Ocean & Coastal Management 52 (2009) 39–46

Contents lists available at ScienceDirect

Ocean & Coastal Management

journal homepage: www.elsevier.com/locate/ocecoaman

Key natural and anthropogenic parameters enhancing the effect of sea level rise: The case of Israel's Mediterranean coast

A. Melloul*, M. Collin

Hydrological Service, Water Authority, Jerusalem, Israel

ARTICLE INFO

Article history:
Available online 8 November 2008

ABSTRACT

Sea level rise (SLR) adversely impacts groundwater quality and capacity of coastal regions. The objectives of this paper are to determine key natural and anthropogenic parameters which may influence and enhance adverse SLR impact upon coastal environments, as well as to assess these natural and anthropogenic components contributing to SLR, and enhance adverse effects of SLR on the environment. This would enable assessment of vulnerability of coastal areas. Components are evaluated in this paper by averaging data relative to respective measured parameters, along with given weightings and assessed ratings, vis-à-vis world maximal reference values. Israel's Mediterranean coast is utilized as an example for such an approach. This can indicate where operational long-term planning measures would be recommended, along with development of effective monitoring and the carrying out of helpful engineering and ecological activities.

1. Introduction

1.1. SLR level and its on-going trend throughout the world

1.1.1. The overall SLR trend

The overuse of fossil fuels and industrial emissions over recent decades has lead to excessive emissions of particulates, aerosols, new chemical products, and numerous greenhouse gases such as CO_2, N_2O, CH_4, etc. One of the most significant of these gases is CO_2. Over the past 400 years, the amount of this gas in the earth's atmosphere has increased in parallel with average ambient atmospheric temperature. There has been a sharp increase in CO_2 over the course of the industrial era [1–3]. Recently, according to IPCC, 2007, between 1970 and 2004, this increase has amounted to around 80%.

Increased CO_2 in the atmosphere is now considered a prime factor responsible for global warming, and ancillary global climatic changes. The latest reports of the World Meteorological Organization (WMO) and the United Nations Programme for the Environment (UNEP) indicate a sharp increase in world ambient temperature of between 1.4 and 5.8 °C by 2100. Thus, ocean and seawater temperatures may also increase significantly by 2100 [4–6]. According to IPCC 2007 [2], the years between 1995 and 2006 have been the hottest years on record since 1850, the date on which they began measuring temperatures instrumentally throughout the world.

Global warming has accelerated over the past 25 years. Since the inception of the industrial era global CO_2 levels have risen gradually, in parallel to average global temperature. However, between 1980 and 2005, there has been an exponential increase in temperature of between 1 and 1.5 °C. Indeed, 2005 was one of the hottest year on record for the past century, and was accompanied by the most significant storms over past decades [5,6].

Reports of the International Programme of Climate Changes [2,7], based on data from Topex–Poseidon satellite measurements, indicate that seawater warming has caused SLR of more than twice that noted in previous measurements ([8,9]; Table 1). Earlier reports, based upon pre-1961 data, indicated SLR of between 1.3 and 2.3 mm/y. Subsequent reports, based on later data (1993), indicate SLR of between 2.4 and 3.8 mm per year [2].

From current global warming data alone, it would appear that melting of polar icecaps and terrestrial glaciers could contribute to an SLR of around 10 cm by 2100 [10]. Such a trend of increasing SLR values has been noticeable over recent years (1992–2002) in measurements from tidal gauging stations along the eastern Mediterranean Sea, including the Israeli coasts of Tel Aviv, Ashdod, and Hadera [11,12]. These latest measurements indicate that an SLR between 50 and 100 cm could be expected by the end of the 21st century. According to the National Oceanic and Atmospheric Administration (NOAA), 2008 [6], June 2008 was the eighth hottest month of this decade. This can enhance theories that predict sea level may be rising faster in the coming decades than previously expected.

---

* Corresponding author. Hydrological Service, P.O. Box 36118, IL 91 360, Jerusalem, Israel. Tel.:+972 2 644 2517;fax: +972 2 644 2529.

E-mail address: abrahamm20@water.gov.il (A. Melloul).

0964-5691/$ – see front matter © 2008 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ocecoaman.2008.10.010

Table 1
Sea level rise data in various periods and sources.

Data information about global sea level rise (SLR)			
Sources	Region	Date used (Years)	SLR (mm/yr)
Gornitz & Lebedeff (1987) and IPCC	Global	1880–1982	1.2 ± 0.3
Millinan (1992)	Mediterranean Basin	<1991	1–2
Shennan & woodworth (1992)	Northwestern Europe	<1991	1.0 ± 0.2
Zerbini et al, (1996)	Genoa	1884–1988	1.3
Nichollas and oozmans (1996)	Warselle	1885–1992	1.2
Gernitz (1995)	Eastern USA	<1994	1.5
Topex-Poseidon satellite	Global	1993–1998	2.5
IPCC 2007	Global	1993–2006[a]	3.1 ± 0.7
Shirman (2001)	Tel Aviv Ashdod	1990–2002	20.25 ± 10
Rosen (2002)	Hadera (Israel)	1992–2002	11 ± 5

[a] According to IPCC 2007, about 11 years from this period of time are considered as the hottest since 1850.

The International Programme of Climate Changes (IPCC) attributes the majority of recent sea level rise to a steric effect, and melting of glaciers as a major explicative component of SLR. This steric effect involves thermal expansion of salt water. For water at 15 °C, an 1 °C increase of a seawater column of 1000 m would raise the height of the column by 16 cm ([2,7–9,13,14], Table 1).

The degree of ocean water warming can be the result of a mixture of different water types. These can be of both natural and anthropogenic origin, involving such sources as fresh water from the melting of coastal glaciers, warmer water coming from active volcanic areas, submarine sea currents, as well as from industrial outflows. All or any of these can consequently alter ambient seawater temperature by means of the steric effect.

The relative steric effect is influenced by the volume of water concerned. Thus, the steric effect is most apparent in areas with shallower water, where influence by greenhouse warming would prove most critical. The steric effect should prove less pronounced in water bodies having a deeper bathymetry. Mapping of this effect has been carried out between 1955 and 1995 [8,9].

Owing to the variety of types of water involved, the steric effect, and consequently SLR, can differ drastically from positive to negative from one region to another. According to Rahmstorf 2006 [14], the next decade will be the hottest since the beginning of the industrial era. As a result, the steric effect could be expected to be more positive. A positive steric effect indicates that import of warmer water is higher in the area concerned as compared to an area having a negative steric effect, which would indicate that colder water sources are predominant in such a region.

1.1.2. The complexity in assessing the SLR trend

SLR can be influenced by a wide range of natural and anthropogenic causes [15]. From the dawn of earth's history, sea level rise has occurred as a consequence of many natural factors. Seismic phenomena supply hot material from the bottom of oceans by means of eruptive magma from the mantle below [16–18]. Storms lead to erosion of some areas and sediment deposits in others. Also, according to the Solid Earth-science Working Group (SEWG) 2003 [15], the 10–20 cm global sea-level rise recorded over the 20th century has been broadly attributed to two effects: the steric effect of changes in global climate, and mass-budget changes due to a number of competing geophysical and hydrological processes in the solid Earth–atmosphere–hydrosphere–cryosphere system. Those effects can cause serious consequences to humans and their environment. Generally, these events alter the geometry of the ocean bottom and of coastal aquifers, and consequently alter SLR [12–15].

Another effect that can influence global warming and consequently SLR is "global dimming" [19–21]. This process involves the gradual reduction in the amount of sunlight reaching the earth's surface. The process can result from increased anthropogenic particulates as well as pollutants that can become nuclei for cloud droplets. The smaller droplets make clouds more reflective and as a result, less sunlight reaches the earth's surface [21]. This then results in reduced evaporation. Globally, there is alleged to have been an approximate reduction of the amount of sunlight reaching the Earth's surface of between 8% (Australia) to 30% (Russia), and thus a world average of 15%, between 1950 and 1985 [19–21]. This global dimming can mitigate the process of global warming, leading to a reduction in the photosynthetic process, and thus reduced vegetative growth. With less vegetation, CO_2 levels increase further, thus resulting in SLR. In a polluted atmosphere, clouds are darker and intercept more solar radiation. Diminished solar radiation means lower temperatures, lower evaporation, and consequently lower precipitation, very critical for arid areas. The influence of global dimming requires further attention and study, especially as regards its potential towards mitigating global warming and its consequences [19,20].

Cleansing of atmospheric aerosols could actually enhance global warming, leading to higher SLR in some areas in the world. Considering the rising trend in levels of CO_2 and other greenhouse gases, as well as the sharp increase in ambient global temperature over recent decades, significant global climatic alteration, accompanied by more frequent and severe storms, could then be expected to lead to sudden and ephemeral local rises in sea level. Furthermore, rising sea level could be influenced by the feedback loop that increases exponentially the rate of melting of ice from year to year as the poles' bright white surface shrinks and changes the quantity of the sun's radiation reflected from the earth [5].

Over coming decades, global warming, which can contribute directly and indirectly to non-uniform changes in SLR throughout the world, can also lead to certain alarming scenarios for specific coastal areas. The results of such influences and changes mean that the adverse effect of SLR will be more significant in some areas than others, owing to varying environmental parameters [7]. It is therefore critical to identify those parameters that influence SLR and enhance its adverse effects upon the coastal environment.

1.2. The adverse effects of sudden SLR on coastal environments over recent years

The problem of sudden SLR is critical owing to its adverse effects upon the world's coastal environments. Especially over the past decade, the world has recently and in short order witnessed these adverse effects. This has been demonstrated by such natural events as tsunamis, which have lead to apocalyptic aftermaths in various regions of the world, such as those that occurred as a natural consequence of a major earthquake on 26 December 2004, which engendered huge waves that struck coastal regions of many countries bordering the Indian Ocean with waves up to 20 m in height, leaving in their aftermath nearly complete destructions of coastal settlements, with hundreds of thousands of people dead, and millions of homeless. A more recent tsunami occurred on 17 July 2006, following an earthquake of 7.7 Richter magnitude in Indonesia, where more than 660 people died and more than 50,000 were made homeless [17,22–24].

Another example of a severe event that also causes sudden sea level rise is a hurricane. Hurricane "Katrina" struck the southeastern US along the Gulf of Mexico coast in August 2005, coming ashore with tremendous wind speeds, with large seawater waves intruding far inland along the low relief coastal areas bordering the Gulf of Mexico, causing destruction to levees and other facilities, and ultimately causing maximum destruction to New Orleans, surrounding areas of Louisiana, and southern Mississippi [25,26].

Many scientific sources link recent hurricane events to changes in meteorological systems that create atmospheric instability, increasing the frequency and intensity of storms such as hurricanes, consequently generating higher and potentially harmful waves [13,25,26]. It thus appears that hurricanes can be correlated with global warming, whilst tsunamis appear to be natural effects linked to tectonic events, mostly located in high actively tectonic oceanic coastal areas.

The potential adverse effects of sudden SLR, as represented by tsunamis and hurricanes, can be characterized by significant numbers of mortalities, and destruction of human settlements. Their dramatic impact upon the human communities results also from a loss in a sense of safety and security as well as from a significant additional loss of natural resources and environmental assets. The latter could involve salinization of coastal soils and significant erosion 1–2 km inland, along hundreds of kms of coast, eliminating agricultural use of such areas, while altering groundwater below these saline soils. Lateral seawater intrusion into the aquifer alters drainage basin bases of coastal groundwater systems, annihilating fresh groundwater reservoirs and surface water [23,24].

1.3. Parameters that enhance the adverse effects of SLR

The two types of events noted above affect respective coastal areas differently [18,23,24]. Natural enhancing parameters that can augment the adverse effect of SLR upon a coastline would have maximum effect upon coasts having low relief and coastal geomorphology. Furthermore, areas with low supplies of sand owing to construction of dams and levees can consequently experience increased erosion, as has occurred along the eastern coast of the Mediterranean Sea resulting from the construction of the Aswan Dam on the flow of sediments in the Nile [27,28]. Such damming can profoundly disturb coastal biota and fauna, as well as human population and facilities bordering the seashore, and would thus be subject to augmented impact of these catastrophes [23].

Enhancement of SLR impact on coastal environments could likewise be linked to coastal regions bounded by erodible lithology tides, waves and fractured rocks which can experience erosion far more rapidly [29]. This can lead to embayments, further enhancing likelihood of SLR intrusion of seawater inland, as compared to regions with less erodible lithologies and compact rocks.

Anthropogenically-linked enhancing parameters that can augment the adverse effect of SLR include:

- lack of sufficient public awareness and governmental preparedness that can lead to over-exploitation of natural resources without consideration of consequences;
- destruction of the environment by excessive excavation and quarrying of sand dunes during construction of beach resorts, walkways, and roads, etc., leaving some coastal areas without natural barriers against incoming waves;
- destruction of such buffering vegetation as mangroves and beach forest, leaving the seashore open to erosion and seawater intrusion, without effective coastal barriers [30–33];
- emplacement of engineered facilities such as dams and levees, which curtail sediment supply to the coast, leaving the coast without protective sediment [27,28].

Furthermore, SLR enhancement can result from growth in population and feedback loops that then produce rising CO_2 levels in the atmosphere and thus augment global warming. As a result, recent exponential increases in melting ice at the Arctic pole due to shrinkage of areas of ice have followed increased absorption of solar radiation in polar areas. Reduction in vegetative cover may cause another feedback loop, resulting in an exponential increase in global warming. Such a feedback effect is augmented when a number of feedback loops work together in additive fashion.

1.4. Objectives of the study, and the area of application

In the face of the complexity in explaining and assessing SLR values, and the evident ancillary enhancement parameters that can increase the adverse effect of SLR on environmental biotopes, the main objectives of this study are:

(1) to delineate and assess the main contribution of key natural and anthropogenic parameters that influence SLR, and enhance the adverse impact of SLR, and
(2) to characterise the vulnerability of the study area to SLR by assessing relative indices of natural, anthropogenic, and enhancement components of SLR vis-à-vis their global context.

To demonstrate the utility of the approach, this paper focuses upon Israel's eastern Mediterranean coast, contrasting it with a world context.

2. Assessment of parameters influencing SLR and the enhancement of its adverse effects upon coastal environments

2.1. Key parameters influencing SLR

The key natural and anthropogenic parameters selected for this study are presented in Table 2. Some of these parameters can have a direct influence, whilst others may have an indirect influence on SLR.

2.1.1. SLR as a result of natural parameters

Natural parameters that can influence SLR can include tectonics, glaciers and icecaps, bathymetry, and forest cover (Table 2).

Tectonics come into play chiefly near intersections of continental plates, generating high levels of tectonic activity. Such activity can include introduction of hot material to the ocean bottom by means of eruptive and intrusive magma from volcanoes and faults [34];

Glaciers and icecaps can be involved in SLR owing to both melting and alteration in continental topography owing to glacial weight load [35]. Global warming is a natural process that can melt glaciers and icecaps, leading directly to SLR. This is mostly significant in proximity to peripheral polar glaciers in the Arctic and Antarctic, but also involves continental glaciers [10,35]. Changes in glacial load, as a direct consequently of SLR, can lead to glacial isostatic adjustment (GIA), which can, in turn, lead to changes in coastal topographic levels [35].

Bathymetry is a critical factor in areas of shallow water, correlated with the increased sensitivity in volume of shallow sea and oceanic coasts involved in the warming of any given body of water. In shallow coastal shelves, the buffering effect of seawater depth is less effective and the warming of water is more efficient than in deeper seas. This parameter involves the steric effect and is inversely correlated to SLR [36–38].

Forest cover has a natural buffering effect upon CO_2 emissions. This exerts a significant influence upon global warming, and indirectly, upon SLR [38–40].

In certain areas in the world, some of these parameters can act additively. This could then augment SLR.

2.1.2. SLR as a result of anthropogenic parameters

As indicated in Section 1, the most critical anthropogenic parameter in general and of the greenhouse gases in particular is CO_2. Its increase results mostly from human activities, a prime factor responsible for global warming and ancillary global climatic changes. This parameter is mostly anthropogenic, especially ubiquitous and characterizing regions having large populations and/or a high degree of urbanization and industrialization, and with

Table 2
Key parameter ratings and weightings ranges and values involved in SLR as attributed to the study area.

Parameter names	Weight	Sources: measured or estimated	Total range [extreme values] for area of study (units)	Correlation with SLR (+ direct) (− indirect)	Assessed value Israel's Mediterranean Coast (R_j)	Rating[a] of Israel's Mediterranean Coast (RR_j)	References[b] [Serial number]
1. Natural parameters that influence SLR							
Tectonic activities:	9	Arbitrary estimation	[0–1]	(+)	0.3	0.3	[34]
Glacial melting	8	Arbitrary estimation	[0–1]	(+)	0.1	0.1	[10]
Bathymetry (at 100 km from the seashore)	7	From geographic maps	[0–3000] (m)	(−)	1000	0.7[a]	[36]
Present forest cover	3	Evaluation	[0–38,611] (×1000 km^2)	(−)	1.3	0.9	[39]
2. Anthropogenic parameters that influence SLR							
Total carbon emissions	9	Evaluation	[0–24 × 10^3][a] (10^6metric tons of CO_2)	(+)	67	0.003	[1–3]
Urban population	7	Evaluation	[0–11.6 × 10^3] (10^6metric tons of CO_2)	(+)	61	0.005	[41]
3. Parameters enhancing SLR effect on coastal environment							
Slope	9	From geographic maps	[0–10 × 10^{-3}] [10^{-3}]	(−)	0.005	0.50	[37]
No. of estuaries per coastal length each 10 km	8	From geographic maps	[0–1]%	(+)	0.5	0.5	[37]
Tides	6	Satellites maps	[0–500] (cm)	(+)	30	0.006	[47]
Waves	7	Satellites maps	[0–600) (cm)	(+)	200	0.34	[46]
Lithology	8	Arbitrary estimation	[0–1]	%	0.7	0.7	[37]
Coastal vegetation wetlands, mangroves	5	Arbitrary estimation	[0–1]	%	0.7	0.7	[30,31]

[a] Use of accessory graphs.
[b] See references list in manuscript.

significant levels of energy usage, such as the Mediterranean coast of Israel [1,3,4,8,41–43].

2.1.3. *Parameters enhancing the adverse effect of SLR on the environment*

As explained in Section 1, parameters that can enhance the adverse effect of SLR on coastal environments include such natural geomorphologic parameters as low slope (Sl) and estuaries. These further enhance lateral seawater intrusion into coasts, and can lead to rapid destruction of facilities and infrastructures. This effect also engenders permanent groundwater and other natural resource losses ([24,33,44,45]; Table 1).

Two other natural dynamic enhancing parameters altering coastal environments are waves and tides. In closed seas, amplitudes can be 10 times lower than those found in open seas and oceans. Their influence on coasts is on-going, but alters significantly over space and time [46,47].

Natural geological parameters specifically involve lithologic erodibility, a potential enhancing parameter that can significantly influence alteration of a coastal profile. In a relatively short time period, areas whose coasts are formed by more erodible rock can be seriously abraded and washed away [12,33,45]

Another natural enhancing parameter that must be considered is increased coastal deforestation, which can thus augment CO_2 buildup in a major way, enhancing coastal erosion [30,31,39,41].

In the future, in highly populated areas such as India and China, the most significant anthropogenic parameter that can enhance adverse effects of SLR is population growth. World population can be expected to double between 2000 and 2050 [48–51]. Accompanying this would be increased energy consumption, positively correlated with burning of fossil fuel and resultant production of greenhouse gas [49]. This parameter can also be correlated with increasing over-exploitation of groundwater and other natural and energy resources. Along with this increased input of heated water resulting from power plant outflow there can be expected a wide variety of industrial effluents, increased anthropogenic alteration of coastal land-use, as well as overpumpage of near-coastal groundwater, with resultant lowering of coastal topographic levels.

The intensity of all these enhancement parameters and consequent augmentation of adverse effects of SLR can be function of the intensity of climatic change. This can amplify wave amplitude and frequency of more severe hurricanes and tropical storms, resulting in more significant erosion, and destruction of coastal environment. However, many of these parameters are far more difficult to measure in various areas of the world than CO_2 levels, and as a result, this study will not focus on them. Nonetheless, it should be noted that in certain areas in the world some of the parameters noted above can act additively, or be enhanced by feedback loop effects, augmenting SLR.

2.2. *Estimation of rating of natural and anthropogenic causal parameters of SLR, and parameters of enhancement of the SLR effect upon coastal environments and resultant components*

The rating of a parameter (j), as referred to in this paper, is the ratio of the measured or assessed parameter (R_j) to the reference value $(R_f)_j$ of that parameter (j). This reference value is an extreme value which can also be a standard or comprehensive arbitrary value.

The weighted rating $(RRw)_j$ of each indexed parameter (j) is evaluated by multiplication of the measured rating of each parameter (RR_j) by its respective weight $(We)_j$. The weighting of the specific natural parameter $(We)_j$, expresses its degree of influence on SLR. Weighting values $(We)_j$ of between 1 and 10 are arbitrarily attributed to all parameters influencing SLR, and their effects upon coastal areas. The greater the weighting, the more significant the influence of these parameters on SLR.

The assessment of natural (n) and anthropogenic (a) causal parameters of SLR and parameters of enhancement (e) of the effect of SLR upon coastal environments and resultant components is evaluated by respectively averaging the weighted rating of the different parameters that belong to each component. For the natural component (C_n)

$$C_n = \sum_{j_n=1}^{N}\left(\left(Rj_n/R_{fj_n}\right)_{j_n}\times(We)_{j_n}\right)/N = C_n = \sum_{j_n=1}^{N}(RRw)_{j_n}/N \quad (1)$$

where j_n represents the index of natural parameters involved in assessment of the natural component. "N" is the total number of natural parameters introduced in formula (1).

In a similar way, the anthropogenic component (C_a) is obtained by the formula:

$$C_{\mathrm{a}} = \sum_{j_{\mathrm{a}}=1}^{A} (\mathrm{RR_W})_{j_{\mathrm{a}}}/A \tag{2}$$

where j_a represents the index of the anthropogenic parameters involved in assessment of the anthropogenic component. "A" is the total number of anthropogenic parameters introduced in formula (4). In a similar fashion, the component of enhancement of the adverse effect of SLR upon a coastal environment, (C_e), can be given by the formula:

$$C_{\mathrm{e}} = \sum_{j_{\mathrm{e}}=1}^{E} (\mathrm{RR_W})_{j_{\mathrm{e}}}/E \tag{3}$$

where j_e represents the index of the parameter's enhancing the effect of SLR, for assessment of the enhancing component (C_e). "E" is the total number of parameters enhancing the effect of SLR introduced in formula (3).

In the case of negative correlation between any key parameter and SLR, as is the case with such parameters as bathymetry, slope, and forests, the $\mathrm{RR_j}$ of such parameters is arbitrarily assessed by use of accessory graphs. Each of these accessory parameter graphs delineates a linear function correlating the arbitrary rating ($\mathrm{RR_j}$) to a measured or assessed value of the parameter in question, indicating directly its influence upon SLR. This enables use of this value directly in equations (2)–(4) in a similar manner to that for other parameters which have a positive correlation between the parameter and SLR, in order to maintain the same logic for all parameter ratings.

2.3. Graphic presentation of natural, anthropogenic, and enhancing components, indicating vulnerability of coastal areas to SLR

Formulae (2)–(4) give the average value of all weighted rating values of parameters that belong to the same component. The objective is to compare the situation of any specific parameter of any particular region to the worst possible situation existing in the world. To make such a comparison, a maximal rating value of 1 can be attributed to the worst possible situation for any particular parameter on a global basis. For the global situation, the component value should be the average of the weightings attributed to the various parameters. Thus, the highest value for any specific component would be that component's global value. The higher a component's value for any specific region, the closer its value to the world component, and the greater its influence on SLR and its potential adverse effect on the environment. This maximal, or worst possible global situation, would then represent the reference value to which any particular region could be compared. The component's estimated value: $C_{(n)}$ and $C_{(a)}$, would express SLR, whilst the value $C_{(e)}$ would express the adverse enhancing effect of SLR, enabling a graphic presentation of the component for a particular study area, as well as for a worst possible global situation. Such a graphical representation could thus illustrate more clearly the relative vulnerability of any given region to SLR, as regards world values.

3. Application to Israel's eastern Mediterranean coast

Israel's eastern Mediterranean coast has been selected for application of the approach noted above regarding the effect of SLR (Fig. 1). The key natural, anthropogenic and enhancing parameters are represented in Tables 2 and 3, with their respective weightings and ratings. The parameter's ratings are related to the study region as well as to a global context, indicated by a maximal reference value, representing as a worse case, as given in Table 3. It should be noted that weightings represent a consensus of recommended values contributed in response to a questionnaire distributed to a group of local experts. Based on these data, the components have been estimated in Table 3 and their graphical illustration in Fig. 2.

3.1. Key natural and anthropogenic parameters influencing SLR along Israel's eastern Mediterranean coast

Based upon data represented in Table 2 it can be seen that the natural parameters that may have significant influence on SLR in

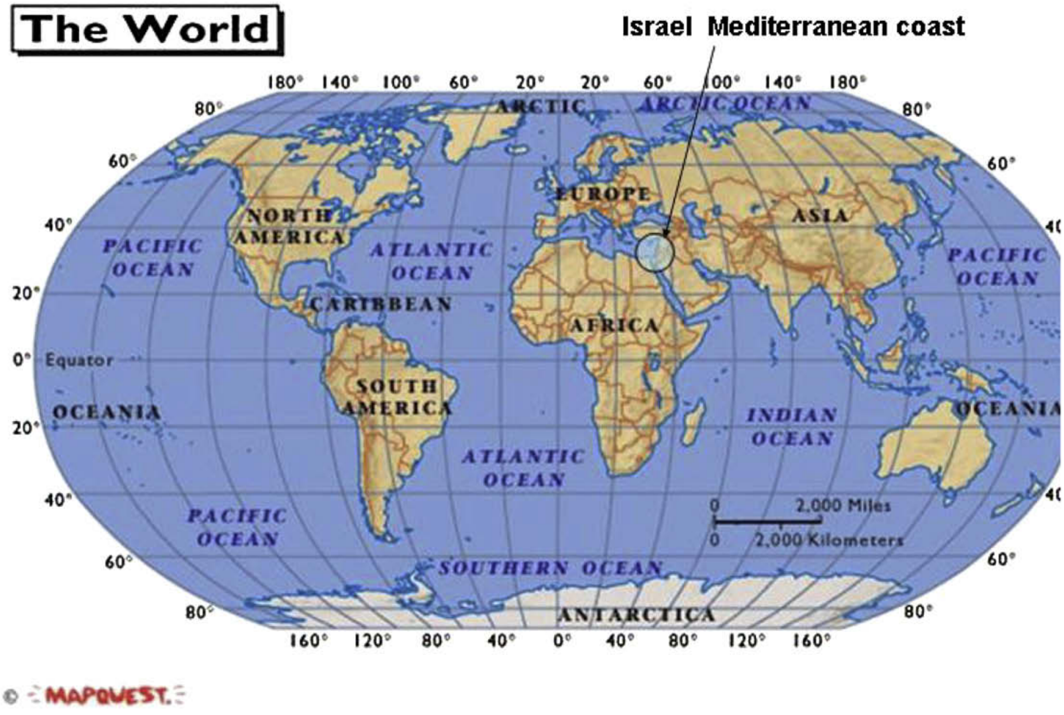

Fig. 1. Location map of study area.

Table 3
Parameter and component indices related to SLR and their adverse enhancing effects upon environment in the area of study.

Parameters	Estimated rating	Maximal rating value	Weights	Weighted rating index
Natural parameters				
Tectonic	0.3	1	9	2.7
Glaciers	0.1	1	8	0.8
Bathymetry	0.7	1	7	4.9
Forest	0.9	1	3	2.7
The natural component (average value)		1		2.8
Anthropogenic parameter				
Total CO_2 emitted	0.003	1	9	0.027
The anthropogenic compound		1		0.027
Parameters enhancing the adverse effects of SLR				
Slope	0.5	1	9	4.5
Estuaries	0.5	1	8	4.2
Tides	0.1	1	6	0.4
Waves	0.3	1	7	2.4
Lithology	0.7	1	8	5.5
Mangroves and wetlands	0.7	1	5	3.5
The enhancing component index (average value)		1		3.4

the study area are lack of forest cover and bathymetry (Table 3). In this eastern coastal part of the Mediterranean Sea, the influence of the melting of glaciers and icecaps would be expected to have minimal influence. Nonetheless, volume of flow into the Mediterranean from rivers and streams augmented by meltwater emanating from Alpine glaciers to the north could contribute towards a small rise in the sea's water level. Tectonic parameters would be expected to influence sudden SLR owing to tsunamis resulting from earthquakes which regularly occur along the inter-plate conjunction where the African plate is pushing northwards into the Eurasian plate to the north. Tectonic parameters appear to contribute to on-going SLR to a lesser extent in closed seas such as the Mediterranean, as compared with the worst-case global situation mostly found in open ocean regions [9,17,22].

Various anthropogenic parameters can influence SLR. Near urban regions, such parameters can include heated water resulting from inflows of industrial effluents and power plants (having a direct influence on the steric effect), destruction of CO_2-absorbing vegetation, and overpumpage of near-coastal groundwater that can lower littoral topographic levels. However, the greatest influence could be expected to be contributed by output of greenhouse gases from industrialized coastal regions. Amongst these gases, the most significant would be total CO_2 emissions. Such emissions have a long history of continuous measurement, and they influence both local microclimate as well as global warming. Far less data are available regarding other greenhouse gases. For that reason, total CO_2 emissions are represented in this study as the key anthropogenic parameter influencing on-going SLR. Estimation of the anthropogenic component will thus be exclusively based in this paper upon total CO_2 emissions in the region of study (a) and its weight ($We_{\text{total } CO_2}$), in comparison to global values, as presented in the following equation:

$$CO_2 \text{for any area} a = \left(R_{\text{total } CO_2} / R_{\text{global total } CO_2} \right) \times We_{\text{total } CO_2} \quad (4)$$

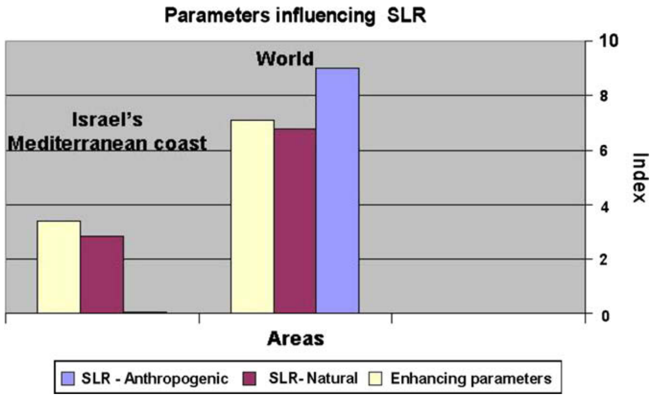

Fig. 2. Graphical presentation of components influencing and enhancing the SLR effect of SLR.

As shown in Table 2, when compared to worst-case global values (R_{global} total CO_2), a rating of 0.003 for total CO_2 emissions from Israel's coastal region would indicate a minimal contribution to global CO_2 balance, estimated as equal to 24×10^9 metric tons/year, but may have a significant influence of the local climate of the region [3,7,14,41,42].

3.2. *Key actual and potential parameters enhancing the adverse effect of SLR along Israel's eastern Mediterranean coast*

As shown in Table 2, it should be noted here that in the case of Israel's eastern Mediterranean coast, other natural and anthropogenic parameters can enhance the adverse effect of SLR on local environments. Amongst these parameters are low slopes and the presence of estuaries. For Israel's eastern Mediterranean coast, with a rating of around 0.5 for slopes and estuaries, these enhancing parameters are of moderate intensity as regards worst possible global situations. Waves and tides, which represent the most significant dynamic enhancing parameters, have relatively low rating values of 0.34 and 0.006, respectively, in the study area. This reflects the character of the closed Mediterranean Sea basin, especially as regards tides [46,47].

Another key natural enhancing parameter which would be expected to have significant influence upon coastal area is lithology, assigned a 0.7 rating for Israel's coast (Table 3). This value reflects the erodible properties of rocks characterizing this coastal region, as compared to global highest levels of erodibility [52]. This parameter results in high levels of erosion and landscape changes, and plays a significant role in creating further embayments, removing impermeable lithologic layers, and thus altering hydrologic boundary conditions of the Coastal aquifer. This could then lead to exposing more permeable layers, thus increasing or mitigating seawater intrusion [33].

Parameters of over-exploitation characterizing anthropogenic activities that can enhance the adverse affects of SLR along Israel's coast would include increasing loss of wetlands and vegetation (Table 3), which reduces protective vegetation of the natural surface media. Another parameter of this sort would be such engineering activities as construction of dams, which could disturb the natural environment by cutting off alluvial sediment supply downstream. A very important example of this would be the Aswan dam. The dam has sharply reduced sand supply along the eastern Mediterranean that had previously been contributed by the Nile [27,28]. Mediterranean seawater flows in an anti-clockwise fashion along the eastern shore of the Sea, such that natural sand and silt deposition coming from the Nile Delta is a key factor in beach development along that shoreline. Furthermore, lack of adequate engineering facilities to protect the sandy coast enables sea waves to eat away at erodible coastal lithology, facilitating gradual intrusion of seawater inland into the coastal aquifer [30]. The influence on this local region could be significant, affecting local microclimate, and leading to crucial adverse effects upon local ecology and environment.

An additional enhancing parameter highly correlated to anthropogenic activities along Israel's coast and coasts elsewhere around the globe would be the recent increase in coastal population and urbanization. Even when assuming lower fertility levels in developed countries and a constant value for standards of living in developing countries, world population, especially in coastal areas, is expected to double by the middle of the 21st Century. Israel's coastal region is one of those in which rising population is likely to be significant by 2050 [50,51].

This parameter is all the more important owing to its correlation with a consequent rise in total CO_2 emissions. Population growth could thus become one of the most critical parameters enhancing global warming and consequently on the adverse affect of SLR worldwide, and specifically along Israel's Mediterranean coast [48,49]. The population of Israel's coastal region is relatively small, and for this reason this parameter plays a local role, with a negligible global contribution.

The key question faced by regional planning authorities is thus what long-term resource management planning could best minimize parameters that can influence SLR, and its adverse enhancing effects upon regional coastal environments. One of the aims of this study is to assess these natural, anthropogenic, and enhancing components at play in target regions.

3.3. Graphic presentation of natural, anthropogenic, and enhancing components, indicating vulnerability of Israel's eastern Mediterranean coastal areas to SLR, vis-à-vis global values

Based upon formulae (2)–(4), the natural and anthropogenic components influencing SLR, and the enhancing component of the adverse effect of SLR on environment, have been assessed in Table 3, with their values represented in Fig. 2. From these results one can conclude that SLR results from a combination of natural and anthropogenic components. For Israel's eastern Mediterranean coast, the importance of the anthropogenic as compared to the natural component is relatively less significant. And, in this case, when compared to a global worst-case situation, the contribution of the anthropogenic component to SLR can be seen as negligible. On the other hand, the component of enhancement of the adverse effect of SLR appears more critical in this study region than the other components. A key parameter of this component would be coastal lithology, but future population growth would likely also play a part.

4. Conclusions

In coming decades, on-going global warming will augment the probability of climate change. This may trigger alteration in SLR magnitude and rate, as well as increase the impact of enhancing factors, as shown in on-going global SLR as well as instances in sudden SLR situations over recent years. Higher winds and wave levels, owing to hurricanes and other natural phenomena, along with rapidly increased erosion, could be expected to lead to further intrusion of seawater. Subsequently, it should be noted that in many global regions such abnormal natural events and anthropogenic enhancing parameters come into play, such that their accumulated adverse effects could be augmented, owing to feedback loops and other factors. This could be expected to seriously endanger coastal environments and cities, where effective environmental management measures have not been taken.

To improve the scientific basis for future recommendations, questionnaires should be distributed to an expanded circle experts throughout the world and in a wider variety of areas of expertise, in order to arrive at better estimations of weighting values for the various components that characterise the vulnerability of particular regions of study. As noted at the beginning of Section 3, above, questionnaires in this present study were sent only to local experts in the area of hydrology.

Special attention should be paid to regions having relatively low coastal slope and relief. In such areas, high-resolution coastal topographic contour mapping should be undertaken, in order to delineate critical areas or paths where SLR could significantly intrude inland. Such areas would be especially vulnerable to hurricanes, storms, and tsunamis, which could create embayments, and enlarge estuaries, leading to further seawater intrusion inland, as is the case along the central portion of Israel's Mediterranean coast. The vulnerability of such areas is all the more significant when coastal aquifers offer high levels of storage and rates of pumpage of fresh groundwater.

Highest priority should thus be directed towards anthropogenic activities, in order to curtail or mitigate coastal erosion, and thus prevent inland seawater intrusion. Measures that could be employed in this regard include creation and expansion of protective vegetation belts, such as coastal forests and wetlands, as well as construction of environmentally-sound hydrological and engineering facilities. Where engineering construction such as the Aswan dam could have adverse impact on neighboring coastal regions, such as supply of sand to the eastern Mediterranean coast, parameters such as sand supply should be regularly and accurately monitored.

Awareness can be increased regarding the affects of climatic change by measuring frequency and expected intensity of storms. It would appear critical to improve coastal monitoring systems, i.e., emplacement of additional gauges and meteorological stations at appropriate seashore locations, as well as by upgrading existing observation boreholes and by utilizing satellite measurement of SLR. Such measures would provide early-warning signals and improved data levels and accuracy.

A necessary condition for improving operational management should include consolidating personnel and inter-agency communication and coordination involved. A unified authority could consist of personnel from a wide variety of governmental ministries and academic institutes of engineering, science and economics, to cope in an integrated manner with variegated problems, and focus upon a common objective.

References

[1] Jean-Marc Jancovici. Le rechauffement climatique: quelques notions elementaires de physique, Qu'est ce que l'effet de serre ?. pp. 6. Available from: http//www.manicore.com/documentation/serre/physique.html; 2003 [in French].

[2] IPCC. Intergovernmental program climate change 2007 IPCC fourth assessment report: climate change 2007with technical papers and the IPCC debate on SLR. Available from: http://www.ipcc.ch/ipccreports/technical-papers.htm; 2007 http://www.ipcc.ch/ipccreports/assessments-reports.htm; 2007. and technical papers.

[3] SHOM. Service Hydrographique et oceaographique de la Marine. Available from: http://www.shom.fr/fr_page/fr_act_oceano/maree/elevat.htm; 2005 [in French].

[4] Mc Bean Gordon, Weaver Andrew, Roulet Nigel. The science of climatic changes: where we are in our knowledge's?. Available from: http:www.isuma.net/v02n04/mcbean/mcbean_f.shtml; Winter 2001 [in French].

[5] NGM. National geographic magazine. Global Warming 2004;206(3):2–75.

[6] NOAA. The national oceanic and atmospheric administration: eighth warmest June on record for globe. Available from: http://climatechangepsychology.blogspot.com/2008/06/noaa-2008-global-temperature-seventh.html; 2008.

[7] IPCC. International programme of climate change report. Climate change, the scientific basis technical summary. Available from: http:www.ipcc.ch; 2001.

[8] Cnrs info. Thermic dilatation and rise of water steric effect and SLR. Measures by temperatures and also by Topex – Poseidon satellite measurements. Available from: http://www.cnrs.fr/Cnrspresse/n40/html/n400rd06.htm; 2004 [in French].

[9] Tsimplis MN, Marcos M, Somot S. 21st century Mediterranean sea level rise: steric and atmospheric pressure contributions from a regional model. Global and Planetary Change. Available from: http://eprints.soton.ac.uk/50378/ 2008.

[10] Glaciers. Sea level rise owing to glaciers melting. Available from: http://www.ens-lyon.fr/Planet–Terre/infosciences/climats/ocean/Articles/elevation-glaces.htm; 2004 [in French].

[11] Shirman B. Israel coast sea level changes during 1958–1991. Survey of Israel, Report No RD4/1. Available from: http//www.pol.ac.uk/PSML/; 2001.

[12] Rosen DS. Long term remedial measures of sedimentological impact due to coastal developments on the south-eastern Mediterranean coast. Proc. Littoral 2002. The Changing Coast EUROCOAST/EUCC. Ed. EUROCOAST. Paper 40, vol 2; 2002. pp. 322–31.

[13] Vivien Gornitz. Global coastal hazards from future sea level rise. Paleogeography, Paleoclimatelogy, Paleoecology(4):379–98. Global and Planetary Change Section. Elsevier Science Publishers B.V., Amsterdam. Available from: http://www.giss.nasa.gov/research/intro/gornitz_05/, 1991;89.

[14] Rahmstorf S. A semi-empirical approach to projecting future sea-level rise. Science(5810):368–70. Available from: www.sciencemag.org, 14 Dec 2006;315.

[15] SEWG, Solid earth science working group. What are the interactions among ice masses, oceans, and the solid earth and their implications for sea-level changes?. Available from: http://solidearth.jpl.nasa.gov/PAGES/sea01.html; 2003.

[16] Dominey-Howes Dale TM, Humphreys Geoff S, Hesse Paul P. Tsunami and palaeotsunami depositional signatures and their potential value in understanding the late-Holocene tsunami record. SAGE Publications Macquarie University, Australia. The Holocene(8):1095–107. doi:10.1177/0959683606069400 ddominey@els.mq.edu.au, 2006;16

[17] NOAA 2007. Center for Tsunami research. Tsunami Event – September 12, 2007 Indonesia. Available from: http://nctr.pmel.noaa.gov/sumatra20070912.html.

[18] Soloviev SL. Large-scale volcanic cone collapse: the 1988 slope. Basic data on tsunamis on the Pacific coast of the USSR, Institute of Oceanology, Academy of Sciences of the U.S.S.R., 23 Krasikova, 117218 Moscow, U.S.S.R. 989; 1988. Available from: tsun.sscc.ru/tsu_catalogs.htm.

[19] Lumiere sur l'Obscurcissement_ global 2004. Available from: http://www.sciencepress.qc.ca/archives/2004/man170504.html [in French].

[20] Global dimming. Cause and effects from: Wikipedia free encyclopedia. Available from: http://en.wWikipedia.org/Global_dimming; 2005.

[21] Alpert Pinhas, Kishcha Pavel, Kaufman Yoram J, Schwarzbard Rotem. Global dimming or local dimming: effect of urbanization on sunlight. Geophysical Research Letters 2005;32:4.

[22] Bryant E. In: Inby Edward, editor. "Tsunami": where they happen and why. Cambridge University Press. Available from: http://www.Fathom.com/feature/122490/; 1991.

[23] IUCNE. Early observations of tsunami effects on wetlands and water resources. Available from: http://www.Iucn.orgpress@iucn.org; 2005.

[24] Wikipedia the free encyclopedia, the Indian ocean earthquake and the Asian Tsunami 2006. Available from: http://en.wikipedia.org/wiki/2006_Indian_Ocean_earttn quake.

[25] Hurricane watch, Pictures from "Katerina" hurricane. Available from: http://outhouserag.typepad. com/hurricane_watch/pictures/index.html; 2005.

[26] Katerina. Understanding responsibilities for hurricane Katerina. Available from: http://www.see.kfind.net/Amazing_Facts/Understanding_Responsibilities_For_Hurricane_Katerine; 2005.

[27] Sharaf el Din H. Effect of the Aswan high dam on the Nile flood and on the estuarine and coastal circulation pattern along the Mediterranean Egyptian Coast. Limnology and Oceanography Mar 1977;22(2):194–207.

[28] Zviely D, Kit E, Klein M. Longshore sand transport estimates along the Mediterranean coast of Israel in the Holocene. 2007. Department of Geography and Environmental Studies, University of Haifa, Haifa, 31905, Israel. Faculty of Engineering, Department of Fluid Mechanics and Heat Transfer, Tel-Aviv University, Ramat-Aviv, Tel-Aviv 69978, Israel.

[29] Fernand Verger. The consequences of the seawater rise on low tide slope coasts. Available from: http://www.x-en; 2000 [in French].

[30] Wetland plants. Available from: http://www.lethsd.ab.ca/mmh/grade5/wetlands/page5.htm; 2006.

[31] Mangrove map of the world. Available from: http://www-peda.ac-martinique.fr/fondlahaye/foret/mangrovemonde.htm; 2006 [in French].

[32] Melloul AJ. Sea water rise and its impact on the Israel coastal aquifer. Agamit Water in our Country Journal May–June 2004;168:6 [in Hebrew].

[33] Melloul A, Collin M. Seawater rise and its adverse input on stressed coastal aquifers and their groundwater reserve. In: Cunha MC, Brebbia CA, editors. Water resources management III. In section 4: coastal and estuarial problems. Wessex Institute of Technology, UK; 2005. pp. 184–192.

[34] Nova Terra. Plaques tectonic. Available from: http://www.dinosoria.com/tectonique_plaque htm; 2003 [in French].

[35] Archfield S. Hazards of sea level. Available from: http://cfa-www.harvard.edu/space_geodesie SEALEVEL; 2003.

[36] Global information. Bathymetry topography and relief. Available from: http://www. intermarginsorg/maps/bathymetry.htm; 1996.

[37] World atlas maps.

[38] PNAS. Proceeding of the National Academy of Sciences of the United States of America, vol 99(10);2002. Available from: http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=124434.

[39] World forest. Country deforestation data. From food and Agriculture Organisation of UN: The state of the world's forest; 2003. Available from: http:www.mongabay.com/deforestation_simple.htm.

[40] La deforestation de la planete prend des proportions alarmantes. Available from: http//ecolesdifferentes.free.fr/OVERT.htm; 2005.

[41] World bank data. The little green data book 2005. Available from: http://www.worldbank.org/depweb/english/modules/social/pgr/map1.html; 2005.

[42] Saaroni H, Ziv B, Edelson J, Alpert P. Long term variations in summer temperatures over the Eastern Mediterranean. Geophysical Research Letters 2003;30(18). CLM 8-1–8-4.

[43] Cabanes C, Cazenave A, Le Provost C. SLR rise during past 40 years determined from satellites and in situ observations. Science 2001;294:840–2.

[44] Porat Itamar. The influence of sea level rise on the strip and cliff the Israel Coastal aquifer. Report 2004. pp. 35–40 [in Hebrew].

[45] Brunn P. Sea level rise as a cause of shore erosion. Journal of Waterways, Harbors Division, ASCE 1962;71:1729–54.

[46] Waves. Waves maps based on data from Topex – Poseidon satellite. Available from: http://smcs.cnes.fr/Fr/oceans.htm; 2002 [in French].

[47] Tides. Between sky and earth. Available from: http://www.cosmovisions.com/CT.marees.htm; 2005 [in French].

[48] L'internaute. Population in 2050. Available from: http://www.linternaute.com/0redac actu/0501-janvier/population-2050.shtml; 2005.

[49] US Census Bureau. Total midyear population of the world 1950–2050. Available from: http://www.census.gov/ipc/www/worldpop.html; 2006.

[50] World population: major trends 2006. Global Chapter 1. Available from: http://www.iiasa.ac.at./Research/LUC/Papers/gkhl/cha1.htm.

[51] James White. Global change 2: an earth sciences perspective: population. university of Colorado. Available from: http://earthscape.org/t1/wij01/wij01ae.htm; 1–9, 1999.

[52] Tolmach Y. Hydrogeological atlas of Israel, Coastal aquifer, Areas of Tel Aviv through Hadera. Hydrological service report, Jerusalem. 1979;3–5:70 [in Hebrew].