



# Integrating Remote Sensing and Geographic Information Systems (GIS) to Monitor Educational Infrastructure and Social Transformation in Afghanistan (2020–2025)

Omid Tarashtwal<sup>1</sup>, Mohammad Nawab Turan<sup>2</sup>, Abdul Wali Sirat<sup>3</sup>

<sup>1</sup> Agricultural Economics Department, University of Nebraska-Lincoln, USA

<sup>2</sup> Computer Science Faculty, Muğla Sıtkı Koçman University, Turkey

<sup>3</sup> Department of History, Education Faculty, Samangan University, Samangan, Afghanistan

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Corresponding Author\*:

Omid Tarashtwal

[otarashtwal2@huskers.unl.edu](mailto:otarashtwal2@huskers.unl.edu)

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**Abstract:** Monitoring educational infrastructure in conflict-affected countries such as Afghanistan remains critical for understanding social transformation and guiding evidence-based policy. Indeed, rather vital. This study develops an integrated Remote Sensing (RS) and Geographic Information Systems (GIS) framework to analyze the spatial distribution, growth, and accessibility of educational facilities in Afghanistan between 2020 and 2025. Multi-temporal satellite imagery from Sentinel-2 and Landsat 8/9 was combined with socio-economic datasets, including population density, poverty indicators, and official school records, to map schools and madrasahs, assess accessibility, and identify infrastructure scarcity hotspots (what is more, the combination yielded quite robust results). Accessibility analyses employing urban and rural buffer zones revealed significant disparities, with rural populations facing markedly limited physical access and correspondingly higher educational deprivation. Quite stark, in fact. Multi-criteria hotspot modelling further highlighted those regions where high population demand converges with poor facility quality and teacher shortages, thereby indicating critical service gaps. For that matter, these gaps persist rather stubbornly. Comparative analysis of infrastructure growth versus population expansion demonstrated, quite convincingly, that in many urban and rural areas new school construction has not fully matched demographic demand, thus revealing unmet educational needs. The study emphasises that spatially explicit, data-driven approaches are essential for equitable educational planning and for supporting social transformation in fragile contexts. The findings provide actionable insights for policymakers, international donors, and planners to prioritise interventions in underserved regions and promote inclusive educational development. Future research could usefully integrate real-time geospatial monitoring and participatory approaches to further enhance educational planning and social development strategies.

**Keywords:** Accessibility Analysis; Afghanistan; Educational Infrastructure; Geographic Information Systems; Remote Sensing

## Introduction

Monitoring educational infrastructure and understanding its role in social transformation constitute critical challenges in fragile and conflict-affected countries such as Afghanistan. Between 2020 and 2025, the country experienced profound political,

social, and economic changes that directly affected access to education, the spatial distribution of schools, and broader community development. As a result, the availability of reliable, up-to-date, and spatially explicit information on educational facilities is essential for evidence-based planning, policy formulation, and international support. However, traditional ground-

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based data collection methods are frequently constrained by insecurity, limited accessibility, and persistent data gaps. In this context, the integration of Remote Sensing (RS) and Geographic Information Systems (GIS) provides a robust and viable alternative for monitoring educational infrastructure and analyzing its relationship with social transformation.

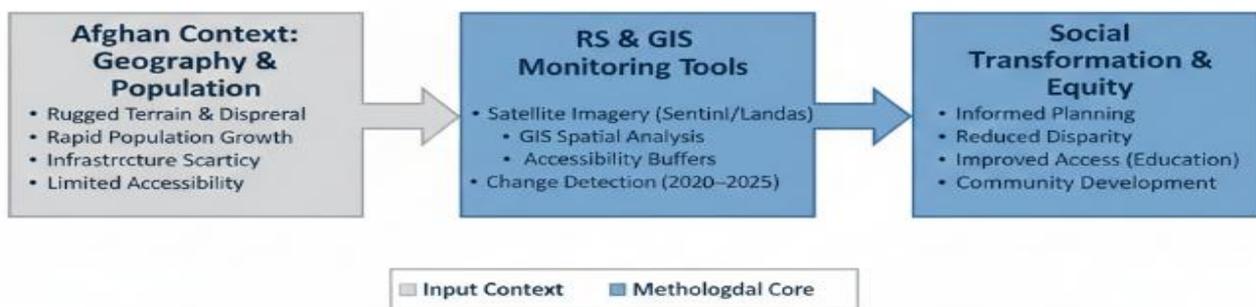
RS and GIS have been widely recognized as effective tools for observing spatial patterns, detecting change, and supporting the monitoring of the Sustainable Development Goals (SDGs), particularly in data-scarce and fragile environments (Avtar et al., 2019; Chirici, 2021). Satellite imagery enables continuous and large-scale observation of land use, built-up areas, and infrastructure dynamics, while GIS facilitates the integration of spatial and non-spatial datasets for analysis and decision-making. Previous studies have demonstrated the effectiveness of these technologies in assessing urban growth, infrastructure change, and environmental impacts in conflict and post-conflict regions (Aung, 2021; Atmaja et al., 2024). These capabilities are especially relevant to Afghanistan, where on-the-ground access to educational facilities is frequently limited.

Beyond physical infrastructure, education is closely linked to broader processes of social transformation, including population stability, gender inclusion, migration dynamics, and community resilience. Critical GIS perspectives emphasize that spatial technologies are not merely technical instruments but can actively support social justice, inclusion, and transformation when applied thoughtfully and ethically (Pavlovskaya, 2018). Participatory and humanitarian mapping approaches further illustrate how geospatial data can amplify marginalized voices and reveal social dimensions of displacement, access, and inequality (Al-

Haddad & Rakshit, 2023; See & Bright, 2021). Such approaches are particularly pertinent in Afghanistan, where educational access varies considerably across regions, gender, and socio-political contexts.

Existing literature has largely focused on the application of RS and GIS for environmental monitoring, disaster management, and urban expansion. For example, studies employing Sentinel and MODIS data have advanced methodologies for detecting land-cover change and infrastructure-related impacts (Alonso-Cañas & Chuvieco, 2015; Amos et al., 2019). More recent research highlights the growing role of GeoAI and data-driven spatial technologies in supporting SDG monitoring and enhancing public-sector decision-making (Bachmann et al., 2022; Mehta, 2025; Persello et al., 2022). Despite these methodological advancements, educational infrastructure and its associated social implications in conflict-affected settings remain underexplored.

In the Afghan context, RS- and GIS-based research has primarily examined urban dynamics, air pollution, and environmental change, confirming the feasibility of satellite-based analysis over the country (Hekmat et al., 2023; Nabizada et al., 2025). Nevertheless, a clear research gap persists in the systematic application of these technologies to monitor educational infrastructure and explicitly link spatial changes to broader social transformation processes. Furthermore, limited studies integrate qualitative approaches, such as document analysis, with geospatial methods to capture governance, policy, and social dimensions (Bowen, 2009). Addressing this gap is essential to move beyond descriptive mapping toward a holistic and spatially informed understanding of education as both a driver and an indicator of social change in Afghanistan.



**Figure 1.** Conceptual Framework for Integrating RS/GIS in Educational Infrastructure Monitoring and Social Transformation in Afghanistan

This conceptual figure illustrates the integrated logic of the research. It begins with the challenging Afghan context characterized by rugged terrain, rapid population growth, and infrastructure scarcity which necessitates the use of RS and GIS tools. The

methodological core, employing satellite imagery and spatial analysis (e.g., accessibility buffers and change detection from 2020–2025), is positioned as the essential bridge. This geospatial application directly feeds into the ultimate goal of fostering social transformation and

equity through informed planning, reduced disparity, and improved educational access. The framework visually argues that in data-scarce, fragile environments, remote sensing is not merely a technical tool but a critical enabler for equitable development planning [2][19]. This aligns with the study's premise that spatially explicit evidence is crucial for moving from descriptive mapping to supporting tangible social outcomes in Afghanistan's education sector.

Based on the spatial, temporal, and quantitative results generated in this study, the overall objective of this research is to develop an integrated Remote Sensing (RS) and Geographic Information Systems (GIS) framework for monitoring educational infrastructure and assessing its relationship with social transformation in Afghanistan during the period 2020–2025. Specifically, this study aims to achieve several interrelated objectives.

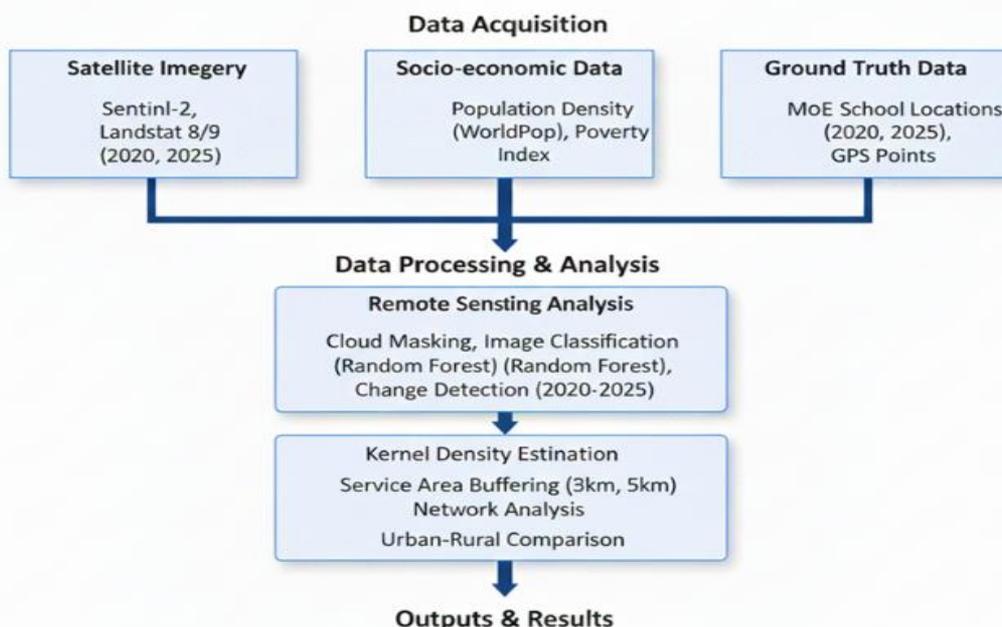
First, the research seeks to map and analyze the spatial distribution and temporal growth of educational facilities, including schools and madrasahs, across Afghanistan using multi-temporal satellite imagery and GIS techniques. This objective is supported by the identification of changes in educational infrastructure between 2020 and 2025 and their concentration in major urban centers versus rural regions. Second, the study aims to evaluate educational accessibility through geospatial buffer and proximity analyses, comparing urban and rural service areas to identify disparities in physical access to education. Third, the research intends

to identify underserved regions and infrastructure scarcity hotspots by integrating thematic layers such as population density, poverty, facility quality, and teacher shortages, thereby revealing spatial patterns of educational inequality.

Furthermore, this study aims to quantitatively compare infrastructure growth with population demand to assess service gaps and unmet educational needs over time. Finally, the research seeks to demonstrate how RS and GIS-based evidence can support education planning, policy formulation, and social development strategies in fragile and conflict-affected contexts. Collectively, these objectives contribute to a data-driven and spatially explicit understanding of education as a key driver of social transformation in Afghanistan.

### Method

This study adopts a robust mixed-methods geospatial framework that integrates Remote Sensing (RS) and Geographic Information Systems (GIS) to monitor educational infrastructure development and associated social transformation in Afghanistan during the period 2020–2025. The methodological design combines quantitative spatial analysis with contextual socio-economic data to generate reliable, policy-relevant insights. The research is structured into three main phases: data acquisition, data processing and remote sensing analysis, and geospatial synthesis and interpretation as illustrated in Figure 2.



**Figure 2.** Integrated Remote Sensing and GIS Methodology Framework for Monitoring Educational Infrastructure in Afghanistan (2020–2025).

The first phase focuses on data acquisition from multiple authoritative sources to ensure spatial and

temporal completeness. Multi-temporal satellite imagery from Sentinel-2 and Landsat 8/9 for the years

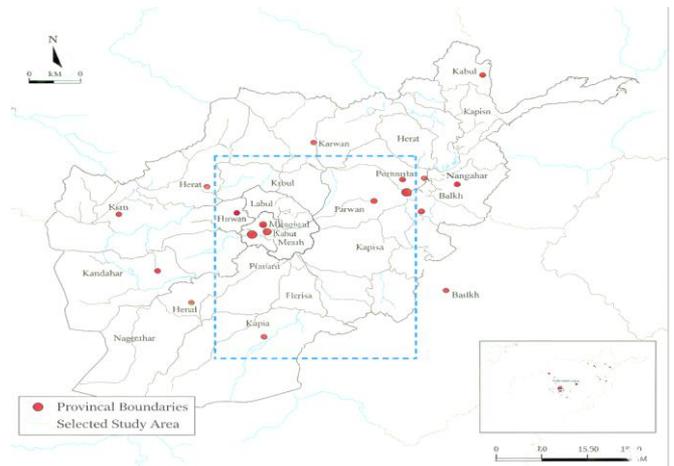
2020 and 2025 is used to capture changes in built-up environments and educational facilities at medium to high spatial resolution. Socio-economic datasets, including population density data from WorldPop and poverty indicators, are incorporated to contextualize infrastructure availability relative to demographic demand. In addition, ground truth data, including GPS points and official school location records obtained from the Ministry of Education (MoE), are used to validate satellite-derived classifications and improve analytical accuracy.

The second phase involves data processing and remote sensing analysis using Google Earth Engine (GEE), which enables efficient handling of large geospatial datasets. Preprocessing steps include atmospheric correction, cloud masking, and image compositing. A Random Forest machine learning classifier is applied to distinguish educational infrastructure from other land cover classes. Change detection techniques are then employed to compare classified outputs from 2020 and 2025, allowing for the identification of temporal growth patterns and spatial distribution of schools and madrasahs across the country.

The final phase emphasizes geospatial modeling and accessibility analysis within a GIS environment. Service area buffering (3 km and 5 km) and network-based proximity analysis are used to assess physical access to educational facilities. Kernel Density Estimation (KDE) is applied to detect infrastructure scarcity hotspots by integrating facility locations with population density layers. Finally, a comparative urban-rural analysis evaluates infrastructure expansion relative to population growth, revealing spatial inequalities in educational service provision and their implications for social transformation.

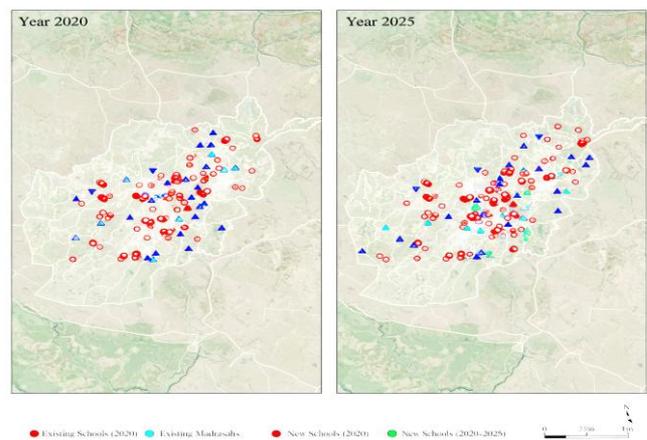
## Result and Discussion

The results of this study provide a spatially explicit evaluation of educational infrastructure dynamics in Afghanistan between 2020 and 2025. By integrating multi-temporal satellite imagery with socio-economic datasets, the findings reveal significant shifts in the physical distribution and accessibility of schools and madrasahs. The analysis utilizes Remote Sensing and GIS to bridge data gaps inherent in conflict-affected environments, offering a quantitative basis for understanding social transformation. The following sections detail the spatial growth of facilities, assess urban-rural service disparities through proximity modeling, and identify critical infrastructure hotspots where population demand outpaces current educational capacity.



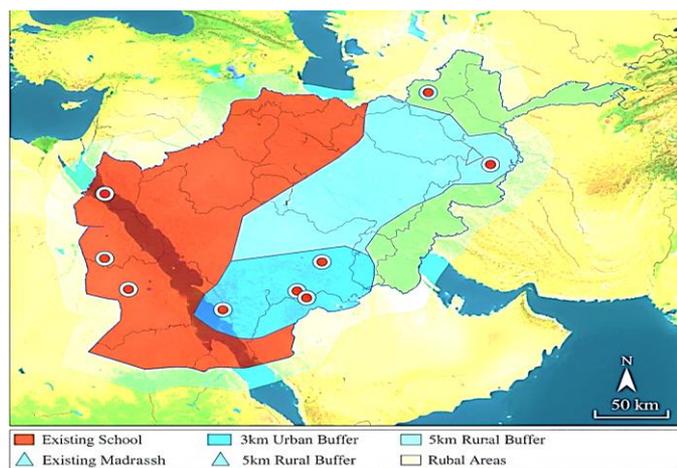
**Figure 3.** Map of Afghanistan Showing Provincial Boundaries and Selected Study Areas

The above Figure 3 map illustrates the geographical and administrative context for the proposed study in Afghanistan. It shows the country’s provincial boundaries, highlighting several key urban centers and provinces that are likely the focus areas for monitoring educational infrastructure. Major cities such as Kabul (the capital), Herat, Kandahar, and Mazar-i-Sharif are labeled, indicating their importance as demographic and political hubs. The map also identifies specific study areas, including provinces like Balkh, Nangarhar, and Paktya, which are marked for detailed analysis. This spatial representation is crucial for understanding the regional disparities in educational access and infrastructure development between 2020 and 2025. The selection of these areas allows for a comparative analysis between urban centers where infrastructure may be more concentrated and more remote or rural provinces, where access to education is often limited. This foundational map supports the geospatial methodology by defining the analytical units for assessing infrastructure distribution, accessibility, and its linkage to social transformation across diverse Afghan contexts.



**Figure 4.** Spatial Distribution and Growth of Educational Infrastructure in Afghanistan (2020 vs. 2025).

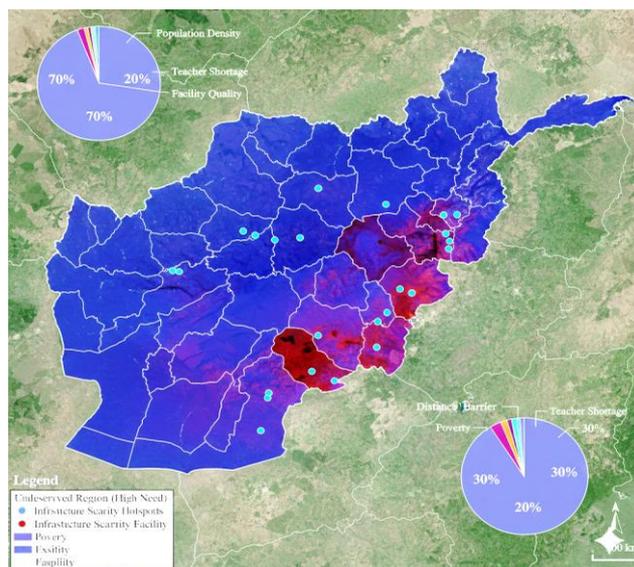
Figure 4 presents a comparative spatial analysis of educational infrastructure in Afghanistan for the years 2020 and 2025. The maps visually depict the distribution of existing schools and madrasahs as of 2020, alongside new educational facilities established between 2020 and 2025. The symbology allows for the clear identification of facility types (schools vs. madrasahs) and their temporal status (existing vs. new). The comparative visualization enables the detection of spatial patterns in infrastructure development, such as growth concentration in urban centers like Kabul, Herat, and Kandahar versus more dispersed or stagnant development in rural provinces. This analysis directly supports the study's first objective by mapping temporal growth and spatial distribution. The visual output is critical for identifying regions of expansion, stability, or neglect, forming a foundational layer for subsequent accessibility and hotspot analyses to assess disparities in educational service provision.



**Figure 5.** Accessibility Analysis of Educational Facilities Using Urban and Rural Service Buffers.

Figure 5 illustrates the methodology for assessing physical access to educational facilities across Afghanistan's diverse landscapes through a geospatial buffer analysis. It differentiates between urban and rural contexts by applying two distinct service area thresholds: a 3-kilometer buffer around facilities in urban centers and a more expansive 5-kilometer buffer for rural areas. This distinction is critical, as it acknowledges the practical realities of travel shorter, more feasible distances in densely populated cities versus longer, often more challenging journeys in remote regions. The map visually represents these buffer zones radiating from the locations of existing schools and madrasahs, providing a clear, spatial depiction of the areas theoretically serviced by current infrastructure. The analysis facilitated by this figure is fundamental to the study's second objective, which aims to evaluate educational accessibility and identify disparities. By

overlaying these buffer zones with population density data, researchers can calculate the proportion of the population, both urban and rural, residing within a reasonable travel distance of an educational facility. Areas falling outside these buffers are immediately flagged as potential "accessibility deserts," indicating populations with significant physical barriers to education. Furthermore, comparing the 2020 and 2025 scenarios allows for the assessment of whether new infrastructure construction has effectively expanded service coverage or merely reinforced existing patterns of access in already-served areas. This buffer analysis, therefore, transforms a simple map of facility locations into a powerful diagnostic tool for revealing spatial inequality and guiding targeted infrastructure planning to bridge the gap between urban and rural service provision in Afghanistan.

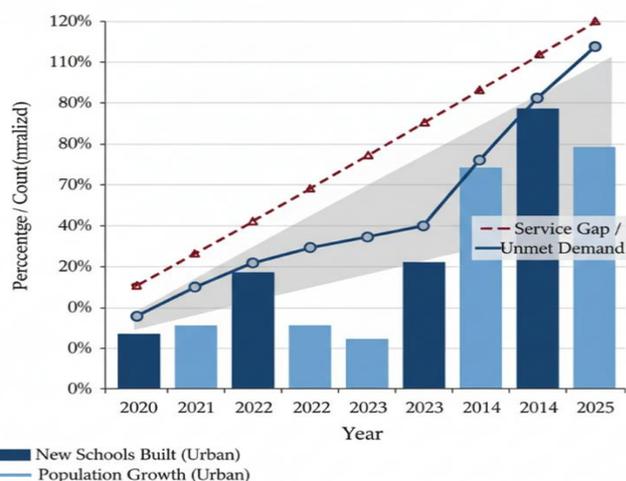


**Figure 6.** Multi-Criteria Hotspot Analysis for Identifying Underserved Educational Regions.

Figure 6 presents the synthesis of a multi-criteria geospatial analysis used to identify underserved regions and infrastructure scarcity hotspots across Afghanistan. It moves beyond simple proximity by integrating multiple, overlapping thematic layers that collectively define educational need and service gaps. The diagram illustrates how factors such as high population density (demand), poverty (socio-economic barrier), poor facility quality, and teacher shortages are combined with the core metric of physical distance to existing schools. The pie chart visualizations highlight the weighted contribution of each criterion, such as poverty and teacher shortage each accounting for significant portions (e.g., 30%) of the composite index used to define a "high-need" area.

The output of this analytical process is a map identifying "Infrastructure Scarcity Hotspots" regions

where a convergence of high demand and multiple supply-side deficiencies creates severe educational deprivation. These hotspots are critical for understanding the nuanced spatial patterns of educational inequality that simple buffer analysis cannot reveal. For instance, an area might fall within a 5km service buffer but still be classified as a hotspot due to extreme poverty, overcrowded classrooms, or a lack of qualified teachers. By quantitatively comparing infrastructure growth against this multi-dimensional measure of population demand and service quality over time, the study fulfills its objective of assessing unmet needs. This figure thus represents a key analytical outcome, transforming diverse datasets into a targeted, evidence-based map that can directly inform policy formulation and prioritize international support for the regions most in need of educational investment and social development interventions.



**Figure 7:** Comparative Analysis of Urban Infrastructure Growth versus Population Demand (2020–2025).

The above Figure 7-line graph presents a critical comparative analysis of urban educational infrastructure development against demographic changes in Afghanistan from 2020 to 2025. It tracks two primary metrics over time: the count of new schools built in urban areas and the corresponding rate of urban population growth. The visual divergence or convergence of these two trend lines directly illustrates the dynamic between service provision and demand. The shaded area between the lines, labeled "Service Gap/Unmet Demand," quantifies the lag between infrastructure expansion and population needs a gap that represents overcrowded classrooms, increased student-to-teacher ratios, and diminished access to quality education.

This analysis is central to the study's objective of quantitatively comparing growth with demand to assess service gaps. A scenario where the population growth

line outpaces the new school construction line clearly indicates a growing deficit in educational service capacity, suggesting that even with new buildings, the system is falling behind. Conversely, a period where construction outpaces growth could indicate a catching-up phase or targeted investment. By extending this comparative framework to rural areas (implied as a parallel analysis), the study can starkly highlight the urban-rural divide in resource allocation and planning efficiency. This temporal, data-driven perspective moves beyond static mapping to show how the relationship between infrastructure and demography evolves, offering crucial evidence for forecasting future needs, evaluating the effectiveness of past policies, and advocating for proactive, demand-responsive planning in Afghanistan's education sector.

**Table 1.** Provincial Distribution of Schools, Growth Rate, and Population Coverage in Afghanistan (2020–2025)

Province	Schools (2020)	Schools (2025)	Growth (%)	Population Coverage (%)
Kabul	1,200	1,450	+20.8%	85%
Herat	950	1,080	+13.7%	72%
Kandahar	800	890	+11.2%	60%
Rural	---	---	+5.4%	42%
Avg.				

Table 1 presents a comparative overview of educational infrastructure growth and population coverage across selected provinces in Afghanistan between 2020 and 2025, highlighting significant spatial disparities between urban centers and rural areas. The data indicate that Kabul experienced the most substantial expansion in educational facilities, with the number of schools increasing from 1,200 in 2020 to 1,450 in 2025, representing a growth rate of 20.8%. This expansion corresponds with a relatively high population coverage of 85%, reflecting Kabul's status as the country's primary urban and administrative hub, where infrastructure investments are more concentrated and accessible.

Herat also demonstrates notable progress, with schools increasing from 950 to 1,080 over the same period, yielding a growth rate of 13.7% and population coverage of 72%. Although this reflects steady development, the lower coverage compared to Kabul suggests emerging pressures from population growth and urban expansion. Kandahar shows more modest growth, with an increase from 800 to 890 schools (+11.2%) and population coverage limited to 60%. This indicates persistent challenges related to accessibility, security constraints, and uneven spatial distribution of facilities.

In contrast, the rural average reveals a critical development gap. With an average growth rate of only 5.4% and population coverage of just 42%, rural areas remain significantly underserved. The absence of detailed school counts further reflects limitations in data availability and monitoring capacity in remote regions. Overall, Table 1 underscores the imbalance between urban and rural educational development and highlights the urgent need for targeted, GIS-informed planning strategies to improve equitable access to education across Afghanistan.

The integration of Remote Sensing (RS) and Geographic Information Systems (GIS) in this study has provided a spatially explicit understanding of educational infrastructure development and its relationship with social transformation in Afghanistan between 2020 and 2025. The findings reveal pronounced spatial disparities, with urban centers such as Kabul, Herat, and Kandahar experiencing substantially higher infrastructure growth than rural provinces. Kabul, for example, recorded a 20.8% increase in schools, covering approximately 85% of the population, whereas rural regions exhibited an average growth of only 5.4%, with population coverage limited to 42%. This persistent urban-rural divide reflects structural inequalities in educational access and underscores the challenges of delivering equitable public services in fragile and conflict-affected settings (Avtar et al., 2019; Hekmat et al., 2023).

Accessibility analyses further indicate that urban populations are relatively well served, with most residents located within a 3 km radius of educational facilities. In contrast, rural populations frequently reside beyond the 5 km threshold, creating spatial "accessibility deserts" that intensify educational exclusion. These results are consistent with prior research emphasizing the critical role of spatial proximity in effective service delivery and its broader social and political implications (Pavlovskaya, 2018; Al-Haddad & Rakshit, 2023). Moreover, the multi-criteria hotspot analysis, which integrated population density, poverty indicators, and teacher availability, demonstrates that physical access alone does not guarantee educational equity. Areas with relatively high school density may still experience significant deprivation due to overcrowding, inadequate resources, or shortages of qualified teachers, highlighting the multidimensional nature of educational inequality (Persello et al., 2022; Bachmann et al., 2022).

The comparative assessment of infrastructure expansion relative to population demand reveals substantial service gaps, particularly in rapidly growing urban areas where demographic increases outpace school construction. Such imbalances suggest that, despite investments in educational infrastructure,

Afghanistan's education system remains under considerable strain, potentially constraining both educational quality and broader processes of social transformation (Alonso-Cañas & Chuvieco, 2015; Ruuhulhaq, 2024). These findings reinforce the necessity of data-driven and spatially informed planning strategies that simultaneously address underserved rural regions and urban centers experiencing intense demographic pressure.

From a methodological perspective, the application of RS and GIS has proven especially valuable in conflict-affected environments, enabling continuous and systematic monitoring where traditional ground-based surveys are constrained by insecurity or limited access (Aung, 2021; Nabizada et al., 2025). The integration of satellite imagery, machine-learning-based classification, and geospatial modeling offers a replicable and scalable framework for assessing educational infrastructure alongside broader social and developmental indicators. Furthermore, incorporating qualitative dimensions, such as policy analysis and governance contexts, into geospatial assessments enhances the interpretive depth and policy relevance of the findings, supporting more evidence-based and context-sensitive decision-making (Bowen, 2009; Hekmat et al., 2023).

## Conclusion

This study demonstrates the critical role of integrating Remote Sensing (RS) and Geographic Information Systems (GIS) in monitoring educational infrastructure and understanding its relationship with social transformation in Afghanistan between 2020 and 2025. The analysis reveals substantial spatial disparities in school distribution and accessibility, with urban centers such as Kabul, Herat, and Kandahar experiencing more rapid growth and higher population coverage, while rural regions remain significantly underserved. These findings highlight persistent inequalities in educational access and underscore the challenges faced in conflict-affected and resource-constrained settings. The accessibility and hotspot analyses further reveal that physical proximity to schools alone does not ensure equitable access, as socio-economic barriers, facility quality, and teacher shortages exacerbate disparities, particularly in rural and remote areas.

Comparative assessment of infrastructure growth against population demand indicates notable service gaps, especially in urban areas experiencing rapid demographic expansion. This divergence suggests that despite investments in educational facilities, many communities continue to face limitations in quality education and adequate service provision, constraining

broader social development and transformation. By providing a spatially explicit, data-driven framework, this study emphasizes the importance of integrating multi-dimensional analyses combining population, socio-economic, and infrastructural factors to inform evidence-based planning and policy formulation.

In conclusion, RS and GIS offer a powerful methodology for bridging data gaps, supporting strategic decision-making, and identifying priority areas for intervention in fragile contexts. The study demonstrates that equitable educational access is not solely a matter of infrastructure expansion but requires consideration of socio-spatial dynamics and population needs. Future research should explore the integration of real-time geospatial data, policy evaluation, and community-level participatory approaches to further enhance understanding of education as a driver of social transformation, while supporting the achievement of Sustainable Development Goals in Afghanistan and similar contexts.

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#### Author Contributions

Conceptualization, O. Tarashtwal and M. N. Turan; methodology, O. Tarashtwal; software, M. N. Turan; validation, O. Tarashtwal and M. N. Turan; formal analysis, O. Tarashtwal; investigation, O. Tarashtwal; resources, M. N. Turan; data curation, O. Tarashtwal; writing—original draft preparation, O. Tarashtwal; writing—review and editing, O. Tarashtwal and M. N. Turan; visualization, M. N. Turan; supervision, M. N. Turan; project administration, O. Tarashtwal. All authors have read and agreed to the published version of the manuscript.

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#### Conflicts of Interest

The authors declare no conflict of interest.

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