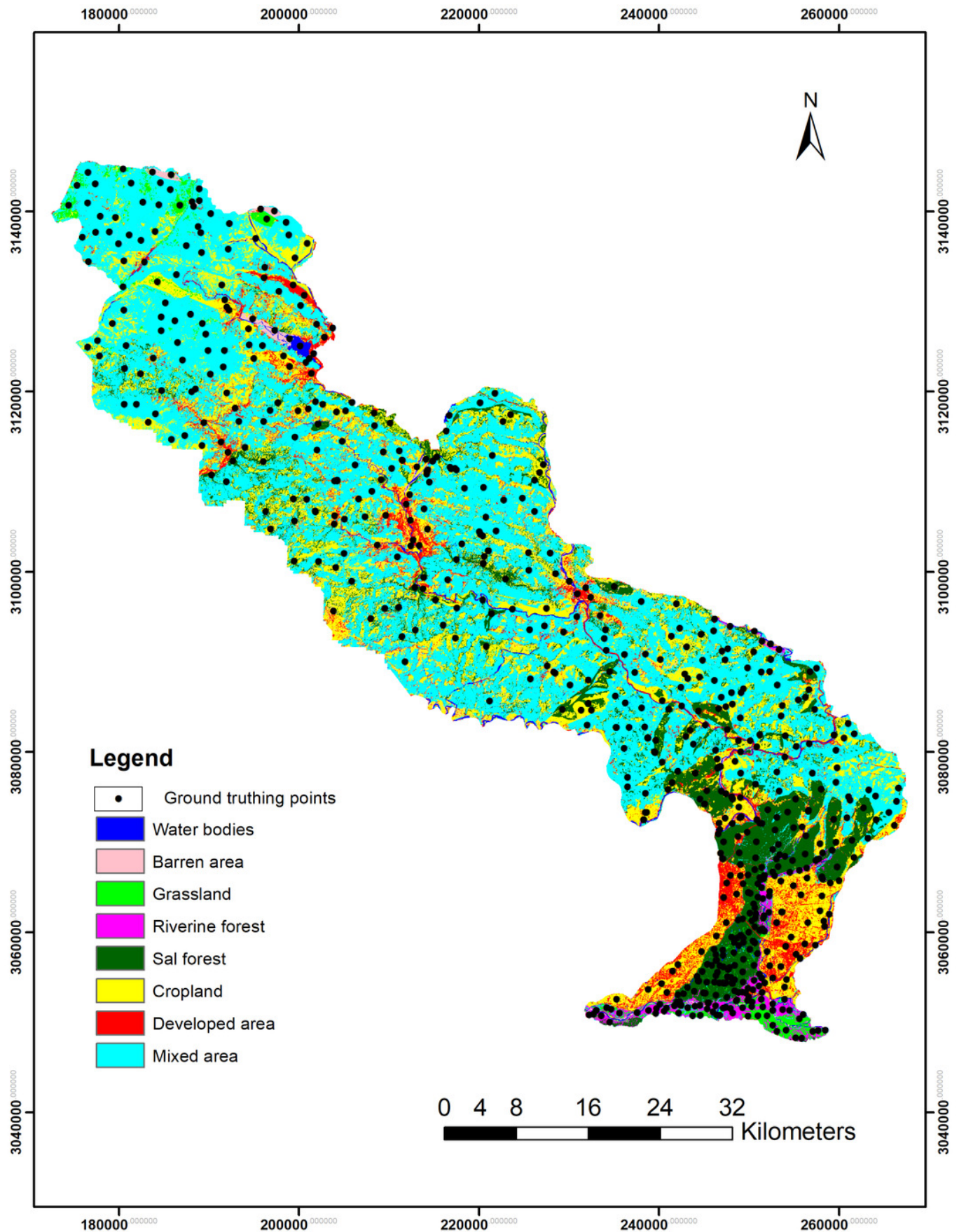land cover image of 2020.

Figure 4

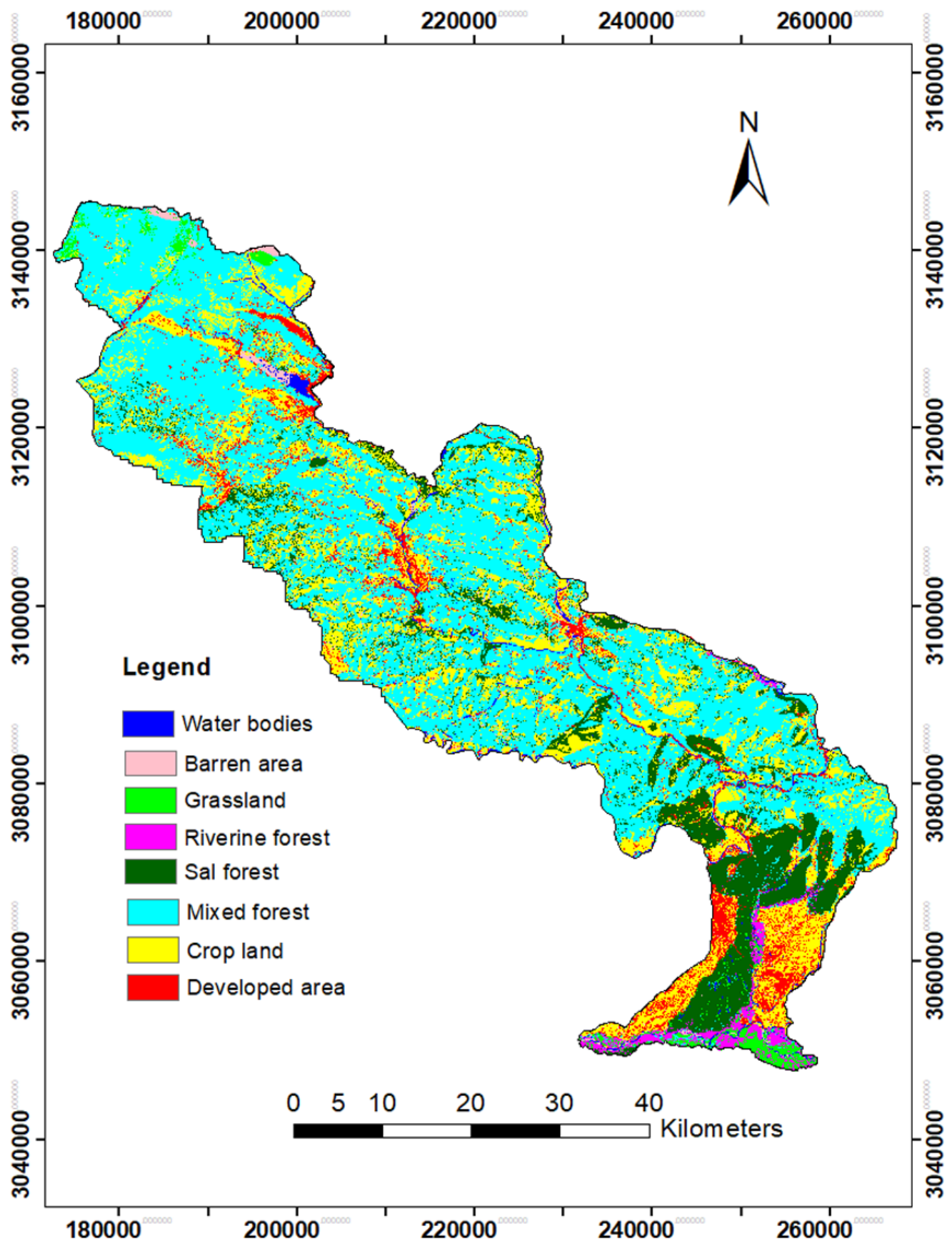Land cover types of the central part of the Chitwan-Annapurana Landscape in 2020

Legend

- ■ Water bodies
- ■ Barren area
- ■ Grassland
- ■ Riverine forest
- ■ Sal forest
- ■ Mixed forest
- ■ Crop land
- ■ Developed area

0 5 10   20   30   40
Kilometers

Figure 5

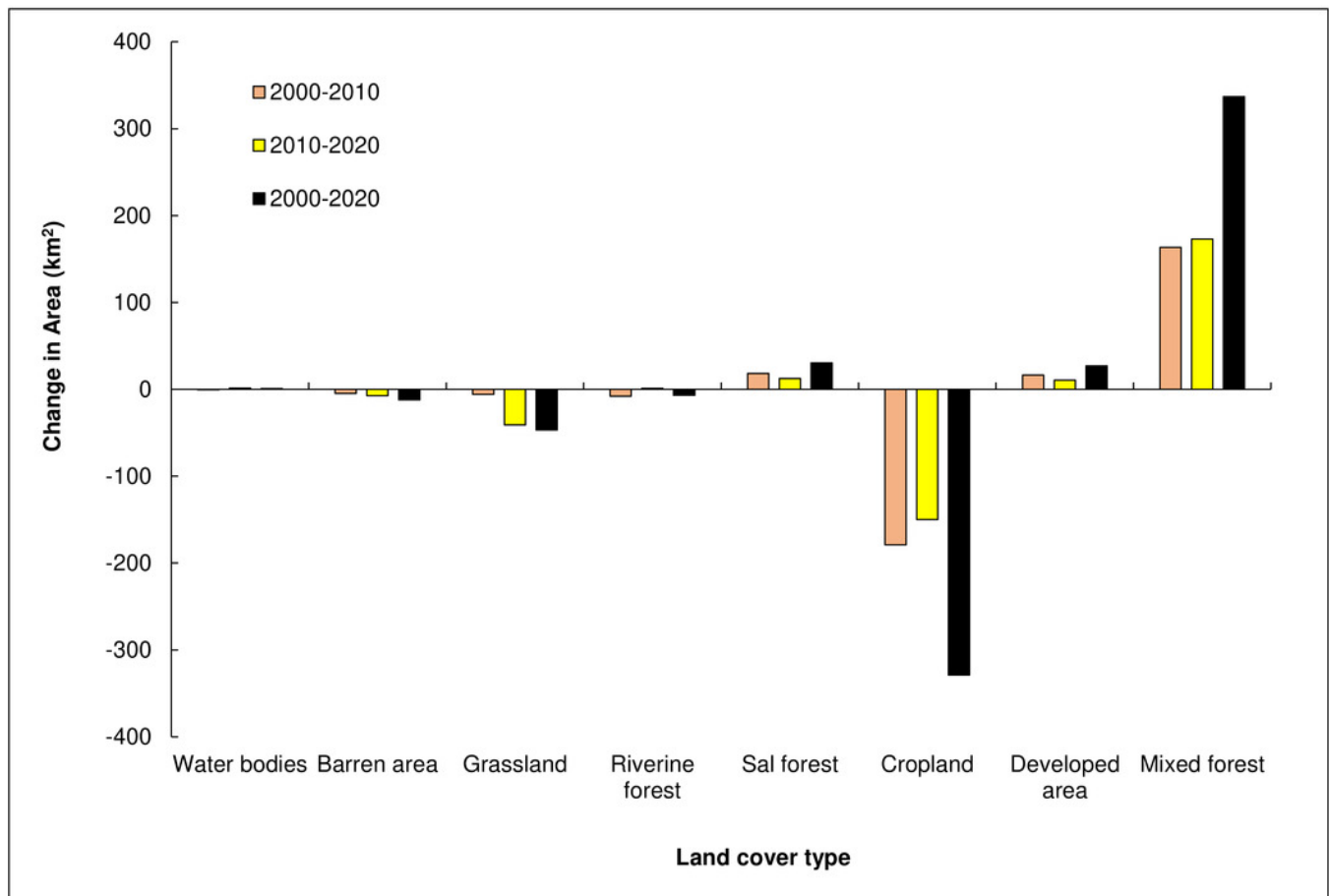The land-use / cover change in area during the period of 2000–2020

Figure 6

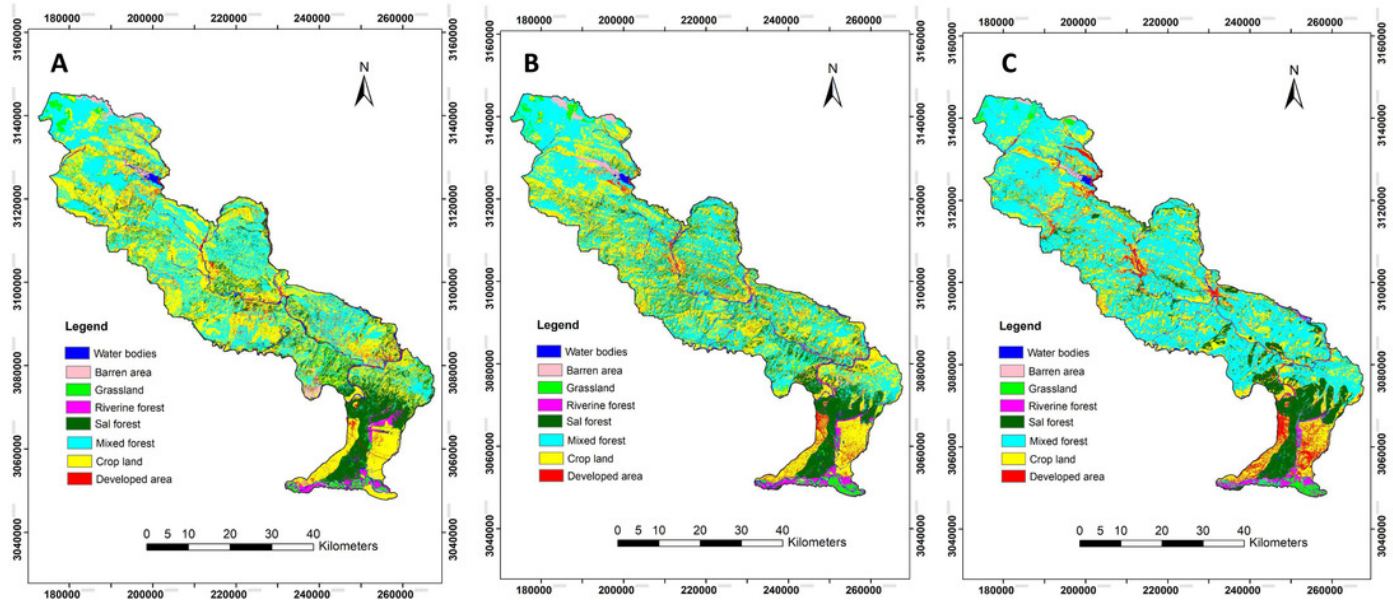Land cover change between A. 2000, B. 2010 and C. 2020

Figure 7

Synergic change in land cover in the part of study area from 2000 to 2010. Here, A1-A3: Land cover change in Old Padampur area; B1-B3: Land cover change in New Padampur area; C1-C3: Land cover change in Byas area; D1-D3: Land cover change in Panchase prot
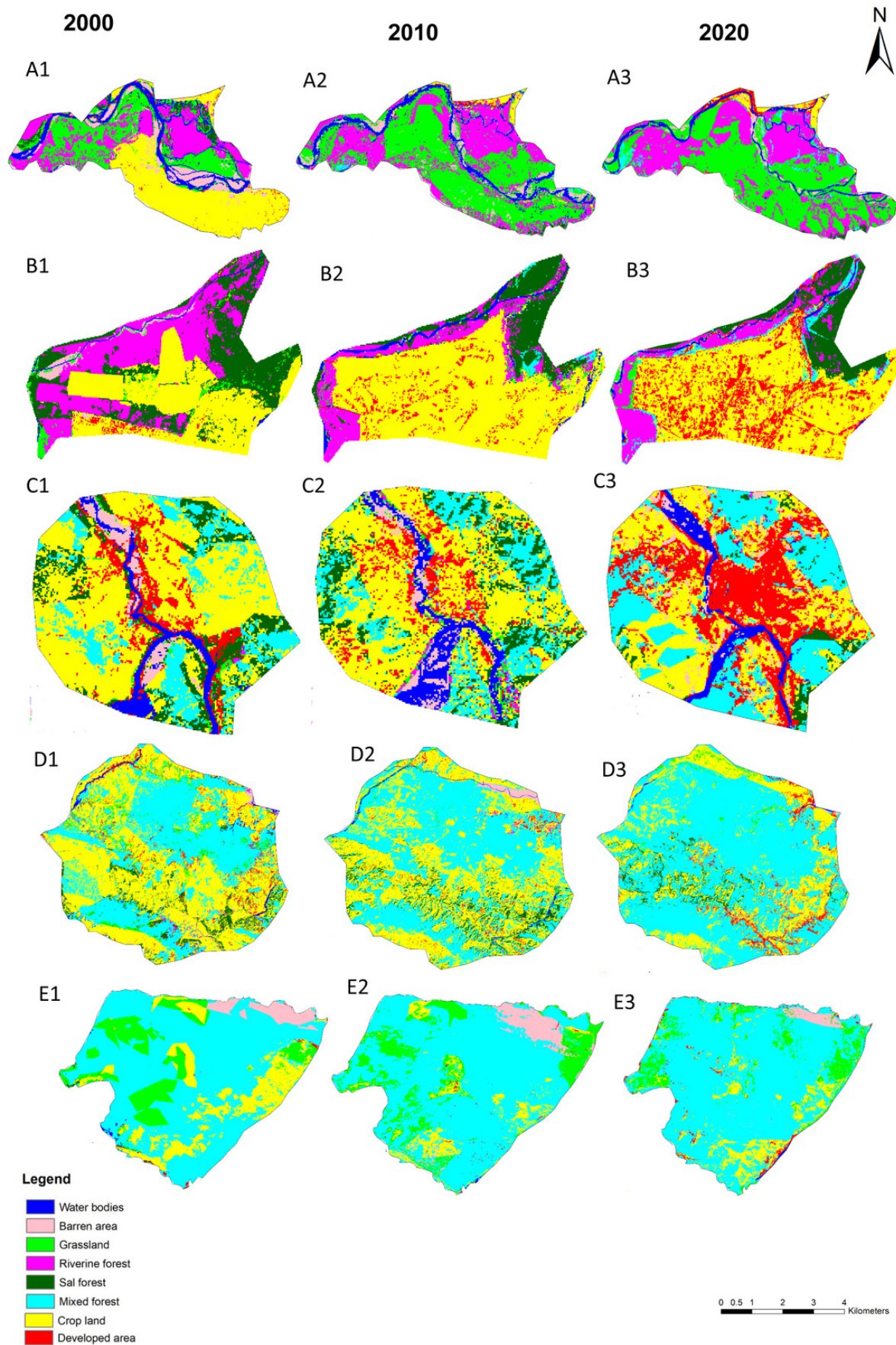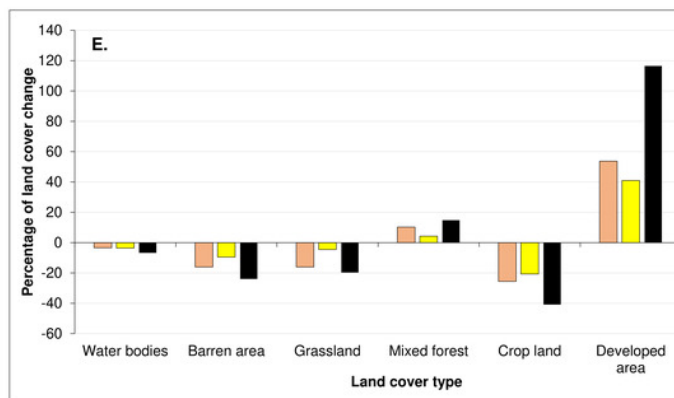
2000

2010

2020

N

A1

A2

A3

B1

B2

B3

C1

C2

C3

D1

D2

D3

E1

E2

E3

Legend

- Water bodies
- Barren area
- Grassland
- Riverine forest
- Sal forest
- Mixed forest
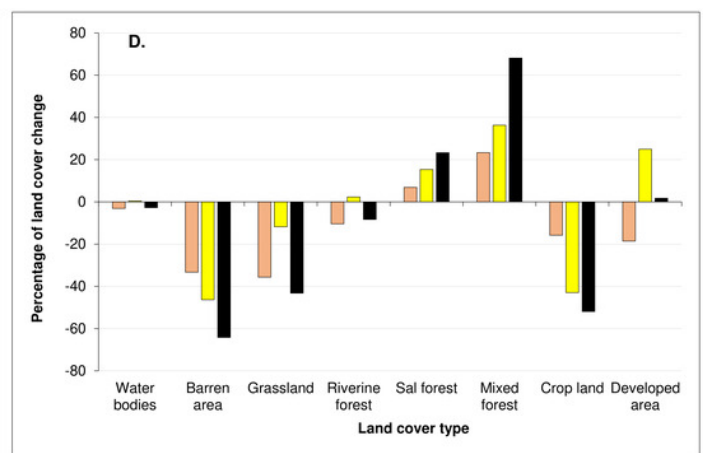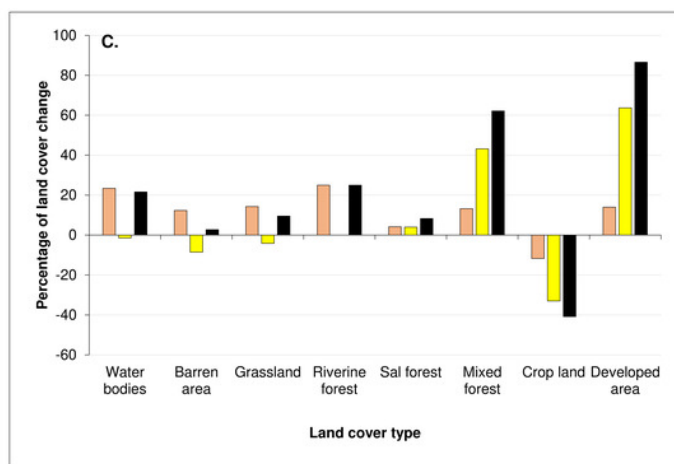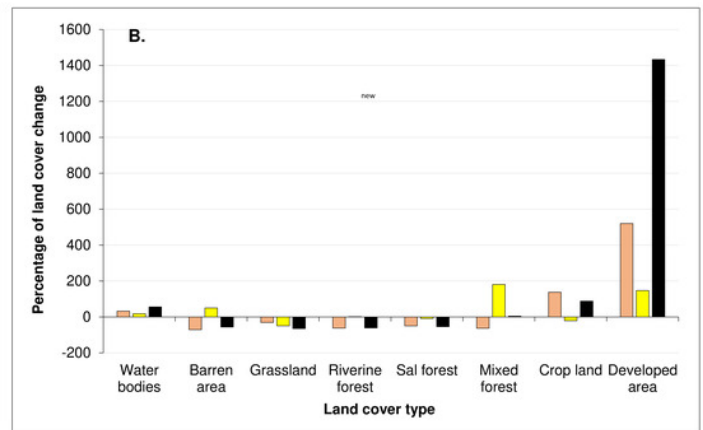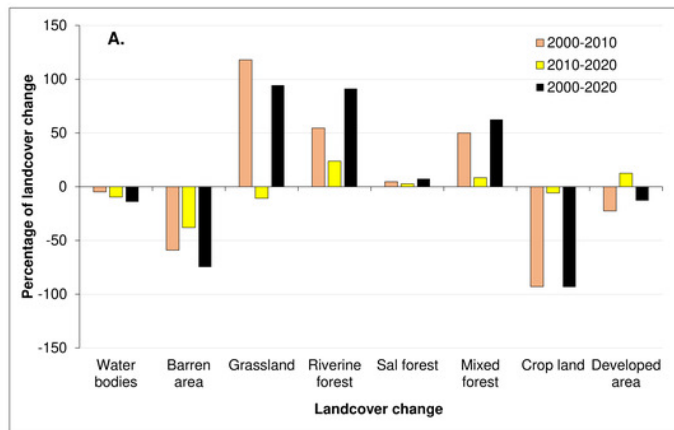- Crop land
- Developed area

0 0.5 1   2   3   4
Kilometers

Figure 8

Percentage of Land cover change from 2000 to 2020. Here, A- Old Padampur area; B-New Padampur and associated area, C-Byas and associated area (an example of populated area of mid-hill); D-Panchase and associated areas (an example of rural area of Midhill)

Table 1(on next page)

List of dataset used in the study.

1   **Table 1** List of dataset used in the study.
2

SN	Acquisition date	Data category	Spatial resolution	Band properties	Sources
1	3 April 2000	Landsat 7, Enhanced Thematic Mapper (ETM)	30m	Multispectral	https://glovis.usgs.gov/app
2	18 February 2010	Landsat 5, Thematic Mapper (TM)	30m	Multispectral	https://glovis.usgs.gov/app
3	17 March 2020	Landsat 8, Operational Land Imager (OLI)	30m	Multispectral	https://glovis.usgs.gov/app
4	1999/2000	Topographic map	1:25000 1:50000		Department of survey, Kathmandu
5	2018-2020	Ground truth (reference data)			Field survey- GPS
6	2000, 2010, 2020	Google earth pro			https://earth.google.com/web/
7	2010	ICIMOD		Classified	http://rds.icimod.org/

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Table 2(on next page)

Major land use and land cover types in the central part of the Chitwan Annapurna Landscape, Nepal.

1 **Table 2** Major land use and land cover types in the central part of the Chitwan Annapurna
2 Landscape, Nepal.
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SN	Land cover types	Description
1	Water bodies	River, lakes, ponds, marshy land
2	Barren area	Sand, gravel, dry beds, flood plains without vegetation, landslide, snow feed area and no vegetation areas
3	Grassland	Grasslands, scattered shrub
4	Riverine forest	Simal (*Bombax ceiba*), Khair (*Acacia catechu*), Sisso (*Dalbergia sissoo*), Veller (*Trewia nudiflora*), Padke (*Litsea doshia*), Kutmero (*Litsea monopetala)* and associates plants
5	Sal dominated forest	Sal (*Shorea robusta*), Saj (*Terminalia alata*), Karma (*Adina cordifolia)* and associates plants
6	Mixed forest	Dhairo (*Woodfordia fruticose*), Kyamuno (*Syzygium cumini*), Amaro (*Spondias pinnata*), Chilaune (*Schima wallichii*), Katus (*Castanopsis tribuloides*), Kafal (*Myrica esculenta*), Utis (*Alnus nepalensis*), Paiyu (*Prunus cerasoides*), Ritha (*Sapindus mukorossi*), Lapsi (*Choerospondias axillaris*), Champ (*Michelia champaca*), Rakchan *(Daphniphyllum himalense)*, Rhododendron and oak (*Quercus* spp), and associate plants
7	Crop land	Crop lands
8	Developed area	Urban and rural settlements, commercial areas, industrial areas, hydropower project areas, roads construction, airport

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Table 3(on next page)

Land cover classes in the central part of Chitwan-Annapurna Landscape in 2020.

1 **Table 3** Land cover classes in the central part of the Chitwan-Annapurna Landscape in 2020.

SN	Land cover type	Area_2020 (Km^2)	Percentage
1	Water bodies	54.04	1.97
2	Barren area	48.62	1.76
3	Grassland	47.32	1.73
4	Riverine forest	53.25	1.93
5	Sal dominated forest	423.65	15.4
6	Mixed forest	1235.9	44.95
7	Cropland	753.35	28.13
8	Developed area	113.35	4.13
	Total area	2749.48	100

Table 4(on next page)

Land cover changes in study area from 2000 to 2020.

1 **Table 4** Land cover changes in study area from 2000 to 2020.

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SN	Land cover type	Land cover area (km²)			Change 2000-2010		Change 2010-2020		Change 2000-2020	
		2000	2010	2020	Area	%	Area	%	Area	%
1	Water bodies	53.2	52.7	54.04	-0.5	-0.9	1.34	2.54	0.84	1.57
2	Barren area	60.8	56.1	48.62	-4.7	-7.7	-7.48	-13.3	-12.2	-20.03
3	Grassland	94.1	88.24	47.32	-5.86	-6.2	-40.9	-46.4	-46.8	-49.71
4	Riverine forest	60.03	52.16	53.25	-7.87	-13	1.09	2.09	-6.78	-11.29
5	Sal dominated forest	393.15	411.3	423.65	18.15	4.62	12.4	3	30.5	7.76
6	Mixed forest	899.1	1062.48	1235.9	163.38	18.2	173	16.3	337	37.46
7	Cropland	1102.8	923.7	773.35	-179.1	-16	-150	-16.3	-329	-29.87
8	Developed area	86.3	102.8	113.35	16.5	19.1	10.6	10.3	27.1	31.34
	Total	2749.48	2749.48	2749.48						

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Table 5(on next page)

Accuracy assessment of the classified images from 2000-2020.

1 **Table 5** Accuracy assessment of the classified images from 2000-2020.

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Land cover	2000		2010		2020	
	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy	User's accuracy	Producer's accuracy
Water bodies	81.81	90	76.92	76.92	90	81.18
Barren area	73.33	73.33	80	72.73	82	69.49
Grass land	78.37	80.5	75	80	80.95	76.11
Riverine forest	87.09	81.8	76.92	71.4	84.61	84.61
Sal dominated forest	84.21	80	83.11	80	90.69	95.9
Crop land	82.73	80.41	83.33	83.3	85.32	83.78
Developed area	77.77	72.41	73.68	66.67	84.62	80.88
Mixed forest	78.43	83.3	83.77	86.95	80.26	89.7
Over all accuracy	81		81.6		84.77	
Kappa coefficient	0.76		0.79		0.82	

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