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Locating Telecommunications Antennas in the Seventh District of Kabul City Using Geographic Information System (GIS)

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Abstract

In recent years, simultaneous with the rapid growth of urbanization, the return of migrants from neighboring countries, and the development of urban infrastructure, including the repair and construction of several new roads in Kabul city, the pattern of physical expansion of the city and the distribution of land use have undergone significant changes. These developments, especially in densely populated urban areas, have highlighted the need for precise spatial planning and the use of modern spatial analysis tools, thereby increasing the importance of Geographic Information Systems (GIS) in urban decision-making processes.The main objective of this study is to identify the optimal locations for telecommunication antennas in Seventh District of Kabul City using GIS and the Digital Elevation Model (DEM). In this context, spatial and descriptive data were collected from reliable sources and analyzed using ArcGIS 10.8 software. To simulate spatial conditions and determine the most suitable locations for antenna installation, raster-based analyses and the Viewshed model were used to assess visibility and coverage areas.The results of the study indicate that the installation of telecomm-unication antennas at suitable elevations on the Sultan Mountain provides better telecommunication coverage for the majority of the population in the district. This outcome is significant because, in densely populated urban areas, adequate and optimal coverage of telecommunication networks can have a positive impact on the quality of urban life and improve access to telecommunication services.

Keywords: Digital Elevation Model, Geographic Information System, Location Selection, Remote Sensing Telecommunication Antenna, Viewshed.

Introduction

In recent years, alongside the rapid growth of urbanization, the return of migrants from neighboring countries, and the development of urban infrastructure—particularly the repair and construction of new roads in Kabul city—the pattern of physical expansion of the city and the distribution of land use have undergone significant changes. These urban transformations, especially in densely populated areas, have underscored the urgent need for precise spatial planning and the application of modern spatial analysis tools. This situation has, in turn, highlighted the importance of Geographic Information Systems (GIS) in urban decision-making processes, as GIS offers comprehensive spatial data analysis and decision support (Elwood & Leszczynski).

As urban centers evolve, the planning and management of city infrastructure become increasingly complex. For instance, Kabul, like many other cities in developing regions, faces the dual challenges of rapid urban growth and the demand for efficient telecommunication services. The geographical and topographical features of the city further complicate the planning process, as they influence factors such as visibility, signal propagation, and network coverage. In this context, spatial data and geospatial tools, such as GIS and Digital Elevation Models (DEM), have proven to be indispensable for identifying optimal sites for telecommunication infrastructure, such as antennas. GIS-based spatial analysis allows for a detailed evaluation of factors like terrain, population distribution, and existing infrastructure, enabling the creation of optimal location models for antennas (Rashed & Jurgens, 2010).

The installation of telecommunication antennas is a critical component of modern urban development, particularly in cities with high population density. Efficient network coverage improves access to telecommunication services, which has become an essential part of daily life. Studies have demonstrated that a well-planned telecommunication network not only enhances connectivity but also supports the economic and social development of urban areas (Miller et al., 2014). However, the success of such installations largely depends on the accurate assessment of geographic features that affect signal quality and coverage. Therefore, the integration of GIS and DEM in site selection processes provides a reliable approach to achieving high-quality, wide-reaching coverage (Zhang, Liu, & Sun, 2019).

This research aims to identify the most suitable locations for telecommunication antennas in Seventh District of Kabul City using GIS and DEM. By utilizing spatial data collected from reliable sources and analyzing them through ArcGIS 10.8 software, the study seeks to provide valuable insights into the potential for improved telecommunication coverage in this densely populated district. The research employs raster-based analyses and the Viewshed model to assess visibility and coverage areas, allowing for the determination of the optimal antenna locations that would best serve the majority of the district's population. In recent years, numerous international studies have examined the application of Geographic Information Systems (GIS) in the spatial planning of telecommunication infrastructure. Research indicates that GIS, with its capability to integrate spatial and descriptive data, provides a powerful tool for simultaneously analyzing factors such as topography, population density, and land use (Jensen, 2007). These studies demonstrate that GIS plays a crucial role in improving the efficiency and effectiveness of infrastructure planning by incorporating a variety of spatial factors into the decision-making process.

In 2025, Researchers conducted a study in the Kulai region of Johor Bahru, Malaysia, where they utilized GIS and multi-criteria analysis to evaluate the spatial suitability of 5G telecommunication towers. The results of this study indicated that factors such as population density, elevation, and the existing telecommunication network were key determinants in the selection of appropriate tower locations. Although valuable, this study primarily focused on planned urban areas and did not fully address the complexities of rapidly developing cities (Tarmidi & Azizan, 2025).

In another study conducted in 2015, Researchers analyzed the location of 22 telecommunication towers in the city of Sulaymaniyah, Iraq, using GIS and the Viewshed model. Their findings showed that the uneven distribution of towers led to areas of poor coverage and reduced telecommunication service quality. This study highlights the importance of considering visibility and topography in tower placement; however, it did not adequately account for the simultaneous analysis of population density and urban development (Haitham, Mohammad, & Abdaljabar, 2015).

In Indonesia, Scientist utilized GIS and the Haversine method in the OKU region to design a computational approach for mapping and managing telecommunication towers. The results demonstrated that the use of a spatial information database and distance analysis could significantly enhance the spatial planning of telecommunication infrastructure. However, this study did not extensively explore the role of elevation factors or Viewshed analysis in the context of telecommunication infrastructure planning (Arbai & et al, 2023).

Similarly, in 2025, Researchers conducted a GIS-based study in the Semarang region of Indonesia, analyzing the locations of Base Transceiver Stations (BTS). BTS are crucial components of telecommunication networks, responsible for transmitting and receiving radio signals between devices (such as mobile phones) and the telecommunication network. The study also proposed optimal routes for access and maintenance of these stations. While the primary focus of this research was on routing, it concluded that GIS is an effective tool for spatially analyzing telecommunication infrastructure (Haitham, Mohammad, & Abdaljabar, 2015).

Despite the scientific value of these studies, a comprehensive investigation that combines raster-based analysis, Digital Elevation Models (DEM), and Viewshed analysis in the complex urban environments of developing countries, such as Kabul, has not yet been conducted. Furthermore, the impact of rapid urban population growth and the increasing demand for telecommunication services due to demographic changes has received limited attention in previous research. This study, focusing on Seventh District of Kabul City, aims to fill these research gaps by providing a comprehensive GIS-based spatial analytical framework. Additionally, it seeks to serve as a reliable source for urban decision-making and telecommunication companies involved in infrastructure planning.

Material and Method

This research is applied in terms of its objective and descriptive-analytical in terms of its nature. The primary aim of this study is to utilize Geographic Information System (GIS) tools for spatial analysis and to determine the optimal locations for telecommunication antennas in an urban environment. The study focuses on providing practical solutions to improve telecommunication coverage in Seventh District of Kabul City. The findings of this research can be utilized in both managerial and technical decision-making processes related to telecommunication infrastructure.

The study area is Seventh District of Kabul City, which is one of the most densely populated urban areas. Due to rapid urbanization, population growth, and the development of urban infrastructure, the district faces numerous challenges in terms of telecommunication coverage (Figure 1).

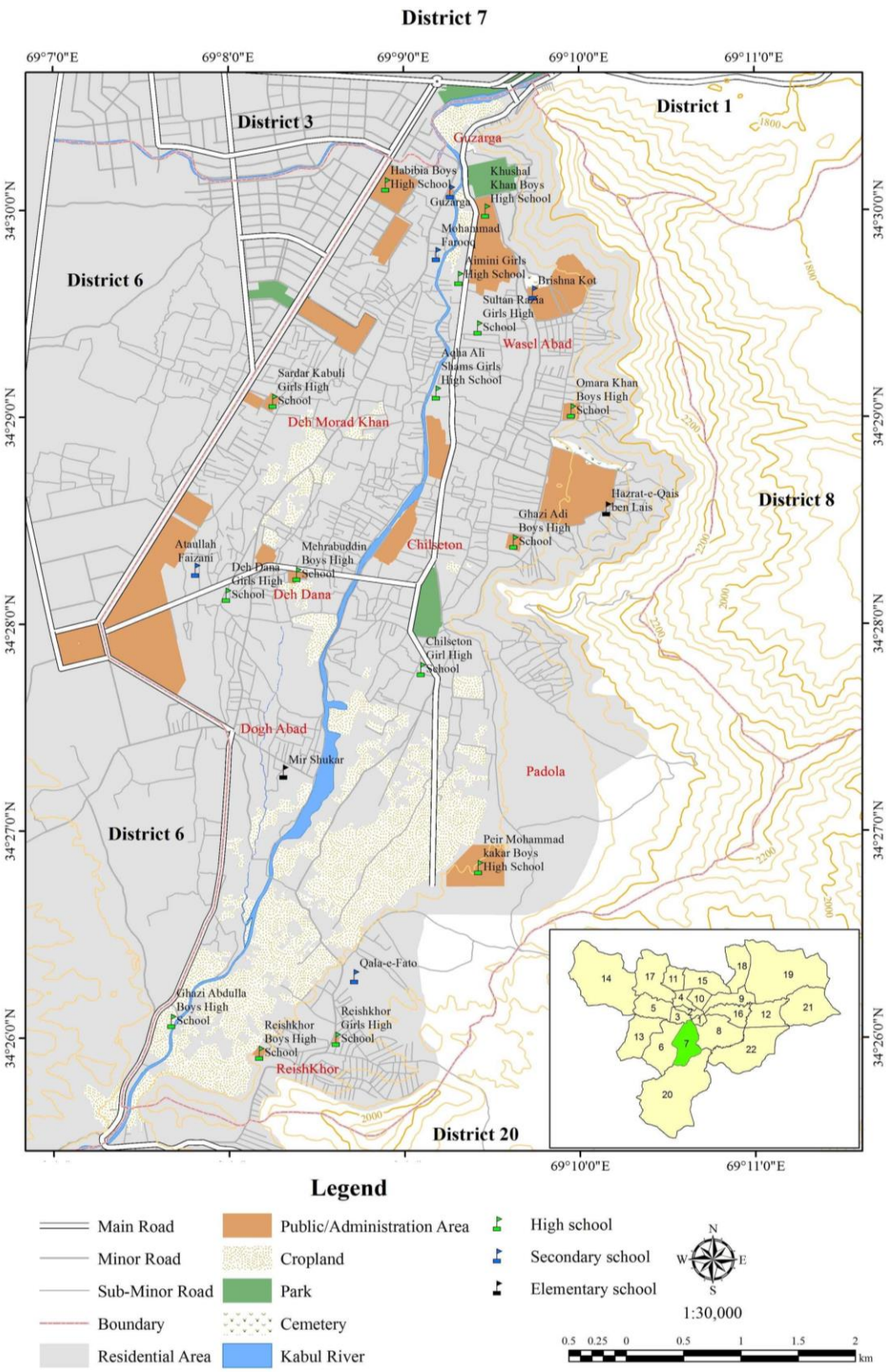

Figure 1: Geographic Location of Seventh District of Kabul City

Source: Sediqi, 2025

Geographically and topographically, this district is characterized by significant elevation changes, making it an ideal area for studying the location of telecommunication antennas. The topographical features of the region, including its elevation variations, play a critical role in determining the effectiveness of telecommunication networks, as they directly influence signal propagation and coverage (Kaiser, Lawrence, & Peters, 2014).

GIS tools are essential in identifying optimal locations for telecommunication infrastructure in urban areas, particularly in regions with complex geographical and topographical conditions. In this research, GIS-based spatial analysis is employed to evaluate various factors such as terrain, population density, existing telecommunication networks, and visibility from potential antenna locations. Additionally, a Digital Elevation Model (DEM) is used to model the terrain and assess areas with favorable line-of-sight conditions for antenna placement (Chakraborty & Kwan, 2016). The combination of these tools enables the identification of sites that can provide the best coverage for the local population.

This study will contribute to the improvement of telecommunication services in Seventh District, providing a data-driven framework for decision-making that can be applied not only to Kabul but also to other urban areas facing similar challenges.

In this study, two types of data were utilized:

1. Spatial data, which included a Digital Elevation Model (DEM) with appropriate resolution, as well as spatial layers representing the boundaries of the district and urban streets.
2. Descriptive data, comprising population information and other relevant data related to the urban structure of the study area.

All required data were collected from reliable sources, and ArcGIS 10.8 was used as the primary tool for spatial data processing and analysis. The nature of the data in this research is a combination of raster and vector formats. Raster data primarily consisted of the DEM, which was used for elevation analysis and Viewshed modeling, while vector data included points (antenna locations), lines (streets), and polygons (district boundaries and coverage areas).

The unit of analysis in this study was the spatial areas and urban streets within Seventh District of Kabul City. Following data collection and quality assessment, the data analysis was conducted within the GIS environment. Initially, raster and vector data were prepared and managed within a geodatabase (Figure 2). Subsequently, raster-based analyses were applied to identify suitable elevations for antenna installation.

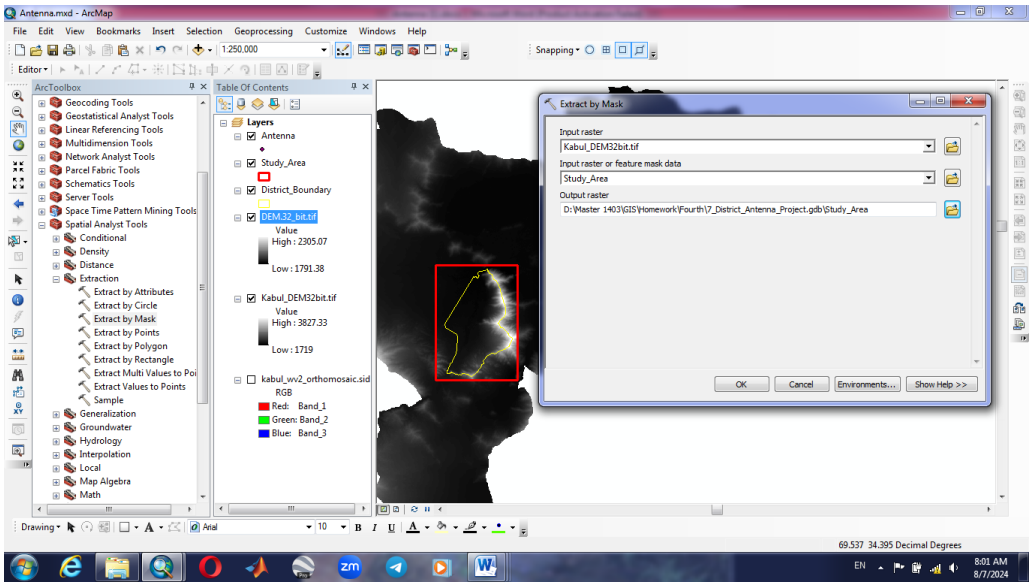

Figure 2: Digital Elevation Model (DEM) of Seventh District, Kabul City
Source: Sediqi, 2026

Subsequently, the Viewshed model was applied to analyze the line-of-sight from potential antenna locations and to estimate the spatial coverage of telecommunication signals. The Viewshed analysis, when integrated with the Digital Elevation Model (DEM), allowed for the assessment of terrain effects on signal propagation, identifying areas that are visible from each potential antenna site and those that are obstructed by natural or built features. This integration is particularly important in urban environments like Seventh District of Kabul, where elevation changes, hills, and urban structures can significantly influence coverage patterns (Chakraborty & Kwan, 2016).

The outputs of the Viewshed analysis were overlaid with population data to quantify the number of residents within the coverage area of each potential antenna location. By combining spatial coverage with population density, it was possible to evaluate not only the geographic reach of each site but also its effectiveness in serving the highest number of people. This approach ensures that telecommunication infrastructure planning is both technically sound and socially responsive, addressing areas with high demand for connectivity.

Ultimately, the optimal antenna location was selected based on a multi-criteria assessment, prioritizing sites that maximize both spatial coverage and population density. This methodology demonstrates the value of using GIS-based tools, including DEM and Viewshed analysis, to provide data-driven recommendations for urban telecommunication planning. Such an approach can significantly enhance the quality of service, reduce coverage gaps, and support sustainable urban development in densely populated and topographically complex areas (Rashed & Jurgens, 2010).

Findings

The findings of this study are derived from the analysis of spatial and descriptive data, including the Digital Elevation Model (DEM), street network information, population distribution, and other analyses conducted within the ArcGIS 10.8 environment. The

results illustrate the telecommunication coverage status of Seventh District in Kabul City under various antenna installation scenarios.

The analysis of the Digital Elevation Model (DEM) of the study area revealed that the terrain elevation ranges from approximately 1,800 meters to over 2,300 meters above sea level (Figure 3).

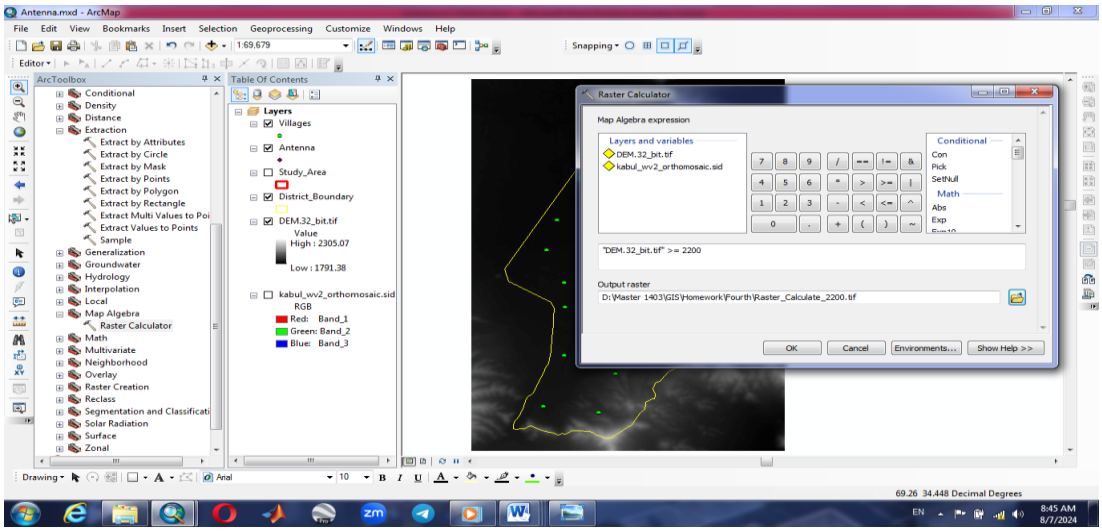

Figure 3: Analysis of the Digital Elevation Model (DEM) of the study area showing elevation ranges

Source: Sediqi, 2026

This significant variation in elevation plays a crucial role in the planning of telecommunication infrastructure, as higher areas can provide enhanced line-of-sight for antennas and broader signal coverage, whereas lower-lying areas may experience limited connectivity due to topographical obstruction (Kaiser, Lawrence, & Peters, 2014).

The elevation analysis, combined with population distribution data and the urban street network, provides a comprehensive understanding of areas that are well-served or under-served in terms of telecommunication coverage. Such integrated analysis enables urban planners and telecommunication providers to make informed decisions regarding the placement of antennas to maximize coverage efficiency and address population needs effectively.

Elevation analysis indicated that the higher areas of Sultan Mountain possess greater potential for telecommunication antenna installation compared to other locations within the district, due to their superior line-of-sight and signal coverage capabilities (Figure 4).

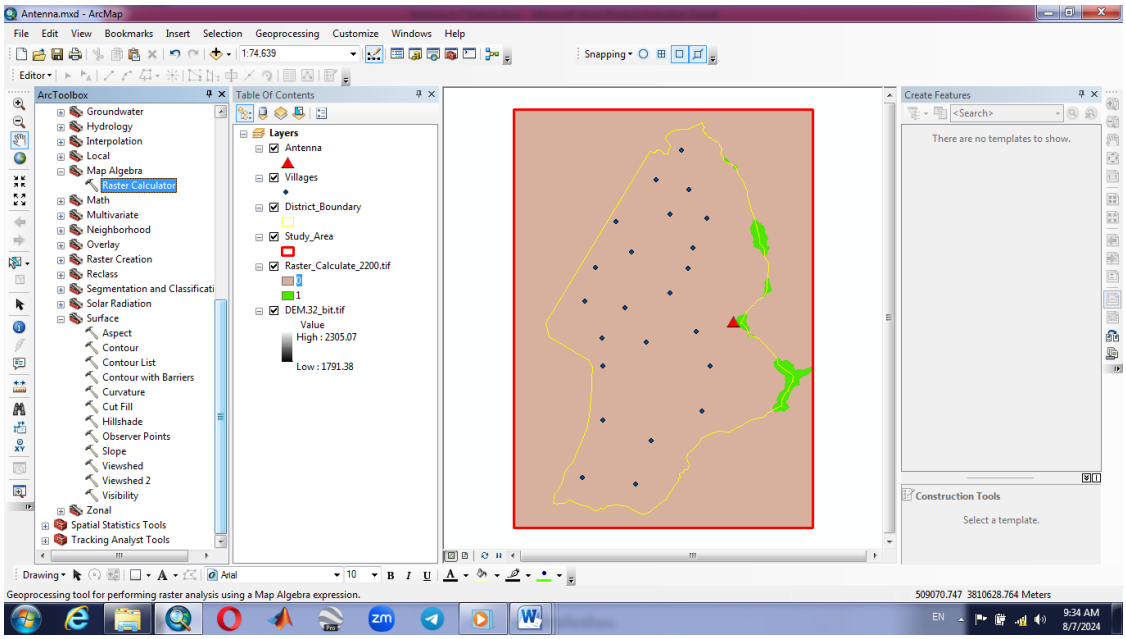

Figure 4: Proposed telecommunication antenna location in Seventh District, Kabul City
Source: Sediqi, 2026

In the first phase of analysis, an antenna location was selected at an elevation of approximately 2,200 meters, and a Viewshed model was executed to assess line-of-sight coverage. The analysis revealed that approximately 16.2 square kilometers of the district, encompassing 21 urban streets, fall within the direct visibility and coverage area of the antenna.

However, the results also indicated that certain areas of the district, particularly Paduleh, Qala-e-Fatuh, and Chehelston Bala, remain outside the coverage range (Figure 5). These uncovered zones highlight the limitations of a single antenna installation, emphasizing the need for additional sites or complementary solutions to achieve comprehensive telecommunication coverage.

By integrating Viewshed results with urban street networks and population data, it is possible to identify underserved areas and prioritize them for future antenna placement. This approach demonstrates the importance of combining topographical analysis with spatial planning in order to optimize network performance and ensure equitable access to telecommunication services across all parts of a densely populated and topographically diverse urban area (Chakraborty & Kwan, 2016); (Rashed & Jurgens, 2010).

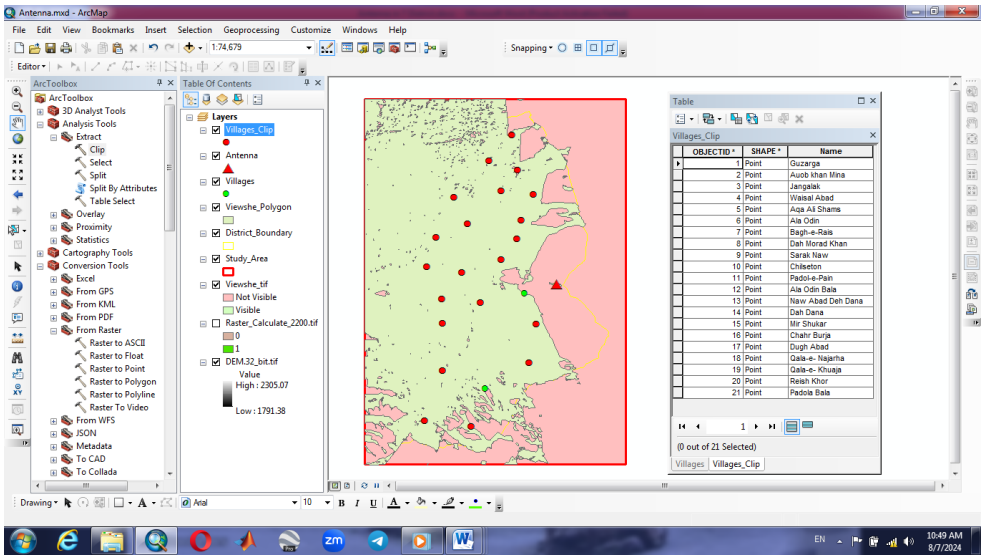

Figure 5: Viewshed analysis and coverage area of the antenna at the initial base elevation
Source: Sediqi, 2026

In the second phase of analysis, the antenna base height was increased by 100 meters, and the Viewshed analysis was repeated. As a result, the coverage area expanded by approximately 18 square kilometers. Under this scenario, all 23 urban streets within Seventh District fell within the line-of-sight and coverage area of the antenna, indicating a significant improvement in telecommunication coverage distribution (Figure 6).

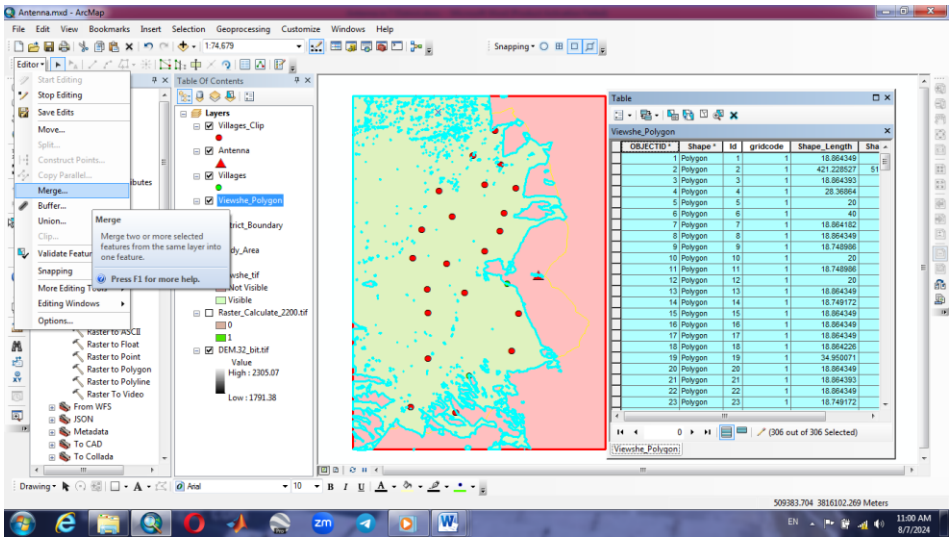

Figure 6: Viewshed analysis after increasing the antenna base height, showing improved telecommunication coverage
Source: Sediqi, 2026

This analysis demonstrates the critical impact of antenna elevation on signal reach and network efficiency, particularly in topographically complex urban environments. By elevating the antenna, previously underserved areas were brought within coverage,

reducing shadow zones and ensuring that a greater portion of the population receives reliable telecommunication services. These results underscore the importance of integrating elevation data, Viewshed modeling, and population distribution analysis in GIS-based telecommunication planning to optimize infrastructure placement and maximize service accessibility (Kaiser, Lawrence, & Peters, 2014); (Rashed & Jurgens, 2010).

A comparison of descriptive data tables for urban streets before and after increasing the antenna height indicated that, with the improved spatial coverage, approximately 378,000 residents of the district gained access to telecommunication services. This finding highlights the direct impact of antenna location and elevation on expanding coverage and enhancing service delivery in densely populated urban areas.

Overall, the results of raster-based spatial analyses and Viewshed modeling demonstrate that installing a telecommunication antenna on the elevated areas of Sultan Mountain—particularly with an increased base height—leads to wider coverage, a reduction in signal shadow zones, and improved telecommunication accessibility across Seventh District of Kabul City. These findings underscore the critical role of topography and elevation in telecommunication planning and illustrate the effectiveness of GIS-based approaches in optimizing network infrastructure in urban environments with complex terrain and high population density (Chakraborty & Kwan, 2016) ; (Kaiser, Lawrence, & Peters, 2014); (Rashed & Jurgens, 2010).

Discussion

The primary objective of this study was to identify optimal locations for telecommunication antennas in Seventh District of Kabul City using Geographic Information Systems (GIS), Digital Elevation Model (DEM), and Viewshed analysis. The findings indicate that selecting antenna locations based on topographical criteria and line-of-sight considerations has a direct and significant impact on improving telecommunication coverage, thereby effectively addressing the main research objective.

The DEM analysis revealed that the elevated areas of Sultan Mountain, due to their relative height advantage and absence of major obstacles, possess the highest potential for antenna installation. This finding aligns with fundamental principles of telecommunication networks, as appropriate antenna elevation plays a crucial role in maximizing the line-of-sight (LOS) and minimizing signal attenuation (Rappaport, 2002). The observed increase in coverage area following the elevation of the antenna base further confirms the direct effect of height on network efficiency and signal reach.

The Viewshed analysis demonstrated that in the initial scenario, some streets and residential areas remained outside the coverage area. However, by increasing the antenna base height, nearly all streets in the district came within the line-of-sight and coverage zone. This result is consistent with the findings of Haitham, Mohammed, and Abdaljabar (2015) in Sulaymaniyah, Iraq, who reported that inadequate antenna height and uneven distribution lead to network shadow zones, while improving elevation significantly enhances coverage.

Furthermore, the results of this study are in agreement with the research by Arba'i et al. (2023) in Indonesia, which highlighted that GIS-based site selection improves spatial decision-making and facilitates more efficient use of existing infrastructure. The key

distinction of the present study lies in its focus on Viewshed analysis and the complex topographical conditions of Kabul City, a factor often underemphasized in previous research.

Compared to studies conducted in well-planned urban areas, the results of this research indicate that in rapidly growing, densely populated, and relatively unplanned cities like Kabul, GIS-based spatial analyses become even more critical. This finding is consistent with the perspective of Lee and Wong (2001), who emphasized that elevation and line-of-sight analyses are powerful tools for supporting spatial decision-making in complex urban environments.

Overall, the discussion of results shows that this study not only achieved its stated objectives but also addressed gaps in local research by focusing specifically on the conditions of Seventh District in Kabul. The findings provide a robust framework for the placement of telecommunication infrastructure in developing urban areas and can serve as a reference for broader studies on optimizing telecommunication network planning in cities with similar topographical and demographic challenges.

Conclusion

This study focused on Seventh District of Kabul City and employed Geographic Information Systems (GIS), Digital Elevation Models (DEM), and Viewshed analysis to develop a scientific framework for the spatial planning of telecommunication antennas in urban environments with complex topography. The results indicate that location-based decision-making, grounded in elevation and line-of-sight analyses, can effectively enhance telecommunication coverage in densely populated and rapidly expanding urban areas.

The findings demonstrate that installing antennas on the elevated areas of Sultan Mountain, particularly with consideration for optimal base height, not only reduces coverage gaps but also ensures a more balanced distribution of telecommunication services across the district. This highlights the importance of integrating natural terrain features with human factors in the planning of telecommunication infrastructure—a consideration often overlooked in practical urban decision-making processes. From a practical perspective, the results of this research can serve as a scientific basis for decision-making by urban planners, regulatory agencies, and telecommunication companies. The GIS-based modeling approach presented in this study allows for the evaluation of different antenna placement scenarios prior to implementation, thereby preventing unnecessary costs associated with suboptimal site selection. This approach is particularly relevant for rapidly growing cities like Kabul, which face unplanned urban expansion and high population growth. From a knowledge development standpoint, this study fills a critical gap in Afghan urban research by integrating Viewshed analysis with elevation data within the urban fabric of Kabul. The study demonstrates that advanced spatial analysis techniques can produce reliable results even in data-limited environments. This framework can serve as a model for similar studies in other urban areas of the country and contributes to the growing body of literature on GIS applications in urban infrastructure planning. For future research, it is recommended to incorporate additional factors such as population density, land-use patterns, signal interference, and service quality indices alongside spatial analyses. Moreover, comparing GIS-based predictions with field measurements and active telecommunication network data could further enhance the

accuracy and generalizability of the results.

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Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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