LANDSCAPE CHANGE IN AIZAWL CITY: A GEOSPATIAL APPROACH TO ASSESS LANDSCAPE INDICES AND HUMAN-INDUCED TRANSFORMATION

ZULOTOSHI IMCHEN*[1], PHIBAN KHAMTI RYNGNGA[2]

[1, 2] Department of Geography, School of Human & Environmental Sciences, North-Eastern Hill University Umshing Mawkynroh Shillong
*Email: zimchen28@gmail.com

Received 30 May 2022, accepted in revised form 17 August 2022

Abstract
The change in an area's natural surroundings and inhabitants is called landscape change. This change may be gradual or accelerated depending on the factors that influence the change. Natural elements such as native animals and birds seldom bring about any modification to the environment. However, human-induced change is devastating and severely transforms the environment.
Aim: Environmental transformation can be evaluated with the land use/ land cover assessment through satellite imagery and calculation of landscape indices.
Objective: This paper attempts to ascertain the direction and the nature of the human-induced change in the city of Aizawl. To this end, the city has been divided into four zones to enable inter-zone comparisons.
Result: A northeast and southwest direction of human landscape transformation has been ascertained with the help of GIS and remote sensing techniques and landscape indices in Aizawl city.

Keywords: landscape indices, zonation, land-use/land cover, environmental change, GIS, Remote sensing

1. Introduction

Landscape ecology analysis uses landscape indices to relate patterns and processes (Li & Wu, 2004). The semantics between the terms landscape indices and landscape metrics are similar; the former was used commonly in the 1990s and the latter in the 2000s (Uuemaa et al., 2009). Paramount heed ought to be taken when selecting the scale before using landscape indices, as the analysis results may change according to the resolution of the pixel (Šímová & Gdulová, 2012). Inherent characteristics of landscape pattern and its scale-reliant ascititious characteristics prevent a universally accurate representation of landscape pattern (Lustig et al., 2015). Forest applications in a sustainable manner rely on identifying the best configuration and composition of a landscape for optimal utility of lands (Haines-Young & Chopping, 1996). Furthermore, an investigator must be well-versed in the intricacies and drawbacks of each landscape indices to compensate for their shortcomings with applicable adjustments in an attempted analysis (Hargis et al., 1998).

Since the ecosystem provides essentials for sustaining human civilisation, lasting conservation of the multi-use landscapes is essential (Rodríguez-Loinaz et al., 2015). The synergy of landscape metrics with GIS enables to some degree, the meaningful measurement of landscape fragmentation to be applied appropriately (Ferreira et al., 2018).

The land transformation of the earth's surface brought about by human activities has decreased the availability of natural resources (Amin & Fazal, 2012). Human activities' transformation introduced into the landscape accounts for more than half of the earth's dry surface (Hooke et al., 2012). Most studies on land transformation gravitate towards assumed parameters instead of experimental factors as the basis for analysis (Palatnik et al., 2011). The fundamental components of land transformation are of two types, i.e. land exacerbation and land modification (Richter, 1984). This transformation is not confined to inland areas but also present abundantly in the coastal environments (García-Ayllón & Miralles, 2014).

The human-induced transformation of the landscape transcends from the urban limits onto the rural fringes, thereby modifying the characteristics of the core and periphery (Singh, 2018). This modification of rural to urban has its developmental benefits but also creates negative issues in the landscape as displacement remains a concern (Sakketa, 2022). Thus, the study of the landscape characteristics and transformation is significant as it directly affects the natural environment as well as the human component.

Considering the literature on landscape indices and human induced transformation mentioned above, landscape characteristics in Aizawl city, Mizoram, India, will be uncovered in this paper. Additionally, the land use/ landcover dynamics brought about by the human-induced transformation of the landscape will be highlighted. The location map of the study area is given in Figure 1.

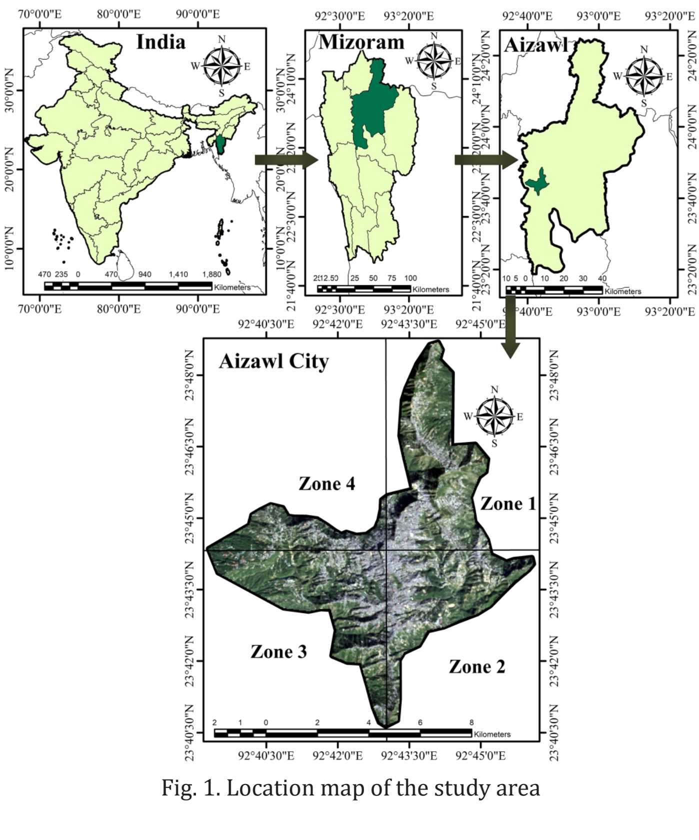

Fig. 1. Location map of the study area

The study area has a unique level of urban concentration in the northeastern region of India. The city of Aizawl is known for the unscientific and haphazard construction of settlements caused by unabated migration into the area. Since the city is growing at an extraordinary pace, transforming the surroundings into human habitation areas is unavoidable. By dividing the study area into quadrants, it enables ascertaining the direction of the spread of the built-up class, which can aid in selecting the areas most urgently needing government attention. Thus, the zone-wise demarcation allows for identifying the more congested parts where alleviation measures may be taken in a timely fashion. The zones themselves are a device of convenience.

Objectives

1. To analyse the zone-wise characteristics of the landscape with the help of landscape indices. ('Zone' here referes to the quadrant divisions based on the mean centre of the study area)
2. To determine the direction of human-induced land use/ land cover change and transformation in each zone.

Data

Primary data has been used in the form of Landsat TM/OLI satellite imagery obtained from https://earthexplorer.usgs.gov/ of 1988, 2002 and 2022 of Aizawl city. The shapefile utilised to extract the area of interest has been sourced from google maps.

Date of satellite imageries:

i. 10-11-1988

ii. 26-02-2002

iii. 08-01-2022

2. Research methodology

The research methodology includes ArcGIS, ERDAS Imagine and Fragstats software to process satellite imagery and calculate landscape indices for the selected study area. The research methodology flowchart is given in Figure 2.

The pre-processing of the satellite imagery includes the sequence of layer stacking, sub-setting, supervised classification with maximum likelihood parametric rule, recoding, accuracy assessment, and fishnet tool in the zonation of the imageries. All classified images have greater than 85 per cent assessment accuracy and are thus used for further analysis.

Zone creation: The zonation here denotes the division of the satellite imageries into four subsets. The division was created using the 'fishnet' tool in ArcGIS, taking the mean centre of the imageries as the origin point from where the quadrants were created. These shape files were used for clipping each of the four zones in ERDAS Imagine to make four separate classified imageries for each of the three years.

The results have been divided into two broad headers: landscape indices and Human induced-transformation of land use/land cover zonation. The former will deal with the characteristics of the zone-wise landscape measured by various landscape indices. At the same time, the latter will quantify the human transformation as per zone-wise classified land use/ land cover classified imagery.

Using landscape indices often reveals that a natural landscape's spatial pattern and process differ markedly from that seen in a human-altered one (O'Neill et al., 1988). Indices on their own are lacking and are usually supplemented with the accompaniment of some additional factors to augment the landscape analysis (O'Neill et al., 1999). Rather than a one-size-fits-all, selecting specific levels and particular indices should be phenomenon and scale based and with a well-defined purpose (Gustafson, 2019).

In the multitude of available landscape indices, a compatible blend of specific indices recurringly can represent the critical characteristics of the landscape pattern at different levels (Cushman et al., 2008).

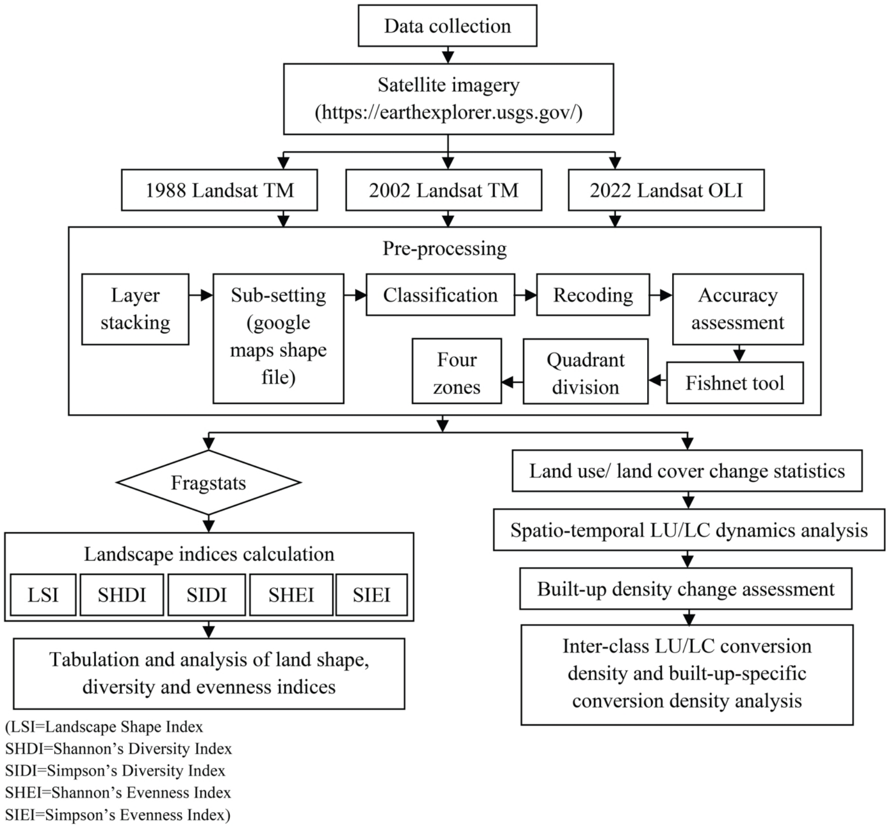

Fig. 2. Research methodology flowchart

Landscape metrics offer the differentiation between multiple points of time or at the same point of time within the same landscape, or even both (Lafortezza et al., 2005). The real-world application of indices is the effective monitoring and optimising of the planning and preservation of the landscape (Vos et al., 2001). Range of scale is indispensable when considering the appropriate landscape indices as a small number of indices are significantly affected while others are usable within a limit (Fu et al., 2021).

Land use/ land cover is closely related to landscape transformation in assessing degradation mitigation potential, particularly with remote sensing and GIS (Pandit, 2020). Since the turn of the century, anthropogenic land transformation points to an overall landscape wherein the greater part will continue to come under human activities (Ellis et al., 2010). Social complexities and economic activities substantially influence the ebb and flow of the land transformation, which is also directed according to the political regimes of the era (Munteanu et al., 2014).

The spatial configuration of the landscape in urban areas observes transformation with the introduction of restructuring and policies to tackle congestion and usher in the development of a city (Giuliano et al., 2008). Medical care, population dynamics, and ecology are some of the directly affected aspects of the urban landscape as far as transformation is concerned (Haase & Schwarz, 2020). In the context of India, the conversion is now picking up pace in the lower tier towns, which means that the urbanisation into the agrarian centres is a significant problem in the country (Mitra et al., 2020).

The classified imageries have been divided into four zones to conduct a comparative density distribution analysis of built-up area since the human-induced transformation is the focus. Zonation will facilitate the identification of which part of the study area has a higher density of the built-up area in a static as well as dynamic context.

The change detection of barren land to built-up, vegetation to built-up, and built-up to built-up have been marked in yellow, red, and cyan for each zone. Since the zones have unequal area coverage, the change detection analysis is based on the change class divided by the sum of change classes other than the built-up to built-up class of each zone. The land use/land cover change detection (built-up) 1988-2022 in Figure 8 has been analysed by taking the sum of each zone's LULC change class and using it to divide each LULC change class to determine the percentage change proportion. Three classes of 'high', 'moderate', and 'low' to categorise the change proportion have been made viz., above 35 per cent, 13-35 per cent, and below 13 per cent respectively.

3. Results

Landscape indices

Table 1 shows the landscape indices of Aizawl city. Landscape Shape Index (LSI), Shannon's Diversity Index (SHDI), Simpson's Diversity Index (SIDI), Shannon's Evenness Index (SHEI), and Simpson's Evenness Index (SIEI) have been calculated for 1988, 2002, and 2022. The overall classified images of 1988, 2002, and 2022 have been divided into four zones to enable spatial and temporal comparison.

Table 2 shows the categories into which the various landscape indices have been grouped: Low, Medium, and High. All four zones for the three years have been considered in the categorisation.

Table 1. Landscape indices of Aizawl city (1988, 2002, 2022)

Index	Year	Zone 1	Zone 2	Zone 3	Zone 4
LSI	1988	7.0799	6.6185	6.4576	3.3912
	2002	6.8396	6.155	6.6138	3.5991
	2022	8.0493	7.4814	7.7679	4.0648
SHDI	1988	0.6295	0.5571	0.5922	0.296
	2002	0.6407	0.5588	0.611	0.3019
	2022	0.6417	0.5602	0.6168	0.3031
SIDI	1988	0.3101	0.259	0.2974	0.124
	2002	0.3108	0.2594	0.3007	0.1244
	2022	0.311	0.2596	0.3016	0.1245
SHEI	1988	0.4541	0.4018	0.4272	0.2135
	2002	0.4622	0.4031	0.4407	0.2178
	2022	0.4629	0.4041	0.4449	0.2186
SIEI	1988	0.4134	0.3454	0.3966	0.1653
	2002	0.4143	0.3459	0.4009	0.1659
	2022	0.4146	0.3461	0.4021	0.166

*LSI=Landscape shape index, SHDI= Shannon's diversity index, SIDI=Simpson's diversity index, SHEI=Shannon's diversity index, SIEI=Simpson's evenness index

Source: Author's construct

Table 2. Categorisation of landscape indices of Aizawl city (1988, 2002, 2022)

Category	Index				
	LSI	SHDI	SIDI	SHEI	SIEI
Low	<6.2	<0.5587	<0.2591	<0.403	<0.3458
Medium	6.2-6.9	0.5587-0.6111	0.2591-0.3008	0.403-0.4408	0.3458-0.4020
High	>7	>0.612	>0.3009	>0.4409	>0.4021

Source: Author's construct

- LSI: Zone 4 in all three years accounts for the low category LSI values and zone 2 in 2002 with 3.3912, 3.5991, 4.0648, and 6.155, respectively. Zone 3 in 1988, 2002, zone 2 in 1988, and zone 1 in 2002 fall under the medium LSI values of 6.4576, 6.6138, 6.6185, and 6.8396, respectively. Zone 1 in 1988 and 2022, zone 2 in 2022 and zone 3 in 2022 comprise the high category LSI values with 7.0799, 8.0493, 7.4814, and 7.7679, respectively.
- SHDI: Zone 4 in 1988, 2002, and 2022, and zone 2 in 1988 have low SHDI values with 0.296, 0.3019, 0.3031, and 0.5571 respectively. Zone 3 in 1988 and 2002, zone 2 in 2002 and 2022 comprise the medium SHDI values with 0.5588, 0.5602, 0.5922, and 0.611 respectively. Zone 3 in 2022, and zone 1 in all three years have high SHDI values with 0.6168, 0.6295, 0.6407, and 0.6417, respectively.
- SIDI: Zone 2 in 1988 and zone 4 in all three years have low SIDI values with 0.124, 0.1244, 0.1245, and 0.259, respectively. Zone 2 in 2002 and 2022, zone 3 in 1988 and 2002 have medium SIDI values of 0.2594, 0.2596, 0.2974, and 0.3007, respectively. Zone 4 in 2022, zone 1 in 1988, 2002, and 2022 have high SIDI values with 0.3016, 0.3101, 0.3108, and 0.311.
- SHEI: Zone 4 in 1988, 2002, and 2022, and zone 2 in 1988 have low SHEI values with 0.2135, 0.2178, 0.2186, and 0.4018 respectively. Zone 3 in 1988 and 2002, zone 2 in 2002 and 2022 comprise the medium SHEI values with 0.4031, 0.4041, 0.4272, and 0.4407 respectively. Zone 3 in 2022 and zone 1 in all three years have high SHEI values with 0.4449, 0.4541, 0.4622, and 0.4629, respectively.
- SIEI: Zone 2 in 1988 and zone 4 in all three years have low SIEI values with 0.1653, 0.1659, 0.166, and 0.3454, respectively. Zone 2 in 2002 and 2022, zone 3 in 1988 and 2002 have medium SIEI values of 0.3459, 0.3461, 0.3966, and 0.4009, respectively. Zone 4 in 2022, zone 1 in 1988, 2002, and 2022 have high SIEI values with 0.4021, 0.4134, 0.4143, and 0.4146, respectively.

LSI (Landscape shape index) determines the movement towards randomness in a landscape's configuration. The lower the value, the less random and the higher the value, the more random will be the developed landscape to the natural environment (Gyenizse et al., 2014).

Diversity landscape indices are the indicators for class richness within a given landscape. The greater the diversity index, the greater the presence of land use/ land cover classes and vice versa in terms of abundances (Kuchma et al., 2013). More class diversity shows that the transformation is present to a greater extent in zone 1 and 3.

Evenness indices are essential for identifying the proportion of class richness, i.e., indicating the homogenous property and dominance; the ratio of individual classes to overall classes (Heip et al., 1998). Strictly speaking, evenness indices are diversity indices. The more the value, the more will be the evenness of the classes, while the less the value, the less evenness will be the classes. If the classes have more or less similar characteristics, it points to a favourable landscape.

It becomes clear from the results that the inter-zone comparison of landscape indices indicate that zone 1 and 3 are the zones that likely experience more randomness in landscape configuration with higher levels of diversity and evenness than zone 2 and 4. Since the values of the LSI are high, it can be inferred that the type of landscape pattern present in the city is mainly unplanned in nature.

Human induced-transformation of land use/land cover zonation

Table 3 shows the zone-wise distribution of land use/land cover and the change and change density, as illustrated in Figure 3, Figure 4, and Figure 5. In 1988, the vegetation coverage was 11.55 sq km, 7.65 sq km, 12.52 sq km, and 4.38 sq km in zone 1, 2, 3, and 4, respectively. Barren land area was 2.71 sq km, 2.61 sq km, 1.74 sq km, and 0.66 sq km

Table 3. Land use/land cover zonation of Aizawl city (1988, 2002, 2022)

Zone 1	Area			Density		
Year	1988	2002	2022	1988	2002	2022
Vegetation	11.5479	10.3401	10.0602	0.64	0.58	0.56
Barren land	2.7081	3.1383	2.8845	0.15	0.17	0.16
Built-up	3.7809	4.4919	5.0256	0.21	0.25	0.28
Total	18.04	17.9703	17.97	1	1	1
Zone 2	Area			Density		
Year	1988	2002	2022	1988	2002	2022
Vegetation	7.6473	7.4871	7.2405	0.52	0.51	0.50
Barren land	2.6091	2.6901	2.7387	0.18	0.18	0.19
Built-up	4.3281	4.4235	4.6215	0.30	0.30	0.32
Total	14.58	14.6007	14.60	1	1	1
Zone 3	Area			Density		
Year	1988	2002	2022	1988	2002	2022
Vegetation	12.5163	11.5218	10.8486	0.72	0.66	0.62
Barren land	1.7379	2.475	2.2635	0.10	0.14	0.13
Built-up	3.1905	3.5379	4.4226	0.18	0.20	0.25
Total	17.44	17.5347	17.53	1	1	1
Zone 4	Area			Density		
Year	1988	2002	2022	1988	2002	2022
Vegetation	4.383	4.0599	3.7665	0.66	0.61	0.57
Barren land	0.6579	0.8467	0.8532	0.10	0.13	0.13
Built-up	1.5642	1.7084	1.9953	0.24	0.26	0.30
Total	6.61	6.615	6.62	1	1	1

in zones 1, 2, 3, and 4, respectively. Built-up accounted for 3.78 sq km, 4.33 sq km, 3.19 sq km, and 1.56 sq km in zones 1, 2, 3, and 4, respectively. In 2002, the vegetation coverage was 10.54 sq km, 7.49 sq km, 11.52 sq km, and 4.06 sq km in zone 1, 2, 3, and 4, respectively. Barren land area was 3.14 sq km, 2.69 sq km, 2.48 sq km, and 0.84 sq km in zones 1, 2, 3, and 4, respectively. Built-up accounted for 4.49 sq km, 4.42 sq km, 3.54 sq km, and 1.70 sq km in zones 1, 2, 3, and 4, respectively. In 2022, the vegetation coverage was 10.60 sq km, 7.24 sq km, 10.85 sq km, and 3.77 sq km in zone 1, 2, 3, and 4, respectively. Barren land area was 2.88 sq km, 2.74 sq km, 2.26 sq km, and 0.85 sq km in zones 1, 2, 3, and 4, respectively. Built-up accounted for 5.03 sq km, 4.62 sq km, 4.42 sq km, and 2.00 sq km in zones 1, 2, 3, and 4, respectively.

Zone-wise comparison of built-up area

Zone-wise, landscape planning enables the efficient management of finite land resources according to the needs of a region, especially in the transformation that has taken place in inaccessible terrain (Pokhrel, 2021).

The absolute increase in built-up area is self-evident over the years in the table. However, density and density change will uncover the actual urbanisation dynamics in the study area.

Except for zone 2, the remaining zones have seen either an increase or no significant difference in built-up density change. This increase indicates that the built-up density change in 2022 is relatively even in its distribution compared to 1988. Figure 6 reveals that the built-up density shifted from

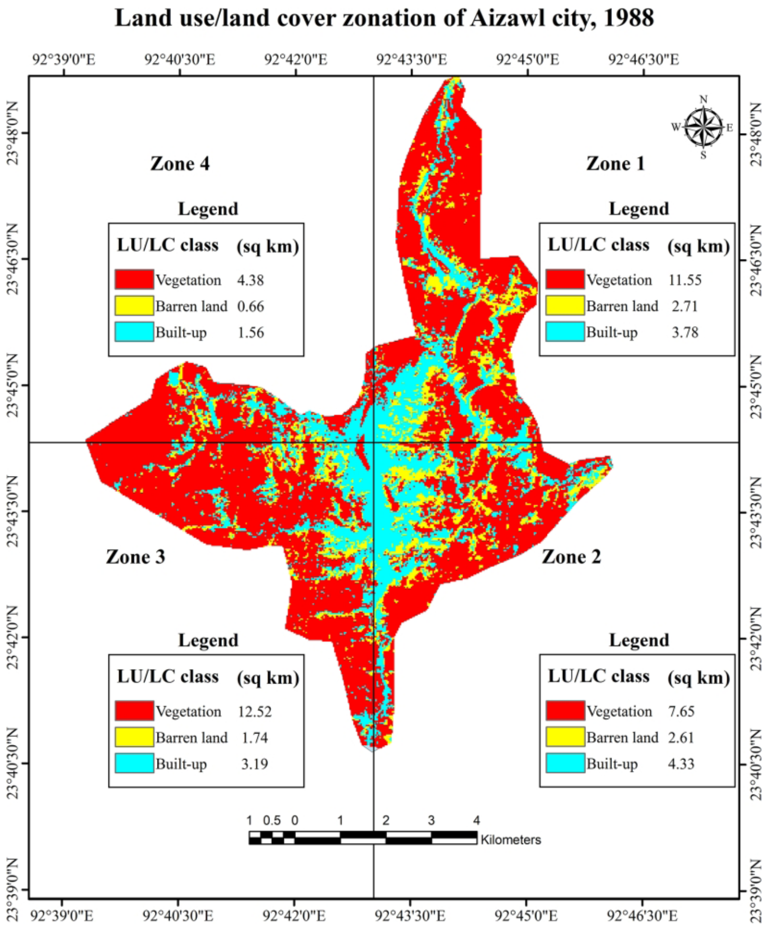

Fig. 3. Land use/land cover zonation of Aizawl city, 1988

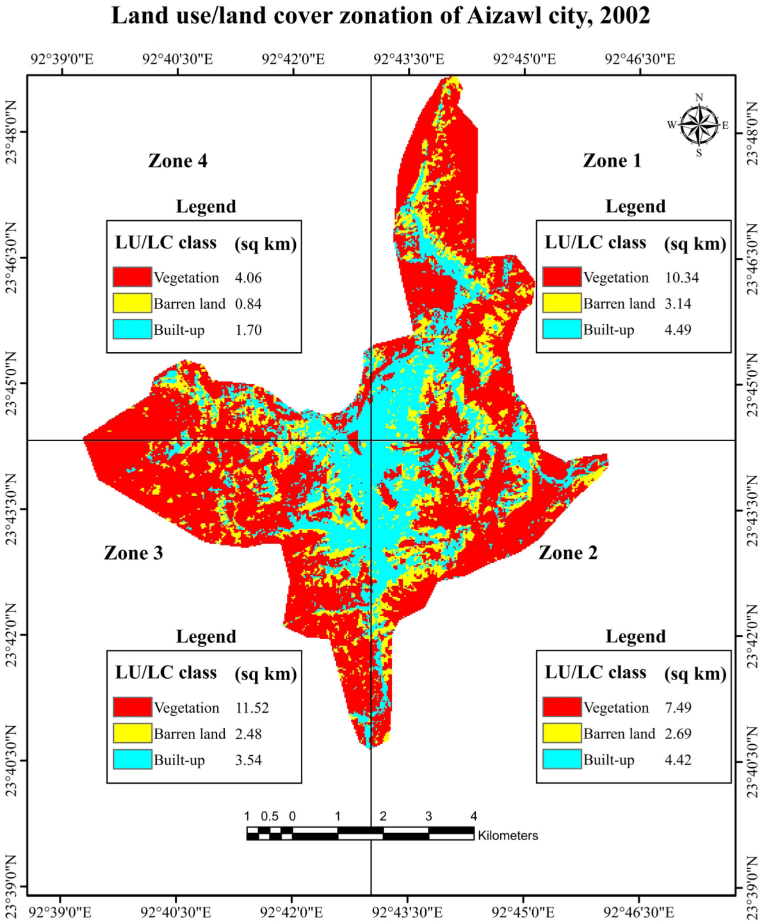

Fig. 4. Land use/land cover zonation of Aizawl city, 2002

zone 2 in 1988 to zone 1 and more so in zone 3 in 2022. This shift indicates the direction of urbanisation, i.e., towards the northeast and southwest. Detailing the human-induced land transformation is critical since they have extensive repercussions on the ecology and environmental sustainability (Oyebode, 2008).

Zone-wise conversion of land use/land cover

Land transformation is born from the ever-growing human activities and habitation requirements and encroaches upon an area's landscape (Narayanan & Hanjagi, 2009). These transformations can be exposed with the land use/ land cover inter-class conversion between 1988 and 2022.

Table 4 shows the zone-wise inter-class conversion of land use/land cover conversion from 1988 to 2022. Since the transformation from a class to itself is not indicative of any change, only the inter-class transformation categories are considered in the analysis.

Table 4 has been graphically shown in Figure 7, and it is clear that the densities vary vastly between each conversion class. In the case of transformation density from the barren land class to the built-up class, zone 1 and 2 have a high-density change of 0.04 and 0.05, respectively. Zone 3 and zone 4 have a moderate transformation density of 0.03.

To make sense of the computed conversion densities in the context of urbanisation, the zone-wise transformation of different classes into the built-up class has been analysed in

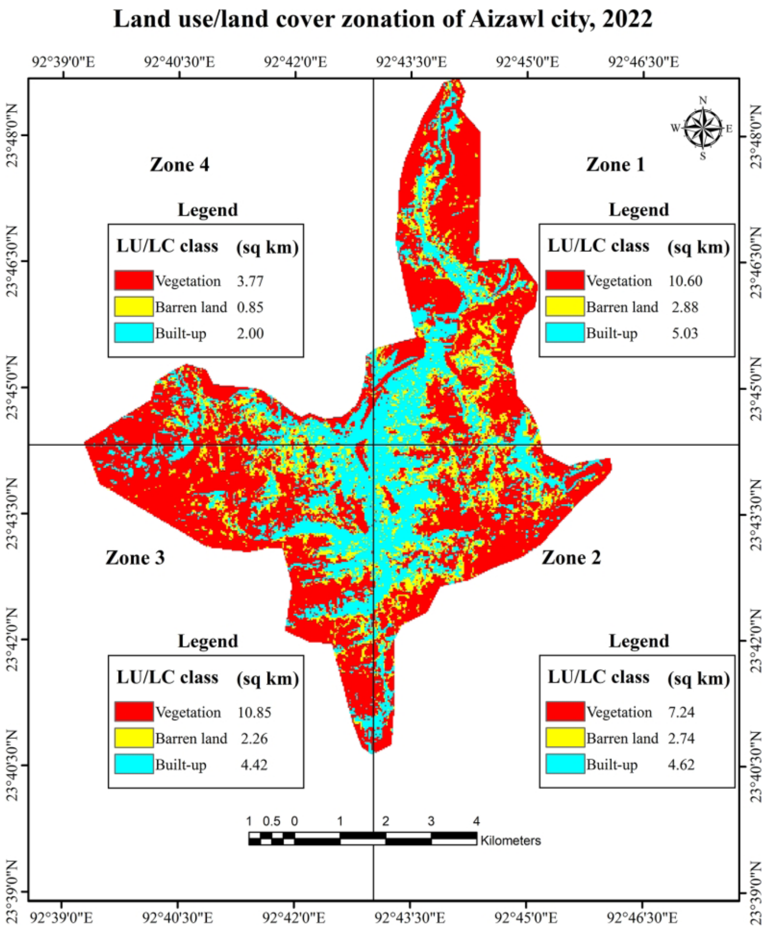

Fig. 5: Land use/land cover zonation of Aizawl city, 2022

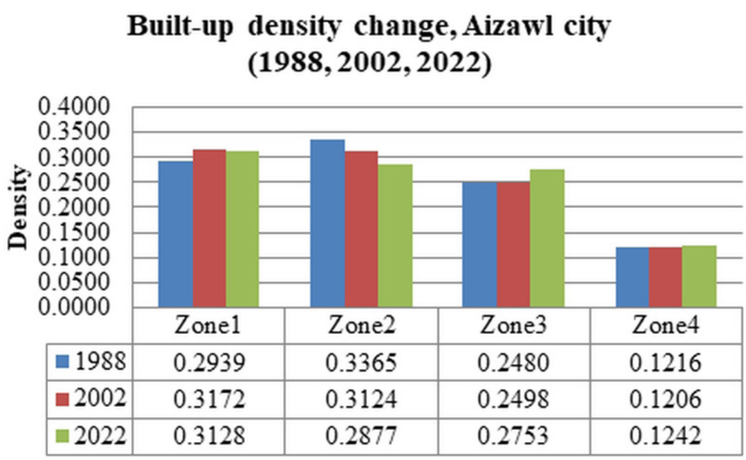

Fig. 6. Built-up density change, Aizawl city (1988, 2002, 2022)

Table 4: Zone-wise inter-class LU/LC conversion density of Aizawl city (1988-2022)

I-C LU/LC C	BL-BL	BL-BU	BL-V	BU-BL	BU-BU	BU-V	V-BL	V-BU	V-V	Total
Zone 1	0.05	0.04	0.07	0.03	0.14	0.04	0.08	0.10	0.45	1
Zone 2	0.06	0.05	0.07	0.04	0.20	0.05	0.09	0.07	0.37	1
Zone 3	0.04	0.03	0.03	0.02	0.12	0.04	0.07	0.10	0.55	1
Zone 4	0.03	0.03	0.03	0.03	0.14	0.06	0.07	0.13	0.47	1

*BL=Barren land, BU=Built-up, V=Vegetation, I-C LU/LC C= Inter-class land use/land cover conversion

Source: Author's construct

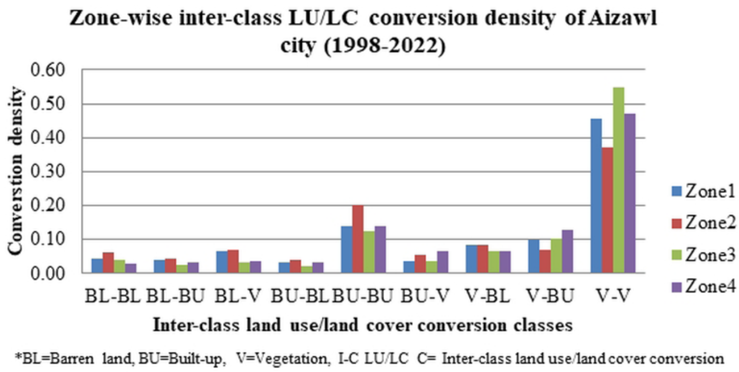

Fig. 7. Zone-wise inter-class LU/LC conversion density of Aizawl city (1998-2022)

Table 5. Table 5 indicates that zone 1 and zone 3 have seen 33.2 per cent and 32.8 per cent of the total transformation from the vegetation class into the built-up class density, respectively, meaning that these two zones are experiencing significant urbanisation as they account for more than half of the change among the four zones. Zone 2 and zone 4 account for a transformation density change of only 18.5 per cent and 15.5 per cent, respectively.

Figure 8 demonstrates the cartographic representation of the land use/land cover change detection from 1988 to 2022. The most change proportion has been recorded in the vegetation to built-up class in zones 4 (42.10%) and 3 (40.40%). Moderate change proportion has been observed in zone 1's vegetation to built-up class (35.83%), zone 2's vegetation to built-up class (21.75%), and zone 2 and 3's barren land to built-up class (14.34% and 13.82% respectively). A low change proportion has occurred in zone 4 and zone 3's barren land to built-up class (11.28% and 10.33%).

4. Discussion

The universal increase in the built-up area across the city means an inevitable anthropogenic transformation of the natural environment. One commonality between the landscape indices and the human-induced transformation results is that zone 1 and zone 3 are the zones which are of greater significance than the other two zones. Aizawl is the most urbanised district in Mizoram and among the most urbanised in the entire country (Saitluanga, 2015). Unsurprisingly, Aizawl city has experienced a considerable transformation in the last three decades.

Over three-fourths of the urban population in the district is localised in Aizawl city itself (Khawas, 2005). This vast

Table 5. Zone-wise transformation of vegetation to built-up density and barren land to built-up density

I-C LU/LC C	Vegetation to built-up area (sq km)	Density	Barren land to built-up area (sq km)	Density
Zone1	1.801	0.332	0.695	0.341
Zone2	1.004	0.185	0.662	0.325
Zone3	1.781	0.328	0.455	0.223
Zone4	0.840	0.155	0.225	0.110
Total	5.426	1.000	2.038	1.000

Source: Author's construct

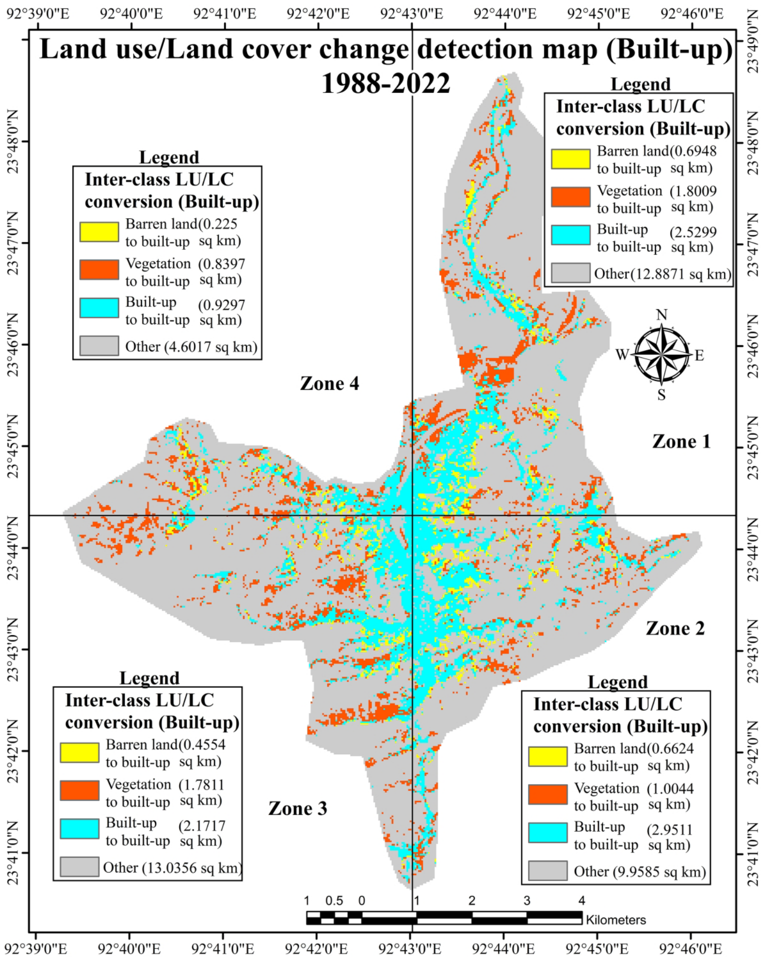

Fig. 8. Land use/land cover change detection (built-up) 1988-2022

urban concentration is reflected in the rapid landscape transformation to make way for the influx of migrants into the city.

The landscape indices of the study area

LSI has increased in all the zones from 1988 to 2022, indicating a change toward increasing randomness in landscape configuration. The most affected zone is zone 1, followed by zone 3 and zone 2. A minor change has taken place in zone 4. This change may indicate anthropogenic modification of the natural landscape as an agent of change.

SHDI, SIDI, SHEI, and SIEI have the same grouping regarding the selected 'low, medium, and high' class categorisations. Each year, zone 1 has the SHDI, SIDI, SHEI, and SIEI values in the high category. These high values indicate that the evenness and diverseness of classes are greater in zone 1. The same is less so in the case of zone 4, where SHDI, SIDI, SHEI, and SIEI values are in the low category from 1988 to 2022. Such low values correspond to lesser evenness and diverseness of classes in zone 4.

Considering the landscape shape index and diversity indices together, the joint takeaway from the analysis is that zone 1 and 3 represent the areas where the most change has occurred, and zone 2 and zone 4 are the areas of lesser change. As such, the concentration of urban growth has been observed in the northeast and southwest direction.

In terms of overall landscape characteristics of the area, LSI, SHDI, SIDI, SHEI, and SIEI values progressively increase from 1988 to 2022. Aizawl city is unplanned in its settlement pattern, which attributes to the increasing randomness and arbitrary spread of structures. This unscientific and reckless settlement pattern can lead to insecurity and urban hazards and hamper the carrying capacity of the land and its periphery to sustain the growing population.

The land use/land cover analysis of the study

In every zone, the vegetation density has reduced from 1988 to 2022, and the built-up and barren land has increased. Zone 1 and zone 3 have seen the most change in built-up density (seven per cent increase each), which indicates that the direction of the human-induced transformation is moving into the north-east direction and the southwest direction.

Vegetation density in zones 1, 3 and 4 have reduced by as much as ten per cent. This reduction indicates significant tree shrinkage in Aizawl city. Urban centres often experience land transformation whereby the non-urban landscape is replaced with growing artificial structures (Naqshbandi et al., 2016). This replacement of vegetation with artificial structures highlights how the ecology and environmental sustainability are compromised since the environment is affected negatively. The urban heat island phenomenon increases, and the overall vegetation health diminishes as the habitats get fragmented and reduce area coverage. Barren land density in zone 2 is greater than in the other zones in all three years. Compared to the 1988 values of barren land density, 2002 and 2022 have increased. The slight increase and decrease in barren land density between 2002 and 2022 are possibly due to landslides and vegetation growth between the two years. Linear growth is present in the built-up class in all zones from 1988 to 2022.

Regarding the interclass conversion change detection between 1988 and 2022, zones 4 and 3 have recorded significant proportional change in the vegetation to built-up class. A combined 2.6208 sq km of vegetation to built-up conversion in zones 4 and 3 indicates a considerable loss of vegetation for the sake of urban expansion. Likewise, zone 1 accounted for substantial vegetation to built-up conversion in absolute terms, i.e., 1.8009 sq km, with zones 2's vegetation to built-up and zone 2 and 3's barren land to built-up not far behind. Zone 3 and 4's barren to built-up class have been identified as the ones with the least change proportion.

Figure 9 is a photograph of the cityscape of Aizawl city as seen in March 2022; the compactness and concentration of structures are evident, which indicates a dense assemblage of settlements. Several buildings are constructed on steep slopes and are vulnerable to strong earthquakes or torrential downpours (Verma, 2014). Comparing the landscape indices with Figure 9 shows that the landscape transformation is not planned.

The urban growth is random, and new structures are constructed mainly without adherence to scientific and policy regulations. The added problem of the connectivity in the city makes it increasingly tricky for solid waste disposal and distribution of water supply to large parts of the city (Chakraborty et al., 2021).

These issues will only be aggravated as the transformation continues to replace the natural landscape with human-induced change. The study of urban transformation of the natural landscape requires an extensive field survey (Bhattacharjee, 2021). However, geospatial technology has enabled, at least to some degree, the freedom to analyse the city without requiring extensive and expensive field surveys.

5. Conclusion

Aizawl city has the potential to be one of the most progressive cities in the country. With its vast population of 293,416 (Census of India, 2011), Aizawl is the primate city in Mizoram, meaning it is the most important administrative and socio-economic unit in the state (Saitluanga, 2015). The following observations have been uncovered in this study:

- The landscape of Aizawl city has a landscape shape tending toward a random configuration according to the landscape shape index (LSI). Thus, the landscape is unplanned, which is not conducive to long-term sustainability as effective alleviation methods are difficult to ascertain due to the city's irregular shape.
- The diversity indices of SHDI and SIDI are relatively high, which means that the city landscape is rich in the presence of heterogeneous classes, particularly in the northeast and southwest directions.
- The evenness indices of SHEI and SIEI

Fig. 9. Cityscape of Aizawl city, 2022

are lower in the northwest and southeast directions. The reverse is true in the northeast and southwest directions. This reversal denotes that the evenness of the distinct classes tends to have a more proportional distribution in the northeast and southwest directions than in the northwest and southeast directions.

- Education, administration, business, and access to services and infrastructure make Aizawl city attractive to migrants from adjoining areas. These pull factors cause households to immigrate to the city. The built-up density is augmented to make additional dwellings for the new inhabitants. The landscape transformation is more prominent in zone 1 and 3 and less so in zone 2 and 4.
- The landscape indices and the land use/ land cover statistics point to a perceived shift of human-induced transformation in zones 1 and 3 and a slower transformation in zone 2 and zone 4. The remedial and planning efforts to curb unchecked landscape transformation should emphasise these zones to slow the pace of urban expansion.

The following areas of further research to improve the present study would be the physical setting and socio-cultural factors influencing the city's progression. These influence factors will be necessary to achieve a more wholesome assessment of the present situation in Aizawl city. The three selected points of time between the chosen images have disclosed unprecedented transformation and change to the landscape. Predictive models with multi-criteria analysis can be applied to the study area to create a robust framework for transformation vulnerability prediction in the future.

Acknowledgements

No financial support was received for conducting research and the preparation of the article. The authors acknowledge the assistance of a correspondent who has requested to not disclose their name in providing the cityscape photograph of Aizawl city.

6. References

Amin, A., & Fazal, S. (2012): Land Transformation Analysis Using Remote Sensing and GIS Techniques (A Case Study). Journal of Geographic Information System, 04(03), 229–236. https://doi.org/10.4236/jgis.2012.43027

Bhattacharjee, D. (2021): Urban congestion: An empirical story from Northeast India. In M. A. Singh & K. Singha (Eds.), Understanding Urbanisation in Northeast India Issues and Challenges (1st ed., pp. 26–47). Routledge.

Census of India. (2011): Aizawl City Population 2011 - 2022. Government of India. https://www.census2011.co.in/census/city/185-aizawl.html

Chakraborty, S., Ghosh, S., Agarwal, S., & Chakraborty, S. (2021): An integrated performance evaluation approach for the Indian smart cities. OPSEARCH, 58(4). https://doi.org/10.1007/s12597-021-00527-3

Cushman, S. A., McGarigal, K., & Neel, M. C. (2008): Parsimony in landscape metrics: Strength, universality, and consistency. Ecological Indicators, 8(5), 691–703. https://doi.org/10.1016/j.ecolind.2007.12.002

Ellis, E. C., Klein Goldewijk, K., Siebert, S., Lightman, D., & Ramankutty, N. (2010): Anthropogenic transformation of the biomes, 1700 to 2000. Global Ecology and Biogeography, 19(5), 589–606. https://doi.org/10.1111/j.1466-8238.2010.00540.x

Ferreira, I. J. M., Ferreira, J. H. D., Bueno, P. A. A., Vieira, L. M., Bueno, R. de O., & Do Couto, E. V. (2018). Spatial dimension landscape metrics of atlantic forest remnants in paraná state, Brazil. Acta Scientiarum - Technology, 40(1). https://doi.org/10.4025/actascitechnol.v40i1.36503

Fu, G., Wang, W., Li, J., Xiao, N., & Qi, Y. (2021): Prediction and selection of appropriate landscape metrics and optimal scale ranges based on multi-scale interaction analysis. Land, 10(11), 1–21. https://doi.org/10.3390/land10111192

García-Ayllón, S., & Miralles, J. L. (2014): The environmental impacts of land transformation in the coastal perimeter of the mar menor lagoon (SPAIN). International Journal of Design and Nature and Ecodynamics, 9(2), 109–128. https://doi.org/10.2495/DNE-

V9-N2-109-128

Giuliano, G., Agarwal, A., & Redfearn, C. (2008): Metropolitan Spatial Trends in Employment and Housing. In Special Report 298: Driving and the Built Environment: The Effects of Compact Development on Motorized Travel, Energy Use, and Co2 Emissions (pp. 1–39). University of Southern California.

Gustafson, E. J. (2019): How has the state-of-the-art for quantification of landscape pattern advanced in the twenty-first century? Landscape Ecology, 34(9), 2065–2072. https://doi.org/10.1007/s10980-018-0709-x

Gyenizse, P., Bognár, Z., Czigány, S., & Elekes, T. (2014): Landscape shape index, as a potencial indicator of urban development in Hungary. Landscape & Environment, 8(2), 78–88. https://ojs.lib.unideb.hu/landsenv/article/view/2311

Haase, D., & Schwarz, N. (2020): Urban Land Use in the Global Context. In K. Seto, W. Solecki, & C. Griffith (Eds.), The Routledge Handbook of Urbanization and Global Environmental Change (1st ed., pp. 50–63). Routledge.

Haines-Young, R., & Chopping, M. H. (1996): Quantifying landscape structure: a review of landscape indices and their application to forested landscapes. Progress in Physical Geography, 20(4), 418–445. https://doi.org/https://doi.org/10.1177%2F030913339602000403

Halder, B., Haghbin, M., & Farooque, A. A. (2021): An Assessment of Urban Expansion Impacts on Land Transformation of Rajpur-Sonarpur Municipality. Knowledge-Based Engineering and Sciences, 2(3), 34–53. https://doi.org/10.51526/kbes.2021.2.3.34-53

Hargis, C. D., Bissonette, J. A., & David, J. L. (1998): The behavior of landscape metrics commonly used in the study of habitat fragmentation. Landscape Ecology, 13(3), 167. https://doi.org/10.1023/A:1007965018633

Heip, C. H. R., Herman, P. M. J., & Soetaert, K. (1998): Indices of diversity and evenness. Océanis, 24(4), 61–87. http://www.vliz.be/imisdocs/publications/221019.pdf

Hooke, R. L. B., Martín-Duque, J. F., & Pedraza, J. (2012): Land transformation by humans: A review. GSA Today, 22(12), 4–10. https://doi.org/10.1130/GSAT151A.1

Khawas, V. (2005): Urbanisation in the North-East: Patterns, trends, and policy prongs. Social Change, 35(2), 47–69. https://doi.org/10.1177/004908570503500204

Kuchma, T., Tarariko, O., & Syrotenko, O. (2013): Landscape Diversity Indexes Application for Agricultural Land Use Optimization. Procedia Technology, 8, 566–569. https://doi.org/10.1016/j.protcy.2013.11.080

Lafortezza, R., Corry, R. C., Sanesi, G., & Brown, R. D. (2005): Quantitative approaches to landscape spatial planning: clues from landscape ecology. WIT Transactions on Ecology and the Environment, 84, 239–250. https://www.witpress.com/Secure/elibrary/papers/SPD05/SPD05024FU1.pdf

Li, H., & Wu, J. (2004): Use and misuse of landscape indices. Landscape Ecology, 19(4), 389–399. https://doi.org/https://doi.org/10.1023/B:LAND.0000030441.15628.d6

Lustig, A., Stouffer, D. B., Roigé, M., & Worner, S. P. (2015): Towards more predictable and consistent landscape metrics across spatial scales. Ecological Indicators, 57, 11–21. https://doi.org/10.1016/j.ecolind.2015.03.042

Mitra, C., Pandey, B., Allen, N. B., & Seto, K. C. (2020): Contemporary Urbanisation in India. In K. Seto, W. Solecki, & C. Griffith (Eds.), The Routledge Handbook of Urbanization and Global Environmental Change (1st ed., pp. 64–76). Routledge. https://books.google.co.in/books?id=2prLDAAAQBAJ&printsec=frontcover#v=onepage&q&f=false

Munteanu, C., Kuemmerle, T., Boltiziar, M., Butsic, V., Gimmi, U., Lúboš Halada, Kaim, D., Király, G., Konkoly-Gyuró, É., Kozak, J., Lieskovský, J., Mojses, M., Müller, D., Ostafin, K., Ostapowicz, K., Shandra, O., Štych, P., Walker, S., & Radeloff, V. C. (2014): Forest and agricultural land change in the Carpathian region—A meta-analysis of long-term patterns and drivers of change. Land Use Policy, 38, 685–697. https://doi.org/10.1016/j.landusepol.2014.01.012

Naqshbandi, Z. K., Fayaz, S., & Bhat, M. S. (2016): Urban Growth and Its Impact on Land Transformation in Medium Sized Urban Centres of Kashmir Valley. Journal Of Humanities And Social Science, 21(2), 46–51. http://www.iosrjournals.org/iosr-jhss/papers/Vol. 21 Issue2/Version-4/H021244651.pdf

Narayanan, P., & Hanjagi, A. D. (2009): A Threat on Bangalore's Ecology - A Challenge for Sustainable Development. Theoretical and Empirical Researches in Urban Management, 4(1S), 38–47. http://www.jstor.org/stable/24872407

O'Neill, R. V., Krummel, J. R., Gardner, R. H., Sugihara, G., Jackson, B., DeAngelis, D. L., Milne, B. T., Turner, M. G., Zygmunt, B., Christensen, S. W., Dale, V. H., & Graham, R. L. (1988): Indices of landscape pattern. Landscape Ecology, 1(3), 153–162. https://doi.org/10.1007/BF00162741

O'Neill, R. V, Riitters, K. H., Wickham, J. D., & Jones, K. B. (1999): Landscape pattern metrics and regional assessment. Ecosystem Health, 5(4), 225–233. https://doi.org/10.1046/j.1526-0992.1999.09942.x

Oyebode, O. (2008): Application of GIS and Land Use Models-Artificial Neural Network based Land Transformation Model for Future Land Use Forecast and Effects of Urbanization within the Vermillion River Watershed. In Papers in Resource Analysis (Vol. 9, pp. 1–13). Saint Mary's University of Minnesota Central Services Press. Winona, MN. http://www2.smumn.edu/ra/gis/GradProjects/OyebodeO.pdf

Palatnik, R. R., Kan, I., Rapaport-Rom, M., Ghermandi, A., Eboli, F., & Shechter, M. (2011): Land transformation analysis and application. 1–30. https://www.researchgate.net/profile/Mordechai-Shechter/publication/228416154_Land_transformation_analysis_and_application/links/09e4150921608bbe6b000000/Land-transformation-analysis-and-application.pdf

Pandit, G. (2020): Mapping of land transformation Purba Medinipur district: using Remote sensing and GIS techniques. Innovations, 61(1), 23–32. http://www.journal-innovations.com/assets/uploads/doc/5efa7-23-32.23103.pdf

Pokhrel, K. P. (2021): Land resource management and livelihood transformation in mountain region: A case from Chandanath municipality, Mugu, Nepal. Biodiversity International Journal, 5(2), 60–67. https://medcraveonline.com/BIJ/BIJ-05-00199.pdf

Richter, H. G. (1984): Land use and land transformation. GeoJournal, 8(1), 67–74. https://doi.org/10.1007/BF00155612

Rodríguez-Loinaz, G., Alday, J. G., & Onaindia, M. (2015): Multiple ecosystem services landscape index: A tool for multifunctional landscapes conservation. Journal of Environmental Management, 147, 152–163. https://doi.org/10.1016/j.jenvman.2014.09.001

Saitluanga, B. (2015): Residential Pattern and Quality of Life in Aizawl City [Mizoram University]. http://hdl.handle.net/10603/230559

Sakketa, T. G. (2022): Urbanisation and rural development in developing countries A review of pathways and impacts. In German Development Institute. German Development Institute. https://doi.org/10.23661/dp5.2022

Šímová, P., & Gdulová, K. (2012): Landscape indices behavior: A review of scale effects. Applied Geography, 34, 385–394. https://doi.org/10.1016/j.apgeog.2012.01.003

Singh, R. (2018). Land Transformation Around Chandigarh: A Study of Eastern Periphery Using Remote Sensing And GIS Technology. Internation Journal for Science and Advance Research In Technology, 4(1), 4–10. http://ijsart.com/Home/IssueDetail/19429

Uuemaa, E., Antrop, M., Roosaare, J., & Marja, R. (2009): Landscape Metrics and Indices: An Overview of Their Use in Landscape Research Living Reviews in Landscape Research. Living Rev. Landscape Res, 3(1), 1–28. http://lrlr.landscapeonline.de/Articles/lrlr-2009-1/download/lrlr-2009-1Color.pdf

Verma, R. (2014): Landslide Hazard in Mizoram: Case Study of Laipuitlang Landslide, Aizawl. International Journal of Science and Research, 3(6). 2262 - 2266 https://www.ijsr.net/get_abstract.php?paper_id=2014721

Vos, C. C., Verboom, J., Opdam, P. F. M., & Ter Braak, C. J. F. (2001): Toward Ecologically Scaled Landscape Indices. The American Naturalist, 157(1), 24–41. https://doi.org/10.1086/317004