COASTAL CLIFF RETREAT RATES AT BEIT-YANNAY, ISRAEL, IN THE 20TH CENTURY

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ABSTRACT

Research indicates that the aeolianite (Kurkar) cliffs along the Israeli Mediterranean coastline have continuously retreated eastward during the last few decades. There seems to be no dispute among Earth scientists regarding the general trend of cliff retreat. However the majority of papers displaying cliff retreat rates are based upon comparison of aerial photographs. Their lack of advanced geometric measurement methods causes a high margin of error. Public attention is focused upon the Beit-Yannay coastal cliff since private homes are located along the southern section of the cliff crest. The current research compares the historic location of the cliff crest edge at Beit-Yannay as observed in a series of aerial photographs taken during the period 1918–2000. Quantitative measurement methods included applications of satellite geodesy and digital photogrammetry and mapping. Research results offer quantitative, consecutive and highly accurate data regarding retreat rates over a relatively long period of 82 years. It is concluded that: 1. Annual average cliff retreat rates of the cliff crest is 20 cm/year. 2. Categorization of the study time span reveals periods displaying varying retreat rates such as 27 cm/year during 1918–1946, 21 cm/year during 1946–1973 and 10 cm/year during 1973–2000. 3. Maximum retreat distances of the cliff crest, over the study period were found to be approximately 25 m along the northern, lowest section of the cliff. Minimum distances of 11 m were identified at the highest, southern section of the cliff. 4. The aeolianite (Kurkar) cliffs along the Israeli Mediterranean coast throughout the 20th century have been an important source of sediment, contributing approximately $24 \times 10^6$ m$^3$ of sediments to the sediment balance of Israeli beaches. Copyright © 2004 John Wiley & Sons, Ltd.

KEY WORDS: Mediterranean coast; Israeli beaches; coastal cliff erosion; Sharon escarpment; Beit-Yannay; digital vector mapping; remote sensing

INTRODUCTION

The aeolianite (Kurkar) (Gvirtzman et al., 1983) cliffs flanking the Mediterranean beaches of Israel, and especially the Sharon escarpment, have recently been studied in detail by numerous Israeli researchers. The Sharon escarpment forms a sharp dividing line between the coastal plain and the beach. The escarpment rises up to 50 m above the beach, and usually slopes about 75–90° in a laterally variable profile. The cliff usually cuts two layers of cross-bedded, carbonate-cemented quartzose dune sand (the Lower and Upper Kurkar) each topped by a fossil loam (Hamra). The foot of the escarpment is at most times covered by 30–55° talus aprons over much of its length. The height of the talus apron never exceeds that of the remaining cliff face above it, except in the rare cases of compound slumping or artificial dumping. A full list of research regarding stratigraphy and lithologic properties is presented by Perath and Almagor (1996). Geotechnical properties, slope stability and hazard assessments were presented by Wiseman and Hayati (1971), Wiseman et al. (1981), Nir (1992), Ben-David (1995), and Perath and Almagor (2000). Schwarz (1997) and Schwartz et al. (1999) took field measurements of the rates of the geomorphic processes along the cliffs (Michmoret to Givat Olga section) during the years 1991–1996. In spite of the general consensus regarding cliff retreat rate magnitudes, there are few authoritative quantitative, geometric works on the subject of determining spatial and temporal aspects of cliff retreat rates (Perath and Almagor, 1996, p. 35).

Table I summarizes previous works regarding estimated coastal cliff retreat rates and illustrates the common finding that retreat magnitudes are of tens of centimetres per year during the last 50 years (despite differing measurement methods).

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Table I. Coastal cliff retreat rates along the Israeli beaches

<table>
<thead>
<tr>
<th>Research</th>
<th>Location</th>
<th>Period</th>
<th>Method</th>
<th>Rate of retreat (cm/year)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golik and Goldsmith (1984, 1985)</td>
<td>3 km north of Khan Yunis</td>
<td>1956–1984</td>
<td>Aerial analytical Photogrametry</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>Golik and Goldsmith (1984, 1985)</td>
<td>Gaza (north)</td>
<td>1956–1967</td>
<td>Aerial analytical Photogrametry</td>
<td>30</td>
<td>In 1972 two groynes were built in Gaza. Average</td>
</tr>
<tr>
<td>Perath (1982)</td>
<td>7 sections between Tel-Aviv (north) and Beit-Yannay</td>
<td>1982</td>
<td>Field measurements</td>
<td>15–22</td>
<td>For cliff section with slides.</td>
</tr>
<tr>
<td>Nir (1992)</td>
<td>Beit-Yannay</td>
<td>1991–1939</td>
<td>Comparison aerial Photographs, and maps (no corrections)</td>
<td>30–15</td>
<td>Sum of all the cliff sections distance is 20.3 km</td>
</tr>
</tbody>
</table>

The locations in the table are from the southern part of the Israeli coast to the north.
The coastal cliff retreat rates along the world’s beaches tend to have high rates in the 20th century compared to historical times. The high rates of retreat may be a result of increase in sea level rise. Golik and Goldsmith (1985) measured the changes of the cliff crest and base along the southern coast of Israel and found that using aerial photograph interpretation, maximum horizontal accuracy is approximately ±2 m. This implies that throughout their 28 year study time span, retreat rates below 7 cm/year are within the error range and thus represent ‘no changes’. The methods applied in most of the works are based upon single point and non-continuous sampling of the cliff location, resulting in a limited database of the defined cliff section. This may imply that calculations of the mean retreat distance are influenced by lone extreme data points that are by their nature unrepresentative.

Consistent data of Israeli Mediterranean coastal retreat rates are available only since 1948, while previous research has incorporated aerial photographs from 1945. Nir (1992) applied Mandatory maps from 1939 that include mapping results of coastal cliffs from 1937.

**RESEARCH GOALS**

1. To accurately measure the rate of retreat of the coastal cliff at Beit-Yannay, along sections where cliff retreat hazards induced planning complications (Ben-David and Yuger, 2000).
2. To lengthen and maximize the ‘study time span’ based upon German Air Force aerial photographs from World War I (1918).
3. To identify the significance and impact of cliff retreat upon the sediment balance along Israeli beaches.

**RESEARCH METHODS**

Quantitative research compares the historic location of a 750 m section of the Beit-Yannay coastal cliff (Figure 1), seen in aerial photographs during the period 1918–2000. Research methods combine digital measurement techniques and geometric computerized mapping using space geodesy, digital photogrammetry and mapping. For the first time, this enables quantitative, continuous, highly accurate data of retreat rates of the cliff crest over a period of 82 years, substantially longer than previous studies.

**MAPPING PROCESSES**

*Aerial photograph selection*

Sixteen aerial photographs were examined for the research. Four aerial photographs were chosen for detailed analysis (Table II). The photograph dates encompass the whole study time span with approximate intervals of 27–28 years between each set.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Source</td>
<td>German Air force</td>
<td>British Air force</td>
<td>Survey of Israel</td>
<td>Survey of Israel</td>
</tr>
<tr>
<td>Flight</td>
<td>F/304</td>
<td>DEV/8</td>
<td>MM366</td>
<td>ML696</td>
</tr>
<tr>
<td>Photograph</td>
<td>282</td>
<td>6075</td>
<td>9355</td>
<td>5656</td>
</tr>
<tr>
<td>Time</td>
<td>14:30</td>
<td>Unknown</td>
<td>08:37</td>
<td>13:23</td>
</tr>
<tr>
<td>Height (m)</td>
<td>3700</td>
<td>Unknown</td>
<td>880</td>
<td>1970</td>
</tr>
<tr>
<td>Scanning resolution (dpi)</td>
<td>1200</td>
<td>600</td>
<td>600</td>
<td>1200</td>
</tr>
<tr>
<td>Pixel size (m)</td>
<td>0·70</td>
<td>0·16</td>
<td>0·35</td>
<td>0·33</td>
</tr>
<tr>
<td>Number of control points</td>
<td>8</td>
<td>11</td>
<td>30</td>
<td>21</td>
</tr>
<tr>
<td>X-residual (m)</td>
<td>0·16</td>
<td>0·16</td>
<td>0·16</td>
<td>0·20</td>
</tr>
<tr>
<td>Y-residual (m)</td>
<td>0·40</td>
<td>0·20</td>
<td>0·19</td>
<td>0·20</td>
</tr>
<tr>
<td>XY-residual (m)</td>
<td>0·28</td>
<td>0·17</td>
<td>0·19</td>
<td>0·22</td>
</tr>
</tbody>
</table>

Aerial photograph scanning

Digital image processing and mapping techniques required scanning and subsequent transformation of analogue aerial photographs to digital images.

The aerial photographs were scanned in a photogrammetric scanner at a minimum resolution of 600 dpi in order to preserve surface geometric separation higher than 1 m/pixel.

Geodetic mapping

Thirty control points were measured at the study site in order to achieve highly geodetically positioned scanned aerial photographs. The points were measured along a 1250 m transverse between Beit-Yannay in the
north and Neurim in the south. The maximum transverse width was 400 m between the cliff crest in the west and the coastal highway in the east. Measurements were sampled using a geodetic GPS at surface elevation with a horizontal accuracy of 0.75 m. Following their measurement, each point was transferred from the geographic projection and datum WGS84 to UTM (Zone 36) and the European 1950 datum.

**Photogrammetry**

The raw scanned aerial photographs and the corresponding control points were imported into a digital mapping system that includes a monoscopic–photogrammetric mapping software program. This was followed by applying a transformation module ‘Projective’ – a model from Microstation Descartes (Bentley Systems Inc. 2000a), on the raw aerial photograph files. This resulted in geometrically correcting, warping and rectification of the photographs into the UTM coordinate system (see residuals in Table II).

**Digital mapping**

Following geometric corrections, the cliff crest upon the aerial photographs was mapped using a vectored method by applying Microstation Java (Bentley Systems Inc. 2000b) mapping software. Determination of the cliff crest as a mapped vector object was then possible by observing the contrasting grey-scale shades in the photographic images.

The cliff crest was identified on the aerial photographs by a clear change in colour, due to two physical characteristics: (a) the sharp change in lithology between the bright Kurkar rock at the top of the cliff; and (b) the darker Hamra loam and the steepness of the cliff.

**Measurement of the retreat distance of the cliff crest**

Merging the digital vector files for each time period created a visual timeline to illustrate the trend in coastal retreat. Actual measurement was then conducted by the application of the ‘Measure Area’ command of Microstation Java mapping software. The average rate of cliff retreat was calculated by subdividing the measured area by the length of the line parallel to the cliff. The average is therefore an integration of all the study area.

**Cumulative measurement error**

Each stage of the mapping process contributes a horizontal error in the accuracy of the top of the cliff crest line. The maximum cumulative error due to measurement in the worst case out of the four aerial photographs is (Shoshany et al., 1996):

\[
\frac{(G + I + D)}{\sqrt{n}} = \frac{(0.8 + 1.4 + 2)}{4.12} = 1.02 \text{ m}
\]

where \(G\) is error due to the photogrammetric warping process (for exaggeration twice the maximum RMS, Table II, 1918), \(2 \times 0.4 = 0.8\) m; \(I\) is error due to mistake in the identification of the top of the cliff crest line (for exaggeration twice the maximum worst resolution in the scanning process, Table II, 1918), \(2 \times 0.7 = 1.4\) m; \(D\) is error due to mistake in the location of the top of the cliff line, in the vector mapping process (for exaggeration up to 2 m); \(n\) is number of average control points on each aerial photograph; in this study, \(n = 17.\)

**RESULTS AND DISCUSSION**

The research results show that mean retreat rates of the Beit-Yannay coastal cliff along a 750 m section were 20 cm/year during the period 1918–2000. Subdivision of the time reveals that in the years 1918–1946, the rate of retreat was 27 cm/year, in the years 1946–1973 the rate of retreat was 21 cm/year, and in the years 1973–2000, the rate of retreat was 10 cm/year. Figures 2 and 3 show an orthophoto from 2000; superimposed on the vector map are the lines of the top of the cliff crest in the years 1918, 1946, 1973 and 2000; the data are given in Table III.

Over 82 years (1918–2000) the highest value of point retreat in the study area was 25 m, and the smallest was 11 m. The high retreat occurred in the northern part where the cliff is lower, and there is an open area between the top of the cliff and the private land (Figure 4). The lowest retreat took place where the cliff is high and where
private land bordered the top of cliff (Figure 5). In 2000 the distance between the houses and the cliff is only 10–15 m. Barring serious remedial action, those houses will be in danger in the near future (Figure 6).

Very high rates of retreat were given by Ron (1982) of 150 cm/year, Perath and Almagor (1996) of 320 cm/year, Ben-David (1995) of 78 cm/year and Schwartz et al. (1999) of 74 cm/year. These values were measured locally and are only indicative of a point along the cliff shortly after a slide event. In the method used in this study the local effect of each individual slide integrated over time is low.

The Beit-Yannay cliffs are about 16 m high on average, 12 m in the northern part of the study area and 20 m in the south. The length of the cliff is 750 m, and the average rate of retreat during the study is 20 cm/year. Hence it can be calculated that the Beit-Yannay cliff contributed an additional 240 000 m$^3$ of sediment annually in the 20th century to the Israeli beaches. The height of the Kurkar cliffs along the coasts of Israel varies from 5 to 50 m; the total length of the Kurkar cliff in Israel is about 70 km and the average height is approximately 16 m. The data presented in Table I and the data measured in this study show that retreat of 20 cm/year is a fair value for the coastal cliffs in Israel, hence the contribution of cliff retreat to the sediment budget in the 20th century was more than 20 $\times$ 10$^6$ m$^3$.

<table>
<thead>
<tr>
<th>Aerial photograph year</th>
<th>1918</th>
<th>1946</th>
<th>1973</th>
<th>2000</th>
</tr>
</thead>
<tbody>
<tr>
<td>1918</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1946</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table III. Coastal cliff retreat rates (cm/year) at Beit-Yannay during the period 1918–2000
Figure 3. Orthophoto of the south section of the study area and the lines of the top of the cliff crest

Figure 4. North section of the Beit-Yannay cliff (13 Dec. 2001)
CONCLUSIONS

1. The Coastal cliff at Beit-Yannay (Israel) has been in constant regression throughout the study time span (1918–2000).

2. The retreat process of this coastal cliff has declined during the research period, especially since the early 1980s, in accordance with Nir (1992). The decline in retreat may be a result of the construction of artificial wave defence enforcements along sections of the cliff base (Figure 7), and enlargement of the vegetative cover of the cliff crest and slope.

3. Application of recently developed digital aerial photogrammetric methods was found to be an efficient means of determining precise, quantitative measurements of cliff retreat distances.
4. This work shows that the detection error of the cliff crest has been up to 2 m and that the mean annual measured cliff crest retreat rate throughout the study time span is approximately 20 cm/year. Thus, in order to extract statistically significant results (where data reliability exceeds the margin of error), the minimum time gap between two aerial photographs should be greater than 10 years.

5. Israeli Mediterranean coastal cliffs throughout the 20th century have been an important source of sediment, contributing approximately $24 \times 10^6$ m$^3$ of sediments to the sediment budget of Israeli beaches.

REFERENCES


