Caesarea in Coastal Israel: A Benchmark for Sealevel Changes during the 1st-13th Centuries

Yossi Mart1 and Natalia Tiulienieva2
1. Recanati Institute of Maritime Studies, University of Haifa, Haifa 3498838, Israel
2. Charney School of Marine Sciences, University of Haifa, Haifa 3498838, Israel

Abstract: Geodetic measurements of a Roman aqueduct in Caesarea, on the Mediterranean coast of central Israel, show that the massive structure preserved its original gradient of 0.05% in places where it was founded on rock, suggesting that that domain has been tectonically stable for the last two millennia. Consequently, since the land was stable, dated archaeological sealevel proxies that recorded their contemporaneous sealevels when the city was active, reflect global sealevel and their variations. The evidence suggests that sealevel was similar to the present some 2,000 years ago, it was nearly 0.5 m higher than the present some 1,300 years ago, and about 0.5 m lower nearly 800 years ago. These measurements match earlier climatological evidence of the early Medieval Warm Period and the early stages of the Little Ice Age, respectively. No sealevel evidence was encountered in Caesarea after the collapse of the Crusaders' kingdom.

Key words: Neotectonic stability, geoarchaeological proxies, sealevel variations, historic climate changes.

1. Introduction

The level of the sea, a global equipotential surface, is commonly measured in reference to the adjacent landmass, which is presumed stable, and serves as a proxy to climate changes, present and past. However, already Emery, et al. [1] used sealevel data from tide gauges in numerous Mediterranean ports to measure changes in sealevel, and to show that the land is also not stable. They suggested that the vertical offsets of the land are controlled by the local neotectonic and sedimentological processes, which change land elevations within relatively short time. For example, sealevel at Port Said, on the eastern flank of the Nile Delta, was measured to rise 4 cm/year, probably due to the subsidence of the delta resulting from the accumulation of fluvial sediments. Contrariwise, the tide gauge in Messina Sicily, reported annual sealevel drop of 19.4 cm/year, probably due to tectonic uplift of the island (Fig. 1). These sealevel measurements indicate that coastal observations of sealevel markers could be meaningful regarding global sealevel variations, only where independent evidence regarding landmass stability in the investigated domain was encountered for a well-determined time-span. While measurements of present sealevel and its variation can be surveyed also by satellites, to verify coastal observations independent of land offsets, historic sealevels require reconstruction based on archaeological, geological and neotectonic assessments, and provided that land stability was established.

Temporal large-scale sealevel variations, such as those that occurred in the Plio-Quaternary, are commonly used as one of the proxies for climate changes, because sealevel drops during cold periods, when glaciers accumulate on land, and rise in warm climatic events when the land glaciers melt. That mode of evaluation is somewhat simplistic because changes in the volume of continental ice would generate flow in the upper mantle that would produce geodetic variations that are independent of the prevailing climate (e.g. [2, 3]).
Sealevel is a global phenomenon because it is an equipotential surface, therefore its drop in the Mediterranean Sea would indicate global cooling and ice accretion on polar lands, while its rise would suggest global warming and melting of continental ice. Direct evidence and other implied indications to such marine changes could be biological, sedimentological, erosional, fluvial or man-made [4], however, these marine parameters by themselves are insufficient to determine global sealevel variations because reliable evidence that the adjacent land is firm is required. Furthermore, since the landmass is commonly dynamic, due to neotectonics, sedimentology or flow in the upper mantle, its stability should not be taken for granted [5], even more so as indications for land stability are rare and should be searched for.

In the course of multidisciplinary investigations in Caesarea in coastal Israel, large sections of massive Roman aqueducts were explored (Fig. 2). The Roman technique of building aqueducts is known due to a surviving civil engineering handbook *De Architectura* by Marcus Vitruvius Pollio, written in the 1st Century BCE, which recommended that aqueducts should be built at gradient of approximately 0.05% (less than
Fig. 2  (a) Caesarea high aqueduct is a massive structure that crosses the coastal plain of Israel. (b) It comprises two units, the one on the left was built in Herodian times, circa 20-10 BCE, and the other, on the right was built in the time of the Roman Emperor Hadrian, ca. 135 CE.
Caesarea in Coastal Israel: A Benchmark for Sealevel Changes during the 1st-13th Centuries

Fig. 3  Geological map of the coastal plain at Caesarea domain, off the SW edge of Mt. Carmel. The lithology of the mountain is calcareous Cretaceous rocks, but two Pleistocene and two recent units are exposed in the coastal plain—few outcrops of hard calcareous sandstone, and abundant occurrences of unconsolidated loam, sand dunes and soil respectively. Location of ancient Caesarea and modern settlements are presented as well. The high aqueduct is depicted from its origin just south of Mt. Carmel, to run across the coastal plain and then southwards along the shore to ancient Caesarea. Marked settlements and rivers are 1—Benjamina, 2—Beit Hannania, 3—Jisr az-Zarka, 4, 4a—modern Caesarea and its extension, 5—Or Aqiva, 6—ancient Caesarea, 7—Sdot Yam, 8—Crocodiles River, 9—Hadera River. After Sneh, et al. [7].

0.1°). Present hydraulic engineering handbooks still recommend the Vitruvian gradient for open water channels.

The high Roman aqueducts of Caesarea comprise two units that are linked together, column for column and arch for arch. The older unit was built at the end of the 1st Century BCE by King Herod the Great and the second, by the soldiers of the Roman Emperor Hadrian, who ruled the empire during 117-138 CE [6]. The Herodian aqueduct survived better than Hadrian’s, but even that structure subsided in many places where it was founded on unconsolidated soil of marshland, which abounds in the coastal plain (Fig. 3). Therefore, the present research surveyed the elevation of the
water channel of the Herodian aqueduct where it was founded on sandstone, and suspected geodetic data were obtained elsewhere.

Caesarea flourished for more than 1,200 years under the rule of the Romans, the Byzantines, the Muslims and the Crusaders, until it was razed to the ground by the Mamelukes in 1265. While the aqueduct survived to the present, sealevel proxies from the period after the destruction of the city were not discovered [6].

At present Caesarea and the adjacent areas are populated and cultivated. In addition to the site of Crusaders’ Caesarea, which is a National Park, there are villages—Sdot Yam, Jisr ez-Zarka and Beit Hannania, and urban areas—modern Caesarea, or—Aqiva, and Benjamina (Fig. 3). The area has been cultivated and urbanized for generations. Extensive urbanization took place from the 1st Century BCE to the 13th Century CE. The collapse of the Crusaders’ rule of the Holy Land in 1291 CE was followed by centuries of destruction and public neglect, where the water reservoirs turned into malaria-infested marshes, but the area has been revived in the last century. Engineering works during the last 70 years of urbanization changed many surface and shallow underground features, therefore geological investigations should consider possible effect of archaeological artefacts and human activity and discard doubtful data.

The present research conducted a high-precision geodetic survey along two selected sites of the well-exposed western segment of the Herodian high aqueduct of Caesarea (Fig. 4). Unlike previous surveys that used optical theodolites, and the link between the eastern and western segments of the aqueduct was dubious (e.g. [8, 9]), the present survey was carried out using the Differential GPS system Leica Viva GS14 operating on double frequencies of 5 and 20 Hz, which supplied high-precision spatial information.

2. Materials: Geological Setup

The coastal plain of Caesarea is located off the southwestern edge of Mt. Carmel, where the lithology is calcareous with abundant occurrence of volcanic tuffs, both of late Cretaceous age. Farther to the west, the coastal plain is characterized by Pleistocene lithology of calcareous sandstones with interbedded layers and lenses of red loam occur (e.g. [10, 11]), commonly covered by soil derived from marshland mud (Fig. 4).

The morphology of the coastal plain is characterized by soil-covered flats and sand dunes, where a few shallow ridges of calcareous Pleistocene sandstone, oriented parallel to the present shore, protrude through the unconsolidated sediments between the shore and the mountains. These sandstone ridges are lithified coastal sand dunes that accumulated parallel to the shore due to the growth of shrubs above the edge of the phreatic coastal aquifer of fresh water [12]. Since sealevel rose and fell during the Pleistocene, the coastal sand dunes migrated with the contemporaneous shores. Subsequently the dunes were lithified to produce series of parallel shallow ridges in many places along the present coastal plain and continental shelf [13]. When sealevel reached its present elevation some 6,000 years ago, the linear series of shallow shore-parallel ridges on land formed natural dams that interfered with the flow of rivers from the mountains to the Mediterranean Sea, producing extensive marshlands. That series of sandstone ridges and intervening trough extends to the continental shelf down to depth of 120 m (e.g. [14]).

Groundwater that accumulated in the calcareous sandstone at shallow depth under the coastal plain formed a usable phreatic aqueduct, where the rain water floated on a wedge of seawater that penetrated landwards. Many wells were excavated into that aquifer and supported human settlements in the coastal plain since prehistoric times [15].

The geological investigations of Caesarea domain interacted repeatedly with the archaeological research, which encountered a large collection of artefacts, and dated them precisely, therefore some historic
Fig. 4  Satellite image of Caesarea domain, showing the location of the high aqueduct (green line), running from Mt. Carmel (marked 1), crossing the soil-covered eastern coastal plain to Beit Hannania, where the aqueduct is founded on hard sandstone and its elevation of 9.11 m above sealevel was surveyed there (red triangle). The aqueduct crosses the western coastal plain, bypassing a marsh, then it ran under the coastal ridge of calcareous sandstone in a tunnel (blue line). Farther westwards, it was built along the shoreline southwards to the water distributor (another red triangle) where it was founded on sandstone and its elevation is 6.49 m. A segment that underwent marine erosion and anthropogenic destruction is marked by dashed red line. Caesarea harbor, where the Crusaders’ jetty is located, is marked 2, and the Herodian palace and its swimming pool are marked 3. Insert: location map courtesy www.geomapapp.org, Ancient Caesarea is marked by a red arrow.

Background is required to understand the recent geology of that region. The construction of Caesarea as a major city and harbor was a project of majestic dimensions, initiated by King Herod the Great (ruled 37-4 BCE) and inaugurated in 10 BCE. A large city of that time required large amounts of water for public use, such as its public baths or the public latrines. Therefore a high aqueduct was built at ca. 10 BCE and other aqueducts were added during the prolonged Roman and the Byzantine rule of Palestine (1st to 7th Centuries CE), to which Caesarea served as a principal administrative center. Caesarea was prominent also during the Islamic (7th to 11th Centuries) and the Crusaders rule (12th-13th Centuries), but when the Mamelukes conquered the land in 1265, they razed the city to the ground.
Caesarea in Coastal Israel: A Benchmark for Sealevel Changes during the 1st-13th Centuries

Fig. 5 Surveyed subsidence of the Roman aqueducts west of Beit Hannania led to leaks in the water supply system and the deposition of travertine (green arrows). The travertine indicates that the stability of the section of the aqueduct where it occurs is suspect.

The Herodian high aqueduct acquired its water from mountain springs in southern Mt. Carmel, and transported it across the coastal plain westwards, than along the shore southwards to reach Caesarea. A second aqueduct that followed the Herodian one, column for column and arch for arch, was build ca. 135 CE. The aqueducts were founded mostly on soils of the coastal plain and coastal sand dunes, and they commonly subsided laces, leading to abundant water leaks and deposition of travertine (Fig. 5). Therefore, reliable stability of the aqueducts was encountered only near Beit Hannania and near the water distributor at the end of the structure (Fig. 4). Elsewhere along the aqueducts, their present day gradient does not reflect their original slope.

The present survey of the high aqueduct found out that only two sites along the structure were founded on the Pleistocene calcareous sandstone, and no evidence suggesting subsidence was encountered there. Therefore, these sites served as benchmarks for measuring the original gradient of the structure. One such site was discerned near the village of Beit Hannania, and the other site that seemed stable was observed at the southern edge of the aqueduct, near the structure used to distribute the water to its various public purposes in the city (Fig. 4). The elevations of
Table 1  Geographic coordinates of the northeastern and southwestern edges of the Herodian aqueduct in Caesarea, where the structure was founded on solid calcareous sandstone of Pleistocene age. The aqueduct crosses the coastal plain from the east westwards, and its southern segment runs along the beach. See Fig. 3 for its geographic setting. The surveyed edges are marked by red triangles in Fig. 3 and the SW edge of the aqueduct is marked 2 in Fig. 2b. Longitudes and latitudes are in WGS84 setting, and the mean sea level was set by Israel Surveying Authority.

| Sites and elevations of the water channel of the Herodian aqueduct of Caesarea |
|--------------------------|----------------|-------------------------|
| Sites                     | Northing       | Easting                 | Elevation above mean sea level |
| Beit Hannania             | 32°31’55.87″   | 34°55’35.24″             | 9.11 m                         |
| Roman water distributor   | 32°30’25.84″   | 34°53’40.34″             | 6.49 m                         |

the water channel of the aqueduct near Beit Hannania and near the water distributor were determined as reliable sites to measure the slope of the Herodian aqueduct.

Traces of a water channel were discerned in the Roman aqueducts and the present DGPS (Differential Global Positioning System) geodetic survey measured their elevation where the aqueduct was founded on Pleistocene sandstone ridge. One such site is in the middle of the coastal plane, where the elevation of the water channel is 9.11 m above the mean sea level (which had been determined geodetically by the Geodetic Survey Authority). The elevation measurement of that water channel at the end of the aqueduct, near the relicts of the Herodian municipal water distributor, is 6.49 m above the mean sea level (Table 1). The elevation difference between these two sites is 2.62 m and the distance between the two measured spots is 5.2 km (Fig. 4).

The elevation difference of 2.62 m along a distance of 5.2 km, presents a gradient of 0.05%, which is in good agreement with the slope of water channels recommended by Vitruvius. Since the aqueduct was constructed both in east-west and north-south orientations, it is suggested that the Vitruvian gradient of the aqueduct indicates the tectonic stability of Caesarea domain. Had tectonic displacement affected the domain after the construction of the aqueduct, the original slope of the structure would have been disrupted.

Once neotectonic stability in Caesarea seems established, there are several well-dated sites there that indicate ancient sealevels there. One such location is the swimming pool in the Herodian Royal palace, built some 2,000 years ago right at the waterfront, the pool was excavated in the Pleistocene sandstone there. Small channels were cut in the rock to enable free flow of water in and out of the pool to keep its water fresh. These channels are partly submerged at present, with water still flowing in and out of the relicts of the pool, suggesting that the global sealevel some 2,000 years ago was similar to the present one (Fig. 6).

Considering that the maximal daily tide is less than 40 cm, the presented interpretation of sealevel variations probably indicates that the climate some 2,000 years ago resembled the present climate.

Additional indication of historic sealevel and its variations was encountered at a jetty built by the Crusaders, and dated to the 12th-13th Centuries (Fig. 7). At that time, sealevel was lower than the present, the relicts of the Roman harbor of Caesarea made harbor use risky [16]. Consequently, sea-crossing vessels were probably unsafe to maneuver in the harbor and probably anchored at safe depth offshore and were serviced by boats. These boats used a jetty that was built of numerous granite and diorite large and heavy columns that were set on the smoothed Pleistocene sandstone with no evidence of founding or supporting construction, and were probably covered by wood planks for loading and unloading stuff by porters. At present, the columns are inundated, suggesting that the sealevel during the Crusaders’ period in the 12th-13th Centuries was approximately 0.5 m lower than the present [8, 9, 15]. Such change of sealevel could propose colder climate than the present.
Fig. 6 A flushing channel between the open sea and the royal swimming pool in Caesarea, built ca. 2,000 years ago, shows similarity between the ancient sealevel and the present one (Courtesy Raban Collection, Recanati Institute of Maritime Studies, University of Haifa).

A method to evaluate and reconstruct historic sealevels that were higher than the present in coastal Israel was developed by Nir and Eldar [17], through geoarchaeological exploration of water wells at archaeological sites. The wells along the Israeli coast get their water from the coastal phreatic aquifer, where rain-derived freshwater floats on seawater that penetrates inland. Therefore, variations in the level of the sea would change the level of the water in the wells as well. Where the historic sealevels were higher than the present, that water level in the wells is marked by a line of dried algae that had floated at the surface water and stuck to the walls of the well. The difference between the present water level and the ancient algae line can be readily measured, and dating the activity period of the well would be derived from the ceramics style and the manufacturing technology of shards of ancient jugs encountered in the well.

Dating numerous domestic wells in Caesarea showed that during the late Byzantine—early Islamic period, in the 6th-9th Centuries CE, sealevel was higher than the present one by more than 0.5 m [15] and climate was probably warmer.

4. Discussion

The tectonic instability of many locations in the landmass, such as the prolonged uplift of Africa since the Oligocene, as well as changes of sealevel like the considerable sealevel drawdown during the Last Glacial Maximum in the late Pleistocene is well known in the earth sciences. Furthermore, land instability during historic times was noticed in the Mediterranean domain by Emery, et al. [1], and apparently recent sealevel rise was reported from the Yangtze Delta in East Asia [18]. However, sealevel reconstruction in Lebanon based on faunistic evidence,
which suggested two phases of tectonic coastal uplift during the last 6,000 years [19], presumed that sealevel has been stable during that period and can serve as a reliable reference for land motion, which is debatable.

The benefit of a series of short-term analog measurements of proxies to sealevel changes during historic times in a zone where the land is known to be structurally stable is of interest. Such measurements support models of sealevel variations based on the occurrence of unique fauna and flora in salt marshes, which is a very powerful tool to assess historic climate variations in historic time, provided that the stability of the landmass is verifiable (e.g. [20, 21]). The motion of the landmass does not necessarily take place only during dramatic tectonic events, but slow and
continuous accumulating of sediments at river deltas could gradually inflect the lithosphere and suggest a continuous but apparent sealevel rise [22].

The tectonic stability of the Caesarea domain during historic times was questioned in the past. Neev [23] and Neev, et al. [14] presented oysters, barnacles and other shells of marine mollusks that stuck to Byzantine ceramic shards, which were found on the beach in Caesarea, as relics of marine fauna found in situ. Therefore, they suggested that these shards indicate that the western section of the Caesarea sandstone ridge was downfaulted several meters after the construction of the Herodian Harbor in the 1st Century CE, and then it was uplifted tectonically to its original elevation before the Crusaders’ period in the 12th Century. However, subsequent assessment of those ceramic shards during the extensive archaeological excavations in Caesarea on land and at sea [6] found out that the Byzantine ceramics shards and the shells that stuck to them were probably dredged during the rehabilitation of Caesarea harbor in the 6th Century [24]. As for the suggestion of large vertical faulted offsets along the shore zone of Caesarea, the present geodetic survey of the high aqueduct, described above, shows that the aqueduct and its lithological foundation, were tectonically stable during the last 2,000 years. Therefore, the downfaulting of several meters, and the rebound precisely to the same elevation within a few hundreds of years subsequently are highly unlikely. That surveyed stability suggests that sealevel variations measured in Caesarea indeed indicate global climatic variations rather than local structural events.

The evidence that sealevel rose in Caesarea in the 7th-9th Centuries supports the observations of the contemporaneous climatic warming event of the Medieval Warm Period that was encountered elsewhere (e.g. [25, 26]). And the discerned sealevel drop during the Crusaders’ time could be a harbinger of the Little Ice Age that started to affect NW Europe from the 13th to the 17th Centuries (e.g. [27, 28]).

It seems that the Caesarea aqueduct provides an analog benchmark for land stability during the last two millennia, and the low tidal range of the easternmost Mediterranean Sea enables acceptable precision in measurements. Therefore, the presented sealevel measurements and their climatic characteristics of 2,000, 1,300 and 800 years ago could serve as an adjustment and calibration tool for powerful numeric models of sealevel changes (q.v. [2, 3]).

5. Conclusions

The preserved original gradient of the Roman high aqueduct, and its proximity to the Mediterranean coast, mark the Caesarea domain as a global benchmark of a stable landmass by the sea during the last 2,000 years. Consequently, the variations of sealevel measured in Caesarea reflect climatic changes of environmental significance during historic times. The marker of the sealevel discerned in the Royal swimming pool built in the 1st Century CE, suggests similarity between the global climates then and now. Global warming that occurred in the 7th-9th Centuries, is indicated in Caesarea by the high water levels in domestic wells, and the lower sealevels observed in the Crusaders’ jetty there indicate that the global climate was colder than the present some 800 years ago.

Acknowledgements

Authors are indebted to Michael Sneh and his team of surveyors, who measured geodetically the high Caesarea aqueduct, its track and its gradient. Authors are thankful to Ilana Perecman, Beverly Goodman-Tchernov and the late Avner Raban for prolonged cooperative research, fruitful discussions and exchange of ideas. The translation of Vitruvius Latin text by Eleanora Badin and the fieldwork of Daniela Friedmann during the early stage of this investigation are gratefully acknowledged. A modest support of the University of Haifa to YM enabled some of the fieldwork of this research.
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