Ocean & Coastal Management 59 (2012) 47–62

Contents lists available at SciVerse ScienceDirect

Ocean & Coastal Management

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

Assessing the costs of sea-level rise and extreme flooding at the local level: A GIS-based approach

Michal Lichter*, Daniel Felsenstein

Department of Geography, Hebrew University of Jerusalem, Mt. Scopus, Jerusalem 91905, Israel

A R T I C L E   I N F O

Article history:
Available online 5 January 2012

A B S T R A C T

This paper presents a systematic framework for assessing the costs of sea-level rise (SLR) and extreme flooding at the local level. The method is generic and transferable. It is built on coupling readily available GIS capabilities with quantitative estimates of the effects of natural hazards. This allows for the ex ante monetization of the main costs related to different scenarios of permanent inundation and periodic flooding. This approach can be used by coastal zone planners to generate vital information on land use, capital stock and population at risk for jurisdictions of different sizes. The simple mechanics of the method are presented with respect to two examples: one relates to the two largest coastal cities in Israel (Tel Aviv and Haifa) and the other to the Northern Coastal Strip region containing a variety of small towns and rural communities. The paper concludes with implications for coastal zone planning praxis.

1. Introduction

While most of the costs of sea-level rise (SLR) and extreme coastal flooding (EF) are felt at the local level, much emphasis is paid to assessing these costs at the national level. This seems to be a legacy of the IPCC Common Methodology (1992) and the follow up guidelines that emerged through the UNEP Handbook on Methods for Climate Change Impact Assessment and adaptation strategies. The assessment praxis inspired by these guidelines has invariably looked at coastal impacts of SLR and extreme flooding (through storms or tsunami-type events) in macro-spatial terms (Hinkel and Klein, 2009; Anthoff et al., 2010). The sub-national or local level has been invariably overlooked. This is surprising given the stress these studies place on issues of vulnerability and adaptation to climate change. Paradoxically, the emphasis on vulnerability assessment at the national scale may have raised the awareness of local decision makers to the costs of SLR and extreme flooding events while concurrently driving home the lack of tools and methods available to them for assessing these costs.

The paper tries to fill this gap by presenting an applied and reproducible method that allows local authorities to assess the vulnerability of their jurisdictions. The paper shows how local planners can generate meaningful data at a high level of spatial resolution needed for rational decision making. Traditionally, coastal zone issues have been the province of geologists, ecologists and engineers. The approach presented here however is directed at a very different audience comprising urban, coastal and emergency planners charged with mediating the threats to coastal and urban development in an uncertain physical environment.

We endeavor to show how the GIS capabilities and data that are invariably available to planners can be harnessed to provide a structured and systematic framework for analyzing the economic costs of physical/natural processes as they apply at the local level. This in turn should provide meaningful information for local decision makers called on to make choices in an area in which they have had little experience. While not a 'how-to' guide, the method presented here is generic and transferable enough to be applied in different local contexts. The paper begins by surveying the current state of the art and the various tools available for assessing the impacts of natural processes at the local level. We proceed to describe the assumptions, data requirements and limitations of our approach, highlighting the resources and capabilities needed and their likely availability. Given the state of current practice, we present the simple mechanics of our evaluation approach by way of a worked example relating to the two largest cities in Israel as well as distinct region that comprises a selection of different sized small communities – the Northern Coastal strip (Fig. 1). We conclude with some reflections on the need for generic and accessible evaluation frameworks for coastal zone planners and the contribution of such tools to coastal zone management praxis.

---

* Corresponding author. Tel.: +972 54 2336773; fax: +972 4 6897135.
E-mail addresses: mlichter@gmail.com (M. Lichter), msdfels@mscc.huji.ac.il (D. Felsenstein).

0964-5691/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ocecoaman.2011.12.020

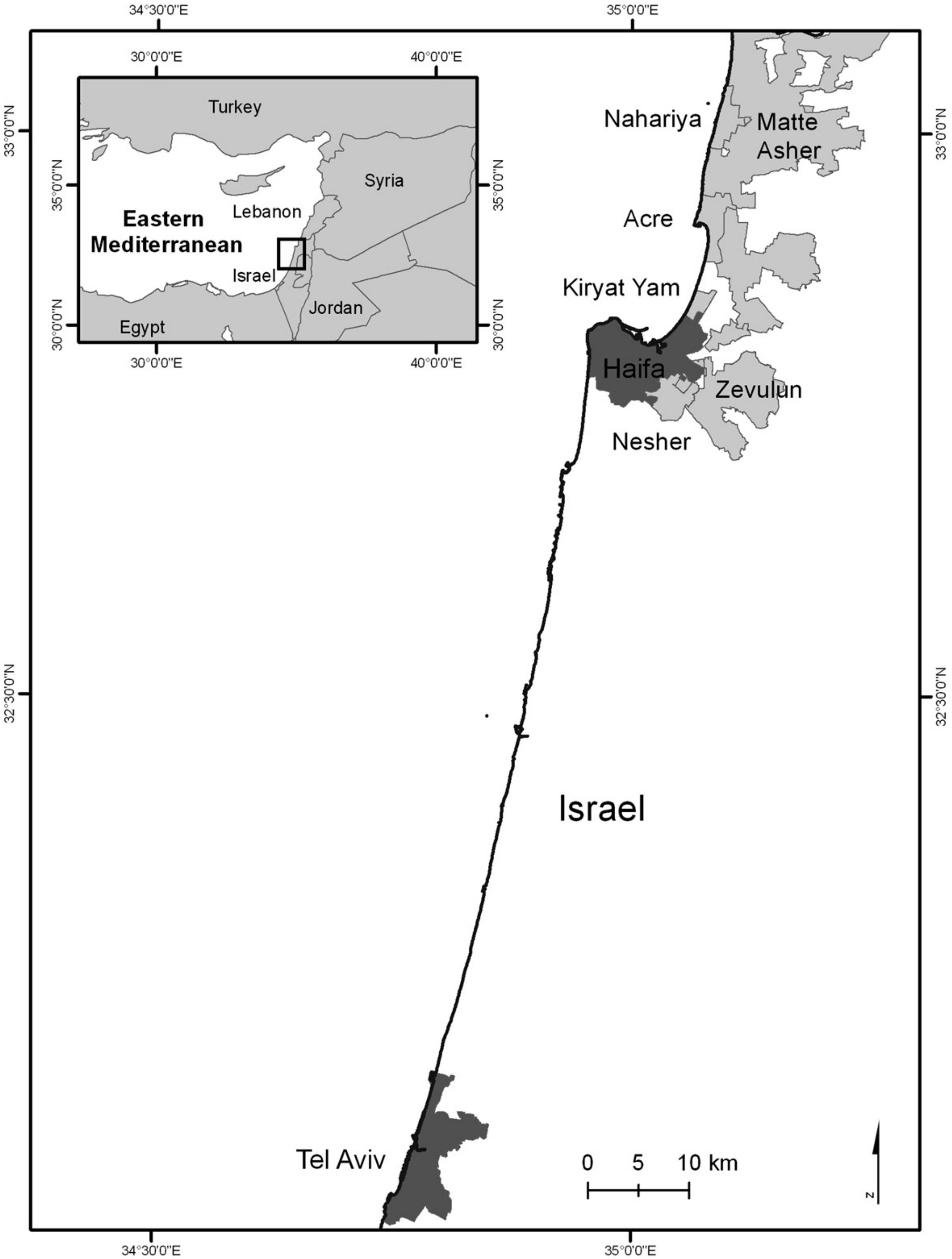

Fig. 1. The study area.

2. Literature review

The current state of the literature encompasses a broad spectrum of tools. Much of this consists of applications of methods developed outside the context of SLR and climate change and adapted on an ad hoc basis. The result is a diverse and sometimes dichotomous toolbox. This comprises on the one hand, bespoke tools to deal with particular micro situations and on the other hand, aggregate, analytic frameworks for dealing with macro (global) scale issues. In between, there is a surprising vacuum of applicable approaches grounded in readily available platforms and providing local level information for cities and small communities trying to mitigate some of the excesses of climate change.

In terms of approaches, the literature is also dichotomized by the scale of analysis. At the micro scale there is a range of studies attempting to isolate the effect of SLR on social and economic processes which borrow from tools of economic impact analysis. For example, Bin et al. (2011) use spatial hedonic modeling to simulate outcomes of different SLR scenarios on house prices in 4 counties in South Carolina. Alternatively, Xiao (2011) illustrates the judicious use of a control groups (difference in differences) approach to estimate the impact of the 1993 flooding in the US on various Midwest counties in terms of income and job losses. Using a less-structured method but with a broader socio-economic focus, Kleinosky et al. (2007) present a case study of the impacts of hurricane storm surges to an area of southeastern Virginia comprising 16 counties. They map the various flood risk zones under different storm surge scenarios and estimate the social vulnerability of particular sub populations in the area such as the poor, disabled, immigrants, single mothers etc. In a study of SLR and storm flooding along the coast of Maine, Colgan and Merrill (2008) define coastal hazard zones on the basis of a hurricane forecasting model (SLOSH). This information is then overlaid on a geocoded data layer of economic establishments (in trade and commerce) and their employment and wages, available from institutional sources. This is done for areas at risk to both storm surge flooding and SLR inundation. Because of the particularities of their settings, their intricate data requirements and the sophistication of their approaches, the methods used in these case studies are not readily transferrable. Thus they remain as interesting prototypes but of limited application to wider contexts.

At the other end of the spectrum, a range of global scale, integrated approaches to looking at coastal vulnerability exist. For example, the DIVA framework (Hinkel and Klein, 2009) describes a systematic, large-scale and data-intensive approach to assessing dynamic process change along coasts. This includes geophysical, ecological and socio-economic processes and the interactions between them. The system comprises a suite of linked models for predicting river flooding, coastal erosion, salinity intrusion and socio-economic effects following different SLR scenarios. Broad projections of population and land uses types flooded under different scenarios are provided at highly aggregated spatial scales. This kind of output has provided useful to national agencies and cross-national research collaborations, for example in the PESETA study (Richards and Nicholls, 2009). In this research effort, the DIVA model was applied to assessing the costs of mitigation and adaptation and not just for estimating coastal damage. However macro-scale models of this kind have less to offer to local level decision makers and professionals dealing with urban, emergency and coastal planning and offer little opportunity for incorporating local knowledge or the utilization of generic platforms such as GIS for analyzing local data.

In similar vein, Anthoff et al. (2010) use a highly aggregate model (the FUND model) to estimate costs of SLR at a coarse level of spatial resolution. This provides estimates of global and country-level welfare costs due to land loss (wet and dry lands), protection costs and costs of displaced populations. The cost calculations are grounded in the principles of cost–benefit analysis and include present values of costs, different discount rates and sensitivity tests. The key insight of this approach is the inclusion of human behavioral response as a quantifiable outcome (protect or retreat) and the estimation of the relative magnitude of protection in respect to all the other SLR induced costs.

Many studies of coastal vulnerability at more localized levels use readily available platforms, data and tools (GIS, Remote Sensing data, Digital Elevation Models) but their treatment of socio-economic impacts is limited. For example, for Bryan et al. (2001) vulnerability is identified in physical terms such as aspect, slope, elevation and physical exposure in a study of the coastal changes in the Northern Spencer Gulf in South Australia. They make extensive use of GIS techniques in order to model the spatial distribution of the physical parameters that impact on coastal processes such as inundation, erosion and exposure to wave attacks. Other studies focus on vulnerability index building but offer little in the way of general methods or attention to socio-economic costs associated with coastal vulnerability (Hegde and Reju, 2007; Özyurt and Ergin, 2010). Work by Snoussi et al. (2008) assesses the vulnerability of the eastern part of the Mediterranean coast of Morocco but offers little more than simple overlay analysis in which future inundation scenarios are superimposed on current broad land uses (urban, agricultural, tourism etc) and with no satisfactory attempt to estimate socio-economic costs.

Marfai and King (2008) present a risk assessment of SLR, coastal inundation and land subsidence for Semarang city in the Central Java province of Indonesia. In some ways their approach is close to that adopted in this paper. Starting with DEM generated land elevation data and land subsidence scenarios they create successive GIS raster presentations of the effects of SLR, tidal water levels and inundation in order to calculate the total coastal area affected by inundation. To this they add population data by villages in the study area and the economic value of different land uses and the economic activities they harbor that are potentially affected. While only a rough cut approach to estimating costs, this study nevertheless illustrates the integration of readily available tools with local data in a structured fashion in order to create value added in terms of new information.

In an Israeli context, the work by Yehoshua et al. (2006) presents an ad hoc attempt at attaching monetary value to various sections of the Israeli coast. This is based on the loss of its use as an environmental good in the event of SLR of 1 m by 2060 and the consequent shoreline erosion. Using contingent valuation and travel cost methods for valuing public goods, they present annual discounted monetary values of coastline potentially flooded until the target date. This work attempts to monetize the partial costs of natural events in a very particular context using a method for valuing intangible coastal features.

Finally, a wealth of tools exists for evaluating socio-economic impacts of SLR and other extreme natural events (storms, hurricanes, floods). Many of these are accessible via the Ecosystem Based Management Tools Network (http://www.ebmtoolsdatabase.org/) a loose international alliance of tools, developers, users, NGO's, government agencies and research institutes which administers a repository of tools suitable for the management of marine and coastal environments. These are available in two primary formats: either as standalone models or as individual components in integrated packages (or 'toolkits').

The former category includes tools such as the Land Use Portfolio Model, LUPM (Taketa et al., 2010) which is an analytic framework for comparing across different risk reduction actions in the event of natural hazard scenarios. The method is rooted in the theory of portfolio analysis and evaluates the risk and returns of investing in different portfolios of mitigation methods and locations under a given natural hazard scenario (or set of scenarios) and given specific user preference schedules. The model outputs a set of indices common to the cost-efficiency paradigm that include the number of mitigated locations, costs of mitigation, return on investment and rate of return to mitigation, expected value of losses etc. The model looks at costs to both structural assets such as land, buildings and infrastructure and non structural commodities such as agriculture, livestock and capital resources (machinery). The chief obstacle to the general applicability of this tool is its data intensity. Hard estimates on hazard mitigation demand interdisciplinary inputs from engineering, materials science, economics etc. Invariably other bespoke models are needed in order to provide these estimates. One example is the use of the FEMA model for geospatial natural hazards loss estimation, HAZUS-

MH (Buriks et al., 2004) as an obvious source of inputs for the LUPM. However this further compounds the problem of the accessibility of these bespoke models. More sophisticated models demand ever more sophisticated parameter inputs thereby decreasing their potential applicability.

The other form of tool delivery is as part of an integrated coastal management package. The tools offered in this instance are generally part of a suite of models, many of which serve as ArcGIS extensions. A key example is the 'resilient community' package (Hittle, 2011) which combines a GIS platform, a GIS extension for creating and comparing scenarios (Community Viz), a natural habitat-conservation tool (VISTA) and the NOAA methodology for identifying hazards, risks and producing hazard-risk maps. A similar but less integrated toolkit initiative is the 'Decision Support Tools for Marine Spatial Planning' (Coleman et al., 2011) which offers more of a toolbox than a systemic evaluation approach. The 'Inundation Toolbox' is an in-house tool developed by a commercial consulting company that couples a storm surge model with GIS to generate maps of areas at risk (www.asascience.com). A similarly integrated approach can also be found in the COAST model (Coastal Adaptation to Sea-Level Rise Tool) (Merrill et al., 2010). This model is an advance on Colgan and Merrill (2008). Aside from coupling the NOAA natural hazards model (SLOSH) with limited economic indicators it offers a much richer array of economic losses that define the 'economic floodplains' under threat. Aside from the standard costs of lost real estate value, economic output and infrastructure, the COAST approach also considers costs of displaced persons, lost natural resources and lost cultural resources.

3. Material and methods

Our approach is concerned with estimating the socio-economic costs associated with SLR and extreme coastal flooding events. We generate quantitative estimates of the effects of a given natural stimulus and show how to monetize the main costs of natural hazards. A series of coastal permanent inundation and periodic flooding scenarios is examined from an ex ante perspective. Despite our focus on costs, the main thrust of our approach is their quantitative impact rather than their social valuation. Unlike full-blown cost–benefit analyses, we do not consider alternative uses or opportunities foregone given the currents costs but do endeavor to look at some of the broader socio-economic effects associated with the observed costs.[1]

In terms of identifying costs, our method follows the spirit of the IPCC (1992) Guidelines. We look at people displaced by SLR and placed at risk by EF, the value of land and capital stock lost through SLR inundation and periodic flooding and some of the welfare implications of these impacts. Together, these factors identify the parameters of socio-economic 'vulnerability'. We are aware of the lack of any consensual definition of this concept (Füssel and Klein, 2006). However given our emphasis on creating an applied tool, we choose indicators that are measurable and operational. It should be noted that all our assessments relate to present conditions of the parameters assessed and do not project inevitable future changes (for example population increase, changes in-house values etc).

Our general approach is depicted in Fig. 2. We delimit three stages, each characterized by three separate activities: data collection, data processing and outputs. Stages 1 and 2 are parallel steps dealing with the physical processes and the spatial distribution of population and assets affected, respectively. Stage 3 is a sequential step that combines the above and generates a comprehensive picture of local socio-economic costs. The data inputs and outputs generated in this process are summarized in Table 2. To facilitate data description, each input/output in the table is given a unique identifier. We now describe the blocs of activity that comprise each stage.

3.1. Stage 1– creating inundation increment maps

In the first instance, inundation maps are created. These later serve as the platform for the spatial analysis. The borders of each inundation map are determined by two main factors: topography and hydrological connectivity to the sea.

Global SLR scenarios for the 21st century range from 0 to over 1.5 m (Grinsted et al., 2010; Meehl et al., 2007; Rahmstorf, 2007). Due to constraints inherent in the elevation data, we use five different equal interval SLR scenarios: 0, 0.5, 1, 1.5 and 2 m (see Table 1a). Periodical flooding is estimated by considering return periods (probabilities) of extreme high tides and extreme events such as Tsunamis (see Table 1b, c), again in increments of 0.5 m. The periodic flooding scenarios are combined with the SLR scenarios to account for the entire range of possible permanent inundation and periodic flooding possibilities.

3.1.1. Data processing

An automated procedure using ArcGIS geo-processing commands in Python is created for processing the data as follows:

- An elevation contour layer (1C in Table 2) is interpolated into a raster format DEM (1E in Table 2) in order to be able to reclassify and distinguish between the land and the sea for each elevation increment. The contour layer is interpolated using ArcGIS "Topo to Raster" interpolation, which is specifically designed for the creation of hydrologically correct DEMs. This is an interpolation method that allows the fitted DEM to follow abrupt changes in the terrain, such as streams and ridges. In order to create a submerged area layer for each elevation increment the new raster elevation values are reclassified to a binary raster of sea and land, where the sea values include the land at elevations lower than or equal to the respective increment (the inundated area). This is done in 0.5 m increments.
- In order to mask out inland areas with no direct connection to the coastline, the reclassified output raster is converted into a vector layer. This enables erasing all polygons in the vector layer that are not hydrologically connected to the 'sea polygon'. The sea polygon includes the sea and the hydrologically connected inundated land.
- A vector layer of the current shoreline is used in order to extract the inundated area at each elevation increment from the sea polygon (1D in Table 2).
- Five future sea-level rise scenarios are considered: No SLR, 0.5 m, 1 m, 1.5 m, and 2 m (1A in Table 2). In these scenarios, inundation up to the new sea level is assumed to be permanent.
- On top of each sea-level scenario, the probabilities of short-term non-permanent flooding from the sea, either by extreme high tides or by extreme events such as a Tsunami wave are considered (1B in Table 2).
- In addition, the whole 'Low Elevation Coastal Zone' (LECZ), defined by McGranahan (2007) as "the area below 10-m elevation which is hydrologically connected to the sea", is extracted as well.

---

[1] The approach presented here is closer to impact analysis than any form of cost–benefit framework. Despite our attention to 'costs', we do not utilize the arsenal of cost–benefit analysis and its sub-fields (cost-effectiveness, cost-utility, cost feasibility) (Levin and McEwan, 2001). While we attempt to attach monetary values to costs, we are not concerned with valuation in the broader welfare economics sense of the term (producer and consumer surpluses, opportunity costs etc). However, our 'costs of impacts' approach can be reconciled with a standard cost–benefit approach as has been noted by Burgan and Mules (2001).

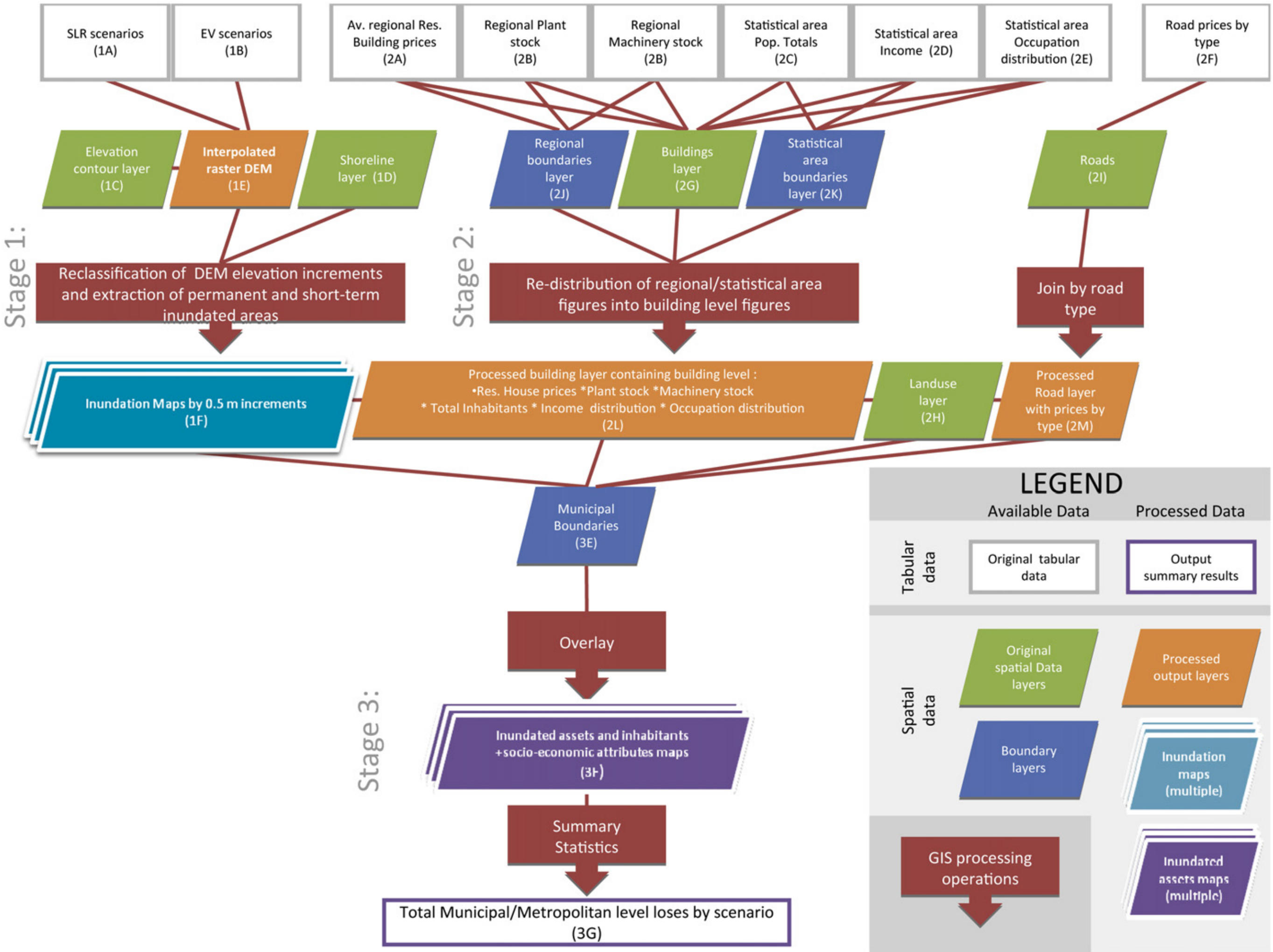

Fig. 2. Outline of the approach: datasets and GIS procedures employed (datasets labels corresponding to Table 2 are in parentheses).

Table 1
Global sea-level rise scenarios and local EF events recurrence probabilities.

a. Projected 21st century SLR		
IPCC AR4 (Meehl et al., 2007)	(Rahmstorf, 2007)	(Grinsted et al., 2010)
0.18–0.59 m	Up to 1.4 m	Up to 1.6 m
b. Extreme sea levels in Israel (Golik and Rosen, 1999)		
Return period (y)	Low SL (m)	High SL
1:1	−0.41	0.6 m
1:50	−0.79	1 m
1:100	−0.9	1.06 m
c. Tsunami events in Israel (Salamon et al., 2007)		
Return period (y)	Source	Run-up [varies locally]
	Earthquakes originating beneath the sea on nearby subduction zones (Hellenic Arc, Cypriot Arc)	1–3 m
	Submarine landslides produced by on-land rupture of active faults (DST system)	4–6 m

The output is a set of 0.5 m increment inundation maps (1F in Table 2) which define the spatial extent of our analysis and for which the future impacts of SLR and EF are assessed in Stage 3.

3.2. Stage 2 – spatially distributing assets and population and calculating costs

In the second stage our purpose is to collect social and economic data at different aggregate levels and to distribute it spatially. This allows us to generate estimates of the costs of SLR in social and economic terms, at a level of spatial disaggregation not generally available. To facilitate this we make use of a GIS buildings layer (described below) that identifies each structure and its use. Our use of GIS allows for the disaggregation of spatial units (for example total capital stock per region) into micro units (capital stock per m^2) and their re-aggregation into discrete units such as buildings, yielding total capital stock per building. In this way, we use GIS as a method for re-combining data in contrast to its more frequent use as a tool for visualization. Given a buildings' aerial footprint and height we calculate total floor space. This enables us to estimate the value of each residential building (using residential house prices per m^2), and the value of non-residential (industrial, commercial and office) buildings. We also estimate the value of industrial equipment and machinery which is done by proportionate spatial re-distribution of national capital stock.

Table 2
Data sources used in the study: each data set is categorized as a tabular or spatial input or output. It is identified by a numeral depicting the stage in which it is used in the analysis (row) and a letter by which it is referred in the text (column).

<table>
<tr><th colspan="2">Stage</th><th colspan="11">Inputs</th><th colspan="2">Outputs</th></tr>
<tr><td rowspan="4">1</td><td rowspan="2">Data-set</td><td colspan="6">Tabular</td><td colspan="5">Spatial</td><td colspan="2">Spatial</td></tr>
<tr><td colspan="3">A</td><td colspan="3">B</td><td colspan="2">C</td><td colspan="3">D</td><td>E</td><td>F</td></tr>
<tr><td>Name</td><td colspan="3">**SLR scenarios**</td><td colspan="3">**Extreme Flooding (EF) scenarios**</td><td colspan="2">**Elevation contour layer**</td><td colspan="3">**Shoreline**</td><td>**Interpolated raster DEM**</td><td>**Inundation Maps**</td></tr>
<tr><td>Description</td><td colspan="3">Since there are large differences in 21st century SLR projections (Table 1 a) a range of scenarios from 0 to 2 m in increments of 0.5 m are considered</td><td colspan="3">Return period of extreme tides and storm events based on wave measurements offshore (Golik and Rosen 1999) (Table 1 b). Magnitude of Tsunami waves from Salamon et al. (2007) (Table 1 c)</td><td colspan="2">Topographic contour layer with an accuracy of ±2 m (Survey of Israel)</td><td colspan="3">Vector shoreline layer (Survey of Israel)</td><td>Interpolated using ArcGIS "Topo to Raster" interpolation, which is specifically designed for the creation of hydrologically correct DEMs</td><td>by 0.5 m increments</td></tr>
<tr><td rowspan="5">2</td><td rowspan="3">Data-set</td><td colspan="6" rowspan="2">Tabular</td><td colspan="5">Spatial</td><td colspan="2" rowspan="2">Spatial</td></tr>
<tr><td colspan="3"></td><td colspan="2">Boundaries</td></tr>
<tr><td>A</td><td>B</td><td>C</td><td>D</td><td>E</td><td>F</td><td>G</td><td>H</td><td>I</td><td>J</td><td>K</td><td>L</td><td>M</td></tr>
<tr><td>Name</td><td>**Residential building prices and size**</td><td>**Plant and machinery stock**</td><td>**Pop. Totals**</td><td>**Earnings**</td><td>**Occupation distribution**</td><td>**Road Price**</td><td>**Buildings layer**</td><td>**Landuse layer**</td><td>**Road layer**</td><td>**Regional boundaries layer**</td><td>**Statistical area boundaries layer**</td><td>**Processed building layer**</td><td>**Processed Road layer**</td></tr>
<tr><td>Description</td><td>Ministry of construction and housing monthly bulletin (May 2011). The prices were surveyed during April 2010 to March 2011 and are regionally averaged</td><td>Plant (Table 2 b.) and machinery (Table 2 c.) stocks in 2006 by 9 regions from Beenstock et al. (2011).</td><td>By statistical area(CBS Census of Population 2008)</td><td>Average monthly earnings per household and number of households By statistical area (CBS Census of Population 2008)</td><td>By statistical area</td><td>Value of road capital stock: CBS data prepared for Frish and Tsur (2010)</td><td>Buildings by use (residential, commercial, governmental, agricultural and industrial) and building height. Number of floors per building derived from building height.</td><td>Classification into three 3 general landuses:
*Open area
*Public
*Residential</td><td>Roads by type</td><td>Divides the country into 9 relatively homogeneous regions. Serves as basis of the calculation for residential house prices and vale of plant and machinery capital stock estimates.</td><td>Israel Central Bureaus of Statistics census area units. Serves as basis for spatial distribution of population, earnings, and inhabitants occupation.</td><td>containing building level :
* Res. House prices
*Plant stock *Machinery stock * Total Inhabitants * earnings distribution
*Occupation distribution</td><td>containing road prices by km</td></tr>
<tr><td rowspan="5">3</td><td rowspan="3">Data-set</td><td colspan="11">Spatial</td><td rowspan="2">Spatial</td><td rowspan="2">Tabular</td></tr>
<tr><td colspan="9"></td><td colspan="2">Boundaries</td></tr>
<tr><td colspan="3">A</td><td colspan="2">B</td><td colspan="2">C</td><td colspan="2">D</td><td colspan="2">E</td><td>F</td><td>G</td></tr>
<tr><td>Name</td><td colspan="3">**Inundation maps**</td><td colspan="2">**Processed Building layer**</td><td colspan="2">**Landuse layer**</td><td colspan="2">**Processed Road layer**</td><td colspan="2">**Municipal boundaries layer**</td><td>**Inundated assets and inhabitants +socio-economic attributes maps**</td><td>**Total Municipal level loses by scenario**</td></tr>
<tr><td>Description</td><td colspan="3">Created in stage 1 (Layer 1M)</td><td colspan="2">Created in stage 2</td><td colspan="2">Classifies the country into 3 general landuses: *Open area *Public *Residential</td><td colspan="2">Created in stage 2</td><td colspan="2">Allows extraction of results on the municipal level</td><td>Output inundation maps including assets and population calculations</td><td>Output summary tables including assets and population sums by municipality</td></tr>
</table>

We spatially distribute aggregated population counts, employment distribution and monthly earnings that are available at the statistical area level (the finest level of spatial resolution for spatial data made available by the Israel Central Bureau of Statistics CBS), into single residential buildings. The GIS buildings layer allows us to distribute inhabitants into buildings and to accurately distribute the value of building assets. In the absence of a detailed buildings layer, more spatially aggregate distributions of the same parameters (population, earnings, capital stock etc) can be estimated at a lower level of spatial resolution. The notation for creating the various spatial distributions appears in the Appendix.

In addition to population attributes and the costs of building assets we also estimate costs of SLR and EF in terms of damage to roads and land use. We use the relevant GIS layers coupled with detailed spatial CBS estimates on the capital stock value of roads to estimate these costs.

3.2.1. Data processing

- A polygonal building layer (2G in Table 2) containing land heights and roof heights of buildings is used to calculate the floor space in m^2 (the total area of a building multiplied by its number of floors) for each building.

Building height (H_B) is calculated as follows:

$$H_B = H_R - H_L$$

where H_R is the building roof height and H_L is the building land height (2G in Table 2).

The number of floors in residential buildings (F_R), is calculated by dividing building height by average floor height of 3.5 m:

$$F_R = \frac{H_B}{3.5}$$

In the case of non-residential buildings, the number of floors (F_N) is estimated as the building height divided by average floor height of 5 m:

$$F_N = \frac{H_B}{5}$$

Floor space for each building (S_B) is then calculated by multiplying the number of floors in each building by its polygon area representing roof space:

$$S_B = S_R \times F$$

where S_R is the building roof space (2G in Table 2) and F is the building number of floors.

- As previously mentioned, the GIS buildings layer with building type classification (2G in Table 2) serves as the basis for the calculation of residential building value, non-residential building and equipment value. This layer also allows for the spatial distribution of aggregated population counts (2C in Table 2) into building level inhabitant totals. Given the existence of these spatial estimates, the distribution of aggregate average monthly earnings (2D in Table 2) and occupational distribution (2E in Table 2) into a building level distribution is easily implemented.

In order to calculate residential building value, non-residential building and equipment value the building layer is overlaid by the regional boundary layer (2J in Table 2) in order to attach regional attributes to each building.

To create estimates of residential building value we use average house prices for nine broad aggregated regions (2A in Table 2). The rationale for this regional classification has been presented elsewhere (Beenstock and Felsenstein, 2007).

The average regional price per m^2 *for residential buildings* (P_{RR}) is calculated as follows:

$$P_{RR} = \frac{V_{RR}}{H_{RR}}$$

where V_{RR} is the regional average house prices (2A in Table 2) and H_{RR} is the regional average household size (2A in Table 2).

The value of each residential building (P_{BR}) is calculated as follows:

$$P_{BR} = P_{RR} \times S_{BR}$$

where S_{BR} is the residential building floor space.

Non-residential building values (per m^2*) by region* (P_{RN}) is calculated as follows:

$$P_{RN} = \frac{V_{RN}}{S_{RN}}$$

where S_{RN} is the total regional non-residential floor space and V_{RN} is the total regional non-residential building stock (2B in Table 2).

The non-residential building value per m^2 for each region is multiplied by the floor space of each non-residential building to produce non-residential building values (P_{BN}):

$$P_{BN} = P_{RN} \times S_{BN}$$

where S_{BN} is the non-residential building floor space.

Regional non-residential stock estimates have been calculated by Beenstock et al. (2011) for the same nine aggregate regions.

Equipment value (per m^2*) by region* (P_{RE}) is calculated as follows:

$$P_{RE} = \frac{V_{RE}}{S_{RN}}$$

where V_{RE} is the total regional non-residential equipment stock (2B in Table 2).

The equipment stock per m^2 for each region is multiplied by the floor space of each non-residential building to produce equipment stock totals by building (P_{BE}):

$$P_{BE} = P_{RE} \times S_{BN}$$

where the source for regional estimates of regional equipment and machinery stock is Beenstock et al. (2011) as above.

The average number of inhabitants per m^2 for residential floor space in a statistical area (I_{SR}) is calculated as follows:

$$I_{SR} = \frac{I_S}{S_{SR}}$$

where S_{SR} is the total statistical area residential floor space and I_S is the total population per statistical area (2C in Table 2).

Population counts per building (I_B) are then calculated as follows:

$$I_B = I_{SR} \times S_{BR}$$

Total earnings per building is calculated as follows:

We calculate the total monthly earnings in a statistical area (M_S):

$$M_S = M_{SI} \times H_S$$

where M_{SI} is the average earnings per household per month in a statistical area (2D in Table 2) and H_S is the total number of households in a statistical area (2D in Table 2).

The earnings per m^2 of residential building in a statistical area (M_{SM}) is calculated as follows:

$$M_{SM} = \frac{M_S}{S_{SR}}$$

This figure is then used to produce the total earnings per building per month (M_B):

$$M_B = M_{SM} \times S_{BR}$$

The distribution of inhabitants' occupations (2E in Table 2) per statistical area is multiplied by the number of residents in each building to calculate the total number of inhabitants in each occupational category per building (I_O).

$$I_O = O_S \times I_B$$

where O_S is the % of inhabitants employed in an occupational category (2E in Table 2) and I_B is the population counts per building.

The value of roads infrastructure uses specially prepared CBS data on roads capital stock by natural regions (Frish and Tsur, 2010) (2F in Table 2). The relevant natural regions corresponding to our study areas are identified. For each area we isolate the amount of road infrastructure (2I in Table 2) likely to be inundated under our scenarios and convert this into a monetized value.

- A land use layer (2H in Table 2) classifying the coastal zone into three principal land uses: open area, public and residential is used to characterize areas under threat. This layer covers the entire area as opposed to the building layer which only provides classification for actual built structures.

3.3. Stage 3 – assessing the level of 'local exposure'

In the final stage of data processing the inundation maps created in Stage 1 and the assets, calculated costs, distributed population and socio-economic attributes processed in Stage 2, are merged. The result is a comprehensive analysis of local exposure given the different SLR and EF scenarios.

3.3.1. Data processing

- The inundation layers produced in stage 1 (3A in Table 2) are overlaid with the buildings (3B in Table 2), land use (3C in Table 2), and roads (3D in Table 2) layers processed in stage 2. This results in layers of inundated assets, their costs and population socio-economic attributes profile (appended to the building layer).
- The inundated assets and inhabitants layers (3A–D in Table 2) are overlaid by a municipal boundary layer (3E in Table 2) in order to calculate municipal totals.
- Summary statistics are calculated for each inundation scenario producing total costs per municipality (3G in Table 2).

4. Results

We investigate the costs of SLR and EF under three main headings. Initially, we look at the land area and land use exposed to climatic change and extreme events and attempt to estimate the different levels of inundation and flooding under varying natural hazards scenarios (Tables 3 and 4). We then progress to estimating the costs in terms of capital stock at risk. This encompasses the value of residential and non-residential structures threatened by

Table 3
Land area and land use exposed to SLR and EF: national, Tel Aviv and Haifa totals.

	SLR permanent inundation	Municipality	Total inundated area (thousand m²)	% of total area[a]	Inundated land use						
					Residential (thousand m²)	% Residential[b]	Public use (thousand m²)[c]	% Public use	Open area (thousand m²)	% Open area	Other (thousand m²)
SLR permanent inundation	0.5 m	Haifa	4164	6.44	456	1.51	2295	14.01	1118	6.63	295
		Tel Aviv	822	1.50	198	0.64	89	0.80	500	4.00	0
		National	19,295	0.09	1010	0.09	2428	1.08	9787	0.05	6070
	1 m	Haifa	4593	7.11	584	1.93	2427	14.82	1264	7.50	317
		Tel Aviv	1040	1.90	289	0.93	165	1.49	547	4.38	0
		National	23,421	0.11	1569	0.14	2749	1.22	12,826	0.06	6277
	2 m	Haifa	11,355	17.57	918	3.04	5821	35.55	3862	22.91	754
		Tel Aviv	1622	2.96	572	1.84	348	3.14	659	5.28	43
		National	41,735	0.19	3190	0.28	6989	3.10	6989	0.03	7630
1:50 yr 1 m high tide	0.5 m	Haifa	6334	9.80	319	1.05	3258	19.90	2344	13.90	413
		Tel Aviv	432	0.79	187	0.60	151	1.36	88	0.70	41
		National	16,568	0.08	1406	0.13	4047	1.79	9988	0.05	1126
	1 m	Haifa	6762	10.47	334	1.10	3394	20.72	2598	15.41	437
		Tel Aviv	582	1.06	283	0.91	182	1.65	112	0.90	43
		National	18,314	0.08	1620	0.14	4240	1.88	11,101	0.05	1353
	2 m	Haifa	1325	2.05	285	0.94	515	3.15	459	2.72	65
		Tel Aviv	628	1.15	339	1.09	207	1.87	81	0.65	2
		National	11,606	0.05	1972	0.18	1124	0.50	24,441	0.12	1007
4 m Tsunami	0.5 m	Haifa	10,609	16.42	1366	4.52	4907	29.97	3694	21.91	642
		Tel Aviv	3090	5.64	1574	5.07	944	8.53	557	4.46	50
		National	61,771	0.28	7810	0.70	8120	3.60	41,346	0.20	4494
	1 m	Haifa	12,080	18.70	1991	6.59	5667	34.60	3738	22.17	684
		Tel Aviv	4740	8.66	2136	6.88	1271	11.48	1321	10.59	50
		National	100,118	0.46	11,461	1.02	11,303	5.01	71,515	0.35	5840
	2 m	Haifa	7506	11.62	2630	8.70	3254	19.87	1316	7.80	306
		Tel Aviv	628	1.15	339	1.09	207	1.87	81	0.65	2
		National	116,323	0.53	15,697	1.40	11,072	4.91	100,493	0.49	5999
LECZ	10 m	Haifa	26,084	40.37	7292	24.12	12,042	73.54	5651	33.51	1099
		Tel Aviv	15,788	28.83	8108	26.13	3434	31.02	4180	33.48	67
		National	291,249	1.33	47,044	4.20	30,889	13.70	197,172	0.97	16,144

Note: Shaded cells represent values for the whole floodplain from the shoreline to the relevant elevation increment. Values for EF (non-shaded cells) include only the floodplain above the permanently inundated SLR area. For example, given SLR of 0.5, a 1 m high tide in Haifa would flood an area of 6334 m² additional to the estimated 4164 m² of permanent inundation resulting from SLR of 0.5 m.

[a] Percentage of total urban or national area.

[b] Percentage of total urban or national residential area.

[c] 'Public use' includes commercial, industrial, and governmental land use.

SLR and EF, the equipment and machinery that is embodied in the latter and the infrastructure at risk as represented by road capital stock (Tables 5 and 6). Finally, we examine the population at risk that inhabits the structures exposed to natural hazards, including their earnings levels and occupational structure (Tables 7 and 8).

In each case we begin by observing the extent of the SLR floodplain for scenarios of 0.5 m, 1 m and 2 m SLR increases (Fig. 3). This is considered permanent inundation and is estimated for the two largest coastal cities in Israel, Haifa and Tel Aviv and also nationally. We then progress to two EF scenarios: a 1:50 year high tide of 1 m and a 4 m Tsunami. The effect of the EF events is considered additional to the SLR. Therefore the data in the (non-shaded) cells in the relevant tables relates to the floodplain *additional to the permanently inundated SLR floodplain* (the shaded cells). The upshot of this is that as the scenario become more extreme, this is not necessarily translated into ever-increasing areas of inundation. This is due to the fact that natural topography plays a key role in determining the spatial extent of potential inundation. It could be that given the level of natural elevation, a more extreme natural event, for example a 4 m Tsunami riding on a permanent level of inundation of 2 m, produces less additional damage than a similar Tsunami that accompanies SLR of 1 m. We also calculate estimates for the whole low elevation coastal zone (LECZ) i.e. any area below 10 m elevation which is hydrologically linked to the sea bearing in mind that this area even if not flooded in the given scenarios is highly vulnerable to coastal perturbations.

Finally, our estimates are presented for the whole Northern Coastal Plain that runs north from the city of Haifa to the Lebanese border. This area contains small coastal towns and rural communities and allows us to illustrate the flexibility of the estimation method for different spatial scales and municipal jurisdictions.

4.1. *Land use and land area*

In comparing Haifa and Tel Aviv it becomes obvious that the former is under greater potential risk to SLR and EF than the latter, both in proportional and absolute terms (Table 3). This applies to both public land use and open areas. In terms of residential land use this is also the case but to a lesser degree. The relative share of residential inundation is higher in Tel Aviv than Haifa but of course the absolute levels of exposure to flooding are greater in the latter. Nationally, the inundation potential is negligible except for the case of public land use.

For smaller communities, the results are more striking. Small cities like Acre, Nahariya and Nesher can expect to have up to 60 percent of their public use areas and nearly 30 percent of their residential land uses inundated in the more extreme SLR and EF scenarios (Table 4). The small working class local authority of Nesher for example would seem susceptible to a 1:50 1 m high tide (irrespective of base SLR level). Similarly the historic town of Acre would be particularly affected by a 4 m Tsunami. However these extreme events have differential land use implications. In

Table 4
Land area and land use exposed to SLR and EF: municipalities comprising the northern coastal strip.

	SLR permanent inundation	Municipality	Total inundated area (thousand m^2)	% of total area	Inundated land use						
					Residential (thousand m^2)	% Residential	Public use (thousand m^2)	% Public use	Open area (thousand m^2)	% Open area	Other (thousand m^2)
SLR permanent inundation	0.5 m	Nesher									
		Acre	401	2.95	131	3.08	28	0.96	229	3.62	14
		Nahariya	197	1.79	25	0.43	1	0.07	168	5.41	2
		Kiryat Yam	99	2.17	0	0.00	0	0.00	93	6.52	6
		Matte Asher	626	0.29	69	0.49	5	0.16	542	0.28	10
		Zevulun									
	1 m	Nesher									
		Acre	732	5.38	251	5.91	96	3.33	369	5.85	15
		Nahariya	294	2.66	50	0.86	16	0.79	225	7.24	2
		Kiryat Yam	164	3.60	0	0.01	0	0.00	158	11.06	7
		Matte Asher	1041	0.49	204	1.44	15	0.52	810	0.41	12
		Zevulun									
	2 m	Nesher	2118	16.44	191	5.75	423	31.48	1262	16.08	242
		Acre	1546	11.36	580	13.63	209	7.24	738	11.70	19
		Nahariya	493	4.46	110	1.88	66	3.25	313	10.05	4
		Kiryat Yam	295	6.46	2	0.08	0	0.01	286	20.08	7
		Matte Asher	1871	0.87	409	2.88	32	1.08	1410	0.72	22
		Zevulun	1835	2.97	24	0.46	0	0.00	1807	3.28	4
1:50 yr 1 m high tide	0.5 m	Nesher	2051	15.92	187	5.63	413	30.78	1219	15.53	231
		Acre	694	5.10	265	6.23	122	4.24	304	4.81	3
		Nahariya	198	1.79	50	0.84	36	1.78	111	3.57	1
		Kiryat Yam	132	2.90	1	0.03	0	0.00	131	9.19	1
		Matte Asher	819	0.38	235	1.66	14	0.49	565	0.29	5
		Zevulun	898	1.45	23	0.44	0	0.00	872	1.58	3
	1 m	Nesher	2118	16.44	191	5.75	423	31.48	1262	16.08	242
		Acre	814	5.98	329	7.73	113	3.90	369	5.84	4
		Nahariya	199	1.80	60	1.02	50	2.46	87	2.81	2
		Kiryat Yam	130	2.86	2	0.07	0	0.01	128	9.01	0
		Matte Asher	831	0.39	205	1.45	16	0.56	600	0.31	10
		Zevulun	1835	2.97	24	0.46	0	0.00	1807	3.28	4
	2 m	Nesher	141	1.09	12	0.37	27	2.01	89	1.13	13
		Acre	838	6.16	294	6.91	138	4.79	402	6.38	3
		Nahariya	206	1.87	110	1.87	48	2.36	48	1.54	0
		Kiryat Yam	134	2.94	18	0.68	3	0.74	113	7.91	0
		Matte Asher	1639	0.76	479	3.38	77	2.62	1026	0.52	58
		Zevulun	799	1.29	3	0.06	0	0.00	795	1.44	1
4 m Tsunami	0.5 m	Nesher	2523	19.59	245	7.39	497	37.03	1512	19.27	269
		Acre	4214	30.98	1066	25.05	839	29.08	2244	35.58	65
		Nahariya	876	7.93	415	7.05	188	9.26	271	8.73	2
		Kiryat Yam	572	12.54	129	4.70	25	6.27	418	29.36	1
		Matte Asher	7152	3.33	1128	7.95	170	5.80	5656	2.89	198
		Zevulun	4340	7.02	41	0.78	4	0.88	4286	7.78	9
	1 m	Nesher	3146	24.43	411	12.39	618	46.01	1783	22.72	334
		Acre	5856	43.05	1258	29.55	1626	56.38	2866	45.45	105
		Nahariya	1167	10.57	633	10.75	253	12.45	280	9.01	2
		Kiryat Yam	899	19.69	311	11.36	54	13.43	534	37.53	0
		Matte Asher	15,004	6.99	1453	10.25	321	10.90	12,921	6.60	309
		Zevulun	10,996	17.79	210	3.99	22	5.02	10,591	19.22	173
	2 m	Nesher	1439	11.17	290	8.76	331	24.61	720	9.18	98
		Acre	6378	46.89	1220	28.67	1930	66.91	3109	49.29	118
		Nahariya	1780	16.11	1131	19.22	367	18.04	283	9.10	0
		Kiryat Yam	1344	29.42	621	22.70	99	24.71	624	43.81	0
		Matte Asher	19,386	9.04	1422	10.03	623	21.20	16,885	8.63	455
		Zevulun	12,238	19.80	552	10.49	34	7.84	11,362	20.61	290
LECZ (10 m)		Nesher	4189	32.52	694	20.92	1029	76.60	2112	26.91	354
		Acre	10,458	76.88	2959	69.51	2670	92.56	4681	74.22	148
		Nahariya	5636	51.01	3551	60.36	1225	60.28	851	27.39	9
		Kiryat Yam	4361	95.51	2580	94.28	384	96.28	1390	97.64	7
		Matte Asher	38,467	17.93	2040	14.39	1375	46.77	34,301	17.52	751
		Zevulun	20,975	33.94	1253	23.81	46	10.54	19,367	35.14	309

the case of Nesher, flooding is felt mainly with respect to Public Use land use (i.e. industrial and commercial land use). In the case of a tsunami hitting Acre, assuming more moderate levels of SLR means residential and non-residential land use flooding in equal proportions. However if the tsunami rides on SLR higher than 0.5, this has disproportionate impacts on the flooding of Public Use areas. When looking at the LECZ, other small communities seem exposed to climate related hazards. Foremost amongst these in the coastal municipality of Kiryat Yam which under the most extreme scenarios is forecast to experience over 90 percent flooding of all its land uses. The coastal town of Nahariya is relatively immune to all SLR and EF scenarios However 60 percent of both residential and public use land uses in the town are located below 10 m in the LECZ.

Table 5
Capital stock (residential, non-residential, machinery and infrastructure) exposed to SLR and EF: Haifa, Tel Aviv and national totals.

	SLR permanent inundation	Municipality	Total built area (thousand m^2)	Total floor space (thousand m^2)	Floor space by building type (thousand m^2)		Total residential building value (thousand NIS)	Total non-residential building value (thousand NIS)	Total equipment value (thousand NIS)	Total road value (thousand NIS)
					Residential	Non-residential				
SLR permanent inundation	0.5 m	Haifa	284	621	23	597	154,064	1,726,884	1,630,078	67,415
		Tel Aviv	39	182	45	137	727,612	425,577	401,720	10,471
		National	380	1392	154	1238	1,346,896	3,173,425	2,995,527	81,078
	1 m	Haifa	317	718	92	626	607,444	1,810,479	1,708,987	72,091
		Tel Aviv	65	249	89	160	1,460,681	495,229	467,467	15,708
		National	497	1703	347	1357	2,887,228	3,396,523	3,206,119	97,303
	2 m	Haifa	710	1531	158	1372	1,051,729	3,963,117	3,740,950	176,637
		Tel Aviv	124	315	244	459	2,298,092	541,263	510,921	33,594
		National	1234	3676	847	2829	7,382,886	7,732,898	7,299,404	270,099
1:50 yr 1 m high tide	0.5 m	Haifa	387	815	92	724	609,797	2,089,664	1,972,520	98,712
		Tel Aviv	50	133	96	37	1,570,480	115,686	109,201	10,670
		National	678	1502	404	1099	3,389,766	3,345,475	3,157,933	155,883
	1 m	Haifa	393	812	67	746	444,285	2,152,637	2,031,964	104,547
		Tel Aviv	59	454	155	299	2,526,560	928,163	876,132	17,886
		National	737	1972	500	1472	4,495,658	4,336,375	4,093,285	172,797
	2 m	Haifa	94	235	42	193	275,713	558,402	527,099	23,040
		Tel Aviv	95	446	244	202	3,985,658	626,109	591,010	17,953
		National	478	1252	591	661	5,713,830	1,608,853	1,518,664	62,243
4 m Tsunami	0.5 m	Haifa	664	1505	281	1225	1,861,968	3,535,607	3,337,406	171,804
		Tel Aviv	445	2111	1261	850	20,587,294	2,637,124	2,489,291	82,667
		National	2289	6484	2717	3767	28,649,010	9,523,958	8,990,060	388,337
	1 m	Haifa	835	1979	332	1648	2,202,731	4,758,043	4,491,314	215,760
		Tel Aviv	648	2907	1909	998	31,167,058	3,095,947	2,922,393	113,453
		National	3557	9519	4031	5489	43,127,024	13,780,488	13,007,975	396,195
	2 m	Haifa	691	1722	449	1273	2,978,377	3,676,034	3,469,961	245,057
		Tel Aviv	840	3786	2445	953	41,602,672	3,839,141	3,623,924	129,625
		National	4602	11,663	5643	6020	58,320,007	14,472,751	13,661,431	626,045
LECZ	10 m	Haifa	2536	5960	1777	4183	11,793,591	12,081,079	11,403,833	571,043
		Tel Aviv	2428	11,265	8037	3228	131,221,199	10,012,522	9,451,236	355,072
		National	13,877	38,956	21,203	17,753	211,460,355	46,178,273	43,589,592	1,985,153

4.2. Impact on capital stock

We estimate the extent of SLR inundation and periodic flooding damage to capital stock. This relates to residential, non-residential, equipment/machinery and road stock. The unit of analysis is the micro-level of the individual building and not the broad land uses, as in the previous section. We calculate total built area (i.e. roof space area) likely to be affected under the different scenarios and then expand this figure to include total floor space incorporating the total area of multi-storey buildings. While we are aware that periodical flooding generally results in ground floor inundation of multi-storey buildings, we assume that the extreme conditions of our scenarios will result in very limited accessibility to the structures and in severe damage to vital building infrastructure (water, sewerage, electricity). This will effectively render the other floors inoperable in the short-term.

Our results show that overall, total built area is inundated to a greater extent in Haifa than in Tel Aviv (Table 5). However when total floor space is counted, the latter overtakes the former in extreme inundation scenarios, for example in the case of a 1 m high tide that occurs under conditions of 2 m SLR. Again, in the case of the LECZ, despite the fact that total built area under threat is of similar magnitude in both Haifa and Tel Aviv, given the predominance of multi-storey structures in the latter, total floor space rendered vulnerable is nearly 4 times greater. When examining the impacts by type of building, a general pattern emerges of more damage to non-residential structures for more moderate scenarios in both cities and more residential damage in Tel Aviv once the scenarios become more extreme and more high rise buildings are affected. In the entire LECZ, the picture is one of predominant risk to industrial buildings in Haifa and to residential buildings in Tel Aviv.

Quantifying this in monetary terms we get a similar picture. Costs to Haifa in terms of residential damage are negligible at less extreme scenarios but are non-negligible with respect to damage to industrial and commercial structures. Tel Aviv displays the mirror image of this pattern. For both large cities, equipment costs roughly follow those of non-residential structures. In contrast, the value of capital stock embodied in road infrastructure is consistently higher for Haifa than for Tel Aviv across all scenarios, although the gap does decrease the more extensive the magnitude of the flooding.

In the case of the small cities along the Northern coastal strip, we observe minimal damage when SLR is up to 1 m and more extensive damage in Nesher and Acre above this level (Table 4). These same two communities are likely to suffer from additional flood damage through high tides up to 1 m (beyond the SLR inundation) but with negligible damage beyond that. A 4 m Tsunami is expected to engulf a floodplain beyond the SLR inundated areas adding the small municipalities of Kiryat Yam and Nesher to the areas at risk. It should be noted that Matte Asher and Zevulun are rural regional authorities and by nature have more limited built up areas and structures at risk. However the LECZ incorporates these areas as well. Reflecting their different economic functions, the expected flooding has differential impacts on residential and non-residential structures. For all scenarios a common pattern emerges: Nesher is likely to suffer more damage to industrial floor space than residential. This reflects the character of the municipality and its topography whereby commercial and industrial activity is concentrated in the low-lying

Table 6
Capital stock (residential, non-residential, machinery and infrastructure) exposed to SLR and EF: municipalities comprising the northern coastal strip.

	SLR permanent inundation	Municipality	Total built area (thousand m^2)	Total floor space (thousand m^2)	Floor space by building type (thousand m^2)		Total residential building value (thousand NIS)	Total non-residential building value (thousand NIS)	Total equipment value (thousand NIS)	Total road value (thousand NIS)
					Residential	Non-residential				
SLR permanent inundation	0.5 m	Nesher								
		Acre	9	82	47	36	198,681	44,106	41,634	1327
		Nahariya	1	5	1	4	3027	4870	4597	645
		Kiryat Yam								
		Matte Asher	9	21	19	2	81,688	2210	2086	800
		Zevulun								
	1 m	Nesher								
		Acre	29	136	91	45	387,778	55,232	52,136	2627
		Nahariya	3	6	1	5	5510	5998	5662	1331
		Kiryat Yam								
		Matte Asher	27	47	44	3	187,227	3623	3420	1975
		Zevulun								
	2 m	Nesher	116	218	>0	218	852	1,008,241	951,720	27,291
		Acre	107	385	280	104	1,195,952	128,775	121,556	7330
		Nahariya	8	19	12	7	51,557	8373	7904	2761
		Kiryat Yam	>0	>0	>0	>0	450	1661	1568	580
		Matte Asher	61	162	69	93	296,407	114,405	107,992	4768
		Zevulun	>0	>0		>0		875	826	5833
1:50 yr 1 m high tide	0.5 m	Nesher	115	216	>0	216	852	997,554	941,633	27,091
		Acre	50	179	131	48	557,376	59,246	55,925	3320
		Nahariya	3	6	3	3	14,822	3109	2934	1391
		Kiryat Yam	>0	>0	>0	>0	>0	596	563	311
		Matte Asher	32	43	39	4	167,238	5131	4844	2813
		Zevulun	>0	>0		>0		778	734	5386
	1 m	Nesher	116	218	>0	218	852	1,008,241	951,720	27,291
		Acre	78	249	189	60	808,174	73,543	69,420	4703
		Nahariya	5	13	11	2	46,048	2376	2242	1430
		Kiryat Yam	0	0	0	0	450	1661	1568	580
		Matte Asher	34	115	26	90	109,180	110,782	104,572	2793
		Zevulun	>0	>0		>0		875	826	5833
	2 m	Nesher	2	1	0	1	0	6862	6478	1063
		Acre	90	239	136	102	581,515	126,438	119,350	3973
		Nahariya	16	29	25	4	108,206	4345	4101	1610
		Kiryat Yam	1	12	10	2	59,591	7518	7096	1800
		Matte Asher	111	132	92	39	393,862	48,384	45,671	3607
		Zevulun	>0	>0		>0		146	138	422
4 m Tsunami	0.5 m	Nesher	123	229	0	228	2300	1,056,818	997,574	30,864
		Acre	344	994	518	476	2,207,290	587,230	554,310	16,156
		Nahariya	68	174	126	48	537,572	58,679	55,390	7438
		Kiryat Yam	24	113	81	32	485,777	148,645	140,312	7590
		Matte Asher	239	480	200	280	851,113	345,769	326,386	12,922
		Zevulun	1	1	1	>0	3898	1388	1310	7435
	1 m	Nesher	144	298	1	298	3539	1,378,162	1,300,905	41,651
		Acre	533	1470	638	833	2,719,358	1,027,299	969,710	22,749
		Nahariya	131	371	255	116	1,087,552	142,544	134,553	9939
		Kiryat Yam	55	213	162	50	971,830	232,984	219,923	18,675
		Matte Asher	380	697	248	448	1,059,652	552,858	521,866	20,860
		Zevulun	65	79	10	68	67,476	197,393	186,328	36,781
	2 m	Nesher	59	139	4	135	25,226	625,388	590,330	19,819
		Acre	577	1412	547	865	2,332,533	1,066,987	1,007,173	24,040
		Nahariya	300	734	556	178	2,369,815	219,830	207,506	15,355
		Kiryat Yam	137	412	315	97	1,886,270	446,902	421,850	34,127
		Matte Asher	531	962	250	713	1,065,407	879,038	829,760	24,016
		Zevulun	119	151	55	97	363,543	279,181	263,530	39,917
LECZ (10 m)	10 m	Nesher	232	569	21	548	124,356	2,537,264	2,395,029	55,658
		Acre	1019	2623	1429	1194	6,094,701	1,472,750	1,390,190	50,046
		Nahariya	868	2189	1665	524	7,102,855	646,176	609,953	39,743
		Kiryat Yam	532	1537	1265	272	7,570,550	1,259,029	1,188,450	129,759
		Matte Asher	860	1490	403	1087	1,717,130	1,341,175	1,265,991	43,216
		Zevulun	251	368	133	235	880,880	678,985	640,922	70,367

Table 7
Population at risk due to SLR and EF and their socio-economic profile: Haifa, Tel Aviv and national totals.

	SLR permanent inundation	Municipalities	Total inhabitants	Inhabitants %	Monthly earnings (thousand NIS)	Inhabitants occupation distribution			
						Academic/ management	Administration/ sales & services	Agriculture/ Industry/ Construction	Unknown
SLR permanent inundation	0.5 m	Haifa	165	0.06	793	17	15	8	126
		Tel Aviv	456	0.11	3268	74	41	22	319
		National	1989	0.03	8940	153	150	208	1479
	1 m	Haifa	398	0.15	2014	42	38	20	299
		Tel Aviv	734	0.18	5112	113	62	48	511
		National	4210	0.06	19,493	320	360	394	3136
	2 m	Haifa	1268	0.48	6011	124	113	59	972
		Tel Aviv	2489	0.62	18,907	429	231	135	1694
		National	13,276	0.18	62,233	987	1248	1119	9922
1:50 yr 1 m high tide	0.5 m	Haifa	722	0.27	3257	200	196	95	231
		Tel Aviv	787	0.20	5260	301	225	128	133
		National	5966	0.08	26,966	1235	1648	1684	1399
	1 m	Haifa	870	0.33	3997	246	240	115	269
		Tel Aviv	1754	0.43	13,795	764	568	198	224
		National	9066	0.12	42,740	1903	2571	2447	2145
	2 m	Haifa	690	0.26	3766	233	225	107	125
		Tel Aviv	3193	0.79	26,253	1408	1003	341	440
		National	10,511	0.14	53,219	2420	2788	2392	2911
4 m Tsunami	0.5 m	Haifa	3284	1.24	17,056	1036	1035	507	706
		Tel Aviv	16,385	4.06	145,644	7800	4904	1399	2283
		National	45,983	0.63	263,272	12,614	12,963	9643	10,763
	1 m	Haifa	5355	2.02	26,710	1419	1816	1089	1032
		Tel Aviv	25,973	6.44	236,800	12,289	7687	2089	3908
		National	70,524	0.96	420,744	19,849	20,600	13,962	16,114
	2 m	Haifa	8373	3.16	38,383	1834	2943	2175	1420
		Tel Aviv	34,808	8.63	315,633	16,447	10,351	2647	5362
		National	101,089	1.37	614,830	29,180	30,498	18,922	22,490
LECZ		Haifa	31,960	12.07	169,015	2828	4636	2171	22,326
		Tel Aviv	113,942	28.25	961,519	23,721	12,328	3143	74,751
		National	382,327	5.20	2,297,943	44,653	49,087	21,513	267,075

areas and residential building on the hillside. Acre and Nahariya are expected to suffer damage to industrial and residential structures in roughly equal measures while most of the flood damage in Kiryat Yam is likely to affect residential buildings.

Under all scenarios, the value of damage to residential structures generally exceeds that to non-residential structures buy a factor of 2 or more. The one exception is in the Matteh Asher regional council area where the damage estimations are very volatile and change under the different scenarios and with different base inundation levels. In some cases (for example Acre), it would seem that the combination of SLR with an EF event evokes nearly the same monetary level of damage as that covered by the entire LECZ.

The value of damage to road stock is a function of the concentration of road infrastructure in the flooded area, as there is very little variance in construction costs along the northern coastal strip. The value of road stock affected under the different scenarios remains roughly uniform across the different communities. Large differences only begin to emerge under the most extreme scenarios such as a 4 m tsunami in addition to 2 m SLR.

4.3. Population at risk and their socio-economic profile

As described above, we allocate population to the structures likely to be exposed to SLR and EF. On this basis, we calculate displaced inhabitants. Knowing something about their earnings levels and occupations we extend the analysis to include a rough indication of the loss of earnings due to flooding. It should be noted that this is far from a definitive measure given that we are counting earnings and jobs at place of residence and not place of work (where they are generated). However it is reasonable to suggest that a worker whose home has been flooded represents a temporary loss of earnings and homeless workers are hardly likely to be productive at their place of work.

Table 5 shows that displaceed populations in Tel Aviv exceed those in Haifa, for all scenarios. For the SLR inundation scenario and for flooding under high tide conditions, these estimates are moderate. They tend to increase dramatically under the Tsunami scenario. Translating this into earnings terms shows that there is a further disproportionate jump in lost monthly earnings in the case of Tel Aviv indicating the relative concentration of higher earnings in the city when compared with Haifa. For example, in the LECZ, each inhabitant in Haifa is ‘worth’ 5300 shekels in lost earnings in contrast to 8400 shekels in the case of Tel Aviv inhabitants. Similarly and reflecting these earnings differences, the distribution of jobs ‘lost’ (strictly speaking the occupational distribution of the those displaced through SLR and EF) shows a difference between Haifa and Tel Aviv. Extreme events in the former will elicit a proportionately larger loss in lower grade administrative sales and service jobs in the former. In the latter, workers in academic and management occupations are more likely to be displaced.

Roughly similar patterns on a smaller scale are expected along the small towns of the northern coastal strip. With the exception of Acre, the moderate flooding scenarios have very limited impact in terms of population at risk (Table 5). Only with the advent of a 4 m Tsunami do other municipalities begin to experience significant numbers of displaced inhabitants. The monthly earnings impact is again a reflection of the socio-economic composition of the communities at risk. In the LECZ for example, a displaced Nahariya resident represents an earning loss of 5800 shekels while

Table 8
Population at risk due to SLR and EF and their socio-economic profile: municipalities comprising the northern coastal strip.

	SLR permanent inundation	Municipality	Total inhabitants	Inhabitants %	Monthly earnings (thousand NIS)	Inhabitants occupation distribution			
						Academic/ management	Administration/ sales & services	Agriculture/ Industry/ Construction	Unknown
SLR permanent inundation	0.5 m	Nesher							
		Acre	1046	2.28	2497	102	236	450	258
		Nahariya	15	0.03	86	4	5	2	4
		Kiryat Yam							
		Matte Asher	184	0.84	1588	77	35		73
		Zevulun							
	1 m	Nesher							
		Acre	2300	5.01	6624	278	574	937	510
		Nahariya	26	0.05	155	7	8	4	7
		Kiryat Yam							
		Matte Asher	424	1.93	3780	178	79		166
		Zevulun							
	2 m	Nesher	4	0.02	17	1	2	1	1
		Acre	7650	16.67	26,829	953	2159	2933	1605
		Nahariya	233	0.45	1431	68	71	37	57
		Kiryat Yam	3	0.01	10		1	1	1
		Matte Asher	669	3.04	5825	276	127	1	264
		Zevulun							
1:50 yr 1 m high tide	0.5 m	Nesher	4	0.02	17	1	2	1	1
		Acre	3652	7.96	12,973	490	1051	1378	733
		Nahariya	67	0.13	403	21	20	9	17
		Kiryat Yam							
		Matte Asher	380	1.73	3486	161	70	1	148
		Zevulun							
	1 m	Nesher	4	0.02	17	1	2	1	1
		Acre	5350	11.66	20,205	674	1585	1996	1095
		Nahariya	207	0.40	1276	61	63	33	50
		Kiryat Yam	3	0.01	10	0	1	1	1
		Matte Asher	245	1.11	2046	98	48	1	98
		Zevulun							
	2 m	Nesher							
		Acre	4115	8.97	15,021	450	1157	1605	904
		Nahariya	462	0.90	2945	129	150	63	120
		Kiryat Yam	417	1.10	1283	23	123	164	107
		Matte Asher	1043	4.74	1276	64	44	1	934
		Zevulun							
4 m Tsunami	0.5 m	Nesher	6	0.02	6	1	2	2	1
		Acre	15,565	33.91	44,126	1913	4543	5708	3401
		Nahariya	2361	4.60	14,157	652	750	345	615
		Kiryat Yam	3032	8.02	10,444	268	892	1115	756
		Matte Asher	2092	9.51	5974	370	242	7	1473
		Zevulun	5	0.04	13	1	1	1	3
	1 m	Nesher	6	0.02	6	1	2	2	1
		Acre	19,704	42.93	54,358	2487	5899	6860	4458
		Nahariya	4835	9.43	28,643	1342	1532	731	1230
		Kiryat Yam	5804	15.35	20,870	589	1730	2043	1442
		Matte Asher	2525	11.48	11,069	443	420	9	1653
		Zevulun	89	0.79	229	14	24	5	45
	2 m	Nesher	88	0.37	375	13	33	28	14
		Acre	17,505	38.14	69,828	2281	5320	5760	4144
		Nahariya	10,900	21.25	63,393	3026	3313	1788	2773
		Kiryat Yam	10,447	27.64	38,086	1249	3263	3418	2517
		Matte Asher	2536	11.53	13,442	432	433	9	1661
		Zevulun	518	4.62	1849	76	143	18	281
LECZ (10 m)		Nesher	353	1.51	1444	52	131	114	57
		Acre	40,290	87.78	137,776	5413	12,135	13,114	9628
		Nahariya	32,553	63.46	190,407	9156	9764	5249	8384
		Kiryat Yam	35,891	94.95	155,069	5884	11,871	10,333	7803
		Matte Asher	3766	17.12	16,322	842	688	46	2189
		Zevulun	1204	10.75	3747	194	303	64	643

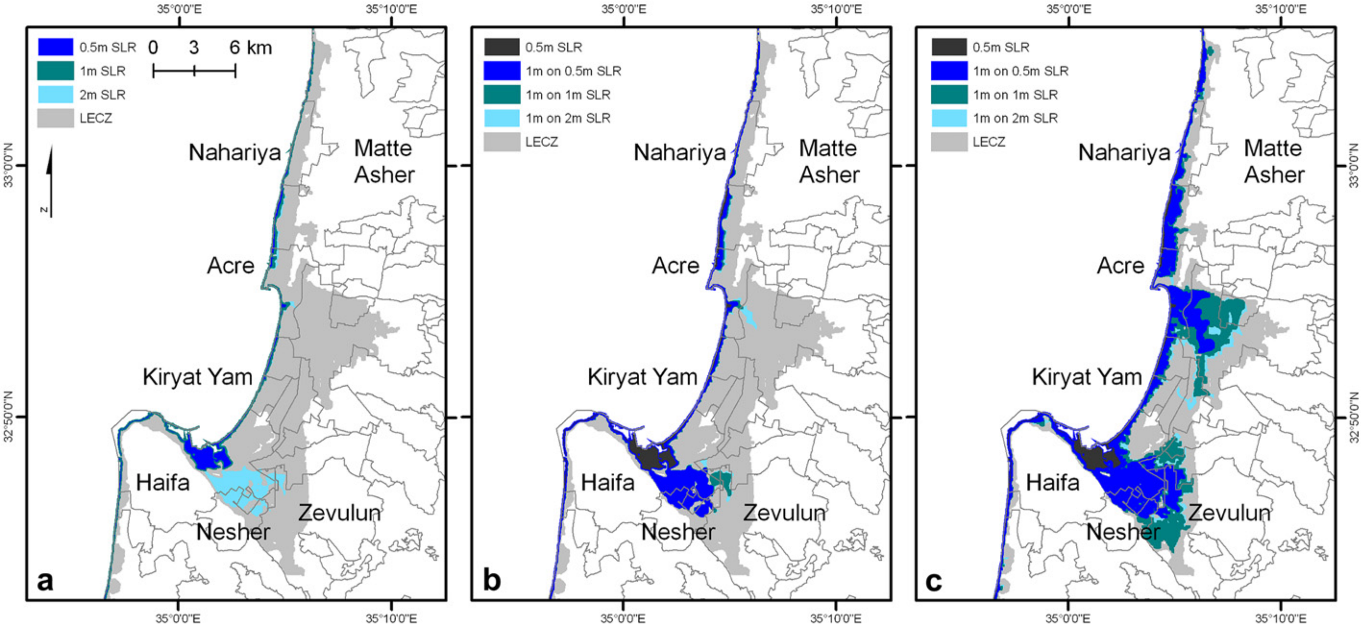

Fig. 3. a. 0.5, 1 and 2 m permanent SLR inundation scenarios. b. 1 m high tide given different SLR scenarios. c. 4 m Tsunami given the different SLR scenarios.

a displaced Kiryat Yam resident represents 74 percent of this figure and a displace Acre resident only 58 percent. The blue collar nature of many of the occupations that these residents occupy is reflected in the large proportion of industrial and sales/service jobs that characterize the occupational distribution of the flood-displaced inhabitants in these municipalities.

Given the above GIS-generated numerical estimates, it is but a short step to produce map-based output of the results. Fig. 4 presents an illustrative 3D example of the LECZ at risk in Tel Aviv. It depicts the vulnerable buildings by type, number of inhabitants (residential buildings only), household earnings associated with them and total value of capital stock (all buildings). Similar maps can be produced for other extreme flooding or SLR scenarios and using different variables as available. Taken together, this gives the coastal planner a powerful visual tool for both illustrating and animating the risks of natural hazards.

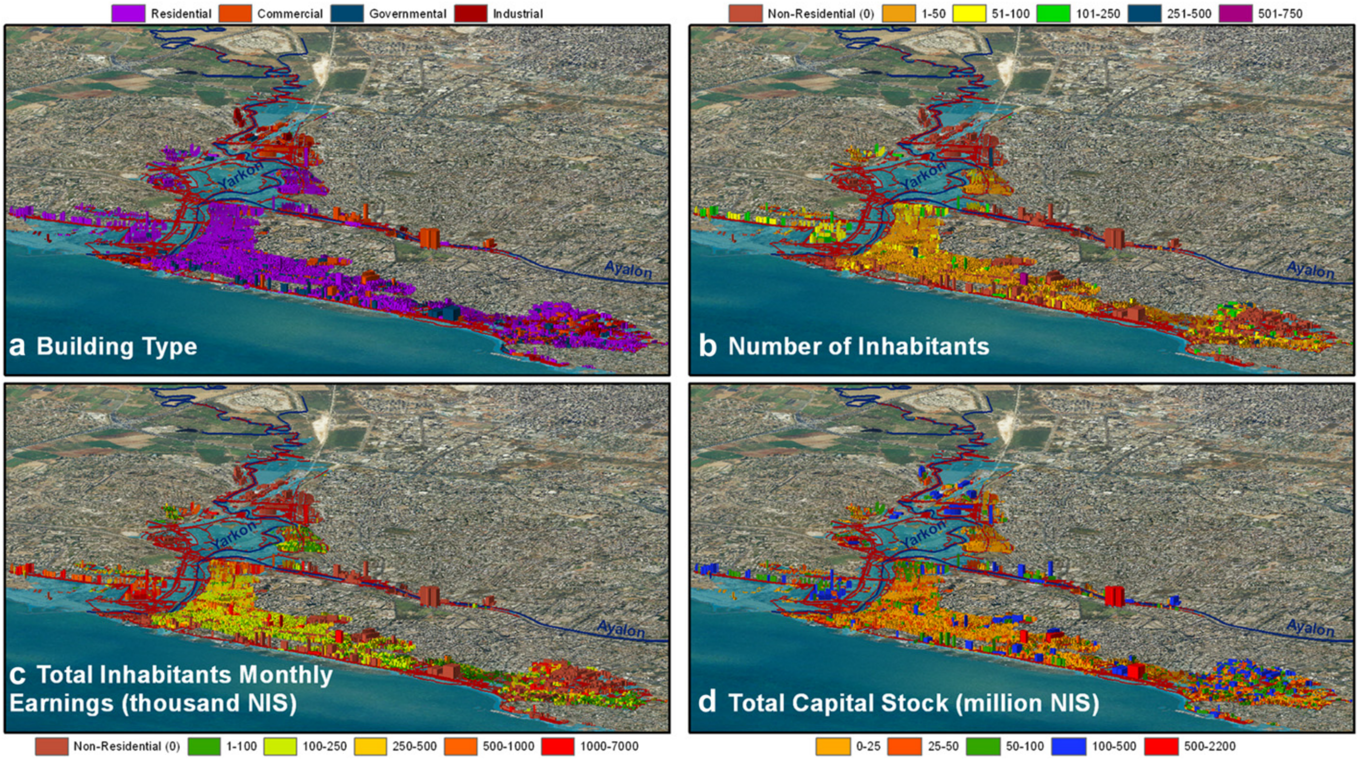

Fig. 4. 3D representation of the effects of vulnerable LECZ area in Tel Aviv by a. building types; b. number of inhabitants per residential building; c. total inhabitants monthly earnings per building and d. total building capital stock.

5. Conclusions

This paper highlights the way in which local coastal planners can generate meaningful new information related to land use, assets and population at risk, in their jurisdictions. Remarkably, this information is generally not readily available at a spatial scale useful to those charged with mitigating the local effects of natural hazards. We provide a structured framework for coupling scenarios of coastal permanent inundation and periodic flooding with socio-economic indicators and provide estimates of the monetized costs of such outcomes. Our emphasis is on method and application. As such we leave issues of economic value and welfare gains to further research. In similar fashion we also consciously avoid engagement with normative policy implications that might be implied from our empirics.

Instead, we choose to highlight the contribution our approach can make to coastal zone management praxis. Our major insight is that many of the platforms, data and skills needed to generate meaningful local information may be more accessible than hitherto appreciated. Real value added can be created by the judicious fusion of existing skills and capabilities. Instead of investing in macro level models on the one hand or micro-level, bespoke (and non-transferable) analyses on the other, the main thrust for embellishing the coastal zone planners toolbox needs to be enrichment of the existing stock of capabilities at hand. As shown above, the systematic geo-processing of socio-economic data allows for the creation of meaningful spatial distributions of variables of interest at a level of resolution useful to local planners. To achieve this we suggest three ground rules to assist in this process:

- *the prudent choice of a 'baseline' spatial distribution*. This dictates the level of spatial resolution for which all socio-economic outcomes are presented. As illustrated above, this involves disaggregating data available at one spatial level of resolution (for example statistical areas or census tracts) and re-aggregating at a higher level of detail (e.g. the level of the individual building). In our instance, the buildings data layer serves as the baseline distribution but of course, this level of detail may not be available in all instances. It should be noted that our method uses GIS capabilities for disaggregating and re-aggregating data rather than the more universal GIS activity of mapping and visualization.
- *the need to avoid double-counting* when specifying a natural hazards scenario. This risk exists when multiple natural processes coalesce. In our context of permanent inundation and extreme periodical flooding it is obvious that the joint effect of these two processes should not be considered as simply additive but rather as incremental. Values for an EF scenario need to count the floodplain over and above that already permanently inundated under the SLR scenario.
- *the imperative of integration*: successful practitioner-driven tools are invariably hybrids that combine known features and platforms in an innovative way. Furthermore, the nature of coastal zone processes calls for integration across disciplinary boundaries, statutory jurisdictions and technologies. Integration is thus a key action in analyzing, mitigating and coping with natural hazards.

The potential of our approach lends itself to many extensions. An immediate embellishment in terms of the analytic framework would be moving from our costs of impact approach to a full welfare analysis. This would include answers to distributional issues such as do lower income populations suffer greater costs under our scenarios than higher income groups? Additionally, it is important to know the alternative uses of the resources and assets lost under our scenarios, in order to reach a proper indication of economic value. In this respect, we cannot assume that 'a job is a job' and 'a building is a building'. Another obvious improvement lies in the area of 3D visualization. A natural extension would be to automate the GIS procedure to generate 3D representations of the socio-economic outcomes at the building level. We have presented an illustrative example above but obviously this can be taken much further. Meeting these challenges would further improve the praxis of local coastal zone management.

Acknowledgment

This research is partially based on work done in the SECOA (Solutions for Environmental Contrasts in Coastal Areas) research project funded by the European Commission, Seventh Framework Programme 2007–2013 under Grant Agreement n° 244251.

Appendix. Notation list by order of analysis

H_{B}	building height
H_{R}	building roof height (2G in Table 2)
H_{L}	building land height (2G in Table 2)
S_{R}	building roof space (2G in Table 2)
F_{R}	number of floors in a residential building
F_{N}	number of floors in a non-residential building
F	building number of floors
S_{RN}	total regional non-residential floor space
S_{SR}	total statistical area residential floor space
S_{B}	building floor space
S_{BN}	non-residential building floor space
S_{BR}	residential building floor space
V_{RR}	regional average house prices (2A in Table 2)
H_{RR}	regional average household size (2A in Table 2)
V_{RN}	total regional non-residential building stock (2B in Table 2)
V_{RE}	total regional non-residential equipment stock (2B in Table 2)
P_{RR}	average regional prices per m^2 of residential buildings
P_{RN}	average regional non-residential building values per m^2
P_{RE}	average regional equipment value per m^2
P_{BR}	residential building value
P_{BN}	non-residential building values
P_{BE}	building equipment value
I_{S}	total population per statistical area (2C in Table 2)
I_{SR}	average number of inhabitants per m^2 of residential floor space in a statistical area
I_{B}	building population counts
M_{SI}	average earnings per household per month in a statistical area (2D in Table 2)
H_{S}	total number of households in a statistical area (2D in Table 2)
M_{S}	total monthly earnings in a statistical area
M_{SM}	earnings per m^2 of residential building in a statistical area
M_{B}	building total earnings per month
O_{S}	% of inhabitants employed in an occupational category (2E in Table 2)
I_{O}	building total number of inhabitants in each occupational category

References

Anthoff, D., Nicholls, R., Tol, R., 2010. The economic impact of substantial sea-level rise. Mitig. Adapt. Strateg. Glob. Change 15, 321–335.

Beenstock, M., Felsenstein, D., 2007. Mobility and mean reversion in the dynamics of regional inequality. Int. Reg. Sci. Rev. 30, 335–361.

Beenstock, M., Felsenstein, D., Ben Zeev, N., 2011. Capital deepening and regional inequality: an empirical analysis. Ann. Reg. Sci. 47, 599–617.

Bin, O., Poulter, B., Dumas, C.F., Whitehead, J.C., 2011. Measuring the impact of sea-level rise on coastal real estate: a hedonic property model approach. J. Reg. Sci. 51, 751–767.

Bryan, B., Harvey, N., Belperio, T., Bourman, B., 2001. Distributed process modeling for regional assessment of coastal vulnerability to sea-level rise. Environ. Model. Assess. 6, 57–65.

Burgan, B., Mules, T., 2001. Reconciling cost–benefit and economic impact assessment for event tourism. Tourism Econ. 7 (4), 321–330.

Buriks, C., Bohn, W., Kennett, M., Scola, L., Srdanovic, B., 2004. Using HAZUS-MH for Risk Assessment: A How-to-Guide. Federal Emergency Management Agency, Washington, DC.

Coleman, H., Foley, M., Prahler, E., Armsby, M., Shillinger, G., 2011. Decision Guide: Selecting Decision Support Tools for Marine Spatial Planning. The Center for Ocean Solutions, The Woods Institute for the Environment, Stanford University, California.

Colgan, C.S., Merrill, S.B., 2008. The effects of climate change on economic activity in Maine: Coastal York County case study. Maine Policy Rev. 17, 66–79.

Frish, R., Tsur, S., 2010. Transport infrastructure investment, commuting and wages. Bank Israel Rev. 83, 7–34.

Füssel, H.-M., Klein, R., 2006. Climate change vulnerability assessments: an evolution of conceptual thinking. Clim. Change 75, 301–329.

Golik, A., Rosen, D.S., 1999. Management of the Israeli Coastal Sand Resources. Israel Oceanographic & Limnological Research Ltd, Haifa.

Grinsted, A., Moore, J.C., Jevrejeva, S., 2010. Reconstructing sea level from paleo and projected temperatures 200 to 2100 AD. Clim. Dyn. 34, 461–472.

Hegde, A.V., Reju, V.R., 2007. Development of coastal vulnerability index for Mangalore coast, India. J. Coast. Res. 23, 1106–1111.

Hinkel, J., Klein, R.J.T., 2009. Integrating knowledge to assess coastal vulnerability to sea-level rise: the development of the DIVA tool. Glob. Environ. Change 19, 384–395.

Hittle, J., 2011. Integrated Planning for Resilient Communities: A Technical Guide to Integrating Hazard, Ecosystem and Land Use Planning. NOAA Coastal Services Center.

IPCC CZMS, 1992. A common methodology for assessing vulnerability to sea level rise. In: IPCC CZMS (Ed.), Global Climate Change and the Rising Challenge of the Sea. Report of the Coastal Zone Management Subgroup, Response Strategies Working Group of the Intergovernmental Panel on Climate Change. Ministry of Transport, Public Works and Water Management, The Hague.

Kleinosky, L., Yarnal, B., Fisher, A., 2007. Vulnerability of Hampton Roads, Virginia to storm-surge flooding and sea-level rise. Nat. Hazards 40, 43–70.

Levin, H.M., McEwan, P.J., 2001. Cost Effectiveness Analysis, second ed. Sage, Thousand Oaks, CA.

Marfai, M., King, L., 2008. Potential vulnerability implications of coastal inundation due to sea level rise for the coastal zone of Semarang city, Indonesia. Environ. Geol. 54, 1235–1245.

McGranahan, G., 2007. The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones. Environ. Urban. 19, 17–37.

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, G.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver, A.G., Zhao, Z.C., 2007. Global climate projections. In: Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (Eds.), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

Merrill, S., Yakovleff, D., Holman, D., Cooper, J., Kirschen, P., 2010. Valuing Mitigation Strategies: A GIS-Based Approach for Climate Adaptation Strategies Fall 2010. www.esri.com.

Özyurt, G., Ergin, A., 2010. Improving coastal vulnerability assessments to sea-level rise: a new indicator-based methodology for decision makers. J. Coast. Res., 265–273.

Rahmstorf, S., 2007. A semi-empirical approach to projecting future sea-level rise. Science 315, 368.

Richards, J.A., Nicholls, R.J., 2009. Impacts of Climate Change in Coastal Systems in Europe: PESETA-Coastal Systems Study. JRC-IPTS, European Commission, Seville, Spain.

Salamon, A., Rockwell, T., Ward, S.N., Guidoboni, E., Comastri, A., 2007. Tsunami hazard evaluation of the Eastern Mediterranean: historical analysis and selected modeling. Bull. Seismol. Soc. Am. 97, 705–724.

Snoussi, M., Ouchani, T., Niazi, S., 2008. Vulnerability assessment of the impact of sea-level rise and flooding on the Moroccan coast: the case of the Mediterranean eastern zone. Estuar. Coast. Shelf Sci. 77, 206–213.

Taketa, R., Ng, P., Hong, M., 2010. Land-Use Portfolio Modeler Version 1.0. U.S. Geological Survey, Washington, DC.

Xiao, Y., 2011. Local economic impacts of natural disasters. J. Reg. Sci. 51, 804–820.

Yehoshua, N., Greenbaum, N., Shechter, M., 2006. Mediterranean Sea level rise along the Israeli coast; economic estimates of coastal land loss arising from climate change. Stud. Nat. Environ. Resour. Manag. 5, 17–36.