Supplementary Materials

1. Image pre-processing, classification and accuracy assessment

1.1. Image pre-processing and extraction of major land use and land cover classes

To capture the landscape characteristics of UGI for the year 2019, Sentinel-2 satellite images, obtained from European Space Agency's (ESA) Copernicus open access hub (ESA, 2020) were used as the fundamental spatial data source. Figure S1 shows the flow-diagram of the adopted methodology. We used Level-2A images which are atmospherically corrected Bottom Of Atmosphere (BOA) reflectance images (details of the acquired images in Table S2). With its 13 spectral bands (four bands at 10 m, six bands at 20 m and three bands at 60 m spatial resolution) Sentinel-2 multispectral imager (MSI) provides enhanced spatial and spectral capabilities for land cover mapping. Especially for vegetation mapping, we included four red-edge (RE) bands of Sentinel-2 which are sensitive to vegetation classes influenced by chlorophyll content and canopy reflectance (Sun et al., 2020). By doing so we considered the red-edge bands that improved the vegetation classification, the overall classification accuracy as well as the Kappa coefficient. In addition, the short-wave infrared (SWIR) bands are known to have strong reflectance from urban land cover and thus help in separating them from agricultural land (Lefebvre, Sannier, & Corpetti, 2016).

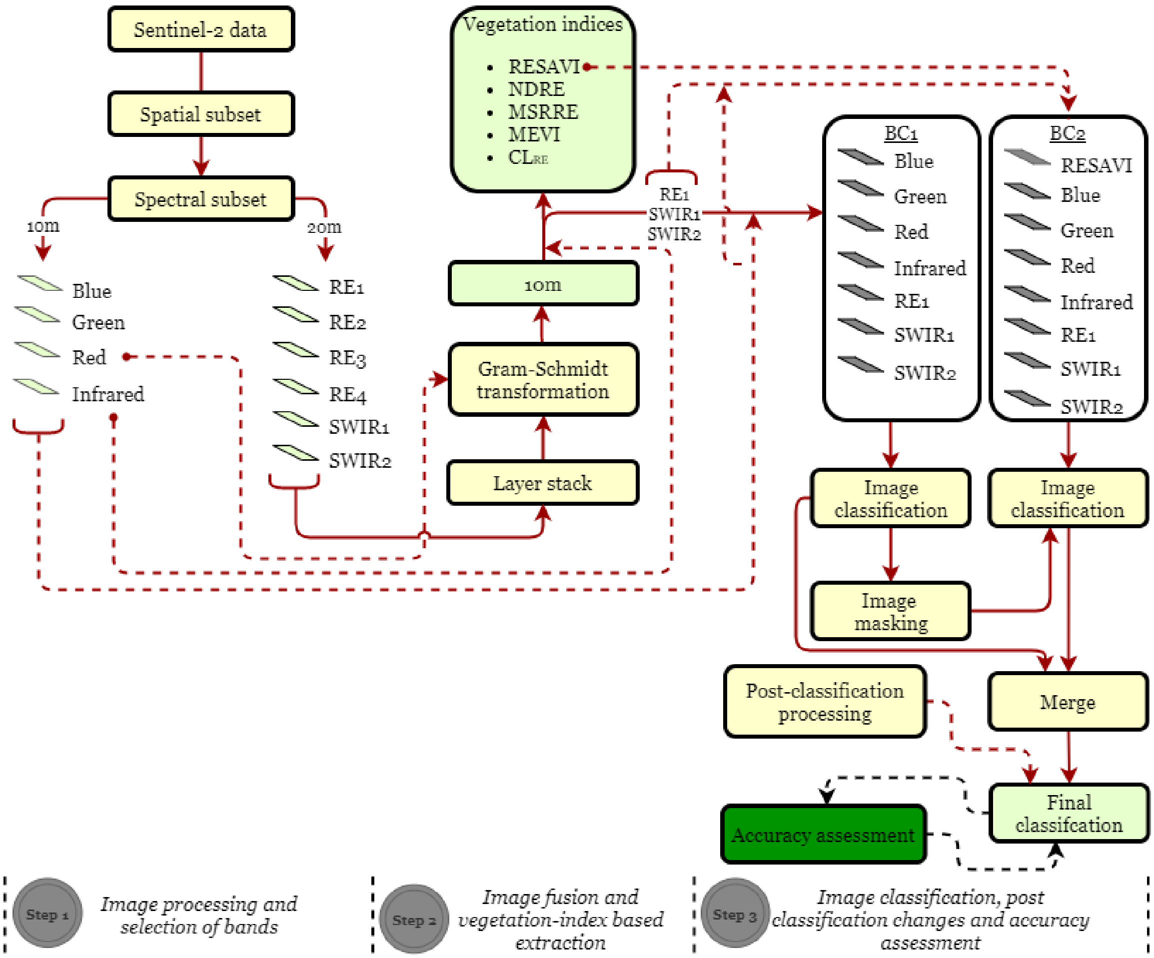

Figure S1 Image classification methodology flow diagram.
RE – Red-edge; BC – Band combination; SWIR - Short Wave Infrared.

Table S1 Description of the selected cities.

City	State/Region	Altitude (msl)	Population*	Area (km²)	Wards	Physical and cultural features
Srinagar	Jammu and Kashmir	1580	1,180,570	245	69	Well-known for its gardens and famous wetland *Dal*. The outer fringes of the city are composed of agroforestry and agriculture along the fertile plains of Jhelum river. Restricted by mountains in the north-east. Largest urban settlement in the Himalayan mountain chain.
Shimla	Himachal Pradesh	2,276	169,578	28	25	A popular tourist destination, particularly in summer months. Topography is dominated by hilly forests which restrict the city to be concentrated on different mountainous peaks, connected by road network.
Dehradun	Uttrakhand	650	574,840	66	60	A number of educational and professional training centers of national importance are located here. Thus hold maintained, but restricted UGI classes. Landscape includes remnant foothill forest patches and ousted agricultural patches due to rapid urban growth after turning into a capital city in the year 2000

*Source- Register General of India, 2011

Table S2 Details of satellite data used.

Date	Year	City	Satellite sensor
18th September	2019	Srinagar	Sentinel-2A MSI
17th October	2019	Dehradun	Sentinel-2B MSI
27th October	2019	Shimla	Sentinel-2A MSI

Table S3 Selected landscape metrics and their description after McGarial & Marks, 1995; McGarigal, 2015. For formula and range, see Supplementary table A4.

Landscape metrics	Measured attribute	Description
Largest Patch Index (LPI)	Area	Measure of the dominance of largest patch. The percentage approaches 100 when the class occupies larger continuous area.
Mean Patch Size (AREA_MN)	Area	Average area of all the patches in a class in a given area. Directly dependent on number of patches. To be interpreted in conjunction with PD.
Edge Density (ED)	Shape	Measures shape complexity on the basis of total edge length of the class per unit area. Higher value indicates increased complexity in the shape.
Landscape Shape Index (LSI)	Shape	Measures shape complexity on the basis of perimeter-area ratio of class in the landscape. Higher value indicates increased irregularity in the shape.
Area-Weighted Mean Patch Fractal Dimension (FRAC_AM)	Shape	Measures shape complexity on the basis of relative patch area by weighting patches according to their size. Higher value indicates increased complexity and fragmentation of the patches.
Contiguity Index (CONTIG)	Shape	Measures the spatial connectedness of the patches in such a way that a shape which results in more connections between the cells of a patch leads to a higher contiguity value.
Mean Euclidean nearest-neighbour distance (ENN_MN)	Aggregation	Measures the isolation aspect of the fragmentation and provides a measure of the shortest Euclidian neighbour distance. Higher values indicate farther patch distance of the class.
Effective Mesh Size (MESH)	Aggregation	Measures of aggregation of patches in terms of area such that total landscape area is considered for the proportional area of each patch, thus providing a relative measure of the patch structure.
Patch Density (PD)	Aggregation	Measures the number of patches of the class per unit area. Higher value generally denotes higher heterogeneity. To be interpreted in conjunction with other metrics

1.2. Image fusion and vegetation index based extraction

Red-edge bands (RE 1, RE 2 and RE 3) and SWIR (SWIR 1 and SWIR 2) have a spatial resolution of 20 m as compared to 10 m in visible and near infrared (NIR). Thus, five bands at 20 m resolution were resampled to 10 m using the Gram-Schmidt (GS) transformation algorithm where one band owning the higher spatial resolution was used to fuse the other lower resolution band set. GS transformation is one of the component substitution approaches for image fusion (Wang, Shi, Li, & Atkinson, 2016) which uses averaging of multispectral bands and their spectral response function to downscale. It simulates the panchromatic band from lower spatial resolution and applies the inverse GS transform to form a pan-sharpened band. With varied wavelength ranges (Table S4), RE bands provide different spectral information for land cover classification, and thus it was important to identify the most suitable one. To do so, we employed different vegetation indices based on RE bands to test the suitability of RE band in extracting vegetation classes such as Red Edge Chlorophyll Index (CL_{RE}), Normalized Difference Red Edge (NDRE), Red Edge Soil Adjusted Vegetation Index (RESAVI), Modified Red Edge Simple Ratio (MSRRE), and Modified Enhanced Vegetation Index (MEVI) (see Cao et al., 2013 for formula). RESAVI, which corrects the influence of background soil and utilizes the advantages of RE bands to appropriately extract vegetation classes, was selected further after comparison of indices. Among the three RE bands, RE 1 performed the best to differentiate vegetation classes across the study area and was thus chosen for further analysis. This analysis was carried out in ERDAS Imagine 2020.

Table S4 Details of Sentinel-2 bands used in the study (European Space Agency, 2015).

Spatial resolution (m)	**Band number**	**Sentinel-2**		
		Band name	**Central wavelength (nm)**	**Bandwidth (nm)**
10	2	Blue	490	65
	3	Green	560	35
	4	Red	665	30
	8	Near infrared (NIR)	842	115
20	5	Red-edge 1 (RE1)	705	15
	6	Red-edge 2 (RE2)	740	15
	7	Red-edge 3 (RE3)	783	20
	8a	Red-edge 4 (RE4) or NIR narrow	865	20
	11	Shortwave infrared 1	1610	90
	12	Shortwave infrared 2	2190	180

1.3. Image classification, post classification analysis and accuracy assessment

Image classification was undertaken in two different band combination layer stacks. This helped to improve the accuracy and utilize the vegetation class differentiation resulting from RESAVI index and further reducing spectral confusion. Band combination 1 (BC 1) (7 bands) comprised of three visible, one NIR, two SWIR and one selected RE 1 band while Band combination 2 (BC 2) (8 bands) comprised of additional RESAVI band to extract vegetation classes. A supervised maximum likelihood classification (MLC) was carried out in ERDAS Imagine 2020 to obtain different land cover classes (each class composition depends on the configuration of the respective city). Table S5 describes the land cover classes classified with respect to each city. A mask of all urbanized classes except vegetation classes (agriculture, marshy vegetation (in case of Srinagar only) and green cover areas such as urban forest, parks, recreational areas etc.) was created using the BC1 classification result in ArcGIS 10.7. Next, the vegetation classes were classified using BC 2 by excluding the masked area. The final classified image was prepared by merging the above two results. Furthermore, post classification processing was carried out to improve the classification result based on local expert knowledge using Google Earth images as the reference base map. A digitized mask of the main urban region was developed to reclassify any pixel classified into agriculture or fallow land to green infrastructure or barren land respectively. Smaller creeks, running through dense urban areas were also carefully digitized.

Accuracy assessment was carried out using a stratified random distribution method which generates testing sites for each class (approximately 40% of reference sites) using probability proportional to size (PPS) sampling. The validity of each site was validated with reference to Google Earth™ and local knowledge of the study sites. Table S5 provides the user's accuracy (UA), producer's accuracy (PA), overall accuracy (OA) and kappa (K) coefficient statistics generated from the error matrix, and it was used to assess the accuracy of land use land cover (LULC) classification results for each city.

Table S5 LULC classes of each city and their respective accuracy assessment (producer's and user's accuracy in %), overall accuracy (in %) and kappa coefficient.

LULC classes	**Producer's acc.**	**User's acc.**
Srinagar		
Barren land	70.83	73.91
Built-up dense	92.31	92.31
Built-up sparse	91.67	75.86
Fallow land	85.00	94.44
Marshy vegetation*	100.00	100.00
River*	100.00	100.00
Sealed surface	100.00	88.89
Forest/Tree clad*	78.57	88.00
Wetlands*	100.00	81.82
Canals*	77.78	87.50
Agriculture*	86.36	90.48
Overall accuracy	86.52	
Kappa coefficient	0.8489	
Shimla		
Barren land	91.67	88.00
Built-up dense	90.91	80.00
Built-up sparse	76.67	85.19
Forest/Tree clad*	95.45	97.67
Overall accuracy	89.17	
Kappa coefficient	0.8521	
Dehradun		
Barren land	90.91	83.33
Built-up dense	95.65	81.48
Built-up sparse	76.67	82.14
Fallow land	84.62	91.67
Forest/Tree clad*	88.00	84.62
Canals*	100.00	80.00
Agriculture*	77.78	100.00
Other vegetation *	84.62	91.67
Overall accuracy	85.82	
Kappa coefficient	0.8341	

- UGI class

Table S6 Details of landscape metrics selected in the study, after McGarigal and Marks, 1995; McGarigal, 2015.

Metrics	**Formula**	**Range**
Largest patch index (LPI)	$\mathrm{LPI} = \frac{\max_{j=1}^{n}(a_{ij})}{A}(100)$ a_{ij}= area (m^2) of largest patch ij A= total landscape area (m^2)	0 < LPI ≤ 100
Mean Patch Size (AREA_MN)	$\mathrm{AREA\_MN} = \frac{\sum_{j=1}^{n} a_{ij}(1/10000)}{n_i}$ a_{ij}= area (m^2) of patch ij n_i= number of patches in the landscape class i	AREA_MN > 0, without limit
Edge Density (ED)	$\mathrm{ED} = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10000)$ e_{ik} = total length (m) of edge in landscape involving class i A = total landscape area (m^2)	ED ≥ 0, no limit
Landscape Shape Index (LSI)	$\mathrm{LSI} = \frac{0.25\ \sum_{k=1}^{m} e_{ik}}{\sqrt{A}}$ e_{ik}= total length (m) of edge in landscape between patch types (classes) i and k; includes the entire landscape boundary and some or all background edge segments involving class i A= total landscape area (m^2)	LSI ≥ 1, without limit
Area-Weighted Mean Patch Fractal Dimension (FRAC_AM)	$\mathrm{FRAC\_AM} = \sum_{j=1}^{n}\left[\left(\frac{2\ln(0.25p_{ij})}{\ln a_{ij}}\right)\right]\left[\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right]$ P_{ij}=Perimeter (m) of patch $_{ij}$ a_{ij}= area (m^2) of patch $_{ij}$	1 ≤FRAC_AM ≤2
Contiguity Index (CONTIG)	$\mathrm{CONTIG} = \frac{\left[\frac{\sum_{r=1}^{z} c_{ijr}}{a_{ij}}\right]-1}{v-1}$ c_{ijr}= contiguity value for pixel r in patch ij v = sum of the values in a 3-by-3 cell template a_{ij}= area (m^2) of patch ij in terms of number of cells	0 ≤CONTIG ≤1
Mean Euclidean Nearest-Neighbour distance (ENN_MN)	$\mathrm{ENN\_MN} = \frac{\sum_{j=1}^{n} h_{ij}}{n_i}$ h_{ij} = distance (m) from patch ij to nearest neighboring patch of the class, based on patch edge-to-edge distance, computed from cell center to cell center	MNN > 0, no limit
Effective Mesh Size (MESH)	$\mathrm{MESH} = \frac{\sum_{j=1}^{n} {a_{ij}}^2}{A}\left(\frac{1}{10{,}000}\right)$ a_{ij}= area (m^2) of patch ij A = total landscape area (m^2)	Ratio of cell size to landscape area ≤ MESH ≤ total landscape area (A)
Patch Density (PD)	$\mathrm{PD} = \frac{n_i}{A}(10000)(100)$ n_i= number of patches in the landscape class i A = total landscape area (m^2)	PD > 0, constrained by cell size

Table S7 Step-wise regression with multicollinearity test for Srinagar. UGIQ is the dependent variable.

Model		Unstandardized Coefficients		Standardized Coefficients	Collinearity Statistics	
		B	Std. Error	Beta	Tolerance	VIF
1	(Constant)	.000	0.604			
	FRAC_AM	11.361	0.604	0.917	1.000	1.000
2	(Constant)	.000	0.512			
	FRAC_AM	10.535	0.536	0.850	0.913	1.096
	AREA_MN	2.795	0.536	0.226	0.913	1.096
3	(Constant)	.000	0.252			
	FRAC_AM	6.061	0.408	0.489	0.382	2.617
	AREA_MN	3.989	0.277	0.322	0.831	1.204
	ED	5.608	0.390	0.453	0.418	2.390
4	(Constant)	.000	0.215			
	FRAC_AM	5.957	0.348	0.481	0.381	2.626
	AREA_MN	4.001	0.236	0.323	0.831	1.204
	ED	4.126	0.443	0.333	0.236	4.243
	LSI	1.902	0.375	0.153	0.328	3.051
5	(Constant)	.000	0.175			
	FRAC_AM	4.940	0.334	0.399	0.275	3.635
	AREA_MN	2.578	0.312	0.208	0.315	3.177
	ED	3.627	0.371	0.293	0.223	4.485
	LSI	2.601	0.329	0.210	0.284	3.527
	LPI	2.222	0.384	0.179	0.208	4.814
6	(Constant)	.000	0.104			
	FRAC_AM	3.918	0.219	0.316	0.224	4.462
	AREA_MN	1.816	0.198	0.147	0.275	3.637
	ED	2.245	0.254	0.181	0.167	5.999
	LSI	3.151	0.202	0.254	0.265	3.767
	LPI	2.863	0.235	0.231	0.195	5.139
	ENN_MN	-2.031	0.188	-0.164	0.306	3.268
7	(Constant)	.000	0.000			
	FRAC_AM	2.882	0.000	0.233	0.165	6.069
	AREA_MN	1.842	0.000	0.149	0.275	3.638
	ED	3.341	0.000	0.270	0.128	7.797
	LSI	2.988	0.000	0.241	0.263	3.807
	LPI	1.897	0.000	0.153	0.153	6.536
	ENN_MN	-3.048	0.000	-0.246	0.208	4.817
	PD	-1.657	0.000	-0.134	0.243	4.110

Table S8 Step-wise regression with multicollinearity test for Shimla. UGIQ is the dependent variable.

Model		Unstandardized Coefficients		Standardized Coefficients	Collinearity Statistics	
		B	Std. Error	Beta	Tolerance	VIF
1	(Constant)	.000	0.620			
	LPI	8.852	0.620	0.948	1.000	1.000
2	(Constant)	.000	0.328			
	LPI	6.217	0.472	0.666	0.482	2.073
	AREA_MN	3.662	0.472	0.392	0.482	2.073
3	(Constant)	.000	0.212			
	LPI	5.114	0.364	0.548	0.341	2.929
	AREA_MN	3.419	0.309	0.366	0.473	2.114

	ENN_MN	-1.755	.313	-0.188	0.461	2.169
4	(Constant)	.000	.149			
	LPI	4.422	.293	0.474	0.258	3.876
	AREA_MN	2.812	.251	0.301	0.352	2.844
	ENN_MN	-1.991	.225	-0.213	0.439	2.279
	ED	-1.268	.265	-0.136	0.315	3.178
5	(Constant)	.000	.000			
	LPI	2.785	.000	0.298	0.101	9.932
	AREA_MN	2.698	.000	0.289	0.348	2.874
	ENN_MN	-2.407	.000	-0.258	0.374	2.670
	ED	-2.666	.000	-0.285	0.132	7.597
	FRAC_AM	1.166	.000	0.125	0.325	3.073

Table S9 Step-wise regression with multicollinearity test for Dehradun. UGIQ is the dependent variable.

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**Collinearity Statistics**	
		B	**Std. Error**	**Beta**	**Tolerance**	**VIF**
1	(Constant)	.000	.401			
	AREA_MN	7.847	.401	0.932	1.000	1.000
2	(Constant)	.000	.204			
	AREA_MN	5.282	.285	0.627	0.513	1.949
	FRAC_AM	3.674	.285	0.436	0.513	1.949
3	(Constant)	.000	.146			
	AREA_MN	5.190	.204	0.616	0.511	1.957
	FRAC_AM	3.425	.207	0.407	0.500	2.002
	CONTIG_MN	1.134	.152	0.135	0.920	1.087
4	(Constant)	.000	.084			
	AREA_MN	2.917	.244	0.347	0.119	8.371
	FRAC_AM	3.050	.124	0.362	0.459	2.177
	CONTIG_MN	1.311	.089	0.156	0.888	1.126
	LPI	2.665	.251	0.317	0.113	8.824
5	(Constant)	.000	.000			
	AREA_MN	2.868	.000	0.341	0.119	8.377
	FRAC_AM	2.393	.000	0.284	0.305	3.279
	CONTIG_MN	.993	.000	0.118	0.722	1.384
	LPI	2.929	.000	0.348	0.111	9.001
	LSI	.929	.000	0.110	0.454	2.204