DOI: 10.4408/IJEGE.2016-01.O-03

SOCIO-ECONOMIC IMPACTS UNDER DIFFERENT SEA-LEVEL RISE SCENARIOS: ANALYSIS AT LOCAL LEVEL ALONG THE COASTAL AREA OF ROME (ITALY)

Armando MONTANARI(*), Luca DERAVIGNONE(*) & Barbara STANISCIA(*)

(*)Sapienza University of Rome - Department of European, American and Intercultural Studies- Piazzale Aldo Moro, 5 – 00185 Rome, Italy
Corresponding author: barbara.staniscia@uniroma1.it

EXTENDED ABSTRACT

Il tema dell'innalzamento del livello del mare (SLR) è spesso associato, in letteratura, ai cambiamenti climatici e all'azione dell'uomo nel modificare la natura e l'ambiente. Si tratta di un tema lungamente e ampiamente dibattuto, come dimostra la vasta letteratura prodotta. Se non vi è totale convergenza nel definire l'aumento in termini quantitativi, vi è, però, unanimità nell'affermare che tale aumento avrebbe effetti negativi, dannosi o, addirittura, disastrosi, data la grande massa di popolazione mondiale che risiede e opera in prossimità della costa. Il SLR è causato da diversi fattori naturali – di natura globale e locale – e legati anche all'attività umana. Gli impatti del SLR sono di tipo naturale-ambientale e di tipo socio-economico.

Lo studio che qui si presenta riguarda gli effetti socio-economici di un ipotetico SLR lungo il litorale romano (Italia), nel Municipio di Ostia. Si tratta di uno studio alla scala locale, che utilizza dati micro-territoriali sviluppato nel contesto del progetto FP7 SECOA – Solutions for Environmental Contrasts in Coastal Areas (www.projectsecoa.eu); lo studio vuole porsi come strumento per supportare e facilitare i policy makers nei loro processi decisionali. L'articolo presenta gli effetti di due scenari di SLR: quello ipotizzato da IPCC e quello ipotizzato nello studio di Rahmstorf, entrambi nel 2007; essi considerano, rispettivamente, un innalzamento di 0.2-0.6 metri e di 1.00-1.40 metri, entro il 2100.

La superficie costiera inondata nello scenario IPCC è pari a ca. 876 mq mentre quella inondata nello scenario Rahmstorf è pari a ca. 690322 mq. Considerando la maggiore significatività delle aree inondate nello scenario Rahmstorf – rispetto a quelle inondate nello scenario IPCC –, è stata eseguita una simulazione includendo, oltre alla fascia costiera, una buffer zone di 10 mt oltre la nuova linea di costa generata da tale scenario. Si è ritenuto opportuno introdurre tale buffer zone per calcolare i danni e i conseguenti costi dell'inondazione. In tale circostanza, l'area inondata risulta pari a ca. 833,335 mq ed è caratterizzata dai seguenti usi: natural habitat (ca. 69580 mq), open space (ca. 660,694 mq, il 9.2% delle aree open space presenti nel Municipio di Ostia), aree residenziali, commerciali, del terziario (ca. 62,205 mq), aree portuali (ca. 40,857 mq, il 13% delle aree portuali del Municipio di Ostia).

Il territorio di Ostia è stato sottoposto ad intensi processi di urbanizzazione che hanno coinvolto molte aree che sarebbe stato più opportuno lasciare al loro stato naturale. Le piene del fiume Tevere, di conseguenza, portano con sé notevoli problemi di gestione delle acque e, in alcuni casi, generano veri disastri ambientali e tragedie umane. La fascia costiera è stata sovrautilizzata con l'installazione di stabilimenti balneari che da strutture temporanee si sono trasformati in strutture permanenti, senza soluzione di continuità. Tali strutture da un lato negano una facilità di accesso al mare, dall'altro sono esposte al rischio di distruzione in caso di SLR. Le abitazioni costruite a ridosso della strada litoranea, le attività commerciali e terziarie lì localizzate sono anch'esse aree a rischio.

La simulazione degli effetti e degli impatti di un SLR sulla popolazione e sulle attività economiche nel caso di studio di Ostia si è rivelata importante per la sua capacità informativa e comunicativa. L'utilizzo di scenari alternativi e di mappe ha consentito il confronto con i decisori pubblici e i rappresentanti locali. E' stato, così, possibile sensibilizzare gli attori territoriali sulle conseguenze di eventi naturali che si trasformano in disastri solo a causa del non corretto intervento umano.

La ricerca potrebbe utilmente continuare seguendo tre percorsi complementari: (i) per rendere più user friendly i risultati delle simulazioni. Ciò al fine di rendere la popolazione più consapevole dei rischi naturali e, quindi, favorire processi virtuosi di gestione del territorio. Dalle mappe, quindi, si potrebbe passare a simulazioni tridimensionali con possibilità di interazione da parte dell'utente; (ii) per includere nell'analisi i costi economici che la collettività subirebbe in seguito alla perdita di immobili, di posti di lavoro, di infrastrutture a causa del SLR; (iii) per considerare, infine, i costi che la collettività dovrebbe sostenere per controllare gli effetti e gli impatti territoriali del SLR.

ABSTRACT

Sea-level rise (SLR) is often associated with climate change and human action in modifying nature and the environment. The research presented in this paper concerns the effects and impacts of different SLR hypotheses in Italy, along the Rome coastal area, in the Ostia district. The study was carried out at the local level, using micro-spatial data, in the context of the European Union's Seventh Framework Programme (FP7) project SECOA – Solutions for Environmental Contrasts in Coastal Areas; its aim is to offer local policy makers a tool to support and facilitate their decision-making processes. Effects and impacts are analysed and presented for two alternative SLR scenarios. The first one follows the hypotheses made by the Intergovernmental Panel on Climate Change (IPCC), the second one those made by Rahmstorf, in 2007. The two scenarios consider a SLR of 0.2-0.6 m and 1.00-1.40 m, respectively, by the year 2100. The coastal surface area flooded in the IPCC scenario equates to ca. 876 m2, while the flooding in the Rahmstorf scenario totalled ca. 690,322 m2. Damages in terms of loss of land with different uses, loss of dwellings, loss of jobs, need for a relocation of resident population are the most severe estimated impacts of that extreme event of the Rahmstorf scenario.

Keywords: *climate change hypothesis, sea level rise (SLR), coastal areas, socio-economic impacts, coastal management, public policy*

INTRODUCTION

Coastal areas are the focus of numerous studies regarding environmental changes and socio-economic effects and impacts, which was one of the main topics of investigation of the FP7 project SECOA – Solutions for Environmental Contrasts in Coastal Areas (www.projectsecoa.eu; Fischhendler *et alii*, 2012; Williams, 2012; Khan *et alii*, 2013a, 2013b; Montanari, 2013; Lan *et alii*, 2014; Montanari, 2014; Di Zio & Staniscia, 2014).

Sea-level rise (SLR) is often associated in a part of the scientific literature, with climate change and human action in modifying nature and the environment. These topics have been discussed widely and at length, as confirmed by the abundant literature. A full convergence in the measurement of SLR has not been reached, while there is complete agreement that SLR produces negative global and local effects that are damaging or even disastrous for the environment and the very large proportion of the world's population located along the coasts.

The research presented in this paper concerns socio-economic effects consequential of this hypothesis and impacts of SLR in Italy, along the Rome coastal area, in the Ostia district. The study was carried out at the local level, using micro-spatial data, in the context of SECOA; its aim is to offer local policy makers a tool to support and facilitate their decision-making processes. Effects and impacts are analysed and presented for two alternative SLR scenarios developed in the SECOA project (SECOA N. 1.1, unpublished internal report). The first one follows the hypotheses made by IPCC (2007), the second one those made by Rahmstorf (2007). The two scenarios consider a SLR of 0.2-0.6 m and 1.00-1.40 m, respectively, by the year 2100 (SECOA N. 1.1, unpublished internal report). It is the first time that the socio-economic effects and impacts of SLR are assessed in the Ostia district of Rome.

The paper begins with a literature review of SLR, its environmental and socio-economic effects and impacts; it continues by presenting the methodology and by describing the data; a presentation of the case study - the Ostia district - follows; then, the socio-economic effects of the simulated SLR are shown and discussed; finally, conclusions are given.

SEA LEVEL RISE: CAUSES AND IMPACTS. A LITERATURE REVIEW

Sea-level changes have been observed and studied throughout history. This phenomenon had, indeed, been noticed by Herodotus, Eratosthenes, Xenophanes, Strabo and Aristotle. Aristotle, as Geikie (1897) reminds us, wrote: "The sea now covers tracts that were formerly dry land, and land will one day reappear where we now find sea". What has been worrying scientists – and, more recently, citizens and policy makers – for some decades, is an increase in the sea level. It has been estimated that the mean sea level has risen by an average of 1.7±0.3 mm/year since 1950 (Church & White, 2006; Nicholls & Cazenave, 2010). This increase was estimated in the Eighties to reach between 0.5 and 2.0 m by 2100 according to the U.S. Environmental Agency (Hoffman *et alii*, 1983). That estimate was later rescaled to tens of centimetres (Meier, 1990). According to a study conducted by the IPCC (1990), SLR will reach 0.3-0.5 m by 2050 and 1 m by 2100. The research carried out by Titus & Narayanan (1996) concludes that there is a 50% probability that, as a consequence of the Earth's temperature, SLR will exceed 34 cm by 2100 and a 1% probability that SLR will exceed 1 m. Among the most recent forecasts, Rahmstorf (2007) estimates a sea level in 2100 between 0.5 and 1.4 m greater than the 1990 sea level, IPCC (Solomon *et alii*, 2007) estimates that sea level will increase up to 0.6 m by 2100, while Pfeffer *et alii* (2008) present the hypothesis of an increase of over 1 m.

If on one hand the uncertainties are very high, on the other SLR is a worrying phenomenon, given the large population concentrated in coastal areas: in fact, 1.2 billion people worldwide live within 100 km from the coast and up 100 m above sea level; the population density along these strips is approximately three times higher than the world average (Small & Nicholls, 2003; Sahin & Mohamed, 2014). In addition, 10% of the world's population is concentrated along the coastal areas at very low level, less than 10 m above sea level (McGranahan *et alii*, 2007).

SLR is provoked by several global and local factors, linked to natural phenomena and human action.

The global factors include the following (Walker, 1992; Titus & Narayanan, 1996; Solomon *et alii*, 2007): (i) Increase in atmospheric CO_2 and concentrations of other greenhouse gases. This alters the Earth's temperature, generating global warming and, as a consequence, modifies the volumes of oceans and seas through thermal expansion, and, finally, their level. In addition, the warmer climates over Greenland and Antarctic would have a very strong influence through ice melting; (ii) Movements in the Earth's crust; (iii) Movements of small glaciers and the related water flows into the oceans and seas; (iv) Alteration in ocean base shape through sea floor subsidence and compaction and mid-ocean ridge growth; (v) Water storage in the atmosphere, ground and on the surface.

Among the local and regional factors, the following are worthy of mention (Walker, 1992): (i) Deformation of the geoid's surface as glacial ice and ocean water quantities and positions vary; (ii) Localized and plate tectonic activity; (iii) Localized subsidence and compaction; (iv) Atmospheric (wind, precipitation, storm surges), hydrologic (runoff), and oceanographic (ocean currents) variations.

The factors due to human action include the following (Walker, 1992; Sahagian *et alii*, 1994; Nicholls & Cazenave, 2010): (i) Alteration of the subsurface by withdrawal of fluids (water, oil, gas); (ii) Disturbance of the sediment input to the oceans by mining, river damming and surface water diversion; (iii) Thermal and other pollution; (iv) Modification of shoreline configuration and nearshore profiles; (v) Reclamation and land use changes; (vi) Alteration of relevant atmospheric conditions such as air temperature.

Impacts of SLR are natural-environmental and socio-economic.

Natural and environmental impacts are relevant for the sea and, above all, coastal areas; the softer, sandier and narrower the coast is, the greater the effects are (van der Meulen *et alii*, 1991). Walker (1992) highlights that the impact on shorelines will vary greatly by shoreline type and slope. Hard rock coasts will be changed slowly; sandy beaches and marshes may be destroyed rapidly. The extent of shoreline retreat due to rising sea levels will be a function of nearshore and onshore gradients. Furthermore, land adjacent to the shoreline may be impacted by a rising sea level. The effects can include submergence and increased flooding (Baarse & Rijsberman, 1987; McLean *et alii*, 2001; Nicholls & Cazenave, 2010), the loss of land because of landward erosion (McLean *et alii*, 2001; Nicholls & Cazenave, 2010), modification of drainage patterns, siltation (Turner *et alii*, 1996), saltwater intrusion into groundwater (Turner *et alii*, 1996; Nicholls & Cazenave, 2010) and changing salinities in coastal aquifers (Kjerfve, 1991; McLean *et alii*, 2001).

The negative spatial and socio-economic impacts are numerous (Walker, 1992; Turner *et alii*, 1996): (i) For the fish industry, since only a few centimetres rise in sea level can alter wetlands, negating their value as nursery grounds. Deeper water also means a higher base level, allowing waves to overcome sea walls more frequently; (ii) For industry, transportation and commerce, since SLR causes structural problems for harbours, airports and all the industrial and commercial structures and infrastructures located in the vicinity of the coast. The same problems occur also as a consequence of coastal erosion; (iii) For agriculture and aquaculture; (iv) For tourism, leisure and recreational activities; (v) For residential areas and real estate; (vi) For culture and heritage sites; (vii) For life expectancy. SLR is the cause of a loss of dry land and wetlands; even in the case that these areas are not inhabited or utilised, they are still a potential resource that is destroyed. Sea intrusion could, in addition, provoke salinisation of freshwater and make this land uninhabitable. This is particularly true in the case of small islands and atolls.

These impacts cause an increase of the vulnerability of coastal zones. SLR costs and vulnerability can be assessed in different ways. Turner *et alii* (1996) define vulnerability as "a multidimensional concept encompassing biophysical, socio-economic, political, and ethical factors. It also includes the institutional capability or capacity of a region or a country to cope with or manage the impacts as well as the relevant physical and socio-economic dimensions". IPCC defines vulnerability as "the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (Parry *et alii*, 2007). Sahin & Mohamed (2014) identify the three main variables constituting vulnerability for a given area: (i) exposure, (ii) sensitivity, (iii) adaptive capacity.

As well as the research concerning the effects of climate change and SLR at the global and international scale (Walker *et alii*, 1992; Titus & Narayanan, 1996; Turner *et alii,* 1996; Darwin & Tol, 2001; Li *et alii*, 2009; Nicholls & Cazenave, 2010; Bosello *et alii*, 2012), there is also a remarkable amount of literature which enhances the need to concentrate on the effects at the macro-regional, regional and local scale (van der Meulen *et alii*, 1991; den Elzen & Rotmans, 1992; Day *et alii*, 1995; McKenzie-Hedger *et alii*, 2000; Gornitz *et alii*, 2002; Parson *et alii*, 2003; Hennecke *et alii*, 2004; Holman *et alii*, 2005; Cooper *et alii*, 2008; Nicholls & Cazenave, 2010; Parkinson & McCue, 2011; Zhang, 2011; Lichter & Felsenstein, 2012; Yin *et alii*, 2012; Cooper *et alii*, 2013; Chang *et alii*, 2014; Sahin & Mohamed, 2014); several of these studies are based on the use of LiDAR and GIS. One advantage of this scale of analysis is that stakeholders are more involved and more reactive if SLR impacts can be shown at a scale that coincides with the one they operate in. Another advantage is that the policies and the measures to be implemented in order to tackle the effects of SLR involve regional and local decision makers. These parties are interested in learning the effects and risks of SLR on their own territory in order to intervene with the most appropriate measures (Lin *et alii*, 2014).

Different scenarios are investigated by the studies assessing the impacts of SLR. Five different equal-interval SLR scenarios – 0, 0.5, 1, 1.5 and 2 m – are proposed by Lichter & Felsenstein (2012). Martinich *et alii* (2013) use three different scenarios, defined as "low scenario" (28.5 cm SLR by 2100 compared to 1990 levels), "mid scenario" (66.9 cm SLR by 2100 compared to 1990 levels), and "high scenario" (126.3 cm SLR by 2100 compared to 1990 levels). Felsenstein & Lichter (2014) propose a combination of possibilities that lead to the following scenarios: 1 and 2 m SLR; a 1:50 year 1-m high tide superimposed over 1 and 2 m SLR and a 4-m tsunami superimposed over 1 and 2 m SLR.

Several variables are used for measuring the impacts; the choice of them depends on the spatial scale of analysis, the scope of the research and the definition used for vulnerability. Among the most significant variables, we can include the following: (i) People at risk over time due to coastal flooding (Lichter & Felsenstein, 2012; Sahin & Mohamed, 2014); (ii) People at risk by occupational status and earnings (Lichter & Felsenstein, 2012); (iii) Socially vulnerable individuals at risk (Martinich *et alii*, 2013; Felsenstein & Lichter, 2014); (iv) Areas at risk (loss of land) due to inundation and coastal flooding (Parkinson & McCue, 2011; Sahin & Mohamed, 2014), classified by land use and land type (Lichter & Felsenstein, 2012); (v) Property at risk, property damage and asset vulnerability (Martinich *et alii*, 2013; Felsenstein & Lichter, 2014;); equipment and infrastructure at risk (Lichter & Felsenstein, 2012); (vii) Response modes and costs of adaptation (Martinich *et alii*, 2013; Kulpraneet, 2013).

MATERIALS AND METHODS

In order to collect all the different types of variables considered in this study, especially environmental, socio-economic and SLR related, different data sources have been used. The first taken into account was the variable to analyse the current coastline situation and identify the future SLR affected areas.

The current shoreline was reconstructed starting with a LiDAR (Grant, 1995) flight survey made in the year 2010 within the scope of the SECOA FP7 project (SECOA, N. 1.1). This method offers high precision with sub-metre measurements of both elevation and horizontal dimensions, allowing the creation of high precision DEMs. The area surveyed by LiDAR included a strip of all the analysed coast, in order to acquire a high precision elevation model of the entire area. Analysis and development of the points cloud, including interpolation of the points, was necessary in order to reconstruct the current shoreline.

Based on this dataset, two different SLR hypotheses were tested, the IPCC (2007) and Rahmstorf's (2007), both relating to the year 2100, forecasting a SLR of 0.2-0.6 m and 1.00-1.40 m, respectively. The original raster layers were converted to vectors in order to create the polygons representing the submerged area for the two different hypotheses. By overlapping these polygons with the current map of the area, we were able to draw the future coastline for both IPCC and Rahmstorf hypotheses. In the scenarios presented herein, occasional precipitation-driven flooding is not considered, therefore all the submerged areas taken into account should be considered affected by permanent inundation by the year 2100.

The main datasets necessary for this approach had to consider at minimum information on land use, population and housing, and also jobs, including industry and services.

For the land use the main source available for the area is CORINE Land Cover, available for the year 2000 for most of Europe. This cartography is organized into 44 classes, and the resulting classification, mostly based on a goal of environmental protection, is mapped at a resolution of 1:100,000.

For the purposes of our study we decided to aggregate these classes into main macro categories: agriculture areas, industrial areas, industrial/commercial areas, natural habitat, open space, and mixed residential/office/government/commercial areas. Minor categories such as airports and port areas were also considered due to their high socio-economic impact on human/goods mobility, as were road networks. Usually, only major infrastructure like highways are classified by CORINE Land Cover in this last category, while roads and streets located in urban areas are considered as part of the area where they are located and of the related category. This is another aspect to consider for the purpose of correctly evaluating and weighting the socio-economic effects of SLR.

In terms of the quality of mapping, CORINE Land Cover is of a lower level (i.e., lower spatial resolution) compared to the LiDAR used for the SLR maps. When it comes to comparing the coastline, apart from the difference in acquisition date (2010 for LiDAR and 2000 for CORINE Land Cover), a significant difference in quality is noticeable between the two, depending on the original scale of the datasets. This aspect was also common to the other cartographic data sources, and was taken into account when choosing a specific approach for the calculations, as later explained.

For population information, a key source was the 2001 Census data from Italy's National Institute for Statistics ISTAT (Istat, 2001a). The variables included in this dataset, distributed over nearly 200 fields, mostly concern information about population and housing. The tables containing all the alphanumeric data from the Census were joined in GIS to the relative polygon layer census tracts in order to map the spatial distribution of population and all the other variables included. The quality of the vector layer was similar to that of CORINE in this case too, and the coastline did not match up precisely even between these two.

Regarding the economic variables, and related to the Population Census, ISTAT has carried out a Census for Industry and Services, also available for the year 2001 (Istat, 2001b), which gives data on local units classified by economic sectors. This dataset is joinable to the same cartographic dataset as census tracts, as they are based on the same spatial subdivision.

Once all the datasets had been collected, the second step was to map all the socio-economic and environmental data in order to spatially distribute them on a common GIS platform. This provides a view of the areas, and more specifically the census tracts and the land-use units, overlapped by the two inundation models.

It was necessary to assign a unique ID to the different records, matching the corresponding ones on the map. This entire task was accomplished in a GIS environment by an automatic join procedure. Since CORINE Land Cover and census tracts are based on a different land subdivision, the procedure was performed separately, given that the IDs were also different.

As previously explained, we had to deal with different scales and quality of the cartographic datasets, especially in regard to the differences in the coastlines derived from LiDAR and the other cartographic sources. In order to keep the resulting errors as low as possible we decided to take the LiDAR as the only correct source for the current and future shorelines when considering the overlapping areas.

The third step followed, in which some GIS spatial queries were performed to identify the areas affected by flooding, in particular to find the polygons crossed by the IPCC, the Rahmstorf and the 10 m buffer-area layers. Since it is not possible to know the exact location of buildings or populations inside the areas, all the entire polygons affected by flooding were considered. To better calibrate this procedure, we also considered that it is not even possible for a building to be located immediately on the shoreline, so we decided to make a new layer considering a minimum buffer of 10 metres from the coastline determined by the Rahmstorf hypothesis. In this case the IPCC hypothesis was not taken into account because the records in a 10 m buffer were the same, and in general the areas to be considered were small.

Due to the issues related to the different cartographic datasets, an absolute area calculation of the inundated areas was also not possible, so it was decided to consider it relatively. As a matter of fact, since every polygon is initially characterised by a unique ID, it is possible to later identify all its parts and perform a calculation considering the original polygon area and the ones concerned by inundation in the different hypotheses. It has to be noticed that "cutting" the original polygons is useful for calculating areas but, from this point on, the records are no longer useful for performing other quantitative analyses due to the resulting duplicates.

Once all the third step operations had been performed on GIS, different tables were exported in order to better filter and process the records, thus obtaining summary statistics for each flooding scenario. Specifically, three tables were exported: one relating to all census variables, one to local units, and one to land use. This was necessary in order to keep the calculations separate and perform them without repetitions, as previously explained. Moreover, in order to mark and subsequently find the records during all the different stages of the analyses, some Boolean fields (1-0, present-absent) were created on the GIS platform in order to identify the District of Ostia, the no-data records from the two considered Censuses (Istat, 2001a and 2001b), the records affected by IPCC and Rahmstorf hypotheses, and the previously mentioned 10 m buffered area. This allowed the records to be filtered and the desired operations and calculations to be performed at all times.

PRESENTATION OF THE CASE STUDY: GEOGRAPHY AND URBAN DEVELOPMENT PROCESSES IN THE OSTIA DISTRICT (ROME, ITALY)

Ostia is a District (Municipio) of the City of Rome. It is located on the Tyrrhenian coast and covers a surface area of ca. 150 km^2, with a resident population of around 220,000 inhabitants. The families of numerous foreign workers living in Ostia should then be added to this figure, both those who are and are not legally registered; these persons live there as the accommodation costs are lower and also due to the possibility to temporarily use second homes during the low tourist season. There are also several persons, living in other areas of the city, spending free time along the coast during the summer. There are numerous bathing establishments offering leisure services and use the narrow strip of sand remaining between the land and sea.

The beach is subject to continual erosion due to the reduced contribution of sand from the Tiber River, from the intensive human use of the coastal area, from the constant increase in the sea level, as well as rapid temporary variations in the sea level (Tarragoni *et alii*, 2014). The Region of Latium has intervened by financing beach nourishment, taking aggregates from the offshore sandy bottom. But the problem of erosion reoccurs regularly, and the operators of the bathing establishments complain of the increasingly meagre sandy area at their disposal. Some operators have estimated the quantity of eroded sand at 150,000 m^3, meaning that 10,000 truckloads of sand would be required to restore the dimensions of the previous sandy shore.

The coastal area of the city of Rome was urbanised beginning in the 4th century BC. Initially this was a military encampment, replaced in the first century BC by a commercial settlement connected to the port of Ostia. After the fall of the Roman

Empire, the area was left exposed to pirate attacks and therefore abandoned. The lack of any form of maintenance and continual flooding from the Tiber transformed the area into a swamp from the 5th century through to the 19th century. During this long period of abandonment, the transformations occurred due to the characteristics of three geomorphological areas: (i) A wooded area of hills which contributed to the flooding of the areas below; (ii) A marshy area (iii); The coastal dunes formed by the action of the wind which impeded the meteoric and flood waters from draining into the sea. Malaria made survival in these locations impractical, and the only possible activities were wild rearing and salt production.

The situation radically changed during the course of the 19th century, when Rome became capital of the Kingdom of Italy in 1870. It was considered unacceptable for such insalubrious areas to exist so close to Rome, and therefore they were reclaimed and subsequently given back over to agriculture. A drainage system was therefore put into place by building a series of canals, of which the main ones are the Pescatori, Dragoncello and Palocco canals. The water lifting stations were inaugurated on December 16, 1889, and in a little over 12 days the waters of the Ostia marshes, an area measuring 1,500 hectares, were pumped into the Pescatori canal. But this reconversion policy was unsuccessful due to the residual salinity of the reclaimed land, which was therefore not sufficiently productive for agricultural purposes.

In the 1920s it was decided to create a residential beach town in the area, located around 30 km from the centre of Rome, connected by a railway and a fast highway. In 1933 the area received the name of Lido di Roma (Rome beach) and was included in the general plan of EXPO 1938, which provided for the expansion of Rome towards the sea. Ostia was then thought of as the “Third Rome”, to be built along the Tyrrhenian Sea. The plan provided for a strip of residential land along the coast with holiday homes for Rome’s middle classes, and a more densely populated area further inland for the working class.

After the end of the Second World War, Ostia underwent more intensive and informal development sustained by construction speculation, with little attention to architectural design and quality. In the last few decades, Ostia has become ever more a “dormitory” town for Rome, with a population spending most of its time working in the city centre.

Beyond Ostia is the Pineta di Castelfusano (Castelfusano Pine Forest); measuring 1,000 hectares, the *Pineta* was planted during the 18th century for the production of pine kernels. The protected area of Castel Porziano and Capocotta, along with the nearby urban park of Castel Fusano, covers a surface area of around 7,000 hectares (Fig. 1).

Today, the number of houses not permanently occupied, as they are used for holiday homes or are rented unofficially, including to unregistered immigrants, remains high: 25-30% in Ostia Ponente and Ostia Levante, and 60-70% in Castel Fusano and Castel Porziano. The property values are still two or three times less than those in the centre of Rome. For this reason, around 40,000 people have moved to Ostia over the course of the last 20 years.

Ostia’s beaches have around 60 bathing establishments, small and medium-sized enterprises which welcome thousands of beach-goers a day during the summer months, and many others for night-time recreational activities both during the summer and the rest of the year. Ostia is nevertheless far from being merely a tourist destination: due to its vicinity to the Fiumicino international airport, arrivals number 200,000 a year, bringing the number of persons present to 440,000.

Ostia was built on marshland and is easily flooded each time the level of the Tiber rises, above all in combination with particular climatic conditions such as high tides, extreme barometric lows and southerly winds which increase the effects of the sea level rise. Another problem is the supply of potable water in relation to a number of consumers that is difficult to estimate precisely, for the reasons outlined above. The number of these occasional, or unidentifiable, users is difficult to determine, but it is estimated to be equivalent to the number of officially registered consumers.

The permanent rise of the sea level, with temporary peaks, contributes to a rise in the level of the water table, with a risk of flooding in the inland residential areas of Infernetto, Saline, Stagni and Bagnoletto. This makes the terrain unstable and leads to breakages in the mains water supply sewerage systems. Incidents of this type occur frequently. The most serious occurred on May 1, 2011 when the town water pipeline burst, opening up a five-metre-deep chasm in the street. In the Infernetto area on October 20, 2011, a Sri Lankan citizen drowned in his basement apartment that had been flooded by a sudden rise in the water table following an intense and prolonged downpour.

RESULTS: FLOODING SCENARIOS AND SOCIO-ECONOMIC IMPACTS IN THE OSTIA DISTRICT (ROME-ITALY)

The Ostia district is normally subject to flooding due to the Tiber bursting its banks. It was therefore decided to ascertain what would happen in the event of a rise in the sea level. The SLR impact analysis for the Ostia District considered the two different scenarios – IPCC and Rahmstorf – already mentioned in section 3. The coastal surface area flooded in the IPCC scenario equates to ca. 876 m^2, while the flooding in the Rahmstorf scenario totalled ca. 690,322 m^2 (Fig. 2)

In the first case the flooded zone only involved the port areas (marina), while in the second scenario the areas affected included the following uses: open space (ca. 55,9867 m^2), natural habi-

Fig. 1 - Ostia district, land use pattern. Source: authors' own elaboration based on CORINE, 2000

tat (ca. 53,765 m^2), port areas (31,749 m^2), residential areas and areas devoted to commercial and tertiary activities (44,941 m^2).

Considering the greater significance of the areas flooded in the Rahmstorf scenario compared to the IPCC scenario, a simulation was performed including a buffer zone of 10 m beyond the new coastline generated by that scenario as well as the coastal strip. Including this buffer zone was considered appropriate in order to calculate the damage and consequent costs of the flooding. Under these circumstances, the area flooded totalled ca. 833,335 m^2, falling under the following uses: natural habitat (ca. 69,580 m^2), open space (ca. 660,694 m^2, 9.2% of the open space area

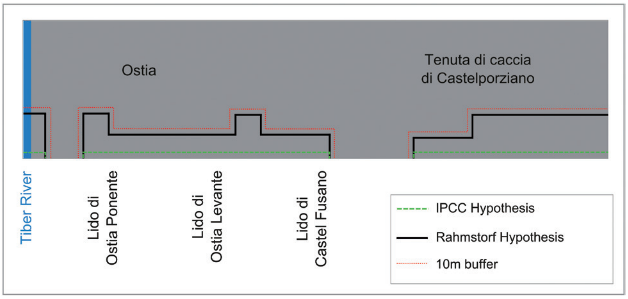

Fig. 2 - Ostia district, a visual interpretation of the IPCC and Rahmstorf inundation hypotheses. Source: authors' own elaboration

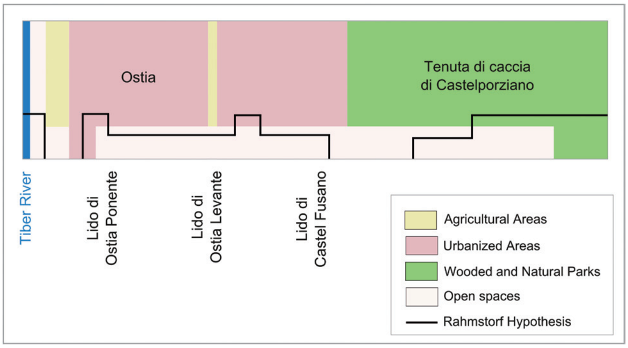

Fig. 3 - Ostia district, land use of the inundated area under the Rahmstorf hypothesis. Source: authors' own elaboration based on CORINE, 2000

present in the Ostia District), residential areas and areas devoted to commercial and tertiary activities (ca. 62,205 m^2), and port areas (ca. 40,857 m^2, 13% of the Ostia District's port areas) (Fig. 3).

The residential buildings involved numbered 539, along with 1600 dwellings and 38 buildings devoted to commercial and tertiary activities (Istat, 2001a). The economic consequences of the losses in the residential areas and areas devoted to commercial and tertiary activities, using average market values as of 2011 (BIR, 2011), can be estimated at €144,367,000. Infrastructure losses should then be added to this, particularly losses in terms of road capital stock.

The resident population affected by the flooding who would then have to find new accommodation (people to be relocated) totals 2261 persons, 229 of them foreigners (Istat, 2001a). Of these residents, 399 are below 14 years of age and 240 over 65. The community at risk of flooding - given their national and local context - is fragile in terms of their independence and self-sufficiency, both social and economic. Its dependency ratio indeed stands at 39.4, and the proportion of foreigners at 10%.

An analysis of the level of education showed that 122 persons were in possession of a university degree (representing 7% of the population aged over 20), and 592 held a high-school diploma or leaving certificate (34% of the population aged over 20). From this we can infer that 60% of the adult population has no education beyond Italian compulsory schooling, and this represents an element of fragility in the impacted community.

The work force/labour force affected by the flooding totals 1033 individuals, of whom 848 are employed. Of those employed, most (77%) are contracted employees, while a minority (18%) are business owners, freelancers and professionals. This is therefore an area strongly characterised by low, yet guaranteed incomes, in the public sector (212 employees); by salaried work with varying incomes in industry (182 employees); and by independent work, with normal business risk, in commerce, and in accommodation (176 employees). Taking the average gross annual income for 2012 in the Rome area (MEF, 2013), the economic damage sustained by the community would equate to € 22,230,000. Added to this cost would be the inactive persons economically dependent on these workers, consisting of 299 home-makers, 110 students, and 147 retirees.

The number of jobs put at risk by the flooding totals 1377, with 245 local units of enterprises and institutions involved. The sectors of economic activity most exposed are, in order: technical, consultancy, transport, family and business services and services supplied to the public administration (number of jobs: 759); education, health and social services, personal services to families, and the activities of associations and NGOs, recreational, cultural and sporting activities (number of jobs: 209); hotels, restaurants, cafés and bars (number of jobs: 187); manufacturing, energy and construction industry (number of jobs: 113); wholesale and retail sales (number of jobs: 109).

DISCUSSION AND CONCLUSIONS

The Ostia area has, in recent decades, undergone intensive urbanisation, which has taken place in many areas that should have best been left in their natural state. Flooding of the Tiber, as a consequence, brings with it significant problems in terms of water management, as well as full-on environmental disasters and human tragedies in some cases. The coastal strip has been overused, with the installation of bathing establishments that have gradually been transformed from temporary structures to permanent buildings, without any continuity. These structures on the one hand deny access to the sea to non-customers, and on the other are exposed to the risk of destruction in the event of SLR. The dwellings built along the coastal road and the commercial and tertiary activities located there are also at risk.

The simulation of the effects and impacts of SLR on the population and economy of Ostia turned out to be important due to its informative and communicative capacity. The use of alternative scenarios and maps - that has already been proven to be a powerful tool (Montanari *et alii*, 2014) - along with the presentation of a detailed set of key information, allowed discussion with policy makers and the public at large. It has thus been possible to familiarise the local players on the consequences of natural events, which become disasters only due to incorrect human intervention.

The main limit of the research presented is the lack of realism of SLR of the proportions put forward by Rahmstorf (2007), given the characteristics of the Mediterranean Sea. It can, however, be used for international comparisons using the same base scenario, and has been a useful tool for sensitising the local community.

The research could be usefully continued along three complementary paths: (i) Making the simulation results more user friendly. The purpose of this would be to raise the level of awareness in the population of the natural risks, and therefore favour better management of the area. From the maps, we could then move to three-dimensional simulations, giving users the possibility to interact; (ii) Incorporating the economic losses the community would suffer from the loss of housing stock, work places and infrastructure due to SLR into the analysis; (iii) Finally, considering the costs which the community would have to bear to control the effects and impacts of the SLR on the area.

ACKNOWLEDGMENTS

The research leading to these results received funding from the European Union's Seventh Framework Programme FP7/2007-2013 under grant agreement n° 244251 (SECOA project). Project website: www.projectsecoa.eu.

REFERENCES

Baarse G. & Rijsberman F.R. (1987) - *A policy analysis approach to the problem of sea level rise*. In: Wind H.Q. (1987, Ed.). *Impact of sea level rise on society*. 21-76, Balkema Publishers, Rotterdam, the Netherlands.

Borsa Immobiliare di Roma-BIR (2011) - *Listino ufficiale della Borsa Immobiliare di Roma. Valori correnti di mercato di Roma e provincia*. Tecnoborsa, Roma, Italy.

Bosello F., Nicholls R.J., Richards J., Roson R. & Tol R.S.J. (2012**) -** *Economic impacts of climate change in Europe: sea-level rise*. Climatic Change, **112**: 63-81.

Chang B., Guan J. & Aral M.M. (2014**) -** *Modeling spatial variations of sea level rise and corresponding inundation impacts: a case study for Florida, USA*. Water Quality, Exposure, and Health, **6**: 39-51.

Church J.A. & White N.J. (2006**) -** *A 20th century acceleration in global seal-level rise*. Geophysical Research Letters, **33**. doi 10.1029/2005GL024826.

Commission of the European Communities (2000) - *CORINE Land Cover*. http://www.eea.europa.eu/publications/COR0-landcover.

Cooper M.J.P., Beevers M.D. & Oppenheimer M. (2008) - *The potential impacts of sea level rise on the coastal region of New Jersey, USA*. Climatic Change, **90**: 475-492.

Cooper H.M., Chen Q., Fletcher C.H. & Barbee M.M. (2013) - *Assessing vulnerability due to sea-level rise in Maui, Hawaii using LiDAR remote sensing and GIS*. Climatic Change, **116**(3-4): 547-563.

Darwin R.F. & Tol R.S.J. (2001) - *Estimates of the economic effects of sea level rise*. Environmental and Resource Economics, **19**: 113-129.

Day J.W., Pont D., Hensel P.F. & Ibañez C. (1995) - *Impacts of sea-level rise on deltas in the Gulf of Mexico and the Mediterranean: the importance of pulsing events to sustainability*. Estuaries, **18**(4): 636-647.

den Elzen M.G.J. & Rotmans J. (1992) - *The socio-economic impact of seal-level rise on the Netherlands: a study of possible scenarios*. Climatic Change, **20**: 169-195.

Di Zio S. & Staniscia B. (2014) - *A spatial version of the Shang method*. Technological Forecasting & Social Change, **86**: 207-215.

Felsenstein D. & Lichter M. (2014) - *Social and economic vulnerability of coastal communities to sea-level rise and extreme flooding*. Natural Hazards, **71**: 463-491.

Fischhendler I., Karasin O. & Rubin Z. (2012) - *Handbook for institutional responses to coastal hazards*. Sapienza Università Editrice, Secoa Series Vol. I, Rome, Italy.

Geikie A. (1897) - *The founders of geology*. Macmillian and Co., London, UK.

Gornitz V., Couch S. & Hartig E.K. (2002) - *Impacts of sea level rise in the New York city metropolitan area*. Global and Planetary Change, **32**: 61-88.

Grant W.B. (1995) - *Lidar for atmospheric and hydrospheric studies*. In: Duarte F.J. (1995, Ed.) - *Tunable Laser Applications*, 1st ed. Marcel Dekker, New York, US.

Hennecke W.G., Greve C.A., Cowell P.J. & Thom B.G. (2004) - *GIS-based coastal behavior modeling and simulation of potential land and property loss: implications of sea-level rise at Collaroy/Narrabeen beach, Sydney (Australia)*. Coastal Management, **32**: 449-470.

Hoffman J.S., Keyes D. & Titus J.G. (1983) - *Projecting future sea level rise. Methodology, estimates to the year 2100, and research needs*. U.S. Environmental Protection Agency, Washington, D.C., US.

Holman I.P., Nicholls R.J., Berry P.M., Harrison P.A., Audsley E., Shackley S. & Rounsevell D.A. (2005) - *A regional, multi-sectoral and integrated assessment of the impacts of climate and socio-economic change in the UK*. Climatic Change, **71**: 43-73.

Intergovernmental Panel on Climate Change-IPCC (1990) - *Climate change. The IPCC impact assessment*. Australian Government Publishing System, Canberra, Australia.

Intergovernmental Panel on Climate Change-IPCC (2007) - *Climate Change. Contribution of Working Groups I and II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Istituto Nazionale di Statistica – ISTAT (2001a) - *XIV Censimento Generale della Popolazione e delle Abitazioni*. Istat, Rome, Italy.

Istituto Nazionale di Statistica – ISTAT (2001b) - *VIII Censimento Generale dell'Industria e dei Servizi*. Istat, Rome, Italy.

Khan A.Z., Le Q.X., Canters F. & Corijn E. (2013a, Eds.) - *Sustainability in the coastal urban environment. Thematic profiles of resources and their users*. Sapienza Università Editrice, Secoa Series Vol.III, Rome, Italy.

Khan A.Z., Le Q.X., Canters F. & Corijn E. (2013b. Eds.) - *Environmental conflicts in coastal urban areas: towards a strategic assessment framework for* *sustainable development*. Sapienza Università Editrice, Secoa Series Vol. IV, Rome, Italy.

Kjerfve B. (1991) - *Prospects of sea level change*. International Marine Science-IMS Newsletter, **57/58**: 4-5.

Kulpraneet A. (2013) - *Coastal household adaptation cost requirements to sea level rise impacts*. Mitigation and Adaptation Strategies for Global Change, **18**: 285-302.

Lan T.D., Almered Olsson E.G. & Alpokay S. (2014, Eds.) - *Environmental stresses and resource use in coastal urban and peri-urban region DPSIR Approach to SECOA's 17 Case Studies*. Sapienza Università Editrice, Secoa Series Vol. VI, Rome, Italy.

Li X., Rowley R.J., Kostelnick J.C., Braaten D., Meisel J. & Hulbutta K. (2009) - *GIS analysis of global impacts from sea level rise*. Photogrammetric Engineering and Remote Sensing, **75**: 807-818.

Lichter M. & Felsenstein D. (2012) - *Assessing the costs of sea-level rise and extreme flooding at the local level: a GIS-based approach*. Ocean & Coastal Management, **59**: 47-62.

Lin B.B., Khoo Y.B., Inman M., Wang C.H., Tapsuwan S. & Wang X. (2014) - *Assessing inundation damage and timing of adaptation: sea level rise and the complexities of land use in coastal communities*. Mitigation and Adaptation Strategies for Global Change, **19**: 551-568.

Martinich J., Neumann J., Ludwig L. & Jantarasami L. (2013) - *Risks of sea level rise to disadvantaged communities in the United States*. Mitigation and Adaptation Strategies for Global Change, **18**: 169-185.

McGranahan G., Balk D. & Anderson B. (2007) *The rising tide: assessing the risks of climate change and human settlements in low elevation coastal zones.* Environment and Urbanization, **19**: 17-37.

McKenzie-Hegder M., Gawith M., Brown I., Connell R. & Downing T. (2000, Eds.) - *Climate change: assessing the impacts - Identifying Responses - The first three years of the UK climate impacts programme*. UKCIP and DETR, Oxford, UK.

McLean R.F., Tsyban A., Burkett V., Codignotto J.O., Forbes D.L., Mimura N., Beamish R.J. & Ittekkot V. (2001) - *Coastal zones and marine ecosystems*. In: McCarthy J.J., Canziani O.F., Leary N.A., Dokken D.J. & White K.S. (2001, Eds.) - *Climate change 2001: impacts, adaptation, and vulnerability*. 343-379, Cambridge University Press, Cambridge, UK.

Meier M. F. (1990) - *Reduced rise in sea level*. Nature, **343**: 115-16.

Ministero dell'Economia e delle Finanze–MEF (2015) - *Dati e statistiche fiscali*, 2013, Available online: http://www1.finanze.gov.it/pagina_dichiarazioni/dichiarazioni.html (accessed on 1 February 2015).

Montanari A. (2013, Ed.) - *Urban coastal area conflicts analysis methodology. Human mobility, climate change and local sustainable development*. Sapienza Università Editrice, Secoa Series Vol. V, Rome, Italy.

Montanari A. (2014, Ed.) - *Mitigating conflicts in coastal areas through science dissemination: fostering dialogue between researchers and stakeholders*. Sapienza Università Editrice, Secoa Series Vol. VII, Rome, Italy.

Montanari A., Londei A. & Staniscia B. (2014) - *Can we interpret the evolution of coastal land use conflicts? Using Artificial Neural Networks to model the effects of alternative development policies*. Ocean & Coastal Management, **101**: 114-122.

Nicholls R. & Cazenave A. (2010) - *Sea-level rise and its impact on coastal zones*. Science, **328**: 1517-1520.

Parkinson R.W. & McCue T. (2011) - *Assessing municipal vulnerability to predicted sea level rise: city of Satellite Beach, Florida*. Climatic Change, **107**: 203-223.

Parry M.L., Canziani O.F. & Palutikof J.P. (2007) - *Technical summary. Climate change 2007: impacts, adaptation and vulnerability*. In: Parry M.L., Canziani O.F., Palutikof J.P., van Der Linden P.J., Hanson C.E. (2007, Eds.) - *Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change*. 23-78, Cambridge University Press, Cambridge, UK.

Parson E. A., Corell R. W., Barron E. J., Burkett V., Janetos A., Joyce L., Karl T. R., MacCracken M. C., Melillo J., Morgan M. G., Schimel D. S. & Wilbanks T. (2003) - *Understanding climatic impacts, vulnerabilities, and adaptation in the United States: Building a capacity for assessment*. Climatic Change, **57**: 9-42.

Pfeffer W.T., Harper J.T. & O'Neel S. (2008) - *Kinematic constraints on glacier contributions to 21st-century sea-level rise*. Science, **321**: 1340-1343.

Rahmstorf S. (2007) - *A semi-empirical approach to projecting future sea-level rise*. Science, **315**: 368-370.

Sahagian D.L., Schwartz F.W. & Jacobs D.K. (1994) - *Direct anthropogenic contributions to sea-level rise in the twentieth century*. Nature, **367**: 54-57.

Sahin O. & Mohamed S. (2014) - *Coastal vulnerability to sea-level rise: a spatial-temporal assessment framework*. Natural Hazards, **70**: 395-414.

SECOA N. 1.1 - *Report on sea level changes along metropolitan cities: past trends and future scenarios*, working paper, unpublished internal report.

Small C. & Nicholls R.J. (2003) - *A global analysis of human settlement in coastal zones*. Journal of Coastal Research, **19**: 584-599.

Solomon S., Qin D., Manning M., Chen Z., Marquis M., Averyt K.B., Tignor M. & Miller H.L. (2007, Eds.) - *IPCC Fourth assessment report (AR4). 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, UK and New York, NY, US.

Tarragoni C., Bellotti P., Davoli L., Raffi R. & Lupia Palmieri E. (2014) - *Assessment of coastal vulnerability to erosion: the case of Tiber river delta (Tyrrhenian Sea, Central Italy)*. Italian Journal of Engineering Geology and Environment, **2**: 5-16.

Titus J.G. & Narayanan V. (1996) - *The risk of sea level rise. A Delphic Monte Carlo analysis in which twenty researchers specify subjective probability distributions for model coefficients within their respective areas of expertise*. Climatic Change, **33**: 151-212.

Turner R.K., Subak S. & Adger W.N. (1996) - *Pressures, trends and impacts in coastal zones: interactions between socioeconomic and natural systems*. Environmental Management, **20**(2): 159-173.

van der Meulen F., Witter J. V. & Arens S. M. (1991) - *The use of a GIS in assessing the impacts of sea level rise on nature conservation along the Dutch coast: 1990-2090*. Landscape Ecology, **6**(1-2): 105-113.

Walker H. J. (1992) - *Sea level change: environmental and socio-economic impacts*. GeoJournal, **26**(4): 511-520.

Williams A.M. (2012, Ed.) - *Human mobility in coastal regions: the impact of migration and temporary mobilities on urbanization*. Sapienza Università Editrice, Secoa Series Vol. II, Rome, Italy.

Yin J., Yin Z., Wang J. & Xu S. (2012) - *National assessment of coastal vulnerability to sea-level rise for the Chinese coast*. Journal of Coastal Conservation, **16**: 123-133.

Zhang K. (2011) - *Analysis of non-linear inundation from sea-level rise using LIDAR data: a case study for South Florida*. Climatic Change, **106**: 537-565.

Received July 2015 - Accepted April 2016