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ASSESSMENT OF EXTENT OF SOIL SEALING AND LAND USE DYNAMICS ALONG THE RURAL-URBAN GRADIENT OF SHIVAMOGGA USING WORLD VIEW-2 IMAGERY

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ABSTRACT

Urban expansion significantly alters land use and impacts natural resources. Soil sealing is emerging as a critical consequence of rapid urbanization. This study assessed the extent of soil sealing and the magnitude of different land uses along the rural-urban gradient of Shivamogga, Karnataka, using high-resolution WorldView-2 satellite imagery. This research employed remote sensing and Geographic Information System (GIS) techniques to classify land use patterns and quantify sealed surfaces across urban, peri-urban and rural zones. A stratified sampling approach was used to demarcate study sites and supervised classification methods, including Normalized Difference Vegetation Index (NDVI), Normalized Difference Built-up Index (NDBI) and False Colour Composite (FCC) were applied to extract land cover information. The study revealed a substantial increase in impervious surfaces in urban areas, with sealed area exceeding (230 ha). In contrast, rural areas maintain a dominance of agricultural land, with minimal soil sealing (23 ha). Statistical analyses confirmed significant variations in land use distribution across the gradient, highlighting urban encroachments on agricultural and green spaces. These findings provide valuable insights for urban planners and policymakers in formulating sustainable land use strategies, mitigating environmental degradation and balancing urban development with ecological conservation. The study underscores the necessity of integrating remote sensing-based assessments into land management practices to ensure sustainable urban expansion while preserving essential agricultural and natural ecosystems.

Key words: Soil Sealing, Urbanization, WorldView-2, Biomass Turnover, Soil Ecological Functions

Introduction

Urbanization refers to the process of increase in urban population, leading to the growth and expansion of cities (Anestis and Stathakis, 2024). This phenomenon is often driven by factors such as industrialization, economic opportunities, improved infrastructure and better access to services. The future growth of the world population will almost entirely occur in urban areas of developing countries (Mahtta *et al*., 2022). As of 2023, around 56 per cent of the global population resides in urban areas, with urbanization progressing rapidly, particularly in developing nations. Projections indicate that by 2050, approximately 68 per cent of the world's population will live in cities. In India, urban areas are home to about 36 per cent of the population as of 2023. Although India's urbanization rate is slower compared to some other developing countries, its urban population is expected to rise significantly, reaching 40 per cent by 2030 and 50 per cent by 2050. Karnataka, one of India's more urbanized states, had approximately 38.6 per cent of its population living in urban areas (Census, 2011).

The urbanization is known to alter the landscape and environment as they encompass more land and other natural resources (Awuah and Abdulai, 2022). Soil sealing is the most significant land cover change caused by urbanization. Soil sealing refers to the process of covering natural soil surfaces with impermeable materials, such as asphalt, concrete, or buildings, which prevent the natural exchange of water, air and nutrients between the soil and the atmosphere (Vieillard *et al*., 2024). Any change in the land use will later soil physical, chemical and biological attributes (Nagaraja, 1997). This phenomenon is a direct result of urbanization and construction activities. The rural-urban gradient of Shivamogga presents a diverse mix of land uses, ranging from densely built urban cores to peri-urban agricultural zones and rural expanses (Nagaraja *et al*., 2016). This gradient provides a unique opportunity to study how urban expansion influences land use patterns and soil surface conditions. High-resolution satellite imagery, such as WorldView-2, offers an advanced tool for precise mapping and classification of soil sealing, enabling the assessment of urban sprawl and land use transitions (Meti *et al*., 2019).

Assessment of land use and soil sealing are critical for understanding the impact of urbanization and human activities on soil ecological functions. This study utilizes World View-2 satellite imagery to analyze the extent of soil sealing and evaluate the distribution of different land use types along the rural-urban gradient of Shivamogga. By integrating remote sensing techniques with GIS-based spatial analysis, this research aims to quantify the magnitude of land transformation, identify hotspots of rapid urbanization and provide insights into sustainable land use planning. The findings will contribute to better decision-making for urban development while minimizing environmental degradation and preserving agricultural land in the region.

Materials and Methods

Site description

Shivamogga, a tier-II city in Karnataka, lies on the banks of the Tunga River at the eastern edge of the Western Ghats (Fig. 1). It is the fourth most populated city in Karnataka, Shivamogga with 3.75 lakh residents. The population surged from 1.48 lakh in 1980-81 to 3.75 lakh in 2020-21. The per capita land availability is reduced from 0.05 to 0.02 hectares. The Municipal Corporation's area expanded from 48.7 sq. km to 70.01 sq. km. Urbanization has led to the growth of infrastructure, amenities and transport networks. Recognizing this, the city was selected for the Smart Cities Project-2016. This might have further led to the drastic changes in land uses across the city.

Identification of different land uses and assessment of extent of soil sealing in the study area

A reconnaissance survey was conducted to identify and select the prominent land uses across the study area. In order to achieve higher accuracy in assessing area under different land use systems and extent of soil sealing in urban, peri-urban and rural areas, five circular plots of 1 km radius were demarcated in each zone.

Image processing and classification

The land uses in the study area were identified using the worldview-II satellite imagery (0.5 m resolution) obtained from the Karnataka State Remote Sensing Application Centre (KSRSAC), Government of Karnataka. Initially, False Colour Composite (FCC), Normalized Difference Vegetation Index (NDVI), Normalized Difference Water Index (NDWI) and Normalized Difference Built-up Index (NDBI) were generated using ArcGIS 10.8 software by using the following equations (Zheng *et al*., 2021).

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR}$$

$$NDBI = \frac{SWIR - NIR}{SWIR + NIR}$$

where,

NIR, *RED*, *GREEN* and *SWIR* are the spectral reflectance in the near infrared band, red band, green band and short wavelength infrared band, respectively.

All these images were subjected to supervised classification using 150 training sites. All the outputs were

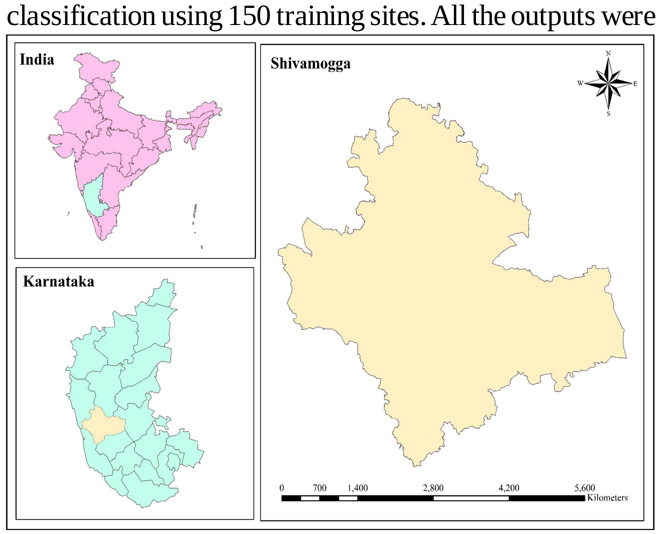

Fig. 1: Map showing the Shivamogga district in Karnataka, India.

vectorized and stacked to obtain the final land use map of the study area. The flow methodology adopted is depicted in the Fig. 2.

Accuracy assessment

To evaluate the accuracy quantitatively, stratified random sampling method was applied and Google Earth data was used as reference for accuracy assessment. For this purpose, 50-pixel points were randomly collected for each class. Kappa co-efficient was used to evaluate the accuracy of the classification model used in this study. Kappa co-efficient was computed by using the below mentioned formula (Zheng *et al.*, 2021).

Quantification of different land uses and extent of soil sealing

The FCC, NDVI, NDWI and NDBI of the delineated circular blocks were subjected to maximum likelihood classification as described in the previous section. The resultant imagery obtained was reclassified as forest/ forest plantations, water bodies, horticultural orchards, arecanut, coconut, paddy, rainfed crops, waste lands, compacted areas and sealed areas. The extent of soil sealing and the magnitude of different land uses in each block was derived. The mean values were used to develop area under different land use systems and cumulative sealed areas in urban, peri-urban and rural areas separately.

Statistical analysis

The data on extent of soil sealing and magnitude of different land uses in urban, peri-urban and rural zones were analyzed statistically by using analysis of variance (ANOVA) with equal number of observations and ANOVA was performed in OriginPro 2024. Means for different land uses were compared by using Fisher's least significant difference (LSD) test. Differences in land-use mean at $p < 0.05$ were considered to be statistically significant at 5 per cent level of significance (Chew, 1977).

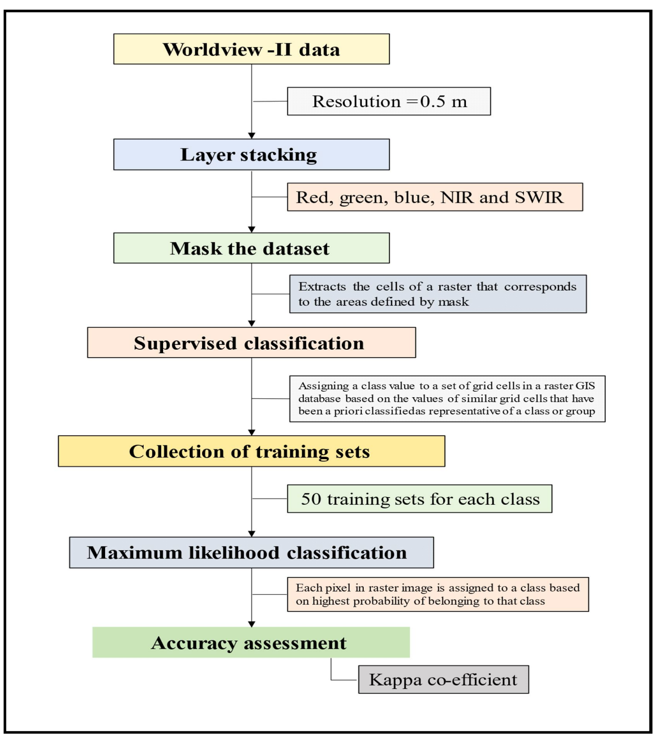

Fig. 2: Workflow of image acquisition and pre-processing.

Results and Discussion

The land use land cover (LULC) map of the study area (Fig. 3.) was derived using the FCC, NDVI, NDWI and NDBI in ArcMap 10.8. This resultant image provided the spatial representation of different land cover types across the rural-urban gradient, highlighting variations in vegetation cover and impervious surfaces with a kappa coefficient of 0.94. The LULC map provided a comprehensive spatial overview, enabling a better understanding of landscape dynamics. The differentiation in land use patterns is primarily influenced by urbanization, agricultural intensification and soil sealing processes (Mahtta *et al.*, 2022).

The urban areas exhibited significant land use transformations with predominant soil sealing and built-

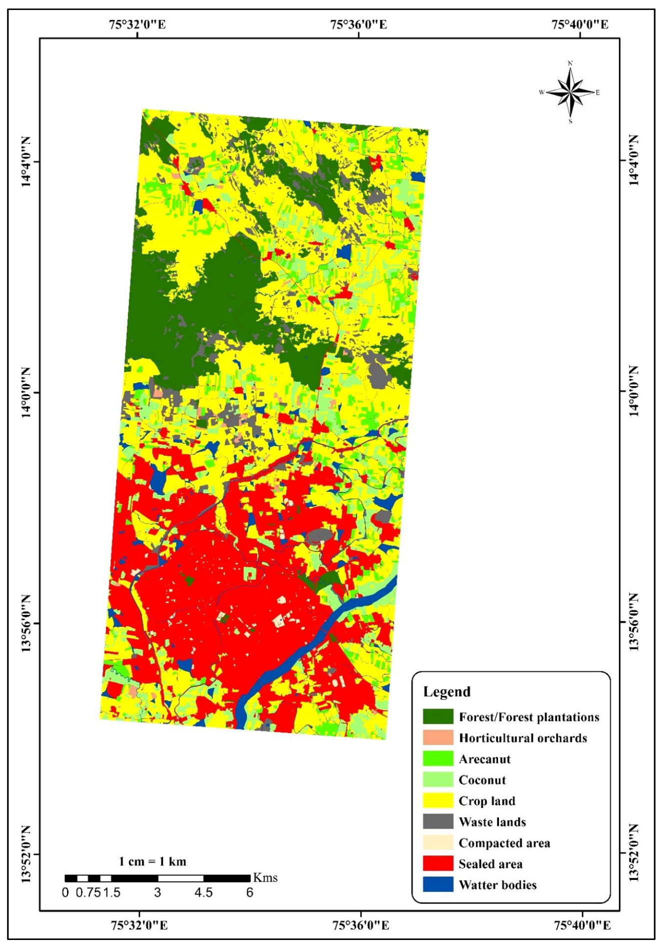

Fig. 3: Land use land cover map of the study area.

Table 1: Magnitude of different land uses and extent of soil sealing in rural-urban gradient of Shivamogga.

Land uses	Urban	Peri-urban Area in ha	Rural
Forest/forest plantations	1.55	2.14	3.52
Waterbodies	9.96	20.36	1.83
Mango	2.18	8.49	10.34
Arecanut	9.47	31.72	40.98
Coconut	15.20	33.27	54.90
Paddy	4.83	19.42	49.13
Rainfed Crop	26.75	81.86	123.86
Waste lands	8.89	6.86	5.91
Compacted area	4.23	1.05	0.14
Sealed Area	230.79	108.58	23.29
S.Em±	**0.34**	**1.07**	**0.86**
CD @ 0.05	**0.96**	**3.04**	**2.43**

up structures. As observed in Fig. 4 and Table 1, the sealed area was the highest in urban regions (230.79 ha), drastically reducing available arable land. Forest and plantation areas accounted for only 1.55 ha, whereas waterbodies occupied 9.96 ha. Agricultural land use was minimal, with mango (2.18 ha), arecanut (9.47 ha), coconut (15.20 ha) and paddy (4.83 ha) indicating the pressure

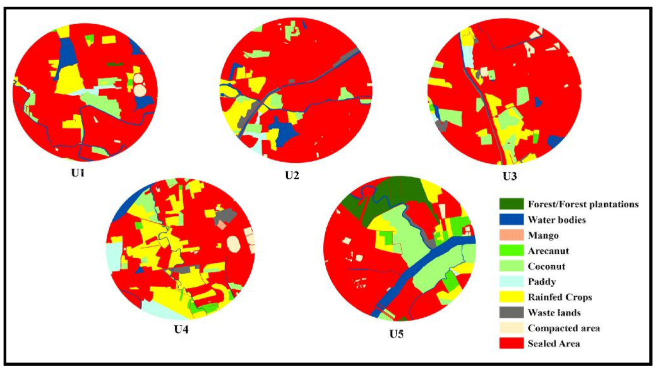

Fig. 4: Pictorial depiction of magnitude of different land uses and extent of soil sealing in five circular areas of urban zone (**Note:** U1 to U5 represents the five circular areas of urban zone, r = 1 sq. km)

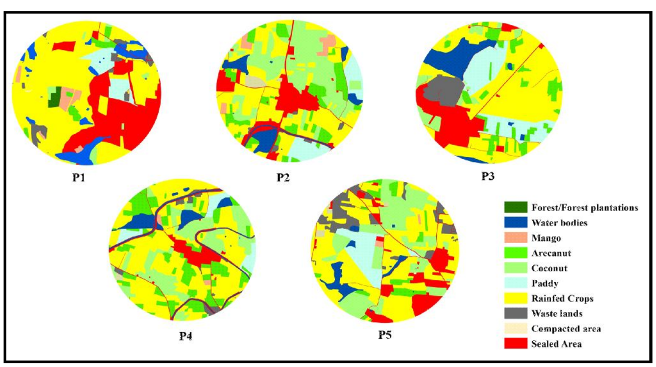

Fig. 5: Pictorial depiction of magnitude of different land uses and extent of soil sealing in five circular areas of urban zone. (**Note:** U1 to U5 represents the five circular areas of urban zone, r = 1 sq. km)

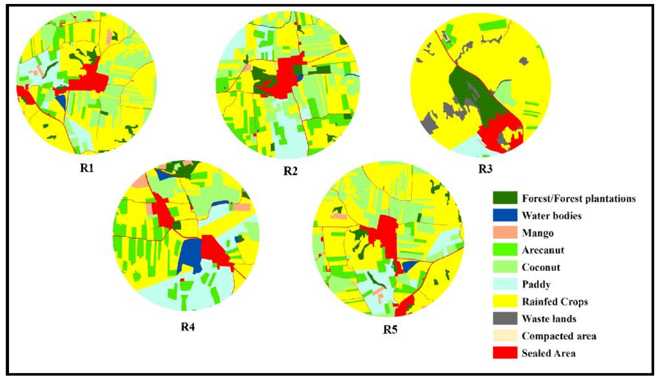

Fig. 6: Pictorial depiction of magnitude of different land uses and extent of soil sealing in five circular areas of rural zone (**Note:** R1 to R5 represents the five circular areas of rural zone, r = 1 sq. km)

of urban expansion. The prevalence of rainfed cropping (26.75 ha) suggested limited irrigated agricultural activities. The compacted area, largely consisting of paved and semi-permeable surfaces, was 4.23 ha. The statistical significance (p = 0.05) confirmed the clear demarcation of urban influence on land use. Urbanization is known later landscapes and environment by encompassing land and other natural resources (Awuah and Abdulai, 2022).

Peri-urban regions showed a transition between urban and rural land use, with moderate soil sealing (108.58 ha). Fig. 5 and Table 1 highlight a balanced mix of agricultural and non-agricultural land. Compared to urban areas, higher proportions of agricultural land were observed, with arecanut (31.72 ha), coconut (33.27 ha) and paddy (19.42 ha) constituting major land uses. Waterbodies occupied a significant portion (20.36 ha), supporting irrigation and biodiversity. The presence of wastelands (6.86 ha) indicated unused or degraded land, often resulting from urban sprawl. The compacted area was relatively lower (1.05 ha), suggesting that urbanization pressures were not as pronounced as in urban zones. The statistical significance (p = 0.05) highlighted notable variations in land use patterns within the peri-urban zone. This could be attributed to the

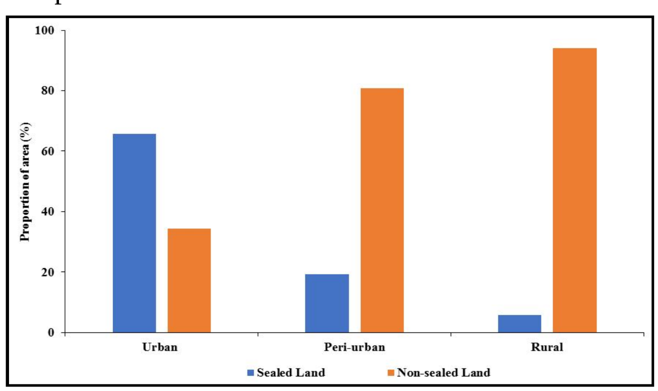

Fig. 7: Proportion of sealed land, arable land and open land across the rural-urban.

intermediate nature of peri-urban zone as it acts as transition between urban and rural zone (Xi, 2024).

Rural areas were predominantly agricultural, with significantly lower soil sealing (23.29 ha) and compacted area (0.14 ha), as shown in Fig. 6 and Table 1. Agricultural land use was the highest in this zone, with rainfed cropping (123.86 ha), paddy (49.13 ha) and coconut (54.90 ha) occupying extensive areas. Arecanut (40.98 ha) and mango (10.34 ha) were also substantial components of the agricultural landscape. Forest and plantation coverage was the highest in rural areas (3.52 ha), supporting ecological balance and biodiversity conservation. The minimal extent of wastelands (5.91 ha) indicated efficient land use management. The statistical results ($p = 0.05$) confirmed significant differences in land use distribution compared to urban and peri-urban zones. Fig. 7. demonstrates the proportion of sealed and non-sealed land across the rural-urban gradient. The urban areas had the highest soil sealing, significantly limiting water infiltration and increasing surface runoff, which can exacerbate urban flooding and reduce groundwater recharge. In contrast, the peri-urban and rural areas exhibited higher proportions of non-sealed land, crucial for maintaining ecological balance and agricultural productivity. This may be attributed to the higher biomass turnovers and modification of soil bio-chemical factors (Nagaraja *et al*., 2018)

The results highlight the pressing need for sustainable urban planning and land management strategies. The increasing soil sealing in urban areas suggests a loss of productive land, necessitating green infrastructure integration (Janiszek and Krzysztofik, 2023). In peri-urban zones, careful land use policies can ensure a balanced transition between urban and rural characteristics. The preservation of agricultural land in rural areas is crucial for food security and environmental sustainability.

Conclusion

The study highlighted the significant impact of urbanization on land use and soil sealing along the rural-urban gradient of Shivamogga. The findings revealed a considerable increase in sealed surfaces within urban areas, while peri-urban regions exhibit a transitional mix of built-up and agricultural land. Rural areas, however, remain largely dominated by agriculture with minimal soil sealing. These insights emphasize the need for sustainable land-use planning to balance development and environmental conservation. Integrating remote sensing techniques into urban management strategies can help mitigate the adverse effects of urban expansion while ensuring the preservation of agricultural and ecological resources.

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