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Article

Developing and Disseminating a New Historical Geospatial Database from Kitchener's 19th Century Map of Cyprus

Christos Chalkias [1,*], Evangelos Papadias [1], Christoforos Vradis [1], Christos Polykretis [1], Kleomenis Kalogeropoulos [2], Athanasios Psarogiannis [1] and Georgios Chalkias [1]

[1] Department of Geography, Harokopio University, 17671 Kallithea, Greece
[2] Department of Surveying and Geoinformatics Engineering, University of West Attica, 12241 Egaleo, Greece
* Correspondence: chalkias@hua.gr

Abstract: Extraction and dissemination of historical geospatial data from early maps are major goals of historical geographic information systems (HGISs) in the context of the spatial humanities. This paper illustrates the process of interpreting, georeferencing, organizing, and visualizing the content of a historical map of Cyprus in the context of GISs and highlights the development of a national-scale spatial database of the island in the 19th century. This method was applied to Lord Kitchener's historical map of Cyprus (published in 1885), which is considered the product of the first scientific topographic survey of Cyprus, is rich in geographic information about the area, and covers the entire island at a scale of 1:63,360. Previous attempts to create historical geodatabases have either focused on small areas or, when conducted on a national scale, have been thematically focused. The positional accuracy of the map was found to be 1.08 mm in map units, which was equivalent to 68.76 m on the ground. Accordingly, the main categories of geographic content (land cover, administrative units, settlements, transportation/communication networks, stream networks/water bodies, points of interest, annotations) were digitized from the georeferenced historical map. The Web-based application developed in this study supported the visualization of the historical geographic content of the map and its comparison with modern basemaps. The creation of the geodatabase presented in the study provides a template for similar studies and a basis for further development of the historical geodatabase of Cyprus.

Keywords: historical GIS; spatial humanities; historical maps; historical geospatial databases; Cyprus; Horatio H. Kitchener; Semantic Web; Linked Open Data

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1. Introduction

The rise of historical GIS (HGIS) development has been accompanied by constantly increasing analyses of historical maps [1]. Early maps primarily have esthetic and informational value, while historical maps from the late 18th and 19th centuries have been proven to be more accurate and precise [2], mainly due to the development and widespread use of triangulation techniques employing accurate trigonometric calculations (e.g., the triangulation of France, the Principal Triangulation of Great Britain, the Great Trigonometric Survey of India; see, among others, [3,4]). Accordingly, these maps are suitable for the analysis of regional landscape changes and the reconstruction of geographies of the past [5]. Such maps, which are an essential component of historical GISs, require appropriate digital documentation in order to efficiently use their content effectively in the context of the World Wide Web and the Semantic Web. Although GISs have been at the forefront of research tools for a variety of sciences since the 1960s, their use in the humanities has been sporadic [6]. Nevertheless, use of HGISs is an academic practice that is increasingly recognized in historical research [7]. The study of historical geographic information systems (HGISs) is an interdisciplinary field, and the term is used to describe the application of geographic information science tools and methods (GISs) to assist historical researchers in gaining knowledge about the past through both quantitative and qualitative measurements and sources [8]. This interaction between geography and the humanities has led to a new approach called the GeoHumanities or spatial humanities, referring to this creative convergence [9]. GISs have been used for a variety of research purposes in the GeoHumanities, such as landscape/land cover changes, the simulation of historical battles, and historical surveys (among others) [10–13]. In one study [14], maps from the GIS and the 19th century (Palestine Exploration Fund Surveys, 1872–1890) were used to quantitatively analyze the latter's accuracy in order to gain new insights into the settlement and decentralization processes in Palestine. Furthermore, the same historical maps were recently used in a GIS context to study the changes in the landscape of Israel between 1881 and 2011 [15,16].

Previous work has concluded that early military survey maps are a suitable source for analyzing and evaluating landscape evolution and changes in land cover/use [17,18], as well as other geographic features, such as population distribution [19] and road network development [20]. Nevertheless, the development of polythematic HGISs at the national level is very rare in the international literature. National-level projects, such as the National Historical Geographic Information System of U.S.A. (https://www.nhgis.org/about-ipums-nhgis, accessed on 10 January 2023), the China Historical Geographic Information System project (https://chgis.fairbank.fas.harvard.edu/, accessed on 10 January 2023), and the Great Britain Historical GIS (http://www.geog.port.ac.uk/hist-bound/project_rep/proj_gbhgis.htm, accessed on 10 January 2023) [21–23], focus on populated places, travel records, map navigation, and statistics from various historical censuses across historical administrative boundaries. To the best of our knowledge, there is no relevant work for the island of Cyprus.

Cyprus came under Ottoman rule in 1571. This Ottoman period lasted for about three centuries until 1878, when the administration was handed over to the British after the Congress of Berlin in the same year. However, the transition is not so clear, especially in the rural area [24]. The population of Cyprus declined significantly in the 17th and 18th centuries until 1841 and recovered in the late Ottoman period. For more information on this period, see [25–27]. The topographic survey for the map of Cyprus by H. H. Kitchener began immediately after the British administration took over (1878); thus, it can be assumed that it was the landscape of the late Ottoman era that was recorded in the K-map. However, certain elements of the K-map, such as the road network and administrative boundaries, additionally manifest both ongoing processes and the planning of British administration, rather than the influence of the previous state.

Land registration in Cyprus dates back to 1858, when the Ottoman Land Code came into force. However, during this period, no maps were prepared for the administration of the island [28]. Immediately after the beginning of the British administration in 1878, the High Commissioner of Cyprus, Sir Garnet Wolseley, requested a rough map of Cyprus. The scale of this map for the administration was set at one inch per mile (1:63,360), a common scale used in early Ordnance Survey maps in Britain. Thus, from 1881 to 1883, the island of Cyprus was surveyed, along with the production of large-scale (1:2000) city plans of Famagusta, Larnaca, and Limassol, under the supervision of Lieutenant (later Field Marshal) H. H. Kitchener, R.E. [29]. It is worth noting that the so-called "Kitchener's trigonometric network", which was the starting point for the topographic survey, was used in later survey work and formed the basis for the development of the network that is still used in Cyprus today. In this survey, the compass was used for angle measurements, while distances were measured with the chain method. The coordinates of the geodetic network were defined by resecting both ends of the baseline of the survey with a system of triangles. The advantage of this method was that it was based on angular measurements, which could be easily obtained with a theodolite, rather than the time-consuming and costly measurement of distances. The map produced with this method, at a scale of one inch per mile, consisted of 15 sheets plus the title page (Figure 1). In 1885, the map of Cyprus by Horatio Herbert Kitchener (hereafter referred to as the K-map) was published in London by Edward Stanford. The publisher promoted Kitchener's map by pointing out the rich geographical content of the 15 sheets produced by the first trigonometric survey of Cyprus. Immediately after its publication, it became an exemplary survey that endured until the mid-20th century. This surprisingly accurate map contains rich and valuable information about the island's geography, history, and culture. Earlier maps of the island are not comparable to the K-map in either scale or content. These earlier maps were mostly made by travelers without sound scientific surveying methods or trigonometric calculations. A detailed history of Cypriot cartography can be found in [23–33]. Due to the accuracy and richness of the content of this map, it was selected for this study as the earliest map suitable for a reliable reconstruction of the geography of Cyprus in the 19th century. Therefore, we used the K-map as the main source for the construction of the historical geodatabase of the island.

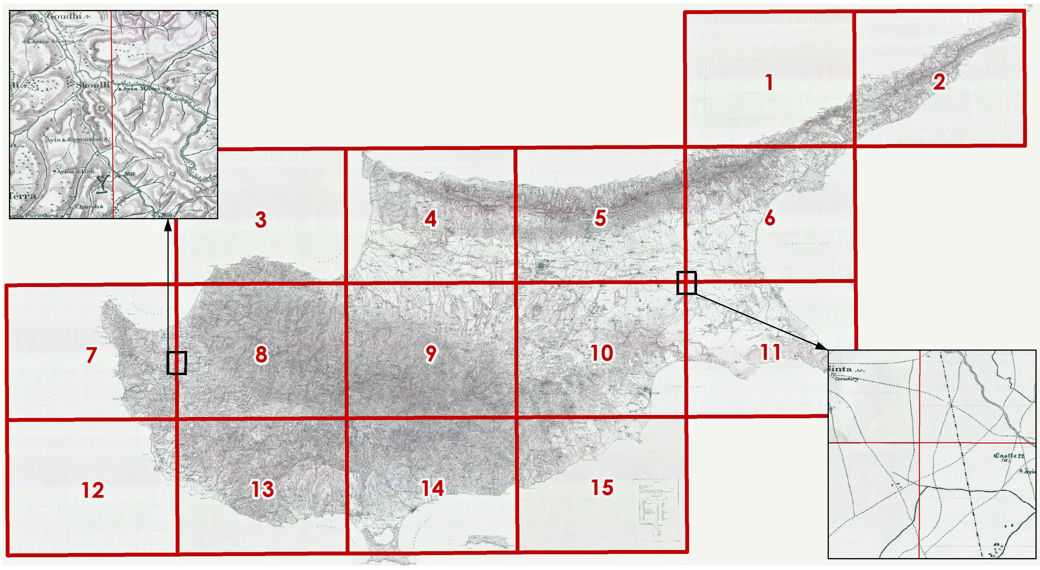

Figure 1. The 15 sheets of Kitchener's map of Cyprus. The inset maps show details from the seamless mosaic (reproduced with the kind permission of the Sylvia Ioannou Charitable Foundation).

The objectives of this study were: (a) to build and visualize a complete historical geodatabase on a national scale for Cyprus in the 19th century and (b) to contribute to the definition of a procedure for the interpretation, organization, and dissemination of the content of old maps in order to achieve the first objective. For this purpose, we used HGIS and Web mapping technologies. The rest of the paper is organized as follows. In Section 2, we describe the material used in this study. In Section 3, we present the methodology used. We then present the results of the empirical analysis (Section 4), focusing on the accuracy and the creation of the geodatabase and the Web application. In Section 5, we discuss this study, and in Section 6, we present the final conclusions and give some perspectives on future work.

2. Material

The K-map selected for analysis comprises 15 sheets covering the entire island of Cyprus. The scale of the map is 1:63,360 (1 inch to 1 mile). This map contains the following main geographical feature categories: 1. administration units, 2. road networks, 3. hydrographic networks and coastlines, 4. points of interest, 5. settlements, 6. land cover, 7. telegraph lines, and 8. annotations. The details used to map the features of the K-map were taken from the trigonometric network for Kitchener's survey. The accuracy and completeness of the K-map have not been previously assessed. All 15 sheets were obtained from the private collection of the Sylvia Ioannou Charitable Foundation as uncompressed TIFF files. To create these files, the original sheets were scanned in a flatbed scanner at a resolution of 600 dots per inch (dpi). For the acquisition of control points (CPs) from modern maps, a current reference basemap available online from the Department of Lands and Surveys of Cyprus (https://eservices.dls.moi.gov.cy/arcgis/services/BASEMAPS/Imagery_Satellite_2009_2013/MapServer/WMSServer?request=GetCapabilities&service=WMS, accessed on 9 October 2022) was used. This basemap is an orthophoto map with a spatial resolution of 0.1 m registered in the World Geodetic System (WGS 84) (EPSG 4326).

3. Methodology

The methodology used in this work included the following phases:

1. Merging and georeferencing of the 15 sheets of the K-map. The result of this phase was the creation of a georeferenced mosaic basemap, which was then used in all subsequent phases;
2. Interpretation of the geographic content of the K-map and creation of the geodatabase. In this phase, the historical geographic content of the map was identified and digitized in a GIS environment. This phase also included the digitization of all place names on the map;
3. Design and creation of the digital map and associated Web application. This step involved the creation and implementation of the interactive Web application that used and presented all of the information generated in the previous phases.

These phases are described in detail below.

3.1. Mosaicking and Georeferencing of the K-Map

After scanning, each sheet was digitally cropped to the printed boundaries and assembled into a seamless mosaic using the geographic grid (longitude/latitude) on the edges of the sheets, as described in previous work [9]. From this process, a seamless mosaic of the K-map was created for the entire island of Cyprus. Although it is known that the Cassini–Soldner projection was employed for the K-map using the Clarke 1858 ellipsoid, the other essential parameters of the coordinate system are unknown because almost all the survey notebooks and other reports and documents have been lost [34]. The absence of the essential parameters of the coordinate system of the K-map indicated that a transformation based on control points had to be used for georeferencing. Moreover, the spatial inequality in the density of the trigonometric network used in the survey was indicative of unevenly distributed accuracy in the K-map. Therefore, we chose to use a rubber-sheet transformation (spline tool in ArcGIS 10.4) to georeference the mosaic map because this method can be applied regardless of the data and projection used. The process of georeferencing was performed as shown in Figure 2. Identifying and collecting control points (CPs) from historical maps is a demanding process, and it seemed to be the most challenging because it required extensive study and careful consideration of additional sources, such as travelers' accounts, other maps, and historical books, to ensure the correct association of geographic features from the historical map with the locations of the corresponding features on modern, more accurate basemaps. In addition, the transformation method used here required a fairly large number of CPs to increase the overall accuracy. In this study, we focused our identification of control points on landmarks, especially churches and monasteries that had not changed their location. We also examined bridges, notable buildings, intersections, and recognizable shoreline features. To assist in the identification of CPs, a temporary similarity transformation was applied to the K-map. Using a scale parameter, a rotation angle, and a displacement vector, the K-map was temporarily aligned with the present-day reference basemap available online from the Department of Lands and Surveys of Cyprus (https://eservices.dls.moi.gov.cy/arcgis/services/BASEMAPS/Imagery_Satellite_2009_2013/MapServer/WMSServer?request=GetCapabilities&service=WMS, accessed on 9 October 2022). This basemap is a detailed orthophoto map with a cell size of 0.1 m. The purpose of this process was to initially determine the locations of CP candidates with high accuracy. The CP candidates were validated using supplementary material, such as historical books [35,36], historical databases (http://www.cyprustemples.com, accessed on 9 October 2022), digital data from the Church of Cyprus website (https://churchofcyprus.org.cy, accessed on 9 October 2022), and other modern basemaps (OpenStreetMap data and Google Maps). A spline transformation was then performed on a set of 669 candidate CPs. The transformed mosaic was then examined to detect and remove CPs causing extreme distortions and geometric inconsistencies.

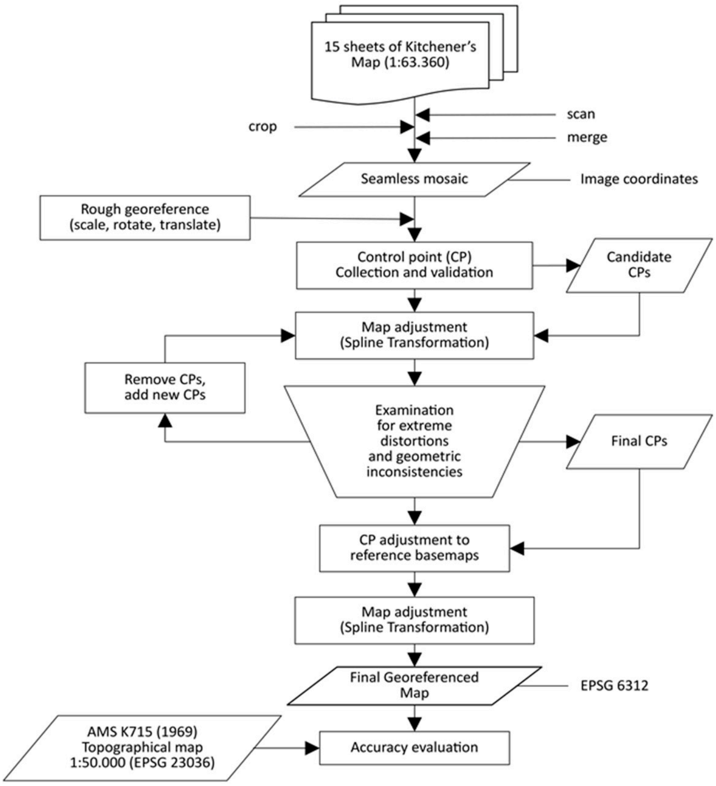

Figure 2. The georeferencing workflow.

Furthermore, during this iterative process, we were able to identify and collect additional CPs, such as important intersections within settlements, fortifications, and coastal features. After this procedure, we had 891 CPs that we eventually aligned with the reference basemap (Figure 3). Specifically, these CPs included 478 churches, 46 monasteries, 175 coastal features, 4 bridges, 182 crossroads, and 7 landmark buildings.

Figure 3. The distribution of control points used in the georeferencing process.

To assess the accuracy of the output georeferenced K-map, we compared the locations of features from this map to the locations of the same features in a modern basemap of the same scale. The results of this analysis can be found in the Results (Section 4).

3.2. Interpretation and Classification of the Geospatial Content of the K-Map

One of the difficulties in interpreting and classifying the geographic content of the K-map concerned the incomplete legend for the map. Cartographers usually include only those symbols in a legend that the reader cannot identify. This is not the case with the K-map: the legend is incomplete and, at the same time, many symbols in the map are not clearly interpretable by the reader. To facilitate the identification of the symbols, we consulted, among other sources, the legend for the map of western Palestine, for which H. H. Kitchener had been a member of the survey team before he took charge of the mapping of Cyprus [29]. This map legend proved to be far more informative than the one on the map of Cyprus. Thus, after careful examination and interpretation of the contents of the K-map, the following thematic layers were identified: (1) administrative units; (2) road networks; (3) hydrographic networks and coastlines; (4) points of interest; (5) settlements; (6) land cover; (7) telegraph lines; (8) annotations.

The administrative units layer included both districts and subdistricts (6 and 15 units, respectively), which are marked on the map with different line symbols. The road network was classified into the following three categories: (a) roads constructed following the English occupation; (b) roads under construction; and (c) other, less significant roads. The first two categories constituted the main road network on the island, as they connected the main villages and settlements, while the third category referred to local rural roads, cart tracks, and paths. Next, five types of hydrographic features forming the hydrographic network of the island were identified. These types were: (a) main streams (type1), (b) streams (type2), (c) minor streams, (d) aqueducts, and (e) irrigation channels.

Kitchener's map is undoubtedly a valuable source of information about various points of interest from that period, such as churches, monasteries, ruins, bridges, tombs, windmills, castles and towers, slags and quarries, springs, mills, and much more. All this information was classified in the points of interest category, as well as additional data for each point of interest, such as the name of the place. Geographic names referring to abandoned settlements, toponyms, and other human activities from the past are also found on the K-map. As these names are also found in other historical resources, such as cadastral surveys and censuses, organizing these names in a flexible database could support other GIS derivatives, such as historical gazetteers and automated georeferencing processes. The geographic names were organized into three individual layers: one for settlements, one for place names that follow a horizontal label and refer to geographic units, and one for place names that appear oblique or curved in the K-map and refer to broader areas or geomorphological features. Settlements were also divided into categories based on the size of the writing and the predominant religion. The latter is indicated by a cross or crescent next to the name of the settlement for Christian and Muslim villages, respectively, while no symbol appears for villages where neither religion predominates. At this stage, the interpretation of land cover was one of the most challenging tasks. The only explanation of land cover given in the brief legend of the map concerns vineyards. For the remaining classes, we consulted the legend for the survey of western Palestine and the memo from Kitchener's trip to the island before the survey. In this memo, entitled *Notes from Cyprus*, Kitchener describes some aspects of the island's landscape [37]. Finally, the land cover was classified into six main categories: natural vegetation (including dense and sparse forests), cultivated land (including cultivated land and vineyards), artificial land (for the areas occupied by settlements and *chiftliks*), landforms (including sandy areas, dunes, alluvial deposits, coastal cliffs, etc.), water bodies (for standing water and swamp/marshes), and, finally, unclassified land (for the areas for which the map does not provide any information).

The thematic layers are summarized in Table 1. Lengths and areas were calculated according to Cyprus Geodetic Reference System 1993 (CGRS93)/Cyprus Local Transverse Mercator, EPSG: 6312.

Table 1. Thematic layers of the K-map.

Layer Name	Entities	Type	Length (km)/Area (km^2)
Hydrographic networks		Line	16,727
Road networks/coastlines		Line	15,423/759
Land cover		Polygon	9253
Points of interest	3281	Point	
Place names	1080	Point/line	
Settlements	791	Point	
Elevation points	369	Point	
Milestones	25	Point	
Telegraph networks		Line	335
Subdistricts	15	Polygon	9253
Districts	6	Polygon	9253

3.3. Geodatabase Creation

The data created in the previous steps were generated in two different formats that were stored and managed in different ways: The raster data comprised the georeferenced mosaic of the island of Cyprus (as well as the plans of the cities of Nicosia and Limassol), while the vector data contained the vectorized map elements organized in thematic layers. These two categories formed the starting point for the construction of the conceptual database model. Other requirements included making it possible to: (a) publish the raster map itself, as well as its vectorized content, on the World Wide Web and Semantic Web; (b) search the map content using a keyword (which could be matched to a label or modern name found on the map). Since the georeferenced mosaic was the central component of the interactive Web map, as it was the historical map itself, it was transformed into a tiled Web map—and, more specifically, a Slippy version, following the OpenStreetMap convention [38]. To manage the vectorized map content, we used the open-source relational database PostgreSQL with the PostGIS extension. Vector data were stylized and published as a pre-rendered map using the WMS standard from a GeoServer installation (with custom SLD styling). By using a parameterized SQL view in GeoServer published as a WFS service, we were able to provide the necessary search functionality. The bilingual (Greek/English) application (i.e., data, software, and services) is currently hosted on a server kindly provided by the IT department of the Harokopio University of Athens and accessible at https://kitchener.hua.gr/en (accessed on 10 January 2023).

3.3.1. Raster Data

To create the tiled Web map version of the georeferenced mosaic, we used the QMetaTiles plugin for QGIS desktop, which takes advantage of the QGIS map rendering engine. The final size of the Slippy map tiles was 512 × 512 pixels, and they were created for zoom levels from 0 to 17. By using the above tools and methods, we created a map that only requires some Web server software (in our case, the Apache HTTPD server). The simplicity of this server-side implementation, the fairly limited requirements for software resources, and the broad support from client-side software, including most of the JavaScript Web mapping libraries, were the main advantages of this solution.

3.3.2. Vector Data

All vector layers were imported into the PostGIS database using the *shp2pgsql* utility, which is part of the GDAL library. The original names of the database tables and fields were retained to facilitate later tracking. Each database table row referred to a geographic feature shown on the original map. The database included the following groups and layers:

1. Administrative divisions:
    - District and sub-district boundaries (linear geometry);
    - District polygons;
    - Sub-district polygons;
2. Annotations not associated with any geographic feature depicted in the map:
    - Curved or tilted text (linear geometry);
    - Horizontally placed text (point geometry);
3. Points of interest:
    - Settlements (towns, villages, small villages, and *chiftliks*) (point geometry);
    - All other types of points of interest (point geometry), classified into 35 classes;
4. Water bodies/hydrographic network:
    - Rivers, streams, and canals, classified into five classes;
    - Lakes;
    - Coastlines;
5. Land cover:
    - Polygons with different types of land cover, classified into 19 classes;
6. Technical infrastructure:
    - Road networks (linear geometry), classified in four classes;
    - Telegraph lines.

3.3.3. Map Annotation

Each annotation in the K-map has its own spatial/thematic characteristics, the most important of which were: (a) location, (b) direction (e.g., river and mountain names are shown as curved lines while village and town names are placed horizontally), (c) geometry type (point vs. linear features), (d) annotation type (annotations can refer to the name of a feature or to its geographic category; e.g., the text "Ruin" or "R" is used to refer to ruins), (e) associated geographic feature, (f) font size and family, (g) value, and (h) language.

While most annotations are associated with a specific geographic feature that is explicitly presented (i.e., with a cartographic symbol), other annotations are sometimes place names that are not associated with another entity. This "rogue" cartographic text—i.e., text that is not associated with a visible or identifiable cartographic feature—was stored in separate shapefiles—namely, point shapefiles (for horizontally placed text) and polyline shapefiles (for tilted or curved text orientation)—so that the original placement of the text was also stored.

For annotation storage, we used two separate fields for the Greek and Turkish (if available) transliterated labels as seen on the map.

To improve searchability and enable retrieval via modern names, the official Gazetteers of Cyprus [39,40] were used and some of the official modern names of settlements were retrieved and stored.

3.3.4. Database Automation

A series of *bash* scripts were created to automatically import the shapefiles into the database, create derived tables and views to be later used to provide Open Web Services (namely, WFS and WMS) through GeoServer, etc. One of the goals of the automation scripts was to create additional table rows for map units related to different thematic layers. The scripts also helped to create a main table with all map features (with and without annotations). This table served as an index and provided the point of reference for faster and easier text-based searching instead of searching within individual tables and fields. Another purpose of this table was to provide a central point for querying through both WMS and WFS services. The geometry in this table was stored in a *Geometry* generic field, thus enabling the mixing of rows with different geometry types (point, line/multiline, polygon/multipolygon). To render the search results usable, an SQL view was later published as a WFS service with GeoServer, providing responses in the GeoJSON format, which has a built-in way of documenting the type of geometry for any client.

3.4. Dissemination through the Web

The project requirements involved the publication of the map and its contents through the World Wide Web in the form of an interactive, browsable, and searchable Web map, as well as in one or more machine-readable formats for the Semantic Web. One of our main goals was to disseminate the cartographic data through the Web through appropriate applications and services. To this end, we employed a Web server for the map tiles of the georeferenced mosaic. We also employed a GeoServer installation to publish the vector data as rendered map layers via a WMS service and to make it possible to explore the name databases via a WFS service. Thus, a Web application with viewing and searching functionality was developed. The Slippy map tiles of the georeferenced mosaic are served via an Apache HTTPD 2.4 Web server, minimizing additional server resources.

With the Web application published, any human user can access and interact with the map and its content. However, access to the structured map content itself as structured and machine-readable data was an additional project requirement. "Linked Data", a term coined by Sir Tim Berners-Lee [41], is now widely used as a means of publishing structured data on the Semantic Web. Berners-Lee later proposed a five-star scheme to rank the level of data on the Web, with "Linked Open Data", now commonly known as LOD, ranking the highest [42]. Currently, our work can be rated with 4.5/5 stars: although the dataset has been enriched with modern place names, this information is "hard-coded" and embedded, instead of being linked to other sources. This is because these sources have not yet been published as LOD.

Key benefits of publishing data as LOD include semantic enrichment, disambiguation, and linkage to other online and offline sources. In addition, the principles of being findable, accessible, interoperable, and reusable (FAIR) [43] have received considerable attention in the scientific community. By implementing the combined principles from the LOD and FAIR initiatives, we could adequately verify that the value of the data produced was significantly enhanced. To publish the map and its contents as LOD, we used the schema.org vocabulary and mapped the classes and properties to tables and fields, respectively, in the PostGIS database using the Ontop VKG software [44]. The Ontop system sits between the relational database and presents its data as a virtual knowledge graph. This means that the original data remain in the database and transformation to LOD occurs in real time. Of course, this is just one of the many possible ways to publish Linked Data on the Web. Ontop relies on R2RML mappings, a language for expressing custom mappings from relational databases to RDF datasets. It is a standard maintained by the W3C (https://www.w3.org/TR/r2rml, accessed on 12 October 2022). Other approaches could involve copying the data into a triple store (a database that can manage triples, such as RDF).

4. Results

4.1. Assessing the Accuracy of the Georeferenced K-Map

The mean accuracy of the final output—i.e., georeferenced map after the final spline transformation—was evaluated using CPs collected from an accurate topographic map of comparable scale. For this purpose, we used the 1:50,000 scale topographic map produced in 1969 by the U.S. Army Map Service (Map K715) and retrieved from the Library of Congress [45].

The reference system for this map is the ED50/UTM zone 36N (EPSG: 23036), and it covers the entire island of Cyprus with 25 sheets at a scale of 1:50.000. The mean rectification accuracy of this basemap is 5.5 m. Next, we identified 340 validation CPs in both the K-map and this modern basemap. To ensure accuracy, the on-screen digitization of these CPs was performed at a resolution lower than 1:5000 [46].

The total RMSE calculated with the 340 CPs located on each map was 68.76 m, which corresponded to 1.08 mm in the K-map. Furthermore, we undertook the estimation of the local RMSE for all 15 sheets of the K-map (Table 2).

Table 2. Accuracy assessment (RMSE) for each of the 15 sheets of the K-map.

Sheet	CPs	Validation CPs	RMSE
1	22	2	73.62
2	63	20	65.18
3	22	3	116.79
4	75	18	70.14
5	85	28	60.89
6	73	36	74.52
7	32	6	93.79
8	62	26	87.03
9	102	42	91.07
10	62	25	63.93
11	54	33	28.45
12	22	4	38.95
13	87	40	66.48
14	98	45	47.85
15	32	12	73.35
Total	891	340	68.76

Aggregation of CP residuals showed that the accuracy was higher in relatively flat areas with a smooth surface (sheets 5 and 10–14) and lower in remote and mountainous regions, especially the Karpasia peninsula and Troodos Mountains (sheets 3 and 7–9).

4.2. The Geospatial Content of the K-Map

Based on the interpretation of the contents of the original map, different categories of land cover and other geographic elements were identified. These categories were digitized for the entire island from the georeferenced K-map in the ArcGIS 10.4 environment. The on-screen digitization was performed at a resolution lower than 1:5000 [39]. However, several conceptual ambiguities in the K-map and the lack of an explanatory legend resulted in a dataset in which certain features remained unclear and additional information had to be added to the digital data. The most important incompleteness was found in the land cover layer: no symbols are provided for more than half of the island, potentially leading the reader to interpret the lack of symbols as bare ground soil. In addition, no crops other than vineyards are clearly distinguishable. Further ambiguity arises from the sections of the road network that are labeled as "under construction" in the legend of the K-map. The interpretation process revealed that these were mostly Ottoman roads that the British administration decided to develop and that were fully completed in 1903, although some of them were never built. The interpretation process also revealed that the boundaries of the 15 administrative regions marked on the map fully correspond to the 1891 census divisions and not to those of the census conducted during the survey of the map in 1881. The K-map undoubtedly contains elements of British future planning and has conceptual ambiguities related to time that need to be incorporated into the digital data.

4.2.1. Settlements

The first layer of information compiled was that for settlements. The location of each settlement, stored in the digitization phase as a point with known geographic coordinates, was linked to the descriptive information for the settlement. The description of each settlement included the primary and secondary spelling (if applicable) of the name as recorded on the K-map, the type of settlement, and information about the predominant religion of the settlement. Of the 791 entities in this dataset, 640 corresponded to main settlements (towns and villages), 73 to minor settlements, and 79 to *chiftliks*. A total of

295 of the main settlements consisted mainly of a Christian population, 97 of a Muslim population, and 248 of mixed populations.

4.2.2. Land Cover

According to the K-map, the study area consisted of 36% natural vegetation, 8% agricultural land, 54% unclassified land, and 2% other land (less than 1% was built-up areas). Annual crops, such as cotton, cereals, and bare soil, for which the K-map does not provide a spatial definition, were included in unclassified land. Most of this land (86%) was located in the central plain of the island and below 400 m asl, where most agricultural land is found. Land cover classes across the modern administration districts of Cyprus are summarized in Table 3.

Table 3. Percentage (%) of land cover categories by administration district and elevation zone.

		Natural Vegetation	Cropland	Artificial Surfaces	Unclassified	Landforms	Water Bodies
District	Ammochostos	5.69	1.27	0.19	14.08	0.04	0.14
	Keryneia	4.61	0.28	0.04	2.02	0.01	0
	Larnaka	2.03	1.61	0.08	8.24	0.06	0.11
	Lefkosia	10.48	2	0.24	16.56	0.01	0.07
	Lemesos	7.3	2.08	0.09	5.08	0.24	0.27
	Pafos	5.81	0.93	0.09	8.16	0.1	0
Elevation zone (asl)	0–400	19.74	5.12	0.6	46.54	0.35	0.59
	400–800	10.87	2.03	0.07	6.49	0.11	0
	800+	5.3	1.01	0.03	1.12	0.01	0

The only explicitly depicted land use/cover class in the legend of the K-map is vineyards. This, among other information, enabled a longitudinal study of the distribution of vineyards from the 16th to the 20th century [47]. Out of the total area recorded on the map (238.3 km^2), 47% is located in the southern mountainous and hilly area of Troodos in Lemesos district, 35% in the northern mountainous side of Troodos in Lefkosia district, 12% in the eastern hilly area of Troodos in Larnaka district, and 5% in Pafos. The vineyards are located in the southern part of the island around the mountainous area of Troodos, with small (less than 1.5 km^2) pockets in the districts of Ammochostos and Keryneia. A small excerpt of the land cover layer is shown in Figure 4.

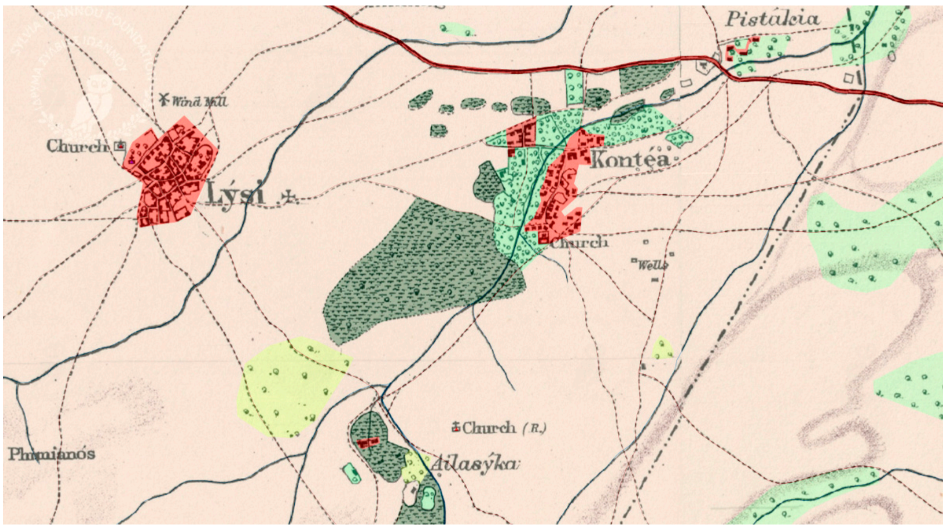

Figure 4. Various geospatial entities in the central plain of the island colored according to GIS layers: red polygons—settlements, green polygons—vineyards, pale green polygons—agricultural land, red lines—roads, blue lines—streams. Wells, ruins, windmills, and churches are also visible.

4.2.3. Road Network/Hydrographic Network

For the road network, which has a total length of 15.42 km, 2.9% consists of roads that had been built following the British occupation, 3.45% of roads under construction at the time of the survey, and 93.5% of cart-tracks and paths. Road density was higher in the districts of Lefkosia and Pafos and lower in Keryneia and Ammochostos. The density of the drainage network, totaling 16.73 km, was higher in the southern part of the island, in the districts of Pafos and Lemesos, and lower in Ammochostos. For some major branches of the stream network, the name of the stream was also recorded on the K-map. This information is often very useful—especially for names that have not survived to the present day—as it is linked to relevant references in other historical documents

4.2.4. Telegraph

The K-map also records 335 km of the telegraph network on the island, connecting the six major cities (Lefkosia, Ammochostos, Larnaka, Lemesos, Keryneia, Pafos) and the two government buildings (outside Lefkosia and Troodos). The junction for the submarine cable connecting the island with Latakia in Syria is also marked on the map outside the village of Ayios Theodoros on the Karpasia peninsula. The network was built partly by the Ottoman Empire in the 1870s, which established 110 km of cable (Larnaka, Lefkosia, Ayios Theodoros) and the connection with the rest of its network, and partly by the British in 1878–1883.

4.2.5. Landmarks

A total of 3281 landmarks or points of interest were identified on the K-map and classified into 33 different categories. These points are summarized in Table 4 using the modern administrative districts of the Republic of Cyprus. Features with low frequency, such as ponds, weirs, forts, stones, reservoirs, towers, sheds, wells, cottages, and castles, were included in the "Other" class. Livestock enclosures are referred to as sheepfolds and *mandra* (i.e., wall). These were evenly distributed across the island, except in the following areas where they were absent: (a) the district of Ammochostos, (b) the non-mountainous area of Larnaka, (c) the northern side of Mount Pendadaktylos in Keryneia, and (d) the hilly, vineyard-dominated area in Larnaka. In contrast, their density was higher in the Pafos district. There were no wells in the entirety of the Troodos Mountains; they were concentrated in the plains of the island, with the highest density around the city of Lefkosia. Churches were evenly distributed throughout the Island.

Table 4. Landmarks collected across administration districts.

	Ammochostos	**Keryneia**	**Larnaka**	**Lefkosia**	**Lemesos**	**Pafos**	**Total**
Well	127	19	145	884	20	17	1212
Church	164	45	80	176	157	120	742
Ruin	53	17	30	74	52	58	284
Sheepfold	16	12	16	71	53	100	268
Water mill	3	5	22	56	21	42	149
Trig. station	9	5	8	52	25	22	121
Spring	11	12	8	29	14	32	106
Bridge	7		5	51	20	10	93
Monastery	8	8	7	20	10	14	67
Kiln	44		7	4	1		56
Other	6	5	6	11	11	6	45
Mandra	1	6		21			28
Cemetery	4	1	2	8	3	2	20
Tank	8			4	6	2	20
Quarry	2			9	3		14
Cave	7		2			2	11
Tomb	5			4	1	1	11
Grave	6			4		1	11

Table 4. *Cont.*

	Ammochostos	Keryneia	Larnaka	Lefkosia	Lemesos	Pafos	Total
Slag				8		1	9
Mosque	1			4		2	7
Windmill	5		2				7

4.3. The Web Application

The Web application was developed as the main resource for dissemination of the historical geospatial data through the Web (Figure 5). Developed using the typical HTML5/CSS3/JavaScript combination, we employed the OpenLayers 6.10 JavaScript library (https://openlayers.org, accessed on 12 October 2022) for all map viewing and navigational functionality. OpenLayers allows dynamic and interactive maps to be embedded in any Web page and supports map tiles, as well as vector data loaded from various sources. The graphical interface was based on the Bootstrap CSS library version 5.1 (https://getbootstrap.com/, accessed on 12 October 2022), which is a widely used, front-end-customizable Web toolkit with features for layout, widgets, content, and typography. The following list presents the main components of the Web application:

1. The main map, consisting of the basemaps—i.e., the georeferenced raster K-map as tiles (Slippy map) and a set of modern basemaps (OpenStreetMap, Stamen, etc.)—and the vectorized thematic layers presented as a single WMS overlay;
2. Tools to enable/disable thematic and basemap layers;
3. Navigation tools (zooming and panning the map);
4. Tools for identifying the properties of individual map features in a pop-up window;
5. Tools for searching for names found in the original map;
6. Informative text about the map itself, the topographic survey, the Web application, and the research project.

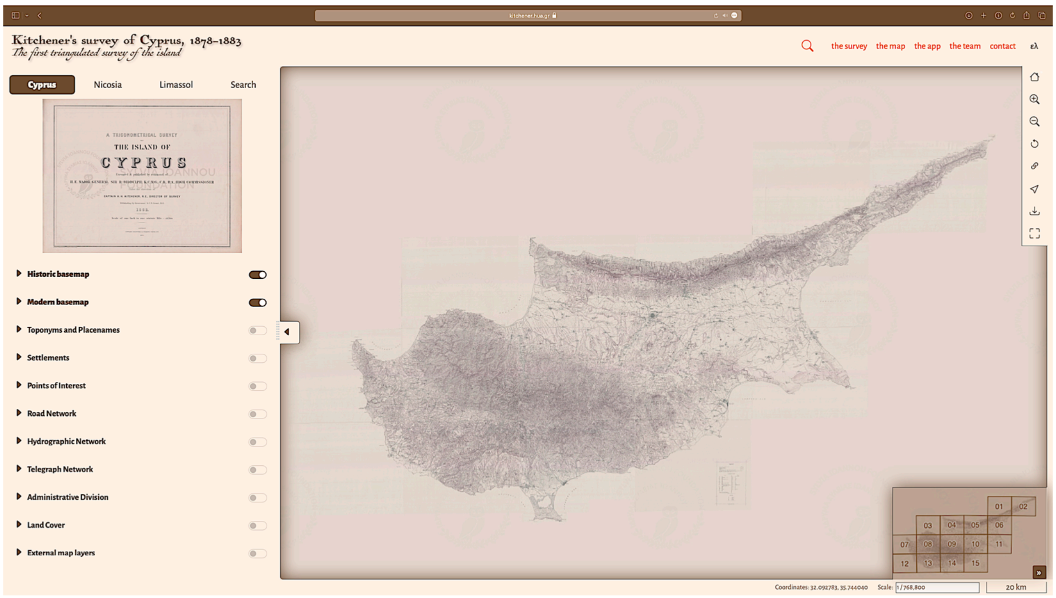

Figure 5. The main screen of the Web application (https://kitchener.hua.gr/en, accessed on 10 January 2023).

The available thematic layers and all application settings were stored in a custom JSON document. Vectorized tiles are requested as a single image, regardless of the visible layers selected by the user, minimizing network requests and server resources. Searching for names is accomplished by calling a properly configured WFS service, returning results in the GeoJSON format. This WFS service is based on the published parametric search view and uses the search term as its parameter. Below is an excerpt from the SQL code used in GeoServer:

```
SELECT * FROM geographic_search_view WHERE lower(unaccent(name)) ILIKE ('%' || lower(unaccent('%term%')) || '%')
```

where "*term*" is the search term entered by the user. By using the "*ILIKE*" operator along with the "*unaccent*" and "*lower*" functions (available as PostGRESQL extensions), the case and any accented characters can be ignored, both in the search term and in the database (as some Greek words contain letters with diacritics).

5. Discussion

We have described a process in the GIS context whereby a historical map of Cyprus was used to gather geographic information and create knowledge. As far as we know, this is one of the first attempts to create a historical geodatabase at the national level and the first complete historical geodatabase for the island of Cyprus.

Historical maps preserve valuable information about the past, and in many cases, they are the only available source that can be used to reconstruct that past. However, depending on the historical period, the techniques, and the cartographer, historical maps may contain a variety of uncertainties that researchers should consider [16,48,49]. The accuracy of early cartographic maps limits the analytical time frames of studies and presents a challenge for methodology [50].

Kitchener and his team surveyed Cyprus immediately after the establishment of the British administration on the island. The detailed K-map focuses mainly on roads, settlements, the hydrographic network, and place names, as well as all major landmarks on the island. The fact that they surveyed an area with complex topography and remote regions and produced an accurate map using the simple equipment of the time is a testament to the professional efforts of Kitchener and his team. This is consistent with the results of other studies that have analyzed the surveys of the British in the Levant and elsewhere [20,51].

The use of GIS technology provides a historical–geographical framework to explore the past. Recording geographic factors and reducing them to the present, as described in this paper, can add value to them [52]. Georeferencing the historical map using carefully selected CPs was the critical first step in this process. Evaluation of the accuracy of the K-map showed an overall RMSE of 68.76 m. Previous work on the map from the 1865 Palestine Exploration Fund yielded an RMSE of 74.4 m for this map [9]. Although the global RMSE is a well-known statistic and an indicative measure of the accuracy of a georeferencing process, it cannot represent the true geographic distribution of inaccuracies. For example, the collection of data by different survey teams over a five-year period (1878–1883) and the varying density of the trigonometric network on the island resulted in significant spatial inequalities in the accuracy of the K-map. These inequalities had to be associated with the digital data produced by the georeferencing process. The largest distortions were found at the extreme ends of the island and over mountainous areas. Survey teams were not always welcomed by local people, who, in many cases, destroyed cairns set up by the teams to facilitate the measurements. The triangulation network was not well-developed, especially on the Karpasia Peninsula and in the Troodos Massif, where the largest variations were found. The inaccuracies in the network prompted the authorities to re-triangulate the island a few years later. From a methodological point of view, the georeferencing process presented here was highly dependent on the selection of many reliable CPs, mainly churches. This was a challenging and time-consuming procedure in our analysis. For this procedure, we used various additional historical and modern data to confirm the location of these CPs.

Symbols on a map represent features or phenomena through concepts, and these concepts can sometimes be used to distinguish between map types. However, when an incomplete map legend is provided, interpretation is dependent on the reader's experience and ability to predict the types of symbols expected on a map [53]. In our case, Kitchener himself and/or Stanford's employees made specific choices and omitted certain symbols from the legend, something that might be understandable and expected for a 19th century map reader (although one can argue that this was not the case, since the legend for the Palestine map, which preceded the K-map, contains more symbols in comparison). Moreover, oral (instead of written) communication of map signs was typical in early maps, something that continued long after the medieval period [54]. However, a 21st century reader cannot assume with absolute certainty that they can interpret these symbols as intended, and so there is an additional personal bias in interpretation. In our attempt to minimize our own personal bias in interpreting symbols not included in the legend, we consulted an earlier map involving both Kitchener (as surveyor and director) and Stanford (as publisher). This disputable, although untypical, choice resulted in a classification scheme for the map symbols. Thus, in its totality, the geospatial content interpreted from the K-map cannot be considered as completely factual, since it not only reflects the assessment of its creator but also the interpretation by our research team, as well as the other technical limitations of the period. Assuming that the class or concept of a symbol is an attribute, it should be possible to document and incorporate this type of attribute assignment occurring during identification and classification into a dataset. However, typical metadata schemas are more suited to modeling unambiguous assignments of properties, and they do not actually consider the structural elements of maps, their properties, or their peculiarities. For this reason, a more semantically oriented and ontology-based metadata model should be used, in which all attribute assignment actions can be clearly documented, modeled, and later queried and compared. Since the schema.org vocabulary does not contain relevant classes, two efforts are worth mentioning in this context: the CRMinf (https://cidoc-crm.org/crminf/, accessed on 12 October 2022) and the CRMsci (https://cidoc-crm.org/crmsci/, accessed on 12 October 2022), both extensions to the CIDOC CRM. The first was motivated by argumentation about facts from (among others) archaeological reasoning and annotations in manuscripts, while the latter is intended to be used for integrating metadata about scientific observations in general. Our future work, since it is already based on the CIDOC CRM, will take advantage of these extensions, and we expect that this practice will be widely adopted by the cartographic community.

Aside from the previously mentioned assumptions and limitations, the results of this work can help to understand the geography of Cyprus in the late Ottoman and early British periods, confirm the results of other work on this period [24,25], and support further research on the K-Map.

6. Conclusions

In this work, a spatial database representing the geography of Cyprus in the late 19th century was created using the K-map and GIScience techniques. Georeferencing the historical map using carefully selected control points was the crucial first step in this work. Another critical aspect of this process was the interpretation and conceptual classification of the map content.

The total RMSE for the K-map was determined to be approximately 68.76 m, which corresponded to a value of 1.08 mm at a map scale of 1:63,360. Based on the georeferenced K-map, various datasets related to the island's settlements, infrastructures, hydrography, place names, and landmarks were interpreted and digitized.

The Linked Open Data approach proposed here, combined with the definition of ontologies representing the context of the historical map, allows the integration of the results of our analysis with other historical geospatial data and similar systems. Moreover, the visualization of the geographic content of the K-map through the Web application will increase the accessibility of this useful material about the geography of Cyprus in the 19th century. The empirical analysis of the K-map illustrates the value of GIScience for the assessment and visualization of the geographic conditions in Cyprus in the late 19th century. Despite the fact that there is still much work to be done to fully overcome the limitations of the proposed analysis of historical maps, these approaches can help scholars and practitioners to better understand the importance of GIScience for research in the spatial humanities.

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