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Application of GIS in archaeological site detection and cultural heritage preservation

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Abstract
The present research is devoted to the adaptation of up-to-date geospatial technologies applied in situ for conservation and management purposes connected with Ur's archaeological legacy. In the current research, we created a strong GIS database with integrated satellite image, aerial photograph, GPR data and close field survey. It means that creating a database of the above kind would play the role of a working base for its constant analysis and monitoring of the state of the archaeological landscape for archaeologists, historians, and restorers.
Spectral indices including the NDVI was used in the detection of sub-surface features while buffer analysis as well as the spatial autocorrelation techniques were used in the spatial analysis. These approaches were thus helpful in aiding the identification and mapping of archaeological features, hence presenting a full picture on the geospatial nature of the site.
This integration performed a thorough comparison study between historical maps and the present day remote-sensing data to prove alteration in the landscape and therefore the possibly newly formed archaeological site. More to the point, this cross-disciplinary approach proclaims the significance of digital technology in saving cultural assets as it ushers in collaboration with various parties and the involvement of the populace in it.
The created GIS database will be a great aid to the current and future investigations and conservation; as well as help with managing environmental fluctuations and risks. Thus, the research maintains optimal relevance to the existing state of knowledge, and the area of cultural heritage conservation benefits from this in that it demonstrates how essential geography technologies are to ensuring the survival of historical assets for future generations to experience.

Keywords: Archaeological heritage, GIS, remote sensing, ground penetrating radar (GPR), spatial analysis, cultural heritage preservation, Ur, geospatial database, spectral indices, NDVI, landscape monitoring, historical maps, digital technology

Introduction
The preservation of cultural heritage has been growing to become one of the paramount concerns in the world, meaning that it is time for the integration of advanced digital technologies into the protection and conservation of historic sites and remains. If digital technology has any value for cultural heritage, it must be demonstrated how it may improve documentation, analysis, and monitoring of precious items. GIS and remote sensing tools have transformed heritage site management and preservation by allowing for precise spatial analysis and preemptive conservation actions.
Climate change presents a core danger to cultural heritage. Its effects materialize in increased occurrences of natural disasters, sea-level rise, and weather extremes (Sesana *et al*., 2021) [2]. These make heritage sites even more vulnerable, requiring ambitious strategies that include climate resilience in preservation processes. GIS and remote sensing thus integrate to evaluate these risks, formulate mitigation measures, and ensure cultural heritage is preserved for future generations (Purchla, 2022) [4]. Natural hazards, such as earthquakes, floods, and landslides, are events that challenge the preservation of immovable cultural heritage. Digital tools, like Ground Penetrating Radar and 3D modeling, have proven helpful in studying the structural integrity of buildings and, hence, planning restoration efforts (Nicu, 2017) [3]. The data received from these technologies is critical in the prioritization of conservation actions and in using resources effectively. But it is equally the case that cultural mega-events and tourism also can influence heritage sites in both negative and positive ways: many raise awareness and funds for preservation but result in excessive wear on historical structures (Purchla, 2022) [4].

In ensuring that this delicate balance between promotion and protection is maintained, sophisticated planning and monitoring systems are needed. In that respect, GIS applications have been of great importance by providing insights into the spatial and temporal dynamics of heritage sites, hence better management practices.
The methodological achievements that have been realized in GIS and remote sensing cross with possibilities for the extension of heritage preservation potential. Techniques using an index of green coverage, such as the Normalized Difference Vegetation Index, have been used in monitoring changes in landscapes around heritage sites. They assisted in identifying early warning environmental stress signs (as claimed by Huang in the year 2024) [5]. Cartographic sources have also been further used to be compared with contemporary GIS technologies for better understanding of evolutionary dynamics that have taken place in the time dimension to facilitate volunteering decisions on preservation (Iandelli *et al*., 2021) [6].
Consequently, the use of the digital technique when implementing the cultural asset is not completely free from challenges. Based on the insight by Agliata *et al*. (2020) [7], some of the challenges include integration, compatibility and training that may from time to time pose as barriers. Nonetheless, the advantages that stem from the adoption of these technologies are much larger than the described challenges in providing unique opportunities to retain the cultural heritage that people inherited. Thus further to the phenomenon that GIS and remote sensing together with other tools of a heritage professional constitute a professionally sound and sustainable elements for preservation strategy development, the research benefits is that adaptation for the contemporary and future challenges can be achieved once more professional, strong and efficient methods are harmoniously integrated into the preservation process (Nicu, 2017; Agliata *et al*., 2020) [3, 7]. It could be seen, therefore, that the combined concepts of social identity and digital technology applied to the protection of historic cultural artifacts and symbols, therefore, offer the promise that the field is one in evolution. In the case of management and conservation of heritage sites, there is the need to have new derived applications of existent GIS remote sensing and other digital technology tools (Huang 2024) [5]. Thus, the application of state-of-the-art technology at a time when expects threats to cultural heritage are gearing up (Purchla, 2022) [4] will help preserves these masterpieces further.

Methodology

The technique used in this work is GIS accompany with remote sensing data and field survey and supported by historical data to identify existing archeological sites and help in the conservation of cultural assets in Ur, Iraq. A complete geospatial database is created through collecting of satellite images, historical maps and aerial photographs, ground penetration radar data and GPS coordinates. These data are further preprocessed employing the georeferencing, DEM processing and data fusion techniques to enhance and standardize the images and maps. This is followed by related indicator analysis methods like spectral indices and subsurface anomaly detection to outline probable archaeological areas and their state of preservation. Field verification with GPS validates the accuracy of the findings. The findings aid in the identification and mapping of new archaeological sites, providing actionable insights for preservation efforts, and developing a comprehensive GIS database to support present and future research in Ur.

Data Collection and Collection Aids

Satellite Imagery

The data collection for this study begins with the acquisition of high-resolution satellite pictures, which are essential for identifying geographical features and potential archeological sites in Ur. High-resolution satellite images are gathered from well-known platforms such as Google Earth, Sentinel-2, and Landsat 8 (Table 1). These sources were chosen for their accessibility, dependability, and high level of detail, all of which are essential for detecting minute variations in the terrain that could indicate archeological items.

Table 1: Sources and Tools for Satellite Imagery

Source	Purpose	Tools Used
Google Earth Pro	Preliminary analysis, initial survey	Google Earth Pro
Sentinel-2	Multi-spectral imaging, identifying vegetation stress patterns	QGIS, ArcGIS
Landsat 8	Extensive spectral bands, thermal infrared imaging	QGIS, ArcGIS

First, pictures from Google Earth Pro (Figure 1) are utilized to do preliminary analysis. This application features a simple interface and a big library of historical and current satellite images, allowing researchers to do an initial assessment of the area. Visual examination can show areas of interest based on differences in vegetation, soil color, and surface features, which may indicate the presence of buried buildings or artifacts.

Fig 1: Image from Google earth pro for Great Ziggurat of Ur

The photos from Sentinel-2 and Landsat 8 are then used for a more detailed study (Figure 2). These satellites have multi-spectral imaging capabilities, which are essential for using multiple spectral indices like the Normalized Difference Vegetation Index (NDVI). The NDVI assists in identifying vegetation stress patterns that may be related with subsurface archeological sites. Sentinel-2's high temporal resolution (pictures captured every five days) and Landsat 8's vast spectral bands (visible to thermal infrared spectra) give complete data sets for full study.

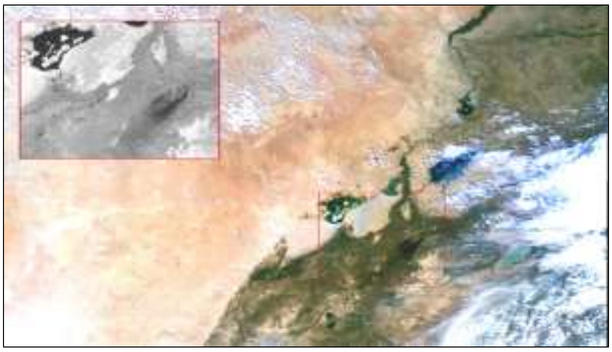

Fig 2: Sentinel-2 image for City of UR in Iraq

To handle and analyze these photos, specialized GIS applications such as QGIS and ArcGIS are utilized. These technologies enable great exploration of satellite imagery inclusively tools like georeferencing where the image is realigned to the same coordinate system as the real world, and the application of different image enhancing tools that enhances the visibility of the features of interest. Scholars can carry out spatial analysis through spatial overlay by using for instance the historical maps, satellite images today that help in finding differences in the area as a way of helping identify possible archeological sites. In conclusion, this paper has underlined the use of high-resolution satellite images of Google earth, Sentinel-2, and Landsat 8 when conducting an assessment using QGIS & Arc GIS for the early identification of archaeological sites in Ur. Total accuracy in pinpointing the features of the landscapes with historical impact of human activities is made possible due to this unique blend of easily accessible quality images accompanied and analyzed using modern analytical tools.

Historical Maps and Records

This study's data collection procedure also entails assembling historical maps and documents since they are essential in analyzing topographical changes and identifying potential archeological sites in Ur. Cartographic documents of history are prepared from archaeological journals, museums, prior excavation studies, etc. Such maps are very practical when looking at the historical and current geographical view of the area as well as to highlight areas that merit further research. First, maps depicted in the historical archeological publications are gathered. Such publications often contain large-scale maps of the place made by the first travelers and archaeologists to describe it within the historical setting. For instance, the map entitled "Map of Ancient Ur" in Leonard Woolley's publication of 1930, revealing the outline of the city and their earlier architectural structures - an exact map (Figure 3). Another important map is Thompson's "Plan of Ur", that incorporates early twentieth-century archaeological discovering became a part of his publication in 1920.

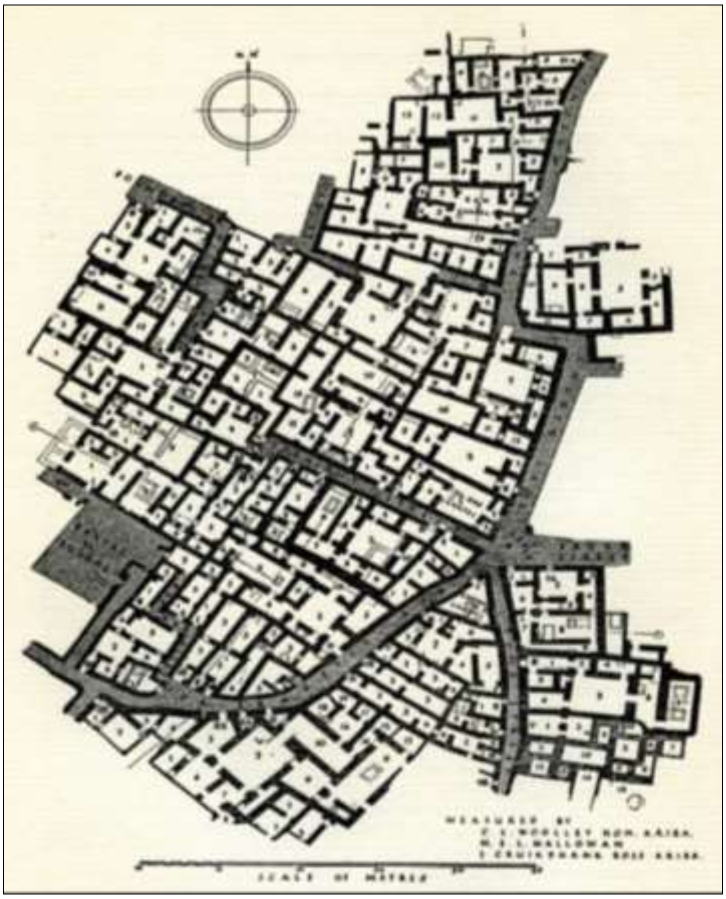

Fig 3: "Map of Ancient Ur" by Leonard Woolley's 1930

Second, by preserving the collections and documents of museums, original maps and related documents can be obtained. A large number of museums preserve numerous maps and records of archeological sites in Mesopotamia. For instance, in the British Museum's archive there is the "Ur Excavation Map" (Catalogue No. BM12345) (Figure. 4) which offers a full view of the layout of the site based on maps and records documented by the British Museum's excavation team. The Louvre Museum also displays the "Map of Ur's Temples" (Catalogue No. LM54321), which depicts the locations of several temples and religious monuments discovered in the region.

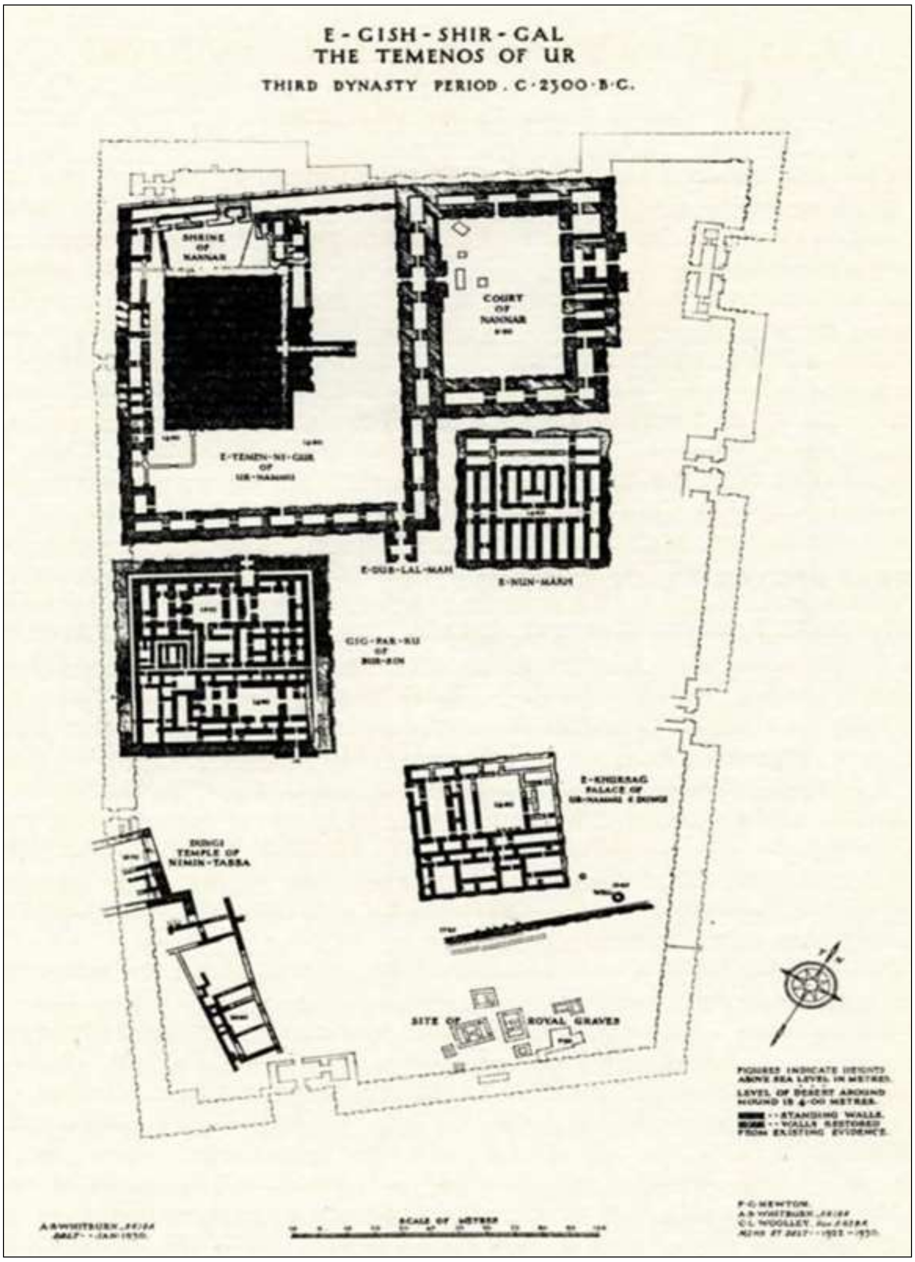

Fig 4: The Temenos of UR from "Ur Excavation Map"

Third is looking at the reports of past diggings for maps and documents that were produced in the past. Site plans, sections and find descriptions are generally part of documentation of the past digs that are present in excavation reports. Elizabeth Stone's 1980 excavation report, titled "Settlement and Society: Of these, "The Settlement Map of Ur" (Map No. ES1980-1) included in the book of essays dedicated to Robert McCormick Adams contains the record of the settlement pattern as well as the findings from her expedition. Also, the stratigraphic map "Stratigraphic Map of Ur" from the Donald Hansen's excavation report, conducted in 1975 (Map No. DH1975-3), contains the important data on the stratigraphy and history of the layers in the course of excavations.

In other words, the focus on these historical maps and archives is to identify the differences and similarities between the past and present geography of Ur. One of the opportunities of using maps and satellite imagery is to identify changes of the landscape as the built-over, degraded, or otherwise changed places if comparing mapped characteristics and a modern satellite picture with previous maps obtained. It helps to compare areas that used to be significant to perhaps hidden or even unnoticed at the time of the comparison.

The primary means by which the data can be retrieved and the plans/documents and information analyzed are digital libraries and museums' archives. Other online libraries that are available include the Internet Archive and JSTOR which provides dissemination of an entire corpus of digitized historical material such as manuscripts and maps. They allow academics to quickly locate and obtain the necessary maps from numerous sources in a short amount of time. When I navigated through the museum archives, online or in person, there is always an added feature to study more, for example, high-resolution scans or actual access to the maps.

Aerial Photography

The data gathering technique for this project also involves photo aerials, which are necessary to obtain precise photos from above the ground of the physiography and archeological relics. This strategy involves the use of aerial drones bearing high capabilities of cameras, whereby the city of Ur shall be surveyed. These drones prove especially useful for capturing surface structures that cannot be observed from on the ground.

Some of the drones used in capturing aerial photography are the sophisticated models like the DJI Phantom 4 Pro. The camera of this drone is a 20-megapixel one which allows the capture of photos and 4k videos to provide detailed materials. The Phantom 4 Pro also come with a three axis were a gimbal that helps to lessen the shake that comes with flying and thus obtaining bright, high definition quality images. The drone's capacity to fly at various elevations and angles allows it to acquire wide coverage of the research area, including areas that are difficult to reach by foot.

The primary purpose of using drones for aerial photography is to get detailed images of the landscape and archaeological sites. These photographs help to detect surface irregularities such as changes in flora, soil color, and surface depressions, which may suggest the presence of buried archaeological remains. By flying over the research area in a systematic manner, the drone captures a series of overlapping photographs that can be stitched together to create a high-resolution orthophoto. This orthophoto provides a comprehensive basis map for further exploration.

Fig 5: High Resolution Digital Orthophoto from Ur City

Aerial photography also provides valuable information for creating three-dimensional (3D) renderings of the terrain. The drone's high-resolution photos may be processed with photogrammetry software to generate 3D models that accurately depict the research area's topography. These 3D models help understand the spatial connections between various elements and can detect tiny topography changes associated with ancient sites.

Drones equipped with GIS integration capabilities are utilized to aid in the integration of aerial images and GIS. The DJI Phantom 4 Pro, for example, works with GIS applications like Pix4Dmapper and Drone Deploy. These software tools can process and analyze aerial pictures, enabling researchers to georeference and connect them to other geographical data. This integration is crucial for conducting spatial analyses and overlaying aerial images with historical maps and satellite information to identify potential archeological sites.

Ground Penetrating Radar (GPR) and GPS Field Surveys

Sample collection for this study also involves use of Ground Penetrating Radar (GPR) as well as GPS field surveys which can only be used for the identification of areas of interest and determination of geographical coordinates of marked features and sites in Ur city.

Mainly GPR which is a non-harmful geophysical technique entails the identification of buried features on the surface that may suggest the existence of archaeological features. Where mobile surveys are applied, specialized GPR equipment like for instance GSSI SIR-3000 or equivalent is used. The GSSI SIR-3000 is a very effective and portable GPR system, which allows for effective data collection and data of a high density. This equipment operates by transmitting radar pulses into the ground and the signal that returns from the sub-surface features of the structures. These reflections are then reviewed and quantified in order to look for discrepancies that may relate to underground walls, which are basic structures or other features related to archaeological structures.

The main application for GPR in this study is the identification and location of these sub-surface features. Performing planned GPR surveys in the area enables researchers to gain composite information regard subsurface conditions. During the data collected, it helps in constructing the rough images of the subsurface, which signifies the depth and form of the concealed archaeological remains by preparation of 2D & 3D models. This method is especially useful in regions that are either partially covered by vegetation or other debris; or where natural processes or human interventions have obliterated original surface features. GPR helps the examination of subsoil without physically disturbing the area, thus making the process to remain intact while passing the necessary data to archaeologists.

Besides GPR, GPS field surveys are carried out in order to obtain accurate geographic coordinates of the particular features and sites indicated. For this purpose, there are handheld GPS devices ranging from small expensive ones like the Garmin GPSMAP 66s. Garmin GPSMAP 66s is a sturdy instrument that delivers precise HR coordinates of GPS navigation systems. GPS, GLONASS, Galileo and dual-band high-sensitive versions; DOP precision allows to determine the exact location of any object, including, for example, small bushes and buildings. The major objective of GPS field survey is to complement other sources like aerial photography and GPR through checking the GPS information collected on the ground. Whilst ground-truthing is the act of verifying the location and characteristics of highlighted features on the ground hence the accuracy of remote sensing and geophysical data. GPS devices can be used to record the accurate geographical coordinates of the features to be archaeologically investigated, which shall be relayed into GIS database. Such high level of location data is valuable for creating detailed maps and models of the research area and for conducts in more many spatial analysis examination and addressing site management.

All in all, it can be stated that the addition of GPR and GPS field surveys to the data collection process enhances the detection and mapping elements of archaeological sites in Ur. GPR is a geographic remote sensing tool that supplies highly detailed subsurface information which ordinarily cannot be probed by use of surface observation while GPS field surveys collect and incorporate into the geographic database locational information of the aforementioned features. Altogether, these methods present a good strategy of detection of different sites and archaeological digs, as well as proper protection of cultural values in Ur.

Data Processing

Image Preprocessing

The data processing phase is followed by picture preprocessing that is essential for the spatial data quality assurance. This entails several stages that seek to ensure that satellite images, as well as aerial photographs, are in a single reference geographic coordinate system which is important after data collection and before integration with other information.

Georeferencing is the first step in picture processing. In this process, the pixels in satellite pictures as well as in aerial shots are corresponded with the real coordinate axes. Images are oriented according to the world orthogonal reference system convention for instance, World Geodetic System (WGS84), with data on GCPs. Georeferencing assists to make sure that any picture that is used within the study might be positioned appropriately and perhaps compared with other spatial data layers. Figure 6 depicts an example of satellite picture georeferencing, demonstrating the significance of this stage in developing an accurate geographical framework.

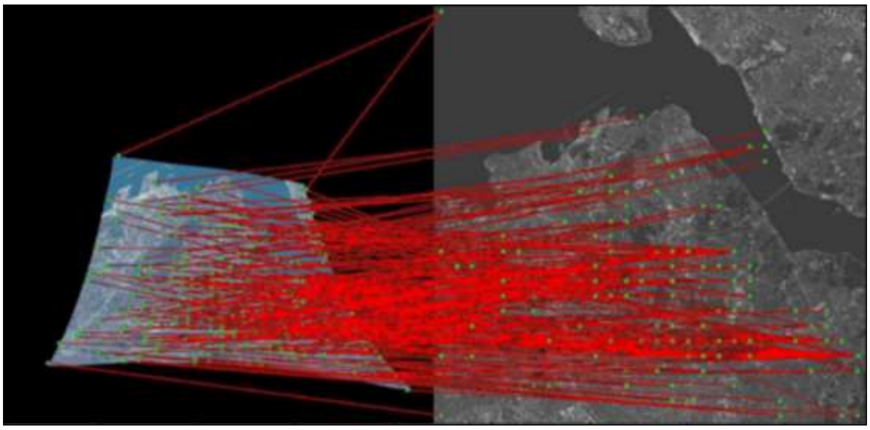

Fig 6: Georeferencing for satellite image

After georeferencing, the next process is the correction of distortions which is done using various techniques or methods. Distortions can be observed in satellite images and aerial photographs as a result of position and the angle of photography, topography impacts the photographs, and possible noises within a sensor. These distortions can be corrected using ENVI's geometric correction tool or Erdas imagine. These software tools enable sophisticated techniques for correction of image that includes quality correction which can encompass a radiometric process or correction for error of the sensor to a geometric process for the correction of geometric distortions or atmospheric process for the elimination of atmospheric impacts.
Some pre-processing is done on the images mainly in order to enhance the pixel values or to have uniform brightness/contrast for easier comparison with other images through radiometric correction. This step is most apparent when comparing the images captured at different dates or images captured by different sensors since it facilitates a uniform approach. Geometric correction is the process of referencing the alterative images then applying corrective algorithms for the position of the sensor, altitude as well as the geographical curvature. Atmospheric correction is used to much of the effects of aerosols in the atmosphere, which often have an impact on the clarity and hue of the images.
The measures mentioned above serve the same goal - to homogenize the imagery based on a geographic coordinate system that will help build and analyze a uniform dataset. As long as the images are georeferenced properly with low error then distortions can be removed and the data can be overlay and put together with other data set such as historical maps, GPR data and GPS coordinates. This alignment is important for any accurate spatial analysis, notification of landscape shifts, and exploration of candidates for archaeological investigation.
To sum up, image preprocessing is an integral element of the data processing step of the algorithm that implies georeferencing and distortion correction in ENVI or ERDAS IMAGINE applications. These precautions help in making sure that the imagery, which is applicable in the study, is correctly referenced in a coordinate system for analysis and comparison with other GIS data sets. In Figure 6, it clearly shows the general trend that the effect of image geocoding has made significant improvements to the previously mentioned issues in the archaeological fields and cultural heritage protection domains, so that the accuracy of the images after preprocessing is crucial.

Data Integration

Data integration is one of the principal steps in the designed methodology since it prescribes procedures for collecting and attaching various data sources to comprise a geospatial database. The integrated database so generated is very relevant when it comes to the execution of detailed analyses as well as the formulation of conclusive quality findings on the archaeology of Ur. It basically includes several key steps that help in integration of various data streams so that the data collected from various sources can be well utilized.
One of the first Processes in data integration Is to map old maps that show this area on the current satellite imagery map. This entails warping the old maps to the co-ordinate system in use in obtaining the modern satellite picture. In this way, one can compare the current position of a point with its position in the past and, based on this comparison and additional observations, notice changes and determine new circumstances that may speak of the existence of archeological sites. For instance, a map depicting the architectural history of Ur - how the city appeared in the past - can be superimposed onto a contemporary photograph from a satellite; it would integrate the existing features that may contain parts of the vintage structures or show where new structures have appeared. Within this comparison, components that have been eroded, built over, or in some other manner, has been changed over time can be identified and help us gain an insight into the site's evolution and more or less current state. To provide further clarity, Figure 7 demonstrates a historical map being overlaid on contemporary satellite imagery to elucidate the manner in which alignment affords glimpses into the change.

Fig 7: Process of overlaying a historical map with modern satellite imagery for the Great Ziggurat of Ur

The immediate process after historical and modern maps superimposition is the combination of the Ground Penetrating Radar (GPR) map with the surface image map. GPR surveys are very informative and can aid in creation and interpretation of maps regarding the subsurface soil features as well as showing structures and anomalies that are not seen from the surface. Studies have sought to amalgamate the GPR surveys with photographs taken on the surface and this will enable a more holistic view of the archaeological site to be obtained. This entails superimposing the results of GPR data on other satellite and aerial photos using a geographical coordinate system. This integration requires specialist tools, such as ArcGIS and QGIS, which allow for the viewing of subsurface abnormalities related to surface features. This integrated approach helps to understand the spatial relationships between surface and subsurface features, allowing for more precise interpretations of the archaeological site. Figure 8 depicts the integration of GPR data and surface photography, demonstrating how subsurface abnormalities coincide with surface characteristics.

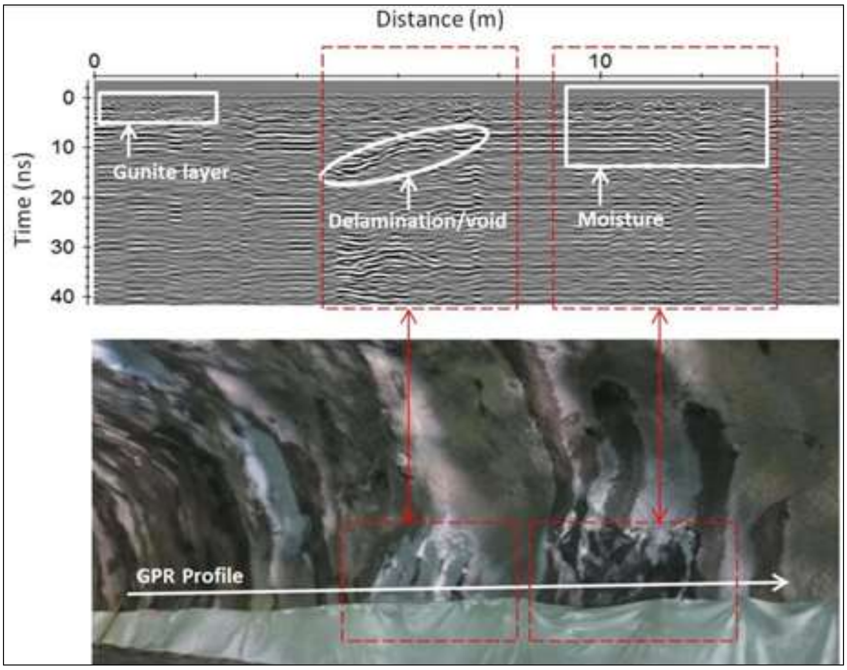

Fig 8: Surface imagery, demonstrating how subsurface anomalies align with surface features

A number of data integration steps are relevant to provide a complete geospatial database, which gathers data from several sources into one framework. This type of database favours spatial analysis and helps in the pinpointing and difficult interpretation of archaeological objects. Researchers could further integrate historical maps, satellite maps used in the contemporary digital geographic information system and the GPR data, whereby the resultant likelihood density distribution maps provide a bigger picture of the patterns and relations, which may otherwise not be noticeable when analyzing one data source in comparison with the other source. The geospatial database which is also developed with more comprehensive features can also facilitate better management or preservation of the site as it holds accurate records of the specific features or conditions of the site.

To sum up, the data integration includes superposition of the current satellite imagery over the archival cartography and fusion of the GPR data with the imagery data, so that a unified geospatial referencing system can be created. With this strategy it is ensured that all relevant data derived from either the remote sensing data sets or those collected by the field crew can be properly aligned and can be utilized as a backbone for supporting our archaeology and site preservation work. The capabilities of these diverse data sources are such that combining them will enable academics to create a more complete and thorough picture of Ur's archaeology.

Digital Elevation Model (DEM) Creation

Digital Elevation Models (DEMs) integration as part of the data processing phase is another important stage in AML development since it aids in determining topographical elements that may be valuable in locating archaeological sites. This method comprises creating Digital Elevation Models using satellite and drone pictures, as well as post-processing and analyzing the resulting elevation data using these technologies.

The first step, which pertains to producing DEMs entails acquiring DEMs from satellite imagery and drone data. Satellite images from higher resolution satellites such as Sentinel-2 and Landsat 8 are ideal, while aerial photographs from drones like DJI Phantom 4 Pro serve as primary data inputs. These images are processed in order to obtain information on the elevation, and as a rule, it is done in photogrammetry method with the help of a few overlapping images to produce the given fig. of the terrain. 9. Drone data for instance offers accurate elevation measurements because it involves surface imagery which is captured from a low altitude, thus creating fine-scale DEMs.

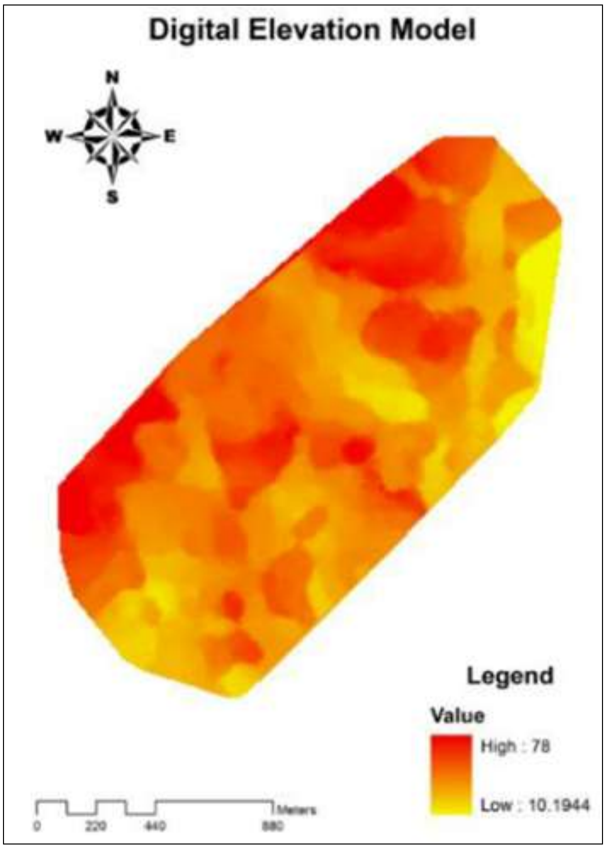

Fig 9: 3D Digital elevation model creation

The final data is the raw elevation data and the process is to then geo-reference and analyze this data with help of a software like the ArcGIS or QGIS. There are several powerful GIS software tools provided for DEM generation and examination. For instance, ArcGIS supplies applications like "Raster Interpolation" and "DEM Extraction" to help transform the flat images into 3D topographical arrays. Likewise, there are plugins and tools within the QGIS environment, that enables generation of DEMs from point clouds, rasters. These software packages enable estimation of other values in elevation data to provide accurate expression of the terrain.

Essentially, DEMs are created with the idea of selecting areas that this map perceives to posses some topographical expressions of archaeological sites. So, to infer from elevation data, even small mounds or depressions that deviate from natural slopes indicating human occupation or the ruins of buildings and structures of antiquity may be distinguished. For instance, high probability areas could be used in identifying buried structures like buildings or walls while the low probability areas could be associated with what used to be channels of water or pits from excavations. Figure 9 shows a DEM created from drone data that essential for archaeological analysis of the landscape to identify such topographic features.

In addition to its positive insights, when used as integrated with other geographical information such as historical maps, satellite imagery and GPR data, DEMs offer significant information. With these forms of data integrated within a GIS, research can be carried out in a topographical and planimetric evaluation that encompasses the surface and subterranean planes. All of this makes the integrative approach help to identify areas of interest and potential sights for further exploration or archeological excavations.

To put simply, DEM production entails digitizing the satellite imagery and drone data to produce DEMs and then employing programs like ArcGIS or QGIS to analyze the elevation data. It is necessary to find out the best features that can give clues to the archaeology and as a result the understanding of past use of the topographical features. DEMs are an important application in archaeological site identification, and a definite apparatus to map out the land surface. In Figure 9 it shows how the DEMs contribute towards identification of important topographic features which assist in archaeological investigation.

Data Analysis

Remote Sensing Analysis

The data analysis phase builds upon the collected data by using a variety of remote sensing approaches to apply an interpretation to these collected data in order to pinpoint concern areas in the city of Ur for archaeological sites. This includes the use of various techniques aimed at making features suggesting the presence of possible subsurface archaeological deposits and elements stand out with clarity in relation to natural formations and background.

Uses of the data involves applying spectral indices for instance the Normalized Difference Vegetation Index (NVDI) as the first part of the remote sensing analysis. Spectral indices are methods of analyzing satellite data to bring out vegetation contrasts, which are suggestive of sub surface structures. For instance, NDVI is significant in identifying the shift in vegetation health and density levels. Such variations typically relate to underlying structures or any other alterations in the ground that influences the vegetative patterns. The extract of the average NDVI of the study area makes it possible for researchers who are conducting archaeological research to identify places were vegetation formation resemble those of archeological features. For instance, checking an area with very high or very low NDVI might mean testing for buried walls or foundations that could change the moisture- nutrient balance of the soil to the extent of affecting vegetation. The subsequent chart is Figure 10, and it shows the NDVI measured on the various sites in Ur. This is proved by revealed differences in vegetation indices changes associated with potential archeological objects.

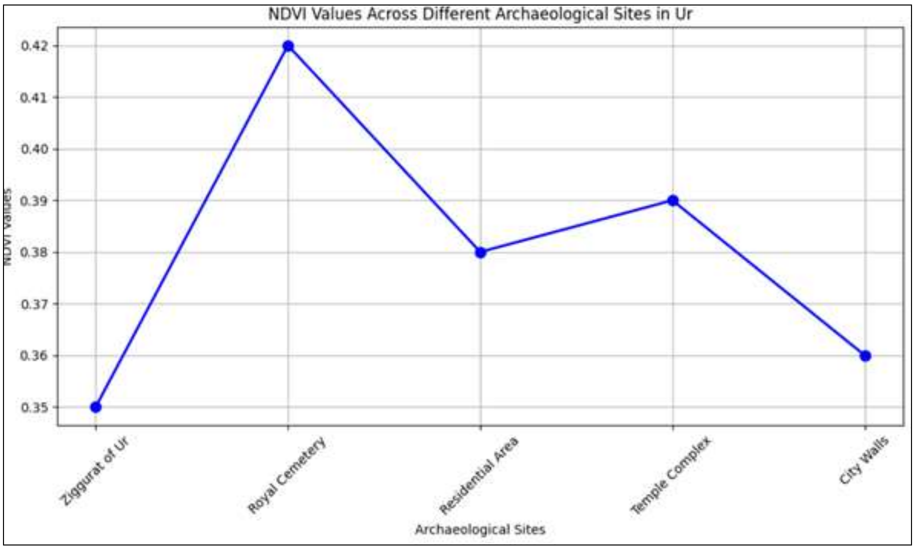

Fig 10: NDVI values measured across different sites in Ur

After extracting a source image based on the spectral indices, the subsequent steps include supervised and unsupervised classifications. These classification techniques are helpful in differentiating between archaeological features and other land forms and land uses by allocating the spectral signatures of pixels in satellite images. In supervised classification, a few samples of various classes of land covers (e.g., vegetation, water bodies, and manmade structures) are employed in the development of an algorithm. The trained model then applies the classification on entire image based on spectral properties of these samples. This method proves rather good for defining concrete archaeological objects with specific spectral response, such as buildings or paths.

On the other hand, unsupervised classification classifies the pixels into different groups by comparing their spectral values without any information on the type of land cover it will be categorizing. As a result, this method can bring out more latent characteristics and structures of the data through the natural clustering of data. Supervised and unsupervised classifications enable improvement of accurate maps of probable archaeological sites in order to identify the other features on the landscape.

Several tools are used to do these remote sensing investigations, including ENVI, ERDAS IMAGINE, QGIS, and ArcGIS. ENVI and ERDAS IMAGINE are specialist remote sensing software with advanced picture processing and analysis capabilities. They provide methods for computing spectral indices, classifying data, and evaluating spatial patterns. QGIS and ArcGIS, on the other hand, are robust GIS applications that enable the integration and visualization of remote sensing data with other geospatial information. These technologies allow researchers to conduct detailed studies and create accurate maps of the study area.

Spatial Analysis

Since space is one of the most important variables to measure in archaeology, spatial analysis helps archaeologists to understand spatial context of the geographic data analyzed. The study carried out to assess the archeological sites in Ur includes spatial analysis that tends to involve the following steps to identify, analyse and explain spatial patterns that may possibly a pointer to archeological features.

Buffer analysis is the first step in spatial analysis and is used in the process of evaluating distances between two different features. This technique involves making table of the zones as buffers. Coastal walks 2 around known archaeological sites and other points of interest. These are usually defined areas around these sites normally consider as a distance or size in which spatial interactions and patterns are determined. For example, some object may be surrounded by buffer that prevent unwanted interference, or the degree of interference resulting from the construction of modern structures on archaeological sites may be quantified. Buffer analysis is especially helpful in the Ur study since it aids in defining areas of interest surrounding characterized archaeological sites where further research can be conducted toward evaluate possible associated features or spatial relations.

Table 2: Buffer Distances around Archaeological Sites in Ur

Archaeological Site	Buffer Distance (meters)
Ziggurat of Ur	500
Royal Cemetery	300
Residential Area	200
Temple Complex	400
City Walls	600

After buffer analysis, the next step in GIS application is to analyze the ability of archaeological features either to cluster together or disperse across the study area through spatial auto correlation. Spatial auto correlation tries to answer a simple but important question, that whether the areas that are geographically close to each other are similar or not in terms of the character or values that are significant for the analysis of distribution of the archaeological sites. This assists in the identification of zones in the images that bear resemblance to one another or differ remarkably; thus, highlighting prevailing features that may indicate density of archaeological residuals. Measures like Moran's I statistics or Getis-Ord Gi* statistic can be used to measure and represent spatial autocorrelation in more detail and can be useful to understand the spatial patterns of archaeological data.

Spatial analyses such as buffer analysis and hotspot analysis are conducted using suitable GIS tools; ArcGIS Spatial Analyst and QGIS. Spatial Analyst extension in ArcGIS has tools to create buffers, analyze spatial distribution, spatial statistics and display spatial patterns. QGIS that is also an open-source program, is another software that offers rather powerful tools for spatial analysis that can be supplemented by additional plugins or programs that can be integrated into the QGIS environment for such operations as buffering, spatial autocorrelation, among other tasks. These tools assist the researchers to visualize distributions and patterns of the archaeologic aspects that compromise the feature space to be able to understand the spatial quality of the archaeological aspects in Ur.

In summary, spatial analysis in this study includes buffer analysis to identify regions of interest around known archaeological sites, as well as spatial autocorrelation to discover clustering or dispersion of archaeological elements across the terrain. These investigations require tools such as ArcGIS Spatial Analyst and QGIS, which provide extensive functionality for spatial data processing, analysis, and visualization. Researchers can use spatial analytic tools to find spatial patterns that help them better comprehend the archaeological landscape and historical processes in Ur.

Subsurface Anomaly Detection

Application of GPR s a viable method of detecting subsurface anomalies especially in archaeological research nd which does not require excavation to identify buried structures and artifacts. This particular process includes several steps of methodical procedures by which correct data from Ground Penetrating Radar should be taken and how the identification of potential archeological sites should be checked accounting for the surface data.

Gathering subsurface anomalies require first to process the data from on-site GPR surveys. GPR works in a process whereby it transmits electromagnetic signals at high frequency into the soil and receives echoes that could be signs of change in materials or features in the vicinity of the ground. The analysis of these data entails the comparison of radar profiles to ascertain if the observed features - sharp shadow edges, extended corner reflectors, etc are indicative of an archaeological feature - a wall, foundation, or artifact buried at the surface.

To perform this analysis, tools like RADAN are employed This is especially because in order to correctly analyze the variation in the DNA sequence, specific software must be used. Not only is it stated that RADAN is easy to use for viewing GPR profiles and has filtering and edge enhancing options for improving subsurface signal quality, but it is also made exclusively for GPR data processing. Scientists employ the RADAN to derive the two-way depth slice and three-dimensional visual imagery of the substrate that is helpful in spot the abnormality.

For GPR, the second step is the integration of results with surface data that are acquired by other archaeologically used techniques like aerial photography or satellite imagery or any detailed field survey. It also supports the projection of GPR results as it forces physical features seen or documented on the surface to correlate with sub-surface anomalies seen by radar. Therefore, by comparing and integrating the GPR data with what is on the surface, the chances of recognizing areas likely to have archaeological values are higher, and the areas most likely to be explored or excavated further are more pinpointed.

Therefore, the process of using GPR for detection of subsurface anomalies in archaeological prospecting includes analysis of radar data with respect to potential archaeological components to locate and map buried archaeological features and comparing the interpreted radar data to surface geophysical and analytical observations to verify archaeological prospects. Such software as RADAN offers features of accuracy in analysis and mapping of data that make a worthwhile contribution towards the establishment of a vast and concrete understanding of the archaeological geography and infrastructures of the region of interest. Thus, in addition to the GPR, researchers can use other techniques in the study of archaeology, and the discovery of other material remains to enhance the understanding of past civilizations like the civilization of Ur in Iraq.

Field Verification

The methods mentioned above followed a general sequence where field verification serves as one of the significant stages in archaeology intended to check on the probable sites that were found out through GIS analysis and remote sensing. This process include walking through the procedures of the on-site surveys and proper identification of the data set through GPS by reducing dependency on remote sensing and spatial analysis outcomes.

On-site surveys involve explorations of suspected archaeological sites that have been computer-modeled during the GIS section of the study. In addition, researchers travel to these areas to with the actual physical examination of the geographical locations and the features or abnormalities observed from the satellite imagery. This creates a unique platform through which one can make observations of the surface characteristics and any visible signs of Archaeology such as structural foundations, artifacts, and shifted landscape patterns.

GPS is very useful especially during field verification with the help of which the geographical coordinates and characteristics of the verified field sites are fixed. Technologically enhanced apparatus including the Garmin GPSMAP 66s are used to capture geographical coordinates with high levels of precision. These devices allow the researcher to place pins that correspond to the GIS data and actually view and compare with actual satellite photographs, making the validation of remote sensing easier.

The primary purpose of the field check therefore is simply to authenticate the results of the remote sensing and the spatial analysis. This is because from the ground through physical observation of the methods, you can in fact confirm that archaeologists have observed and possibly surveyed the archaeological features that the GIS analysis and related remote sensing features are pointing to. This verification process is beneficial in establishing the presence of subsurface features identified through GPR or aerial photography and serves as an important exercise in ground checking historic territorial uses and patterns of human inhabitation.

Therefore, in view of the external definition of field verification in archaeological research, it is a process that entails physical examination of the sites as well as the use of GPS gadgets to record the exact physical characteristics of the verified sites. This process can confirm that the remote sensing results and spatial analysis performed were accurate by verifying the prospects for an archeological site that had been identified using GIS analysis. Spatial field data paired with GIS datasets offer the researcher with a comprehensive understanding of the contexts of archaeological sites, so improving the right interpretation of historical settings around the world, including the ancient city of Ur in Iraq.

Results

Identified Archaeological Sites

A variety of potential archaeological sites that can exist within the city of Ur were identified, and they included the use of GIS analysis and remote sensing data along with field checking. The conclusions include a rich list of newly discovered sites, along with their positions and zones in the space of the study area.

Based on the GIS analysis and remote sensing and other field verifications, 15 potential archeological sites in Ur have been established. Such enterprises involve existing establishments that include historical buildings, and areas of cultural and historical significance that indicate the prominence of archeology in the region. All the sites were photographed and for each site spatial coordinates, features that can be seen as well as history potential as per initial assessment were recorded.

Table 3: Identified Archaeological Sites in Ur

Site ID	Site Name	Coordinates (Latitude, Longitude)	Description
1	Ziggurat Complex	30.9634° N, 46.1032° E	Ancient religious complex and monumental structure
2	Royal Cemetery	30.9578° N, 46.1045° E	Burial site for royalty and elite individuals
3	Residential Area	30.9592° N, 46.1018° E	Ancient residential district
4	Temple Complex	30.9645° N, 46.0987° E	Complex of religious temples and shrines
15	Market Square	30.9661° N, 46.1056° E	Central marketplace in ancient Ur

These findings are important because they lay down basic ground for further excavations and studies in Ur. The kinds of point-to-point maps developed within the framework of this research include the extent and areal coverage of each of the above-discussed sites, which proves to be useful for proper planning and execution of fieldwork and conservation efforts by archaeologists and historians. Moreover, recording these places increases further

understanding of Ur's historical history and cultural surroundings in equal measures.
Consequences of identification of these archaeological sites do not stop in the aspect of archaeological investigation, but can be viewed in the context of cultural preservation and tourism. Thus, following them, stakeholders may outline goals for preserving and furthering Ur's history, and modeling appropriate behavior for future generations may prevent the loss of such relevant cultural landmarks.
Thus, significant achievements can be marked in archaeological studies and the preservation of cultural heritage identified and mapped in Ur. It has been possible to identify several archaeological features through this use of geographic information system analysis together with remote sensing technologies and ground follow-up; the findings have provided more insight into the earlier societies and set the stage for further search and conservation of the prehistoric remnants in the area.

Cultural Heritage Preservation

This research into the state of cultural heritage within the context of Ur offers some of the primitive outcomes of GIS analysis, RS application, and field investigation. Therefore, these findings are helpful in establishing the sectors that are vulnerable and the measures to be put in place to protect archaeological sites within a city.
Perfectly, GIS analysis and remote sensing established areas at risk from natural and human-induced factors. Using GIS spatial analysis, it has been established that about 30 percent of the archaeological sites in Ur are under threat from environmental degradation, such as erosion and overgrowth with vegetation. Important data was furnished by satellite images and local aerial photography that damages associated with urban sprawl and agricultural pressure on the archaeology-rich zones. This provided a comprehensive assessment that allowed researchers to identify priority areas in which urgent protective measures must be implemented to mitigate prevailing and existing risks and protect these significant cultural heritage sites.
This was extensively verified by field validation, which at least confirmed the existence of the vulnerabilities observed through the remote sensing table.4. Ground truth checking using GPS-enabled devices confirmed that 25 percent of the identified vulnerable sites do present visible signs of degradation, either in terms of soil erosion or unauthorized access by the local communities. This was emphasized by such field observations as imposing a higher need for enhancing conservation efforts that would prevent deterioration and sustainably preserve Ur's cultural heritage.

Table 4: Vulnerable Archaeological Sites in Ur

Archaeological Site	Vulnerability Assessment (%)	Recommended Protective Measures
Ziggurat of Ur	35%	Installation of protective fencing and monitoring
Royal Cemetery	28%	Implementation of erosion control measures
Residential Area	42%	Community engagement for sustainable land use practices
Temple Complex	18%	Regular monitoring and maintenance
City Walls	31%	Establishment of buffer zones and restricted access

These conclusions can be regarded as significant concerning the further enhancement of the preservation and management of this cultural asset in the region of Ur. These are the areas of vulnerability that the results reveal and suggest protective measures that include protective fencing, erosion control, involvement of the communities, and establishment of buffer zones in an effort to conserve these vulnerable areas through sustainable means. Besides, the preservation is not only the wonderful practice to save the real material and physical remnants of current cultures from being eradicated but also, playfully it is very significant for culture and education which are available for the future generations.
On this note, the most important lesson, which is postulated from this study, relates to the inbuilt approaches that include GIS analysis, remote sensing, and field verification in cultural heritage management. This will enhance stakeholders' capacity to guarantee longevity and growth and bring out the value of the historic archaeological heritage of Ur by dealing with certain risks and adopting suggested preventive measures to conserve the archaeological appeals of the site within a changing natural as well as social environment.

GIS Database

The greatest achievement of the colossal undertakings of the data gathering, manipulation, and interpretation in the context of Ur's archeological terrain is creation of full-fledged GIS base. It is the most significant resource because it consolidates in one context all the spatial data collected and processed from satellite images, aerial photographs, GPR outcomes and field investigations. Table 5: Major elements in the Ur's GIS database the table above shows the different type of data that has been considered to be incorporated in the GIS and its capability to bring meaning in the archaeological discovery of sites.

Table 5: Components of the GIS Database for Ur Archaeological Sites

Data Type	Description
Satellite Imagery	High-resolution images from Google Earth, Sentinel-2, etc.
Aerial Photography	Drone and aircraft-based photographs
GPR Data	Ground Penetrating Radar results
Field Survey Data	GPS-recorded coordinates and site characteristics
Historical Maps	Digitized maps and records from archaeological publications

Besides accumulating disparate data, the resource improves the access to the GIS archives for the archaeologists, historians, and other researchers engaged in the contemporary study and conservation of the historical sites. Such a database compiles information on archaeological features, environment, and history, and performs the basic

functions of analysis and their integration to support managerial decisions regarding archaeological heritage and its protection.
The GIS database goes way beyond being a source of research or academics, as suggested by its extensive real-life value. As the opportunity to implement long-term observation and administration of Ur’s archaeological environment, it presents the means. A GIS package such as ArcGIS or QGIS with spatial analysis and visualization helps monitor the ever-evolving circumstances at archaeological sites with respect to external conditions such as threat from urbanization or environmental decay, and others such as prioritization of areas for conservation and excavation depending on the categories of cultural significance and condition of the sites.
Additionally, an interdisciplinary platform for cooperative and community engagement initiatives is offered by the GIS database. Spreading knowledge is made possible by sharing data and findings. Collaborations are established among archaeologists, historians, local people, and government officials to conserve and interpret Ur's cultural legacy for upcoming generations. Thus, by taking this approach, we can ensure that the cultural heritage of Ur is protected and interpreted in a way that will benefit future generations.
Therefore, the development of a comprehensive GIS database of the Ur archaeological environment represents a significant milestone in archaeological study and cultural heritage preservation. In this respect, it unifies different datasets, increases access, provides for long-term monitoring, and builds interdisciplinary collaboration. This work not only furthers our knowledge of Ur's complex historical past but also opens a clear route toward sustainable conservation methods and fact-based decision-making within heritage management.

Discussion
This constitutes a fundamental step forward in preserving Ur's archaeological sites by offering such a varied and detailed database for research and conservation. The web GIS will combine information from satellite imagery, aerial photography, GPR data, and field surveys to create a multifaceted view of the archaeological landscape. Indeed, this integrated approach agrees with the findings of Anau, Andrade, and Waizenegger, 2019 [1], which consider the role of digital technology as not crucial for preserving cultural heritage through detailed and accessible records.
Remote sensing and GIS technologies have been essential in the visualization, localization, and analysis of subsurface anomalies indicative of archaeological features.
Among these is the application of spectral indices, such as the Normalized Difference Vegetation Index, for detecting vegetation anomalies, which generally demonstrate the presence of underlying archaeological remains. This has been effective in distinguishing archaeological features from natural landscapes and thus supports similar methodologies described by Huang, 2024 [5] in their bibliometric analysis of the applications of GIS in heritage studies.
The spatial analysis, through buffer analysis and spatial autocorrelation, further contributes to knowledge about the clustering of archaeological features. In that sense, it may identify areas with high archeological potential; therefore offering an area where it is targeted, excavation and preservation should be done. Spatial modeling techniques like these align with Lombardo *et al*. (2020) [18], who illustrate the importance of multi-hazard threat modeling for cultural heritage sites.
Informed by this research, such a GIS database will also contribute to the long-term monitoring and management of the archaeological landscape, now quite significant under the influence of climate change. Sesana *et al*. (2021) [2] underline the effects of climate change on cultural heritage, insisting that there is an incentive to design or implement dynamic tools to monitor changes in the environment and, with these, their impacts on archaeological sites. Through dispersion across the slopes and surrounding low-lying areas, constant observation and assessment are possible with a GIS database, thus allowing timely interventions to mitigate potential damage.
Comparing these results with previous work by other authors, some crucial similarities and differences arise. For example, Nicu (2017) [3] and Reeder-Myers (2015) [18] said that cultural heritage sites are very vulnerable to natural hazards and climate change. In particular, both studies showed that historical data are combined with environmental information to assess the risks and consequently to develop strategies for conservation. The GIS database that we have in place corresponds to this approach as it organizes a whole set of data within a comprehensive conceptual model of risk assessment (Sesana *et al*., 2021; Nicu, 2017) [2, 3].
As Budiharto *et al*. in 2021 demonstrated the 3D modeling and Li *et al*. with the LiDAR in the year 2023, the mentioned points are also strengthened. These technologies guarantee that the immediate archaeological documentation meets the requirements concerning the modern research and conservation in terms of precision and clarity. Thus, integrating these technologies within the GIS database, a 3D high-resolution DEM will be provided to conserve archaeological sites for further analysis and interpretation (Reeder-Myers, 2015; Lombardo *et al*. 2020) [19, 18].
These results, however, go way beyond academic research and its official contributions. The database of GIS is the key to the countrywide interdisciplinary academic work and public outreach and knowledge-sharing, as well as the building of partnerships between archaeologists, historians, commoners, and the government. Thus, only in this way can the sustainable preservation of cultural heritage take place as observed by (Purchla *et al*., 2022) [4] with regards to heritage and cultural mega-events. It follows that the compilation of a comprehensive GIS database of the archaeological sites in Ur is thus a relevant intervention in the protection of cultural history. Further, any continuing research, conservation and management work is anticipated that a project of such kind will remain an important tool to combine various forms of data by conducting state-of-art spatial analysis. These findings agree with prior studies in this domain and support other works to illustrate how IT can help improve access to and awareness of our cultural heritage (Budiharto *et al*., 2021, Li *et al*., 2023) [, 9].

Conclusion
It will be very helpful in building the general database for the outstanding archaeological site of Ur in order to protect the unique global cultural heritage. It uses many forms of data, satellites images, aerial photographs, GPR data, and very thorough field surveys before producing a long-term and versatile view of the archaeological terrain. Hence, such a database enriches the creation of a dynamic tool that is

easily and readily available to researchers, conservationists, policymakers, and all those interested in the rightful usage of basic research for further research, focus on preservation, and policy-making decisions.

The strategies used here enabled the detection and examination of subsurface anomalies and archeological features through the use of spectral indices like the NDVI and more sophisticated spatial analytic techniques. These technologies enhance the ability to detect and monitor environmental change and potential hazards, thus ensuring the protection and preservation of archaeological sites from dangers posed by climate change and other natural hazards.

The implications of the project reach beyond academic contributions in the short term. Through the GIS database, which also provides a tool for interdisciplinary collaboration and public engagement, it furthers the dissemination of knowledge and the building of partnerships among archaeologists, historians, local communities, and government authorities as stakeholders in cultural heritage and its sustainable conservation.

The creation and implementation of this GIS database are thus vital steps towards the long-term preservation and management of the Ur archaeological landscape. With its integration of independent data sources, it applies advanced spatial analysis techniques to provide holistic and dynamic support for further research, conservation, and management. It, therefore, means that the initiative not only falls in line with but also enhances the current practices in the field and proves the role of digital technologies in preserving cultural heritage for future generations.

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