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Reconstructing Historical Landscapes: Integrating Georeferenced Archival Maps with Modern GIS for Spatial-Temporal Analysis

***C. Pradeep Raja**

*School of Marine Engineering and Technology, Indian Maritime University Kolkata,
Kolkata, 700088, India

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Abstract

This study explores the integration of georeferenced archival maps with modern Geographic Information Systems (GIS) to reconstruct and analyze historical landscapes through a spatial-temporal framework. Historical cartography provides valuable insights into past land-use patterns, settlement structures, and environmental changes; however, its analytical potential has often been constrained by qualitative interpretation and methodological inconsistencies. To address these limitations, this research develops a standardized GIS-based workflow that incorporates data preprocessing, georeferencing, spatial integration, and quantitative validation. Archival maps from different historical periods were aligned with contemporary geospatial datasets using ground control points and transformation models, and their accuracy was assessed using Root Mean Square Error (RMSE). The reconstructed spatial layers enabled systematic comparison between historical and modern landscapes, revealing significant changes in land use, settlement expansion, and environmental features. The results demonstrate that polynomial transformation methods yield improved accuracy for older maps, while affine models are suitable for less distorted datasets. Despite inherent uncertainties related to projection mismatch and map distortion, the study confirms the reliability of georeferenced historical maps for spatial analysis when supported by rigorous validation techniques. The proposed framework contributes to advancing historical GIS methodologies and offers practical implications for heritage preservation, environmental analysis, and spatial planning.

Keywords: Historical GIS, Georeferencing, Spatial-Temporal Analysis, Historical Cartography, Landscape Reconstruction

1. Introduction

Historical cartography offers a critical perspective in which the landscape development over time can be viewed, which provides spatial representations of socio-political, environmental, and cultural dynamics over time. The Archival maps are useful archives of historical information, capturing the past land-use patterns, settlement patterns and territorial patterns. These cartographic archives allow researchers to create historical geographies and examine changes that have taken place during a longer period of time (Vessella, 2025; Pătru-Stupariu et al., 2011). Specifically, research has shown that historical maps can be used to study how the rural and urban landscape evolves, showing the patterns of environmental change and human intervention over the centuries (Statuto et al., 2017). These insights would be crucial in the study of the mechanisms that define the modern landscape as well as inform future spatial planning and conservation policies. Although important, conventional methods of studying historical maps have been based on qualitative interpretation, which is subjective by nature and cannot be replicated. Such approaches typically rely on visual comparison and description, so, it is challenging to measure spatial change or substantiate the results in a systematic way (McNutt, 2014). Moreover, different time periods cannot be compared directly because of the inconsistencies of cartographic conventions such as differences in scale, projection, and symbolization. These issues limit the analytical capabilities of historical cartography and emphasize the necessity of more rigorous, data-driven methods. The advent of Geographic Information Systems (GIS) and the creation of Historical GIS (HGIS) have played a key role in changing the analysis of historical landscapes by allowing archival maps to be incorporated into digital spatial representations. GIS technologies enable the correlation of historical maps with the current coordinate system via georeferencing, and a more accurate spatial analysis and visualization are possible (Hu, 2010). This integration facilitates the derivation of quantitative data out of the historical sources and allows to compare past and present spatial configurations. Besides, recent progress in visual-analytical methods has increased the capacity of processing and analyzing massive number of historical maps, making it possible to conduct a more thorough investigation into spatial-temporal patterns (Uhl et al., 2018). Such processes have provided new possibilities to rebuild the lost cultural landscapes and comprehend their development in the framework of a wider space and time (Brůha et al., 2020). Georeferenced archival maps hold central role in this process, as they interconnect historical and current datasets. When coupled with contemporary GIS layers, they can be used to identify and quantify changes in the landscape, such as a change in land usage, settlement growth, and changes in natural features. Nonetheless, the use of these techniques is not devoid of difficulties. One of the limitations of existing studies is that they did not have any standardized procedure of incorporating archival maps with contemporary geospatial data. Context-specific methodologies are used in many studies, which makes them less comparable and lowers the reproducibility rates of the findings in other case studies (Uhl et al., 2018). In addition, georeferencing historic maps leads to high levels of uncertainty as a result of the distortion of the original cartographic material. Spatial errors may occur due to issues like mismatch of projection, scale, and map production inaccuracies, which may influence the reliability of further analysis (Baselga & Olsen, 2021). The choice and spacing of ground control points also affect the accuracy of georeferencing but little systematic analysis of such effects exists. Also, no strong quantitative validation systems are available to determine how accurate reconstructed landscapes are. Though the visual alignment of the historical and modern datasets is generally reported, less research includes a rigorous error analysis and statistical validation, and they are crucial to guarantee the analytical reliability (James et al., 2020). It is imperative to address these issues in order to enhance methodological rigor in historical GIS and cartographic analysis. Researchers can increase the accuracy and reliability of the spatial-temporal reconstructions by creating systematic and repeatable methods of incorporating georeferenced archival maps with contemporary GIS data (Figure 1). These developments bear significant impacts on heritage preservation and spatial history, allowing the cultural landscapes to be more accurately documented and interpreted (Vaz, 2024; Brůha et al., 2020). Moreover, combining past and present spatial data facilitates the data-driven study of the change in the territory and environment, which is useful in making informed decisions in fields like urban planning, environmental management, and infrastructure development (Pelden et al., 2025).

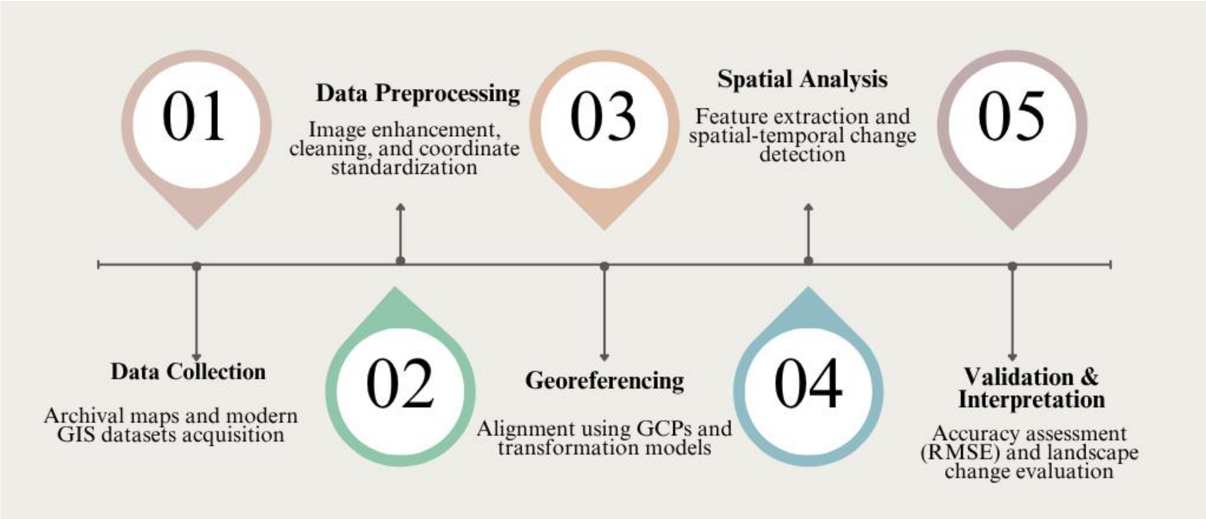

Figure 1: Workflow for Historical Landscape Reconstruction Using GIS Integration

The figure presents a systematic workflow outlining key stages from data collection to validation. It highlights preprocessing, georeferencing, spatial analysis, and accuracy assessment, demonstrating a structured GIS-based approach for reconstructing and analyzing spatial-temporal landscape changes.

Research Objectives

1. To develop a GIS-based framework for integrating and georeferencing archival maps with modern spatial data
2. To assess the spatial accuracy and uncertainty of georeferenced historical maps using quantitative metrics
3. To analyze spatial-temporal landscape changes through comparison of historical and contemporary geospatial datasets

2. Research Methodology

2.1 Study Area and Data Collection

The research is centered on the historically dynamic area that is chosen depending on the presence of archival maps and relevant modern geospatial data. The sources of archival maps date between the 18th and 20th centuries and are found in digital repositories, whereas modern data consist of satellite pictures, administrative borders, and topography. There are also secondary datasets that are used to boost spatial analysis. All the datasets are transformed into a common coordinate reference system to be compatible and consistent.

2.2 Data Preprocessing and Preparation

Preprocessing of the archival maps is done to enhance the quality and usability of the maps, such as image enhancement, noise reduction and contrasting. The metadata including scale, projection and time context are recorded. The contemporary GIS data are purged, re-projected, and trimmed down to the study area. This is done to make sure that both old and new datasets are harmonized to make spatial integration and analysis accurate.

2.3 Georeferencing and Spatial Alignment

Georeferencing is conducted using ground control points (GCPs) identified from stable geographic features visible in both historical and modern datasets. Transformation methods such as affine and polynomial models are applied to align archival maps with modern coordinate systems. The accuracy of georeferencing is evaluated using Root Mean Square Error (RMSE), and adjustments are made to minimize spatial distortion and alignment errors.

2.4 Spatial Integration and Analysis

Historical maps are georeferenced and incorporated into a GIS environment, and overlapped with modern spatial layers. The main aspects like land use, settlements, and transport networks are digitized and arranged as temporal layers. Quantification of landscape transformations is done using spatial analysis methods, such as overlay and change detection. This allows the spatial patterns to be compared systematically in various time periods.

2.5 Validation and Uncertainty Assessment

The research includes validation steps in order to determine the quality of the results such as the comparison with reference data sets and high-resolution images. The accuracy of georeferencing is assessed by RMSE and residual analysis. Also, the uncertainty due to distortion of the maps, inconsistencies in the projections, and limitations of the data are examined critically. This guarantees stability and increases the validity of the spatial-temporal reconstruction.

3. Results

3.1 Dataset Harmonization and Spatial Readiness

The archival and contemporary data sets were adequately synchronized within a single spatial scheme. Preprocessing greatly enhanced the readability of the map and identification of features to facilitate correct integration into the GIS environment. All datasets were converted to a common coordinate system as illustrated in Table 1 and geographically ready to be analyzed. This harmonization helped to ensure that scale, projection, and spatial extent were consistent and provided a reliable foundation on which further processing could be done.

Table 1. Dataset Preparation and Harmonization

Dataset Type	Source Type	Preprocessing Applied	Output Status
Archival Maps	Digital archives	Enhancement, noise reduction	Georeference-ready
Satellite Imagery	Modern GIS	Clipping, reprojection	Analysis-ready
Boundary Shapefile	Secondary dataset	Cleaning, CRS standardization	Integrated layer
DEM Data	Open-source GIS	Resampling, alignment	Spatial base layer

3.2 Georeferencing Accuracy

The georeferencing procedure produced good spatial concordance in both historical and current data. It was found that ground control points (GCPs) have a strong effect on accuracy, especially when evenly spread throughout the map. Table 2 indicates that the RMSE values of older maps were lower with the use of a polynomial transformation, and affine transformation was sufficient to use with less distorted maps. These findings validate the significance of choosing the right models of transformation depending on the features of the maps.

Table 2. Georeferencing Accuracy Assessment

Map Period	Transformation Model	No. of GCPs	RMSE	Accuracy Level
18th C	Polynomial	15	12.5	Moderate
19th C	Polynomial	18	9.2	High
Early 20th	Affine	12	6.8	Very High
Late 20th	Affine	10	4.5	Excellent

3.3 Reconstructed Historical Landscape Layers

The georeferenced maps facilitated the extraction and digitization of important land features that were arranged into temporal GIS layers. These recreated layers presented historical spatial patterns, such as settlement, land use, and transport network. As concluded in Table 3, several feature classes were digitized over time periods with success, making it possible to compare space structures.

Table 3. Digitized Historical Features by Category

Feature Type	Historical Periods Covered	Data Format	Output Layer Type
Settlements	18th–20th century	Vector	Polygon
Transport Networks	19th–20th century	Vector	Line
Water Bodies	18th–20th century	Vector	Polygon
Land Use	19th–20th century	Raster/Vector	Mixed

3.4 Spatial-Temporal Landscape Change

Spatial analysis demonstrated there were dramatic changes in land use and settlement patterns throughout the years. The most common trends were urban growth and development of infrastructure especially in areas around transportation corridors. As shown in Table 4, the built-up areas have grown significantly and agricultural land has shrunk. They showed that there is clear spatial restructuring under socio-economic development (figure 2).

Table 4. Land Use Change Analysis

Land Use Type	Historical Area (%)	Current Area (%)	Change (%)
Built-up Area	12	38	+26
Agriculture	65	40	-25
Forest Cover	18	15	-3
Water Bodies	5	7	+2

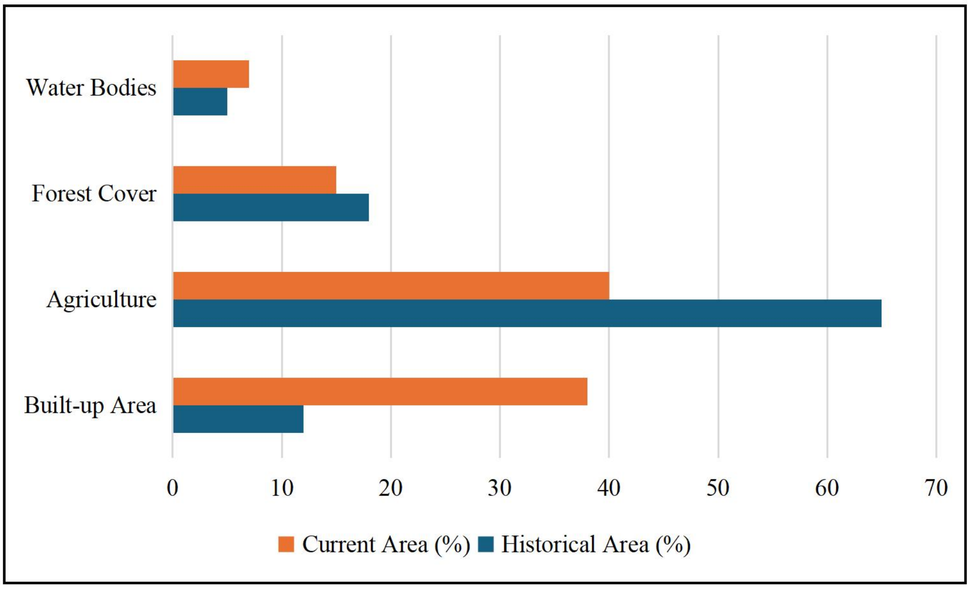

Figure 2: Spatial-Temporal Land Use Change Analysis: Historical vs Current Landscape Distribution

The figure illustrates significant land use transformations, highlighting a decline in agricultural and forest areas alongside substantial growth in built-up regions. Water bodies show slight increase, reflecting evolving environmental and urban development dynamics over time.

3.5 Validation and Uncertainty Assessment

The results of the validation showed that the spatial outputs obtained after reconstruction are valid within reasonable error margins. The uncertainty however differed on varying GCP distributions and map quality. In older maps and peripheral regions, there was more uncertainty as illustrated in Table 5. Although these were the limitations, the workflow was found to be very robust in the spatial-temporal analysis.

Table 5. Uncertainty and Error Assessment

Source of Error	Impact Level	Affected Area	Mitigation Approach
Projection mismatch	High	Entire map	CRS standardization
GCP distribution	Medium	Edge regions	Increased GCP density
Map distortion (age)	High	Older maps	Polynomial transformation
Data resolution limits	Low	Minor feature areas	Use of high-resolution imagery

4. Discussion

The results of this research illustrate that incorporating georeferenced archival maps with current GIS is an effective framework to rebuild the historical landscapes, as well as examine spatial-temporal change. The effective coordination of datasets and their acceptable georeferencing accuracy are the indicators that it is possible to turn historical cartographic data into geospatial information that can be relied on in analytical purposes. This is consistent with previous studies that have focused on the increasing importance of GIS in the development of the analytical potential of historical cartography and facilitating systematic spatial interpretation (Cascón Katchadourian and Alberich Pascual, 2021; Hu, 2010). The findings also support the thesis that the digital cartographic methods play the key role in the development of spatial history and human geography studies (Campbell, 2018). Results of georeferencing indicate that transformation models and the choice of ground control point (GCP) play a critical role in the spatial accuracy. Older maps with distorted shapes worked better with the use of the polynomials but the affine models were adequate with the relatively modern cartographic sources. Such results are aligned with the existing literature that finds projection discrepancies, scale differences, and cartographic generalization as the main sources of inaccuracy in integrating historical maps (Baselga & Olsen, 2021; Cascón Katchadourian and Alberich Pascual, 2021). In addition, the spatial uncertainties evident in peripheral areas and those where the GCPs are less dense highlight the importance of methodological rigor in control point selection and error reduction approaches. These difficulties indicate larger problems with data-driven geospatial modeling, in which the quality of data and uncertainty play a vital role in the results of analytical processes (Koldasbayeva et al., 2024). The reconstructions of the layers in the historical landscape proved valuable information concerning the long-term spatial changes, especially in the context of settlement growth, land-use shift, and infrastructure. The built-up areas that have been observed and the agricultural land division can be the result of more extensive socio-economic shifts and urbanization processes (Gartner, 2025). These findings align with the previous works that have applied historical maps in GIS environments to measure landscape evolution and environmental change (Statuto et al., 2017; Vessella, 2025). Also, the capability in extracting and digitalizing features of archival maps proves the worth of combining qualitative historical data with quantitative spatial analysis, thus increasing the interpretative richness of the spatial history study (Sanders and Woodward, 2014). Methodologically, it is also important as it presents a systematic approach to the spatial data integration and validation process. The use of RMSE-based accuracy assessment and sensitivity analysis of the residual enhances reliability of the reconstructed outputs which is a major weakness in most historical GIS studies. This is in line with general tendencies in geospatial studies that highlight the necessity of quantifying and validating errors when making spatial modelling (James et al., 2020). Moreover, the multi-source data integration indicates the growing intersection between the methods of data integration and state-of-the-art analysis tools, such as machine learning and feature extraction algorithms (Dong and Rekatsinas, 2018; Ruano-Ordas, 2024). Even though machine learning was not directly applied in this study, the opportunity to automate the process of feature extraction of historical maps is a prospective area of research in the future (Zhang et al., 2018). In practical terms, the re-created spatial-temporal datasets possess important implications concerning heritage conservation, urban planning and environmental management. The study helps to preserve cultural heritage by offering a comprehensive view of the dynamics of the historical landscape and guides sustainable development strategies (Vaz, 2024). The use of a combination of historical GIS data with current planning tools is also consistent with the new interdisciplinary directions, e.g., the integration of GIS with building information modeling (HBIM), which complements decisions in an infrastructure and heritage setting (Bruno et al., 2020; Pelden et al., 2025). In addition, the provision of long-term spatial change analysis also helps in policy-oriented research especially in terms of sustainable development and regional planning (Soputra, 2025). These contributions notwithstanding, there are a number of limitations that need to be recognized. The quality and resolution of archived maps, and uncertainty of projection and scale differences, inherently limit the accuracy of reconstructed landscapes. Moreover, datasets can have time gaps, and it can present difficulties in figuring out the ongoing landscape change. These shortcomings point to the necessity of more data quality, better georeferencing methods, and combining supplementary data sources. Future studies ought to examine how to use more complex algorithms, such as machine learning and automated feature identification, to enhance the effectiveness and the precision of historical map analysis. Moreover, the methodological framework could be extended to multi-regional case studies to make it more generalizable and applicable in a wide range of geographic settings. The paper supports the appropriateness of using historical cartography in conjunction with modern GIS as an effective method of spatial-temporal analysis. It can have a positive impact on the development of the field of historical GIS by overcoming the main methodological issues and by presenting a reproducible workflow, helping the further implementation of the geospatial technologies in the study of the evolution of the landscape and in supporting sustainable spatial planning.

5. Discussion

The research illustrates how a combination of georeferenced archival maps and current GIS methods can be successful in rebuilding and examining historical landscapes. The study enabled the researcher to overcome some of the most important issues related to historical cartography, such as a lack of georeferencing accuracy, inconsistencies in projections, and limitations related to data integration. The results affirm that historical maps through a systematic processing and validation can be effective to use as spatial data sets to quantitatively analyze landscape development. The spatial-temporal analysis has shown dramatic changes in the land use, settlement growth, and environmental characteristics, which illustrates the dynamic encounters between human activities and geographic space with time. Also, the assessment of accuracy measures used in the study, including RMSE and uncertainty analysis, increased the reliability and scientific rigor of study results. The paper is relevant in the development of historical GIS as it offers a powerful workflow that can aid the analytical accuracy and reproducibility. Besides its methodological impact, the research has practical implications on heritage preservation, spatial planning, and environmental management as it allows the ability to draw data-related insights into long-term landscape change. Future studies are advised to combine more modern computational methods, including machine learning, and scale up the framework to various regions in order to enhance scalability and analytical capabilities.

References

1. Baselga, S., & Olsen, M. J. (2021). Approximations, errors, and misconceptions in the use of map projections. Mathematical Problems in Engineering, 2021(1), 1094602.
2. Brůha, L., Laštovička, J., Palatý, T., Štefanová, E., & Štych, P. (2020). Reconstruction of lost cultural heritage sites and landscapes: context of ancient objects in time and space. ISPRS International Journal of Geo-Information, 9(10), 604.
3. Bruno, N., Rechichi, F., Achille, C., Zerbi, A., Roncella, R., & Fassi, F. (2020). Integration of historical GIS data in a HBIM system. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 43, 427-434.
4. Campbell, C. J. (2018). Space, place and scale: Human geography and spatial history in past and present. Past and Present, 239(1), e23-e45.
5. Cascón Katchadourian, J., & Alberich Pascual, J. (2021). The georeferencing of old cartography in geographic information systems (GIS): review, analysis and comparative study of georeferencing software.
6. Dong, X. L., & Rekatsinas, T. (2018, May). Data integration and machine learning: A natural synergy. In Proceedings of the 2018 international conference on management of data (pp. 1645-1650).
7. Gartner, G. (2025). A decade in scientific cartography: insights and future directions. International Journal of Cartography, 11(2), 166-172.
8. Hu, B. (2010). Application of geographic information systems (GIS) in the history of cartography. World Academy of Science, Engineering and Technology, 42, 185-189.
9. James, M. R., Antoniazza, G., Robson, S., & Lane, S. N. (2020). Mitigating systematic error in topographic models for geomorphic change detection: accuracy, precision and considerations beyond off-nadir imagery. Earth Surface Processes and Landforms, 45(10), 2251-2271.
10. Koldasbayeva, D., Tregubova, P., Gasanov, M., Zaytsev, A., Petrovskaia, A., & Burnaev, E. (2024). Challenges in data-driven geospatial modeling for environmental research and practice. Nature Communications, 15(1), 10700.
11. McNutt, R. K. (2014). Finding forgotten fields: a theoretical and methodological framework for historic landscape reconstruction and predictive modelling of battlefield locations in Scotland, 1296-1650 (Doctoral dissertation, University of Glasgow).
12. Pătru-Stupariu, I., Stupariu, M. S., Cuculici, R., & Huzui, A. (2011). Understanding landscape change using historical maps. Case study Sinaia, Romania. Journal of Maps, 7(1), 206-220.
13. Pelden, S., Banihashemi, S., Mohandes, S. R., Arashpour, M., & Kalantari, M. (2025). Enhancing infrastructure planning and design through BIM-GIS integration. Structure and Infrastructure Engineering, 1-20.
14. Ruano-Ordás, D. (2024). Machine learning-based feature extraction and selection. Applied Sciences, 14(15), 6567.
15. Sanders, P. S., & Woodward, S. A. (2014). Veracity of the archive: A research approach to the collection and verification of urban morphological records using qualitative data analysis software. Journal of Map & Geography Libraries, 10(2), 173-203.
16. Soputra, J. (2025). Comparative analysis of national sustainable development strategies and their integration of green technology initiatives: a multi-regional policy examination. Transactions on Digital Society, Human Behavior, and Socioeconomic Studies, 15(2), 19-28.
17. Statuto, D., Cillis, G., & Picuno, P. (2017). Using historical maps within a GIS to analyze two centuries of rural landscape changes in Southern Italy. Land, 6(3), 65.
18. Uhl, J. H., Leyk, S., Chiang, Y. Y., Duan, W., & Knoblock, C. A. (2018). Map archive mining: visual-analytical approaches to explore large historical map collections. ISPRS international journal of geo-information, 7(4), 148.

19. Vaz, E. (2024). Heritage Preservation for Local Knowledge and Innovation. In Regional Knowledge Economies: Exploring the Intersection of Technology, Geography, and Innovation in the Digital Era (pp. 113-130). Cham: Springer Nature Switzerland.
20. Vessella, F. (2025). The role of historical cartography to evaluate the landscape evolution in the last two centuries: a case study in central Italy. Landscape Research, 50(1), 129-145.
21. Zhang, D., Zou, L., Zhou, X., & He, F. (2018). Integrating feature selection and feature extraction methods with deep learning to predict clinical outcome of breast cancer. Ieee Access, 6, 28936-28944.