



A city hit by an earthquake: an HGIS approach to reconstructing the damage in Tiberias (Israel) in 1837

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ABSTRACT

On 1 January 1837 a devastating earthquake struck northern Ottoman Palestine, Lebanon and southern Syria, causing considerable damage in many localities. Tiberias, located on the western shores of the Sea of Galilee, suffered badly and many of its inhabitants were injured or perished. Yet, although the earthquake and the resulting damage were described in many contemporary sources, evaluation of the damage and its spatial distribution was never made before. In this study textual and visual sources were collected and compiled to evaluate the damage that resulted. An HGIS (historical GIS) approach was implemented to examine these sources, geo-code the damage and digitally reconstruct Tiberias at the time. The results were a contemporaneous map of Tiberias at the beginning of the nineteenth century and three-dimensional models of the city prior to and after the earthquake. The models enabled a 360° examination of the damage distribution in high resolution and evaluation of the overall impact of the earthquake. This study demonstrates the use of HGIS in the reconstruction of past urban cityscapes and the investigation of earthquake damage. It also suggests extending this methodology to other historical-geographical studies of past landscapes and to the examination of any kind of gradual or dramatic change.

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1. Introduction

On 1 January 1837, a destructive earthquake hit northern Ottoman Palestine, Lebanon and southern Syria. The earthquake was felt from Antakya (southern Turkey) in the north to the Nile Delta (Egypt) in the south (Figure 1(a)). Considerable repercussions were also felt in Cyprus and in several Jordanian localities. The cities of Saida, Tyre, Bint-Jbail, Nabatiah (in southern Lebanon), and Akko (Acre), Safed and Tiberias were severely hit (Ambraseys 1997, 2009). Although many of the historical sources reported the damage in detail, its accurate spread was not evaluated so far in any of these cities. The latter is crucial for understanding the impact of that earthquake and for preparing better for future events.

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📎 Supplemental data for this article can be accessed [here](#).

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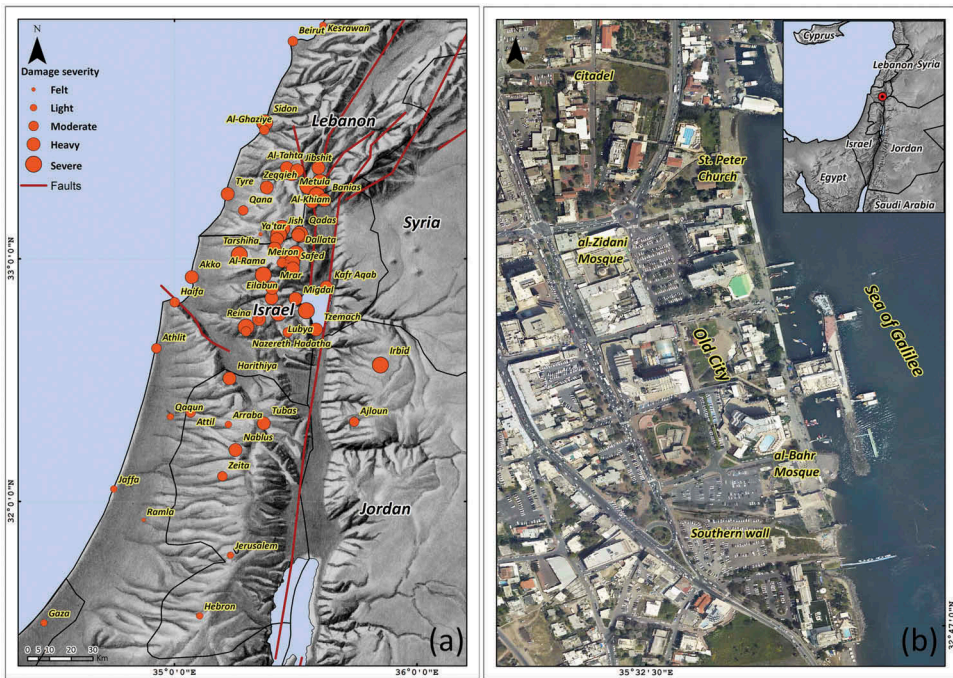


Figure 1. (A) Damage distribution in Ottoman Palestine and its close surroundings caused by the 1837 earthquake (Ambraseys 1997, 2009) and classified by the degree of severity (Zohar *et al.* 2013); (B) general overview of the old city of Tiberias.

In the absence of photography at the time of the earthquake (Nir 1985), the task of mapping the resulting damage in high resolution is rather complex. Yet alternative visual sources available can be used for this purpose and can be cross-validated as accurately as possible with recent field surveys. Tiberias (Figure 1(b)) seems to be a suitable candidate for such a task: (1) many eighteenth and nineteenth century travellers reported on its state; (2) two aid delegations from Jerusalem and Beirut visited the city and reported on the damage extent (Calman 1837, Nee'man 1837, Thomson 1837); (3) remains of the damage are still visible today (Figure 2); and (4) Tiberias was described by many visual sources and was depicted in a few dozen drawings dated prior to and after the earthquake.

Using visual sources to reconstruct past landscapes is fundamental and the phrase 'a picture is worth a thousand words' is more than relevant in such cases. Like the written accounts, visual sources might contain inaccuracies, exaggerations and distortions but once these are sifted out, they provide us with invaluable information of the geographic landscape at the time (e.g., Rose 2001, Karniel and Enzel 2006, Rubin 2006, Levin *et al.* 2010). Nevertheless, as of today only a few scenarios have been evaluated for the study of historical earthquakes (e.g., Ambraseys and Karcz 1992, Hinzen 2013, Zohar *et al.* 2014, 2015). Recently, the rapid development of Geographic Information Systems (GIS) introduced a new approach, referred to as historical GIS (HGIS), providing us with powerful and accurate spatial tools that significantly improve our abilities to resolve past scenarios (Knowles 2005, 2008, Gregory and Ell 2007).

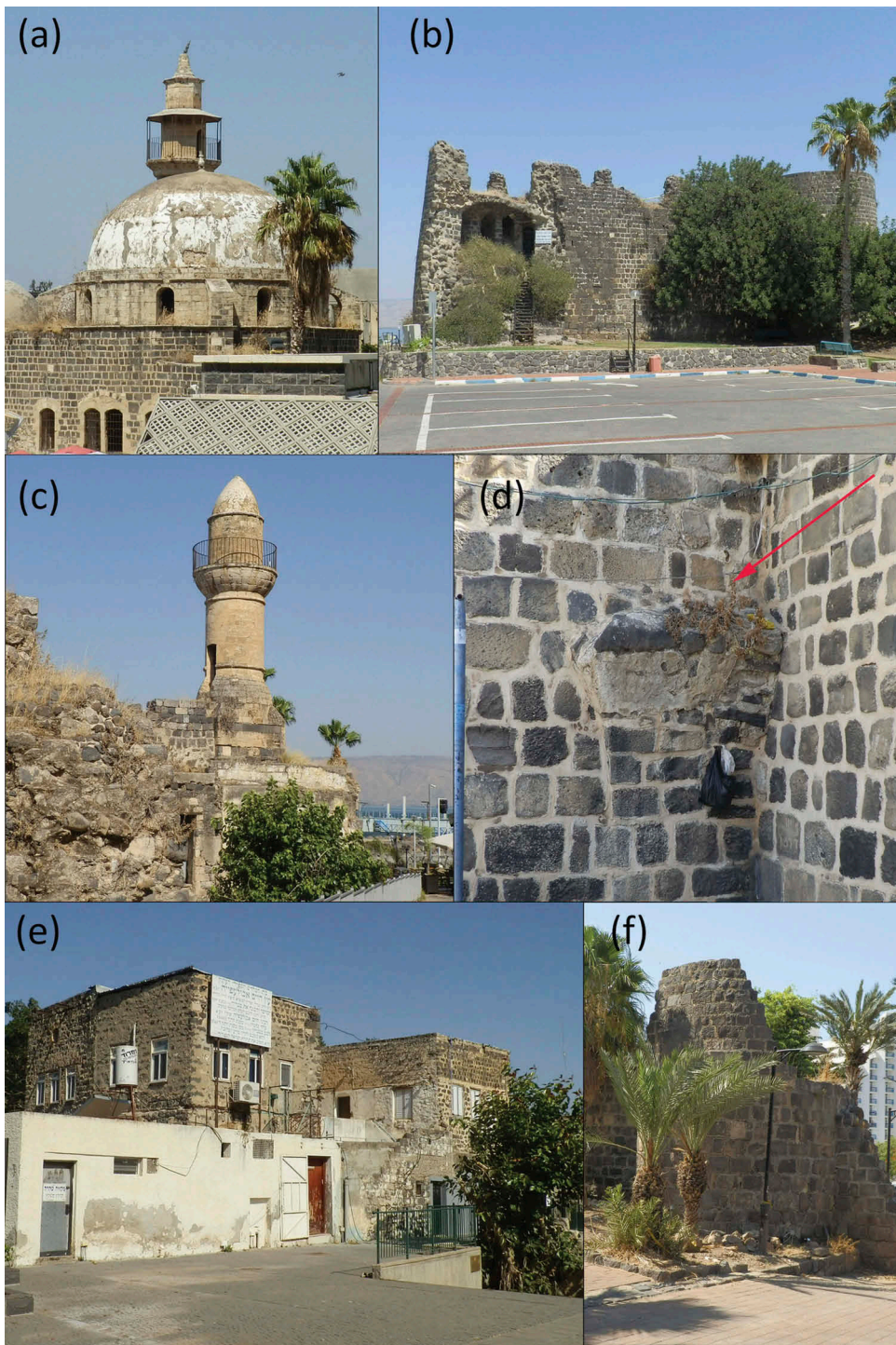


Figure 2. Sites in the old city of Tiberias, in some of which (B and F) the 1837 earthquake damage is still apparent: (A) al-Zaydani Mosque; (B) the Citadel; (C) al-Bahri Mosque; (D) remains of the massive vaults in southern Tiberias (noted by red arrow); (E) Etz-Hay'im Synagogue; (F) one of the southern damaged turrets in Tiberias's walls (Photographs: Motti Zohar, 2015).

In this study the damage in Tiberias after the 1837 earthquake was reconstructed using HGIS. Accordingly, visual and textual sources were compiled together in a GIS-based framework to build 3D models of Tiberias prior to and after the earthquake. The comparison of these two models enables the quantification of the damage that resulted and the inspection of its spatial distribution. It is also expected to assist in evaluations of preparedness towards the future for earthquakes in the region of Tiberias are inevitable.

2. Short history of Tiberias

Tiberias was established in 19 CE by Herod Antipas who named it after the Roman emperor Tiberius. Like the rest of Palestine, during the next 1500 years it underwent Roman, Byzantine, Muslim, Crusader and Mamluk regimes (Avi-Yonah 1951, 1980, Gil 1983). In 1517 the Ottomans conquered Palestine and were mostly interested in subjecting Tiberias to the general governance of Damascus. Their interest was smartly manipulated by Dona Gracia, a wealthy Portuguese Jewess from Istanbul (Turkey) who used her influence and connections at the Sultan's court to increase the Jewish population in the Galilee and to establish Tiberias as a Jewish centre. Ottoman Firmans (written permission) report that between June 1560 and December 1565 Dona Gracia had leased the collection of taxes in Tiberias and a few other villages in the region. The Firmans also imply that she was probably responsible for reconstruction of the surrounding walls of Tiberias in order to increase the security of the inhabitants (Roger 1646, De Aveiro 1927, Heyd 1966).

The prosperity of the Jewish community did not last long and sometime at the beginning of the seventeenth century the Jews were forced to leave due to Ottoman tyranny (Roger 1646, De Thévenot 1971). The turning point for Tiberias was the rule of Dahir al-Umar of the Bedouin Zaydan family. Close to the mid-eighteenth century he gained control of Tiberias and other Galilean regions and gradually accumulated massive power. His dominancy did not escape the eyes of Suleiman, the Pasha of Damascus, who decided to overthrow Dahir's rule by besieging Tiberias three times: in 1738, 1742 and 1743. The first two sieges were failures and during the last attempt Suleiman died of an intestine illness (Bnayahu 1946, Heyd 1969, Nachshon 1980). The son of Dahir, Chulaybi, had fewer confrontations but, like his father, kept strengthening Tiberias and in 1750 also built a citadel on a hill at the northwest corner of the city (Hasselquist 1766). In October and November 1759, the walls and the Citadel were severely hit by two consecutive earthquakes (Ambraseys and Barazangi 1989, Ambraseys 2009), but were gradually restored towards the end of the nineteenth century (Mariti 1791).

In October 1831 the Egyptian Ibrahim Pasha invaded Palestine on his way north and in May 1833 he completed the conquest of Syria and Palestine. In 1834 another damaging earthquake struck Palestine but no damage to Tiberias or northern Palestine was reported (Ambraseys 2009). In the same year a Fellahin rebellion erupted in the mountainous areas of Bethlehem, Jerusalem, Nablus, Transjordan and northern Galilee. The rebels took over Tiberias for a short period but the Egyptians, with reinforcements from the south, eventually managed to gain back control of the city (Ben-Zvi 1954). From that year until the 1837 earthquake the city remained under Egyptian rule.

3. Materials and methods

Textual and visual sources relevant to the history of Tiberias from the mid-eighteenth to the beginning of the twentieth century were examined.

First, the relevant sources were verified, chronologically ordered and classified as prior to and after the 1837 earthquake. The visual sources (see Appendix 1, Supplemental material) required special attention: apart from determining their authenticity, one had to look also for spatial exaggerations, erroneous features and verify whether the artist actually witnessed the view he had depicted for several of the artists never visited Palestine or even copied their work from previous drawings (Ben-Arieh 1997, 2001). Maps and sketches were geo-referenced to a recent orthophoto of Tiberias while drawings, photographs and air photos were spatially attributed by the spot from which they were depicted or photographed, their relative height above Tiberias and the azimuth of drawing or photographing (Figure 3). Determining the spot from which a drawing was depicted or a photograph was taken included field surveys to trace the exact location and perspective the artist at the time had chosen. For air photos however, I have used the height of the flight as well as the azimuth between prominent features

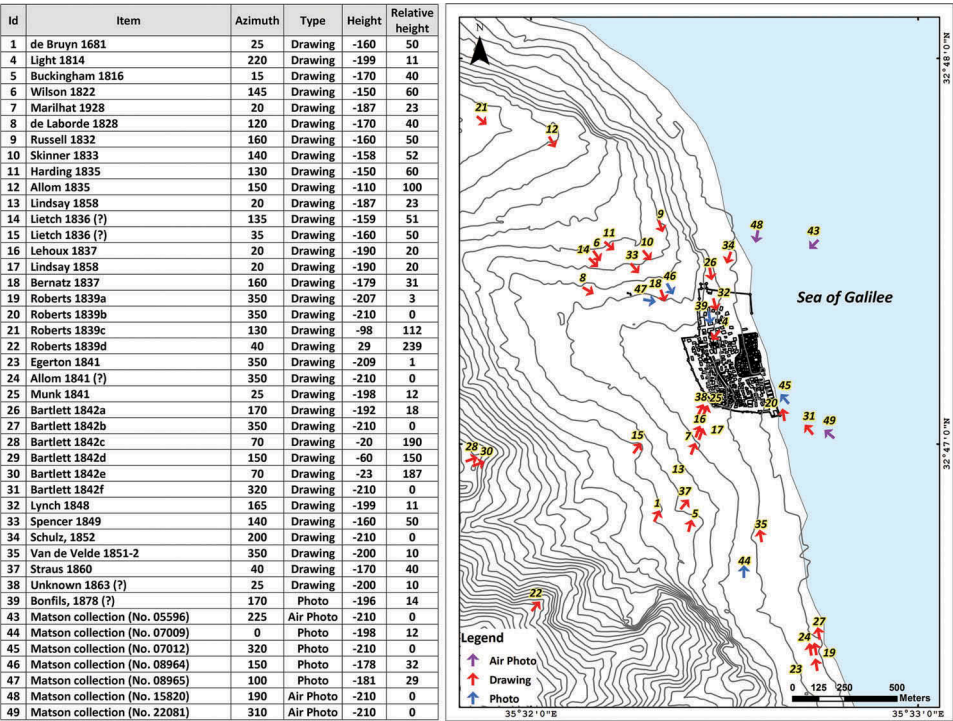


Figure 3. Visual sources used for reconstructing the landscape. On the right: location and azimuth (angle towards Tiberias from the given point) of the visual sources, i.e., air photos, drawings and photographs (Appendix 1). The map also presents topographic contours. On the left: **Id** – sequential numeration in chronological order (compatible with the numbering in Appendix 1); **Item** – reference of the source; **Azimuth** – azimuth of drawing/photographing towards Tiberias; **Type** of the source; **Height** – height above sea level; **Relative height** – height above the city of Tiberias (–210 below sea level).

(e.g., turrets of the wall, the al-Zaydani and al-Bachri mosques, St. Peter's Church) and the airplane photographing (see examples in the Supplemental material, items 48 and 49). Obviously, such geo-tagging of the visual sources is not as accurate as modern GPS geo-referencing. Yet, when inspecting an area of only a few square kilometres, cross-correlation of several sources from each view can reduce possible errors. The detailed examination of the sources included also the identification and notation of the prominent structures of Tiberias. For this purpose, recent photographs were used as some of the damaged structures (Figure 2) still exist today.

Next, a GIS-based platform using 'ArcGIS Desktop™' (ESRI) software was implemented and the noted geographic features were digitized. This was done at two levels of accuracy: (1) ± 5 m for features appearing in at least two reliable sources (textual or visual) and completely or partially existing today (e.g., the Citadel, the walls, St. Peter's Church and al-Zaydani Mosque) and; (2) approximately ± 50 m for features with only a conjecture of location (e.g., houses of the Kadi and Imam). Since the first cadastral map of the city appeared only after 1918, the features were digitized to accord with the British map of Palestine (1938) (Supplemental material, item 50). Obviously, the morphology of the city has changed during the passing century and thus several assumptions were made: (1) although the city was more populated in the twentieth century, the basic ownership of assets remained as it was in the nineteenth century; (2) the dwelling distribution in the Muslim and Christian quarters was less condensed than in the Jewish quarter; (3) the dwelling shapes and street formations within the old city more or less retained the same morphology as prior to the earthquake. The digitations resulted in thematic GIS layers of quarters, structures and streets, forming together a reconstructed 2D map (Figure 6) of pre-1837 Tiberias.

Following, the layers were superimposed on a 5×5 m DEM (Digital Elevation Model) surface (Hall and Cleave 1998) and the structural height was extruded to form a 3D shape. In cases where a structure does not exist today or its height was not assessed in any of the historical sources, the height was estimated as it appears in the drawings and in comparison with the height of other known structures. This process was iterated twice (Figure 4) to produce two models of Tiberias prior to and after the 1837 earthquake. The models were rotated and examined from several directions in order to fit perspectives and views in the visual sources (see example in Figure 5). In cases whereby a feature seemed not to fit according to at least two sources, corrections were made on the spot.

Finally, the damage degree was determined according to the difference in height of the given structures within the prior to and after the event models as follows: (i) 0–0.5 m: no/slight damage; (ii) 0.51–3 m: partial damage; and (iii) above 3 m: total collapse. The intermediate value of 3 m was selected as most of structures and dwellings in Tiberias were of a single floor.

4. Results

4.1. Pre-1837 Tiberias

Compilation results of the sources underlying pre- and post-1837 Tiberias are described in this and the following sections in detail. Much of the sources divide their descriptions of the city by the existing ethnic groups at the time, i.e., Jews, Muslims and Christians.

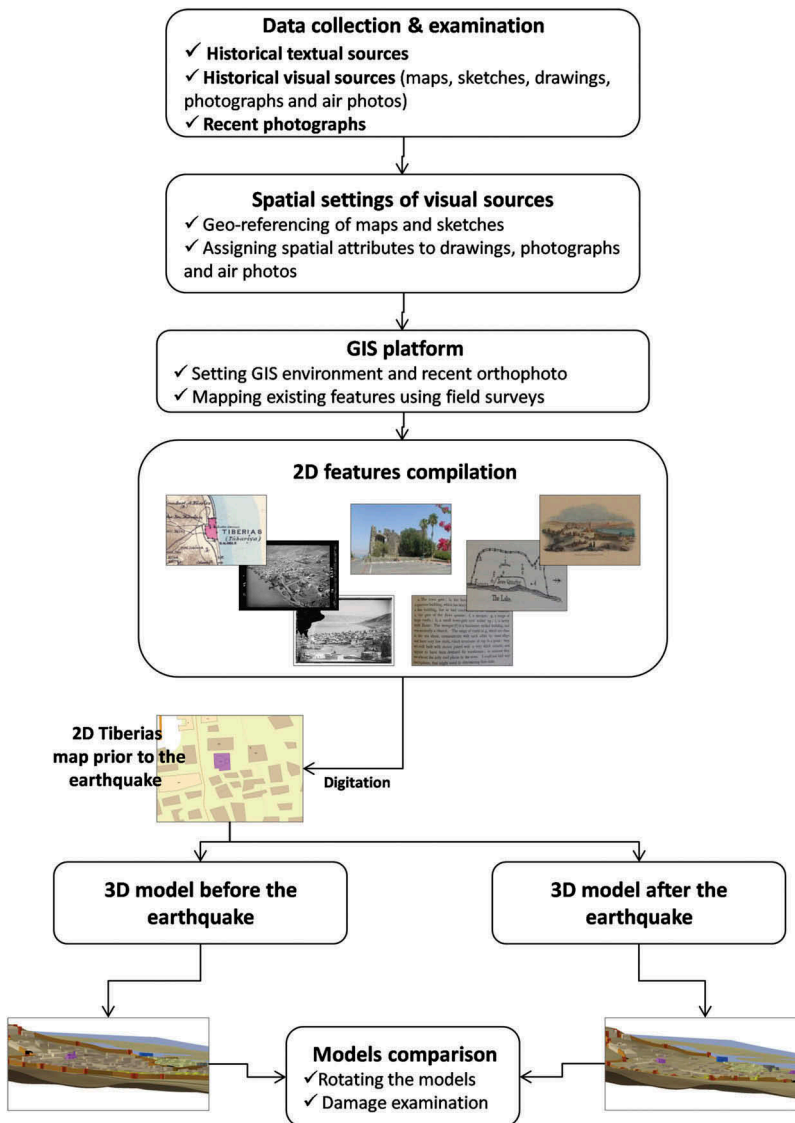


Figure 4. Transforming the historical data into 3D models of Tiberias prior to and after the 1837 earthquake.

Along almost the entire nineteenth century each of these groups resided in a different and separated area within the city. Consequently, the reconstruction of the Tiberias cityscape and the following damage analyses was carried out in light of this sub-division of the city. A summary of the prominent structures, the reconstructed 2D map and the 3D models appear in Table 1, Figures 6 and 7, respectively.

At the beginning of the nineteenth century Tiberias was a desolated city situated on the western shores of the Sea of Galilee (Figure 6) (Volney 1788, Richardson 1822, Irby and Mangles 1823). Roughly, the city was divided into three quarters: (1) the Muslims resided mainly at the northwestern area; (2) the Jews occupied an isolated

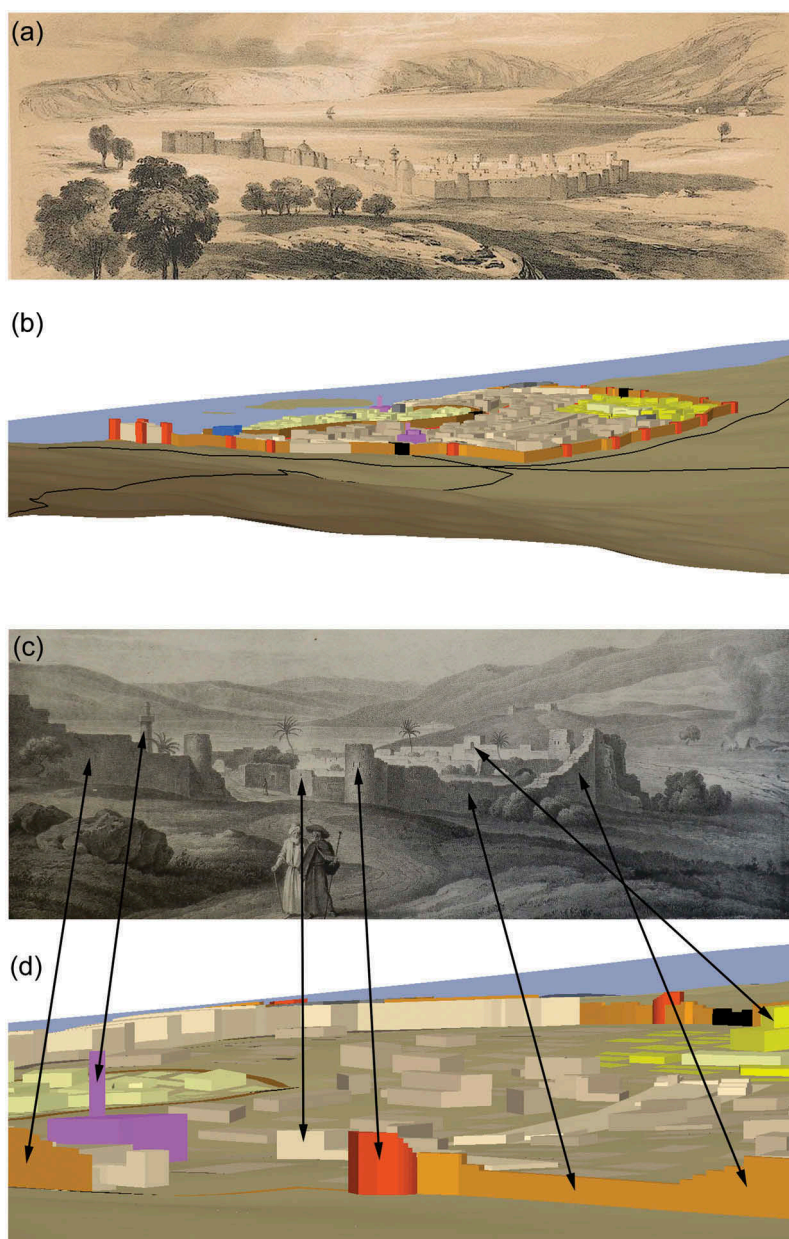


Figure 5. Detecting Tiberias features in visual sources (example, northern view): (A) 1828 (item 8, Appendix 1); (B) 3D model of the city prior to the earthquake; (C) 1837 (item 18, Appendix 1); and (D) 3D model of the city after the earthquake. Note the simultaneous detection of the depicted features in Figure C and in the model (Figure D).

quarter at the eastern side close to the shore; and (3) several dozen Christians lived in the southern end of the city (Avisar 1973, Schur 1987, Ben-Yakov 2001). The total area of the city did not exceed a quarter of a square kilometre and contained only a few hundred dwellings (Pococke 1745, Mariti 1791, Wilson 1823, Mendel 1839). A

Table 1. Localities in Tiberias reported to be damaged during the 1837 earthquake. **Symbol:** identification of the structure (as mapped in [Figure 6](#)); **Damage:** a rough estimation of the scope of the damage: N (no damage), S (slight damage), P (partial damage) and T (total destruction).

<i>Symbol</i>	<i>Locality</i>	<i>Damage</i>
–	Houses	P–T
W1-21	Walls	P
T1-20	Turrets	P
T21	Leaning turret	S
G1	Main gate	T
G2	Southern gate	P
P1	Citadel	P
P2	Aga house	P
P3	Harmon	P
P4	Seraiah	P
P5	Army commander's house (?)	P
P6	Imam's house (?)	P
P7	Bazaar	P–T
P8	Vaulted arcs	P
P9	Ottoman building	P
P10	Ottoman building	P
P11	Ottoman building	P
P12	Kadi's house (?)	P
M1	al-Zaydani Mosque and minaret	P
M2	al-Bahri Mosque and minaret	P
MB1, MB3 (?)	Tabri houses?	P
MB2	Palastina school?	P
C1	St. Peter's Church	N
C2	House of Catholic priest	P
JW1-2	Walls of the Jewish quarter	T
JG1	Gate of the Jewish quarter	T
S1	Etz-Ha'yim ('Sephardim') Synagogue	T
S2	'Hasidim' Synagogue	T
S3	Menahem Mendel of Witabsk Synagogue	P
S4	Reysin Synagogue?	P
S5	Shla domes?	S
S6	Reysin Kollel?	P
H1-5	Weisman hotel and apartments to let	T
Unresolved	Arabic hotel	Unknown
JB1	Hayim Abulafya house	P
JB2	Library (the cliff cave?)	P
JB3	Zee'v Woolf house	P
Unresolved	Schools	Unknown
Unresolved	'Prushim' Synagogue/Kollel	Unknown
Outside the city	Tombs (Rambam, 'Shla', Yochanan ben-Zakai, Kahana close to Yeshimon Mt., Meir Ba'al HaNess (close to the thermal baths)	N
	Thermal baths	N

significant part of the city, in particular in the north, was apparently vacant of buildings and apart from in the Jewish quarter, houses were located far from each other (Richardson 1822, Stephens 1839). The exact number of houses is not clear but according to the contemporary sources, the number of Jewish, Christians and Muslims buildings ranged between 185–230, 40–80 and 150–250, respectively, and all together between 375–560 houses (Turner 1820, Wilson 1823, Jowett 1826, Horne 1836, Schur 1988). Most of the buildings were built of stone and had 1–2 stories, i.e., roughly were between 3 and 6 m high. Many of the houses had little porches used for sleeping outdoors during the hot summer nights (Turner 1820, Pueckler-Muskau 1844).

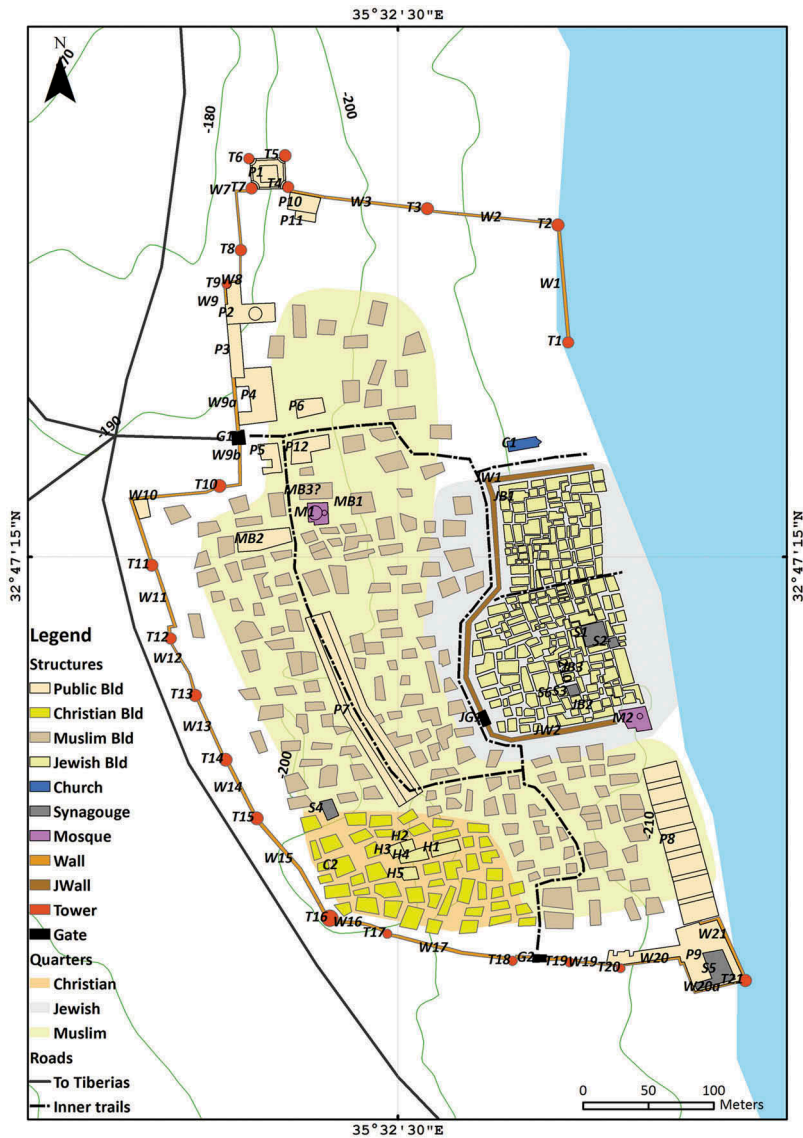


Figure 6. Tiberias and its major features prior to the 1837 earthquake (for notations see Table 1). The city interior was compiled using pre-1837 drawings (Appendix 1), maps of Palestine (1938), PEF (1918), Burckhardt (1822) and historical accounts (Mariti 1791, Clarke 1810–1823, Light 1818, Turner 1820, Buckingham 1822, Richardson 1822, Scholz 1822, Wilson 1823, Carne 1826, Jowett 1826, Maden 1829, Madox 1834, Horne 1836, Stephens 1839, Kinglake 1848).

The city was surrounded by the mid-eighteenth century walls repaired by Dahir al-Umar and his son Chulaybi. Their thickness ranged between 80 and 120 cm and Birav (Bnayahu 1946) reported that they were so high that ladders were needed to climb over them. Other western travellers estimated their height between 6 and 8 m (Pococke 1745, Hasselquist 1766, Spilsbury 1823, Robinson and Smith 1856). The walls were flanked by 21 circular turrets standing at unequal distances between each other (Irby and Mangles

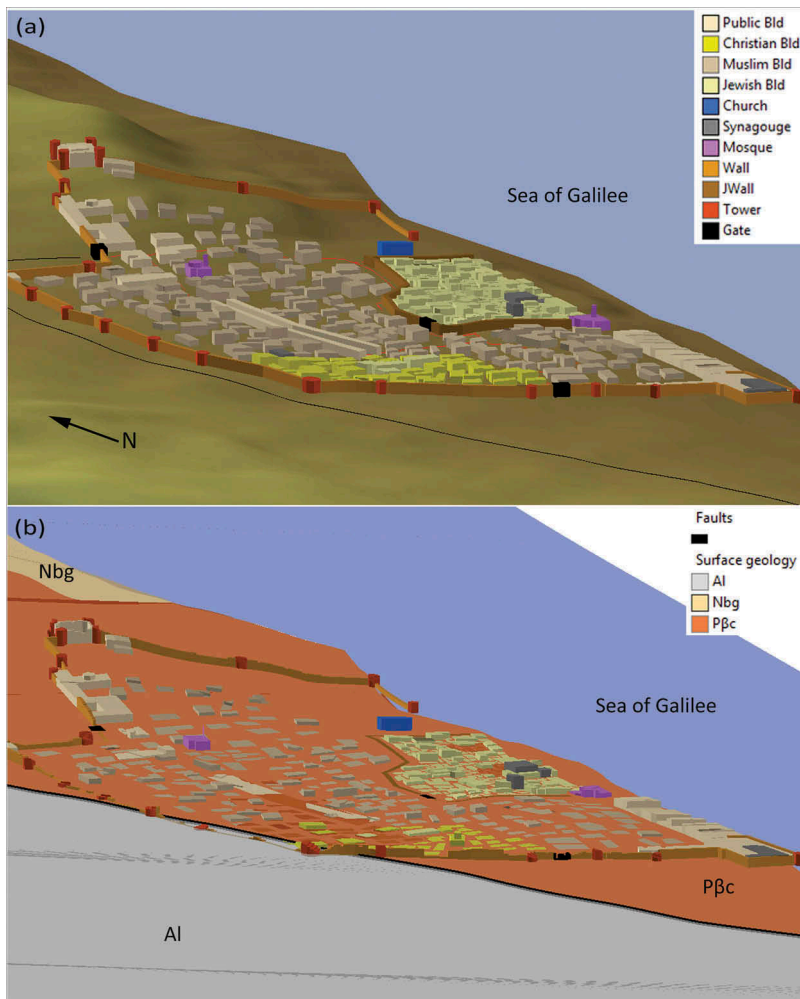


Figure 7. 3D view of Tiberias. (A) Before the earthquake, superimposed on a topographic (DEM) surface; and (B) after the earthquake overlain on a geological surface layer: **Al**: Alluvium, colluvium, soil; **Nbg**: Bira and Gesher formations; and **Pβc**: cover basalt. Prominent features (Table 1) are labelled in black. Note that the majority of Tiberias is located on basalt rocks and note the extensive damage along the fault that crosses the western walls.

1823, Jowett 1826). According to Jacotin's map and Burckhardt's sketch, there were only two gates to the city: a western main gate and a small southern gate (Jacotin 1799, Burckhardt 1822). Like other Ottoman cities, the citadel on the northern hill of Tiberias protected the town from outer invasions (Pococke 1745, Hasselquist 1766, Clarke 1810–1823).

There were two mosques in the city: the largest was the al-Zaydani (al-Umari), named after Dahir's family name, while the other was al-Bahri (the sea mosque), and located south of the Jewish quarter. The Church of St. Peter was situated north of the Jewish quarter but the house of the Catholic priest, however, was at the southern end of the city.

Additional Ottoman buildings, located in the Muslim quarter close to the western gate, were the houses of the Aga (governor house or Seraiah), the Kadi, the Imam and the army commander (Schur 1987, Abbasi 2006). A small bazaar decorated by massive vaults was located in the centre of the city. Other vaulted arches were located at the southern shoreline facing the sea (Burckhardt 1822).

The Jewish quarter occupied a portion of the city close to the shore. It was surrounded by a high wall with a western entrance gate, which was regularly shut at sunset. Apparently, there were at least two synagogues and a 'Kollell' (a Jewish school) within the quarter and probably another one at the southern end of the city: Stephens reported on two synagogues and two schools and Jowett reported on two schools and three synagogues. I assume that the 'Kollell' reported in 1833 in the letter of Rabbi Yaa'kov Menlis, is the 'Reysin' Kollell, located close to Menahem Mendel's house (Stephens 1839, Jowett 1826, Robinson and Smith 1856, David Debith Hillel in Ya'ari 1976, pp. 512–514, Scholz 1822, de Gramb 1840, Schur 2002). Although Christians lived mainly in southern Tiberias, there were also a few dwellings of Jews there: von Puckler-Muskau reported that a wealthy Jew (Hayim Weisman?) had 21 houses to let. He does not mention their exact location but since there are no reports of hotels in the Jewish quarter, I assume they were located in the southern part of the city (Pueckler-Muskau 1844). Located about half a kilometre south of the city were the Jewish and Muslim cemeteries and about one kilometre further south the thermal baths for local and touristic use (Seetzen 1810, Robinson and Smith 1841). North of the city there were several sacred tombs (Mendel 1839, Robinson and Smith 1856, Guerin 1880) and west of it a small agricultural area. One major road led to the city from the south and two others from the west (Jacotin 1799, Buckingham 1822, Olin 1844).

4.2. Post-1837 Tiberias

Apparently, most of the Tiberias dwellings were completely destroyed while public buildings escaped the damage. The drawings of Lehoux, Roberts, Bernatz and Munk (Supplemental material, items 16, 18, 19–22 and 25, respectively) demonstrate that the Christian and Muslim quarters were almost completely destroyed and shortly after the earthquake were left with only a few standing dwellings. The citadel, the surrounding public structures, walls and turrets were damaged but parts of them still remained (drawing 16, 25, 26, 28, 30 and 35 and photograph 44, Supplemental material). The walls were damaged unequally: little damage was observed in the northern part of the walls; the southern part was considerably damaged but parts of it still remained; the western part collapsed almost entirely along with its flanked turrets. Roberts sketched breaches within the walls and a diagonal lean of the southwestern turret¹ (items 19–22, Supplemental material). These damaged structures were never reconstructed and some of them still remain in ruins today (Figure 2).

Inside the city, the al-Zaydani Mosque was damaged and its dome collapsed. Its minaret, however, still remained. On the other hand, the minaret of al-Bahri Mosque did not escape the damage (Robinson and Smith 1841, Olin 1844). The drawings of Lehoux, Bernatz, Roberts, Munk, Bartlett, Lynch, Spencer and van de Velde (Supplemental material, items 16, 18, 19–22, 25, 31, 32, 33 and 35, respectively) depict the minaret of al-Zaydani still standing but no dome and no minaret at al-Bahri mosque. This is also

apparent in a late nineteenth century photograph of Bonfils (Supplemental material, item 39). At the beginning of the twentieth century a new dome and minaret appeared at the al-Zaydani and al-Bahri mosques, respectively (Supplemental material, items 44–46). The vaulted bazaar was damaged but there are no other specific details (Israel of Shklov 1837). I assume, however, that it was completely or badly destroyed for it is not apparent in the drawings of Lehoux and Roberts (Supplemental material, items 16 and 19–22). The vaulted arcs in the south of the city were probably damaged as well; Roberts depicted them as damaged and this is also apparent in a twentieth century photograph (Supplemental material, items 20 and 45, respectively). There are no reports of damage to the Church of St. Peter.

The Jewish quarter, as reflected in various post-1837 drawings, seems to be less damaged than the Christian and Muslim quarters; Lehoux, Lintch and Roberts (Supplemental material, items 16, 20, 21, 22 and 32) depicted the Jewish quarter with more standing dwellings than in the other quarters. Further search through the visual sources to locate the remains of the walls surrounding the Jewish quarter produced no results; they may have been completely destroyed beyond repair.

The total number of casualties during the earthquake is not clear: while the official report of Suleiman Pasha numbers 922 victims, other estimations range between 700 and 2000. The eyewitness Calman reported that the number of Jewish victims was significantly greater than that of the Muslims and Christians. This report conforms to the report of Robinson from 1838 that numbers less Jewish families than Muslim families, although before the earthquake Jews were considered to be the majority in Tiberias (de Gramb 1840, Horne 1836, Debith-Hillel in Ya'ari 1976).

5. Discussion

Rotating the models enabled a 360° examination of damage from almost any direction, even from spots that were not covered by the nineteenth century artists, such as an eastern spot in the Sea of Galilee or aerial views. The two models of before and after the earthquakes were compared (Figure 7) in order to identify the structural damage and examine its spread (Figure 8). It seems that although the Tiberias area was relatively small, the spread of the damage as well as its severity was not uniform. This is clearly observed particularly along the walls and between the residential quarters of the city. In general, such variability in damage within a small area may imply different local site attributes, whereas the distance from the epicentre and the directivity effect are almost identical in any spot within that area. Among the most influencing site attributes, one can count the construction quality, surface geology and topography (Zaslavsky *et al.* 2000). The latter two can hardly explain the differences whereas almost the whole of Tiberias is situated on basalt rocks (Pβc) and apart from the moderate northern slopes, the city lies on a flat plain (Figures 7(a,b)). The construction quality, however, varies and manifests several structural styles for residential dwellings, religious structures and government buildings (Figure 2). Unfortunately, at this stage there is no reasonable understanding of the vulnerability and resistance of these structures to earthquake shaking. Yet, it is still possible to classify Tiberias's structures into two groups.

The first, which was probably more resistant to earthquake shaking, includes the Citadel, walls, turrets and government buildings such as the Seraiah and Kadi houses.

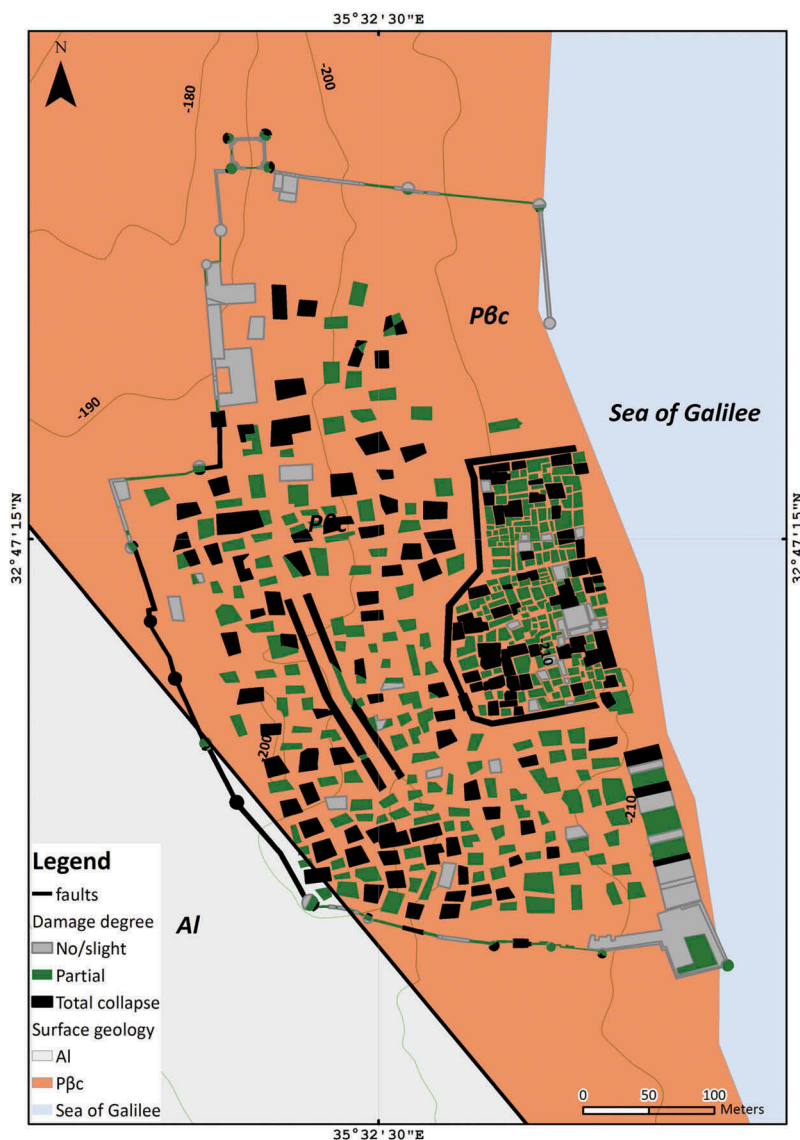


Figure 8. The spread of the earthquake damage that resulted in Tiberias by comparing the two HGIS models of before and after the earthquake (Figure 7).

Most of them, although badly damaged, remained partially standing, even in cases where they were located on a hill in the north of the city. This is, of course, no surprise for these structures were built in advance to withstand outer attacks and thus were probably quite stable. Yet, there is a prominent exception that deserves attention: The western part of the walls (between turrets T-12 and T-16), although built of the same materials and quality as the rest of the walls, collapsed completely, while the northern part, built on a slope, was only slightly damaged. Figure 8 portrays the spread of the damage in relation to the surface geology and suspected active faults. Accordingly, the majority of Tiberias is located on a single geologic foundation of basalt rocks but close

Table 2. The number of damaged dwellings and structures in the Tiberias quarters classified by an estimated damage degree. Note that the maximal degree of damage in the Jewish quarter is less than that of the Muslim and Christian quarters. See also [Figure 8](#).

<i>Quarter</i>	<i>Damage degree</i>	<i>Dwellings</i>	<i>Percentage (rounded)</i>
Christian	No/slight	2	3.6
	Partial	32	57.1
	Total collapse	22	39.2
Jewish	No/slight	21	7.4
	Partial	186	65.9
	Total collapse	75	26.5
Muslim	No/slight	13	5.3
	Partial	147	60.7
	Total collapse	82	33.8

to the western walls, there is a fault. This fault, suspected to be active (Sagy *et al.* 2013), crosses the southern walls between T16–T17 and runs parallel to the western walls for about 200 m within the proximity of only 50 m. In addition, the fault runs in between the basalt and alluvium lithologies and perhaps this transition zone contributed to the increase of the damage. However, further site-specific investigation, which is beyond the scope of this study, is needed to verify the mechanical role of this fault and the lithological contrast in the stability of the western walls and the nearby structures.

The second group includes dwellings and residential houses, most of which were completely damaged beyond repair. The damage in this category varies. The Jewish quarter seems to be slightly less damaged than the other quarters ([Table 2](#)) although the number of Jewish victims was greater (Robinson and Smith 1841). The explanation for this contradiction is not clear at this stage. Located along the shores of the lake, the Jewish quarter was more populated and clustered than the others and thus the dwellings in it were most likely of different architectural styles. In addition, a large part of the Muslim quarter in the north end of the city was located on a sloped hill whereas the Jewish and Christian quarters were located on a plain surface ([Figure 7\(a\)](#)). Thus, these factors also may have influenced the resistance to damage, but until the Ottoman construction styles are fully characterized, resolving this damage differentiation is rather complex.

The gates of the city did not withstand the earthquake and collapsed. Since the walls were never repaired, over the years some of the breaches were enlarged, probably by human activity, resulting in new entrances to the city (Guerin 1880). In late nineteenth century maps (Supplemental material, items 36, 40, 41 and 42), the southern entrance to the city is located between T-17 and T-18, some 50 m west of the original southern gate ([Figure 6](#)). At the north of the city, a new entrance and a trail leading to it appeared between T-2 and T-3. These two entrances and roads still exist today and constitute two of the major transportation entries to the city. The roads to Tiberias are an example of how a catastrophe such as an earthquake may divert and influence the morphology of a city for many years after.

6. Summary

It is clear that during the 1837 earthquake Tiberias was severely damaged. The massive destruction and the number of casualties portray an enormous human catastrophe.

Unfortunately, this may not be the last catastrophe Tiberias experiences since earthquakes in this region are inevitable. The fact that nowadays large parts of Tiberias are built on steep slopes and located close to potentially active faults have already motivated planners and decision-makers to assess the potential hazard to Tiberias (Zaslavsky *et al.* 2009, Hsi-Hsien *et al.* 2015). The study and the 3D GIS models presented here provide them with an important tool for comparing two phases and consequently, to inspect the spread of the damage (Figure 8) and evaluate more accurately the potential consequences to the city from a future event.

The reconstructed map of the pre-1837 Tiberias (Figure 6) is a new contribution to the study of Tiberias and its landscape. It resolves the question of the exact locations and contemporaneous state of public and religious structures, some of which still exist today. The map and the constructed 3D models may provide an initial basis for further studies such as tracking the rehabilitation of the city after the catastrophe it underwent, or changes it underwent during the following years. It is now also possible to better evaluate the morphological developments of the city, in particular when it expanded beyond the ancient walls at the beginning of the twentieth century.

The most important contribution of this study, in my opinion, is the applicability of HGIS for damage inspection and evaluation of pre-instrumentally recorded earthquakes. This research is part of a set of published studies conducted in the last few years that mark the transition to a modelled and computational-based era (e.g., Bender *et al.* 2005, Davie and Frumin 2007). These studies as well as the present article extensively use historical visual sources to reconstruct past landscapes using GIS. This approach facilitates the spatial examination of these sources, enables rectifying them within a geographic framework and enables quantifying their characteristics. These were complex tasks to achieve prior the development of GIS. In fact, the implementation of 2D and 3D geographic models can completely replace the 'traditional' technique of examining several visual sources simultaneously in order to trace a feature from different perspectives (e.g., Zohar *et al.* 2015). The case of Tiberias demonstrates that the HGIS approach to resolve earthquake damage can be applied also to other localities with available textual and visual sources. Furthermore it can be applied to other dramatic events, such as fires, floods and wars, which are no less destructive than earthquakes.

Note

1. Engineers inspecting the turret stated that such a lean could have occurred only by a sudden turbulence and not by gradual subsidence because of the water (Shohat and Levi, personal communication, 2014).

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