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Risk assessment of climate change impacts on Mediterranean coastal wetlands. Application in Júcar River Basin District (Spain)

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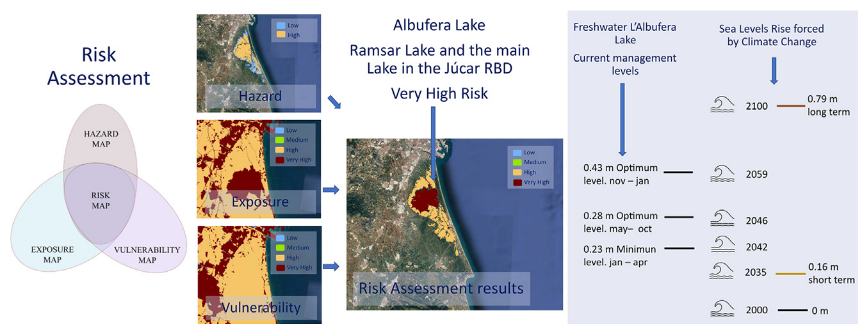
HIGHLIGHTS

- Climate Change SLR analysis in the Mediterranean coastal strip of Júcar RBD.
- GIS-based risk assessment: hazard, exposure, impact, vulnerability, and risk maps.
- Risk maps prioritize the areas where adaptation measures must be applied.
- 90% of the area affected by the SLR in Júcar RBD are freshwater wetlands.
- Mean sea level may reach Albufera of Valencia freshwater lake's level around 2040.

GRAPHICAL ABSTRACT



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ABSTRACT

Sea level rise (SLR) produced by climate change affects severely coastal ecosystems which are currently being impacted by sea level rise in many parts of the world. In relation with coastal wetlands, the most relevant induced effect will occur on water and soil's salt content, especially in areas below sea level. This could lead into a reduction of habitat for the wetlands' biota. In this context, this research assesses the SLR related risk in the Júcar River Basin District (JRBD). Hazard, exposure, impact, vulnerability, and risk maps have been elaborated. The design and application of measures is prioritized in those areas classified as Very High risk with the aim of improving coastal ecosystems' climate change adaptation.

In Western Mediterranean coast, average sea level (ASL) will rise 0.16 m (2026–2045) and 0.79 m (2081–2100) referred to the reference period (1986–2005). High-end scenarios indicate that ASL will rise 1.35 m–1.92 m (2081–2100). The risk analysis results show that 90% of JRBD area affected by SLR, corresponds to coastal wetlands. Half of the affected area belongs to L'Albufera de Valencia wetland with 32.44 km^2 below sea level, which represents a water volume of 42.64 hm^3 (2026–2045) and a surface between 72.53 and 138.96 km^2 representing from 118.36 to 289.70 hm^3 (2081–2100). In the case of L'Albufera de Valencia the impact will be throughout the 21st century, the average rate of SLR will leap from 4 to 11 cm per decade, therefore MSL will reach the current wetland levels by 2040–2045. This makes necessary to modify the lake's management rules, which will lead to an increase of 40 hm3 in water storage and a reduction in water's renewal time compared to current rates (from 15 to 5 times a year).

1. Introduction

Coastal wetlands are among the most valuable ecosystems in the world due the ecosystem services that they offer (Ricaurte et al., 2017). These ecosystem services are shoreline protection from storms and waves, storage, habitat provision for invertebrates, shorebirds and

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mammals, and cultural and recreational uses (Calder et al., 2019), serving also as breeding, resting, and feeding areas for birds (Saintilan et al., 2019) and it can contribute to carbon sequestration, mitigating the effects of climate change (Morant et al., 2020).

Coastal ecosystems are strongly vulnerable to sea level rise produced by Climate Change (Kelleway et al., 2017; Rayner et al., 2021). The expected impacts of climate change on marshes are sea level rise (Nicholls, 2004, Nicholls et al., 2014, Nicholls, 2015; Weisse et al., 2014; Spalding et al., 2014; Dasgupta et al., 2017), more frequent storms and larger wave heights, changes on river discharge, CO2 level rise and higher temperatures (Zhang et al., 2019; Chu et al., 2019). Sea level rise will increase the risk of permanent saltwater intrusions in coastal wetlands (Bailey et al., 2006) and suffering changes in groundwater flow patterns linked to coastal ecosystems (Kløve et al., 2014). This may cause an alteration in key abiotic stressors such as changes in flood patterns, salinity gradients, and sediment biogeochemistry (Adams, 2020). Saltwater intrusion will affect especially coastal aquifers which are already overexploited (Ranjan et al., 2006; Estrela et al., 2012), such as Mediterranean coastal aquifers (García-Menéndez et al., 2016), and coastal wetlands that interact with them (Pérez-Martín et al., 2014). The communities and ecosystems connected with coastal environments are particularly exposed to the current and future dangers of ocean change (Abram et al., 2019; Ferrarini et al., 2021).

Earth's temperature is increasing unequivocally and many of the changes observed since 1950 are unprecedented in decades or millennia. The observed globally averaged combined land and ocean surface temperature data as calculated by a linear trend show a warming of 0.85 [0.65 to 1.06] °C during the 1880 to 2012 period compared to pre-industrial times (1850–1900) (IPCC, 2014a). Human-induced warming has already reached about 1 °C above pre-industrial levels (1850–1900) at the time of writing Special Report on Global Warming of 1.5 °C (year 2018). By the decade 2006–2015, human activity had warmed the world by 0.87 °C (±0.12 °C) compared to pre-industrial times (1850–1900). If the current warming rate continues, the world would reach human-induced global warming of 1.5 °C around 2040 (IPCC, 2018)". As both reports indicate, the temperature has risen 0.87 °C since the pre-industrial era to the average value of the 2006–2015 decade and 1 °C if we include until 2018. This increase has already resulted in profound alterations on human and natural systems, such as the increase in droughts, floods and other types of extreme weather phenomena, sea level rise and biodiversity loss (Allen et al., 2018).

Sea level rise observed in the 20th century has had as main contributors the ocean thermal expansion and the glaciers melting (Church and White, 2011, Church et al., 2013). Total global mean sea level (GMSL) rises 0.16 m from 1902 to 2015. Ocean and Cryosphere in a Changing Climate (SROCCC) states that the rate of GMSL rise for 2006–2015 is 3.6 mm per year, about 2.5 times the rate for 1901–1990 of 1.4 mm per year (IPCC, 2019). The principal cause of global sea level rise since 1970 is anthropogenic forcing (Oppenheimer et al., 2019). Sea level rise will almost certainly accelerate during the 21st century due to global warming, but its magnitude remains uncertain (Nicholls and Cazenave, 2010; Wouters et al., 2013; Fürst et al., 2015) due to the potentially very large contribution of the Greenland and Antarctic Ice Sheet which constitutes a deep source of uncertainty (Ritz et al., 2015; Bamber et al., 2019). Mass loss from the Antarctic ice sheet over the period 2007–2016 tripled relative to 1997–2006 and for Greenland, mass loss doubled over the same period (IPCC, 2019).

The increase in global mean surface temperature in the late 21st century (2081–2100) relative to 1986–2005 is likely to be 1.1 °C to 2.6 °C under RCP 4.5, and 2.6 °C to 4.8 °C under RCP 8.5 (Stocker, 2014). It is projected that global mean sea level change relative to 1986–2005 will be 0.53 m in RCP 4.5 projection (Church et al., 2013) and 0.84 m in RCP 8.5 projection (IPCC, 2019) at the end of the XXI century. There is a 17% of probability that global mean sea level will exceed the sea level rise of the RCP 8.5 scenario (Ranger et al., 2013; Hinkel et al., 2015; Hinkel et al., 2019). For security reasons, it is convenient to consider other scenarios that overcome this sea level rise to inform stakeholders with low-uncertainty tolerance such as climate change adaptation researchers (Thiéblemont et al., 2019), named as High-End Scenarios. Also, events that are historically rare, such as today's hundred-year event, will be common by 2100 in all RCPs (Oppenheimer et al., 2019).

Sea level changes can substantially differ at regional scale due to the thermal expansion factor (Meyssignac and Cazenave, 2012) (IPCC, 2019). Projections of regional sea level change on European coasts at the end of the 21st century (RCP 8.5) show an average rise in sea level of 0.5 m on average and the maximum change in coastal sea level is projected in the North Sea and Mediterranean areas. (Thiéblemont et al., 2019).

The risk assessment is made up of three core elements: hazard, exposure, and vulnerability (Eq. (1)), (IPCC, 2014a) and it is convenient to know in which areas we should implement adaptation measures to reduce the risks associated with climate change.

$$\text{Risk} = \text{Hazard} \cap \text{Exposure} \cap \text{Vulnerability} \quad (1)$$

Hazard referred to the degree of a disaster, such as sea level rise projections, exposure referred to the land uses or environments exposed to hazard and vulnerability referred to the sensitivity of a system exposed to certain hazards as well as its inherent characteristics, such as its response, resistance, and resilience ability.

Feng and Chao (2020) develop a risk assessment and affirm that water resources in the northwest and north of China which are in high risk will be a source of concern in the next decades. Gussmann and Hinkel (2021) highlight that the integration of sea-level rise considerations into the adaptation policy would improve the effectiveness. Gissi et al. (2021) results strengthen the need of climate change studies at local-scale to identify adaptation measures. Kazakis et al. (2019) assess the aquifers vulnerability to seawater intrusion by assigning certain weights to the different elements (river, wetland, lagoon, distance from the shore, thickness of the aquifer). Gornitz et al. (2020) highlight that planned coastal defenses will need to be strengthened and relocated in some cases. Mehvar et al. (2019) evaluate the flood area due SLR under the climate scenarios of RCP 2.6 (0.25 m of Relative Sea Level Rise, RSLR), RCP 6.0 (1.18 m of RSLR), and RCP8.5 (1.77 m of RSLR) and evaluate the potential losses on food provision (5%), raw materials (16%), recreation/tourism and art (17%). Toimil et al. (2020) assume that more comprehensive risk frameworks are needed to determine risk due to various impacts and hazards, including multi-sector and vulnerability interactions. Carrasco et al. (2016) determine the need of evaluating the SLR impacts on coastal communities and the effectiveness and efficiency of adaptation interventions. Shi et al. (2020) conduct an exposure and vulnerability assessment of coastal wetland to obtain the evolution of the study area in recent years. Ibáñez et al. (2010) assess the effect of sea level rise in the Ebro Delta Wetlands using Surface Elevation Tables, marker horizons, ^{210}Pb techniques and illustrate the importance of sediment and freshwater subsidies in deltaic environments. There is no single approach to quantify future impacts of sea level rise on coastal retreats, as shown, for instance, for the Asturian coast (Toimil et al., 2017), the Balearic Islands (Enríquez et al., 2016) and the Júcar's coast (Serrano et al., 2020).

The Water Framework Directive (WFD) 2000/60/EC (European Commission, 2000), framed by the concept of integrated water resources management, include among its main objectives to achieve good state in all waterbodies and to prevent their deterioration. WFD aimed to promote a good state of waterbodies, by requiring the Member States to implement River Basin Management Plans (RBMPs). Fidelis and Rodrigues (2019) analyze the integration of climate change risks in hydrological planning such as sea level rise. The Spanish Strategy for Coastal Adaptation to Climate Change (SSCACC) includes saltwater intrusion and changes in groundwater level as impacts (Losada et al., 2019).

The motivation of this work is based on the knowledge gap on the impacts of climate change in relation to the sea level rise and its affection to coastal ecosystems, such as the wetlands of the Júcar River Basin District (JRBD). The proposed methodology allows the development of a risk assessment to identify the main exposed and vulnerable areas to reduce the risk of sea level rise due to climate change in coastal ecosystems. Hazard, exposure, impact, vulnerability, and risk maps have been obtained for Júcar River Basin District (JRBD) and risk maps prioritize the areas where adaptation measures must be applied. Getting a deep knowledge of the impacts of climate change in the most sensitive coastal areas will allow Júcar River Basin Authority to reduce vulnerability and propose climate change adaptation measures in the most affected areas, such as L'Albufera Lake of Valencia.

This work is part of the Project "Climate Change Adaptation Measures in the Júcar River Basin District" which aim is to include the impacts of climate change in the hydrological planning and its scope is Júcar River Basin District (Estrela Segrelles and Pérez Martín, 2020). Simulations were carried out to determine the effect of several sea level rise scenarios, including RCP 4.5 and 8.5 projections. For security reasons, it is convenient to consider other scenarios that overcome IPCC sea level rise to inform stakeholders with low-uncertainty tolerance such as climate change adaptation researchers. IPCC (2013) sea level projections, which are provided as a probable range (probability greater than 66%), but do not reflect the full range of uncertainties in sea level projections (Stephens et al., 2017). Informed by the latest literature, two high-end sea level rise scenarios have been considered. They are defined as plausible, although unlikely, high-impact sea-level scenarios. The first is based on the upper limit of the probable range, while the second follows a "worst model" approach (Stammer et al., 2019).

The manuscript is organized as follows: Section 2 describes extensively the methodology applied; Section 3 presents the results obtained for the several sea level rise scenarios, hazard, exposure and vulnerability maps and a discussion of the obtained results. Finally, Section 4 includes the main conclusions of this study.

2. Methodology and study CASE

2.1. Jucar River Basin District

The Júcar River Basin District (JRBD) (44.892 km^2 including coastal water bodies) is located on the Mediterranean side of the Iberian Peninsula. JRBD population is around 5 million inhabitants (JRBA, 2015). This work considers all the coastal wetlands located in the JRBD coastal strip: Marjal de Rafalell i Vistabella, Cuadro de Santiago and the Natura 2000 Network wetlands L'Albufera de Valencia, Prat de Cabanes, Santa Pola salines, Marjal dels Moros, Els Bassars – Clot de Galvany, Marjal i Estanys d'Almenara, Marjal de la Safor and Marjal Pego-Oliva (Fig. 1). In relation to the salinity of the analyzed wetlands, all of them except the Santa Pola Salines are freshwater, so the 85% of the waterbodies analyzed are freshwater.

The Digital Elevation Models (DEM) used in the development of the project, DEM25, have been obtained from The Download Center (CdD) of the National Center for Geographic Information (CNIG) http://centrodedescargas.cnig.es/CentroDescargas/. Digital Elevation Models contain altimetric information that represents the landform of the national territory. DEM25 Digital Elevation Model with first coverage 25 m grid spacing for a general evaluation. GRS: ETRS89 for the Iberian Peninsula (this system is compatible with WGS84). The study area corresponds to UTM Projection Zone 30.

L'Albufera de Valencia is the JRBD main wetland and is included in the list of wetlands of international importance defined by the Ramsar Convention. L'Albufera Natural Park occupies an area of 21,120 Ha of which, 2,394 Ha belong to L'Albufera lake that is surrounded by 14,100 Ha of rice fields. At present, a very small area of L'Albufera lake and its surroundings are below sea level. The rice fields are irrigated by ditches, locks and motors that pump the water so that the rice field never runs out of water. The cultivation lasts 5 to 6 months, although the fields are prepared, filling and emptying all year (IVIA, 2017). Rice cultivation is quite relevant in this area as it constitutes an important part of its economy. It is a key element in the Valencian culture and a tourist element of great magnitude.

2.2. Sea level rise

Mean Sea Level (MSL) projections provide the estimated increases of the MSL for future greenhouse gas emission scenarios RCP 4.5 and RCP 8.5. To develop this work, Sea Level Rise data have been obtained from the project "Preparation of the methodology and databases for the projection of climate change impacts on the Spanish coast (C3E Project)", developed by the Cantabria University in 2016 (C3E-Cantabria, 2016). For each climate model, annual mean sea level rise values are available from 2007 to 2100 (94 years), with a spatial resolution of 1.0°. These increases are referenced to the average value of the MSL in the period of reference 1986–2005. The models that were used in the C3E project to

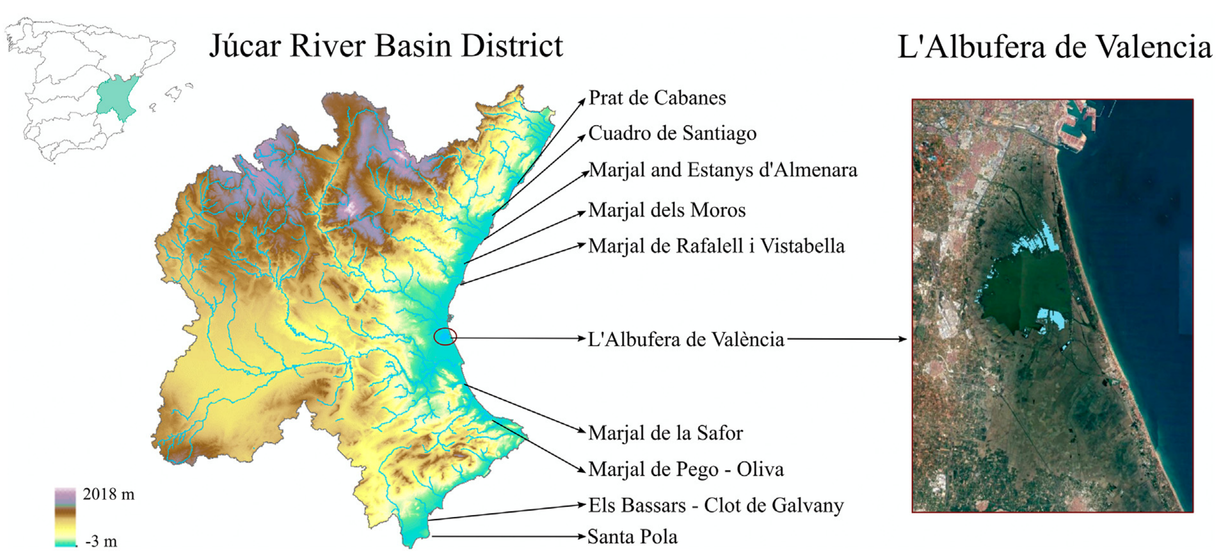

Fig. 1. Júcar River Basin District location including wetlands, DEM and L'Albufera de Valencia wetland in detail (in turquoise areas below MSL at present). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

generate the projections of the variable mean sea level are MIROC5, MIROC-ESM-CHEM, MIROC-ESM, IPSL-CM5A-MR, GFDL-ESM2G, GFDL-CM3, GFDL-ESM2M, CNRM-CM5, ACCESS1.0, ACCESS1.3, HadGEM2-ES, CCSM4, CSIRO-Mk3–6-0, CanESM2, MPI-ESM-LR, MPI-ESM-MR, MRI-CGCM3, NorESM1-M, NorESM1-ME N and INM-CM4. Further details are given in the Appendix. The MSL climate projection products were calculated using the multimodel mean ensemble of the sea-level anomaly in the period 1986–2005, and they also offer the associated uncertainty (standard deviation and limits (5%, 95%) of the 90% confidence interval). The database with the results for regional projections with complete information in NetCDF (network Common Data Form) format is housed in a repository that accessible through a Thredds server (TDS, Thematic Realtime Environmental Distributed Data Service) https://ihthredds.ihcantabria.com/thredds/PRME/catalog.html.

The ensemble mean regional Sea Level Rise (SLR) shows the following anomalies 0.15 [0.14, 0.16] m for RCP 4.5 and 0.16 [0.15, 0.17] m for RCP 8.5 in short term (2026–2045). For long term (2081–2100), it shows 0.43 [0.28, 0.58] m for RCP 4.5 and 0.58 [0.38, 0.79] m for RCP 8.5.

Since the publication of the IPCC AR5 (Fifth Assessment Report of the Intergovernmental Panel on Climate Change), the debate over long-term projections of GMSL has focused heavily on the potentially main contribution of the Antarctic ice sheet. It constitutes a deep source of uncertainty (DeConto and Pollard, 2016). Chen et al. (2017) analysis reveal that acceleration of thermal expansion in response to the anthropogenic forcing may emerge over the next decade, resulting in a further rate of acceleration compared to the one reported in their study and recent estimates.

The Greenland ice sheet contains enough water to raise the mean global sea level by 7.4 m (Shepherd et al., 2020). Fluctuations in the mass of the Greenland ice sheet occur due to variations in snow accumulation, runoff from meltwater, ocean melt, and icebergs. These changes have produced increases in surface runoff, iceberg detachment, retreat of the glacier end and ice flow, leading to widespread changes in the global sea level.

Delhasse et al. (2018) shown that Coupled Model Intercomparison Project Phase 5 (CMIP5) models cannot reproduce some changes observed in the last two decades in atmospheric circulation. They use a subset of CMIP5 models, including the second-generation Canadian Earth System Model (canESM2) and compare it with reanalysis. The global mean sea level can exceed the sea level rise of the RCP 8.5 scenario with a probability of 17% (Ranger et al., 2013; Hinkel et al., 2015; Hinkel et al., 2019).

Projections of future regional sea level are essential to support adaptation planning. Coastal adaptation researchers have relied on the IPCC (2013) sea level projections, which are provided as a probable range (probability greater than 66%), but do not reflect the full range of uncertainties in sea level projections (Stephens et al., 2017).

Therefore, high-end scenarios have been considered, which explore plausible, although unlikely, high-impact sea level scenarios beyond the probable range (Thiéblemont et al., 2019). High-end scenarios have a low probability of occurrence, but it is convenient to consider them due to the low-uncertainty tolerance that a risk analysis needs. They are particularly useful for planning the full range of coastal adaptation responses (Nicholls et al., 2014).

Thiéblemont et al. (2019) define the High-end scenarios as plausible, although unlikely, high-impact sea-level scenarios. The high-end A which is less pessimistic, defined based on the upper limit (percentile 95) of the RCP8.5 likely range, while the high-end B follows a "worst-model" approach which may exceed current modeling outcomes. High-end scenarios are designed based on representative IPCC RCP scenarios, assumptions about physical processes, subsets of models and based on elicitation from experts. Thiéblemont et al. (2019) defined the high-end A and B scenarios according to the Sterodynamic and the Barystatic components of global mean sea level rise (GMSLR).

The Sterodynamic Component is the relative sea-level change due to the sum of the global-mean thermosteric sea-level rise due to the thermal expansion of the ocean in response to global warming, and ocean dynamic sea-level change (which includes the inverse barometer correction). Thiéblemont et al. (2019) study focuses on coastal zones, where discrepancies in the spatial coverage of atmosphere and ocean general circulation model (AOGCMs) that participated in CMIP5 are particularly pronounced. Thiéblemont et al. (2019) note that regional influence of ocean dynamics and circulation changes on sea level is significant and they selected CMIP5 models that better represent the reality in Europe seas. The study follows the IPCC AR5 method to define the "likely-range" and calculate it as the standard deviation interval around the mean of multiple models. For the two high-end scenarios, the sterodynamic contributions for each cell in the grid are defined using the upper limit of the probable range of multiple models (high-end A) and the maximum value of the result of multiple models (high-end B, worst model estimate).

The Barystatic-GRD Components is the global ocean mass change associated with changes in mass of water and ice on land. It considers Glaciers, Greenland, Antarctic SMB, Antarctic DYN and Groundwater. Table 1 summarizes sea level rise contributors.

According to groundwater component, although Wada et al. (2016) recently showed that previous studies could have overestimated the contribution of groundwater depletion to sea level rise, as the total drainage of groundwater to the ocean was assumed without considering the pumped water remaining in the land (~20%).

The Regional sea-level change projections designed in Thiéblemont et al. (2019) are available online at https://www.mdpi.com/2073-4441/11/12/2607/s1.

The high-end scenarios include a greater rise in sea level associated with the possibility of a greater speed in the ice melting during the 21st century. For this reason, although being less probable, they are primarily considered because of security reasons in urban areas. The High-end A scenario, called moderate, represents an additional increase of 0.56 m and corresponds to the consideration of the upper values of the range, the 95th percentile, established by the results of the IPCC scenarios. On the other hand, the extreme high-end B scenario includes an additional rise in sea level of 1.13 m compared to the RCP8.5 50th percentile scenario, which corresponds to the consideration of a more accelerated melting of the Antarctic during the century. XXI, with a greater increase in sea level associated with the Antarctic, going from 0.16 m (50th percentile) to 0.8 m (extreme scenario).

In summary, sea level rise at the end of the 21st century for the RCP8.5 scenario associated with the 50th percentile is 0.79 m, and for the less probable scenarios but associated with greater ice melting, the sea level would rise, in the moderate scenario 1.35 m (High-End A) and in the extreme scenario 1.92 m (High-End B).

2.3. Methodology

Risk analysis of Climate Change allows to define the priority areas to apply adaptation measures and prevent the effects of climate change. This methodology is based on the determination of the Risk Map, which is the intersection between Hazard Map, Exposure Map and Vulnerability Map (IPCC, 2014a) (Fig. 2a).

Hazard maps, considered as events or physical trends related to the climate or its physical impacts (IPCC, 2014b), show the spatial and temporal distribution of a certain variable in the different proposed climate change scenarios. In this study, the hazard maps show the areas whose elevation is expected to be below the sea level for the future scenarios established for the JRBD (Fig. 2b).

The exposure map shows the presence of people, livelihoods, species, or ecosystems, environmental functions, services and resources, infrastructure, or economic, social or cultural assets in places and environments that could be negatively affected (IPCC, 2014b). In this work, the economic value of land uses is applied (Fig. 2b).

The impact maps, considered as the effects on natural and human systems (IPCC, 2014b), determine the impact degree caused by climate

Table 1
Global mean sea-level changes in the Western Mediterranean by 2100 relative to 1986–2005 of each stereodynamic and barystatic-GRD contribution for (left) the SROCCC median and likely range (in brackets), (middle) the high-end scenario A and (right) the high-end scenario B. (own elaboration based on Thiéblemont et al., 2019).

Sea level rise Western Mediterranean	Component	RCP8.5 IPCC SROCCC Percentile 50 2081–2100	High-end A moderate RCP8.5IPCC SROCCC Percentile 95 2081–2100	High-end B extreme The WORST MODEL 2081–2100
Sterodynamic component	Thermal expansion	0.30 m	0.35 m	0.36 m
Barystatic-GRD components	Glaciers	0.18 [0.10 to 0.26] m	0.26 m	0.29 m
	Greenland (SMB + DYN)	0.15 [0.09 to 0.28] m	0.28 m	0.34 m
	Antarctic (SMB)	−0.05 [−0.09 to −0.02] m	−0.02 m	0 m
	Antarctic (DYN)	0.16 [0.02 to 0.37] m	0.37 m	0.8 m
	Groundwater	0.05 [−0.01 to 0.11] m	0.11 m	0.11 m
	Total	0.49 [0.11 to 1] m	1 m	1.54 m
Total sea level rise		0.79 m	1.35 m	1.92 m

change in the analyzed case. The combination of hazard and exposure maps determine the impact degree that occurs on the JRBD coastal strip (Fig. 2b).

The vulnerability map, defined as the propensity or predisposition to be negatively affected, comprises a variety of concepts and elements that include sensitivity or susceptibility to damage and the lack of response and adaptation capacity (IPCC, 2014b). The vulnerability map depends on the impact analyzed and includes information of the system's adaptive capacity. In this work, the Vulnerability map shows the land capability to assimilate the impacts of sea level rise (Fig. 2b).

Finally, the risk maps have been defined as a combination of the impact and vulnerability maps (Fig. 2b). They show the eventual consequences in situations in which something valuable is in danger and the outcome is uncertain, recognizing the diversity of values, and it also referring the possibilities of adverse consequences for life occurring, the subsistence means, health, ecosystems, and species, economic, social, and cultural assets, services (including environmental services) and infrastructure (IPCC, 2014b).

The first step to carry out the risk analysis is to obtain the elevation data using a Digital Elevation Model and to collect data of sea level rise change for the different climate change projections. The second step is to contrast the elevation data with that of sea level rise. In this way, those areas where the elevation is expected to be below sea level in each projection have been detected.

The hazard map is composed of the areas whose elevation is expected to be below the sea level for the future scenarios. These areas are obtained with the interaction of the sea level elevation layer and the digital elevation model. Two levels of hazard have been established for each of the scenarios studied: High and Low. The portion of land where the sea level is expected to be greater than 0.3 m is considered to have a high level of hazard, whereas when it is less than 0.3 m a low level of hazards has been established.

The exposure map has been elaborated using the Spanish Land Occupation Information System SIOSE 2014. It is a land use database from Spain at 1:25000 scale which is composed with the information available from the Spanish Government. SIOSE 2014 has been obtained from The Download Center (CdD) of the National Center for Geographic Information (CNIG) http://centrodedescargas.cnig.es/CentroDescargas/.

Four levels have been established in the exposure map: Very High, High, Medium, and Low. Each land use has been classified in one of them according to the economic value of the land, as it is shown in the Table 2. Urban and industrial areas have been associated to a very high exposure level, agriculture land uses as a high exposure level and natural ecosystem uses are distributed in the four established groups, considering the ecosystems associated with freshwater bodies and beaches with a very high level of exposure, the land associated with forests and natural vegetation with a high level of exposure. The land uses where there is no vegetation have a medium level of exposure and the marshes, rocks, salines and sea are classified with a low level of exposure.

The vulnerability map shows the habitats capability or lack of ability to assimilate the impacts of sea level rise. The vulnerability map is the result of considering two indicators. One establishes the land vulnerability to the superficial penetration of the sea in the land and the other quantifies the vulnerability to the displacement of the saline wedge in the underground water bodies. Table 2 shows the assessment of surface vulnerability for four established levels: Very High, High, Medium, and Low. Vulnerability levels are related to the system's ability to face the adverse effects of climate change and its recovery capacity. It has been established that urban, industrial, and continental natural ecosystem areas such as beaches have a very high vulnerability because it is very difficult for them to recover from an increase in sea level by themselves. Agriculture, and forestry have a High level of vulnerability. A medium level of vulnerability has been assigned to some types of land uses and ecosystems related to coastal environments have been associated with a low level of vulnerability.

Vulnerability associated with the groundwater component has been assessed by using the results of the quantitative status assessment of the

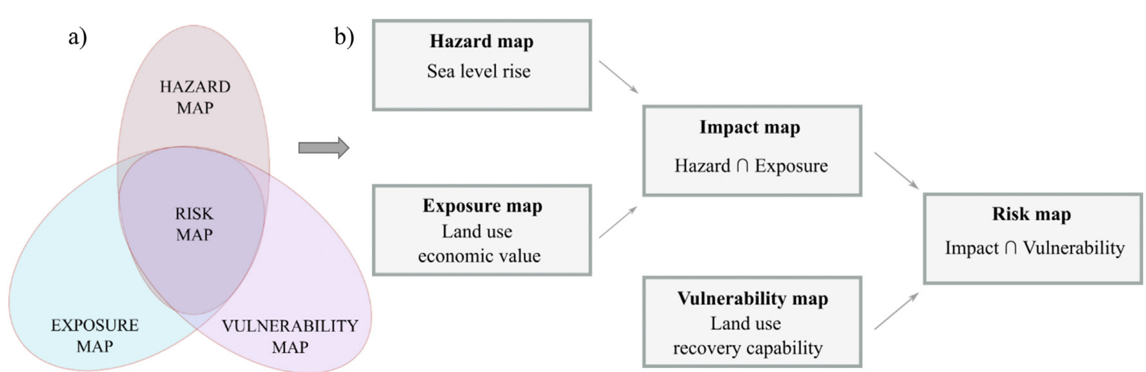

Fig. 2. a) Theoretical methodology based on (IPCC, 2013). b) Applied methodology for obtaining the JRBD risk map related to sea level rise.

Table 2
Exposure and vulnerability levels of the different land uses.

Land use classes	Land use subclasses	Exposure level	Vulnerability
Urban and supply	Airport	Very High	Very High
	Discontinuous a	Very High	Very High
	Discontinuous b	Very High	Very High
	Endowment service	Very High	Very High
	Expansion	Very High	Very High
	Port	Very High	Very High
	Reservoir	Very High	Very High
	Road or rail network	Very High	Very High
	Supply infrastructure	Very High	Very High
	Urban area	Very High	Very High
	Urban green area	Very High	Very High
	Waste infrastructure	Very High	Very High
Industry	Industrial	Very High	Very High
	Mining extraction	Very High	Very High
Agriculture	Agricultural and/or livestock facility	High	High
	Citrus fruit tree	High	High
	Combination of crops	High	High
	Combination of crops with vegetation	High	High
	Combination of woody crops	High	High
	Greenhouse	High	High
	Herbaceous crop	High	High
	Non citrus fruit tree	High	High
	Olive grove	High	High
	Other woody crops	High	High
	Vineyard	High	High
Natural ecosystems	Lake or lagoon	Very High	High
	Marsh	Very High	High
	Water course	Very High	High
	Wetland	Very High	High
	Artificial waterbody	High	High
	Coniferous forest	High	High
	Grassland	High	High
	Leafy forest	High	High
	Mixed forest	High	High
	Scrub	High	Medium
	Vegetation combination	High	Medium
	Bare ground	Medium	Low
	Beach, dune or sand	Very High	Very High
	Temporarily treeless by fire	Medium	Medium
	Rocks	Low	Low
	Saline	Low	Low
	Sea	Low	Low

groundwater bodies. It has been considered that if the quantitative state is not good, the vulnerability associated to surface will be one step higher than if the quantitative state of the groundwater body is good, in which the surface component will be considered to establish the level of vulnerability.

The quantitative status of coastal groundwater bodies data has been obtained from the Júcar River Basin Authority (JRBA) database. JRBA defines good quantitative status as the quantitative status achieved by a groundwater body when the long-term annual average rate of extraction does not exceed the available water resources. The exploitation level is evaluated based on the exploitation index (K) which is defined by the total pumping and the available resource ratio. If K index is greater than one, the groundwater body will not be in good quantitative state.

The interaction between the exposure map and the hazard map results in the impact map. It shows the exposure levels of those areas that are below sea level and divides JRBD in different levels of impact (Very High, High, Medium, and Low), calculated according to Table 3. The risk map is obtained with the combination of impact and vulnerability maps (Table 3). Four levels of risk have been established: Very High, High, Medium, and Low risk.

The risk map is useful to prioritize where to apply climate change adaptation measures. The areas where the level of risk is very high will be the first where risk reduction measures should be established.

3. Results & discussion

3.1. Hazard, exposure and impact maps

The hazard maps show the area below the sea in the CMIP5 and High-end climate change scenarios, which are showed in Table 4 along the total coastal strip of Júcar River Basin District.

Thiéblemont et al. (2019) long term SLR for the RCP 8.5 (percentile 50) scenario coincides in our study area with the SLR proposed by C3E-Cantabria (2016) for the RCP 8.5 (percentile 95) scenario. This means that scenarios have been actualized considering IPCC SROCCC and 0.79 m SLR is more likely to happen than 0.58 m SLR. Table 4 shows a summary of all the analyzed scenarios and highlights those that have been used in the risk assessment (in bold).

As result of the spatial distributed analysis (size cell 25 × 25 m), five hazard maps have been obtained. Currently, there are 11.68 km^2 below sea level and this variable increases throughout the 21st century, resulting in 44.26 km^2 in the short term (RCP 8.5 – CHJ_016) and 129.48 km^2 (RCP 8.5 – CHJ_079), 222.02 km^2 (High end A – CHJ_135), 317.03 km^2 (High end B – CHJ_192) in the long term. In relation to the previous surfaces, the percentage of the total surface that corresponds to a high level of hazard is 62% (RCP 8.5 – CHJ_079), 78% (High end A – CHJ_135) and 84% (High end B – CHJ_192).

The land uses analysis shows that natural ecosystems and agricultural areas predominate in JRBD. It is especially relevant that the main population centers (urban areas) are bordering the coastal strip. There are also extensive areas of agricultural use zones bordering the coastal strip, which is highly anthropized. The exposure map divides the JRBD into four exposure levels based on land economic value (total area percentage): Very High (4.52%), High (92.64%), Medium (2.49%) or Low (0.35%).

The impact map is the result of the hazard map and the exposure map combination and divide the JRBD into Very High, High, Medium and Low impact zones. Impact Maps are available in the Supplementary Materials.

Sea level rise mainly affects to the coastal wetlands in the JRBD (Fig. 3). The ten wetlands analyzed covers around 90% of the area below sea level

Table 3
Impact level classification derived from Hazard and Exposure and Risk level classification derived from Impact and Vulnerability.

Impact		Exposure levels			
		Low	Medium	High	Very High
Hazard levels	Low	Low Impact	Low Impact	Medium Impact	High Impact
	High	Low Impact	Medium Impact	High Impact	Very High Impact
Risk		**Vulnerability levels**			
		Low	**Medium**	**High**	**Very High**
Impact levels	Low	Low Risk	Medium Risk	Medium Risk	High Risk
	Medium	Medium Risk	Medium Risk	High Risk	High Risk
	High	Medium Risk	High Risk	High Risk	Very High Risk
	Very High	High Risk	High Risk	Very High Risk	Very High Risk

Table 4
Sea Level Rise (SLR) scenarios. CMIP5 scenarios and High-end scenarios.

Scenario name	Source	ΔSLR (m)	Percentile	Hypothesis
CHJ_000 Baseline	–	0		Baseline scenario (1986–2005)
RCP 4.5 CHJ_016	IPCC AR5 RCP4.5 (C3E-Cantabria, 2016)	0.15	50	Short term scenario (2026–2045)
RCP 8.5 CHJ_016	**IPCC AR5 RCP8.5 (C3E-Cantabria, 2016)**	**0.16**	**50**	**Short term scenario (2026–2045)**
CHJ_043	IPCC AR5 - RCP4.5 (C3E-Cantabria, 2016)	0.43	50	Long term scenario (2081–2100)
CHJ_058	IPCC AR5 - RCP8.5 (C3E-Cantabria, 2016)	0.58	50	Long term scenario (2081–2100)
CHJ_079	IPCC AR5 - RCP8.5 (C3E-Cantabria, 2016)	0.79	95	Percentile 95 scenario (2081–2100)
RCP 8.5 CHJ_079	**IPCC SROCCC - RCP8.5 Thiéblemont et al., 2019**	**0.79**	**50**	**Percentile 50 scenario (2081–2100)**
High end A CHJ_135	**IPCC SROCCC - RCP8.5 Thiéblemont et al., 2019**	**1.35**	**95**	**High-end scenario A Percentile 95 scenario (2081–2100)**
High end B CHJ_192	**Thiéblemont et al., 2019**	**1.92**	**Extreme**	**High-end scenario B The worst scenario**

of the JRBD, 97.4% (RCP 8.5 – CHJ_016) in the short term and 86.9% (RCP 8.5 – CHJ_079), 88.2% (High end A – CHJ_135) and 86.8% (High end B – CHJ_192) in the long term. Only in High-end scenarios the urban areas have significative values under the sea level, 10 km^2 (High end A – CHJ_135) and 27 km^2 (High end B – CHJ_192). The area below sea level is 1 km^2 (RCP 8.5 – CHJ_016) and 3.6 km^2 (RCP 8.5 – CHJ_079).

The evolution of the areas under sea level of the main wetlands analyzed are shown in Fig. 4. The entire coastal wetlands of the JRBD are affected by climate change. The impacts are more severe as the 21st century progresses. The results obtained for Els Bassars - Clot de Galvany and Marjal de Rafalell i Vistabella wetlands are remarkable due to the severe increase on the area below the sea level, which goes from 0.01 km^2 at present to roughly 700 km^2 in 2100 (High end B – CHJ_192).

L'Albufera of Valencia is the wetland with the largest area below sea level in the JRBD. More than 50% of the areas below sea level belong to this zone; furthermore it is a protected natural area (Nature Park of Spain) reason why it has been considered as high interest to zoom in on it in order to analyze the situation in detail (Fig. 5). L'Albufera and its surroundings are at Medium, High and Very high impact levels.

Within L'Albufera Nature Park, the lake has a very high impact level. It is a freshwater aquatic ecosystem protected by international instruments and must be preserved. L'Albufera lake is surrounded by rice fields, the main crop in the area, very sensitive to changes in salinity. In this agriculture area, a high and medium impact has been obtained depending on

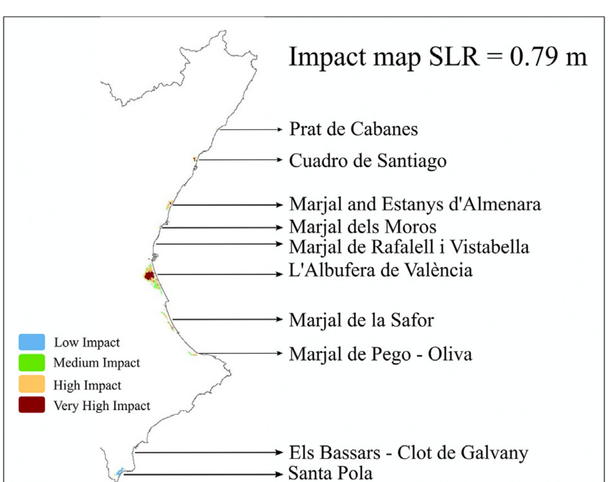

Fig. 3. Impact map in JRBD and zoom in L'Albufera (RCP 8.5 2081–2100).

whether the hazard is expected to be high or low. An area is defined as high hazard whether below sea elevation is greater than 30 cm.

In this scenario, is expected a reduction in rice cultivation because of the salinization processes of soils and water resources. Considering the possible partial abandonment of rice cultivation due the expected increase in marsh areas, with a greater extension of their typical vegetation. This will affect the usual sources of food for certain groups of birds linked to the wetland, mainly waders and Ardeidae which could see reduced both the number of individuals present and the number of species. (Palop Guillem, 2016). The group of ducks would be affected to a lesser extent by this change, even some specific species could be favored by a greater extension of marsh areas, since the reed beds are particularly favorable for the nesting of these species and can provide an additional surface of free water sheet that would increase the available fish fauna habitats.

Beaches are ecosystems affected by the SLR. The short-term impacts on these ecosystems are not major, except in some river mouths such as the Carraixet ravine and in the already eroded beaches where greater penetration of sea water is observed. In the long term, a greater area of affected beaches is observed, although still in a localized way, but it is in the High End scenarios where these elements are severely and generally affected. It has been observed that in JRBD areas where the dune ecosystems are preserved, the sea does not penetrate superficially in any of the scenarios proposed (including the extreme scenarios High-end A and High-end B). Therefore, preserved dune ecosystems can be considered as an efficient barrier to face sea level rise impacts on beaches, wetlands and coastal urban areas.

Fig. 6. shows examples of the barrier effect in wetlands and urban areas. a) L'Albufera de Valencia and b) Prat de Cabanes are JRBD main wetlands. Part of L'Albufera de Valencia is protected by the dune ecosystem, and this protection is seen in the lack of surface sea penetration whereas in Prat de Cabanes wetland, there is a complete surface sea penetration. On the other hand, c) and d) are examples of ecosystem protection by dunes in urban areas. Is expected the coastal neighborhoods of Valencia will be impacted by SLR. They are the most touristic areas of the city and have a great economic value. Canet de Berenguer has a well conserved dune ecosystem that protects the city from surface sea penetration.

3.2. Vulnerability and risk maps

The vulnerability map combines land capability to assimilate the sea penetration on land and the displacement of the saline wedge in groundwater bodies, so the high level of vulnerability predominates in the coastal strip.

The coastal groundwater bodies with a poor quantitative state are Plana de Vinaroz, Plana de Oropesa – Torreblanca, Plana de Castellón,

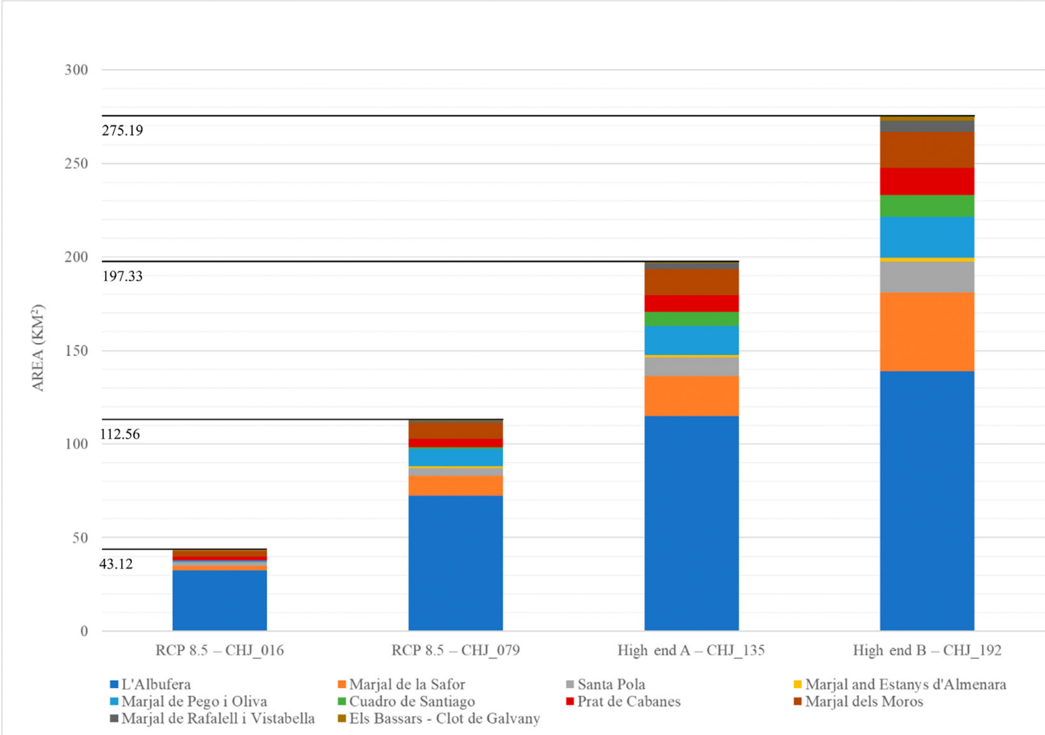

Fig. 4. Area Below Sea Level (km^2) in wetlands.

Plana de Sagunto, Plana de Gandía, Oliva – Pego, Ondara – Denia, Jávea. In those areas, the level of surface vulnerability increases one step in the vulnerability level.

The risk maps are prepared by combining the impact maps for each of the scenarios and the vulnerability map. They are available in the Supplementary Materials.

A considerable growth for high and very high risk areas in the JRBD is observed in Fig. 7. Very high areas are closely associated with coastal wetlands, beaches and urban areas.

Very high and High risk areas mainly coincide (90%) with the JRBD wetlands and its surroundings. L'Albufera is the wetland with the largest surface area at very high risk in the JRBD and therefore requires

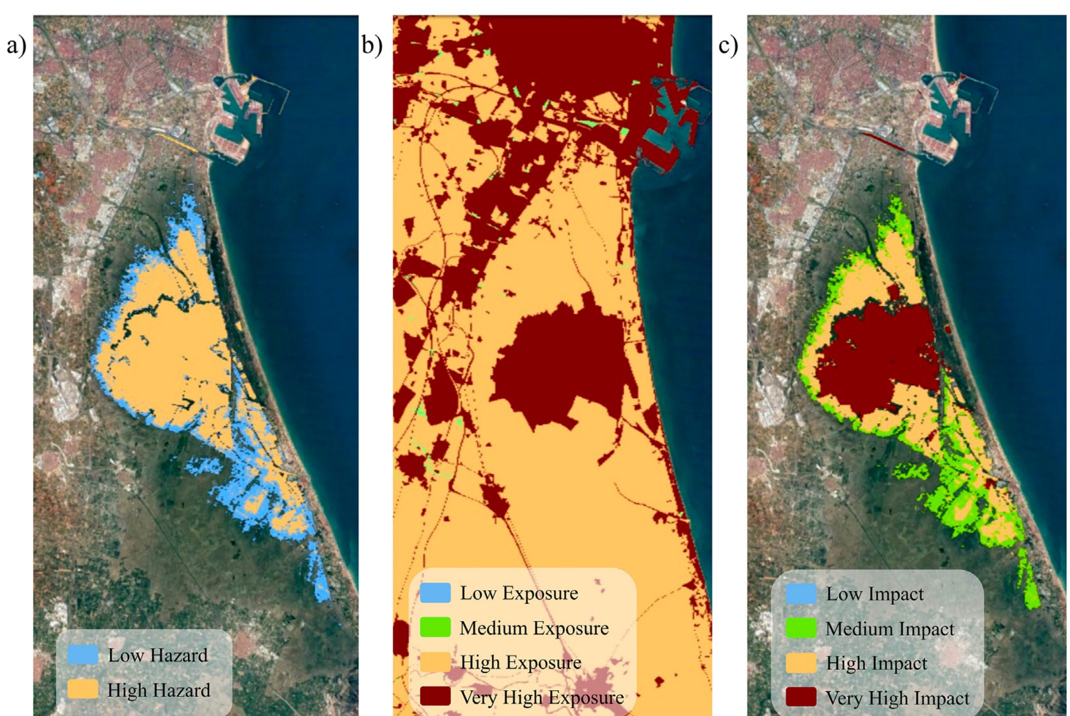

Fig. 5. a) Hazard Map, b) Exposure Map and c) Impact map. RCP8.5 2081–2100 scenario (RCP 8.5 – CHJ_079). L'Albufera.

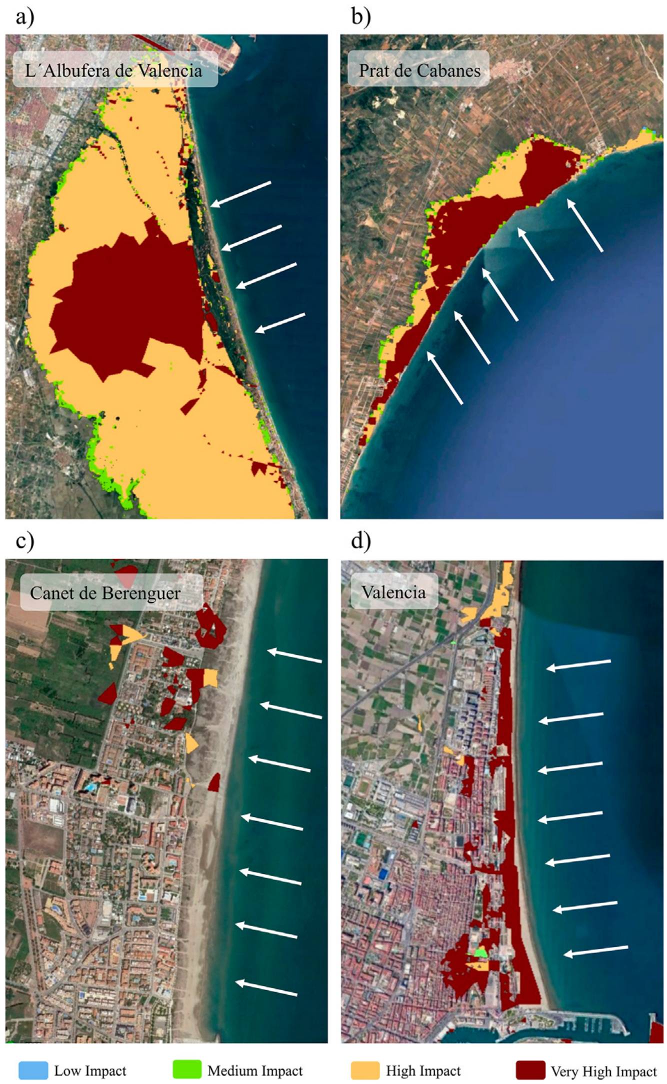

Fig. 6. Impact map (High end B – CHJ_192): a) L'Albufera de Valencia wetland, Prat de Cabanes c) Canet de Berenguer, d) Valencia city without protection.

special attention. Fig. 8 shows the evolution of the areas below sea level in the different proposed scenarios.

The sea level rise foreseen in future scenarios does not imply the direct entry of seawater into the lake and its surroundings, but it does represent an increase in the surface below sea level, which makes difficult to drain water and it can increase water salinity in the lake and the aquifer. The Very High risk area remains stable in the climate change scenarios studied because it is associated with the size of the lake. On the other hand, the High risk area increase in the different scenarios since it is associated with the agricultural zone of rice fields that surrounds the lake.

The rice cultivation areas will be seriously affected by the salinization of water resources. Therefore, there may be a material or economic impossibility of growing rice in this area in the future.

In the short term, RCP 8.5 – CHJ_016 establishes for the wetlands an area below sea level of 43.12 km^2, of which 32.44 km^2 correspond to L'Albufera. In the long term, RCP 8.5 – CHJ_079 establishes an area below sea level of 112.56 km^2 for the wetlands, 72.53 km^2 correspond to L'Albufera. Wetlands total area below the sea is multiplied by 4 in the short-term (RCP 8.5 – CHJ_016) and multiplied by 8 in the long-term scenario (RCP 8.5 – CHJ_079).

In relation to the extreme scenarios proposed, High end A – CHJ_135 establishes for the wetlands an area below sea level of 197.33 km^2, of which 114.98 km^2 correspond to L'Albufera. High end B – CHJ_192 scenario establishes for the wetlands an area below sea level of 275.19 km^2, 138.96 km^2 correspond to L'Albufera.

Water volume could be used to calculate the necessary drainage system to permit the current land uses.

In the baseline situation, L'Albufera's water volume related to the area being below sea level, this reaches 4.2 hm^3. In the short term, the volume may increase up to 42.6 hm^3 whereas in the long term, water volume is expected to be 82.40–289.7 hm^3 depending on the scenario as it is shown in Table 5. This outcome will cause a considerable increase in the water extraction costs in the rice cultivation areas during the agricultural practices.

To avoid the entrance of salt water in the lake due to the SLR, the redesign of the lake management levels in the forthcoming years is necessary. Currently, the monthly level of the lake is established as a minimum level of 10 cm above the base level indicated as level 0 marked on the reading scale installed in the Pujol gate during the rice growing season (May 1–31 October) and 25 cm during the winter flood (November 1–January 15). During the rest of the year, the average monthly level of the lake that will tend to be reached will oscillate between 5 and 10 cm above the base level (level 0 marked on the reading scale installed on the Pujol gate, which corresponds to 18 cm ASL - coinciding with the Maximum High Spring Tide) (ORDEN 5/2018).

Currently, sea level in Valencia increases at rate of 0.422 ± 0.064 cm/year. This have been measured in the Valencia Tide Gauge 3 from the REDMAR network. Data available on (http://www.puertos.es/es-es/oceanografia/Paginas/portus.aspx).

Based on the predictions of sea level rise made by global climate models, the rate of increase in mean sea level will rise from 4 cm per decade in the short term to a rate of 11 cm per decade in the long term, therefore sea level rise will reach the current levels of the L'Albufera

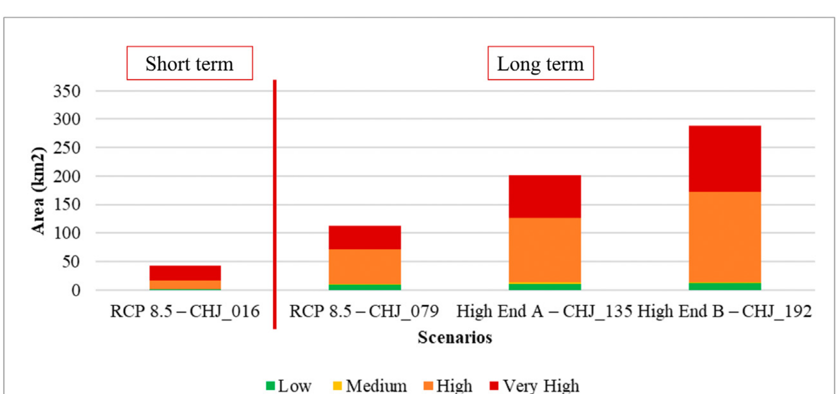

Fig. 7. Area with different Risk Level (RCP 8.5 – CHJ_016, RCP 8.5 – CHJ_079, High end A – CHJ_135 and High end B – CHJ_192).

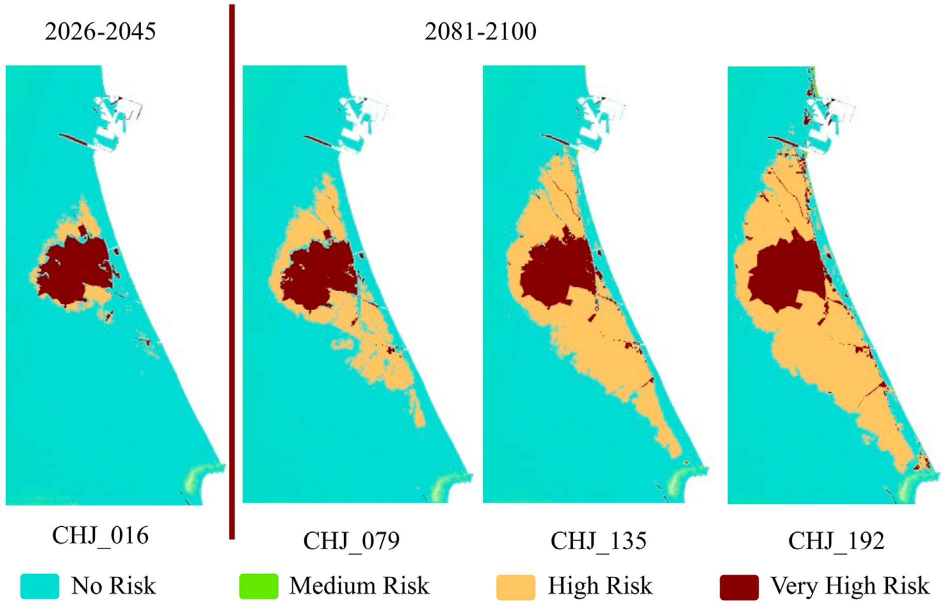

Fig. 8. Risk Maps for L'Albufera (RCP 8.5 – CHJ_016, RCP 8.5 – CHJ_079, High end A – CHJ_135 and High end B – CHJ_192).

lagoon between the years 2040 and 2045. If the current rate of 4 cm per decade is maintained, the level would be reached by the year 2053.

These results indicate that it is necessary to modify the lake management rules in the coming years to maintain lake levels higher than sea level which will generate higher water levels in the lake, and it will increase the volume of water stored in it.

Table 6 summarizes the results. New water levels lead to an increase of the lake water volume of 60–90 hm^3.

The water renewal time in the lake is a function of the volume of water inputs that it receives, and its volume stored. The number of renewals greatly affects the physical-chemical and biological quality of water because the flow of water through the system leads to the renewal rate and the elimination of pollutants. Therefore, it is a key aspect for the control of eutrophication and a determining factor in defining the response time of the lake to recover from changes in the nutrient loads entering the system. In the same way, the flow of water contributes to the creation of different habitats and facilitates the migration of species, which is why it is directly related to biodiversity. As the volume of the lake increases, the number of renovations decreases and therefore the lake is more vulnerable against the aforementioned effects (Estrela Segrelles et al., 2021). Currently, the lake receives contributions of approximately 300 hm^3/year, and it stores a volume of 20 hm^3. This implies a water renewal rate of 15 times a year. If this volume increases to 60 hm^3, the renewal rate would decrease to 5 times a year. If it is desired to maintain the renewal rate, it would be necessary to increase the contributions to the lake.

4. Conclusions

In the Mediterranean area, the models included in the CMIP5 indicate a rise in sea level of 0.16 m (RCP8.5) in the short term (2026–2045) and 0.79 m (RCP8.5) by the end of the 21st century (2081–2100). On the other hand, and based on safety criteria, the extreme proposed scenarios indicate rises from 1.35 m high-end A scenario to 1.92 m high-end B scenario by the end of the 21st century.

Table 5
Area below the sea in L'Albufera (km^2) and the percentage of the area that would be affected (%) in the proposed scenarios.

Scenario	CHJ_000 Baseline	RCP 8.5 CHJ_016 Short-term	RCP 8.5 CHJ_079 Long-term	High end A CHJ_135 Long-term	High end B CHJ_192 Long-term
Area below the sea (km^2)	5.07	32.44	72.53	114.98	138.96
Area affected of the Wetland (%)	2.4%	15.4%	34.3%	54.4%	65.8%
Water volume (hm^3)	4.19	42.64	118.36	219.53	289.70

Table 6
L'Albufera Lake water management levels and year expected to be reach by mean sea level for each scenario.

Period of the year	Water levels	Increase ratio m/decade				New water levels
		Current 0.04	RCP 8.5 CHJ_079 0.11	High end A CHJ_135 0.22	High end B CHJ_192 0.32	
May 1st–October 31st	0.28	2066	2046	2041	2039	**0.56**
November 1st–January 15th	0.43	2103	2059	2048	2044	**0.86**
January 16th–April 30th min	0.23	**2053**	**2042**	**2039**	**2038**	**0.46**
January 16th–April 30th max	0.28	2066	2046	2041	2039	**0.56**

The rise in sea level causes an increase in the area below the level of the mas in the JRBD. Lands that are below sea level tend to salinization due to the penetration of the saline wedge.

The IPCC scenarios produce a scenario with a water surface below the sea level of 96 km^2, which mostly (90% of the area) affects the JRBD main wetlands. They are classified as Very High risk and it is important to preserve these humid areas with high ecological value, most of which are protected with international instruments such as the RAMSAR list or the Natura 2000 Network, by applying risk reduction measures. In the scenarios associated with CMIP5, no significant impact on urban areas is observed.

The inclusion of high-end scenarios significantly increases the areas with very high risk, 142 km^2, and the effect on urban areas is significant (27 km^2). For this reason, improving knowledge about glacier and ice sheet contributions is crucial to obtain a better estimates of the impact-risk of sea level rise in urban areas.

The results of this study can address the lack of knowledge in relation to climate change impacts in the study area. The results can provide a better understanding for decision makers/politicians on how vulnerable the region is to the hazards caused by climate change and help decision makers to apply adaptation measures and reach a compromise between ecosystem conservation schemes and economic activities present in the coastal strip.

In all the proposed scenarios, L'Albufera de Valencia Lake and the agricultural area that surrounds it are the most affected areas in the whole JRBD. Regarding JRBD's area being below the sea level, a half is in this wetland. Therefore, it is a very high risk area in which the application of measures is necessary as a priority. The proposed adaptation measures are the establishment of a drainage system that prevents the flooding of agricultural land with water with high concentrations of salinity and the introduction of varieties of rice seeds more tolerant to the increase in soil's salinity and effective management of the gates that regulate the entry and exit of seawater into the wetland.

The studied scenarios point out an increase of the area below the sea level. In the short term, 2026–2045, (RCP 8.5 – CHJ_016) 32.44 km^2 will be below sea level rise, whereas in the long term, 2081–2100, (RCP 8.5 – CHJ_079, High end A – CHJ_135 and High end B – CHJ_192) the area above the sea will be 72.53–138.96 km^2. The results mean that water volume increases up to 42.6 hm^3 in the short term whereas in the long term, water volume is expected to be 118.36–289.7 hm^3 depending on the scenario.

This outcome will cause a considerable increase in water extraction costs for the rice cultivation areas during the agricultural practices and the soil salinization. Besides pumping water, some measures that could be implemented would be the increase of external freshwater contributions, the recharge of the aquifers to prevent the entry of the salt wedge and promoting changes in land use to establish less vulnerable land uses or reduce the vulnerability of current uses such as the introduction of changes in crops with species with a greater tolerance to salinity in the most hazard areas.

According to the current lake's water management levels, due to the expected increase in sea level, it will reach the lake's water management levels around the year 2045. Therefore, the lake's management levels will have to be redefined. This will lead into an increase in the lake's water volume, from the current 20 hm^3 to 60 hm^3. This will influence, among others, the lake's water renewal time, from the current 15 times per year to 5 times per year, so it will have important environmental and economic effects. Finally, it has been proof that well preserved beaches and dune ecosystems turn out to be an effective barrier against surface sea's penetration and they protect the most vulnerable uses even in the worst scenarios.

CRediT authorship contribution statement

Clara Estrela Segrelles: Writing – original draft, Data curation, Resources, Investigation, Conceptualization, Methodology, Software, Validation, Formal analysis, Visualization. **Gabriel Gómez Martinez:** Writing – review & editing, Investigation. **Miguel Ángel Pérez-Martín:** Supervision, Project administration, Funding acquisition, Writing – review & editing, Resources, Conceptualization, Methodology, Validation.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

Global climate models (GCMs) belonging to CMIP5 used in the (C3E-Cantabria, 2016).

GCM	Institution	Country	Atmospheric resolution (latitude°× length)
MIROC5	MIROC	Japan	1,40°× 1,40°
MIROC-ESM-CHEM	MIROC	Japan	2,79°× 2,81°
MIROC-ESM	MIROC	Japan	2,79°× 2,81°
IPSL-CM5A-MR	Institut Pierre-Simon Laplace	France	1,25°× 1,25°
GFDL-ESM2G	NOAA Geophysical Fluid Dynamics Laboratory	USA	2,0°× 2,0°
GFDL-CM3	NOAA Geophysical Fluid Dynamics Laboratory	USA	2,0°× 2,5°
GFDL-ESM2M	NOAA Geophysical Fluid Dynamics Laboratory	USA	2,0°× 2,5°
CNRM-CM5	Centre National de Recherches Météorologiques	France	1,40°× 1,40°
ACCESS1.0	CSIRO-BOM	Australia	1,25°× 1,90°
ACCESS1.3	CSIRO-BOM	Australia	1,25°× 1,90°
HadGEM2-ES	Met Office Hadley Centre	UK	1,25°× 1,90°
CCSM4	NOAA Geophysical Fluid Dynamics Laboratory	USA	0,94°× 1,25°
CSIRO-Mk3–6-0	CSIRO-BOM	Australia	1,87°× 1,87°
CanESM2	Modelling - Canadian Centre for Climate Modelling and Analysis	Canada	2,79°× 2,81°
MPI-ESM-LR	Max-Planck-Institut für Meteorologie	Germany	1,86°× 1,87°
MPI-ESM-MR	Max-Planck-Institut für Meteorologie	Germany	1,86°× 1,87°
MRI-CGCM3	Max-Planck-Institut für Meteorologie	Germany	1,12°× 1,12°
NorESM1-M	Norwegian Earth System	Norway	1,89°× 2,5°
NorESM1-ME N	Norwegian Earth System	Norway	1,89°× 2,5°
INM-CM4	Russian Institute for Numerical Mathematics	Russia	1,5°× 2,0°

Appendix B. Supplementary data

Impact Maps (RCP 8.5 – CHJ_016, RCP 8.5 – CHJ_079, High end A – CHJ_135, High end B – CHJ_192) Risk Maps (RCP 8.5 – CHJ_016, RCP 8.5 – CHJ_079, High end A – CHJ_135, High end B – CHJ_192). Supplementary data to this article can be found online at doi:https://doi.org/10.1016/j.scitotenv.2021.148032.

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