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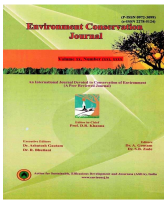

Assessment of environmental sustainability using ecological footprint in urban ecosystems of North Western Himalayas

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ABSTRACT

Rapid urbanization in cities is crafting major environmental problems, leading to degradation of urban ecosystems and is responsible for creating an imbalance between demand and supply of resources. Ecological Footprint Analysis (EFA) is a tool that can be used to assess this imbalance scientifically and determine the sustainability of a particular area. Our study aims to determine the urban sustainability of Kangra district in Himachal Pradesh, a hilly state in North Western Himalayas, India situated in North western Himalayas by using one of the Ecological Footprint Analysis (EFA) components, the built-up land footprint, as a pragmatic tool for analysis and planning of the urban region. The total built-up land footprint, total biocapacity and total ecological deficit are 18146.095 g ha,15968.564 g ha and 2177.531 g ha respectively whereas built-up land footprint per capita, built-up land biocapacity per capita and ecological deficit per capita are 1.371 g ha, 1.206 g ha, and 0.164 g ha respectively in different urban areas. Consequently, it is concluded that the built-up land results in an ecological deficit, and the system is considered unsustainable because its ecological footprint exceeds its bio capacity. It is suggested that urban sustainability should move and work on ecological principles so that the vision encompassing global goals and agenda 2030 for sustainable development can be achieved.

Introduction

Urban dwellers are expected to make up 68% of the world's population by 2050, according to the United Nations (2018). The global population is projected to reach approximately 9.6 billion by 2050, with 2.5 billion people living in urban areas, indicating a high concentration of growth in these areas (Turok, 2014). The 2011 census revealed that there were 1.21 billion people living in India, of which 31.1% were urban dwellers (Shaban *et al.,* 2020). Urbanization in India is accelerating at an alarming rate, which is supported by the statistics (Sudhira and Gururaja, 2012). Various issues related to urbanization exist on a local, national and international scale (Taipale *et al.,* 2012). The rapid pace of urbanization in recent decades has hastened the demand for urban land, leading to major challenging issues (Seto *et al.,* 2012; Uttara *et al.,* 2012) such as overpopulation, overconsumption, shortage of housing, infrastructure depreciation, overcrowding, water scarcity, poor air and water quality, increased pollution levels, expanded energy utilization, increased impervious surfaces and alteration in the functions of natural ecosystems such as biogeochemical processes and circulation patterns (Geng, 2012; Newman, 2006), collectively leading to ecological imbalance (Ren *et al.,* 2012; Karkazis and Boffey, 1997; Rees, 1996). Sustainable development gained popularity in the late 1980s and early 1990s from the Brundtland Report (Brundtland, 1987), which defined sustainable development as a form of development that meets the needs of the present without

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compromising the ability of future generations to meet their own needs (Wackernagel, 2014). However, sustainable development is interrelated with urbanization in three dimensions: economic, social, and environmental (United Nations, 2018).
Several methods for exploring and assessing sustainability exist across the globe, including emergy analysis, material flow analysis, data envelopment analysis (Geng *et al.,* 2013; Zhao *et al.,* 2006), analytical hierarchy process (Yue *et al.,* 2011), and ecological footprint analysis (EFA) (Wackernagel and Rees, 1996; Wackernagel *et al.,* 2005; Wackernagel, 2014; Swaider *et al.,* 2020). Of these, the EFA technique (Wackernagel and Rees, 1996) will be the most useful and will be employed to have a comprehensive view of the urban ecosystems existing in the Himalayas. In an ecological footprint analysis, six components are taken into consideration: carbon lands, built-up areas, forests, fishing grounds, cropland, and pastures.Ecological footprint is a function of these components together (Wilson and Anielski, 2004) (Figure 1). EFA is an approach to trace human impacts on the regenerative capacity of an ecosystem by calculating the amount of bio-productive land needed to sustain the average annual consumption and waste output of a given entity based on technology at the time (Wackernagel *et al.,* 2005; Monfreda *et al.,* 2004; Wackernagel *et al.,* 2002; GFN, 2017).

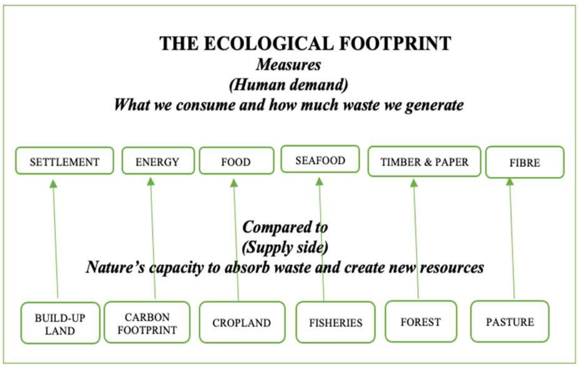

Figure 1: Illustration of the demand on and supply of nature

Cities are not only engines of economic and social development but also transportation corridors that pose significant challenges and risks to the environment, making planning a difficult task. However, sustainable and smart development can be achieved through urban planning, (Corrigan, 2004; Livingston, 2017) , which requires a comprehensive approach that includes new knowledge, inclusivity, integration, management, and sustainable ecosystems for urban habitats (Minea, 2008; Soltani and Sharifi, 2012).
To evaluate the environmental sustainability of one of the urban ecosystems in the North-western Himalayas, this study focuses on the *built-up land component*, such as buildings and infrastructure for housing, transportation, and industrial production. Kangra, which has 3,559,422 working people, is the most populous district in Himachal Pradesh, with a population of about 15.10 lakh and a density of 263 people per square kilometre. Therefore, it holds the first position among the 12 districts in terms of population, literacy rates, and working population (Census of India, 2011).
As no similar study has been conducted in Kangra district, in order to develop a utilitarian model to address ecological imbalance caused by the fast pace of urbanization, and to generate strategies for urban resilience that incorporate adaptive capacity and sustainability to face the challenges of the 21st century. (Dadashpoor and Ahani, 2019a; Diamond, 2012).

Material and Methods

Study area

The study was conducted in the Kangra district of Himachal Pradesh, located in the North western Himalayas. Kangra was selected for its diverse population, and it is the most populous district in Himachal Pradesh with a total population of approximately 1,510,075 and a geographical area of 5,739 square kilometres, which accounts for 10.31% of the state's total area. The district's coordinates lie between 31˚ 21′ to 32˚ 59′ North latitude and 75˚ 47′ 55″ to 77˚ 45′ East longitude (see Figure 2). The study included three types of urban areas based on their degree of urbanization: Municipal Corporation, Municipal Council, and Nagar Panchayat (refer to Table 1). These urban areas account for approximately 5.7% of the state's population.

Methods and measurements of EFA tool

This study was carried out during 2019-2020 in the urban areas of Kangra district. The necessary data, including the built-up area, the equivalence factor, and the yield factor, were gathered from field

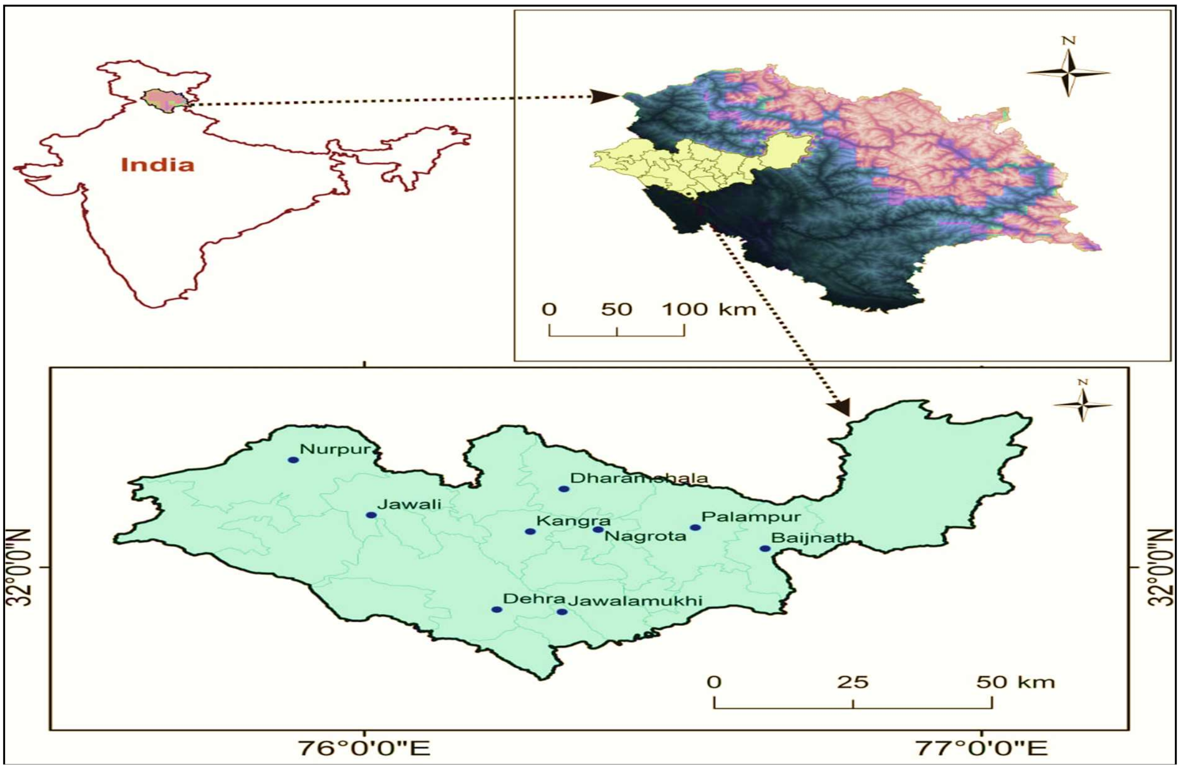

Figure 2: Map showing study area

Table 1: Description of different urban areas of Kangra district

Urban Areas	No. of wards	No. of Households	Total population
	Municipal Corporation		
Dharamshala	17	12500	53543
Municipal Council			
Kangra	9	2250	9528
Nurpur	9	2160	9807
Palampur	7	766	3543
Nagrota	7	1779	5900
Dehra	7	1221	4816
Jawalamukhi	7	1428	5361
Nagar Panchayat			
Baijnath-Paprola	11	2661	16124
Jawali	9	2966	10564
Total	**83**	**27731**	**119186**

surveys, official records from the Census of India, and global footprint account data.

Built-up land Footprint (EF $_{\text{Built-up land}}$)

"The footprint of built-up land is calculated based on the area covered by man-made infrastructure, such as transport, housing, industry, and reservoirs for hydropower generation." According to the National Footprint Accounts (NFA, 2011), which assumes that built-up land is located in fertile areas, it can lead to irreversible losses of biocapacity (Kandil *et al.,* 2019; Geng *et al.,* 2014). The ecological footprint (EF) of built-up land was derived using the following equation and methodology, based on the assumption that the built-up area was largely converted from prime agricultural land (NFA, 2011; Wackernagel *et al.,* 2005).

$$\mathbf{EF_{Built-up\ land}(gha)} = \frac{\mathbf{A(ha) \times EQF}\left(\frac{gha}{ha}\right) \mathbf{\times YF}}{\mathbf{N}}$$

Where;

- **EF built-up land is the ecological Footprint of built-up area per capita in global hectares**
- **A stands for the area in hectares of the built-up land**
- **EQF is the global equivalence factor per hectare of built-up land**
- **YF is the yield factor of built-up which is equal to the yield factor of the cropland**
- **YF stands for yield factor of the cropland which equals yield factor of built-up land**
- **N is the population of the area under study**

Built-up land Biocapacity (BC $_{\text{Built-up land}}$)

"As a lens, an important aspect of biocapacity is its ability to regenerate and provide the necessary natural resources and services to meet the competing needs of humans, such as producing energy, eliminating waste, recycling water, and making urban areas productive and liveable". Overall, biocapacity gives us a sense of how sizable the material metabolism of human economies is in comparison with what nature can replenish. It is standard practice to allocate 12% of available land for the preservation of domestic biodiversity when determining the biocapacity (BC) of a given land use type. The biocapacity was calculated using the methodology described by Kandil *et al.* (2020), Zhao *et al*. (2006), and Borucke *et al*. (2013).

$$\mathbf{BC_{Built-up\ land}(gha)} = \frac{\mathbf{A(ha) \times EQF\left(\frac{gha}{ha}\right) \times YF(100-12\%)}}{\mathbf{N}}$$

Where;

- **BC stands for total built-up land bio-capacity**
- **A stands for the total available supply in a given year**
- **EQF stands for the Equivalence Factor**
- **YF stands for the Yield Factor**
- **N stands for the population of the area under study**

Equivalence Factor (EQF)

It is used to convert actual areas (hectares) of different land types into global hectares. Equivalence factors represent the relative productivity of world average hectares of different land use types that apply to all countries and change slightly from year to year. For the year 2017, the equivalence factor for built-up areas was 2.49 global hectares per hectare, while for 2019 it was 2.51 global hectares per hectare (Lin *et al.,* 2019; NFA, 2021)

Yield Factor (YF)

According to the yield factors, each country, for each land use type, has its own yield factor. The yield factor represents the average productivity of both national and global hectares of a given land use type. These yield factors are included in biocapacity calculations when the biocapacity statistics are expressed in global hectares. Similarly, there are similar yield factors for all countries, which change slightly from year to year. For the year 2017, the yield factors for built-up areas were 1.05 global hectares per hectare, while for 2019 they were 1.08 global hectares per capita (Lin *et al.,* 2019; NFA, 2021).

Ecological deficit (EF$_D$)

Ecological deficit or an ecological balance issue can be determined by deducting ecological footprint from biocapacity. If the ecological footprint is greater than the biocapacity, it results in an ecological imbalance problem; then the system is considered to be unsustainable and there is a presence of Ecological Deficit (ED). On the other hand, if biocapacity exceeds ecological footprint, then the system is considered sustainable and Ecological Reserves (ER) are present (Geng *et al.,* 2014; Cucek *et al.,* 2012; Galli *et al.,* 2019).

$$\mathrm{EF_D = EF - BC}$$

Where

- **EF$_D$ stands for ecological deficit of the study area**
- **EF stands for ecological footprint by various categories of consumption**
- **BC stands for biocapacity given by bio productive area**

Results and Discussion

Built-up land footprint

The Ecological Footprint (EF), Biocapacity (BC), and Ecological Deficit (ED) vary largely as separate variables. These can be used to determine how much the local environment is capable of supporting the study system when the first two variables are larger, or when they are present in pools. The built-up land footprint is an important factor that gives insight to planners and researchers to ensure the balance ratio of EF and BC. The data presented in Figure 3 illustrates that the total built-up land footprint and built-up land footprint per capita are 18,146.095 and 1.371 g ha, respectively, in different urban areas. The Kangra district of the hilly state has different total built-up land footprints ranging from 181.624 to 7,988.728 g ha. Urban areas exhibit the following trends: Dharamshala (7,988.728 g ha) > Jawali (2,434.298 g ha) > Baijnath-Paprola (2,339.420 g ha) > Nurpur (1,287.630 g ha) > Jawalamukhi (1,225.282 g ha) > Nagrota (959.623 g ha) > Dehra (883.721 g ha) > Kangra (845.770 g ha) > Palampur (181.624 g ha). Dharamshala has the highest built-up land footprint (7,988.528 g ha), likely due to the rapid development of the area.

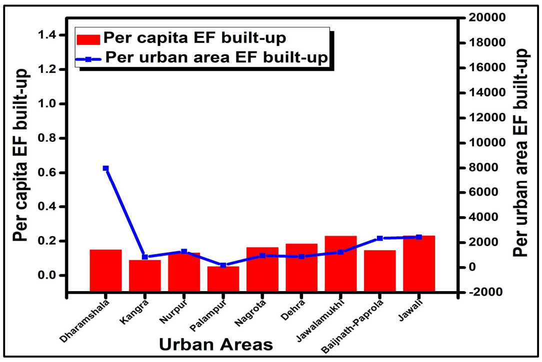

Figure 3: Built-up land footprint EF $_{built-up}$ (g ha) in different urban areas of district Kangra

These results are in line with Kassouri (2021), Pandit et al. (2021), and Jain et al. (2021), who have reported a positive and significant effect of urbanization on built-up land footprints. The results clearly depict that increased rates of urbanization will result in elevated levels of built-up land footprint as the growth of urbanization increases the amount of space needed for infrastructure, including buildings, bridges, roads, and industrial structures. High population pressure, tourism, waste generation, educational hubs, as well as material accumulations, including an abundance of many private and governmental offices, may also contribute to the high footprint. While Palampur has the smallest footprint of built-up land (181.624 g ha), which might be due to reasonably lower anthropogenic and developmental activities and lesser levels of population in the region compared to other urban areas.Per capita built-up land footprints varied among different areas, ranging from 0.051 to 0.230 g ha/capita and resulted in trend: Jawali (0.230 g ha/capita) > Jawalamukhi (0.229 g ha/capita) > Dehra (0.183 g ha/capita) > Nagrota (0.163 g ha/capita) > Dharamshala (0.149g ha/capita) > Baijnath-Paprola (0.145 g ha/capita) > Nurpur (0.131 g ha/capita) > Kangra (0.089 g ha/capita) > Palampur (0.051 g ha/capita). Similar results has been found by Kandil *et al.* (2020) and Pandit *et al.* (2021)*;* based on different population sizes, diverse geographic areas, and the different populations under study not proportionate to the current area available, no significant trends in per capita built-up land footprint were observed.

Built-up land biocapacity

The biocapacity of built-up land provides insight into the demands of humans for renewable resources in the study area. Calculating these values can help to clearly identify the balance between supply and demand over time. With respect to urban areas, Figure 4 shows a total biocapacity of 15968.564 g ha and a per capita built-up land biocapacity of 1.206 g ha. Different urban areas had a total built-up land biocapacity between 7030.081 and 159.829 g ha. The urban area-wise trend was: Dharamshala (7030.080 g ha) > Jawali (2142.183 g ha) > Baijnath-Paprola (2058.690 g ha) > Nurpur (1133.114 g ha) > Jawalamukhi (1078.248 g ha) > Nagrota (844.468 g ha) > Dehra (777.674 g ha) > Kangra (744.277 g ha) > Palampur (159.829 g ha). It is likely that Dharamshala has the highest built-up biocapacity due to its maximum built-up land area and Palampur has the lowest built-up biocapacity due to the smallest built-up land area.

Different urban areas exhibited varying levels of built-up biocapacity per capita from 0.045 to 0.203 g ha/capita and the order was : Jawali (0.203 g ha/capita) > Jawalamukhi (0.201 g ha/capita) > Dehra (0.161 g ha/capita) > Nagrota (0.143 g ha/capita) > Dharamshala (0.131 g ha/capita) > Baijnath-Paprola (0.128 g ha/capita) > Nurpur (0.116 g ha/capita) > Kangra (0.078 g ha/capita) > Palampur (0.045 g ha/capita). The results are in line with findings of Kandil *et al.* (2020) and Pandit *et al.* (2021) who reported that varying degrees of population density and lack of proportionate geographic area might result in no particular pattern in built-up land biocapacity.

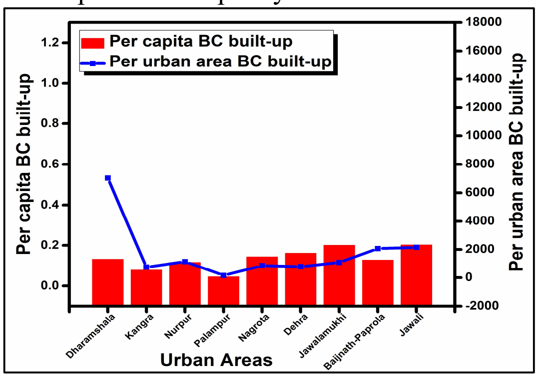

Figure 4: Built-up land Biocapacity BC $_{built-up}$ (g ha) in different urban areas of district Kangra

Ecological deficit

Ecological deficits highlight the need for more bio productive built-up land than is currently available in order to promote sustainability in urban ecosystems. When an ecological deficit occurs, it indicates that the demands of the particular area have exceeded the critical capacity of the ecosystem. This can result in the scarcity of ecological reserves due to faster consumption of resources, which leads to ecological overshoot. According to Figure 5 , the total ecological deficit in different urban areas is 2177.531 g ha and the per capita ecological deficit is 0.164 g ha. The total ecological deficit in different urban areas ranges from 958.647 to 21.795 g ha, and it is arranged in the order : Dharamshala (958.647 g ha) > Jawali (292.116 g ha) > Baijnath-Paprola (280.730 g ha) > Nurpur (154.516 g ha) > Jawalamukhi (147.034 g ha) > Nagrota (115.155 g ha) > Dehra (106.046 g ha) > Kangra (101.492 g ha) > Palampur (21.795 g ha). These findings are in line with the results obtained from Kassouri (2021) and Zhang *et al.* (2019). Different consequences of expanding urbanization can be seen on ecological resources across different spatial locations occurring on a multidimensional scale including environment and social processes which are shaping sustainability as a whole.The greatest ecological deficit was recorded in Dharamshala (958.647 g/ha). This suggests that due to fancy lifestyles and rapid urbanization with a massive population, resources are being consumed at a faster rate than they can be regenerated or renewed. This could be attributed to the high clustering of various hubs of private, semi-government, and public institutions, companies, and a high flux of tourists to the region. Consequently, the natural capital of this region is under increased pressure. The lowest ecological deficit of 21.795 g/ha in Palampur may be explained by the low levels of anthropocentricity in the region, as well as the relatively low levels of development in the area.The ecological deficit per capita in different urban areas ranged from 0.004 to 0.027 g ha/capita and followed the following pattern: Jawali (0.028 g ha/capita) > Jawalamukhi (0.027 g ha/capita) > Dehra (0.022 g ha/capita) > Nagrota (0.020 g ha/capita) > Dharamshala (0.018 g ha/capita) > Baijnath-Paprola (0.017 g ha/capita) > Nurpur (0.016 g ha/capita) > Kangra (0.011 g ha/capita) > Palampur (0.006 g ha/capita). The results are in congruence with the findings of Kandil *et al.* (2020) and Pandit *et al.* (2021);the per capita ecological deficit has no characteristic pattern because of varying geographical areas and capricious amount of population which has not relatively magnified in these areas. According to the data, the expanded built-up land footprint of different urban areas exceeds the biocapacity of the environment, rendering the system unsustainable and pointing out the existence of an Ecological Deficit (ED). This implies that various urban areas must have vast built-up land in order to provide back up to urban sprawl in the hilly region and to sustain its associated activities which in turn also highlights the major losses to urban ecosystems and degradation of natural capital and its resources followed by elevated levels of accumulation of waste in the study area.

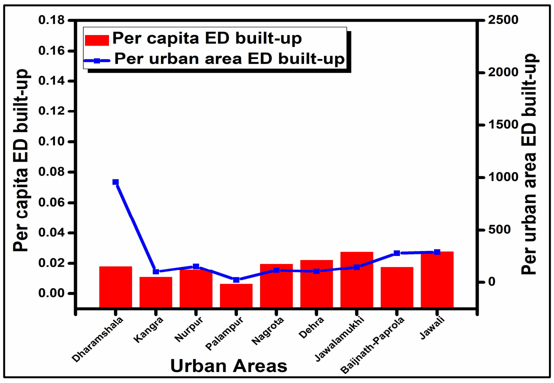

Figure 5: Ecological deficit EF_D (g ha) in different urban areas of district Kangra

Conclusion

The study revealed that there is a high total EF $_{\text{built-up}}$ in comparison to BC $_{\text{built-up}}$ in Kangra district, HP, which indicates unsustainability and a need for more bio-productive built-up land to support urban activities. To achieve sustainability in the urban ecosystems of the North Western Himalayas, it is important to rely on ecological principles and promote urban renewal through the development of smart cities/eco-cities. Additionally, more focus should be placed on advocating for regular updates and revisions to address significant shifts in the environment, society, and economy. To ensure ecological balance and resource sustainability for future generations, development should be carefully planned with similar studies followed by regular monitoring and assessments. Mitigation measures should be adopted through green practices such as improving production systems, altering consumption patterns, managing overpopulation, and recovering, improving, protecting, preserving, managing, and recovering natural ecosystems.

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Conflict of interest
The authors declare that they have no conflict of interest.

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