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ANALYZING LAND USE DIVERSITY AROUND ADDIS ABABA LIGHT RAIL TRANSIT STATIONS: INTEGRATING AHP AND GIS

Ashenafi Wondimu Tekolla[1]*, *Abrham Gebre Tarekegn*[2], *Getu Segne Tulu*[2]

[1]Addis Ababa University, Addis Ababa Institute of Technology, African Railway Center of Excellence, Addis Ababa, Ethiopia; e-mails: ashenafi.wondimu@aait.edu.et; ashudahu99@gmail.com
[2]Addis Ababa University, Addis Ababa Institute of Technology, Civil and Environmental Engineering Department, Addis Ababa, Ethiopia; e-mails: abrham.gebre@aait.edu.et; getu.segni@aait.edu.et

Abstract: Land use diversity is the main prerequisite for sustainable urban development models such as Transit Oriented Development (TOD). Understanding the existing land use composition is essential when planning to implement TOD. This study assesses the level of land use diversity within an 800 m radius of four stations along the Addis Ababa Light Rail Transit (LRT), located in the central Business District (CBD). The methodology integrates the Analytic Hierarchy Process (AHP) with the Geographical Information System (GIS) using the Weighted Overlay Analysis tool. This method assigns relative weights to key land-use diversity indicators using the AHP method. The weighted layers are overlaid in GIS to generate composite land use diversity represented by three different colors (green, yellow, and red representing high, moderate, and low diversity, respectively) on a spatial map. The results of the analysis revealed that 68.18% of the study area exhibits a moderate level of land use diversity, followed by 18.91% high and 12.91% low levels. Spatial analysis also revealed the ratio of diversity variance among the four stations, indicating Autobus Tera station has the highest level of diversity among the others. The results offer a clear visual representation of diversity levels and provide valuable input for planners and decision-makers seeking to promote more diversified land use to enhance an integrated, transit-supportive urban form. This research demonstrates the effectiveness of integrating AHP-GIS as a decision-support tool for assessing land use diversity and guiding strategic interventions to improve.

Keywords: Addis Ababa transit stations; GIS based land use analysis; spatial planning; Transit Oriented Development; urban land use diversity

1. Introduction

Urban land use diversity is a key component of sustainable urban form, such as Transit Oriented Development (TOD). A balanced mix of residential, commercial, public services, and public recreational space around transit stations reduces the physical separation of functional land uses, thereby enhancing accessibility, walkability, and encouraging public transportation use (Appleyard & Frost, 2019). Studies also confirmed that neighboring land uses have an influence on each other within a limited spatial range, which fosters economic

*Corresponding author, e-mail: ashenafi.wondimu@aait.edu.et

activity and social cohesion (Manaugh et al., 2013; Song et al., 2013; Zagorskas, 2016). In the context of TOD, land use diversity is the main prerequisite to maximize economic and social benefits of transit infrastructure. Diversified land use supports mixed economic activity, attracts high pedestrian volume, and creates consistent transit ridership, which are the main goals of TOD.

Therefore, in advance of TOD implementation, it is crucial to measure the existing land use diversity of the area. However, measuring optimal land use diversity to achieve the desired objectives is a complex process that involves multiple variables. The most commonly used method of measuring land use diversity is the entropy index (Cervero, 1988; Im & Choi, 2018), which focuses on the equal presence of different land use types within a particular location. For example, if there are four land use types, this method distributes an equal 25% proportion for each land use type, ignoring the fact that each land use type provides a different proportion of the ultimate benefit to overall sustainability. On the other hand, this method failed to capture the influence of different land use types on one another (Abdullahi et al., 2015; Im & Choi, 2018; Manaugh et al., 2013). Therefore, finding a spatial approach to measure land use diversity considering multidisciplinary approaches is vital for effective TOD and urban planning.

The capital of Ethiopia, Addis Ababa, faces challenges related to urban mobility. As part of an effort to modernize urban transportation, the city administration introduced Light Rail Transit (LRT) in 2015. LRT presents an opportunity to stimulate development along its corridor by integrating transit stations with urban land use. However, the success of such infrastructure depends on the effective configuration of land use around transit stations (Jinollo et al., 2024). Additionally, empirical studies examining the manifestation of land use diversity around Addis Ababa LRT stations are limited.

This research aims to address this gap by a hybrid approach combining Analytic Hierarchy Process (AHP) and Geographical Information System (GIS) to measure land use diversity of areas around four stations along the Addis Ababa LRT located in the Central Business District (CBD). The results revealed that the studied areas predominantly exhibit a moderate level of land use diversity. These findings highlight the uneven distribution of mixed land uses in the city centre and underscore the need for strategic interventions to integrate urban land use with transit nodes.

2. Literature review

The combination of various land use types: residential, commercial, public open space, and public service with appropriate proportion is known as a "rich land use diversity" and it promotes sustainable urban form such as TOD (Ghosh & Raval, 2016; Jacobs, 1961; Zagorskas, 2016). Numerous studies revealed that diverse land uses in cities have a positive impact on various sectors, including transportation, public health, economics, and environmental sustainability. In the transportation sector, it reduces travel time and distance, as well as the usage of private vehicles (Creutzig et al., 2015; Hess et al., 2001; Jabareen, 2006; Manaugh et al., 2013; Zagorskas, 2016), and improves mobility and local traffic congestion (Cervero, 1988; Song & Knaap, 2004; Song et al., 2013, 2021; Tekolla et al., 2021). Regarding public health, it promotes the proximity of different land use types, encouraging active modes of transport such as walking and cycling, consequently reducing carbon footprint (Cervero & Duncan, 2003; Frank et al., 2006; Manaugh et al., 2013; Song et al., 2013;

Tekolla et al., 2024; Zhang & Zhao, 2017). Regarding urban economies, a rich land use mix reduces the cost of providing important utilities such as water, sewerage, and energy (Abdullahi et al., 2015; Cervero, 1988; Song & Knaap, 2004; Song et al., 2013).

In measuring land use diversity, identifying performance indicators (influencing factors) is crucial. Based on previous studies (Brown et al., 2009; Frank et al., 2006; Hajrasouliha & Yin, 2015; Hess et al., 2001; Sung et al., 2014), Im and Choi (2018) identified street environment and accessibility as indicators for land use diversity. In their study, Mashhoodi and Berghauser Pont (2011) emphasized the importance of density, accessibility, and mixed-use composition as indicators of land use diversity. In analyzing urban features and the influence of land value, Topcu and Kubat (2009) identified density, security, accessibility, and environmental features. To visualize land use diversity of Pune city, in India, Ghosh and Raval (2016) mentioned connectivity, urban grain pattern, population density, and access to amenities as the influencing parameters.

There are no universally accepted standard frameworks or methods to measure land use diversity. Entropy index is the most often used method since it was originally introduced in urban studies by Cervero (1988) and later formalized by Cervero and Kockelman (1997) in "3D – density, diversity, and design" to become a standard to quantify the land use diversity (Ewing & Cervero, 2010; Ford et al., 2015; Song et al., 2013). For example, if there are four land use types, this method assigns an equal 25% share to each, disregarding the fact that the contribution of each land use type to the overall sustainability may vary. However, in research clarifying the relationship between pedestrian volume and land use mix, Im and Choi (2018) pointed out the limitations of the entropy method. A GIS-based quantitative method for analyzing land use diversity was used by Song and Knaap (2004). In addressing the limitation of GIS alone in measuring land use diversity, Aburas et al. (2015) emphasized the importance of integrating it with AHP to determine the relative weight of variables. To generate a GIS-based land use diversity index that assesses suburban sprawl, Randall and Baetz (2015) further demonstrated the potential of combining it with a multi-criteria evaluation technique using Weighted Overlay Analysis.

3. Methods and materials

3.1. Study area

This study was conducted in Addis Ababa, the commercial, political, and diplomatic capital of Ethiopia. The city is situated in East Africa at an average elevation of 2,400 m above mean sea level (m.a.s.l.) and covers an estimated area of 572 km². According to the 2007 census, the population of Addis Ababa is estimated to be 2.7 million, with a growth rate of 3.8% per year (Population of Ethiopia, 2025). Although national censuses are scheduled to be conducted every ten years, subsequent surveys have not been conducted due to political challenges in the country. However, according to the World Population Review, Addis Ababa's 2025 population is estimated to be 6 million (Population of Ethiopia, 2025). Regarding urban form, Addis Ababa is characterized by haphazard and unplanned settlements, particularly in the old central part of the city. A significant proportion of households in Addis Ababa lack access to basic sanitation facilities (Yallew et al., 2024).

Like many African cities, Addis Ababa has faced persistent challenges in providing adequate transportation services. These limitations have hindered the ability to fully leverage its development potential. In response, the city administration has undertaken significant efforts to improve urban mobility, most notably through the implementation of the LRT, which commenced operations in 2015. Additionally, recent corridor development initiatives in the city have incorporated pedestrian walkways, cycling lanes, and public recreational spaces along major networks, making a shift toward more inclusive and sustainable urban infrastructure.

Ever since commissioning service in 2015, LRT has delivered state-of-the-art service at an affordable price. However, LRT faced a challenge that would jeopardize its ability to sustain its operations. The primary challenge is the lack of funding to purchase the necessary spare parts for the trains. TOD is considered one of the potential options for financing the LRT and ensuring its long-term viability.

A study conducted in 2015 aimed to identify ten suitable stations for TOD implementation in Addis Ababa (Teklemariam & Shen, 2020). Out of these, four stations were prioritized for the first phase of TOD implementation. These stations include Leghar, Lideta, Autobus Tera, and Menelik Square, as shown in Figure 1. The study encompasses an 800 m radius around these transit stations. The reason for selecting these four stations as examples is that implementing TOD would visibly impact the urban economy, society, and overall sustainability of the city.

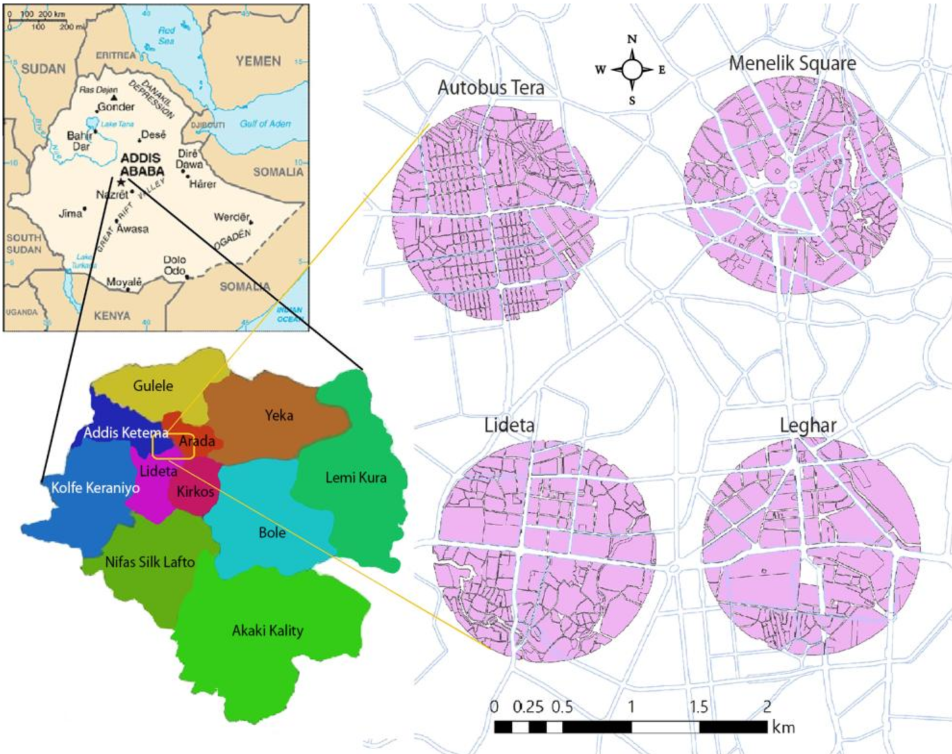

Figure 1. Graphic representation of the study area.

3.2. Method

This research employs a hybrid method that combines AHP and GIS, utilizing the Weighted Overlay Analysis tool. This approach allows the quantification and visualization of land use heterogeneity and identifies areas with high, moderate, and low levels of land use diversity on an illustrative spatial map. The method is structured in four main stages: a) Selection of the study area, b) Identification of performance indicators and weighting their significance to impact land use diversity, c) Spatial analysis using GIS, and d) Classification and visualization of diversity levels on a special map. The flow diagram of the methodology is presented in Figure 2.

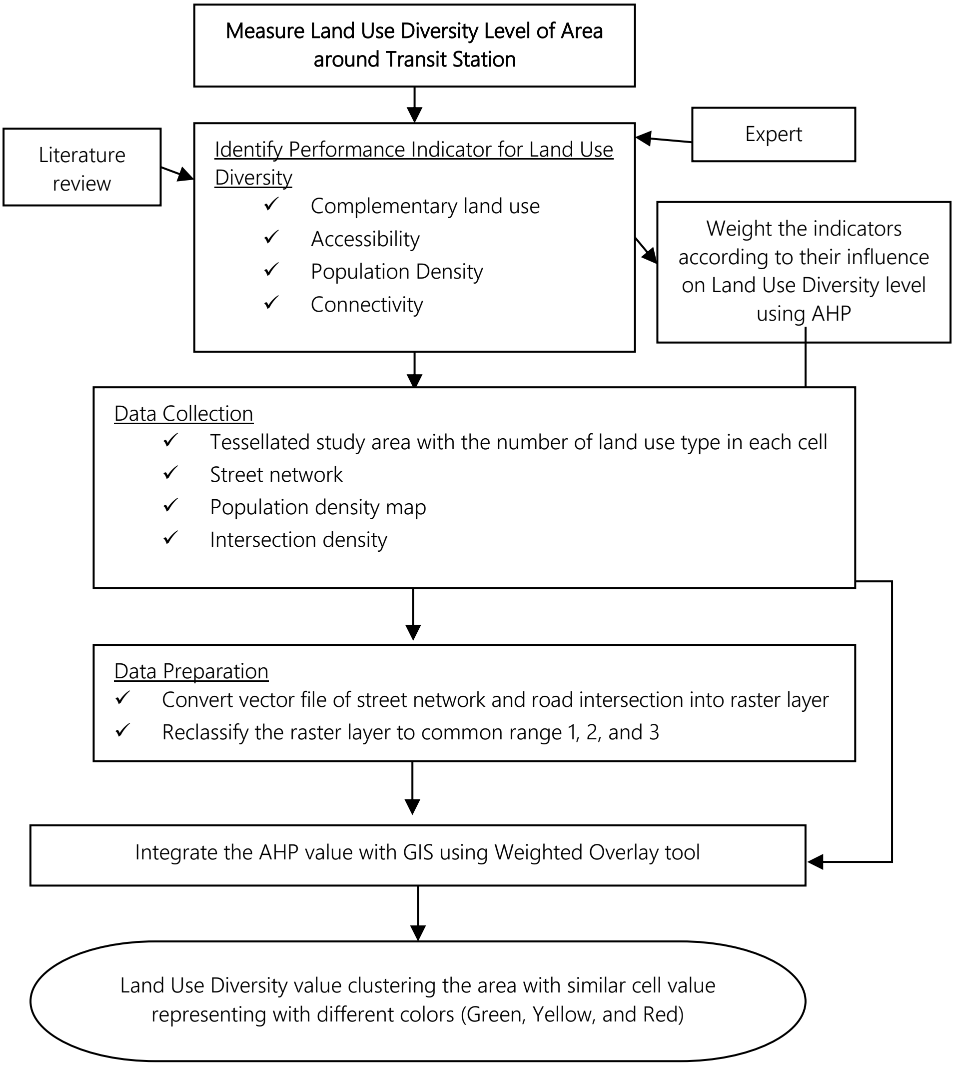

Figure 2. Schematic representation of the methodology.

3.3. Identifying performance indicators, data collection and preparation

Following a comprehensive review of the relevant literature and consultations with experts in the field, a set of performance indicators for assessing land use diversity was identified. These indicators include complementary land use, accessibility, population density, and connectivity as shown in Table 1. Data used to evaluate the performance indicators are obtained from the Addis Ababa City Administration Plan and Development Bureau (AAPDB). These data were extracted and rearranged to make them suitable for analysis, which included converting the vector file into a raster layer and reclassifying the raster layer to normalized values of 3, 2, and 1.

Table 1. Influencing parameters, data used to assess, and data source

No	Influencing parameters (Indicators)	Data used	Source
1	Complementary land use	Tessellate existing land use	AAPDB and Google earth
2	Accessibility	Road network	AAPDB
3	Population density	Population density	AAPDB
4	Connectivity	Block size	AAPDB

3.3.1. Complementary land use

Complementary land use refers to the presence of different land use types, such as residential, commercial, and public open spaces, within an urban block. To examine the complementary land use, the area has been divided into 200 × 200 m area finite elements using the tessellate tool in GIS. Then, by using the land use layer, count the number of land uses within each cell. If the number of land use types within a cell is greater than or equals to 3, then give an attribute value of 3 in the cell; if the number of land use type in the cell equals to 2, the give an attribute value of 2, and if the number of land use type in the cell is only 1, then give an attribute value of 1 in the particular cell. Finally, convert the vector layer to a raster layer with cell values of 3, 2, and 1 as shown in Figure 3A.

3.3.2. Accessibility

Accessibility refers to the convenience of reaching different land use types within an urban block (Berawi et al., 2020). A well-connected road network provides access to every land use type within close proximity, thereby encouraging local residents to walk or cycle (Nyimbili, 2020). To compute accessibility, the road network shape file has been converted to a raster layer using the Line Density tool in GIS. Then the raster file was reclassified to a common range of 3, 2, and 1, as shown in Figure 3B.

3.3.3. Population density

Population density is a critical factor in shaping urban dynamics, as it contributes to the generation of diverse activities within urban blocks. It is widely regarded as a key driver in promoting land use diversity, with higher population densities often associated with increased complexity of urban functions and a greater degree of land use mixing. In this study, population density was derived from converting the vector data of population density into a raster format and subsequently reclassified into three standardized categories: high (3), moderate (2), and low (1), as illustrated in Figure 3C.

3.3.4. Connectivity of the area

Connectivity refers to the ease of movement within the built environment, particularly in accessing different land use types. In this study, connectivity is examined using the density of intersection points (crossings) in an urban block. Higher density intersection point indicates smaller blocks and a higher level of connectivity, thereby enhancing the effectiveness of land use diversity. In contrast, lower density of intersection is characterized as poor connectivity and limited accessibility (Song & Knaap, 2004). To analyze connectivity level of the study area, shape file of the intersection (crossing points) obtained from AAPDB was converted into raster format using point density tool in GIS, and then reclassified into standardized connectivity values of high (3), moderate (2), and low (1), as illustrated in Figure3D.

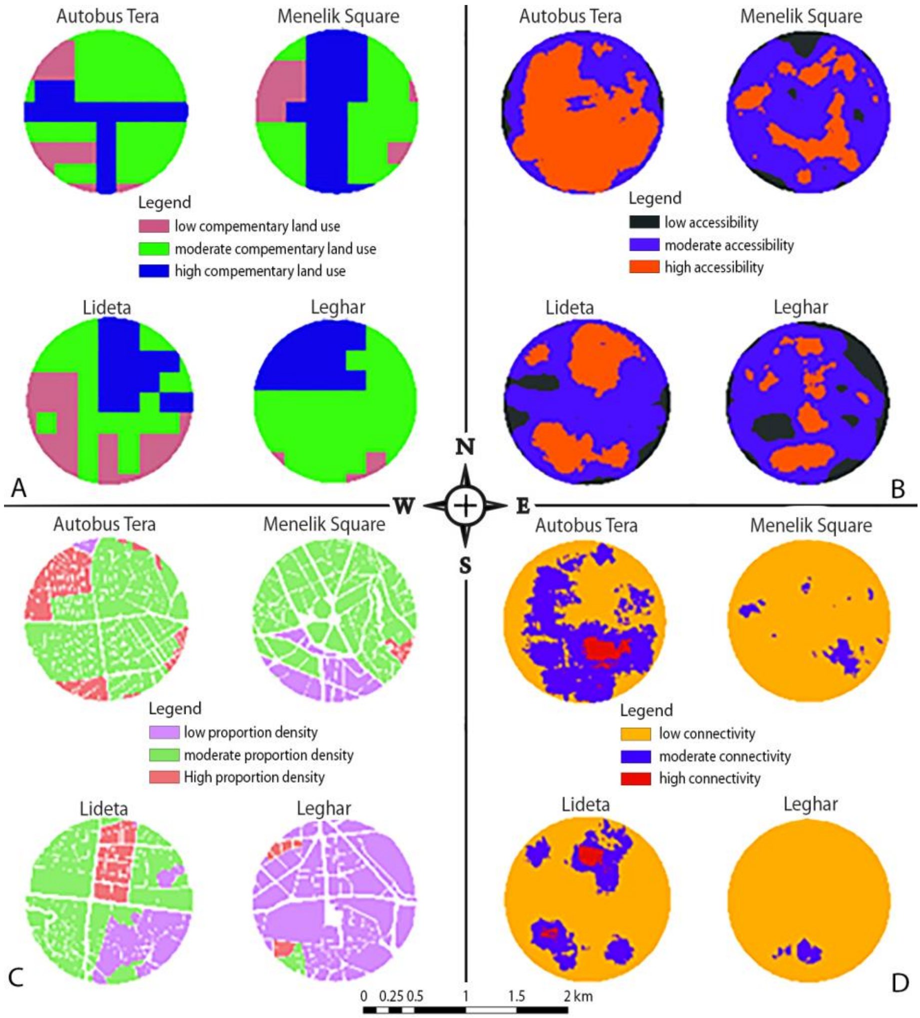

Figure 3. Reclassified raster layer of complementary land use, road network, and intersection density to the common three ranges (3, 2, and 1).

3.4. Weighting the significance of performance indicators

Weighting the significances of identified indicators among each other, based on the context of Addis Ababa, was undertaken using AHP, which is a multi-criteria decision making method. The process uses hierarchical structures to weight the significance of performance indicators based on expert judgment. The four basic steps of AHP are: create a hierarchy, build a pair-wise comparison matrix, evaluate the local weights, and check the consistency of judgments.

3.4.1. Creating hierarchy

Creating hierarchy involves organizing elements from the main goal to the specific criteria. These criteria define the necessary conditions for an area to be recognized as having diversified land use. This process is illustrated in Figure 4.

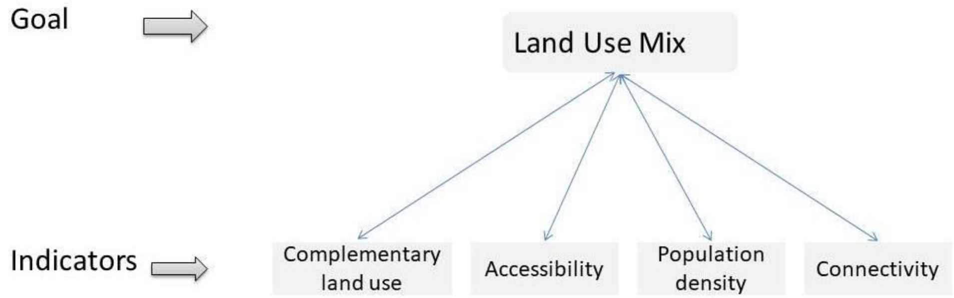

Figure 4. Hierarchal diagrams of the main goal to the performance indicators to weight the significance of the identified performance indicators of land use diversity.

3.4.2. Building a pair-wise comparison matrix

Pair-wise comparison matrix is performed based on Saaty (1980). Values of 1 to 9 are assigned by comparing the importance of each performance indicator to the others. For the present research, the significance of the performance indicators has been compared using the judgments of experts from the relevant field (Liberatore, 1982). The pair-wise matrix in Table 2 is diagonal. The upper triangle, above the diagonal line, is filled with the value of comparison value indicators based on expert judgments, while the lower triangle represents the reciprocal values of the upper diagonal.

Table 2. Pair-wise matrix of indicator for effective land use diversity, based on the context of Addis Ababa city

	CLU	AOD	PD	Con
CLU	1	1	2	2
AOD	1	1	1	2
PD	0.5	1	1	2
Con	0.5	0.5	0.5	1

Note. CLU = complementary land use; AOD = accessibility of origin and destination PD = population density; Con = connectivity of the area.

3.4.3. Evaluation of local weight

Computing the priority vector in the AHP involves normalizing the principal eigenvector of the pair-wise comparison matrix. The process ensures that the sum of the vector components equals one, thereby allowing for meaningful comparisons of relative priorities. The priority vector is calculated using Saaty's (1980) formula, which divides each element of the eigenvector by the sum of all its components as follows:

$$Pri = \frac{Eg_i}{\sum_{i=1} Egi} \tag{1}$$

where Eg_i = Eiegen-value for the row i

$$Egi = (a11 \cdot a12 \cdot a13 \ldots ann)\char`^(1/n) \tag{2}$$

$$\lambda \max = \sum \left[wi \cdot \sum aij \right] \tag{3}$$

where aij is the summation of the performance indicators in each column in the 4 × 4 matrix and wj is the criteria weight value, which is equal to priority vector in the matrix.

3.4.4. Checking the consistency of judgments

The consistency index (CI) is calculated using Equation 4 to evaluate the reliability of expert judgments in AHP. Once the CI is obtained, the consistency ratio (CR) is then computed using Equation 5, which compares the CI to random index (RI) to determine whether the level of inconsistency is within acceptable range.

$$CI = \frac{(\lambda \max - n)}{n-1} \tag{4}$$

where CI is the consistency index, Λ_{max} is Eigen value or Lambda and n is the number of indicator.

$$CR = \frac{CI}{RI} \tag{5}$$

where CR is consistency ratio and RI is the random index

Table 3. Saaty's random ratio for different value of *n*

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.46

Eigen value (Lambda max) is calculated to be 4.0665, consistency index equals to 0.001, and consistency ratio equals to 0.01 which is 1%. Since the consistency ratio is less than 5% threshold, the pair-wise comparison is consistent and the results are shown in Table 4.

3.5. Weighted Overlay Analysis

The weighted overlay tool in GIS enables the analysis of complex and multi-criteria problems to generate an aggregated spatial map. The spatial data for each performance indicator used in the research includes street network density, intersection density, population density, and block size. All spatial data extracted from the geospatial database of the study area were converted to a raster layer and reclassified to a common scale (3, 2, and 1) to standardize the values in each cell. The cell value in all reclassified raster layers is multiplied by their corresponding weight, resulting from AHP. A new raster layer is generated by summing the values in each raster layer, and a new raster layer cell value is calculated using Equation 6:

$$\textit{Land Use Diversity} = \sum wi * xi \tag{6}$$

where *wi* is weight assigned for each performance indicator using AHP and *xi* is the cell value in raster file of spatial data.

The entire process of measuring land use diversity is demonstrated in GIS Model Builder, a visual programming tool used to create a geoprocessing workflow, as shown in Figure 5.

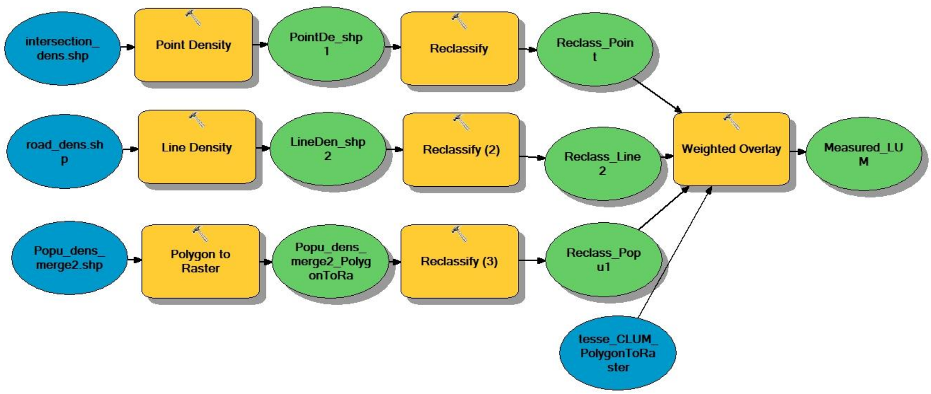

Figure 5. GIS model of the methodology of Weighted Overlay Analysis to measure land use diversity.

4. Results and discussion

The results illustrate the spatial distribution of land use diversity around four Addis Ababa LRT stations: Leghar, Lideta, Autobus Tera, and Menelik Square. The study employs an integrated methodological approach that combines AHP and GIS using Weighted Overlay Analysis. AHP is used to assign weights to key performance indicators based on their relative significance in influencing land use diversity. At the same time, GIS is applied to overlay and visualize the results on a spatial map.

The result of AHP revealed that complementary land use is more significant in altering land use diversity than other indicators, with 33.6%, as shown in Table 4. Since the consistency ratio is equal to 1%, which is less than 5% of the threshold, the pair-wise comparison matrix of 4 × 4 is considered consistent.

Table 4. Priority of performance indicators for land use mix

Indicators and Description	Symbol	AHP Weight (%)
Complementary Land Use	CLU	33.6
Accessibility to important destination	AOD	28.32
Population density	PD	23.82
Connectivity of area	Con	14.16

The spatial analysis of diversity around each station, using an 800 m radius buffer, is conducted using GIS. A composite land use diversity index was calculated using a Weighted Overlay Analysis tool in GIS software, as in Equation 6. Each grid cell is represented in number (3, 2, and 1) and three different colors: green for high, yellow for moderate, and red for low land use diversity level, as shown in Figure 6.

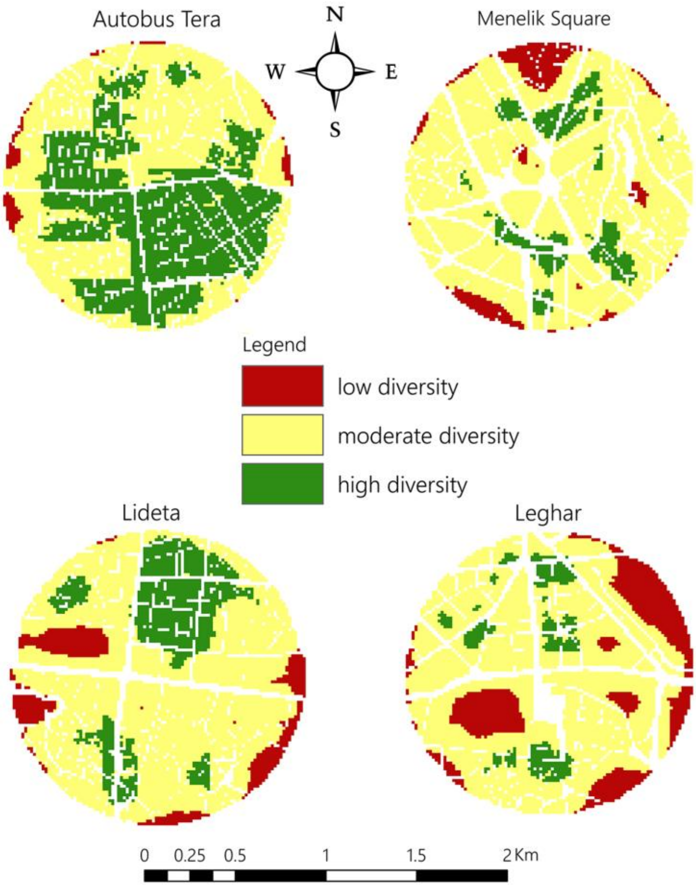

Figure 6. The areas with relatively higher land use mix level.

The results showed that most areas are mainly classified as having moderate (medium) land use diversity, making up approximately 68.18% of the study area. This is followed by high diversity, which accounts for about 18.91%, while a low level of land use mix was observed in 12.91% of the study area. Spatial analysis also revealed variation in land use diversity among the four selected stations, as shown in Table 5. For instance, Autobus Tera station demonstrated relatively balanced land use diversity, whereas Leghar station had the highest proportion of low land use diversity.

Table 5. Proportion of high, moderate, and low land use diversity level of the four stations

LRT stations	Land Use Diversity Level (%)		
	high	moderate	low
Leghar	5.42	60.39	34.19
Lideta	15.26	71.43	13.31
Autobus Tera	44.55	55.45	0
Menelik square	10.42	85.45	4.13

According to the analysis, areas with the highest concentration of low-level land use diversity are found around Leghar station. This area is mainly composed of governmental institutions, hotel compounds, and urban slums, resulting in larger block sizes that negatively affect the area's connectivity. Urban tissue characterized by small plot patterns is linked to a higher land use mix.

Lideta station was recorded as the second highest share of high level diversity. The recent renovation efforts by the city administration, particularly the promotion of mixed use buildings, have a significant role in enhancing land use diversity in this area.

A significant portion of high diversity is concentrated around the Autobus Tera station, where 44.55% of the area surrounding this station exhibited high level of land use diversity, while the remaining 55.45% reflected moderate level land use diversity. The presence of Ethiopia's largest market in the vicinity has significantly contributed to the higher diversity in the area. Vibrant business activities, well gridded road network, and higher population density have played significant role in increasing land use diversity of level.

Only 10.42% of the area around Menelik Square station shows a high level, while 4.13% displays a low level, and the remaining 85.45% is characterized by a moderate level diversity. Compared to the surrounding regions, the area with greater land use diversity also has a higher population density. Ghoerniasih et al. (2024) stated that an increase in population density results in a land use mix. However, recent developments, particularly those related to broader corridor development and river-side restoration projects have significantly altered the area's demographic and spatial characteristics.

4.1. Implication for TOD

The observed land use patterns around four Addis Ababa LRT stations show that while the study areas have a relatively balanced land use mix, there are still gaps that need to be addressed. The findings support the literature, which emphasizes that land use diversity is a key pillar of TOD success (Appleyard & Frost, 2019; Cervero & Duncan, 2003). They also highlight the importance of integrated planning approaches, such as encouraging mixed-use development, enhancing public amenities, and reviewing zoning policies to create a more functional urban environment with a focus on TOD principles.

The ongoing corridor development and river-side restoration projects in Addis Ababa represent significant steps toward fostering a more diversified land use by integrating ecological restoration with infrastructural improvements. These initiatives not only enhance the city's environmental quality but also create opportunities for more balanced and multifunctional land-use patterns.

However, the study has its limitations that should be recognized. The analysis relied primarily on secondary data, which may not fully capture the dynamic and qualitative aspects of land use mix. Despite these limitations, the findings offer valuable insights that highlight the need for deeper integration between land use planning and transit infrastructure as a pathway toward a more sustainable and equitable future for Addis Ababa.

5. Conclusion

The study assessed land use diversity of areas around four stations along the Addis Ababa LRT using a hybrid approach combining AHP and GIS. AHP was employed to weight indicators of land use diversity, while GIS overlay techniques enabled spatial analysis and visualization, categorizing areas into high, moderate, and low levels of diversity.

The results revealed that 68.18% of the study area exhibits a moderate level of diversity, followed by 18.91% with high diversity and 12.91% with low diversity. These outcomes demonstrate that while there is some degree of mixed-use development around the LRT stations, a significant portion of the surrounding land still lacks the integrated land use patterns required to support an effective TOD. The spatial analysis further highlighted notable variation among the four stations: Autobus Tera station displayed relatively balanced diversity with 44.55% of its area categorized as high, whereas Leghar station exhibited only 5.42% in the same category.

The scientific contribution of this paper lies in its methodological and contextual application. By combining AHP and GIS, the study provides a robust framework for evaluating land use diversity that addresses both the weighting of criteria and their spatial representation. As data analysis techniques advance, combining AHP and GIS will offer a convenient approach to evaluating land use diversity in the future. Despite its contributions, the study has its limitations in overlooking the dynamics of urban changes, socioeconomic, institutional, and governance factors, which are critical components of TOD success.

Overall, the study demonstrates that the hybrid approach of AHP and GIS has proven to be an effective and adaptable method for assessing land use diversity by generating actionable, spatially explicit evidence. The study equips urban planners and policymakers with insights to prioritize interventions that enhance land use integration. Strengthening land use diversity around Addis Ababa's LRT stations is essential not only for advancing TOD but also for long-term sustainability of the city.

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