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Article

Application of GIS Technologies in Archaeological Research

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Abstract: Geographic Information Systems (GIS) have become an important methodological tool in contemporary archaeological research because they enable researchers to integrate, visualize, analyze, and interpret archaeological data in their spatial context. This article examines the application of GIS technologies in archaeological research, with particular attention to spatial analysis, archaeological mapping, remote sensing, digital elevation models, landscape reconstruction, and cultural heritage monitoring. The study is based on a review of scholarly literature on archaeological GIS and an analysis of practical archaeological research conducted in Uzbekistan, particularly within the Uzbek-Italian Archaeological Project (UIAP) in the Samarkand region. The research applies descriptive, comparative, cartographic, and spatial-analytical approaches to identify the principal applications and methodological advantages of GIS in archaeology.

Keywords: GIS, archaeology, spatial analysis, archaeological landscape, remote sensing, QGIS, QField, Samarkand, Zarafshan Valley, cultural heritage.

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1. Introduction

The spatial dimension of archaeological research is fundamental to understanding past human societies. The location of an archaeological site, its relationship with water resources, agricultural areas, transportation routes, topography, and neighboring settlements can provide important evidence concerning settlement organization, economic activities, mobility, and human–environment interactions. Consequently, contemporary archaeology increasingly considers archaeological sites not as isolated objects but as components of broader cultural landscapes. Geographic Information Systems (GIS) provide an effective methodological framework for examining these spatial relationships [1]. The application of GIS in archaeology initially focused primarily on digital mapping and the management of archaeological records. However, its role has progressively expanded to include spatial statistics, visibility analysis, least-cost path analysis, predictive modelling, landscape reconstruction, and the integration of remote sensing data. A systematic review of GIS applications in archaeology analyzed 671 publications indexed in Scopus and demonstrated that visualization, information management, and spatial analysis represent major areas of GIS application in archaeological research [2]. One of the principal advantages of GIS is its ability to integrate heterogeneous sources of information into a single spatial framework. Geographic coordinates of archaeological sites, topographic maps, digital elevation models (DEMs), satellite imagery, historical maps, hydrological data, field-survey records, and excavation results can be incorporated into a common geodatabase. This integration makes it possible to examine archaeological phenomena at multiple spatial scales [3].

GIS has particular relevance for archaeological landscape studies. Instead of focusing exclusively on individual monuments or excavation sites, researchers can examine the relationship between settlements, natural resources, communication routes, agricultural systems, and environmental conditions. Such an approach allows archaeologists to investigate how human communities interacted with and transformed their surrounding landscapes [4, 5]. The application of GIS in Uzbekistan has also expanded, particularly through archaeological research conducted in the Samarkand region. The Uzbek-Italian Archaeological Project (UIAP), initiated in 2001, has investigated Samarkand and its surrounding territory through archaeological surveys, geoarchaeological studies, remote sensing, cartography, and GIS-based modelling. The project has examined settlement patterns, landscape transformation, irrigation systems, and human–environment interactions across different historical periods [5, 6].

A particularly relevant example is the archaeological survey conducted in the Karatyube Piedmont south-west of Samarkand. During the 2019 and 2021 field seasons, researchers used QField for QGIS as a mobile data-collection tool. Approximately 150 previously unidentified archaeological features were recorded, many of which were low stone burial mounds or *kurgans* [7]. This case demonstrates how mobile GIS can improve the efficiency and consistency of archaeological field documentation.

2. Materials and Methods

The study is based primarily on published scholarly literature concerning GIS, archaeological spatial analysis, remote sensing, landscape archaeology, and digital archaeological documentation. Particular attention was given to studies examining the methodological development of GIS in archaeology and its application to archaeological survey and landscape reconstruction.

For the Uzbekistan case study, publications and research outputs associated with the Uzbek-Italian Archaeological Project were examined. The project has conducted archaeological and geoarchaeological investigations in Samarkand and the surrounding Middle Zarafshan Valley since 2001.

A specific case study was selected from the systematic archaeological survey conducted in the Karatyube Piedmont. The study area is located south-west of Samarkand, between the villages of Egrikul and Mirankul, at approximately 750–1000 m above sea level. During the 2019 and 2021 field seasons, researchers employed QField for QGIS to collect and manage spatial information during archaeological fieldwork. Approximately 150 previously unidentified archaeological features were recorded.

Several complementary methods were used in the study.

A literature review was employed to identify the principal theoretical approaches to GIS-based archaeological research.

Comparative analysis was used to examine different applications of GIS, including archaeological mapping, spatial analysis, remote sensing, and landscape modelling.

Cartographic analysis was used to examine the role of digital maps and geospatial databases in archaeological documentation.

Spatial analysis was considered in relation to the distribution of archaeological sites and their relationships with environmental and geographical variables.

Remote sensing analysis was examined as a complementary approach for identifying archaeological features and reconstructing historical landscapes.

Digital Elevation Model (DEM) analysis can be used to examine elevation, slope, aspect, and terrain characteristics that may have influenced past settlement and mobility.

Least-cost path analysis can be applied to model possible routes between archaeological sites by considering terrain and other environmental variables.

Viewshed analysis can be used to determine areas that are visually accessible from a particular archaeological location. This approach is particularly relevant to the study of fortified settlements, watchtowers, monuments, and sites where visibility may have had social or defensive significance.

The study does not claim to establish a new experimental GIS dataset. Instead, it synthesizes existing archaeological research and evaluates documented GIS applications, with particular emphasis on the Uzbekistan case study.

3. Results

The analysis demonstrates that GIS performs three major functions in archaeological research: data management, visualization, and spatial analysis [8]. Archaeological information such as geographical coordinates, site type, chronology, artifact distribution, preservation condition, and excavation records can be stored within a geospatial database. Each archaeological object can be represented as a point, line, or polygon and linked to descriptive attributes.

This approach provides several advantages. First, it allows researchers to manage large numbers of archaeological sites systematically. Second, it facilitates the comparison of archaeological sites from different chronological periods. Third, it enables spatial relationships between archaeological and environmental variables to be examined.

For example, archaeological settlements can be mapped together with rivers, irrigation canals, elevation, modern settlements, roads, and agricultural land. Such integration makes it possible to investigate whether particular settlement patterns were associated with water availability, terrain, agricultural potential, or transportation routes. GIS therefore transforms archaeological records from isolated descriptive information into spatially interconnected datasets.

Remote sensing represents an important complementary technology in GIS-based archaeological research. Satellite imagery, aerial photographs, drone imagery, LiDAR data, and other remotely sensed datasets can be integrated into GIS platforms to investigate archaeological landscapes [9].

Satellite imagery can be particularly useful for surveying large territories where systematic ground survey would be time-consuming or difficult. Archaeological features may sometimes be recognized through differences in vegetation, soil characteristics, surface morphology, or geometric patterns. Remote sensing can also support archaeological heritage monitoring. Repeated imagery from different dates can be compared to identify changes caused by urban development, agricultural expansion, erosion, infrastructure construction, or other processes.

However, remote sensing data should not be interpreted without verification. A visible anomaly in satellite imagery does not necessarily represent an archaeological feature. Agricultural activity, geological formations, erosion, and modern construction can generate similar patterns. Consequently, field verification remains an essential component of archaeological remote sensing [10]. The Uzbek-Italian Archaeological Project provides an important example of GIS-based archaeological research in Uzbekistan. Since 2001, the project has investigated Samarkand and its surrounding territory through archaeological survey, geoarchaeology, remote sensing, cartographic analysis, and GIS modelling. The research has focused on settlement distribution, landscape transformation, irrigation systems, and human–environment relationships [11], [12]. One of the project's objectives has been to develop a spatial archaeological database for the Middle Zarafshan Valley. Such a database enables archaeological sites, historical maps, archaeological inventories, satellite imagery, and textual information to be linked within a common geographical framework [13].

The application of GIS is particularly significant because the Samarkand region has experienced substantial environmental and anthropogenic transformation. Historical irrigation systems, agricultural development, urban expansion, and modern infrastructure have altered parts of the archaeological landscape. GIS allows researchers to compare archaeological evidence with modern spatial data and investigate these transformations.

The Karatyube Piedmont Case Study

The Karatyube Piedmont survey represents a particularly important practical example of mobile GIS application in Uzbek archaeology.

During the 2019 and 2021 field seasons, systematic archaeological surveys were conducted in the Karatyube Piedmont area south-west of Samarkand. The research employed QField for QGIS, allowing field researchers to record archaeological features and associated spatial information directly in a digital environment [13].

The importance of this result extends beyond the number of recorded archaeological features. Traditional field documentation may involve paper forms, separate GPS measurements, photographs, and later office-based data entry. A mobile GIS workflow can integrate these activities more directly by linking geographical coordinates, descriptions, photographs, and other attributes during fieldwork. Consequently, mobile GIS reduces the separation between field data collection and subsequent GIS analysis. The resulting dataset can be incorporated into a broader archaeological geodatabase and used for subsequent spatial analysis.

GIS makes it possible to investigate the spatial organization of archaeological landscapes. One important technique is **least-cost path analysis**. This method estimates possible movement routes between two or more locations by assigning different movement costs to landscape characteristics such as slope or terrain. In archaeological research, the method can be used to investigate possible routes connecting settlements, burial sites, water sources, mountain passes, and other archaeological locations. The resulting paths should not be interpreted as definitive historical roads; rather, they represent spatial models based on specified assumptions. Another important method is **viewshed analysis**. This technique determines which parts of the surrounding landscape are visible from a particular location. It can be applied to investigate the spatial organization of fortified settlements, hilltop sites, watchtowers, and monuments [14]. For example, if a fortified site has extensive visibility over surrounding valleys and routes, researchers may investigate whether its location was associated with surveillance or communication functions. Such interpretations require archaeological and historical evidence in addition to GIS modelling [15].

4. Discussion

The results demonstrate that GIS has moved beyond its traditional role as a digital cartographic tool and has become an analytical framework for archaeological research. One of its major advantages is the ability to integrate archaeological, environmental, historical, and modern geographical information. This is particularly important for landscape archaeology because archaeological sites are influenced by their geographical context. The systematic review of GIS applications in archaeology indicates that visualization and information management remain major areas of application, while spatial analysis provides additional opportunities for investigating archaeological patterns. GIS therefore provides both descriptive and analytical capabilities.

The Samarkand case demonstrates the particular value of this approach in Uzbekistan. The integration of archaeological survey, GIS, remote sensing, and cartography enables researchers to investigate archaeological sites within the wider context of the Middle Zarafshan landscape. The Karatyube Piedmont survey provides further evidence of the practical value of mobile GIS. The recording of approximately 150 previously unidentified archaeological features demonstrates that digital field documentation can contribute substantially to archaeological site inventories. Nevertheless, GIS-based archaeological research has methodological limitations. The accuracy of spatial analysis depends on the quality, scale, resolution, and completeness of the input data. Errors in coordinates or inappropriate spatial assumptions can influence the final interpretation. Similarly, predictive models and least-cost analyses are dependent on the variables and weighting schemes selected by researchers. A computer-generated route represents a model based on predefined assumptions rather than direct evidence of historical movement.

Remote sensing also requires caution. Not every spatial anomaly corresponds to archaeological remains. Ground verification remains essential for confirming interpretations derived from satellite or aerial data. Another important issue concerns archaeological heritage protection. GIS databases can assist authorities and researchers in monitoring archaeological sites and identifying areas exposed to urbanization, agriculture, infrastructure development, and erosion. At the same time, detailed coordinates of vulnerable archaeological sites should not necessarily be made publicly available because unrestricted spatial information could increase risks to archaeological heritage. Thus, GIS should be regarded as a methodological framework that complements, rather than replaces, traditional archaeological fieldwork, excavation, historical research, and laboratory analysis.

5. Conclusion

The study demonstrates that Geographic Information Systems have become an important methodological component of contemporary archaeological research. GIS enables researchers to integrate archaeological records with topographic, environmental, historical, and remote sensing data within a unified spatial framework. Overall, the integration of GIS, remote sensing, mobile field applications, archaeological survey, and digital databases provides a powerful framework for studying archaeological landscapes. For Uzbekistan, the further development of standardized archaeological geodatabases and the integration of GIS with satellite imagery, UAV/drone surveys, digital elevation models, and systematic fieldwork could provide valuable opportunities for documenting and preserving the country's archaeological heritage.

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