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# Follow the road: historical GIS for evaluating the development of routes in the Negev region during the twentieth century

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**ABSTRACT**

At the beginning of the twentieth century, a British mapping team led by Captain S. F. Newcombe surveyed and mapped the Negev region, Sinai, and western Jordan. The map was mainly produced for military use. Consequently, it included a network of branched routes, water supplies and facilities, and topographic contours. This study used this map to examine the development of routes in the Negev region between the beginning of and until the end of the twentieth century. First, the individual sheets comprising the study area were pieced together and the accuracy of the map was evaluated. The accuracy found on the Newcombe map was 0.76 mm on the map scale, equivalent to 100.3 m. Route development during the twentieth century was then evaluated by comparing the routes digitized from the Newcombe map to digitized routes on a late twentieth-century map. The results do not reveal tremendous changes in path, shape, or number of routes. Instead, they merely indicate the natural development in their quality. This Historical GIS-based approach provided a useful technique for analyzing and comparing the line segments extracted from historical and modern maps. The implemented approach may also serve other geographical or historical studies aiming to examine the development of branched networks throughout history.

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Historical GIS; historical maps; Palestine; Newcombe; routes; accuracy of historical maps

## Introduction

The Negev region at the beginning of the twentieth century was deserted and sparsely populated (Biger, 1986). Because of the extreme aridity of less than 200 mm of annual precipitation (Goldreich, 2003), the majority of the population was nomadic and concentrating primarily around available water supplies (Ben-David, 1986). Considering the absence of urbanized settlements and steady population, the main artificial landscape features were routes which connected the Negev region with northern Sinai, Arabia, and Transjordan (Figure 1). Some ancient routes, such as the Incense Road (Erickson-Gini & Israel, 2013; Meshel & Tsafrir, 1974), were merely remains of old trading routes while others were established by the Ottomans and the Germans, their ally at the time (Rubinstein, 2000, pp. 12–16). Aside from a few exceptions such as the Peutinger (Finkelstein, 1978) and Madaba (Avi-Yonah, 1953) maps, the limited attention to the region until the beginning of the twentieth century was probably the reason that these routes were hardly surveyed and mapped.

The first topographic map of Palestine that used trigonometric measurements was conducted in 1799 during Napoleon's military expedition, surveying Palestine on the way from Egypt to Acre. The map produced by the escorting French cartographer Pierre Jacotin included six sheets at 1:100,000 scale (Jacotin, 1818). However, the map was incomplete and contained unsurveyed regions, thus resulting in considerable errors (Karmon, 1960). In mid-nineteenth century significant geopolitical changes occurred. The Crimean war (1856), the opening of the Suez Canal (1869), and British takeover of Egypt (1882) kindled the interests of Britain, France, and other European nations in Palestine (Ben-Arieh, 1972). As part of their competition and imperialistic ambitions and awareness of the power of maps in promoting their geopolitical interests (Edney, 2009; Harley, 2009; Withers, 2013), the European nations initiated surveys and mapping expeditions primarily for scientific purposes but later on, also for military use (Collier & Inkpen, 2001; Goren, 2001; Hopkins, 1968; Jones, 1973; Moscrop, 2000). In 1865, the British established the Palestine Exploration Fund (PEF) conducting a comprehensive survey of Palestine between 1871 and 1877, led by professional officers of the Royal Engineers Corps of the British army (Moscrop, 2002). An important product of their survey was a reliable and accurate map of Palestine comprising 26 sheets on a scale of an inch to a mile (1:63,360) published in 1881 (Conder &

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Supplemental data for this article can be accessed here.

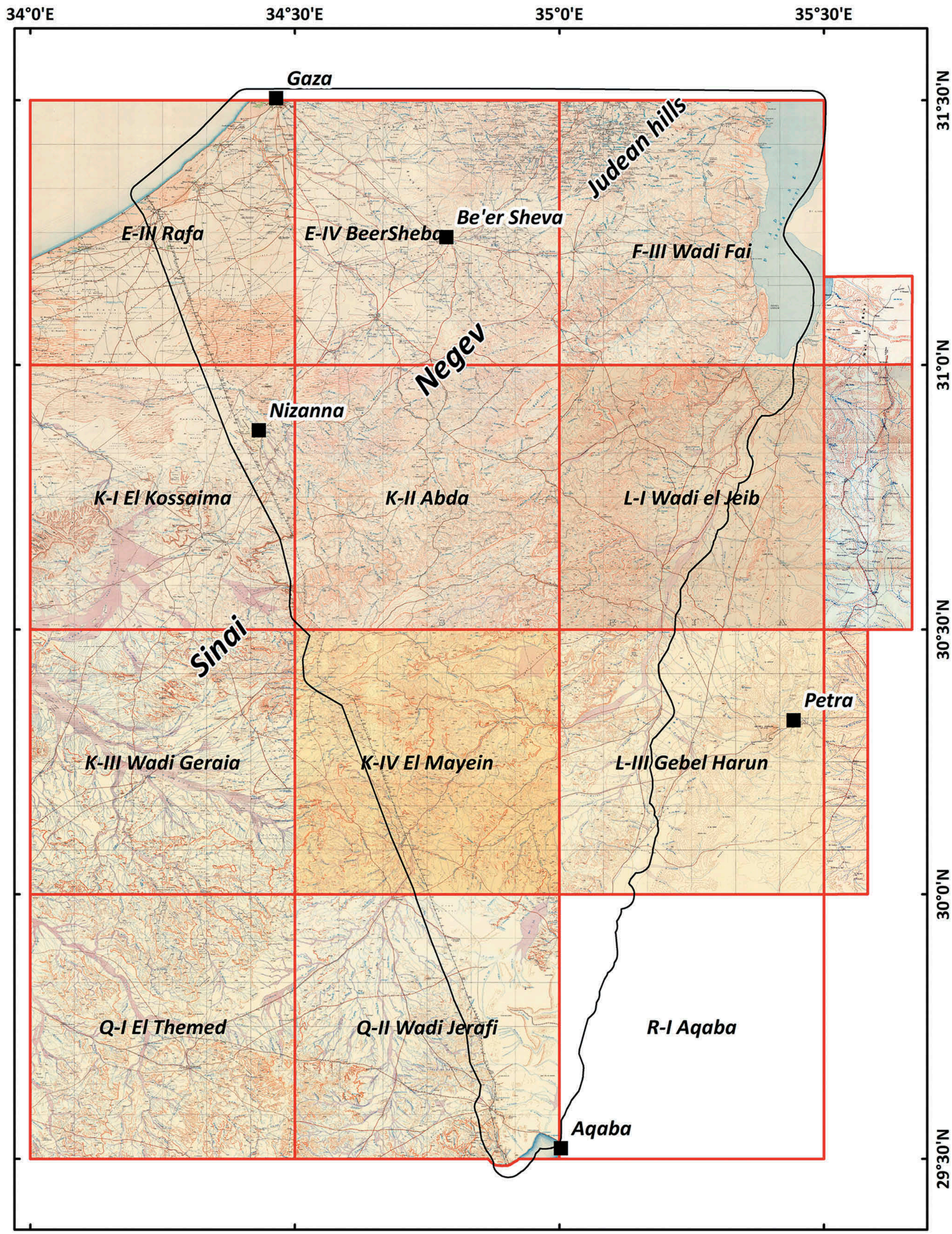


**Figure 1.** The study area of southern Palestine (delineated in black) and the mosaic of the relevant Newcombe sheets (red grid). Note: the sheets of Wadi Fai, Wadi el-Jeib and Gebel Harun are wider than the other sheets.

Kitchener, 1881). At the same time, the French also dispatched a delegation to map the central and western Galilee (1870) while other foreign efforts were made by individual Germans, Dutch, and Russians (Goren, 2002). Ottoman maps were also made during the second half of the nineteenth century (Ben-Bassat & Ben-Artzi, 2015), along with attempts to determine land ownership using cadastral maps (Gavish & Kark, 1993; Kark, 2009). Nevertheless, none of the maps covered the geographic area south of Be'er Sheva while the Negev region and northern Sinai were neglected. In the late 1890s, the British officer George Armstrong extended the coverage of the PEF map to the Negev region. However, important details in many parts of this map were omitted or were relatively poor (see, for example, the areas labeled as "Unexplored" in sheet 20, Armstrong, 1890).

Perhaps the first detailed maps that fully cover the Negev region (including existing routes) were compiled in 1915 by the British War Office. These maps, on the scales of 1:125,000 and 1:250,000, were based on a survey conducted during 1909–1913 (before the war) by five mapping teams led by Captain S. F. Newcombe (Collier, 1994). The 1:125,000 map, comprises 23 sheets, contains information relevant to military purposes, such as routes (whether passable by light-wheeled traffic or laden camels), water resources (including their quality and quantity), topographic height contours, sand dunes, and boreholes. In addition, it contains general information (as notes) describing specific attributes of the geographic extent of each sheet. Due to the richness of details in this map, it was chosen for this study as the earliest map suitable for reconstructing routes in the Negev region at the beginning of the twentieth century.

## Historical sources for geographic analysis

Utilizing historical maps for past landscape reconstruction is gradually increasing. Historical maps provide valuable spatial information (Rumsey & Williams, 2002) and are considered among the useful resources for this purpose. In many cases, they are the sole source of past scenes long after the landscape was changed or specific features no longer exist. Historical maps also enable accurate geographic analysis of the features under investigation and facilitate the detection of locations and place names (Knowles, 2008). Obviously, like any other historical sources, maps should be carefully inspected for inaccuracies, errors, and exaggerations that may exist (e.g., Tucci & Giordano, 2011). This is true in particular for non-referenced maps; namely, maps lacking a Coordinate Reference System (CRS) and thus may contain substantial horizontal and vertical errors. To evaluate the accuracy of a given historical map, the best practice known so far is georeferencing it to a modern map surveyed and produced using accurate and digital techniques (Zitova & Flusser, 2003). This approach has gained popularity and has been applied in many studies (e.g., Bender, Boehmer, Jens, & Schumacher, 2005; Bromberg & Bertness, 2005; Haase, Walz, Neubert, & Rosenberg, 2007; Manzano, Martínez, & San-Antonio-Gomez, 2012; Petit & Lambin, 2002; San-Antonio-Gómez, Velilla, & Manzano-Agugliaro, 2014; Schaffer & Levin, 2016, 2014).

Until a few decades ago, georeferencing a historical map was almost entirely manual, thus leading to potential human errors. The introduction of the Geographic Information System (GIS) has significantly decreased these potential errors and facilitated georeferencing by providing geo-computational techniques (Gregory & Ell, 2007). The use of GIS also fosters the development of specific tools and customizations (e.g., Jenny, Weber, & Hurni, 2007), as well as the awareness of accuracy verification (Schaffer & Levin, 2015; Schaffer, Peer, & Levin, 2016). With GIS the digitization, visualization, and analysis of historical maps are more efficient, and the results can be presented in 2D (Levin, 2006) or 3D (Davie & Frumin, 2007; Zohar, 2017). The rapid assimilation of GIS by various scientific disciplines did not skip historical studies (Gregory & Geddes, 2014; Knowles, 2008) and in fact evolved lately into a new subdiscipline, referred to as Historical GIS (HGIS) (Bailey & Schick, 2009). However, only a few HGIS-based studies have been conducted for the Negev region (e.g., Levin, Kark, & Galilee, 2010; Saidel & Christopherson, 2005).

In this study, the 1:125,000 Newcombe map is used to trace routes at the beginning of the twentieth century and analyze their development toward the end of that century. The underlying hypothesis is that due to the aridity of the region and its remoteness, many of the early twentieth-century routes still exist a century later, even preserving their initial paths and shapes. Thus, the targets of this study are: (1) Combining the Newcombe sheets that span the Negev region and creating a single, continuous map (mosaic); (2) Evaluating the planimetric accuracy and completeness of the Newcombe map; (3) Demonstrating an HGIS methodology to examine the similarity between two route networks; and (4) Characterizing the development of routes in the Negev region based on two snapshots, the first at the beginning and the second toward the late twentieth century.

## Material and methods

The Newcombe map chosen for analysis comprises 23 sheets spanning present eastern Egypt (including Sinai), southern Israel and western Jordan. The map scale is 1:125,000 (1 inch to 1.97 miles) with topographic height contours in intervals of approximately 100 feet. The map includes the following geographic features in several colors and symbols: (1) height contours – light brown shading; (2) rivers, wadis, and all types of boreholes and springs – dark blue; (3) towns and settlements – light gray while their names are in black; and (4) major routes – light red, categorized into roads passable by light-wheeled traffic and roads passable by laden camels (see Figure 2(a)). The details used to map the area north of Be'er Sheva were taken from the trigonometric network of the PEF map and were also adjusted to conform to the Sinai Survey (Newcombe, 1914a). Yet the accuracy and completeness of the Newcombe map had not been previously evaluated.

The area under investigation mainly includes the sheets of the Newcombe map between 29.5°N and

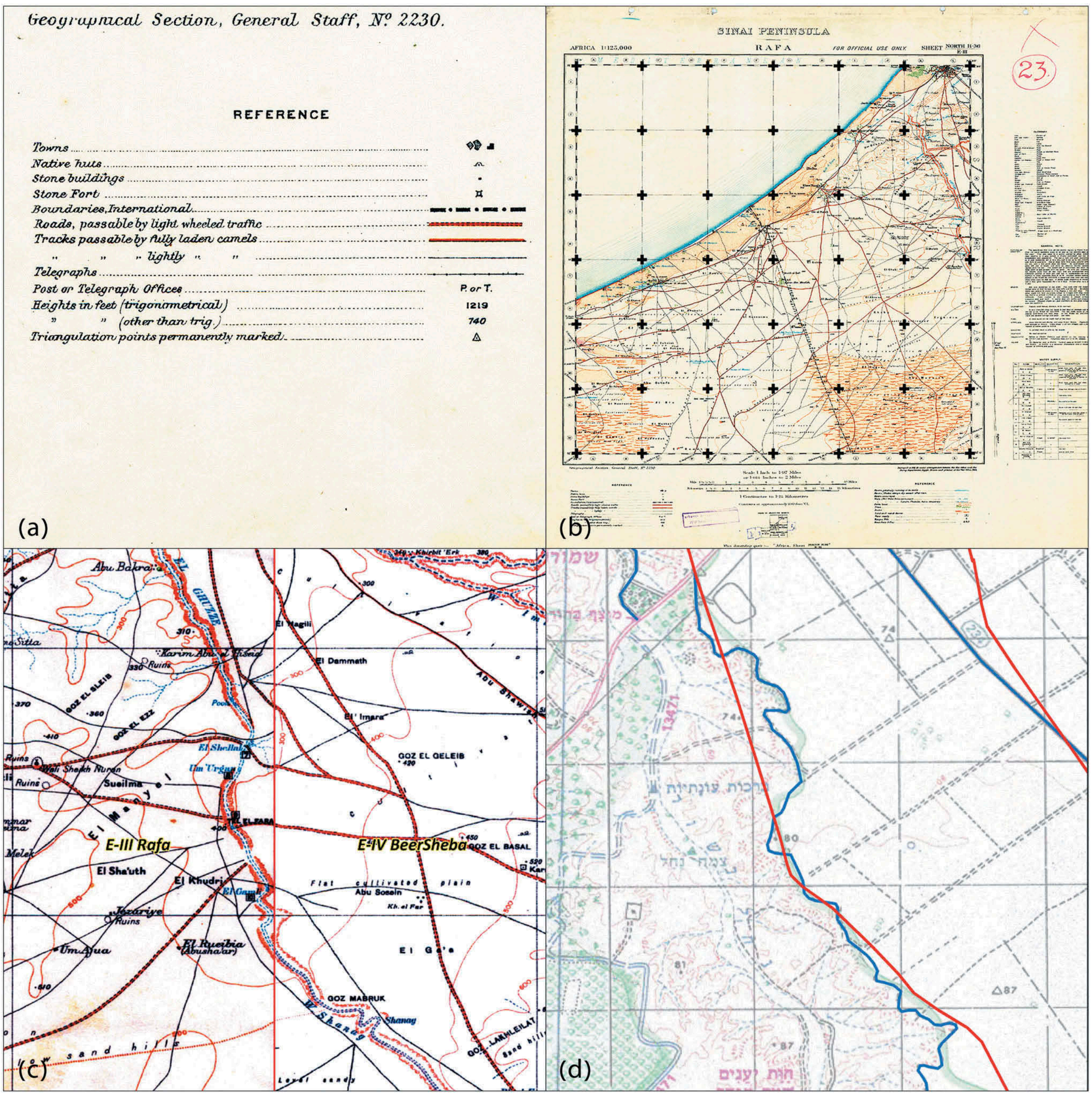


Figure 2. (a) Legend of the Newcombe map with the classification of the surveyed routes; (b) Control Points (CPs, denoted by black crosses) used for the rectification of the Rafa sheet; (c) Mosaic of Rafa and the Be'er Sheba sheets using rubber-sheeting. Note the continuity of routes and rivers across the meeting line of the two sheets; (d) Line features as digitized using the Newcombe and the 1:50,000 modern topographic maps noted by red and blue lines, respectively. The accuracy and completeness of the latter occasionally yield a longer route, in particular when it follows the track of a curved river such as the Besor River.

31.5°N, and between northern Sinai to the southwest and the Jordan river to the east (Figure 1). Altogether, the study area and its close surroundings are displayed in 11 of the 23 sheets (Table 1). Exceptionally, the district of Aqaba was not surveyed by Newcombe and his teams due to the unwillingness of the Ottoman authorities to permit a survey in that area. Instead, Newcombe relied on the previous mapping made by Major Kitchener in 1883 (Newcombe, 1914b) and perhaps this explains why the sheet of the Aqaba district is not included in his 1:125,000 map. Most of the 11 sheets cover a geographic area of 30'*30' (~2,650 $km^2$) except the sheets for Wadi Fai and Wadi el-Jeib, which cover an area of 30'*40' (~2,913 $km^2$, excluding the area covered by the legend of the map), and Gebel Harun, which covers an area of 30'*35' (~3,130 $km^2$). The 11 sheets were obtained from the map library at the Hebrew University of Jerusalem as uncompressed JPEG files at a resolution of 300 dpi (dots per inch).

## Combining the 11 sheets into a single map

The technique most commonly used to piece together (mosaic) separate sheets into a single map is referred to as rubber-sheeting (Doytsher, 2000) or zipping that apply also topological validation on two sides of map sheets adjustment (Beard & Chrisman, 1988). Since the Newcombe sheets were consistently produced together by the same cartographers (Newcombe, 1914b), one may assume that the original matching procedure between the sheets was fairly accurate. That is, for piecing together the 11 Newcombe sheets the rubber-sheeting is sufficient and thus adjacent sheets were combined along their meeting lines using a local transformation of CPs. Each of the Newcombe sheets has a network of geographic coordinates with an interval of 5'and notable labels at the edges. Accordingly, CPs were digitized and pinpointed along the edges and corners of each sheet and in the sheet interior at the crossings of longitude and latitude grid-lines (Figure 2(b)). To assure accuracy, the on-screen digitization of these CPs was made at a resolution of less than 1:5,000 (Schaffer & Levin, 2015). Once the CPs were digitized and well-fitted, each of the sheets was rectified using the ArcGIS Desktop© software "Adjust" transformation module, which preserves the CPs positions to fit locally using a triangular interpolation technique and polynomial transformation. Accordingly, the topology and shape of overlapping features between two sheets or more are preserved, thus reducing potential deformations that might have occurred during the scan of the paper sheets into digital files (Shimizu & Fuse, 2003). The cell resolution of the rectified sheets was set to 0.00001 decimal degrees (~1 m) using bilinear interpolation. The rectification details of the 11 sheets and the resulting plenary accuracy are summarized in Table 1.

**Table 1.** Rectification results and accuracy assessments (RMSE) for each of the 11 sheets of the Newcombe map that comprise the study area.

| Sheet No | Original sheet (full title) | ~Area ($km^2$) | No of CPs | Total RMSE (meters) |
|---|---|---|---|---|
| 1 | North H36 E-III Rafa | 2,650 | 49 | 4.73 |
| 2 | North H36 E-IV Be'er Sheba | 2,650 | 49 | 4.18 |
| 3 | North H36F-III Wadi Fai | 2,913 | 55 | 3.15 |
| 4 | North H36K-I El-Kossaima | 2,650 | 49 | 5.12 |
| 5 | North H36K-II Abda | 2,650 | 49 | 4.70 |
| 6 | North H36L-I Wadi el-Jeib | 2,913 | 63 | 4.72 |
| 7 | North H36K-III Wadi Geraia | 2,650 | 49 | 3.43 |
| 8 | North H36K-IV El Mayein | 2,650 | 49 | 4.32 |
| 9 | North H36L-III Gebel Harun | 3,130 | 56 | 5.37 |
| 10 | North H36Q-I El Themed | 2,650 | 49 | 4.05 |
| 11 | North H36Q-II Wadi Jerafi | 2,650 | 49 | 4.87 |
| Average | | | | 4.42 |

The accuracy of the rectification process was estimated using the Root Mean Square Error (RMSE). This value presents the average of the horizontal and vertical differences in the locations of the CPs, as digitized on a given sheet, to their actual placed locations following a Least-Squares Fitting calculation. Equations (1) and (2) demonstrate the process:

$$\text{RMSE} = \sqrt{u^2 + v^2} \quad (1)$$

$$\text{Total RMSE} = \sqrt{\frac{\sum_i^N RMSE^2}{N}} \quad (2)$$

where RMSE is the error of each CP; $u$ and $v$ are the horizontal and vertical errors, respectively, and $N$ is the number of CPs.

The 11 rectified sheets were clipped to their geographic extent without the margins and other descriptive items such as legend and notes and pieced together into a single file (Figure 1). During this process, adjacent sheets were matched along their borders and a continuous map across meeting lines was generated, notwithstanding the various overlapping features (whether routes, rivers, mountains, ridges, etc.). An example demonstrating the edge match between the Rafa and Be'er Sheba sheets is presented in Figure 2(c).

## Registration of the Newcombe map

Map registration methods are based on matching identical geographic features both on the map to be registered and on a modern map produced with high standards of accuracy (Minnesota-Planning, 1999). The matching features, referred to as Ground Control Points (GCPs), may be any landscape feature that can be pinpointed with precise longitude and latitude coordinates. The modern map used is a topographic map on a 1:50,000 scale produced in the late 1990s by the Survey of Israel and registered in the Israel Transverse Mercator (ITM) CRS (Mugnier, 2000). The scan of this map was made at a resolution of 150 dpi and was obtained through the courtesy of the GIS computing center at the Hebrew University of Jerusalem. The chosen GCPs were: (1) 59 triangulation points digitized with their elevation values; (2) 601 points of interest (POI) such as monuments, crossroads, ruins, mosques, churches and forts, springs, wells, and boreholes, as well as topographic tops. Altogether, 660 GCPs were digitized in both maps and matched at a screen resolution of less than 1:5,000 (Figure 3).

After the various GCPs were matched, several transformation models were examined, and the best fit was chosen (see the Results section). Using the fitted model, the Newcombe map was resampled and rectified to the ITM CRS (Mugnier, 2000).

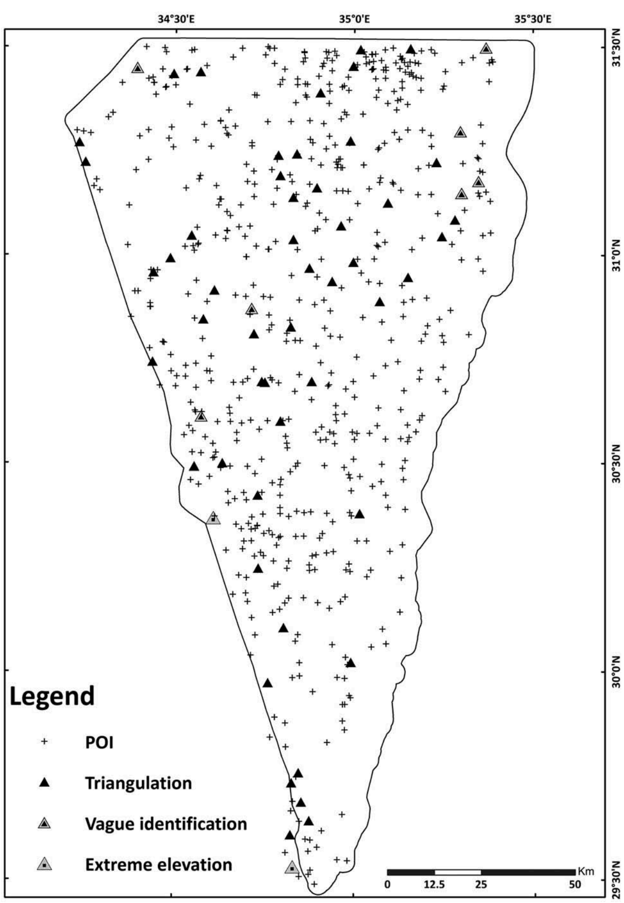


**Figure 3.** GCPs used for feature detection and feature matching: (1) 601 POIs (Points of Interest); (2) 52 Triangulation points; (3) and seven Triangulation points with vague identification or whose registration error was greater than 200 m. Two of the triangulation points with extreme elevation differences (in comparison with the analog values on the modern map) are also indicated.

## Digitization of routes

Once the Newcombe map was rectified to the same CRS as the modern map (ITM), routes on both maps were digitized, and two sets of route networks were created: the set based on the Newcombe map which corresponds to the beginning of the twentieth century and a set representing modern routes from the end of the twentieth century (Figure 4). A modern route was digitized only in case it is located within proximity of less than 2500 m from the Newcombe routes (Figure 2(d)). Altogether, 116 pairs of routes were digitized. For comparison purposes, each of the modern routes was assigned with the same unique identifier of the closest Newcombe route within the 2,500 m buffer zone. Thereby, the spatial and nonspatial properties of adjacent Newcombe and modern routes can be compared and examined based on a common identifier.

The Newcombe routes are divided into two categories (Figure 4(a)): (1) roads passable by light-wheeled traffic; and (2) roads passable by laden camels, as these were the main carriers for Newcombe's team (Newcombe, 1914b). The rest of the routes in the Newcombe map were not digitized for they seem to have had minor transportation significance at the time. The digitized routes based on the modern map were divided into seven categories (Figure 4 (b)): (1) two-way main roads; (2) main roads; (3) secondary roads; (4) paved roads or roads passable by any vehicle; (5) roads passable only by 4 × 4 vehicles; (6) unpaved roads (type A and B); and (7) paths.

### Similarity of the two route networks

Evaluating the similarity between two route networks is best achieved if there is a common identifier linking two analogous objects from both networks (Haunert, 2005; Mantel & Lipeck, 2004). In case such an identifier exists, the level of similarity depends mainly on the geometrical differences between the two objects, as well as the difference between their nonspatial properties (Mustière & Devogele, 2008). For a pair of linear objects, the perpendicular distance between them, the difference between their length, and their spatial bearing are likely to determine the geometrical similarity; analogous objects tend to be similar if they are close to each other and share similar length and orientation (Goodchild & Hunter, 1997; Li & Goodchild, 2011; Wirtz & Paulus, 2016). In case they also have equal nonspatial properties then the similarity level increases more. Accordingly, the similarity between the routes in the Newcombe network to their counterparts in the

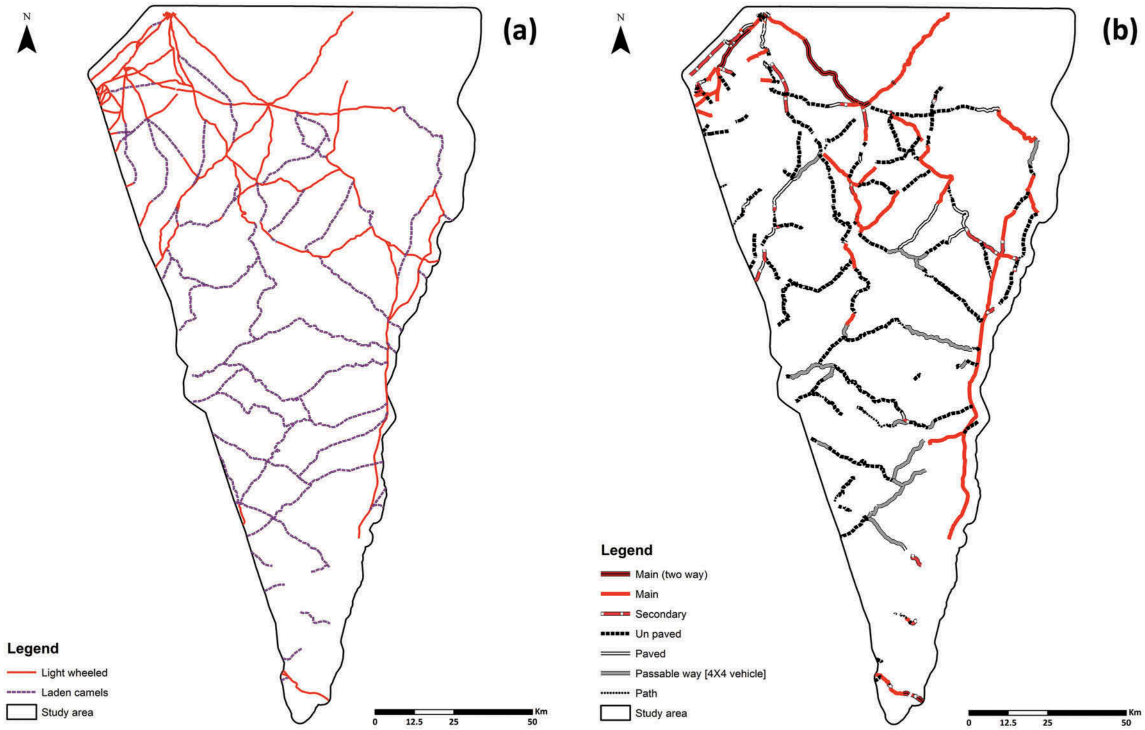


**Figure 4.** (a) Digitized routes based on the Newcombe map; (b) Digitized routes based on the modern topographic map.

modern network was tested. Since most routes are curved and their lengths are at least several kilometers, the routes in both networks were segmented and a comparison was made between segments of a given Newcombe route to analogous segments in the modern route, which had the same route identifier as the Newcombe route. To meet this goal, the study area was binned into several polygonal grids ("Fishnets") defined by cell resolution of 50, 100, 250, 500, 1,000, and 2,500 m. Each cell in each grid was assigned with a unique identifier. When intersecting separately the Newcombe and the modern networks with a given polygon grid, the unique identifier of a given cell was assigned to each segment contained within that cell. Then, the confined segments in each cell were dissolved by the cell identifier and route identifier (given earlier at the digitization stage) to unify segments of the same route into a single segment. That is, each unified segment was given a unique identifier, which is actually the combination of the cell identifier and the segment identifier. Using ArcGIS Desktop tools, the average azimuthal bearing and the total length of each Newcombe and modern segment were calculated. Additionally, a proximity value from each mid-point of Newcombe segment to the mid-point of the nearest modern segment referred to as one-sided nearest neighbor seam (Beeri, Doytsher, Kanza, Safra, & Sagiv, 2005). The networks were then joined based on the unique identifier (cell and route identifier jointly). The join resulted in three types of outcomes: (1) no matching pairs were found within a given cell; (2) only a single pair of matching segments was found within a given cell (Figure 5(a)); and (3) several matching pairs were found within a given cell (Figure 5(b)). In case of the latter, and when the closest modern segment found had a different identifier than that of its Newcombe counterpart, the proximity between these segments was assigned the value of the cell size. Additionally, the difference between the length of two analogous segments in each pair was calculated as well as the angular deviation between them as follows:

$$diff = |Bn - Bm| \tag{3}$$

If ($0° \le diff \le 90°$) then $\alpha = diff$
else If ($90° < diff \le 270°$) then $\alpha = |180° - diff|$
If ($270° < diff \le 360°$) then $\alpha = 360° - diff$

Where α is the angular deviation, Bn is the bearing of a given Newcombe segment, Bm is the bearing of the closest modern segment, and diff is the angular bearing difference.

## Results

### *Accessing the accuracy of the Newcombe map*

The lowest Total RMSE for each of the 11 Newcombe sheets is presented in Table 1. Accordingly, the lowest value is 3.15 m for Sheet 3 (North H36F-III Wadi Fai);

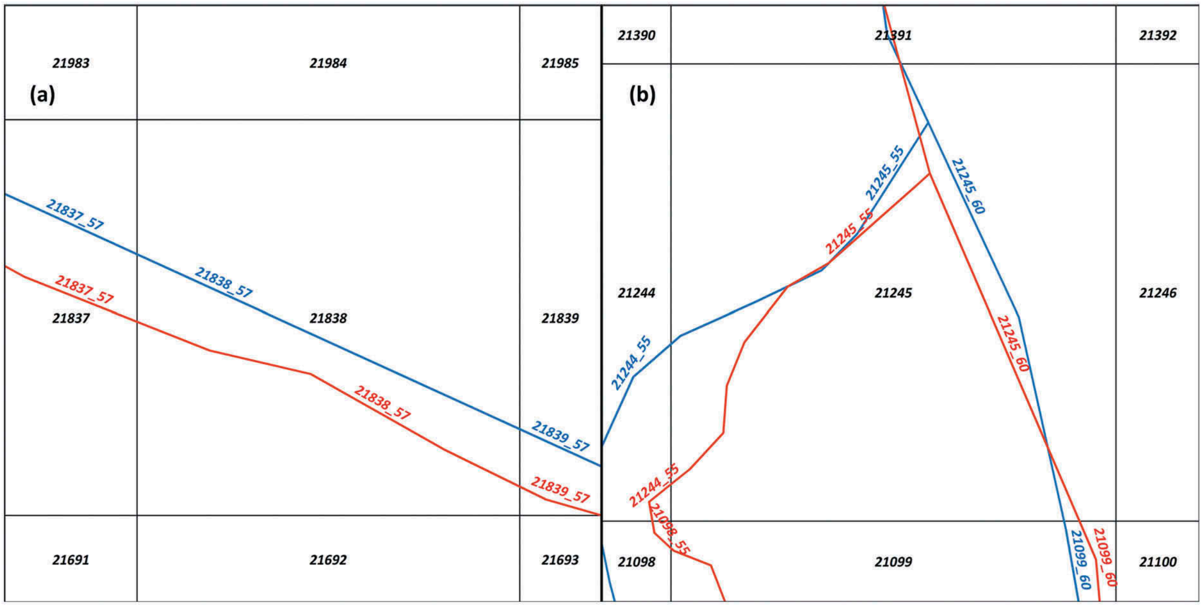


**Figure 5.** (a) A single matching pair within a given cell. Newcombe segments are denoted by red while the modern segments by blue. Note the matching unique identifier (combination of a cell identifier and route identifier) to be used for geometrical comparison between pairs of segments; (b) multiple matching pairs within a given cell.

whereas, the highest value is 5.37 m for Sheet 9 (North H36L-III, Gebel Harun). The average Total RMSE for the 11 sheets is 4.42 m, which reflects an error of ~0.035 mm on a map scale of a 1:125,000. The accuracy of the combined Newcombe map using global 1st, 2nd, and 3rd polynomial transformations is presented in Table 2. Accordingly, using only the 59 triangulation points resulted in a Total RMSE of 100.4 m, 81.97 m and 72.13 m for the 1st, 2nd, and 3rd polynomial transformations, respectively. The 2nd and 3rd polynomial transformations are useful if there is some evidence for bent or curvature while the 1st order can handle affine transformations, most likely due to sheet geometry (rotation, translation, and scale). Thus, should the map only be stretched, scaled, or rotated, the 1st order polynomial transformation is preferred (Zitova & Flusser, 2003). This is the case for Newcome map. Figure 6(a,b) describe the correlation between the horizontal and vertical differences (x and y residuals) using only the triangulation points as GCPs. Since no significant correlation is found, bent or curving of the Newcombe map is not required, thus concluding that the 1st polynomial transformation is the one to be applied. When omitting triangulation points with vague identification or those whose RMSE was greater than 200 m (see Figure 3) the Total RMSE using 1st polynomial transformation decreases further to 95.9 m, which equals to 0.76 mm on map scale. In modern standards of 95% confidence level, the latter is multiplied by 1.7308 (Minnesota-Planning, 1999) resulting in accuracy of 1.31 mm on map scale. The addition of the other 601 GCPs does not contribute to a better accuracy assessment. Of the 59 triangulation points, 48 provided elevations (in feet). Comparing these to the elevations of the analogous triangulation points in the modern map (Figure 6(c,d)) demonstrates that the average vertical difference between the maps is 5.6 m with a median of 3.23 m. When omitting two extreme differences of 38.67 m and 75.23 m of the triangulation points close to Mt. Arif and west of Thaba (Figure 3 and records No 46, 57 in Supplementary Material, Appendix 1), the average vertical difference decreases to 3.45 m with a median of 2.86 m (For a complete list of the triangulation points see Supplementary Material, Appendix 1). With a 95% confidence level, the vertical accuracy is multiplied by 1.96 (Minnesota-Planning, 1999) resulting in a vertical accuracy of 6.72 m. The vertical differences cannot be explained by significant landscape changes; the Negev region is arid with slow erosion processes and no tectonic activity during

**Table 2.** Accuracy results of 1st, 2nd, and 3rd order polynomial transformations using different sets of GCPs comprised of triangulation points and POIs.

| GCPs Type | No | RMSE 1st (meter) | RMSE 2nd (meter) | RMSE 3rd (meter) |
|---|---|---|---|---|
| Triangulation points | 59 | 100.4 | 81.97 | 72.13 |
| Triangulation points without vague identification | 52 | 95.9 | 75.49 | 66.38 |
| POIs | 601 | 295.3 | 292.72 | 287.05 |
| All GCPs (Triangulation points and POIs) | 660 | 284.5 | 281.93 | 276.39 |

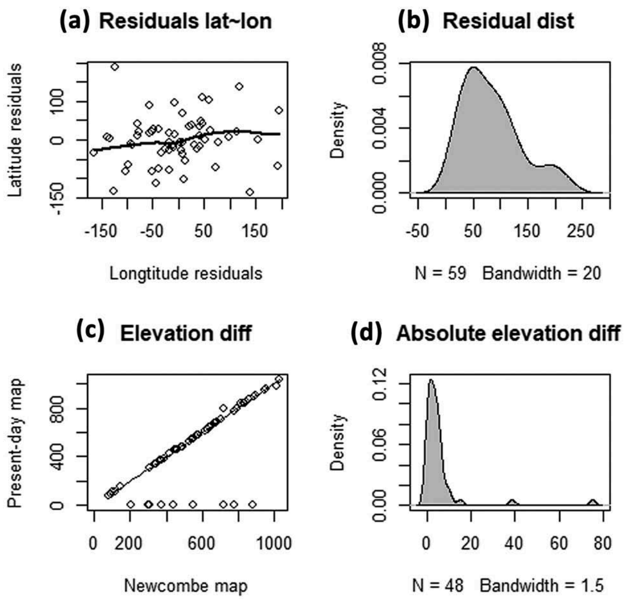


**Figure 6.** (a) Longitude vs. latitude residuals of the 59 GCPs of triangulation points. The random distribution implies that no bending or curving of the map is required to transform it into the ITM Coordinate Reference System. Hence, 1st order polynomial transformation is preferred; (b) Residual (errors) distribution of the 59 triangulation points implying normality; (c) Correlation between the elevations of triangulation points on the Newcombe map (converted to meters) and those on the modern map; (d) Distribution of the absolute elevation difference between the triangulation points as digitized on the Newcombe and present-day maps. Note the two extreme elevation values of 38 m and 75 m (see also Figure 3).

the twentieth century is evident. Thus, although the vertical datum of the Newcombe map cannot be established, the vertical differences might stem merely from mapping errors.

## Comparison of early and late twentieth-century routes

The routes digitized from the Newcombe and modern maps are presented in Figure 4(a and b), respectively. The total length of the Newcombe routes is 2,054.1 km: 1087.1 km and 966.9 km classified as light-wheeled and laden camel routes, respectively. The total length of the routes digitized from the modern map is 1,605 km: 67.3 km, classified as main roads (two-way), 406.1 km as main roads, 122.1 km as secondary roads, 107.9 km as paved roads, 671.2 km as unpaved roads, 169.7 km as routes passable only by 4 × 4 vehicles, and 60.4 km classified as paths. The difference in total length between the networks is 449.1 km.

Table 3 presents the binned grids used for assigning a spatial common identifier to segments of the Newcombe and the modern networks that compound pairs to be compared. Six grids were tested; each represents a resolution in which matching is inspected. Naturally, the smaller the cell size (which represents higher spatial accuracy) the number of cells containing a single matching pair is greater. In each grid, the ratio between cells containing matching pairs (bins with at least one matching pair) of Newcombe and modern segments was evaluated (MT). Similarly, it was also done for cells containing pairs with the proximity of the matched object less than the cell size to yield the MTF ratio. The MT and MTF ratios were used to determine which grid was most suitable to test the similarity between the two networks. Figure 7 presents the MT and MTF ratios. Accordingly, for grids with a cell size of 500 m and below, the ratio of matching cells is less than 50%. A ratio above 50% is achieved for grids with a cell size of 1,000 m and above. This is also the point where the slope of the ratio levels out, that is, an increase in the cell size above 1,000 m contributes a smaller addition of matching cells than in grids with a cell size less than 1,000 m. Thus, testing the similarity between the two networks is likely to be effective in terms of spatial accuracy and completeness when using a cell size of 1,000 m.

Accordingly, 1,591 pairs of matching segments were found (Table 3). Grouping these pairs by the unique identifier given at the digitization stage reconstructed

**Table 3.** The properties of binned grids for assigning common identifier between the Newcombe and modern networks. Fields: **Grid No** – grid number; **Cell size** – the cell size (resolution) of the grid; **TC** – total number of cells; **CC1** – number of cells with a single matching pair; **CCM** – number of cells with several matching pairs; **PMP** – the number of potential matching pairs; **MP** – the number of matching pairs; **NMP** – the number of non-matching pairs; **MT** – matching ratio (MP/PMP); **MPF** – the number of matching pairs with proximity less than the cell size; **MPA** – the number of matching pairs with proximity equal to cell size value; **MTF** – matching ratio for pairs with proximity less than the cell size (MPF/PMP).

| Grid No | Cell size | TC | CC1 | CCM | PMP | MP | NMP | MT | MPF | MPA | MTF |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 50 | 13,022,250 | 3630 | 4 | 52,887 | 3638 | 49,249 | 6.8 | 1949 | 1689 | 3.6 |
| 2 | 100 | 3,256,290 | 3675 | 9 | 26,501 | 3693 | 22,817 | 13.9 | 2048 | 1645 | 7.7 |
| 3 | 250 | 520,890 | 3162 | 25 | 10,676 | 3217 | 7459 | 30.1 | 1868 | 1349 | 17.4 |
| 4 | 500 | 130,368 | 2330 | 45 | 5403 | 2432 | 2971 | 45.01 | 1500 | 932 | 27.7 |
| 5 | 1000 | 32,704 | 1426 | 69 | 2766 | 1591 | 1175 | 57.5 | 1088 | 503 | 39.3 |
| 6 | 2500 | 5310 | 574 | 95 | 1192 | 807 | 385 | 67.7 | 577 | 230 | 48.4 |

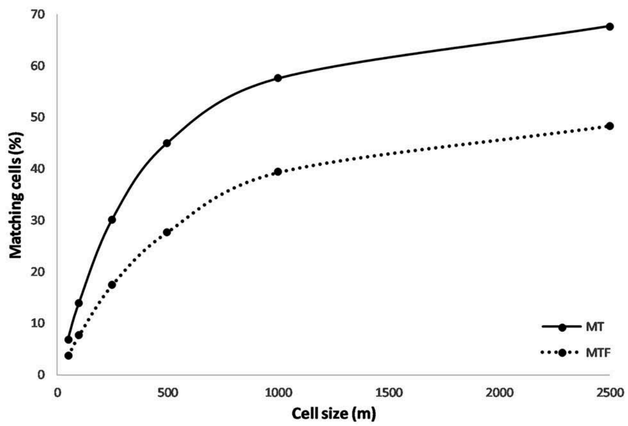


Figure 7. The ratio between matching cells (%) and the resolution of the binned polygonal grid (cell size). The ratio is steep until 1,000 m and becomes moderate at about 2,500 m.

the original Newcombe routes back again but only this time, with geometrical differences to their counterpart modern routes (Supplementary Material, Appendix 2). Altogether, out of 117 digitized Newcombe routes, 114 similarities were found within the spatial binning of 1,000 m. To assess the similarity level between two analogous routes from the two networks, four characteristics were evaluated: (1) the difference between the total route lengths; (2) the difference in the average length of the compounding segments; (3) the difference in the averaged bearing of the compounding segments; and (4) the averaged proximity of the compounding segments. Then, the values for each of these characteristics were quartiled and were used to level each with values ranging from 1 to 4, representing the highest to lowest similarity. The leveled characteristics were then averaged to result a weighted similarity level (Supplementary Material, Appendix 2 and Figure 8).

Accordingly, the average, minimum, and maximum of the weighted similarity level of the routes are 2.5, 1.0, and 3.75, respectively. The ratio between the overall length of the matching (1264.5 km) and original routes (2054.2 km) is 61.5%. That is, nearly two-thirds of the early twentieth-century routes preserve their spatial characteristics within boundaries of 1,414 m (the diagonal of a 1,000 m cell size) toward the end of that century.

Table 4 presents the changes in the nonspatial characteristics of the routes. The type of Newcombe routes, categorized in the early twentieth century as laden camels or light-wheeled routes, evolved into modern routes categorized differently (Figure 4). Accordingly, only 38.4% and 33.1% of the Laden camels and Light-wheeled routes do not match any modern routes, respectively. Notable changes of their type, however, are evident for many of them, which were paved or artificially developed. Many of the roads passable for light-wheeled vehicles in 1915 were paved by the end of the twentieth century, much more than those characterized as passable for laden camels. The ratio of light-wheeled routes evolved into main (two-lane), main, secondary and paved routes are 55.2%; whereas, that of laden-camel routes is only 16.5%. However, the passable way for 4 × 4 vehicles, seems to be the present-day version of laden-camel routes, while 11.6% of the latter were converted into a 4 × 4 vehicle road as compared to only 3.4% for the light-wheeled routes.

The spatial summary of these changes, classified by regions, appears in Appendix 3(see Supplementary Material), which presents the similarity level in the 11 Newcombe sheets. Accordingly, the sheets containing the best matches are of Wadi Fai, Wadi el-Jeib, and Abda, with similarity, fits of 84.5%, 77.9%, and 75.7%, respectively. The lowest ratios were found in the sheets of Wadi Jerafi, Rafa, and Gebel Harun, with ratios of only 49.7%, 44.1%, and 27.1% of the non-matching routes, respectively. The rest of the sheets contain a matching ratio (MT) of more than 50%.

## Discussion

The RMSE for the Newcombe map using 59 triangulation points as GCPs is 100.4 m. When omitting seven points with vague identification the RMSE decreases to 95.9 m. The latter presents an error of 0.76 mm on the map scale but rises to 1.31 mm when tested within the 95% confidence level. Adding another 601 POIs as GCPs does not improve the accuracy validation; whereas, the Total RMSE value does not decrease but instead increases. This is not surprising as the measurements taken for many of these features were far less accurate and incomplete than for the triangulation points. Thus, for future accuracy evaluations of such historical maps, it is suggested using triangulation points or well-defined features measured and mapped at the same level of accuracy as the triangulation points. In other words, the level of accuracy evaluated for the Newcombe map may be appreciated in modern standards, as it matches triangulation and well-defined points. Features that are not well-defined such as routes, railroads, dunes, and land uses may have a lower accuracy level. It is to be stressed that using only 11 out of 23 sheets of the Newcombe map limits the accuracy assessment only to the covered geographical regions; i.e., the whole Negev region, northern Sinai and parts of western Jordan.

The Newcombe map is not the first historical map of Palestine to be tested for accuracy evaluation. The RMSE of the PEF map, as tested by Levin (2006) was found to be 74.4 m. This figure is more than 20 m less

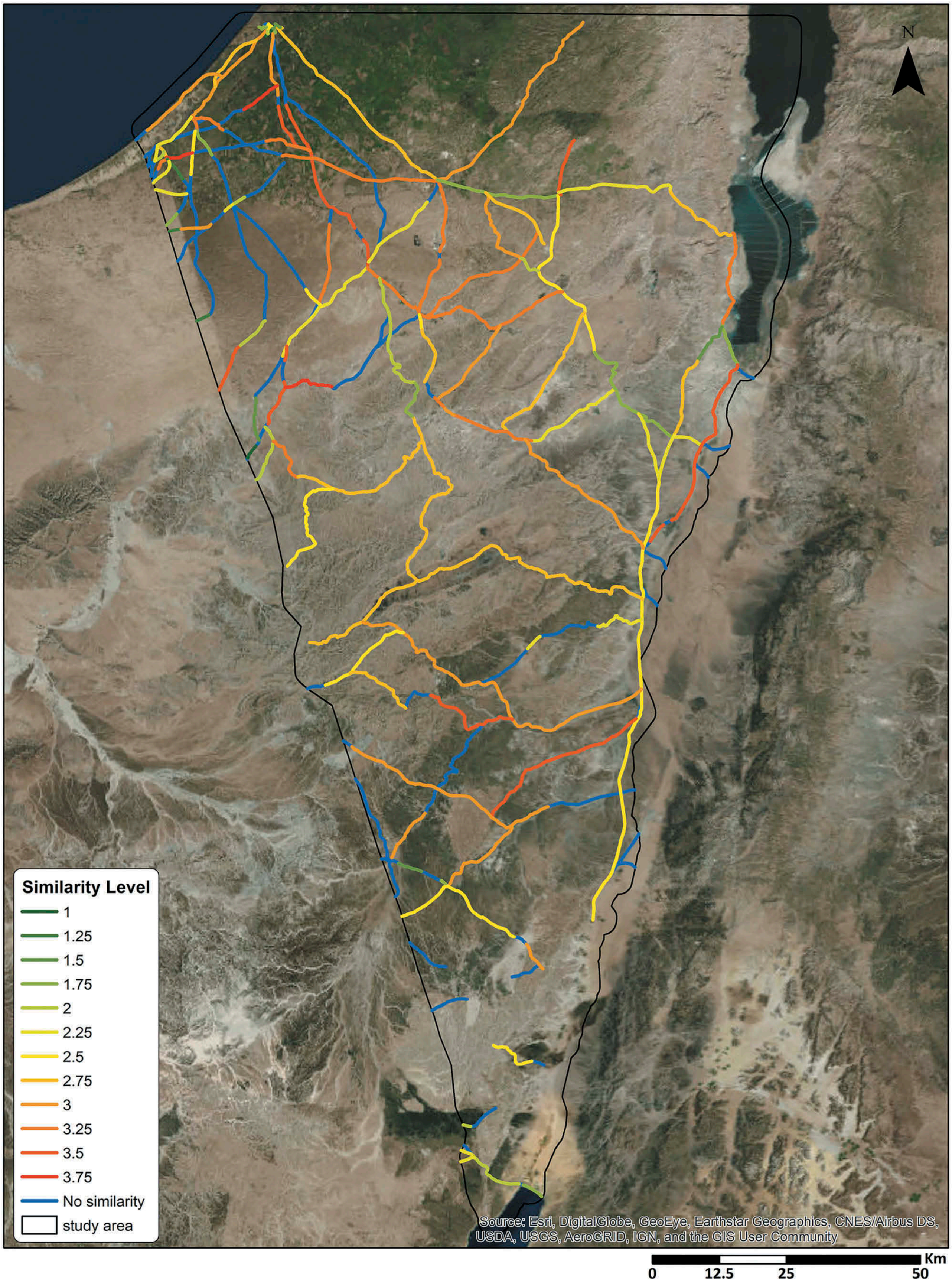


**Figure 8.** Similarity level (ranging from 1 to 3.75) for each of the Newcombe routes. The best matching route is graded 1 while the worst is graded 3.75. No match at all is notated in blue.

**Table 4.** Types of Newcombe routes and how they have evolved into modern route types.

| Type (Newcombe) & Total length | Length Newcombe (km) | Type (modern) | Length Modern (km) | Ratio (Length Modern/Total length) |
|---|---|---|---|---|
| Laden camels (totaling 1086.1 km) | 450.8 | No matching | | 38.4 |
| | 104.7 | Main | 107.7 | 9.9 |
| | 117.8 | Passable way [car+4x4] | 126.0 | 11.6 |
| | 31.1 | Path | 31.4 | 2.9 |
| | 41.0 | Paved | 44.8 | 4.1 |
| | 22.9 | Secondary | 26.6 | 2.5 |
| | 317.5 | Unpaved | 33.2 | 30.6 |
| Light-wheeled (totaling 964.9) | 337.8 | No matching | | 33.1 |
| | 160.1 | Main | 171.0 | 17.7 |
| | 45.5 | Main (two-way) | 48.7 | 5.0 |
| | 19.6 | Passable way [car+4x4] | 21.6 | 2.2 |
| | 25.9 | Path | 28.1 | 2.9 |
| | 47.4 | Paved | 46.8 | 4.9 |
| | 79.1 | Secondary | 79.3 | 8.2 |
| | 249.2 | Unpaved | 250.9 | 26.0 |

than the best accuracy assessment achieved for the Newcombe map (95.9 m). However, the scale of the PEF map is 1:63,360 while the Newcomb map is 1:125,000. Thus, considering the different scales, the accuracy level of the Newcombe map might be greater, under the assumption that GCPs are evenly distributed in both maps. This comparison, however, is beyond the scope of this study.

Newcombe and his team surveyed the Negev region before World War I as the interest of the British in Palestine increased significantly (Goren, 2002). The detailed map focused mainly on routes, water supply, and topography; all key elements for military maneuvers. The map and its features appear to mirror British concern and preparations for a foreseen potential confrontation with the Ottomans in southern Palestine. It is worth noting that the survey was conducted before aerial photography became a popular mapping technique (Collier & Inkpen, 2001; Gavish, 1978). That they surveyed a remote and deserted region and produced an accurate map without aerial photography emphasizes the professional achievement of Newcombe and his team. This is not surprising since the British were well experienced at the time and gained valuable knowledge from previous surveys in the Levant and elsewhere (Edney, 2009). The Ottomans, the rival of the British across the border between Egypt and Palestine, were aware of British capabilities. So, before 1910, they used British maps since they lacked the ability to accurately map the border (Ben-Bassat & Ben-Artzi, 2015). Determining the accuracy of the Newcombe map enables a precise examination of route development in the Negev region, which is the main purpose of this study.

Network matching presented in this paper utilizes the characteristics of proximity, length, and angular bearing differences between analogous pairs of line segments comprising the digitized Newcombe and modern routes. This was achieved using spatial settings (e.g., Goodchild & Hunter, 1997; Zhang, Shi, & Meng, 2005) and binning the study area, thus allowing the geometrical comparison between segments (Figure 5(a,b)). The cell size of the selected binning level of 1,000 m provided a MT of 57.5%, Table 3). In other words, nearly 60% of the Newcombe routes preserved their geometric location within a maximum distance of 1,414 m (diagonal of 1,000 bin) along the entire twentieth century. This finding is similar when inspecting route development in each of the Newcombe sheets (Table 4). In most of the Newcombe sheets, more than 60% of the 1915 routes are similar to equivalent routes as depicted in the modern map implying minor landscape changes during the twentieth century. That is, many of the routes were paved, widened, and junctions were added, but their initial shape and path were preserved. These include major routes such as the one connecting Aqaba with the Dead Sea along the Arava valley as well as old Nabataean routes such as the Incense Road leading from Petra to Gaza (Ben-David, 2012; Meshel & Tsafrir, 1974). Exceptional are the sheets of Rafa, Gebel Harun, and Wadi Jerafi, with a fit of less than 50%. The latter two covers an area that was and still is remote and includes regions that were incompletely mapped due to restrictions by the Ottomans. The case of the Rafa sheet, on the other hand, is different. The establishment of dozens of Israeli settlements in the area located east of the Gaza strip border changed the landscape dramatically. From unpopulated region with only a few nomad settlements at the beginning of the twentieth century, the region became massively settled with agricultural features that practically obliterated most of the existing routes. On the other hand, the Gaza Strip did not undergo massive development, so early twentieth-century routes it contains remained almost intact. It makes sense that a temporary refugee settlement would use existing roads that later get fixed into an unplanned urban development. Altogether, no tremendous changes in the landscape or the number of routes are apparent but rather an ongoing development in the quality of the routes due to greater traffic and higher vehicular speeds. It, therefore, supports the research hypothesis suggesting minimal landscape changes of the routes in the desert regions of the Negev.

## Conclusions

The Total RMSE of the Newcombe map was found to be 95.9 m and 100.3 m when using 52 triangulation points, which is equivalent to 0.76 mm at a map scale of 1:125,000. When testing the accuracy within 95% confidence level the accuracy achieved is 1.31 mm on map scale. Using other natural and artificial features for historical map registration resulted in greater error values. Therefore, it should be carefully reconsidered in the future map registration scenarios. The detailed Newcombe map focused mainly on routes, water supplies, and topography as crucial features for military maneuvers, especially in a desert. The map also reflects the British ambitions and concern toward a foreseen potential confrontation with the Ottomans. The level of map accuracy provides additional reinforcement of British professionalism and the quality of their products. This explains why British mapping was and still is an important contribution for twentieth-century mapping of Israel and its close surroundings. Determining the accuracy of the Newcombe map enables high-resolution examination of route development in the Negev region.

The methodology presented in this paper utilizes the characteristics of proximity, length, and angular deviation between pairs of digitized routes using historical and modern maps. It was found that the landscape changes of routes between the beginning and end of the twentieth century were minor; many of the routes were paved, widened, and junctions added but the initial shape and path of the routes were largely preserved. The results of the study enable portraying the paths and characterizing the usage of ancient routes in the Negev region in future studies when inspecting historical scenarios such as trade, military activity, and landscape changes. Such studies enhance the involvement of GIS in analyzing historical scenarios while rapidly developing and presenting new capabilities with technological progress.

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