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Measuring the Paradigm Shift in Ecological Services in the Mountainous Urban and Peri-Urban Systems of the Himalayas

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ABSTRACT
In the present study, an attempt has been made to understand the dynamics in ecological demand and supply in the mountainous urban systems of the Himalayas using spatial approach during the three decades. The study discusses the spatio-temporal dynamics of urban ecological services (UES) by investigating the pattern of demand and supply patches in the major mountainous urban systems of the Himalaya during the period of 1991-2018. The demand patch (135 %) in the mountainous urban systems of the Himalaya has increased significantly in contrast to a serious decline in the supply patch (-24 %) over the last three decades (1991-2018). The city-scale comparative study indicated Srinagar (80.37 km^2) and Kathmandu (51.82) exhibited higher growth in the demand patch in contrast to Gangtok (3.52 km^2), which observed comparatively lower growth for the same. On the contrary, the supply patches observed higher depletion in Srinagar (-68.03 km^2) and Kathmandu (-54.66 km^2) while lower in Gangtok (3.52 km^2). However, the intensity of rate of change of demand patch was higher in Srinagar (181.69 %), Shimla (163.04 %) and Itanagar (153.75 %), and comparatively lower in Gangtok (71.84 %) whereas the intensity of the same for supply patch was in higher in Kathmandu (-57.48 %), and lower in Shimla (-12.26 %) and Gangtok (-7.66 %). Significant changes in the ecological services, particularly in cities such as Srinagar and Kathmandu, lead to a loss of heterogeneity and wellbeing in urban ecosystems. The cities in Himalayan valleys (Srinagar, Dehradun and Kathmandu) exhibited severe decline in the supply patch and significant rise of demand patch in especially the peri-urban areas followed by the saturation of urban regions. Also, the city on ridges (Shimla, Gangtok and Thimphu) showed moderate growth of demand patch in the urban regions and insignificant growth in the peri-urban regions. As a result, the supply patch exhibited lower depletion in both urban and peri-urban regions. For a robust and sustainable urban system in the Himalaya, the study highlights the implementation of contingent policies combined with resilience methods, particularly in urban and peri-urban areas.

Key words: Urban ecological services, Demand-Supply patches, Peri-urban regions, Himalayan urban system, Remote Sensing.

INTRODUCTION

The rising population in the urban center is crucially affecting the urban, peri-urban and regional ecosystem (Kumar 2016). The intensity of urbanization is so high that it is expected that around 68% of the global population is expected to live in urban areas, which will comprise <4% of landmass (UNPD 2018). Such rapid population growth causes blue-green infrastructure alterations, which frequently result in ecological imbalances (Li et al. 2017). However, humans in the biosphere not only consume natural products but also largely depend upon its ecological services (Folke et al. 1997). Ecological services are described as the derived benefits from a functional ecosystem, consumed by humans directly or indirectly that are required to sustain (Costanza et al. 1997). An ecosystem is a cluster of interacting species with their local and non-biological environment performing together to sustain a living (Moll and Petit 1994). However, urban systems consist of single or multiple individual ecosystems forming a more complex ecosystem (Rebele 1994). The growth of the global economy can hardly be imagined without the ecosystem services, also termed as ecological life-support systems (Costanza et al. 1997). One of the significant outcomes of the Millennium Ecosystem Assessment (2005) indicated 15 out of 24 global ecosystem services are on the verge of declination which are supposed to create a severe impact on mankind in the coming future.

The urban and peri-urban regions are largely dependent on huge hinterlands (supply patch), needed to provide input in the form of resources and services and in turn taking care of output from them (Bolund et al. 1999). These hinterlands are seriously affected and observe significant transformations due to rapid expansion of urban areas (demand patch) (Chaudhari and Kumar 2020). The rising vulnerability in the urban regions can effectively be lessened with the resources, buffers, and capacities of peri-urban ecosystems (Gupta et al. 2021). Despite the widely acknowledged need to integrate peri-urban ecosystem-based methods to increase urban resilience, peri-urban ecosystems are regrettably declining in quantity and quality. (Gupta et al. 2016). Furthermore, the ecological services are dynamic in nature and approach associated with its planning varies spatially as well as with each other, over time (Tripathy and Kumar 2019). The pattern of ecological services in the mountainous landscape is dissimilar with respect to other physiographic features (Tiwari et al. 2018). Mountain ecosystems occupying a moderately significant portion (approx. 24%) of the earth surface (UNEP-WCMC 2002), accommodates around 12% of the global population (Huddleston et al. 2003). These are the most complex landscapes, especially Himalayas, from the perspective of geological forces, ecological sensitivity, seismicity, accessibility, topographic constraints, marginality, climate change and limited development of infrastructures (Meybeck et al. 2001). The Himalayas, being the world's most fragile and uneven mountain system, are highly vulnerable to various geological (earthquakes, landslides etc.) and hydro-meteorological hazards (flash floods, cold waves, heat waves *etc*.) (Kumar et al. 2020). Rapid and unplanned growth of the demand patch in one the highest inhabited regions of the world, is one of the major contributing factors affecting the ecosystem services of the region (Sivaramakrishnan et al. 2005, Diksha and Kumar 2017). The growing changes in the dynamics of urban ecological structures not only transforms the Himalayan landscape but also have a stronger influence on the ecological equilibrium of the region (Jiao et al. 2019). The ecological services have gained significant attention in recent times leading to numerous studies (*viz*., urban climate, soils, urban flora-fauna, urban habitats, urban green spaces etc.) in the past few decades with a goal to estimate the value of a wide variety of ecosystem services (Gill and Bonnett 1973, Sukopp et al. 1990, Fisher et al. 2007). However, the ecosystem services are not completely utilized or adequately quantified in the commercial markets leading to create ecological disequilibrium. This neglect may ultimately compromise the sustainability of humans in the biosphere. Therefore, the present study is focused on the evaluation of changing dynamics of demand and supply patches in the mountainous urban systems of the Himalayas. Later, changes in demand and supply in all major mountainous urban systems were evaluated in order to understand the growing anthropogenic impacts on within the urban and peri-urban regions.

MATERIAL AND METHODS

The urban and peri-urban regions of seven capital urban centers of Himalayas, *namely* Srinagar, Shimla, Dehradun, Kathmandu, Gangtok, Thimphu and Itanagar has been taken up as the study area for a comparative evaluation. The present study utilized multispectral satellite images including *viz*., LANDSAT-TM (5) and Sentinel-2 (A/B) (earthexplorer.usgs.gov) to delineate the ecological services in the mountainous urban and peri-urban systems of Himalayas. *K-Means* iterative clustering algorithm was used to delineate the UES comprising the demand patch, the supply patch and the 'others' patch. The demand patch, also referred to as consumer class, primarily included the built-up area while the supply patch, also considered as major service providers, included the productive lands as vegetation, arable land and water bodies. Furthermore, the remaining areas were classified as 'others' class and excluded in either of the patches (demand or supply). Later, the dynamics of ecological services in terms of demand and supply patches were evaluated with reference to the municipal boundary. The area under municipal boundary is referred to as urban while outside municipal boundary referred to as peri-urban regions. The changes in the demand and supply patches in all major mountainous urban systems were evaluated to understand the rising anthropogenic influences in the valley or ridge-based cities.

RESULTS

Dynamics of ecological services in the mountainous urban and peri-urban region of the Himalayas

The spatio-temporal study of demand and supply patches of ecological services exhibited a significant rise in the demand patch (135%) in the urban systems of the Himalayas during 1991-2018 leading to a remarkable decline in the supply patch (-24 %). The cumulative study demonstrated that the demand patch has grown rapidly from 143.20 km^2 to 336.56 km^2 over the period 1991-2018. On the contrary, a serious decline was observed in the supply patch from 968.74 km^2 to 735.57 km^2. However, the area under 'others' class increased gradually from 222.51 km^2 to 257.22 km^2 (rate of change: 15.6 %; Fig. 1).

Srinagar

The satellite-based study on ecological services of Srinagar city showed a higher increase in the demand patch from 44 km^2 (8.09 %) in 1991 to 124 km^2 (22.78 %) in 2018 with a rate of 181.69 % primarily in the central parts. The urban region exhibited a rapid increase from 40.94 km^2 to 79.99 km^2 while the peri-urban region from 3.29 km^2 to 44.62 km^2 during the period. However, the supply patch decreased drastically with a change of -27.74 % from 312.94 km^2 (57.22 %) to 244.91 km^2 (44.78 %) dominantly in the northern, north-eastern, north-western, and south-western regions. The urban region exhibited a decline from 167.60 km^2 to 145.30 km^2 while the peri-urban regions, from 120.04 km^2 to 120.87 km^2 during the period (1991-2018). Moreover, the area under 'others' patches observed gradual decline by -6.51 % change. The urban region observed an increase from 81.94 km^2 to 89.61 km^2 while the peri-urban region decreased from 107.75 km^2 to 87.74 km^2 during the period (Figs. 1 a, b, 3; Table 1).

Shimla

The satellite-based study on ecological services of Shimla city indicated a moderate rise in the demand patch from 3.49 km^2 (2.91 %) to 9.18 km^2 (7.66 %) throughout the period, primarily occupied by the central part of the city. The urban region exhibited an increase from 2.16 km^2 to 6.41 km^2 while the peri-urban region from 1.33 km^2 to 2.77 km^2 during the period.

In contrast, the supply patch declined gradually from 103.99 km^2 (86.80 %) to 91.24 km^2 (76.15 %) with a change of -12.26 % in all directions. The urban region exhibited a decline from 22.88 km^2 to 3 km^2 while the peri-urban regions, from 100.99 km^2 to 68.36 km^2 during the period (1991-2018). While, the 'others' patches considerably increase by 57.21 % growth. The urban region observed an increase from 0.29 km^2 to 2.45 km^2 while the peri-urban region from 12.05 km^2 to 16.95 km^2 during the period (Figs. 1c, d, 3; Table 1).

Dehradun

The satellite-based study on ecological services of Dehradun city exhibited a remarkable increase in the demand patch from 34.95 km^2 (22.07 %) to 66.70 km^2 (42.13 %) with a rate of 90.84 % throughout the period, basically lying in the city's center. The urban region exhibited an increase from 23.02 km^2 to 34.09 km^2 while the peri-urban region from 11.93 km^2 to 32.61 km^2 during the period. Conversely, the supply patch greatly reduced from 116.95 km^2 (73.86 %) to 87.07 km^2 (54.99 %) with a change of -25.55 %, primarily in the northern and southern directions of the city during the observation period. The urban region exhibited a decline from 30.10 km^2 to 21.17 km^2 while the peri-urban regions, from 86.85 km^2 to 65.87 km^2 during the period (1991-2018). Also, the area under 'others' patch gradually reduced with a change of -28.77% during 1991-2018. The urban region observed a decrease from 4.19 km^2 to 2.05 km^2 while the peri-urban region observed an increase from 2.24 km^2 to 2.53 km^2 during the period (Figs. 1e, f, 3; Table 1).

Kathmandu

The satellite-based study on ecological services of Kathmandu city exhibited a significant rise in the demand patch from 41.80 km^2 (30.21 %) to 93.62 km^2 (67.67 %) with a rate of 123.97 %), extensively clustered in the center of the city region throughout 1991-2018. The urban region exhibited an increase from 27.97 km^2 to 42.50 km^2 while the peri-urban region from 13.83 km^2 to 51.82 km^2 during the period. In contrast, the supply patch severely declined from 95.10 km^2 (68.74 %) to 40.44 km^2 (29.23 %) with a change of -57.48 %, mostly in around the periphery of demand patch during the observation period. The urban region exhibited a decline from

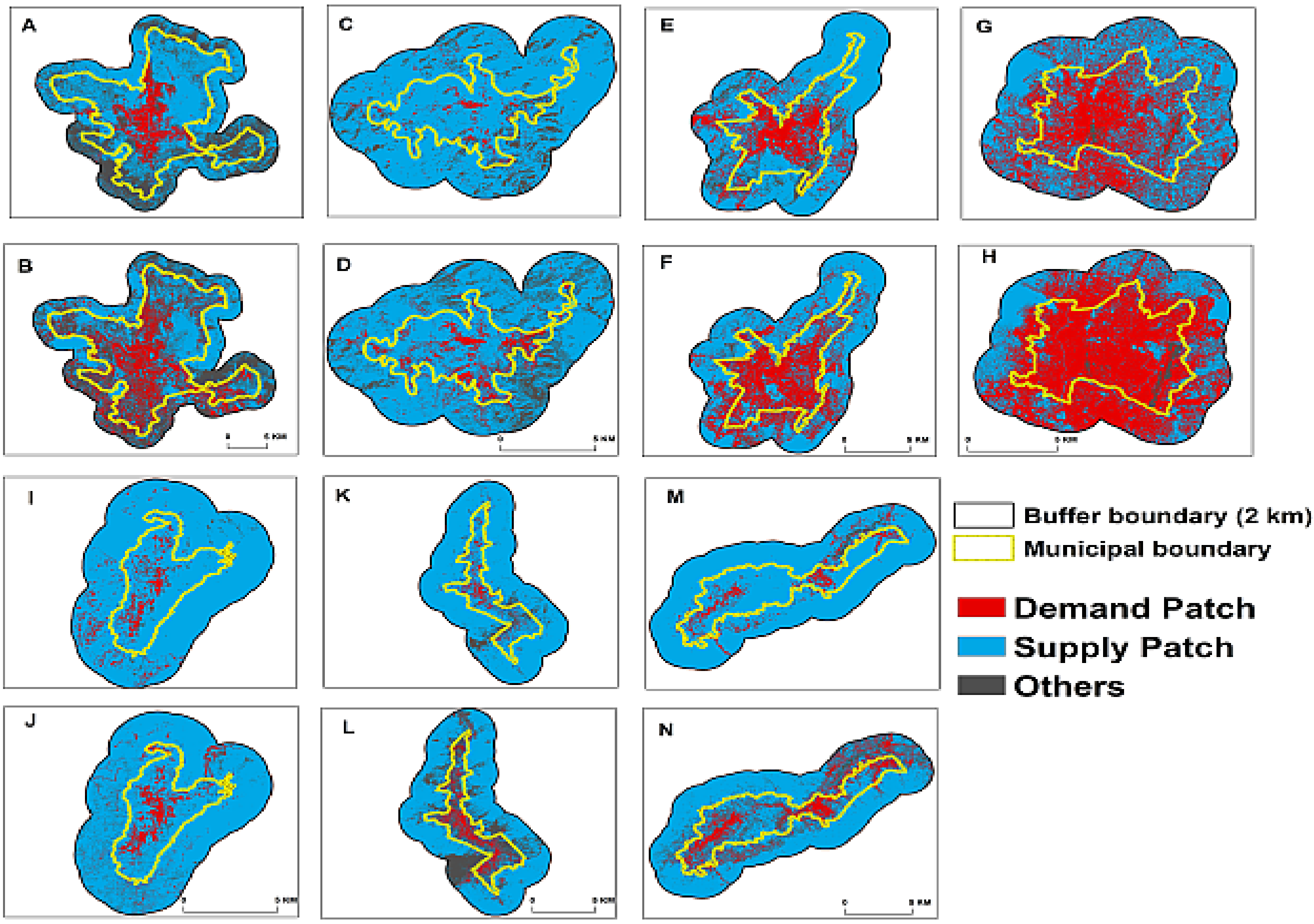

Figure 1. Spatio-temporal distribution of Ecological Services (Demand patch, Supply patch and Others) in the major urban systems of the Himalayas (a. Srinagar 1991, b. Srinagar 2018, c. Shimla 1991, d. Shimla 2018, e. Dehradun 1991, f. Dehradun 2018, g. Kathmandu 1991, h. Kathmandu 2018, i. Gangtok 1991, j. Gangtok 2018, k. Thimphu 1991, l. Thimphu 2018, m. Itanagar 1991, n Itanagar 2018).

Table 1: Area Statistics of UES (Demand patch, Supply patch, Others) for major urban systems of the Himalayas

	Supply patch			Demand patch			Others		
	Area (sq. km)		Change (%)	Area (sq. km)		Change (%)	Area (sq. km)		Change (%)
Cities	**1991**	**2018**	**1991-2018**	**1991**	**2018**	**1991-2018**	**1991**	**2018**	**1991-2018**
Srinagar	312.94	244.91	-21.74	44.23	124.60	181.69	189.69	177.35	-6.51
Shimla	103.99	91.24	-12.26	3.49	9.18	163.04	12.34	19.4	57.21
Dehradun	116.95	87.07	-25.55	34.95	66.7	90.84	6.43	4.58	-28.77
Kathmandu	95.10	40.44	-57.48	41.8	93.62	123.97	1.44	4.29	197.92
Gangtok	85.28	78.75	-7.66	4.9	8.42	71.84	1.61	4.63	187.58
Thimphu	109.92	83.71	-23.84	4.1	9.35	128.05	8.79	29.75	238.45
Itanagar	144.56	109.45	-24.29	9.73	24.69	153.75	2.21	17.22	679.19

18.18 km^2 to 2.02 km^2 while the peri-urban regions, from 76.92 km^2 to 38.42 km^2 during the period. Whereas, the 'others' patch increased gradually with a growth of 197.92 % throughout the period. The urban region observed a decrease from 0.57 km^2 to 0.06 km^2 while the peri-urban region observed an increase from 0.87 km^2 to 4.23 km^2 during the period (Figs. 1g, h, 3; Table 1).

Gangtok

The satellite-based study on ecological services of Gangtok city exhibited a notable increase in the demand patch from 4.90 km^2 (5.34 %) to 8.42 km^2 (9.17 %) with a rate of 71.84 %, which stretches vertically across the city center throughout the period (1991-2018). The urban region exhibited an increase from 2.78 km^2 to 4.42 km^2 while the peri-urban region from 2.12 km^2 to 4 km^2 during the period. On the contrary, the supply patch gradually declined from 85.28 km^2 (92.90 %) to 78.75 km^2 (85.78 %) with a change of -7.66 %, in all directions of the city surrounding the demand patch during the observation period. The urban region exhibited a decline from 27.27 km^2 to 19.13 km^2 while the peri-urban regions, from 64.10 km^2 to 59.62 km^2 during the period. Whereas, the area under 'others' patch observed sudden increase with a growth of 187.58 % during 1991-2018. The urban region observed an increase from 0.83 km^2 to 1.32 km^2 while the peri-urban region from 0.78 km^2 to 3.32 km^2 during the period (Figs. 1i, j, 3; Table 1).

Thimphu

The satellite-based study on ecological services of Thimphu city exhibited a noteworthy increase in the demand patch from 4.10 km^2 (3.34 %) to 9.35 km^2 (7.61 %) with a rate of 128.05 % throughout the period (1991-2018), primarily clustered in the city center. The urban region exhibited an increase from 3.58 km^2 to 7.02 km^2 while the peri-urban region from 0.52 km^2 to 2.33 km^2 during the period. However, the supply patch highly declined from 109.92 km^2 (89.51 %) to 83.71 km^2 (68.16 %) with a change of -23.84 %, in all directions around the demand patch during the observation period. The urban region exhibited a decline from 20.03 km^2 to 9.07 km^2 while the peri-urban regions, from 89.89 km^2 to 74.64 km^2 during the period. On the contrary, the 'others' patch increased significantly with 238.45% growth during the period. The urban region observed an increase from 3.10 km^2 to 10.59 km^2 while the peri-urban region from 5.69 km^2 to 19.16 km^2 during the period (Figs. 1k, l, 3; Table 1).

Itanagar

The satellite-based study on ecological services of Itanagar city exhibited a substantial rise in the demand patch from 9.73 km^2 (6.43 %) to 24.69 km^2 (16.31 %; growth 153.75 %), primarily dispersed in the western and eastern section of the city and its periphery throughout the period (1991-2018). The urban region exhibited an increase from 5.76 km^2 to 12.27 km^2 while the peri-urban region from 3.97 km^2 to 12.42 km^2 during the period. Conversely, the supply patch decreased significantly from 144.56 km^2 (95.50 %) to 109.45 km^2 (72.31 %) with a change of -24.29 %, all over around the demand patch during the observation period. The urban region exhibited a decline from 24.68 km^2 to 37.80 km^2 while the peri-urban regions, from 106.76 km^2 to 84.77 km^2 during the period (1991-2018). However, the 'others' patch observed a sudden increase with 679.19 % growth during the period. The urban region observed a significant increase from 0.36 km^2 to 6.96 km^2 while the peri-urban region from 1.85 km^2 to 10.26 km^2 during the period (Figs. 1m, n, 3; Table 1).

Assuming the other variables of growth being constant, the city-scale based study indicated that the demand patch was higher in Srinagar (80.37 km^2) followed by Kathmandu (51.82 km^2) and Dehradun (31.75 km^2). The demand patch was moderate in Itanagar (14.96 km^2) and lower in Shimla (5.69 km^2), Thimphu (5.25 km^2) and Gangtok (3.52 km^2). Contrarily, a significant decline of supply patch had been observed in all the cities with maximum decline in Srinagar (-68.03 km^2) followed by Kathmandu (-54.66 km^2) and Itanagar (-35.11 km^2), Dehradun (-35.11 km^2), Thimphu (-29.88 km^2), Shimla (-12.75 km^2) and Gangtok (-6.53 km^2). Meanwhile, the 'others' gradually increased in all cities with maximum rise in Thimphu (20.96 km^2) followed by Itanagar (15.01 km^2), Shimla (7.06 km^2), Gangtok (3.02 km^2) and Kathmandu (2.85 km^2) except for Srinagar (-12.34 km^2) and Dehradun (-1.85 km^2) which observed a graduated decline (Figs. 2a, b, c).

The comparative study based on rate of change of UES in the major urban systems of the Himalayas suggested that the demand patch grew rapidly higher

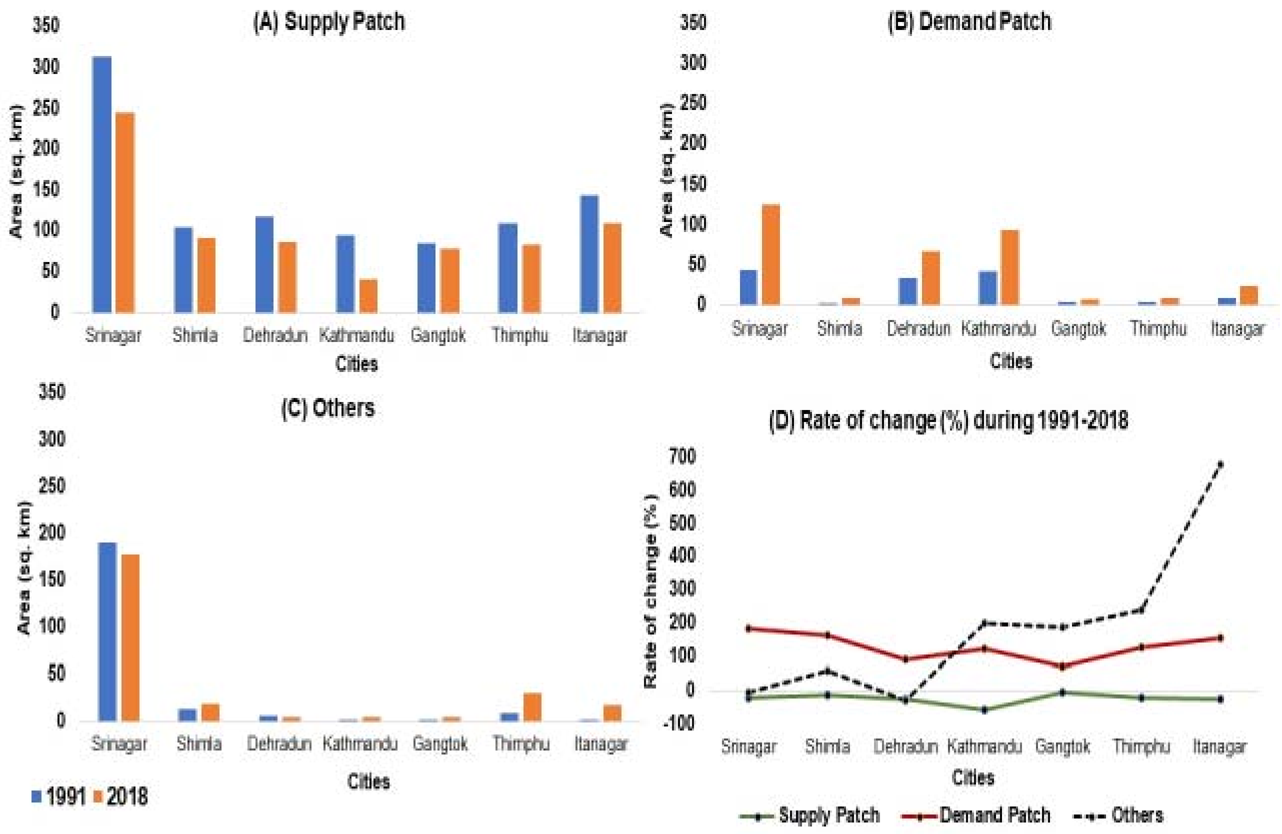

Figure 2. Ecological Services (a) Supply patch (b) Demand patch (c) Others (d) Rate of change (%) during 1991-2018 in the major urban systems of the Himalayas

in Srinagar (181.69 %), Shimla (163.04 %) and Itanagar (153.75 %); moderately higher in Thimphu (128.05 %) and Kathmandu (123.27 %); and comparatively lower in Dehradun (90.84 %) and Gangtok (71.84%). While, supply patch declined in higher in Kathmandu (-57.48 %); moderately higher in Dehradun (-25.55 %), Itanagar (-24.29 %), Thimphu (-23.84%) and Srinagar (-21.74 %) while lower in Shimla (-12.26 %) and Gangtok (-7.66 %; Fig. 2d).

DISCUSSION

The spatio-temporal study of ecological services on the mountainous urban and peri-urban region showed that the supply patches pre-occupied larger sections in the peri-urban regions than urban regions in all the major urban systems of the Himalayas except for Srinagar during 1991. However, it significantly reduced in the peri-urban region followed by the depletion in urban regions in the mountainous urban systems of the Himalayas during 2018. The demand patch progressively increased in all of the Himalayan urban systems; however, the pattern of expansion differs amongst each other. The cities like Srinagar, Dehradun and Kathmandu, located in the valleys indicated serious decline of supply patch and significant rise of demand patch especially the peri-urban areas which may be attributed to comparatively lower attitudinal variations. However, the urban regions were highly saturated in terms of demand patch in the valley cities. Concurrently, the cities like Shimla, Gangtok and Thimphu, located on mountain ridges, exhibited minimal growth of demand patch in the peri-urban region and moderate growth in the urban regions leading to lower depletion of supply patch in the urban and peri-urban regions. Topographic constraint can be one of the major causes for the diversity in the spatio-temporal characteristics of demand and supply patch. The last four decades has witnessed continual and substantial expansion of demand patch mainly at the cost of supply patch (productive areas), which has created serious ecological disequilibrium in the Himalayas.

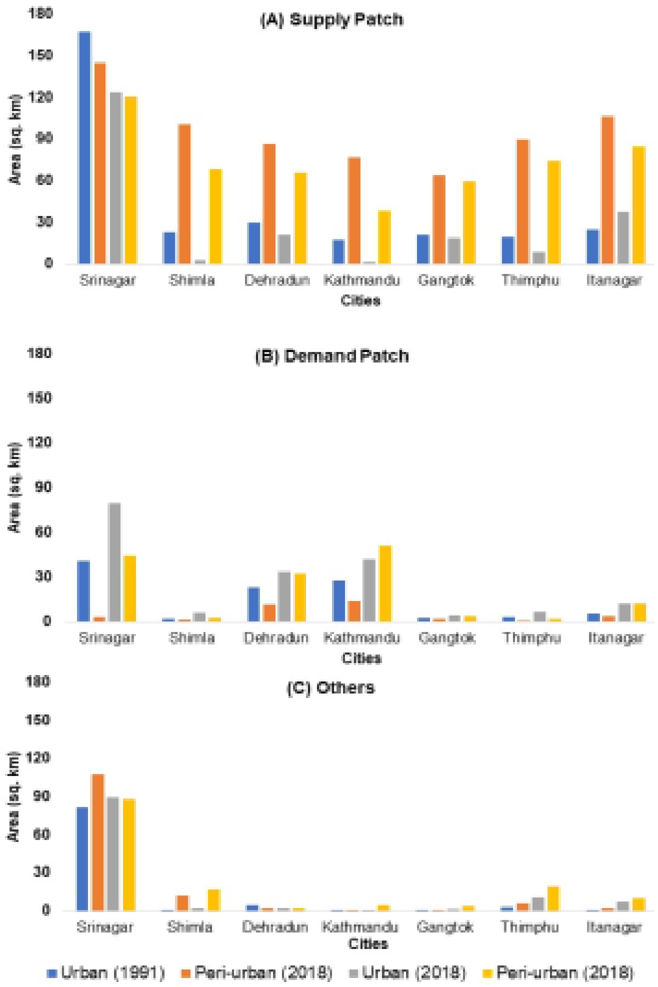

Figure 3. (a) Demand patch (b) Supply patch and (c) Others ecological services in the mountainous urban and peri-urban regions of the Himalayas during 1991-2018

CONCLUSION

The spatio-temporal satellite-based study on urban ecosystem services investigated the pattern of demand and supply patches in the major mountainous urban systems of the Himalayas during the period of 1991-2018. The select urban systems of the Himalayas exhibited a significant inclination in the demand patch (135%) at the cost of a severe declination in the supply patch (-24%) during the observation period (1991-2018). Additionally, the area under the 'others' class observed a gradual increase (15.6%) during the period of 1991-2018. The maximum rise in the demand patch was observed in Srinagar (80.37 km^2) and Kathmandu (51.82) while minimum in Gangtok (3.52 km^2). Similar pattern was shown in the depletion of the supply patch as Srinagar (-68.03 km^2) and Kathmandu (-54.66 km^2) observed higher depletion whereas Gangtok (3.52 km^2) observed least. However, the comparative study based of rate of change (increase) of demand patch indicated that Srinagar (181.69%), Shimla (163.04 %) and Itanagar (153.75 %) observed higher intensity whereas Gangtok (71.84%) exhibited comparatively lower intensity than the rest of the cities. On the contrary, in terms of rate of change of supply (decrease), Kathmandu (-57.48%) exhibited higher intensity while Shimla (-12.26%) and Gangtok (-7.66%) observed lower intensity. The valley cities (Srinagar, Dehradun and Kathmandu) exhibited severe decline in the supply patch mainly attributed to the expansion of the demand patch in especially the peri-urban areas followed by the saturation of urban regions. Apparently, the city on ridges (Shimla, Gangtok and Thimphu) observed lower depletion of supply patch and insignificant growth of demand patch in the peri-urban regions than the urban regions. Moreover, the growth of the demand patch was observed moderate in the core urban region of cities located on mountain ridges. Unlike the other physiographic zones, the Himalayan urban systems need special attention in order to maintain balance between the demand and supply services.

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