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GIS-based analysis of street network structure and urban development patterns in Termez city, Uzbekistan

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Abstract: Street networks play a fundamental role in shaping urban development by influencing accessibility, mobility, and the spatial organization of cities. This study aims to analyze the structure of the street network in Termez City using Geographic Information Systems (GIS) and evaluate its impact on urban development patterns. OpenStreetMap (OSM) data were used to extract street network data, building footprints, and the administrative boundary of the study area. All spatial analyses were conducted using QGIS 3.40. The methodological framework included street hierarchy classification, street density assessment, building distribution analysis, and the evaluation of spatial relationships between the street network and urban development. The results revealed that higher-order streets, including trunk, primary, and secondary roads, are predominantly concentrated in the central districts of Termez City, forming the main transportation corridors. Building distribution analysis demonstrated that urban development is strongly associated with these corridors, where higher concentrations of buildings were observed. In contrast, peripheral areas exhibited lower levels of street network connectivity and relatively dispersed development patterns. The findings confirm that the structure and connectivity of the street network significantly influence the spatial development of Termez City. Furthermore, the study highlights the effectiveness of GIS-based approaches in supporting evidence-based urban planning, improving transportation accessibility, and promoting sustainable urban development in medium-sized cities.

Keywords: street network, GIS, urban development, spatial analysis, OpenStreetMap, transportation infrastructure, Termez City, QGIS

1. Introduction

Urbanization has become one of the most significant socio-economic processes of the twenty-first century. According to the United Nations, nearly 68% of the world's population is expected to live in urban areas by 2050. The continuous growth of urban populations requires the rapid development of transportation systems, land-use structures, and urban infrastructure. In this context, street networks have gained increasing importance as fundamental elements that support the spatial organization of cities, facilitate mobility, and promote economic activities.

The structure and connectivity of street networks directly influence urban development patterns. Well-integrated street systems improve accessibility, reduce travel distances, and facilitate the efficient movement of people and goods. As a result, they contribute to increased economic activity, improved access to urban services, and the creation of favorable conditions for sustainable urban development [1, 2, 7]. In contrast, fragmented and poorly connected street networks often lead to uncontrolled urban expansion, increased transportation costs, and inefficient land use [3].

In recent years, the advancement of Geographic Information Systems (GIS) technologies has created new opportunities for analyzing urban transportation networks. GIS-based approaches enable researchers to evaluate street network hierarchies, assess network connectivity, analyze accessibility, and investigate the spatial relationships between transportation infrastructure and urban development [4]. Such analyses are essential for supporting evidence-based decision-making in urban planning and for improving the management of transportation systems.

Termez City, located in the southern part of Uzbekistan, is one of the major administrative, economic, and transportation centers of the Surkhandarya Region. In recent years, population growth and increasing construction activities have contributed to the continuous expansion of the urban area. These processes have intensified the pressure on transportation infrastructure, highlighting the need to assess the efficiency of the existing street network and identify opportunities for its improvement. However, despite the regional importance of Termez City, limited research has been conducted on the spatial characteristics of its street network and their influence on urban development using GIS technologies.

Therefore, the aim of this study is to analyze the structure of the street network in Termez City using GIS techniques and to evaluate its impact on urban development. To achieve this aim, the following objectives were established:

1. To analyze the hierarchical structure of the street network in Termez City;
2. To assess the spatial characteristics and connectivity of the street network;
3. To identify the spatial relationships between the street network and building distribution;
4. To evaluate the impact of transportation infrastructure on urban development;

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5. To develop practical recommendations for improving transportation planning and promoting sustainable urban development in Termez City.

The findings of this study may provide an important scientific and practical basis for improving the transportation system of Termez City, enhancing accessibility, and supporting the effective planning of future urban development.

Literature review

Street networks are an essential component of urban structure, directly influencing mobility, accessibility, and the spatial development of cities. The configuration of street networks determines the efficiency with which people, goods, and services move throughout urban areas and plays a significant role in shaping urban morphology [1, 5]. Consequently, the analysis of street networks has become one of the key research areas in urban planning and transportation studies.

In recent years, street network connectivity has been increasingly recognized as an important indicator affecting urban development. According to Boeing [2], highly connected street networks reduce travel distances, distribute traffic flows more efficiently, and improve access to urban services. In contrast, fragmented and poorly connected street systems contribute to uncontrolled urban expansion, reduced transportation efficiency, and increased infrastructure costs [3].

The relationship between urban development and street network structure has been widely investigated in previous studies. Porta et al. [4] emphasized that transportation infrastructure is one of the major factors shaping urban morphology and reported higher levels of development intensity along major transportation corridors. Similarly, Sevtsuk and Mekonnen [8] found that areas with higher levels of accessibility are often characterized by greater economic activity and more intensive urban development.

Various indicators have been proposed to evaluate the performance of street networks. Among the most commonly used measures are street density, intersection density, network continuity, and route accessibility [6]. These indicators provide valuable insights into the level of transportation network development and the quality of mobility conditions within urban areas.

Geographic Information Systems (GIS) have become an important tool for analyzing urban transportation systems. GIS technologies facilitate street network classification, the integration of spatial data, the identification of relationships between transportation infrastructure and land use, and the production of thematic maps [4]. Moreover, the increasing availability of OpenStreetMap data has enabled rapid and cost-effective analyses of transportation networks.

Investigating the spatial relationships between transportation infrastructure and urban development has also emerged as an important research direction. Previous studies have shown that higher concentrations of buildings are often found in areas with greater transportation accessibility [1]. Major transportation corridors influence residential distribution, commercial activities, and the provision of social infrastructure, thereby shaping the future directions of urban growth.

Although numerous studies on street networks have been conducted worldwide, limited attention has been given to cities in Central Asia, particularly medium-sized cities in Uzbekistan. In the case of Termez City, research focusing on the assessment of street network structure and its influence on urban development using GIS technologies remains scarce.

From this perspective, the present study aims to analyze the spatial characteristics of the street network in Termez City, identify the relationships between transportation infrastructure and urban development, and provide practical recommendations to support sustainable urban planning.

2. Research methodology

Study Area

The study was conducted in Termez City, the administrative center of the Surkhandarya Region located in the southern part of the Republic of Uzbekistan. Termez is one of the country's important administrative, economic, and transportation centers. Due to its proximity to international transportation corridors, the city plays a significant role in the regional economy. In recent years, population growth, urban expansion, and increasing traffic volumes have highlighted the need to investigate the characteristics of the city's street network development.

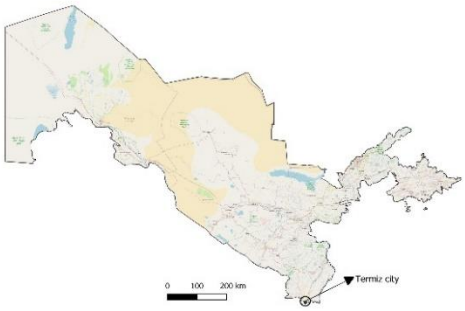

Fig. 1. Location of Termez City within Uzbekistan

Data Sources

This study utilized spatial data obtained from OpenStreetMap (OSM), an open-source geographic database that is regularly updated and freely accessible. The following datasets were collected and used for the analysis:

- street network data (road centerlines);
- building footprint data;
- administrative boundary of Termez City;
- base cartographic layers.

According to the OpenStreetMap classification system, the street network data were categorized into six road classes:

- trunk;
- primary;
- secondary;
- tertiary;
- residential;
- service.

Building footprint data were used to evaluate urban development patterns and the spatial relationships between transportation infrastructure and built-up areas.

GIS Environment and Data Processing

All spatial analyses were performed using QGIS 3.40 software. The research process consisted of several stages, including data collection, preprocessing, classification, spatial analysis, and cartographic visualization. The overall

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methodological framework of the study is presented in Figure 2.

Fig. 2. Research workflow for assessing the street network structure and urban development in Termez City

The study was carried out through the following stages:

- downloading OpenStreetMap data;
- extracting the administrative boundary of Termez City;
- clipping road and building layers to the study area boundary;
- classifying the street network according to functional categories;
- analyzing the spatial distribution of buildings;
- assessing the spatial relationships between roads and buildings;
- preparing thematic maps and interpreting the results.

The following QGIS tools and functions were employed during the analysis:

- QuickOSM Plugin;
- Vector Geometry Tools;
- Field Calculator;
- Clip;
- Buffer;
- Spatial Join;
- Layout Manager.

Street Network Hierarchy Analysis

The street network of Termez City was classified into six categories according to the OpenStreetMap road hierarchy system:

- trunk roads;
- primary roads;
- secondary roads;
- tertiary roads;
- residential streets;
- service roads.

This classification enabled the identification of the hierarchical structure of the urban transportation system and facilitated the assessment of the role of different road categories in urban development.

Street Density Assessment

Street density was calculated to evaluate the level of development of transportation infrastructure within the study area. This indicator represents the ratio between the total length of streets and the area of the study region.

The street density was calculated using the following equation:

$$SD = \frac{L}{A}$$

where: SD – street density (km/km²);
L – total length of streets within the study area (km);
A – area of the study region (km²).

Higher street density values generally indicate better accessibility and more developed transportation infrastructure.

Building Distribution Analysis

Building footprints were analyzed to evaluate urban development patterns in Termez City. The analysis focused on the following aspects:

- spatial distribution of buildings throughout the city;
- concentration of built-up areas;
- distribution of buildings along major transportation corridors.
- Building density was calculated using the following equation:

$$BD = \frac{N}{A}$$

where: BD – building density;
N – number of buildings;
A – area of the study region (km²).

Assessment of Spatial Relationships Between Roads and Buildings

To evaluate the influence of transportation infrastructure on urban development, spatial analysis was conducted between the street network and building layers.

Buffer zones were generated around primary and secondary roads, and the concentration of buildings within these zones was assessed. This approach enabled the identification of the extent to which transportation corridors

Cartographic Visualization

The results of the study were presented through thematic maps prepared in the QGIS Layout Manager environment and exported in high quality.

The following figures were included in the article:

Figure 1. Location of Termez City within Uzbekistan;

Figure 2. Research workflow for assessing the street network structure and urban development in Termez City;

Figure 3. Street network hierarchy of Termez City;

Figure 4. Spatial distribution of buildings in Termez City;

Figure 5 Spatial relationships between the street network and urban development in Termez City**.**

These maps served as the primary basis for evaluating the spatial characteristics of the transportation system in Termez City and analyzing its impact on urban development patterns.

3. Results and Discussion

Street Network Hierarchy of Termez City

The results of the analysis revealed that the street network of Termez City consists of roads with different functional characteristics. Based on OpenStreetMap data, streets were classified into six categories: trunk, primary, secondary, tertiary, residential, and service roads.

The study found that higher-order roads, including trunk, primary, and secondary roads, are predominantly

concentrated in the central parts of the city. These roads form the main transportation corridors of Termez City and facilitate connectivity between residential areas, public buildings, commercial establishments, and administrative centers.

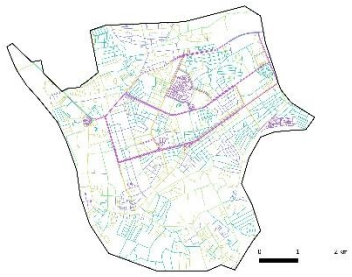

Fig. 3. Street network hierarchy of Termez City

The map analysis further indicated that residential streets constitute the largest proportion of the urban street network and primarily serve local mobility functions. Service roads mainly provide access to service facilities and internal urban areas.

While the street network is relatively dense and well-developed in areas close to the city center, a lower density of streets was observed in peripheral districts of the city.

Spatial Distribution of Buildings

The analysis of building footprints demonstrated that urban development is unevenly distributed throughout Termez City. The majority of buildings are concentrated in the central districts and in areas with favorable transportation accessibility, particularly along major roads.

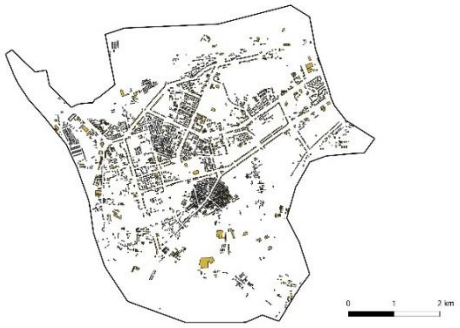

Fig. 4. Spatial distribution of buildings in Termez City

Central districts exhibited high building density, creating a continuous urban fabric. These areas were characterized by a high concentration of commercial establishments, educational institutions, social infrastructure, and service facilities.

In contrast, buildings in peripheral areas were more dispersed, and development intensity was lower compared with the central parts of the city. This pattern reflects the gradual expansion of the city and the subsequent development of outer urban areas.

Spatial Relationships Between the Street Network and Urban Development

The integrated analysis of the street network and building distribution demonstrated that transportation infrastructure plays a significant role in shaping urban development.

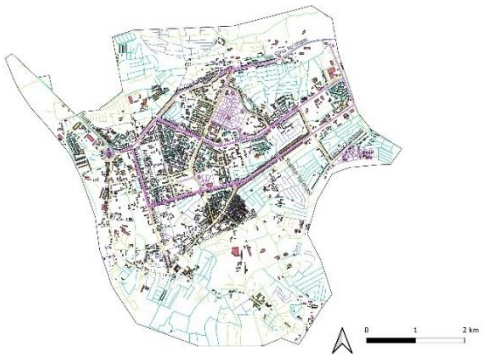

Fig. 5. Spatial relationships between the street network and urban development in Termez City

The findings revealed that building concentrations are particularly high along primary and secondary roads. This suggests that higher levels of transportation accessibility positively influence residential distribution and economic activities. Moreover, a greater concentration of residential and commercial buildings was observed around major transportation corridors. This pattern confirms that transportation infrastructure acts as one of the principal factors guiding urban development.

Conversely, peripheral areas with lower levels of transportation accessibility exhibited relatively sparse building distributions and lower development intensity.

Connectivity Characteristics of the Street Network

The analysis indicated that the street network in the central parts of Termez City is relatively well developed. Central districts are characterized by a higher degree of interconnectivity between streets, providing multiple alternative routes for movement.

In contrast, peripheral districts displayed lower levels of network connectivity. These areas were characterized by longer street segments and fewer intersections, limiting route choices and potentially reducing transportation efficiency and accessibility.

Nevertheless, the existing transportation network generally provides effective connections between the city center and outer urban areas. However, several neighborhoods were found to require further improvements to their internal street networks in order to enhance overall connectivity.

Impact of Street Network Structure on Urban Development

The results demonstrated that transportation infrastructure is one of the major determinants of urban development in Termez City. Well-developed street networks and higher levels of accessibility appear to support increased construction activities and urban growth.

The analysis showed that areas with higher building densities generally correspond to locations with better-developed transportation networks. This finding suggests that the street network exerts a direct influence on the urban morphology and functional organization of the city.

Furthermore, future urban expansion in Termez City is likely to continue along existing transportation corridors. Therefore, improving transportation infrastructure in peripheral districts, enhancing street network connectivity, and adopting integrated approaches to urban development planning are essential for promoting balanced and sustainable urban growth.

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Overall, the findings confirm that the street network structure is one of the key factors shaping the spatial organization and development patterns of Termez City.

DISCUSSION

The findings of this study demonstrate that the structure of the street network in Termez City has a significant influence on urban development patterns. The hierarchical organization of the street network and the spatial distribution of transportation corridors were found to be closely associated with building distribution and the overall spatial configuration of the city.

The analysis revealed that higher concentrations of buildings are primarily located along primary and secondary roads. This finding is consistent with previous international studies. For example, Porta et al. (2006) emphasized that transportation infrastructure is one of the major factors shaping urban morphology. Similarly, Sevtsuk and Mekonnen (2012) reported that areas characterized by higher levels of accessibility tend to exhibit greater economic activity and higher development intensity.

The study also showed that the central districts of Termez City possess relatively dense and well-integrated street networks. These findings support the conclusions of Boeing (2020), who argued that highly connected street networks reduce travel distances, facilitate the efficient distribution of traffic flows, and improve access to urban services.

In contrast, peripheral areas of the city were characterized by lower street density and a limited number of alternative routes. This pattern is similar to the concept of "street-network sprawl" described by Boeing (2021), which refers to declining connectivity in expanding urban areas. Such conditions may reduce transportation efficiency and restrict accessibility in the outer districts of the city.

The analysis of spatial relationships between transportation infrastructure and urban development indicated that transportation corridors play a crucial role in directing urban growth. The concentration of residential, commercial, and social infrastructure around major roads suggests that street networks significantly influence the functional organization of urban areas. These findings are in agreement with Marshall (2018), who highlighted the important role of street networks in shaping the spatial structure of cities.

The application of GIS technologies proved to be an effective approach for assessing the relationships between street networks and urban development. The integration of OpenStreetMap data with the QGIS environment provided a practical and cost-effective framework for evaluating transportation infrastructure, analyzing building distribution patterns, and producing thematic maps.

Overall, the findings of this study support existing theoretical perspectives presented in international literature and contribute to filling the research gap concerning the relationships between transportation infrastructure and urban development in medium-sized cities of Uzbekistan.

4. Conclusion

This study assessed the structure of the street network in Termez City and its influence on urban development using GIS technologies. OpenStreetMap data and the QGIS environment were employed to analyze street hierarchy, building distribution patterns, and the spatial relationships between transportation infrastructure and urban development.

The results showed that the street network of Termez City consists of trunk, primary, secondary, tertiary, residential, and service roads. Higher-order roads were found to be predominantly concentrated in the central districts of the city, forming the main transportation corridors.

The analysis of building distribution revealed that urban development is largely concentrated in areas with better transportation accessibility. In particular, residential and commercial buildings were more frequently located along primary and secondary roads, confirming the influence of transportation infrastructure on urban development.

Furthermore, the study identified higher levels of street density and connectivity within the central parts of the city, whereas peripheral districts exhibited fewer alternative routes and lower levels of accessibility. These conditions may lead to future transportation challenges and reduced mobility opportunities in outer urban areas.

Based on the findings of this study, several practical recommendations can be proposed:

- improving street network connectivity in peripheral districts;
- prioritizing transportation infrastructure in the planning of new development areas;
- creating safe and pedestrian-friendly urban environments;
- integrating transportation planning with land-use planning processes;
- expanding the use of GIS technologies in urban planning and decision-making.

In conclusion, the findings demonstrate that the street network structure is one of the key factors shaping the spatial organization and development patterns of Termez City. The results may serve as a scientific basis for improving the urban transportation system, enhancing accessibility, and supporting sustainable urban development strategies.

Future studies should incorporate additional indicators, including traffic flow characteristics, pedestrian movement patterns, public transport accessibility, and space syntax measures, to provide a more comprehensive understanding of the relationships between transportation infrastructure and urban development.

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