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THE BERYTUS-HELIOPOLIS BAALBAK ROAD IN THE ROMAN PERIOD: A LEAST COST PATH ANALYSIS

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ABSTRACT

The Mount Lebanon range has permanently formed a main barrier to communication between the coast and the Bekaa valley. During the Roman period, official authorities were confronted to a significant challenge in establishing an efficient route joining the colony of Berytus to its territorial possessions in the northern Bekaa which included the town of Heliopolis Baalbak. This case study aims to find the least cost path for the road between both cities based on slope dependent functions using GIS technologies. Three generated models are cross-referenced to historical and archaeological data for validation purposes. The validated path indicates that the planning of the Berytus-Baalbak Heliopolis road seems to have been primarily based on minimizing energy cost by reducing the crossing distance over steep slopes.

KEYWORDS: Least cost path, Spatial analysis, Roman roads, Roman colonies

1. INTRODUCTION

In the years between 16 and 14 BC the administrative landscape of Roman Phoenicia underwent substantial modification with the foundation of a veteran colony in Berytus. The territory of the new colony was extended as far as the sources of the Orontes River in Northern Bekaa (Strabo XVI, 2, 19; Ulpien 50, 15, 1, 1, p. 931)[i] (Fig.1). The proliferation of temples, as well as the large number of Latin inscriptions found in various vicinities of Northern Bekaa, highlights the organic link between the coastal city of Berytus and its hinterland (*IGLS* VI; Aliquot 2009; Abou Diwan and Doumit 2016). As has been argued by numerous scholars, Baalbak Heliopolis has actually formed a fundamental part of the Berytian possessions in the Bekaa for over two centuries until 194 AD (Jones 1937, 272; Pflaum 1960, vol. I, 114-5; Jones 1971, 466-7; Grant 1969, 258; Millar 1990, 19-20; Sartre 2001a, 646, 706; Sartre 2001b, 115; Ball 2000, 39; Butcher 2003, 116, 230; Hall 2004, 51; Sawaya 2009, 186-197; Hošek 2011). Following this date, Heliopolis Baalbak acquired the status of a Roman colony and inherited all the territorial possessions of Berytus in the Bekaa (Jones 1937, 289; Millar 1990, 32-3; 1994, 124)[ii]. Hence the establishment of efficient paths to connect both cities must have been of great necessity for Roman authorities especially with the existence of the Mount Lebanon range which formed an imposing barrier hindering communication between both areas mainly during the snow season (Fig. 2).

The main purpose of this study is to reconstruct a model of the road layout connecting the Roman colony of Berytus to Heliopolis Baalbek in the Roman period based on a least cost path approach and using geospatial analysis with the incorporation of geographic terrain parameters such as digital elevation models and geographic information systems. One of the main issues that beg to be answered in this research lies first in understanding whether the Roman authorities had opted for the most efficient path in connecting Berytus to Heliopolis Baalbak by verifying the existence of any correlation between the spatial distribution of archaeological data and the established least cost paths.

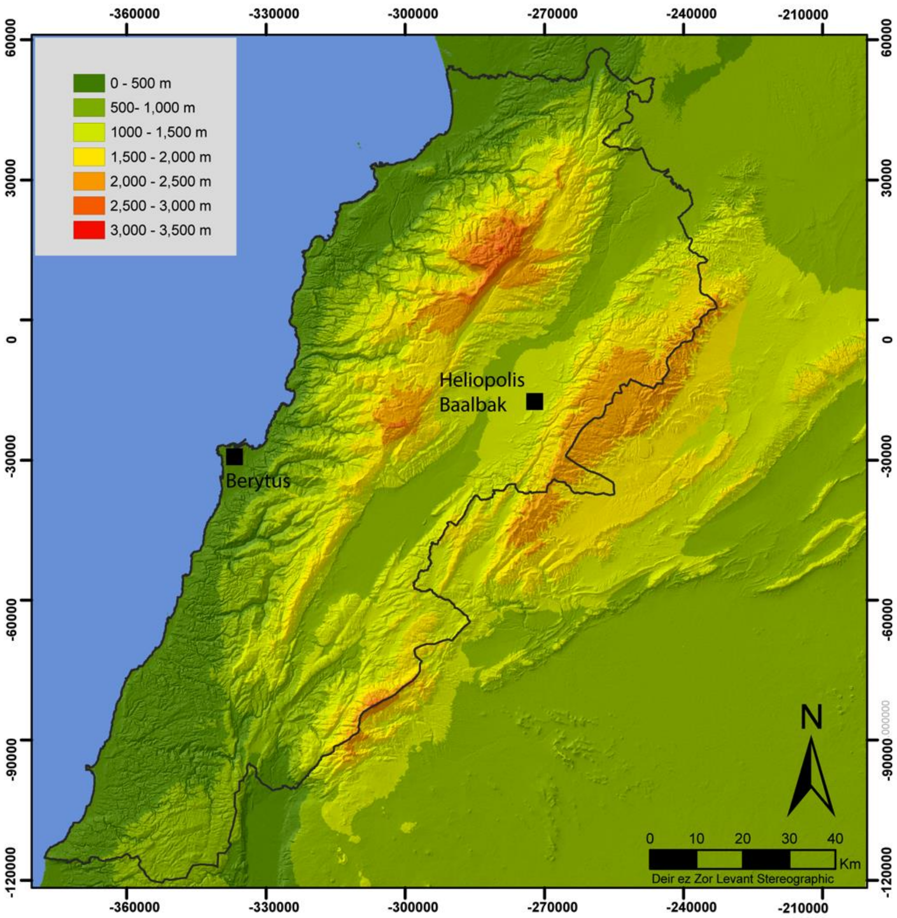

Figure 1. Map showing the borders of the Lebanese Republic and the location of Berytus and Heliopolis Baalbak.

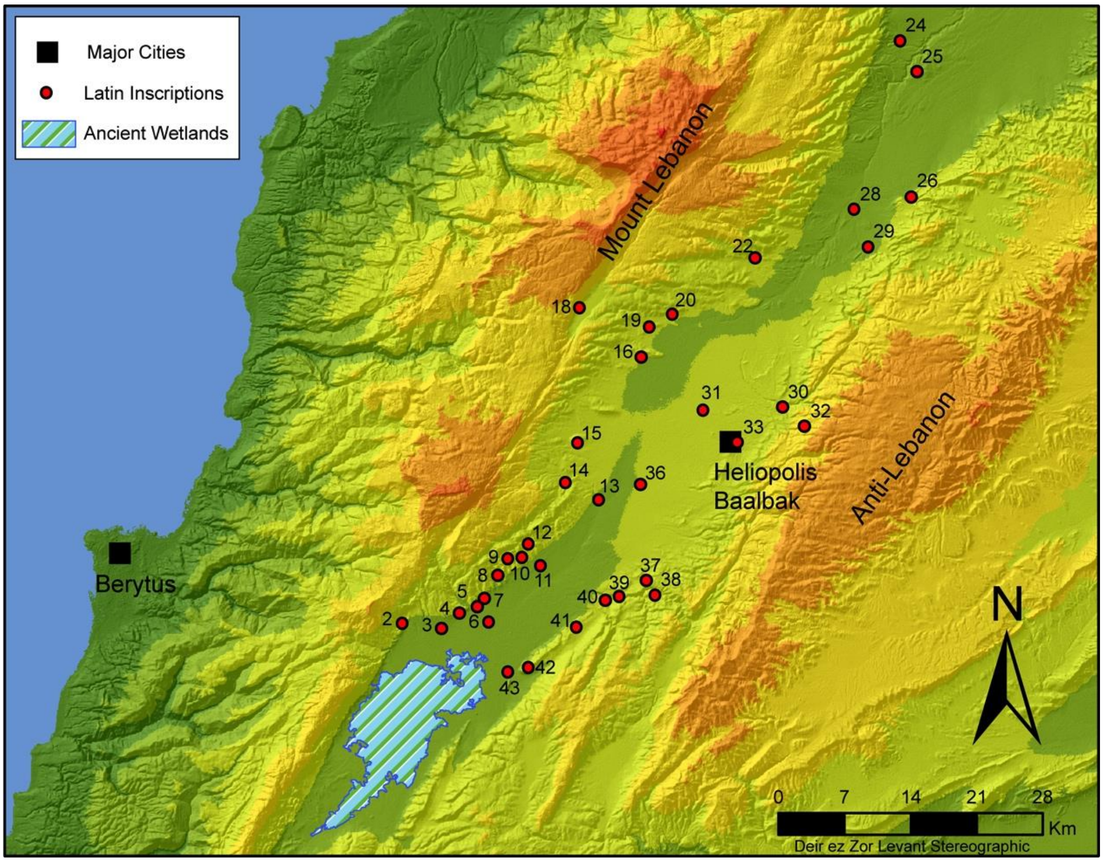

Figure 2. Map showing the extension of the territory of the Roman Colony of Berytus in the Bekaa as evidenced by the Latin inscriptions: 2, Jdita; 3, Saadnayel; 4, Hawch al-Umara- Zahleh; 5, Muaallaqah- Zahleh; 6, Dayr Labas; 7, Karak Nuh; 8, Furzul ; 9, Niha; 10, Area of Niha; 11, Timnin al-Fawqa; 12, Timnin al-Tahta 13, Aayn Hushbay; 14, Shamstar; 15, Hadath; 16, Shlifa; 18, Yammuneh; 19, Batidii; 20, Dayr al-Ahmar; 22, Nabha; 24, Hirmil; 25, Area of Hirmil; 26, Ras Baalbak; 28, Jabbulah; 29, Labwah; 30, Nahleh; 31, Iaat; 32, Aayn al-Lajuj; 33, Baalbak; 36, Hizzin; 37, al-Nabi Shit; 38, Yahfufah; 39, Qana; 40, Masah, 41, Dayr al-Ghazal, 42, Jabal Turbul- Kafr Zabad; 43, Tall Hamzah (Data: IGLS VI).

2. THE BERYTUS-HELIOPOLIS ROAD: WRITTEN SOURCES, ARCHAEOLOGICAL DATA, AND MODERN SCHOLARSHIP

Written evidence of the road network connecting the Roman world is mainly provided by four major road itineraries: The *Tabula Peutingeriana* (Talbert 2010), The *Itinerarium Antoninum Augusti*, The *Itinerarium Burdigalense* (Cuntz and Wirth, 2012), and the *Ravennatis Anonymni Cosmographia and the Guidonis Geographica* (Schnetz and Zumschlinge, 2012). These sources of which only copies from the medieval period have survived provide lists of thousands of geographic vicinities followed by the indication of distance, most of which have been probably based on official road lists established for the benefit of the *cursus publicus* and the Roman army. However, as far as Roman Phoenicia is concerned, the information provided by these *intineraria* has primarily highlighted the *via maris* passing through the Phoenician cost and connecting Antioch (Syria) to Alexandria (Egypt). Berytus is indeed mentioned as a road station in all these itineraries (*Itinerarium Antoninum Augusti,* 21, no. 149; *Itinerarium Burdigalense,* 94, no. 583; *Ravennatis Anonymni cosmographia,* 26, no. 50; *Guidonis Geographica,* 133, no. 94). As for Heliopolis Baalbak it seems to have formed part of another major road pass through the Orontes valley to Scythopolis (*Ravennatis Anonymni cosmographia*, 27, no. 198). The road connecting Berytus to Heliopolis Baalbak seems also to have been of prime importance since the written evidence documenting this road layout is schematically displayed in the *segmentum X* of the Peutinger table. However, it does not indicate the exact path followed by this road. This map, which stands as an official document, was established according to Talbert during the Tetrarchy within the context of a new ideology in which routes were conceived as part of an integrated empire network (Talbert 2012, 16). The archaeological record regarding the existence of this road layout remains very thin. Three milestones have so far come to light between both cities that might possibly indicate the line of this road. The first milestone was discovered during the 1970s during archaeological rescue excavations in the Area of Fyadieh. The exact spot of this milestone is not specified (Khalil 2009, 249-250). A second milestone discovered in 1909 in the vicinity of Karak Nuh was attributed by Rey-Coquais to the road section connecting Shtura to Heliopolis Baalbak and dated to November 194 AD. Ghadban, on the other hand, attributes it to the path connecting Heliopolis to Berytus and update the reading of the date to Spring 195 AD. (*IGLS* VI no. 2958; Ghadban 198, 150-151). A third milestone belonging to the path connecting Berytus to Heliopolis was found in the vicinity of Hizzin and dated to the Tetrarchic period (305-311 AD) (Ghadban 1981, 151 and note no. 27). The reconstruction of the road line connecting Berytus to Heliopolis has been discussed in numerous modern studies. Dussaud proposed in his discussion of the communication network of the Bekaa the following itinerary. According to him the Heliopolis Baalbak- Berytus road passed through the vicinities of Karak Nuh, Muaallaqah-Zahleh and Shtura where it should have joined the actual Beirut-Damascus road (Dussaud 1927, 397). Dussaud argues that the latter road would not have deviated much from the former path used during antiquity as Arab geographers cited intermediate stations along this path such as Hussein east of Aaley and Zebdol near Shtura (Dussaud 1927, 60). Goodchild also raises the same assumption regarding the ancient path linking Beirut to Damascus. The author argues that the road from Heliopolis might have joined the coast (*via maris*) road in the center of Beirut. Goodchild further suggests another road descending from the mountains north of the Beirut River valley towards the east bank of the river (Goodchild 1948, 106). Rey-Coquais suggests a different itinerary for the main road connecting Berytus to Heliopolis in the Roman period, which probably would have passed through Zahleh crossing Jabal al-Knisseh and reaching Berytus via Beit Mery (*IGLS* VI, p. 27; Rey-Coquais 1964, p. 295-296). This assumption was afterwards followed by Breton, according to whom two Hardianic inscriptions located east of Majdel Tarshish bring further evidence to support the existence of this road itinerary (Breton 1980, 34, 39-40, nos. 5004, 5009). According to Ghadban, this route crossed the localities of Karak Nuh and Hizzin (Ghadban 1981, 151). Most recently Khalil endorses Dussaud's assumption and argues that the Roman, Medieval and Ottoman routes joining Berytus to the Bekaa Valley would have followed closely the Beirut-Damascus highway layout. This path stands as the most convenient and easiest to cross since the railroad follows the same track with few exceptions. The author lists the different localities crossed by the road connecting Beirut to the Bekaa valley: Beirut, Fyadieh, Khan al-Hussayn, al-Mghiti, al-Mdayrej, Bawarej, Zebdol, Jdita, Aanjar, Qarn al-Jamus, Khan Maysalun all the way to Damascus. However, the author does not specify the path followed by this route towards Heliopolis Baalbak (Khalil 2009, 250-251) (Fig. 3).

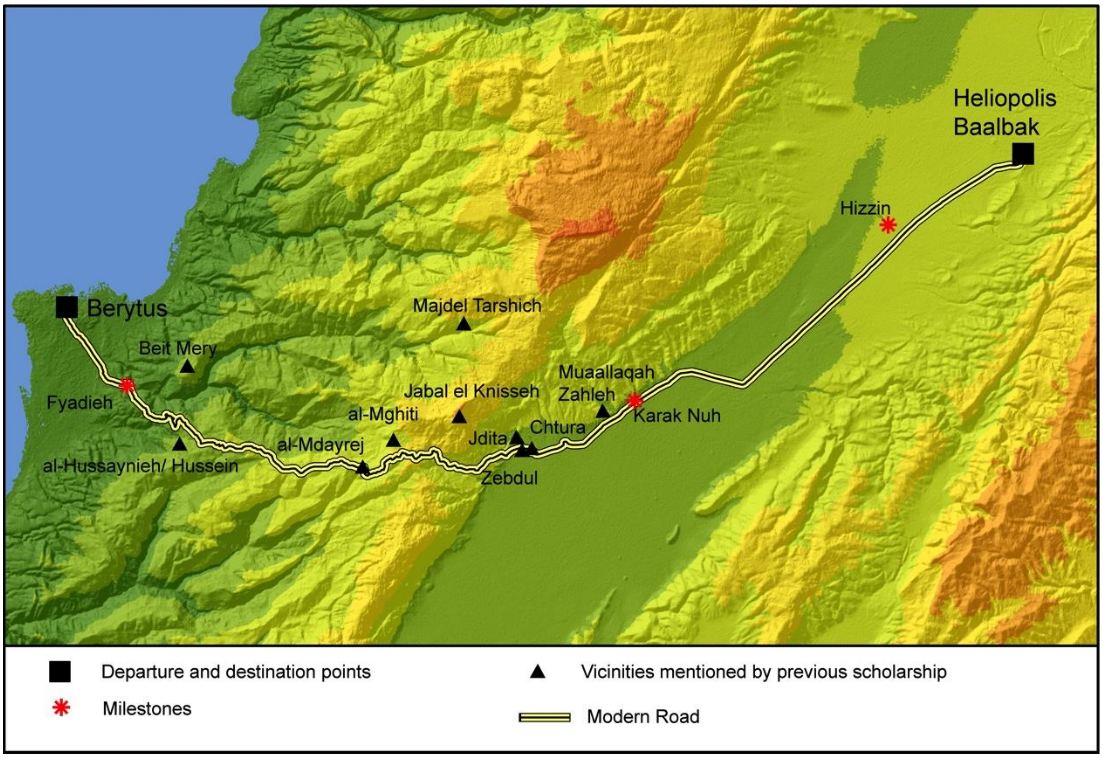

Figure 3. Map showing the vicinities mentioned by previous scholarship in relation to the road connecting Berytus to Heliopolis Baalbak.

3. LEAST COST PATH ANALYSIS

The least cost path analysis is a distance analysis tool within GIS, which serves to establish the most efficient and least effort requiring path between a departure and destination point (Conolly and Lake 2006, 215-221; Surface-Evans and White 2012, 2-3). According to Surface Evans and White, the functioning principle of this tool is rooted in the idea that "… humans will tend to economize many aspects of their behavior encompassing everything from speech to movement …" (Surface-Evans and White 2012, 2). The use of least cost path analysis in archaeology primarily serves to establish predictive models for the reconstruction of ancient routes and communication networks of which little or no traces have been preserved (Conolly and Lake 2006, 252-256; Surface-Evans and White 2012, 2-3; Anderson 2012, 239-240; Herzog 2013, 179; White 2015, 407). The modelling principle of least cost path analysis has been applied to numerous archaeological case studies during the past decade (Herzog 2014).). The use of geographic information system as a tool for archaeological predictive modelling has been increasingly used worldwide (Balla, Pavlogeorgatos, Tsiafakis, and Pavlidis, G 2014). However, in Lebanon this application is still in its infancy. To date, a single study has been conducted by Safadi on the Early Middle and Late Bronze Age sites in the Bekaa Valley (Safadi 2013).

3.1. *Methods*

It would be wise at this point to insert a word of caution regarding the application of least cost path analysis. It should be kept in mind that the most optimal and efficient path is not systematically taken by humans. Various environmental and social factors such as weather impact, the availability of resources and the existence of sacred sites are involved in the process of the establishment of networks and routes (Anderson 2012; Risseto 2012; Supernant 2017). As has rightly been argued by Herzog, "once-in-a-lifetime journeys such *[sic]* during a mass exodus, a crusade or some of the behavior of soldiers at war" do not seem to be compatible with least cost path modelling (Herzog 2013, 180-181). Therefore, a thorough knowledge of the landscape is required to establish the optimal path between two given locations. In the case of Berytus and Heliopolis Baalbak this condition seems to be satisfied as various historical and archaeological evidence accounts for the working knowledge of the Lebanese landscape by the Romans (Abou Diwan and Doumit 2016). The organic link between both cities would have logically favoured the assumption of the least cost path between both cities.

Slope-based cost functions are the most commonly used cost components in archaeological least cost path modelling (Herzog 2010). However, more sophisticated models have included other cost components such as weight and load of the walker (Rademaker, Reid, and Bromley, 2012) and visibility (Verhagen and Jeneson, 2012). However, in the case of the Berytus-Heliopolis Baalbak road, the most appropriate measure of cost used for the generation of the least cost path model is topography based on the assumption that Roman authorities might have been significantly concerned about reducing the impact of slope terrain effect in the establishment of the road given the mountainous nature of Lebanon. Two-slope based functions were actually used for modelling the least cost path based on the pedestrian movement difficulties: the default cost function in ESRI software and the Tobler hiking function[iii]. The cost surface used to conduct this study is generated using a digital elevation model derived from the Shuttle Radar Topography Mission (SRTM) of 30-meter horizontal spatial resolution[iv]. The Origin point in Beirut was selected based on the archaeological ground in the area were the *Decumanus Maximus* crosses the perpendicular *Cardo Maximus* (Saghieh et al. 1999). The Destination point in Baalbak was selected at the entrance of the temple complex. Both Points were digitized as a single, point feature class. The computation of the least cost path was performed in ArcGIS, which is considered fairly sufficient for archaeological applications and easy to use (Surface-Evans and White 2012, 6; White 2015, 408).

3.2. *ArcGIS Spatial Analyst: Cost Distance Tool (Cost Weighted Rasters)*

The generated cost model using this method is isotropic which means that the direction of movement is not taken into consideration and subsequently the costs of travel between both cities back and forth are identical (Wheatley and Gillings, 2002, p.151; Conolly, Lake 2006, 215; Surface-Evans and White, 2012; Herzog 2013; Herzog 2014, 227). Two main variables, slope and hydrographic obstacles (rivers and wetlands), were considered in the process of establishing the least cost path using this method. Other factors like the land cover and population density were excluded from analysis due to the lack of empirical data related to these issues[v]. The process for the generation of the least cost path using Spatial Analyst, Distance Cost Distance Tool (Cost Weighted Rasters) is summarized as follows:

1. Generation of a slope raster using the Slope Spatial Analyst tool of ArcGIS with degrees as the output measurement.
2. Reclassification and weighting of the slope raster values: the weighted slope values were reclassified into nine different categories repre-

senting a range of slope values using the Reclassify Spatial Analyst tool (Table 1). The reclassified value 2 corresponds to a slope ranging between 5 and 10 degrees. This slope range is the most suitable for our path since Roman roads never take slopes over 15 degrees (Verhagen and Jenesson 2012, 125).

3. Creation and weighting of a hydrographic raster containing the rivers and the wetland boundaries: the data representing rivers was vectorized from 1:20000 topographic maps elaborated by the Directorate of Geographical Affairs of the Lebanese army and then converted to a raster data type using the To Raster Conversion Tool. On the other hand, the boundaries of the former wetlands located in Central Bekaa were extracted from DEM (Abou Diwan and Doumit 2016). The two raster data types were then merged in order to form a unique hydrological raster dataset. Hydrographic values were then reclassified using the Reclassify Spatial Analyst tool with a cost value of 5 assigned to rivers and 10 assigned to wetlands.
4. Combination of the weighted two rasters slope and hydrography reclassified maps using the Weighted Overlay Spatial Analyst tool with a slope as the most influential factor at 70% followed by hydrography values at 30%.
5. Creation of a Cost Distance and a Cost Direction or Backlink Rasters by running The Cost Distance Spatial Analyst tool and using the weighted slope and hydrography reclassified raster as input cost raster.
6. Creation of the least cost path by running The Cost Path Spatial Analyst tool using the Cost Distance and the Cost Direction or Backlink rasters. The output result is a new raster layer showing the path from the origin point to the destination. The path was then converted to a polyline using The Raster to Polyline Conversion tool (Fig. 4).

Table 1. Slope classes and weighted values.

Slope degree	Weighted or Cost value
70-80	9
60-70	8
50-60	7
40-50	6
30-40	5
20-30	4
10-20	3
5-10	2
0-5	1

3.3. *ArcGIS Spatial Analyst: Path Distance Tool (Tobler Hiking Function)*

The Tobler hiking function is an anisotropic time-based cost surface algorithm, which greatly depends on the direction of movement: W = 6 exp (-3.5*abs (S+0.05), where W is the walking speed in km per hour and S is the slope in degrees (Gorenflo and Gale 1990). The generated paths using anisotropic calculation may vary according to the direction of movement. In a slope environment, moving upward across a hill logically requires more effort than moving downward (Wheatley and Gillings, 2002, p.151; Conolly and Lake 2006, 215; Surface-Evans & White 2012, 408; Herzog 2013, 181-185; Herzog 2014, 227). The generation of the least cost path using the Tobler Hiking Function was performed in a two-step process using the Path Distance tool and the Cost Path tool in ArcGIS Pro 10.1. The process is summarized as follows:

1. Generation of a Cumulative Cost Surface and Backlink Raster using the Path Distance Tool Spatial Analyst Tool. The SRTM DEM was applied as the Input Surface Raster and Input Vertical Raster and the Vertical Factor Table used to convert slope to time using Tobler's hiking function is based on Tripcevich 2009: Time (Hours) To cross 1 Meter = 0.000166666*(Exp(3.5*(Abs(Tan(Radians(slope_deg))+0.05)))). It is worth noting that where the Slope Raster was used as Input Surface Raster (Shild 2016, 24-25) the generated path would exclusively favour valley bottom surface with a distance of 137 km which is twice longer than the model based on the SRTM DEM.
2. Creation of the Least Cost Path using the Cumulative Cost Surface and Backlink Raster by launching the Cost Path Spatial Analyst tool. The path was then converted to a polyline using the Raster to Polyline Conversion tool (Fig. 4).

3.4. *ArcGIS Spatial Analyst: Cost Distance Tool (Tobler Hiking Function adjusted by White)*

White has highlighted the errors encountered in various publications regarding the computation of the Tobler hiking function (White 2015, 408-409). The author argues that when the function is used incorrectly the algorithm will favour flat areas when generating the least cost path. He proposes some adjustments to the equation in order to give the estimate of travel time over a given distance instead of an estimate of walking speed: (Dem Resolution/ 1000) / (6 * Exp(-3.5 * Abs(Tan(("Slope_Raster" * 3.14159)/180) + .05))). A detailed workflow for the generation of the least cost path is provided by White and summarized as follows:

1. Generation of a Slope Map by launching the Slope Spatial Analyst tool in ArcGIS.
2. Creation of a friction surface based on the modified equation of the Tobler Hiking function using the Raster Calculator.
3. Generation of a Cumulative Cost Surface and Backlink Raster using the Cost Distance Tool.
4. Creation of the least cost path using the Cumulative Cost Surface and Backlink Raster by running the Cost Path Spatial Analyst tool (Fig. 4).

4. RESULTS AND DISCUSSION

As argued by Herzog, the reconstruction of ancient road models by archaeologists using least cost path analysis requires validation through archaeological evidence given the limitation of standard GIS software capacities and the resolution of geographic data (Herzog 2013, 204-205). Therefore, testing the validity of the aforementioned modelling approach will rely greatly on the extent to which the road layout corresponds with the available archaeological and historical data. In terms of distance, the road model connecting Berytus to Heliopolis Baalbak based on the Tobler Hiking Function adjusted by White using ArcGIS Spatial Analyst Cost Distance Tool stands as the shortest path between both cities. On the other hand, the modelled road using the ArcGIS Spatial Analyst: Cost Distance Tool (Cost Weighted Rasters) stands as the longest road with 81 km and seems more consistent with the distance indication marked with the Roman numerals *LXVIII* at the end of the road stretch connecting Berytus (Berizto) to Heliopolis Baalbak (Eliopoli) in the *segmentum X* of the Peutinger Map. The distance is estimated by the map compilers to 58 Roman miles, which should roughly correspond nowadays to 85 km (Fig. 4). The 4 km margin of difference between the length of both roads seems acceptable if one takes into account the approximate nature of the Peutinger map which has been previously highlighted by Goodchild in his study of the Roman coastal road in Phoenicia. The author concludes that the margin of error is more significant on the Peutinger map than that of the Antonine and Bordeaux itineraries for the distance separating Antioch from Ptolemais (Goodchild 1948, 95-6). Two major rivers, the Nahr Beirut and Nahr Litani are located along the generated roads. The paths based on the Tobler Hiking function cross both rivers while the slope-based path using the Distance Cost Weighted tool only intersects with Litani. The crossing of the latter river is unavoidable since Heliopolis Baalbak is located east of the river course. No visible archaeological remains of any bridge are recorded at the junction of the three roads and the Litani. Further investigations are required to confirm the presence of archaeological structures (Fig. 4).

In terms of the road layout, the modelled path using the ArcGIS Spatial Analyst Cost Distance Tool (Cost Weighted Rasters) seems once again more compatible with the available archaeological data, namely three milestones belonging to the Berytus-Heliopolis Baalbak road recorded in the vicinities of Fyadieh, Karak Nuh, and Hizzine. Despite the fact that the location of these milestones is only known to the nearest kilometer and metrics data is not available, it must be recognized that all three vicinities are actually crossed by the modelled road as can be seen in figure 5. Another indicator in assessing the validity of the three-modelled paths lies in calculating the incidence of archaeological sites along each road. For this purpose, the Near Analysis tool was used to plot and compute the number of known archaeological sites of the Roman period located within a 5 km radius[vi]. A significant bias is also noted for the path modelled using the ArcGIS Spatial Analyst Cost Distance Tool (Cost Weighted Rasters) with a total number of 38 sites within a 5 km radius and 11 sites within a range of 1 km. The clustering of sites is particularly conspicuous in the Bekaa area beyond the Mount Lebanon range in the last 50 km stretch of this road. The scarcity of sites in the first 30 km stretch of this path towards the southwestern foot hill of the Mount Lebanon range reflects the available state of documentation and does not automatically mirror the situation that really prevailed in Roman times (Figure 6 and Table 2). The low number of Roman cultic sites has been observed by Aliquot in this area as well as in Sidon and Tyre. He suggests that future discoveries would give a more homogeneous picture of the distribution of the sanctuaries (Aliquot 2009, 72-73). The modelled path using the Tobler Hiking Function by means of the Path Distance Tool is located within a 5 kilometres range of 26 sites (Figure 7 and Table 2). The path generated by the modified equation of the Tobler Hiking function exhibits the lowest site frequency with 21 sites located within a 5 km range (Figure 8 and Table 2).

The Viewshed Analysis tool which provides a map of the visible and invisible sites from a given location also constitutes an efficient instrument for the validation of the least cost path created by the ArcGIS Spatial Analyst Cost Distance Tool (Cost Weighted Rasters). The use of this tool has significantly increased over the past years in archaeological applications especially in assessing the role of visibility in the location of sites (Williams 2017, 5-10). Nevertheless, the theoretical approach towards the use of this tool was liable to a number of criticisms (Connolly and Lake 2006, 233; Whitely and Gilling 2000). The viewshed analysis was conducted with the Viewshed 3D Analyst tool using the SRTM DEM as input raster and the least cost path created by the ArcGIS Spatial Analyst Cost Distance Tool (Cost Weighted Rasters) as input Polyline Observer Feature. The average height of a human observer estimated at 1.75 m (Weathly and Gilling 2000, 33) is taken into consideration when establishing the viewshed. For this purpose, a field named OFFSETA is created in the Least Cost Path Attribute Table where the average value of the height of a human observer could be added. The generated viewshed map indicates that 21 archaeological sites located within a radius of 5 km are actually visible from the generated least cost path (Fig. 9). In this respect, it should be noted that the average distance of human visual acuity is estimated at 6.2 km (Weathly and Gilling 2000, 15-20). Among these sites are two features of high significance which seem highly correlated to the modelled least cost path. The first feature located at a distance of 174 m from the path consists of a bas-relief known as Aain al-Ghadi West of the town of Qab Elias showing a bull seen in profile to the right with head turned out at a right angle facing the viewer. Near the muzzle of the animal 3 deep niches are adorned with figures in a very poorly preserved relief (Fig. 9, site no. 50 and fig. 10). The Heliopolitan triad is recognizable in the divinities of the 3 niches and the great bull, symbol of fertility in relation to this triad (Seyrig 1929, 326 no.1; Ronzevalle 1906, 223-233; Hajjar 1977, no 106). At a short distance from the monument run two water sources (Aain al-Ghadi and Aain al-Haramyeh) and a libation vessel was discovered by Ronzevalle in the immediate surroundings of the bas-relief. With these factors in mind, Ronzevalle considers the erection of this bas-relief as an act of consecration of the beneficent water sources. Traces of ancient buildings and ceramic sherds from the Roman period remain visible nowadays (Khalil 2015, 17). This religious landmark along with the water sources must have probably drawn the attention of the travellers on the Heliopolis Baalbak-Berytus road. Another monumental feature known as Haidara located within the viewshed range of the modelled path runs at a distance of 260 m. This peculiar monument located on the southern outskirts of the village of Qab Elias overlooking the valley of the Bekaa towards the East is carved into a steeply sloping limestone cliff, measuring 13 m wide and about 10 m high (Fig. 9, site no. 1 and fig. 11). Krencker and Zschietzschmann suggested the possibility of a funerary and cultic function to this monument by comparing it to similar structures found in Petra (Krencker and Zschietzschmann 1938, 157-160). This function seems consistent with the least cost path since the act of placing tombs on or near communication roads is a practice attested throughout the Roman world with the purpose of perpetuating the remembrance of the deceased among the living (Gros 2012, 281-283). On a different note, the layout of the least cost path created by the ArcGIS Spatial Analyst Cost Distance Tool (Cost Weighted Rasters) follows closely the current road connecting Beirut to Baalbak. The average distance between the two roads is 682 m with 20 intersections recorded in between. The former railroad connecting both cities also intersects 24 times with the Least Cost Path with an average distance of 684 m separating both roads. Taken together, these data must lead one to conclude that the establishment of all three roads despite chronological differences follows the same logic, that is avoiding steep slopes when possible (Fig. 12). The Roman authority seem to have preferred reducing energy costs by minimizing traversal over steep slopes as can be seen in figure 13 where 64.40 % of the least cost path created by the ArcGIS Spatial Analyst Cost Distance Tool (Cost Weighted Rasters) follows a slope category ranging between 0 and 5 degrees against 34.38% and 29.58% of the paths modelled respectively by the Cost Path Distance tool (Tobler Hiking Function) and Cost Distance tool (Tobler Hiking function adjusted by White). The first modelled path never takes slope beyond 40 degrees whereas the two remaining-modelled paths respectively follow slopes reaching 60 and 50 degrees (Fig. 13). Goodchild has argued that the coastal road of Phoenicia seems to have been a Roman creation (Goodchild 1948, 112). Would the same also apply to this case study? What cannot be disputed is that communication roads joining the Phoenician coast to the Bekaa valley certainly predates the Roman Period (Khalil 2009, 122-129). However, as far as the Berytus-Heliopolis Baalbak road is concerned we can tentatively assume that the identified least cost path reflects a Roman engineered road.

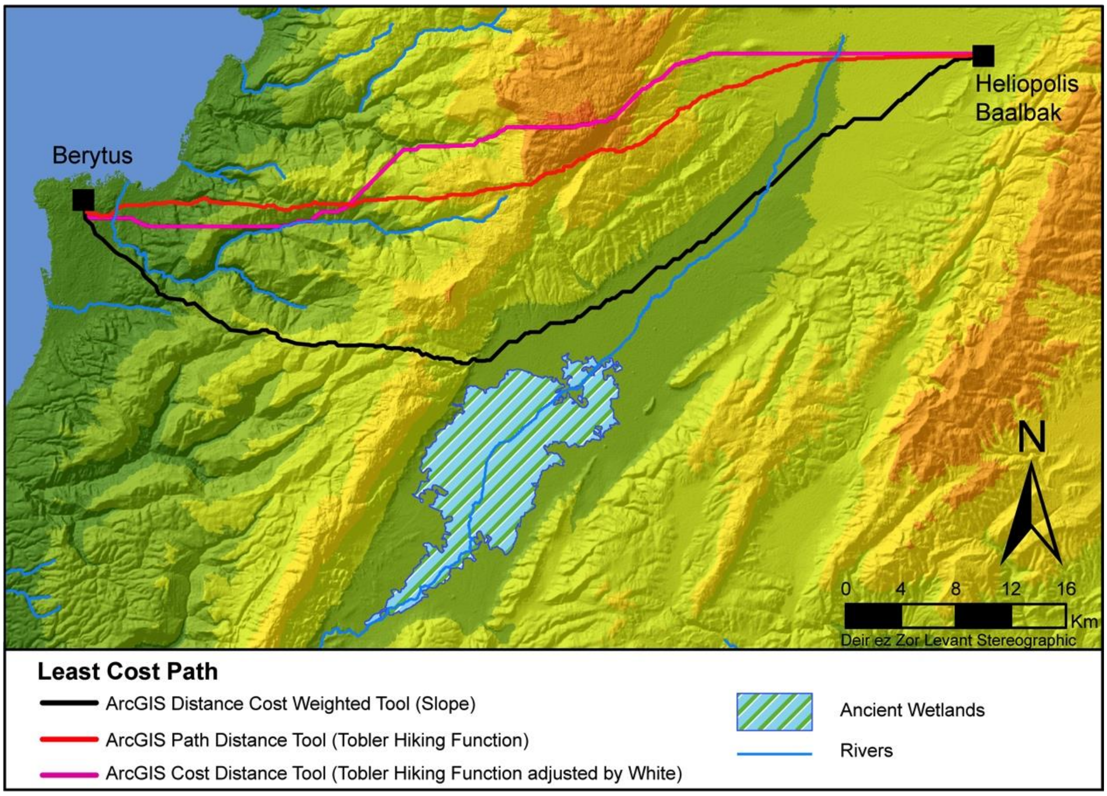

Figure 4. Map showing the reconstructed road models.

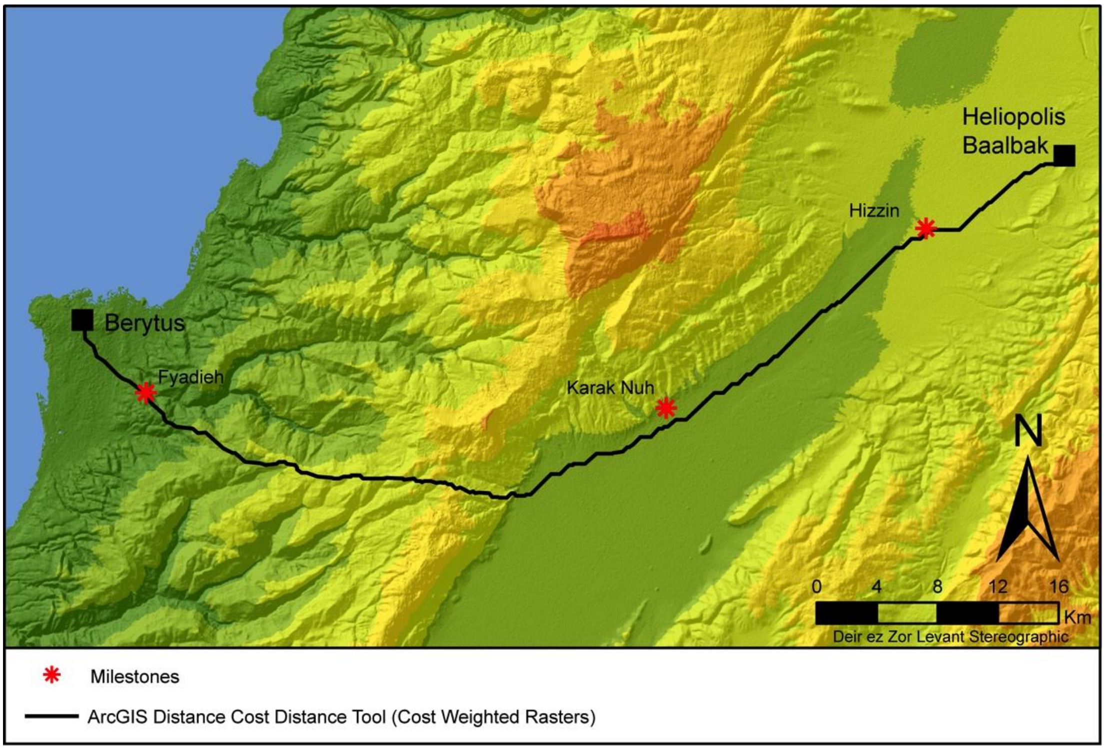

Figure 5. Map showing the location of Roman milestones with respect to the least cost path layout.

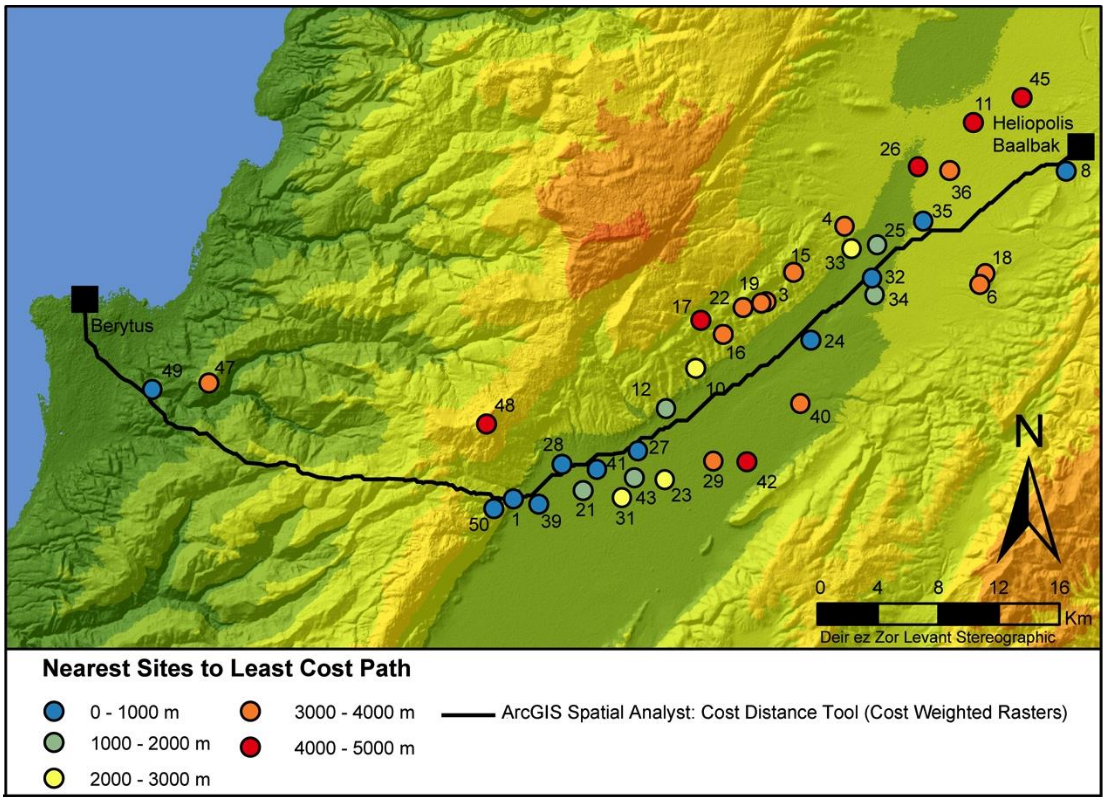

Figure 6. Map showing the location of the nearest sites to the least cost path within a range of 5000 meters.

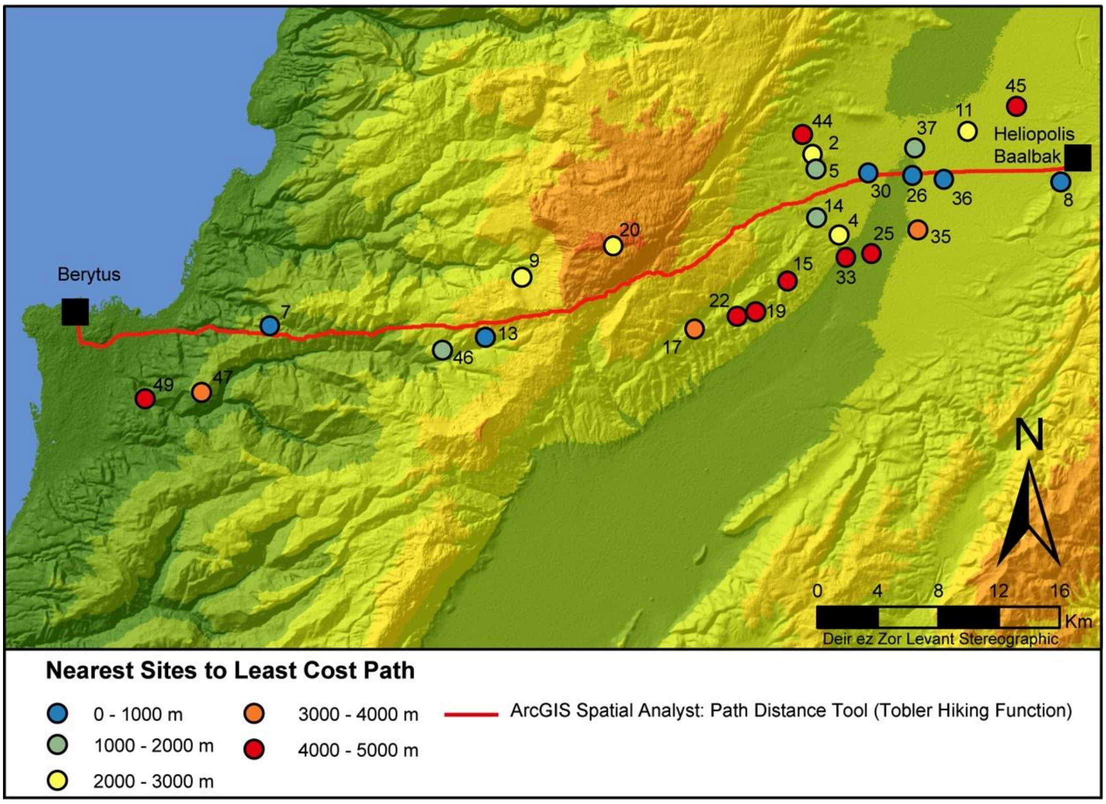

Figure 7. Map showing the location of the nearest sites to the least cost path within a range of 5000 meters.

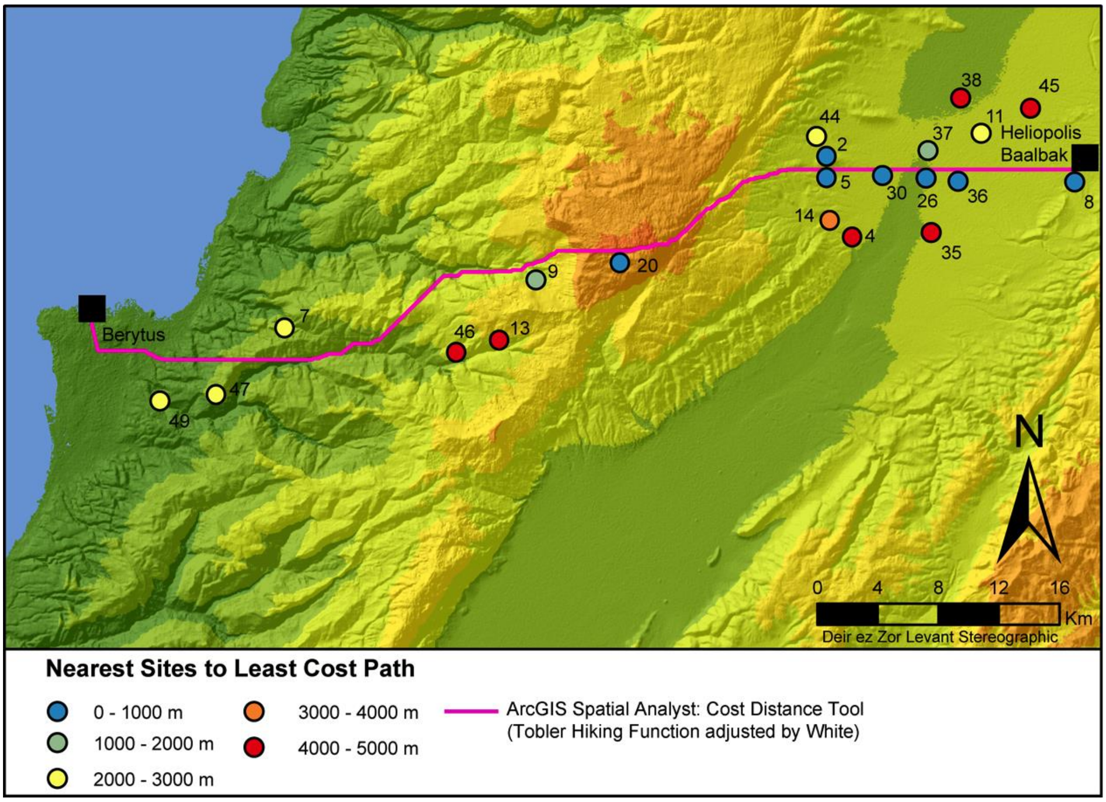

Figure 8. Map showing the location of the nearest sites to the least cost path within a range of 5000 meters.

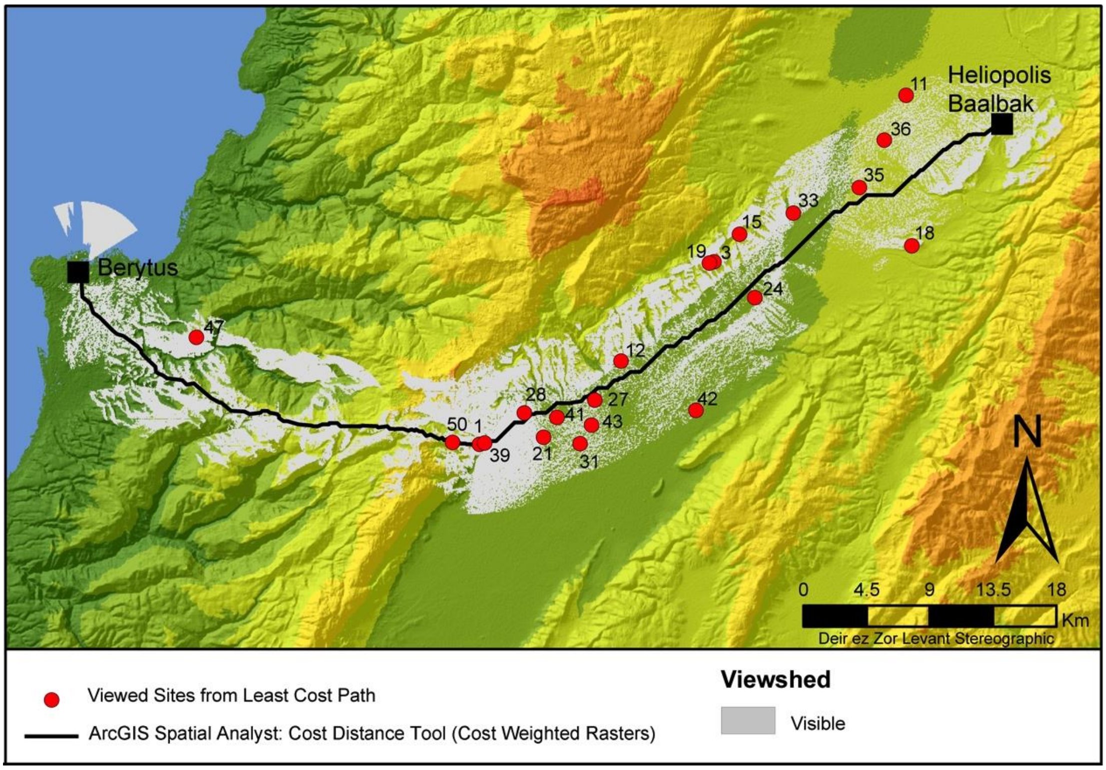

Figure 9. Map showing the visible sites from least cost path.

Figure 10. Photo showing the bas-relief known as Aain al-Ghadi (Qab Elias).

Figure 11. Photo showing the monument known as Haidara located in the town of Qab Elias (after Khalil 2015)

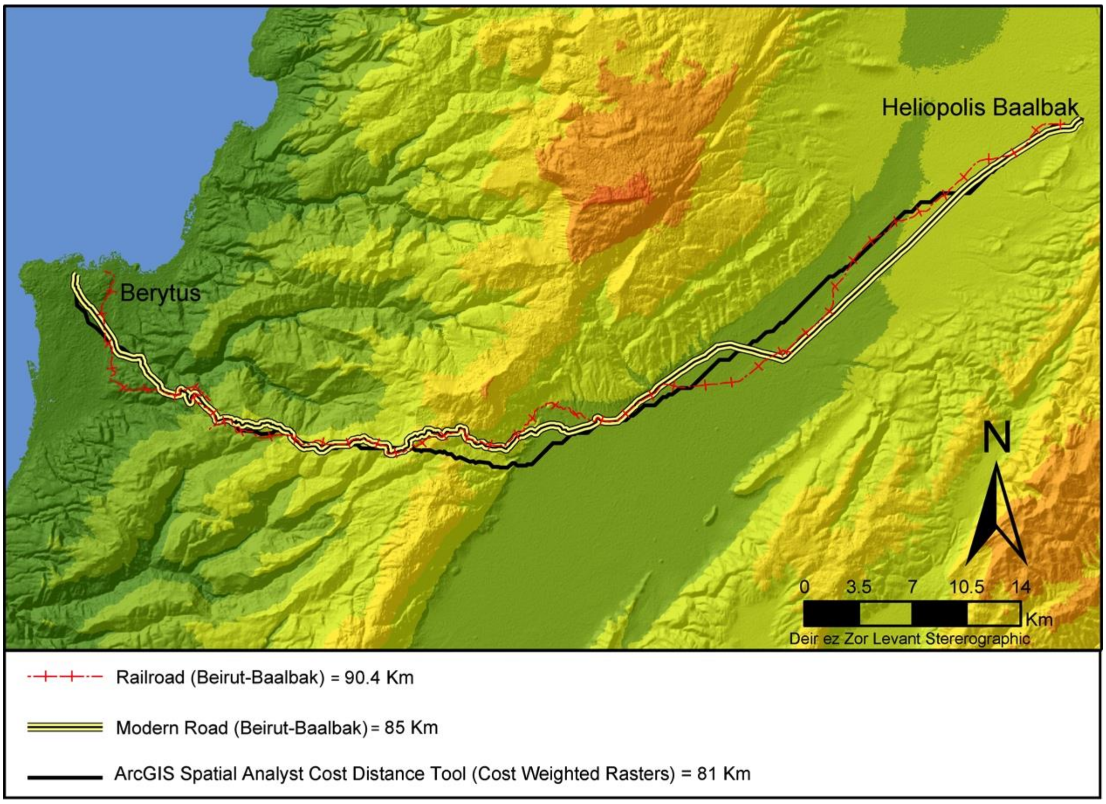

Figure 12. Map showing the layout of the least cost path in respect to the railroad and modern road.

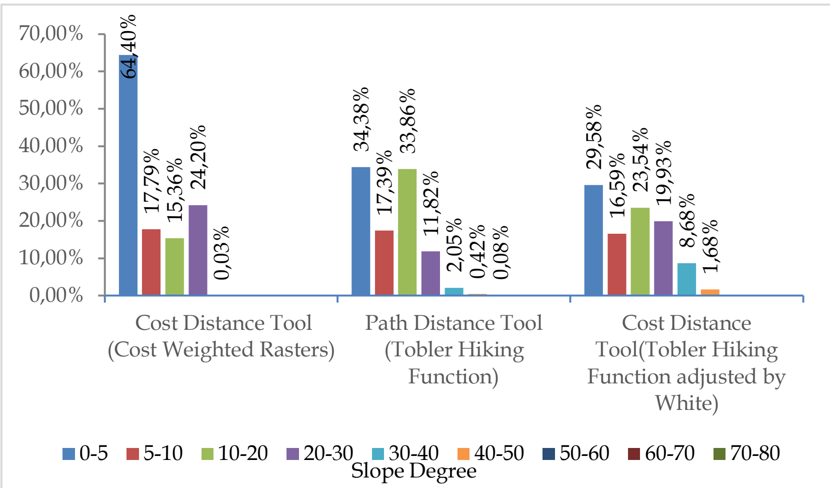

Figure 13. Percentage of Least Cost Path length per slope category

Table 2. List of Roman sites located with a 5 km radius of the modelled least cost paths (only sites to the nearest meters were used for this research)

Site Name	Site no.	Location Source	Settlement Type	References
Haidara Qab Elias	1	GPS	Funerary?	Krencker, Zschietzschmann 1938
Aarid el Hadet	2	Marfoe no.283	N/A	Marfoe no.283
Aain es-Sefli	3	Marfoe no.202	N/A	Marfoe no.202
Aain Hashbai	4	Marfoe no.241	N/A	Marfoe no.241
al Hadaṯ	5	Marfoe no.245	N/A	Marfoe no.245
Brital	6	Marfoe no.250	N/A	Marfoe no.250
Broumana	7	Lebanese maps (1:20,000)	Temple	Aliquot 2009

Cheikh Abdallah	8	Marfoe no.258	N/A	Marfoe no.258
ej-Jawzeh	9	Lebanese maps (1:20,000)	Burials, Quarry, monumental buildings, settlements	Nacouzi 2016
Furzul	10	Marfoe no.201	N/A	Marfoe no.201
Haouch Tell Safiye	11	Marfoe no.292	N/A	Marfoe no.292
Karak Nuh	12	Marfoe no.196	N/A	Marfoe no.196
Majdel Tarchich	13	Lebanese maps (1:20,000)	Temple	Aliquot 2009
Mugharet Hamzeh	14	Marfoe no.247	N/A	Marfoe no.247
Mseidej	15	Marfoe no.246	N/A	Marfoe no.246
Niha	16	Lebanese maps (1:20,000)	Temple	Aliquot 2009
Niha (Husn Niha)	17	Marfoe no.200	N/A	Marfoe no.200
Qalaat et Tannur	18	Marfoe no.252	N/A	Marfoe no.252
Qsarnaba	19	Lebanese maps (1:20,000)	Temple	Aliquot 2009
Saninne	20	Lebanese maps (1:20,000)	Temple	Aliquot 2009
Taanayil	21	Marfoe no.158	N/A	Marfoe no.158
Tamnine al-Fawqa	22	Marfoe no.198	N/A	Marfoe no.198
Tell Aaqaibi	23	Marfoe no.178	N/A	Marfoe no.178
Tell Aain Cherif	24	Marfoe no.206	N/A	Marfoe no.206
Tell Aain ech Chemali	25	Marfoe no.236	N/A	Marfoe no.236
Tell Aain es Saouda	26	Marfoe no.240	N/A	Marfoe no.240
Tell Aain Sofar	27	Marfoe no.186	N/A	Marfoe no.186
Tell Chtaura	28	Marfoe no.160	N/A	Marfoe no.160
Tell Delhamiyeh	29	Marfoe no.177	N/A	Marfoe no.177
Tell el Hadet	30	Marfoe no.269	N/A	Marfoe no.269
Tell el Majdoub	31	Marfoe no.180	N/A	Marfoe no.180
Tell Ghassil	32	Marfoe no.233	N/A	Marfoe no.233
Tell Hashbai	33	Marfoe no.231	N/A	Marfoe no.231
Tell Hawsh en Nebi	34	Marfoe no.242	N/A	Marfoe no.242
Tell Hizzine I	35	Marfoe no.232	N/A	Marfoe no.232
Tell Majdalun	36	Marfoe no.234	N/A	Marfoe no.234
Tell Nebaa Litani	37	Marfoe no.268	N/A	Marfoe no.268
Tell Ouardine	38	Marfoe no.271	N/A	Marfoe no.271
Tell Qab Elias	39	Marfoe no.159	N/A	Marfoe no.159
Tell Rayak	40	Marfoe no.207	N/A	Marfoe no.207
Tell Taalabaya	41	Marfoe no.174	N/A	Marfoe no.174
Tell Terbol	42	Marfoe no.185	N/A	Marfoe no.185
Tellet Qarmita	43	Marfoe no.179	N/A	Marfoe no.179
Wadi Makaness	44	Marfoe no.282	N/A	Marfoe no.282
Yaat	45	Marfoe no.297	N/A	Marfoe no.297
Aaintoura	46	Lebanese maps (1:20,000)	Temple	Aliquot 2009
Dayr al-Qalaa	47	Lebanese maps (1:20,000)	Temple	Aliquot 2009
Jabal el Knisseh	48	Lebanese maps(1:20,000)	Temple	Aliquot 2009
Qanater Zbaydeh	49	Lebanese maps (1:20,000)	Aqueduct	Davie F., M., Makaroun Y., Nordiguian L. 1997.
Aain al-Ghadi	50	GPS	Bas Relief (religious)	Ronzevalle 2006

5. CONCULSION ANF FUTURE DIRECTION

We have attempted through this case study to validate the assumption that Roman official authorities have established the most efficient communication road between Berytus and Heliopolis Baalbak following the annexation of the latter city to the Roman colony of Berytus and the implantation of Roman settlers in the area of northern Bekaa. Three slopes-based least cost paths have been tested for this purpose of which one (ArcGIS Spatial Analyst: Cost Distance Tool (Cost Weighted Rasters) seems to have been the most compatible with the archaeological and historical records. There is good evidence to suggest that the Roman authority seems to have been more concerned about reducing the energy expenditure than distance and time on the Berytus-Heliopolis Baalbak road as the validated path is longer and more time-consuming than the two other paths. The validated modelled path remains however hypothetical as long as the archaeological evidence of this road remains lacking. Further investigations are required in order to ascertain the veracity of our model such as establishing test pits, surface surveys or geophysical surveys along the least cost path.

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[i] Sawaya 2009, 188, summarized the various date assumptions of the foundation of the Roman colony of Berytus.

[ii] Herodianus (Hdn. III, 6., 9) reports that Laodicea and Tyre took the side of Septimius Severus as soon as they learned about Niger's defeat at Issus while Berytus and Antioch remained loyal to Niger.

[iii] For an overview of slope-based cost models see Herzog 2014, 231-235.

[iv] An Attribute Table was created for the DEM (Digital Elevation Model) in order to extract all the values equal to or below 0 using the Extract by Attributes Spatial Analyst tool in ArcGIS.

[v] A similar process for the establishment of the least cost path was applied by Rivera 2014.

[vi] The settlement location used in this research are based on Marfoe 1995 for sites located in the Bekaa as well as topographic maps on a scale 1:20,000 elaborated by the Directorate of Geographical Affairs of the Lebanese Army. Marfoe's locations are in the Deir Ez Zor Syria Lambert Grid Coordinate system which were also geo-referenced from the topographic maps on a scale 1:20,000 in the Deir Ez Zor Levant Stereographic Grid Coordinate. The latter maps are of much higher precision than the remote archaeological site prospecting conducted by Savage and Rempel 2012.