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Modeling Stakeholders' Perceptions in Participatory Multi-risk Assessment on a Deltaic Environment Under Climate Change Conditions

Margarita Katirtzidou[1] · Charalampos Skoulikaris[2] · Christos Makris[3] · Vasilis Baltikas[3] · Dionysis Latinopoulos[1] · Yannis Krestenitis[3]

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Abstract
Modern concepts in water resources management and related risk assessment necessitate participatory approaches with stakeholders having a key role in the respective processes. The objective of the article is to (i) integrate stakeholders' opinions and preferences on identified hazards, i.e., coastal flooding, water scarcity, and heat stress, derived by physically based numerical modeling under current and future climate change conditions and attributed in the form of an Integrated deltaic risk index (IDRI) at a specific case study area, and (ii) investigate whether and how the stakeholders' opinions differentiate the initial outputs coming from the mathematical models. Doing so, stakeholders' mapping was conducted in tandem with interviews for the detection of responsibilities, tasks, importance, and influence, followed by a structured questionnaire for registering the stakeholders' perception on climate change impacts and relevant estimated hazards at the same deltaic case study area. Thereafter, a stakeholder-based risk assessment model was constructed based on two methods: (a) stakeholders' opinion and answers about the impact of each identified hazard are equally taken into consideration, and (b) stakeholders are divided into groups and evaluated through multi-criteria analysis. Finally, the produced weights by the two methods are appropriately coupled with the identified hazards and resulted in the development of a Stakeholder Participatory multi-Risk Index (SPmRI) per method. The comparison of the produced SPmRIs with the IDRI, which was formulated without considering any stakeholders' participation, reveals noticeable differentiation of modeled outputs especially in cases of high index values, corroborating the need for stakeholders' opinion inclusion through the SPmRI approach. The proposed methodology fosters the interaction of stakeholders' perception with modeling-based hazard assessment as a modern tool for decision-making processes.

Keywords Stakeholders' participation · Hazard assessment · Risk perception · Participatory analysis · Deltaic area · Water resources management · Climate change · Nestos river

1 Introduction

It is only the last two decades that very important conceptual enhancements have been made in the management of water resources. Until the end of the twentieth century, the latter was mainly oriented to hydrotechnical works focusing on the engineering reliability and economic efficiency of projects covering water demands and securing human life and wealth [1, 2]. The transition from this dipole development scheme to the current one, where environmental protection and social prosperity forms part of the development equation, emerged with the sustainable development concept [3–5]. At the same period, although initially conceived in the 1950s [6], integrated water resources management (IWRM) established a multidisciplinary and multisectoral approach on setting the management of waters as part of a system rather than an autonomous process [7–9]. A step forward was initiated by upscaling water management to water governance [10–12], i.e., an umbrella concept that integrates technical management with policy, laws, economics, administration, and the society for enhanced

✉ Charalampos Skoulikaris
hskoulik@civil.auth.gr

[1] School of Spatial Planning and Development, Faculty of Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

[2] Division of Hydraulics and Environmental Engineering, School of Civil Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

[3] Laboratory of Maritime Engineering & Maritime Works, School of Civil Engineering, Aristotle University of Thessaloniki, 54124 Thessaloniki, Greece

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decision-making on best use, allocation, development, and management of water resources [13]. One of the latest advancements is attributed to public participation on contemporary water management decision-making processes, also known as stakeholders' participation [14–16]. The role of Information and Communication Technologies (ICTs) as an auxiliary tool in all phases of this development should not be neglected [17].

Stakeholders' participation schemes aim at delivering local knowledge on horizontal policies/solutions/measures of larger implementation scales [18]. They are, thus, considered "bottom-up" approaches that stabilize "top-down" approaches induced by centralized water governance [19, 20]. At the European Union (EU) scale, the importance of stakeholders' participation in decision-making has translated into policy with EU's Water Framework Directive (WFD) to necessitate stakeholder consultation and the active engagement with civil society in the implementation process of Directives (Article 14; [21, 22]). Newig and Koontz [23] outbid that the rationale for having stakeholder involved in the Directive's implementation process is to enhance the effectiveness of policy delivery, while numerous scholars evaluate this coupling [23–27]. Public participation in water management is not an issue solely of the EU, with the literature indicating various research approaches on the thematic [28–30]. Citizen's science [31, 32], i.e., scientific data collection and knowledge generation for hydrological sciences and water resources management by the public with the use of ICTs [33], or active involvement of people in implementation and operation of projects [34], also come under the public participation concept.

The interdependency between water resources and their users highlights the importance of including social components in modeling [35] and justifies the participation of stakeholders as a key principle of successful management [36, 37]. Literature shows various approaches, such as agent-based models (ABMs) used for simulating behavioral and social complexities in water management [38–40] or participatory and collaborative modeling [41–43] or multi-criteria analysis (MCA) [44–46], among others. Particularly, MCA outranking methods, e.g., ELimination Et Choice Translating REality (ELECTRE) family and PROMETHEE, focus on pairwise comparison of alternatives to discrete choice problems and are powerful tools for stakeholders, managers, and scientists in the context of water management and risk assessment [47–50].

Climate change is likely to increase the integrated risk by enhancing exposure to multiple hazards, i.e., by affecting the extent, increasing the frequency, and expanding the spatial distribution of extreme and disastrous events [51]. Hence, adopting multi-risk approaches for the assessment of climate change impacts is a critical issue [52]. The assessment is related to risks derived from both natural and anthropogenic hazardous events and in general focuses on identifying and evaluating the impact of related hazards (e.g., intense precipitation events, extreme heat events, droughts, floods, storm surges) on vulnerable study areas [53–55]. Multi-risk assessment is much more complex than methods focusing on a single-risk factor, e.g., determination of risk arising from a particular hazard in a specific area during a given period, since it analyzes each risk separately, by considering multiple hazards and vulnerability interactions, and leads to the evaluation of integrated risk indexes [56, 57]. Pomeroy and Douvere [58] designate that stakeholders' participation and involvement to risk management is integral to the success of decision-making and policy implementation.

Focusing mostly on environmental management of deltaic areas, the recent relevant literature reports on research concerning the participatory engagement of stakeholders in environmental risk assessment. Adomokai and Sheate [59] used semi-structured interviews and discussions by a prototype questionnaire to engage community participation in environmental decision-making for the Niger Delta, shedding light to future perspectives towards public awareness. Ritzema et al. [60] engaged the outcome of stakeholders' perception in modeling studies, to recommend improvements of the institutional capacity of drainage system management, in close cooperation with the policy-makers. Raaijmakers et al. [61] induced stakeholders' perceptions on flood risk to investigate hazard mitigation by a spatial multi-criteria analysis technique. Buchecker et al. [62] defined the role of risk perception in making flood risk management more effective by a procedure that allows the inclusion of stakeholders' perceptions on prevention measures in risk assessment. Nicholls et al. [63] proposed an integrated framework to analyze changing ecosystem services in deltas, focusing on the agricultural ecosystem services, inland and offshore capture fisheries, aquaculture, etc., for the Ganges–Brahmaputra-Meghna delta. Hagenlocher et al. [64] investigated ways to assess vulnerability and risk of deltaic socio-ecological systems when exposed to multiple hazards based on library analysis of indicators and participatory expert consultations during a series of stakeholder workshops. Pishyar et al. [65] combined Analytic Hierarchy Process, AHP-, and Technique for Order of Preference by Similarity to Ideal Solution, TOPSIS-based approaches in the assessment of desertification disaster risk, on a setup of 32 influential indices in Iran and around the globe through questionnaires, to produce a desertification risk map. Loizidou et al. [66] presented the DeCyDe-4 method, which is based on participatory decision-support concepts, used to develop community-based policy tools and action plans to combat marine pollution by plastic litter.

Our goal is to expand stakeholders' engagement and participation in decision-making on multi-risk issues of water resources management in river deltas. Therefore, in this

study, we propose a Stakeholder Participatory multi-Risk Index (SPmRI) to investigate the extent to which stakeholders' opinions and preferences may affect (positively, negatively, or neutrally) the outputs of a combined resource-based modeling approach focused on the hazard assessment and associated rudimentary estimation of risk on a deltaic environment. Therefore, we set up an analytic local stakeholders' mapping together with informational interviews. We then formulated a structured questionnaire depicting the stakeholders' perception on climate change impacts and relevant estimated risks derived by statistical treatment of modelled hazards and identified spatial exposure. The questionnaire was further analyzed, and stakeholder-based weights were attributed to three individual indexes for coastal floods, water scarcity, and heat stress on farming. Then, two alternative methods are adopted for the development of the SPmRI (both suitable for assessing the influence of stakeholders on the multi-criteria decision-making): (a) stakeholders' opinion and answers are equally taken into consideration and (b) stakeholders are classified into groups, weighted based on their interest in the case study area and then evaluated through multi-criteria analysis. The outputs are compared with a similar index that was developed for the same case study area without considering the stakeholders' engagement. Overall, the methodology enables the interaction of stakeholders' perception with pure physical-modeling assessment of hazards (e.g., floods or heat stress and water demand) as a valuable tool for decision-making processes related to climate change impact and resources management in deltas.

2 Conceptual Framework

2.1 Case Study Area and Reference Research

Our case study refers to the 55,000 ha deltaic area of the transboundary Mesta/Nestos river basin, which is almost equally shared between Bulgaria (upstream country) and Greece (downstream country) (Fig. 1). In the Greek part of the river catchment, the hydrosystem forms a typical water-energy-food-environment nexus, with hydropower generation, extensive irrigated agriculture in the delta, and environmental protection through maintenance of ecological flow for downstream riverine and estuarine ecosystems, to depend on the river's discharges [67]. Furthermore, the deltaic coastal zone activities such as fishing, fish farms, and tourism not only are contingent on sea waters but also may be exposed to the threat of storm surges [68, 69].

By taking into consideration the climate change-related hazards of (a) high temperature stress on agriculture, (b)

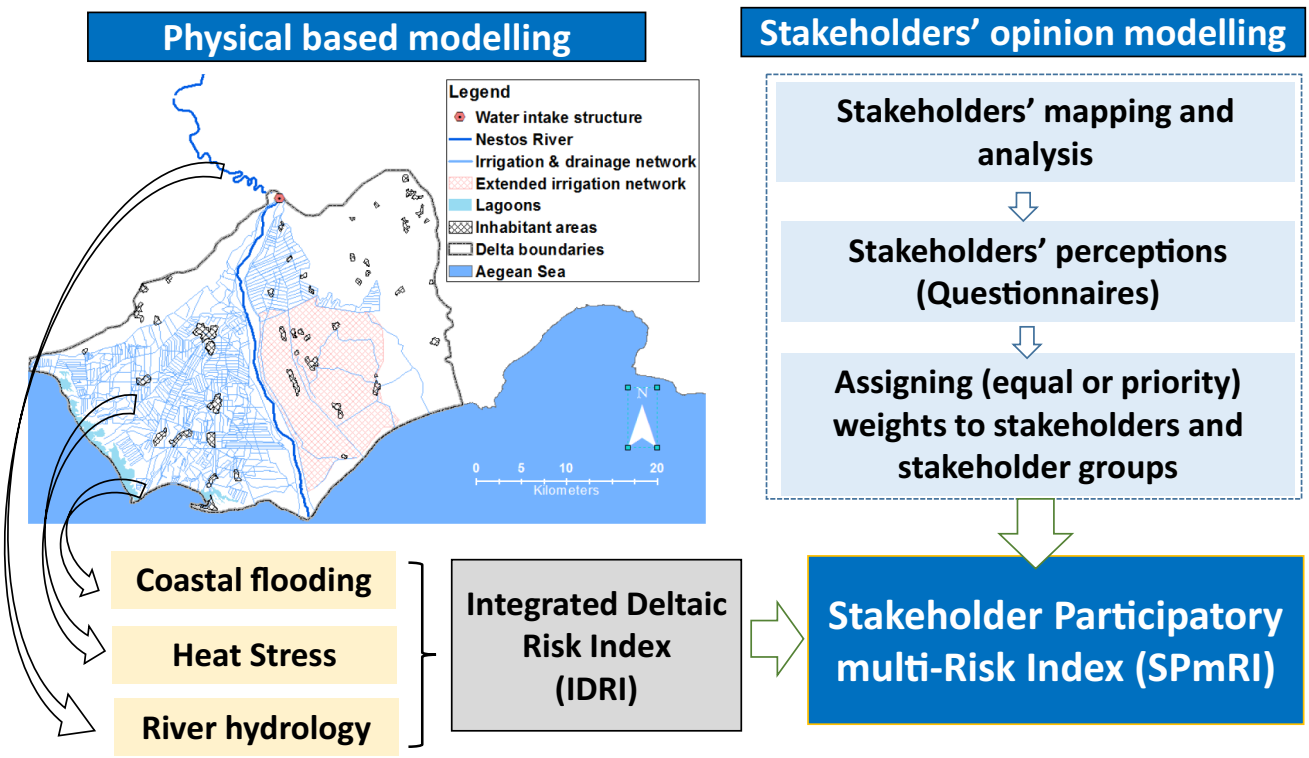

Fig. 1 Overview of the case study deltaic area and illustration of (i) physically based modeling processes leading to the Integrated Deltaic Risk Index (IDRI; left panel) and of (ii) stakeholders' opinion modeling processes for the development of the Stakeholder Participatory multi-Risk Index (SPmRI; right panel)

limited water availability for irrigation, and (c) episodically inundated coastal areas, Skoulikaris et al. [70] developed an elementary Integrated Deltaic Risk Index (IDRI) (Fig. 1) due to climate change. The IDRI was based on the synthesis of three individual indices, namely, the Coastal Flood Risk Index (CFRI), the Water Scarcity Risk Index (WSRI), and the Heat Stress Risk Index (HSRI), with input data coming from advanced numerical modeling for (a) storm surges and consequent coastal flooding (for CFRI), (b) hydrologic regime and hydropower production assessment at river basin scale (for WSRI), and (c) atmospheric temperature for heat stress assessment on agricultural irrigation (for HSRI). The simulations were implemented for two future periods: 2021–2050 (short-term future; STF) and 2071–2100 (long-term future; LTF), with climatic input data driven by three Regional Climate Models (RCMs),[1] based on two Representative Concentration Pathways (RCPs) for projected climatic scenarios.[2] In the proposed methodology, three water consumption scenarios (WCS), regarding irrigation, were also investigated: (a) a reference WCS (abbreviated as REF), based on the current irrigation patterns; (b) a climate change WCS (termed CC), proposing escalating demands on irrigation water supply applied to future climatic variables; and (c) a WCS suggesting extended irrigation (named EXT) networks by using the excess water volumes that are identified when CC WCS is applied (sustainable agricultural patterns).

The mathematical expression used for the development of the IDRI was the geometric mean of the individual risk indices (Eq. 1). The risk in Skoulikaris et al. [70] was defined as the coupling of hazard and exposure integrated in a spatiotemporal probabilistic framework (magnitude × spatial coverage probability × temporal probability of occurrence) yet neglecting the vulnerability (likelihood of measurable impacts on the deltaic region), while exposure is solely conceived in spatial terms, e.g., parts of regions that are economically important to the deltaic community. To this end, the individual risk indices were calculated on specific parts of the delta (e.g., HSRI only in the agricultural area and CFRI in the possibly affected coastal zone) and then upscaled to the possibly affected area of the deltaic region for each identified hazard by normalizing the indices' scores over the reference area (e.g., the coastal zone of the delta for the seawater inundation). Moreover, the Nestos delta is by large an agricultural area with extensive irrigation infrastructures; thus, the integrated indexing of the three major hazards to agriculture (water deficit, heat stress, and coastal inundation) is considered a representative approach to the specific case study area:

$$IDRI = \sqrt[3]{CFRI \times WSRI \times HSRI} = \left(\prod_{i=1}^{n} e_i p_i\right)^{\frac{1}{n}}, \quad (1)$$

where,

- e_i is the modelled hazard's magnitude for each simulation process
- p_i is the corresponding estimated probability of occurrence for each simulation process i ($n=3$), respectively, calculated as the product of the temporal (e.g., interannual) probability of occurrence of each hazard scenario with a 30-year return period, with the spatial probability of occurrence of the investigated hazards
- CFRI is the product of seawater flooded area normalized over the entire possibly affected area and of the corresponding flood probability in spatiotemporal terms
- WSRI is the product of agricultural area not expected to be irrigated, due to water scarcity phenomena, normalized over the entire possibly affected area, and the related water deficit probability in spatiotemporal terms
- HSRI is the product of heat stressed agricultural area, normalized over the entire possibly affected area, and the related HT occurrence probability

The outputs of Skoulikaris et al. [70] demonstrated the importance of integrated approaches, such as the IDRI implementation, recognizing that hazard and risk assessment via standalone indexing might be undermined as compared to the latter. For example, the coastal inundation index (CFRI) is expected to peak in the first half of the twenty-first century (Fig. 2a), while water scarcity phenomena (WRSI) are estimated to have a high to very high index score in the LTF period (Fig. 2b). Furthermore, the heat stress index (by HSRI) seems to increase towards the end of the twenty-first century under the RCP8.5 scenario (Fig. 2c). On the other hand, IDRI (integrally regarding all three hazards) is estimated to peak during the last thirty years of the twenty-first century, only for one combined case of RCM (GUF) and RCP8.5 scenario (Fig. 2d).

2.2 Integrating Stakeholders in Risk Assessment

Risk index assessment, as described in the previous section, was based on integrating technical (numerical simulations) aspects derived by three different domains (floods in the coastal zone, river's discharges availability, and deltaic agriculture stress) with management aspects. However, any region to be managed contains a range of stakeholders who are involved, interested, or affected by decisions regarding natural resources management [58]. Hence, a holistic

[1] The RCMs refer to CMCC-CCLM4-8–19 v.1 (CMCC), CNRM-ALADIN52 v.1 (CNRM), and GUF-CCLM-NEMO4-8–18 v.1 (GUF) (see Skoulikaris et al. [70] and Tolika et al. [94] for details).

[2] RCP4.5 and RCP8.5 (refer to Skoulikaris et al. [70] and Tolika et al. [94] for details).

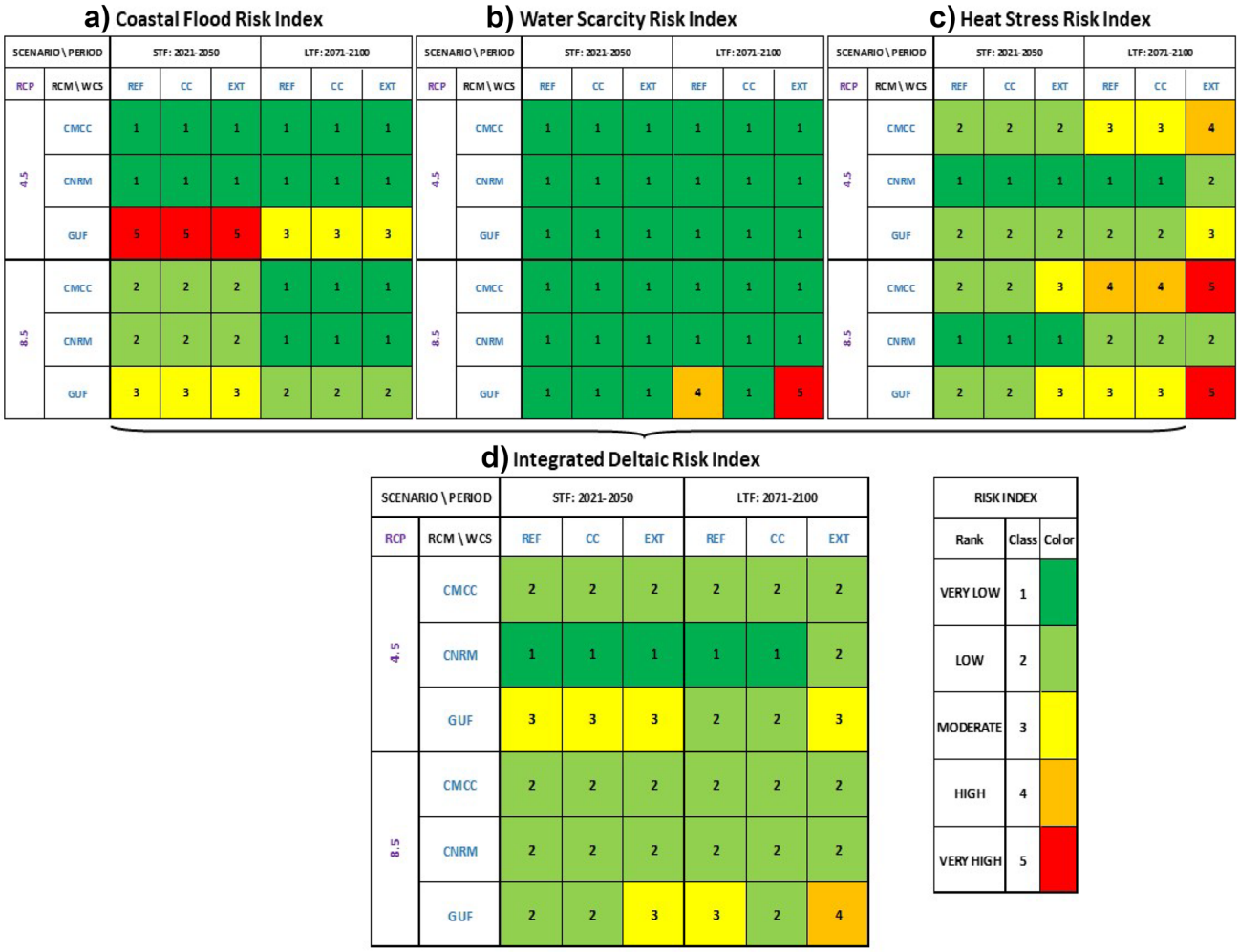

Fig. 2 Matrices for **a** CFRI, **b** WSRI, **c** HSRI, and **d** IDRI. Climate change impact identification is helped by graphing the differences in color scaling for each index, per water consumption scenario (WCS: REF, CC, EXT), climate modeling input (RCM: CMCC, CNRM, GUF), climate change scenario (RCP: 4.5, 8.5), and study period (STF, LTF). Thirty-six cases are given in total for the two 30-year periods of the twenty-first century (Courtesy of Skoulikaris et al. [70] under license of Environmental Modeling & Assessment, Springer)

risk assessment model should also involve stakeholders for demand-responsive climate change mitigation and/or adaptation strategies planning [71].

In the research, we take into consideration all stakeholders related to the water sector, i.e., resources' users and managers, for coupling their opinions, concerns, preferences, and priorities with the estimated IDRI, as conceptualized and calculated in Skoulikaris et al. [70]. To incorporate their opinion, stakeholders' mapping and analysis were conducted. The proposed methodological framework aims to integrate stakeholders' preferences/perceptions in risk assessment models and to investigate the differences between the two approaches (i.e., assessment with or without stakeholders' involvement). The followed procedure is summarized in the following steps (also presented in Fig. 1):

1. Stakeholders' mapping and analysis: preliminary interviews aiming to (a) identify the stakeholders and categorize them into groups (and sub-groups) and (b) give weights to these groups (and sub-groups) according to their importance/influence on the delta's management (see Sect. 3.1)
2. Exploring stakeholders' perceptions: structured questionnaire for (a) assessing stakeholder groups' perception on climate change impacts as well as on the relevant hazards and the associated risks in the study area and (b) assigning stakeholder-based weights to each individual index (CFRI, WSRI and HSRI) (see Sect. 3.2)
3. Constructing a stakeholder-based risk assessment model: Development of a participatory decision-making tool in the form of the proposed SPmRI approach (see Sect. 3.3)

3 Methodology

3.1 Stakeholders' Mapping and Analysis

To identify the stakeholders involved in assessing risks of climate-related hazards in the Nestos deltaic area, several in-person interviews were conducted with local elected officials, directors of public services, coastal managers and engineers, farmers, fishermen, and representatives of associations, cooperatives, unions, non-governmental organizations, and (technical, commercial, etc.) chambers. The interviewees were found to be familiar to the process since they had already participated in other similar developments [72]. We conducted in-person interviews due to their ability to provide qualitative measures. Through this method, we initially identified which stakeholder groups should be represented in our process.

It is noted that not all stakeholder groups (SG) have the same level of interest and, thus, may be less or more active and have different entitlements to a role in the management process [58]. Hence, a stakeholders' analysis was used to identify, differentiate (group), and study them in tandem with their interrelationships, current and (potential) future rights, interests, and objectives. The results of this analysis led to (a) the visualization of the organization chart of public administration in the study area and (b) the comprehension of the stakeholders' responsibilities. The mapping of stakeholders who were further involved in the current study is presented in Table 1.

Stakeholders' analysis also enabled the assigning of weights (scores) to stakeholders' sub-groups according to their importance/influence in the decision-making process. Following Pomeroy and Rivera-Guieb [73], a three-scale evaluation was adopted, according to which stakeholders should be weighted with a primary, secondary, or tertiary interest (or stake) in the study area and/or its resources. The groups who score high in most of the criteria may be considered "primary" stakeholders, while groups with lower scores are assumed as "secondary" and "tertiary" stakeholders, involved in a less important way in the decision-making process. The analysis was based on the following five key criteria adopted from Vierros et al. [74] which were considered equally important (i.e., equally weighted):

1. Existing rights, historical and cultural relations, and continuity of relationship to the resources (i.e., to the ecosystem services) (Criterion 1)
2. Degree of economic and social reliance on the resources (losses and damage) (Criterion 2)
3. Present or potential future negative impact of the activities on the resource base (Criterion 3)
4. Knowledge and skills for management of resources at stake (Criterion 4)

Table 1 Mapping of stakeholders in the Nestos Delta case study area

Stakeholder group	Group category	Description
SG1	Management body of Nestos Delta, Vistonida-Ismarida Lakes, and Thassos Island	SG1.1 Private legal entity, non-profit organization established by the Ministries of Environment, Agriculture, and Development
SG2	Administrative authorities (institutional stakeholders)	SG2.1 Department (Dept.) for Spatial and Environmental Policy* SG2.2 Dept. of Monitoring and Protection of Water Resources* SG2.3 Dept. of Farms and Fisheries * SG2.4 Kavala Forest Service* SG2.5 Dept. of Environment/Hydroeconomics** SG2.6 Dept. of Environmental Structures** SG2.7 Depts. of Plant, Animal Production, and Fishery** SG2.8 Dept. of Civil Protection** SG2.9 Dept. of Technical Services/Dept. of Environment (Municipalities of Nestos & Xanthi)
SG3	Fishery-related stakeholders	SG3.1 Agricultural Fishery Cooperative of Lagoons SG3.2 Institute for Fisheries Research
SG4	Agriculture-related stakeholders	SG4.1 Local Land Reclamation and Improvement Organizations SG4.2 Agricultural Cooperative, Association and Unions, and Producers Organization SG4.3 Agronomists Association of Kavala SG4.4 Geotechnical Chamber of Greece
SG5	Non-governmental organizations (NGOs)	SG5.1Hellenic Ornithological Society, Greenpeace
SG6	Other stakeholders	SG6.1 Public Power Corporation of Greece SG6.2 Keramoti Port Authority

*Authorities belonging to the Decentralized Administration of Macedonia and Thrace

**Authorities belonging to the Region of East Macedonia and Thrace

5. Interest and degree of effort in the management process (Criterion 5)

Table 2 presents the stakeholder weights based on the five abovementioned criteria as well as the number of participants per sub-group and group, with the participants being the higher ranked employees of each group category. The weights' attribution was an expert judgment procedure, i.e., the semi-structured preliminary interviews' outputs on the responsibilities, tasks, and power of influence of each group in the decision-making process, together with the information on the legal jurisdiction of each authority resulted to the initial weighting scores. For example, SG1 (i.e., the Management Body of Nestos Delta, Vistonida-Ismarida Lakes, and Thassos Island) was evaluated as having high existing rights on the resource (Criterion 1), high knowledge (Criterion 4), and interest in the management process (Criterion 5), while it is characterized by a relatively low level of economic and social reliance (Criterion 2) and by a very low (negative) impact of its activities on the resource base (Criterion 3). On the other hand, all the administrative authorities (sub-groups of SG2) were found to have high existing rights on the resource (Criterion 1), a relatively lower level of economic reliance, and a lower impact of their activities on the resource (Criteria 2 and 3). It is also worth mentioning that no specific pattern was observed on SG3 and SG4, as their score (per criterion) varies within their sub-groups of stakeholders.

3.2 Exploring Stakeholders' Perceptions

Subsequently, a more detailed analysis is made regarding the opinion and perception of individual stakeholders on heat stress, coastal floods, and water scarcity (lack of irrigation water), under current and future (projected climate change) conditions. This analysis was carried out by means of a structured online questionnaire survey (see Appendix for the questionnaire's structure). The survey results were used to assign weights to each individual index (CFRI, WSRI, and HSRI) and then to identify and estimate an updated form of the IDRI, viz., the proposed integrated index related to climate change, specifically for the studied deltaic area.

The questionnaire survey was carried out between June and September 2020, and 47 stakeholders were sampled and answered the online questionnaire. Specifically, we received 6 responses from SG1, 24 responses from SG2, 3 from SG3, 9 from SG4, 2 from SG5, and 3 responses from SG6. Focusing on the respondents' individual characteristics, 58.5% were males, nearly 80% were between 40 and 60 years old, while no one was under 30 years old. The majority of respondents (over 95%) had a university degree or higher qualification, while 14.2% had a PhD. Most of

Table 2 Nestos Delta stakeholder analysis

Stakeholders' sub-groups	Stakeholders' evaluation (weight) according to each criterion						
	Criterion 1	**Criterion 2**	**Criterion 3**	**Criterion 4**	**Criterion 5**	**Number of Participants**	**Participants per SG**
SG1	H	L	L	H	H	6	6
SG2.1	H	L	L	M	H	3	24
SG2.2	H	L	L	H	H	4	
SG2.3	H	L	L	H	H	3	
SG2.4	M	L	L	L	L	2	
SG2.5	H	L	L	M	M	2	
SG2.6	H	L	L	M	M	3	
SG2.7	H	L	L	H	H	2	
SG2.8	M	L	L	L	M	2	
SG2.9	M	L	L	L	M	3	
SG3.1	H	H	H	L	L	1	3
SG3.2	L	L	L	H	H	2	
SG4.1	H	M	H	H	H	3	9
SG4.2	H	H	H	M	M	3	
SG4.3	L	L	M	M	M	1	
SG4.4	L	L	L	H	M	2	
SG5	L	L	L	M	H	2	2
SG6.1	H	H	H	M	M	1	3
SG6.2	L	L	L	M	M	2	

H high, *M* medium, *L* low interest or stake

the respondents (78%) were employed in the tertiary sector (administrative/public authorities or Management Body of the Natural Park), 12.2% were employed in agriculture, while only 7.4% were employed in fisheries and aquaculture (lagoons-related activities). A second employment was also reported among the stakeholders, as 24.5% of them have a second job in agriculture and 2.4% in fish farming and tourism. The disparity observed in the number of participants per group, e.g., institutional stakeholders (SG2) accounts for about 50% of the participants, is related to the numerous water-relevant sub-authorities that ought to be represented in this process. The aim was to collect two or three answers per group (or sub-group), giving though a flexibility to single contact person appointment (e.g., SG3.1, SG4.3, and SG6.1), or multiple answers in case of sub-groups with multidimensional organization and relevant multidisciplinary scientists/experts (e.g., SG1.1). Nevertheless, the apparent disproportion between SGs answers is addressed through the weighting approaches. Particularly, the stakeholder-based risk assessment model examines the stakeholders´ opinions averagely per group to smooth out the observed disparity and to prevent the group or groups with many participants from determining the decision-making process.

3.3 Constructing a Stakeholder-based Risk Assessment Model

The answers of local stakeholders concerning their perception on projected future hazard-related impacts leading to the estimation of risks were linked to the following: (i) coastal inundation (Questions 12–14, in Appendix Table 3); (ii) water scarcity (Questions 1–3 and 7–11, in Appendix Table 3); and (iii) heat stress (Questions 4–6, in Appendix Table 3). All answers were processed to determine the relative weight that they give to specific identified hazards in the case study region. The weights that account for coastal floods (W_{CF}), water scarcity (W_{WS}), and heat stress (W_{HS}) were calculated in two ways and thereafter used for the assessment of the proposed Stakeholder Participatory multi-Risk Index (SPmRI):

A. Stakeholders' opinion and answers per group were equally taken into consideration, and W_{CF}, W_{WS}, and W_{HS} are assigned by Eq. (2), with the integrated weight (W) coming from Eq. (3):

$$W_{CF}, W_{WS}, W_{HS} = \frac{\sum_{k=1}^{n} w_k}{n}, \tag{2}$$

$$W = W_{CF} + W_{WS} + W_{HS}, \tag{3}$$

where w_k is the weight attributed to each of the n stakeholders (averaged per group) for each specific future hazard, which follows a 5-point Likert scale (1, not important; 2, slightly important; 3, fairly important; 4, important; 5, very important). W_{CF}, W_{WS}, and W_{HS} are normalized on 0–1 scale.

The weighted risk indexes W_{CFRI}, W_{WSRI}, and W_{HSRI} are coming from Eqs. (4–6) respectively, with CFRI, WSRI, and HSRI being the coastal flood, water scarcity, and heat stress indexes respectively, as identified in Skoulikaris et al. [70].

$$W_{CFRI} = \frac{W_{CF}}{W} \times CFRI, \tag{4}$$

$$W_{WSRI} = \frac{W_{WS}}{W} \times WSRI, \tag{5}$$

$$W_{HSRI} = \frac{W_{HS}}{W} \times HSRI. \tag{6}$$

For this specific approach, the proposed SPmRI is given by the following equation (Eq. 7):

$$\mathrm{SPmRI}_A = W_{CFRI} + W_{WSRI} + W_{HSRI}. \tag{7}$$

B. In the second approach, stakeholder groups (SGs) are evaluated, based on the five criteria of Table 2. To do so, multi-criteria analysis is performed by using the PROMETHEE methods (http://www.promethee-gaia.net/) [75, 76], which are outranking approaches providing a complete ordering of decision options. The underlying idea of this approach is to perform principal component analysis (PCA) on the uni-criterion net flows assigned to each feasible action. The starting point in this analysis was to define a preference function, $P_j(i,i')$, for each pair j of alternative i versus alternative i', where $i \neq i'$ [75]

$$P_j(i,i') = \begin{cases} O & if\ u_{ij} \geq u_{i'j} \\ u_{ij} - u_{i'} & if\ u_{ij} > u_{i'j} \end{cases}. \tag{8}$$

An integrated preference index, π, incorporating the weights, is defined as follows:

$$\pi_{(i,i')} = \sum_{j=1}^{m} P_j(i,i')w_j. \tag{9}$$

As each alternative faces (n-1) other alternatives, a positive and negative outranking flow, φ, is determined by the following:

$$\varphi_{(i)}^{+} = \frac{1}{n-1} \sum_{i'=1}^{n} \pi(i,i'), \tag{10}$$

$$\varphi_{(i)}^{-} = \frac{1}{n-1} \sum_{i'=1}^{n} \pi(i',i). \tag{11}$$

The overall score for each alternative is then determined by calculating the net outranking flow, $\varphi_{(i)}$:

$$\varphi_{(i)} = \varphi^{+}_{(i)} - \varphi^{-}_{(i)} \tag{12}$$

where $\varphi_{(i)}$ is normalized on a 0–1 scale. A zero value indicates the least relevant SG, while a value equal to 1 indicates the most relevant and involved SG with the studied hazards/risks. The weights for risk indices, W_{CF_m}, W_{WS_m}, W_{HS_m} are identified:

$$W_{CF_m}, W_{WS_m}, W_{HS_m} = \sum_{m=1}^{m_{max}} \frac{\sum_{k=1}^{j} w_{k,m}}{j}, \tag{13}$$

where $w_{k,m}$ is the weight that each SG ($m = 1, \ldots, m_{max}$) attaches to each specific future projection of a hazard (reflecting their perceived level of risk) and j is the number of answers given by each group. The weight w_k follows once again a (qualitative) classification of risk, using a 5-point Likert scale (1, not important; 2, slightly important; 3, fairly important; 4, important; 5, very important).

In this case, W_{CFRI_m}, W_{WSRI_m}, and W_{HSRI_m} are calculated by Eqs. (14–16) for each SG respectively:

$$W_{CFRI_m} = W_{CF_m} \times CFRI, \tag{14}$$

$$W_{WSRI_m} = W_{WS_m} \times WSRI, \tag{15}$$

$$W_{HSRI_m} = W_{HS_m} \times HSRI. \tag{16}$$

Finally, in this second approach, the proposed SPmRI is determined by the following equation (Eq. 17):

$$\mathrm{SPmRI}_B = \sum_{s=1}^{m} w_{SG} \times \left(W_{CFRI_m} + W_{WSRI_m} + W_{HSRI_m}\right), \tag{17}$$

where w_{SG} is the stakeholder group (SG) weight and is assumed to be equal to the normalized $\varphi_{(i)}$.

It should be noted that both indexes (SPmRI_A and SPmRI_B) were calculated for each combination of RCM, RCP, WCS, and time period leading to 36 implementation cases in total (future scenarios). The index values were normalized over their min–max range, to make our results directly comparable to our previous study results (IDRI) [70], by following a classification ranging from very low to very high risk (corresponding to a five-scale ranking system).

4 Results

4.1 Questionnaire Analysis

4.1.1 Climate Change Impact Awareness

Stakeholders were first asked whether water scarcity, heat stress, or episodic coastal inundation phenomena have been observed in the past or are expected to occur in the future. Figure 3 portrays the cumulative percentages of stakeholders' answers about their awareness and concern on climate change impacts of coastal flooding, water scarcity, and heat stress in Nestos Delta. A 53.7% of the stakeholders stated that climate change had a negative effect on irrigation water supply in the past decades, while 41.5% of them declared that they were not aware of this issue. The answers also highlighted a low level of knowledge about heat stress phenomena as almost half of the respondents reported that they were unaware of this issue (thermal stress), while only 39% of them stated that temperature increase has already affected the agricultural sector. Finally, 53.6% of the stakeholders reported not being aware of extended coastal inundation

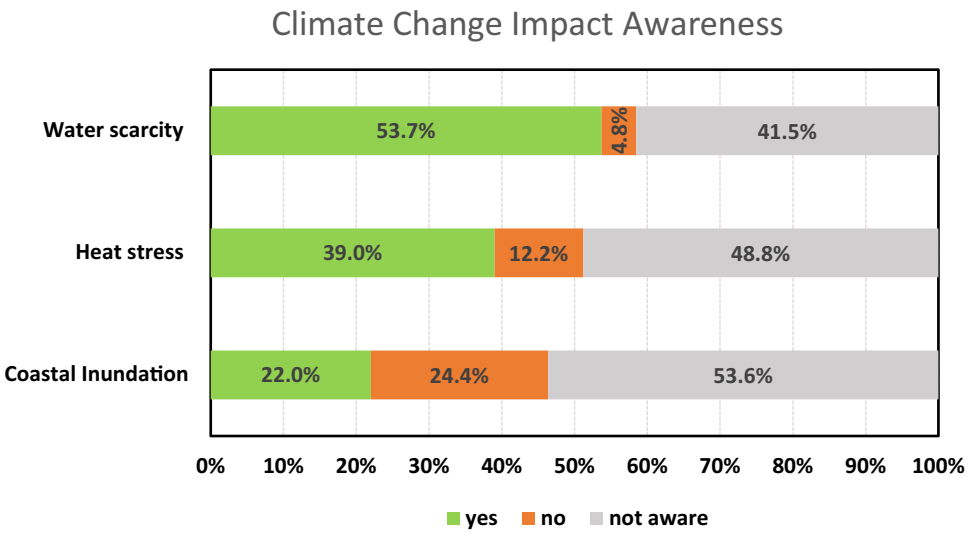

Fig. 3 Stakeholders' awareness and concern about climate change impacts on Nestos Delta

phenomena, while only half of the remaining respondents (i.e., stakeholders aware of coastal flooding events) stated that human-induced climate change has affected economic activities in the coastal zone (yes, 22.0%; no, 24.4%).

4.1.2 Current Risk Perceptions

The stakeholders who reported in the previous question that they were aware and concerned about climate change impacts were asked about the extent of these impacts. Namely, the extent of each impact on local economic activities (agricultural production, lagoon productivity, and touristic activities) was assessed by using a 5-point Likert scale [77]. The results were grouped and presented as cumulative percentages of stakeholders' answers concerning water scarcity, heat stress, and coastal inundation for a subjective qualitative assessment of climate change impacts on current economic activities in Nestos Delta (Fig. 4).

As far as water scarcity impact is concerned, 52.9% of the respondents stated that agricultural production has moderately been affected, while only 6% of the participants reported a severe impact on the agricultural sector due to climate change. Regarding thermal stress phenomena, exactly half of the respondents believe that agricultural activities have moderately been affected, while 12.4% classified this impact as severe for the crop yields. On the other hand, stakeholders believe that coastal inundation does not pose a significant threat to the deltaic area, as nearly half of the stakeholders (44.4%) reported that coastal economic activities have been slightly affected and none of them considered coastal inundation as an extreme impact.

4.1.3 Future Risk Perception

Regarding the stakeholders' risk perception towards potential future losses on economic activities due to climate change-related impacts, stakeholders' answers are presented (as cumulative percentages) in Fig. 5. Almost nine out of ten (89.4%) stakeholders perceived water scarcity risk (i.e., decreased river flows) as important (or as very important). This result highlights the role of agriculture in the regional economy and the importance of ensuring future irrigation water availability/supply for the study area. In terms of agricultural production losses due to temperature increase (heat stress), most of them (59.6%) claimed that the risk of crop yield losses is very important. It is also worth mentioning that almost all the respondents (91.5%) consider the heat stress hazard as important and/or very important. Finally, 42.6% of stakeholders claimed that coastal inundation risk is important, while 22.2% gave a low rate (not important/slightly important).

4.2 Estimating the Stakeholder Participatory multi-Risk Indices (SPmRI)

4.2.1 Equally Weighted Stakeholders

To attribute weights on stakeholders' perception regarding the climate change-related risks, we used the questionnaire outputs depicted in Fig. 5. In this first approach, all stakeholders are equally important; their answers, thus, were equally considered (i.e., equal importance was used). The weights, W_{CF}, W_{WS}, W_{HS}, for each hazard come using Eq. 2 and then are normalized on a 0–1 scale. Heat stress and the consequent reduction of agricultural production were identified as the most significant hazard ($W_{ws}=0.79$), while water scarcity was appraised as slightly less important ($W_{HS}=0.76$). Coastal inundation was considered the least important threat for the Nestos Delta area ($W_{CF}=0.62$). Thus, within the 0–1 importance scale, all three individual risks scored in the high rank of importance (0–0.2 not important; 0.21–0.4 slightly; 0.41–0.6 moderately; 0.61–0.8 highly; 0.81–1 extremely significant).

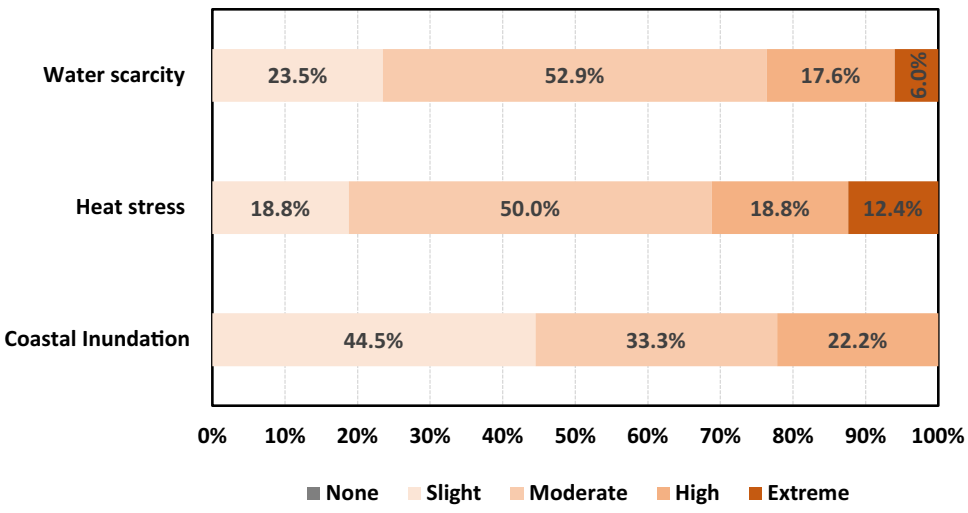

Fig. 4 Stakeholders' qualitative assessment of climate change impacts on current economic activities

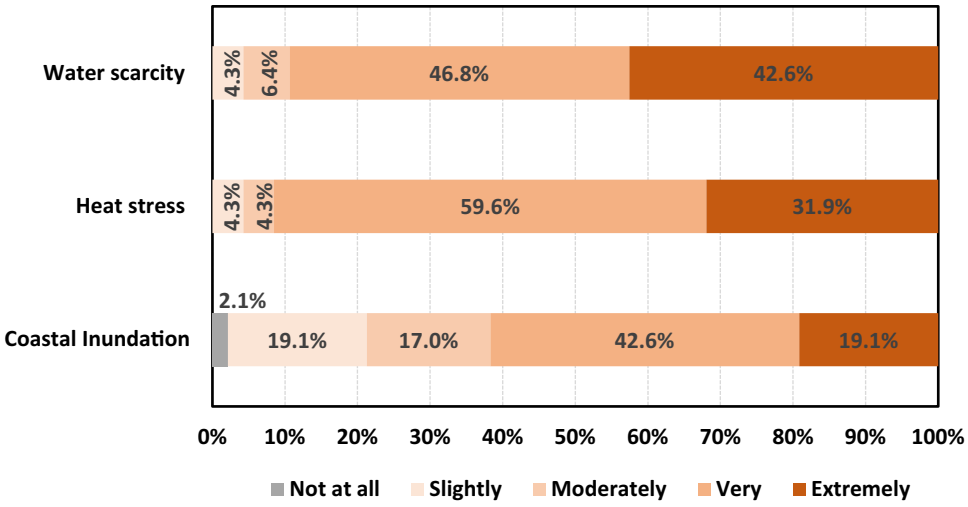

Fig. 5 Stakeholders' qualitative assessment of climate change impacts on future economic activities

Thereafter, the weighted risk indexes (W_{CFRI}, W_{WSRI}, and W_{HSRI}) are calculated based on Eqs. 4–6, for each of the scenarios developed by Skoulikaris et al. [70], resulting thus in the generation of the weighted risk matrices based on the proposed Stakeholder Participatory multi-Risk Index of the first approach ($SPmRI_A$; Fig. 7a).

4.2.2 Categorization of Stakeholders in Groups and Relevant Indexes

In the second approach, where all stakeholders are divided into groups (SGs), a multi-criteria analysis was performed to identify primary and secondary stakeholders (based on Table 2 and Eqs. 8–12). Table 4 presents the net outranking flow $\varphi_{(i)}$ (range: – 1 to 1) in terms of stakeholder group w_{SG} and sub-group w_s weights. SG1 (the Management Body of Nestos Delta, Vistonida-Ismarida Lakes, and Thassos Island) was identified as the higher score group. Administrative authorities (SG2), namely, institutional stakeholders, also play a significant role in the decision-making process. On average, agricultural related stakeholders have a moderate score, while non-governmental organizations (SG5) and other stakeholders (SG6) are not found to be strongly involved in the Nestos Delta management.

A visual approach of the PROMETHEE-GAIA (http://www.promethee-gaia.net/) outranking method [76] is presented in Fig. 6 in the form of a geometrical projection tool that assists the decision-making process in interactively exploring and structuring the decision problem and better representing and understanding the results [75]. GAIA starts from a multidimensional representation of the decision problem with as many dimensions as the number of criteria (five in this research). The PCA (https://towardsdatascience.com/principal-component-analysis-pca-explained-visually-with-zero-math-1cbf392b9e7d) exploratory data analysis method is used to reduce the number of dimensions by projecting each data point onto only the first few principal components while minimizing the loss of information by preserving as much of the data's variation as possible. U is the first principal component, it contains the maximum possible quantity of information, and V is the second principal component, providing the maximum additional information orthogonal to U. "U-V" (Fig. 6) is the best possible 2D view, gathering 90% of information about the significance of influence in the decision-making process and interactions between criteria and SGs. Namely, each SG is represented by a (square) point in the GAIA plane. Its position is related to its evaluations on the set

Table 4 Stakeholder group weight w_{SG}

Stakeholder group	$\varphi_{(i)}^{+}$	$\varphi_{(i)}^{-}$	$\varphi_{(i)}$	w_S	w_{SG}
SG1	0.4	0.0444	0.3556	1.0000	1.0000
SG2.1	0.3111	0.1222	0.1889	0.7826	0.5749
SG2.2	0.4	0.0444	0.3556	1.0000	
SG2.3	0.4	0.0444	0.3556	1.0000	
SG2.4	0.1111	0.5222	−0.4111	0.0000	
SG2.5	0.2111	0.2111	0	0.5362	
SG2.6	0.2111	0.2111	0	0.5362	
SG2.7	0.4	0.0444	0.3556	1.0000	
SG2.8	0.1333	0.4222	−0.2889	0.1594	
SG2.9	0.1333	0.4222	−0.2889	0.1594	
SG3.1	0.2667	0.5222	−0.2556	0.2028	0.4420
SG3.2	0.3111	0.2	0.1111	0.6811	
SG4.1	0.5111	0.2	0.3111	0.9420	0.4782
SG4.2	0.3333	0.3333	0	0.5362	
SG4.3	0.1111	0.5222	−0.4111	0.0000	
SG4.4	0.2111	0.2889	−0.0778	0.4347	
SG5	0.2222	0.2778	−0.0556	0.4637	0.4637
SG6.1	0.3333	0.3333	0	0.5362	0.3768
SG6.2	0.1222	0.3667	−0.2444	0.2174	

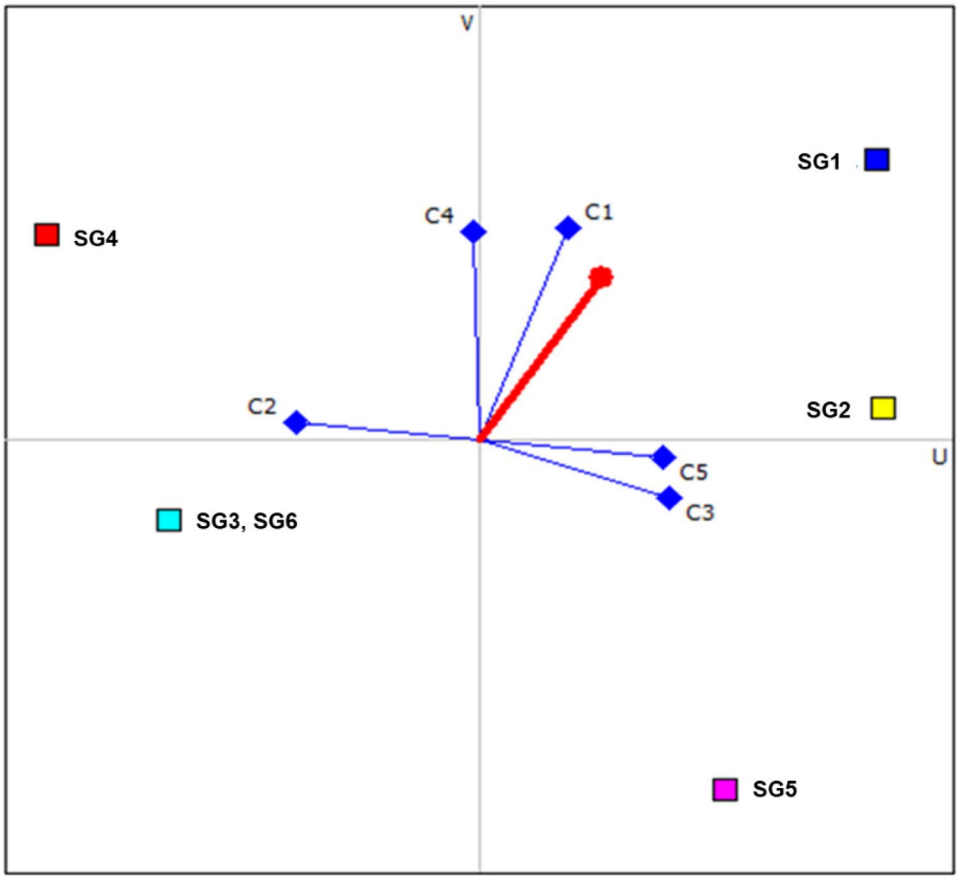

Fig. 6 Multi-criteria analysis GAIA plane. Red dot vector line is the decision axis π on the GAIA plane. U and V axes represent the first two principal components in the PCA method. Please refer to the above text for stakeholder groups (SG, marked with squares) and criteria (C; marked with diamonds) identification. Comparative proximity of SGs to C and π axes define the significance of SGs in the decision-making process

of criteria in such a way that SGs with similar profiles will be closer to each other. Each criterion is represented by an axis drawn from the center of the GAIA plane. The orientation of these axes is important as they indicate how closely the criteria are related to each other. Criteria expressing similar preferences have axes that are close to each other (most probably belonging to the same quadrant on the U-V Cartesian field). Conflicting criteria have axes that are pointing in opposite directions (ordinally opposing quadrants). Conclusively, the closer the SG (square) is to the axis of a given criterion, the more favorable it is by the criterion aspect. In general, the most influencing SG is the one closest to the decision-making axis, π on the GAIA plane (marked with red line).

SG1 achieved a high score in criterias 1, 2, and 5 (C1, C4, C5), as SG1 point is in the same quadrant with the respective criteria axes, and it is oriented in accordance with the decision axis π (red line). SG1 and SG2, belonging in the same quadrant, are stakeholder groups with similar preferences and perceptions. The non-governmental organizations' (SG5) rating in the decision process was influenced by the low impact on the resource base (criterion 3, C3) and by its high interest in the delta management (criterion 5, C5). On the other hand, the last group of stakeholders (other stakeholders, SG6) and the group of stakeholders, which is related to the fishery activity (SG3), exhibit a high score in criterion 2 (C2). According to Fig. 6, both SG3 and SG6 are stakeholder groups with views and preferences that are far from the final management policy vision, as the decision axis π is oriented in the opposite side. Finally, the agriculture-related stakeholders (SG4) could play a quite important role in the management process, as they are strongly depended economically on the resource (C2), with high knowledge and management skills (C4). However, according to Fig. 6, it seems that the final

Table 5 Coastal flood, water scarcity, and heat stress risk-related weights per stakeholders' group (SG)

	Stakeholder groups					
Weights	**SG1**	**SG2**	**SG3**	**SG4**	**SG5**	**SG6**
W_{CF}	0.58	0.69	0.42	0.61	0.75	0.67
W_{WS}	0.71	0.85	0.75	0.92	0.75	0.58
W_{HS}	0.79	0.77	0.75	0.92	0.75	0.75

management decisions are not greatly influenced by them (π axis is perpendicular to the SG4 point).

Thereafter, the index weights W_{CF_m}, W_{WS_m}, W_{HS_m} are calculated by Eq. 13 for each group separately based on stakeholders' answers. Their values are presented in Table 5 which illustrates the importance that each SG attaches to the future estimated risks of water scarcity, heat stress and coastal inundation, respectively.

Importance ranking: 0.00–0.20 none; 0.21–0.40 slight; 0.41–0.60 moderate; 0.61–0.80 high; 0.81–1.00 very high.

Finally, the weighted risk indexes (W_{CFRI_m}, W_{WSRI_m}, W_{HSRI_m}) are calculated based on Eqs. (14–16) for each of the 36

(a) $SPmRI_A$

SCENARIO \ PERIOD		STF: 2021-2050			LTF: 2071-2100		
RCP	RCM \ WCS	REF	CC	EXT	REF	CC	EXT
4.5	CMCC	1	1	1	2	2	2
	CNRM	1	1	1	1	1	1
	GUF	3	3	3	2	2	2
8.5	CMCC	2	2	2	2	2	2
	CNRM	1	1	1	1	1	1
	GUF	2	2	2	3	2	4

(b) $SPmRI_B$

SCENARIO \ PERIOD		STF: 2021-2050			LTF: 2071-2100		
RCP	RCM \ WCS	REF	CC	EXT	REF	CC	EXT
4.5	CMCC	1	1	1	2	2	2
	CNRM	1	1	1	1	1	1
	GUF	3	3	3	2	2	3
8.5	CMCC	2	2	2	2	2	3
	CNRM	1	1	1	1	1	1
	GUF	2	2	3	4	2	5

(c) IDRI

SCENARIO \ PERIOD		STF: 2021-2050			LTF: 2071-2100		
RCP	RCM \ WCS	REF	CC	EXT	REF	CC	EXT
4.5	CMCC	2	2	2	2	2	2
	CNRM	1	1	1	1	1	2
	GUF	3	3	3	2	2	3
8.5	CMCC	2	2	2	2	2	2
	CNRM	2	2	2	2	2	2
	GUF	2	2	3	3	2	4

Color Scale

RISK INDEX		
Rank	Class	Color
Very Low	1	
Low	2	
Moderate	3	
High	4	
Very High	5	

Fig. 7 Stakeholder Participatory multi-Risk Index (SPmRI) matrix calculated for two cases: **a** Stakeholders' opinion is equally considered and **b** stakeholders are categorized and evaluated as groups; **c** the initially derived IDRI without considering stakeholders' perception on future hazard assessment is also provided for comparison (Fig. 2). Climate change impact identification is helped by graphing the differences in color scaling for each index, per water consumption scenario (WCS: REF, CC, EXT), climate modeling input (RCM: CMCC, CNRM, GUF), climate change scenario (RCP: 4.5, 8.5), and study period (STF, LTF). Thirty-six cases are given in total for the two 30-year periods of the twenty-first century [70]

scenarios developed by Skoulikaris et al. [70] resulting in the generation of the weighted risk matrices depicted in Fig. 7b

4.2.3 Constructing the Stakeholder Participatory multi-Risk Index

The integration of the individual index matrices to the SPmRI matrix was conducted (a) with Eq. 7 in the case of equal consideration of stakeholders' opinion ($SPmRI_A$) and (b) with Eq. 17 when stakeholders are evaluated per group ($SPmRI_B$). Both produced SPmRI matrices were compared against the relevant matrix (Fig. 7c) where stakeholders are not taken into consideration (IDRI). All matrices have been calculated for each WCS (REF, CC, EXT), RCP scenario (4.5 and 8.5), as well as for the available climatic input (CNRM, GUF, CMCC) and the study period (SP: STF, LTF). Thus, 36 implementations have been attempted and reported in each matrix shown in Fig. 7.

In comparison to the IDRI without stakeholders' integration (Fig. 7c), where the highest index score is expected for the GUF climate model and the RCP8.5 scenario under the WCS-EXT, the stakeholders' perceptions integration alters the outputs. Particularly, when stakeholders' opinion is equally taken into consideration, it is demonstrated that seawater inundation, heat stress, and freshwater scarcity, in the cases of CNRM and CMCC climatic data, are not conceived as significant ones, as $SPMRI_A$ ranges between very low to low (Fig. 7a). On the other hand, and similarly to IDRI, $SPMRI_A$ reaches higher values in the particular case of the GUF model, RCP8.5 scenario and LTF period, under the WCS-EXT management scenario.

In the case that the stakeholders are divided into groups (Fig. 7b) and evaluated through multi-criteria analysis ($SPmRI_B$), the weight assigned to each group of participants (determining their importance and their involvement degree in the decision-making process) is an important factor for the final risk assessment. $SPmRI_B$ matrix follows almost the same patterns with IDRI in the case that CMCC and CNRM climate data are used. However, when the GUF-driven data are used, the $SPmRI_B$ is likely to reach high and extreme values, especially under the RCP8.5 scenario and the WCS-REF and EXT managing scenarios.

Figure 8 presents the individual SGs' $SPmRI_B$ matrices under the hypothesis that the decision is taken exclusively by each stakeholder group. The Management Body of Nestos Delta, Vistonida-Ismarida Lakes and Thassos Island (SG1), the Administrative Authorities (SG2), as well as the agriculture related stakeholders (SG4), matrices present the same pattern. Hence, there is considerable evidence that these two groups play a key role in defining the final indexes ($SPmRI_B$), since they are identified as primary stakeholders, based on the weights derived from the multi-criteria analysis (see Table 5).

Moreover, according to the perceptions of the fishery-related stakeholders (SG3), no particular threat is expected for the case study area apart from the scheme involving GUF model and the RCP8.5 scenario during the LTF period. On the contrary, the weights attached by the non-governmental organizations (NGOs; SG5) and the other stakeholders (SG6), in combination with the model-based output, result in the highest index values between the $SPmRI_B$ matrices. This is attributed to the higher relative weights (in comparison with the rest SGs); these groups attach to coastal flooding and the lower ones to water scarcity. However, due to their relatively low group weight (w_{SG}), they do not contribute significantly to the determination of $SPmRI_B$, as shown by the comparison of $SPmRI_B$ (Figu.7B) with the $SPmRI_B$(SG5)–$SPmRI_B$(SG6) matrices (Fig. 8).

5 Discussion

Within the present study, a formerly physical modeling-based risk index (IDRI) [70] is enhanced by the inclusion of stakeholders' preferences in the evaluation process. Stakeholders' engagement in decision-making and the investigation of their influence on multi-risk issues of water resources management in river deltas is conducted with the development of a Stakeholder Participatory multi-Risk Index (SPmRI). Although various scholars have proposed solutions fostering the participatory engagement of stakeholders in environmental risk assessment, as clearly depicted in the introduction, e.g., [59–63, 65, 66], we consider our approach novel in (i) developing a multi-parametric index which incorporates stakeholders' opinions on three different hazards, i.e., coastal floods, water scarcity, and heat stress, on river delta environments; (ii) integrating stakeholders' preferences and priorities (derived by stakeholders mapping and analysis through structured interviews and questionnaires) into an existing risk assessment procedure based on extensive numerical modeling under various climate change conditions and water utilization scenarios; (iii) proposing two different approaches, considering stakeholders either as individuals (with equal weights) or as groups (classified based on their relevance on specific hazards) for the coupling of stakeholders' participation with natural based simulation models; and (iv) comparing the $SPmRI_A$ and $SPmRI_B$ indexes produced by the two approaches between each other, as well as against the initial IDRI which does not consider the stakeholders' perceptions/preferences.

5.1 Implication of Findings

Due to the public nature of the study area and the large number of uses and water users, there are numerous potential stakeholders who can participate in decision-making and management processes. Usually, there are four defining questions to

(a) SG1 IDRI

SCENARIO \ PERIOD		STF: 2021-2050			LTF: 2071-2100		
RCP	RCM \ WCS	REF	CC	EXT	REF	CC	EXT
4.5	CMCC	1	1	1	2	2	2
	CNRM	1	1	1	1	1	1
	GUF	3	3	3	2	2	3
8.5	CMCC	2	2	2	2	2	3
	CNRM	1	1	1	1	1	1
	GUF	2	2	3	4	2	5

(b) SG2 IDRI

SCENARIO \ PERIOD		STF: 2021-2050			LTF: 2071-2100		
RCP	RCM \ WCS	REF	CC	EXT	REF	CC	EXT
4.5	CMCC	1	1	1	2	2	2
	CNRM	1	1	1	1	1	1
	GUF	3	3	3	2	2	3
8.5	CMCC	2	2	2	2	2	3
	CNRM	1	1	1	1	1	1
	GUF	2	2	3	4	2	5

(c) SG3 IDRI

SCENARIO \ PERIOD		STF: 2021-2050			LTF: 2071-2100		
RCP	RCM \ WCS	REF	CC	EXT	REF	CC	EXT
4.5	CMCC	1	1	1	2	2	2
	CNRM	1	1	1	1	1	1
	GUF	3	3	3	2	2	2
8.5	CMCC	2	2	2	2	2	3
	CNRM	1	1	1	1	1	1
	GUF	2	2	2	4	2	5

(d) SG4 IDRI

SCENARIO \ PERIOD		STF: 2021-2050			LTF: 2071-2100		
RCP	RCM \ WCS	REF	CC	EXT	REF	CC	EXT
4.5	CMCC	1	1	1	2	2	2
	CNRM	1	1	1	1	1	1
	GUF	3	3	3	2	2	3
8.5	CMCC	2	2	2	2	2	3
	CNRM	1	1	1	1	1	1
	GUF	2	2	3	4	2	5

Color Scale

RISK INDEX		
Rank	Class	Color
Very Low	1	
Low	2	
Moderate	3	
High	4	
Very High	5	

(e) SG5 IDRI

SCENARIO \ PERIOD		STF: 2021-2050			LTF: 2071-2100		
RCP	RCM \ WCS	REF	CC	EXT	REF	CC	EXT
4.5	CMCC	2	2	2	2	2	3
	CNRM	1	1	1	1	1	2
	GUF	3	3	3	2	2	3
8.5	CMCC	2	2	3	3	3	3
	CNRM	1	1	1	2	2	2
	GUF	2	2	3	4	3	5

(f) SG6 IDRI

SCENARIO \ PERIOD		STF: 2021-2050			LTF: 2071-2100		
RCP	RCM \ WCS	REF	CC	EXT	REF	CC	EXT
4.5	CMCC	2	2	2	2	2	3
	CNRM	1	1	1	1	1	2
	GUF	3	3	3	2	2	3
8.5	CMCC	2	2	2	3	3	3
	CNRM	1	1	1	2	2	2
	GUF	2	2	3	4	2	5

Fig. 8 Multi-risk index matrices based on each stakeholder group (SG) perception: IDRI (**a**) for SG1, (**b**) for SG2, (**c**) for SG3, (**d**) for SG4, (**e**) for SG5, and (**f**) for SG6. Climate change impact identification is helped by graphing the differences in color scaling for each index, per water consumption scenario (WCS: REF, CC, EXT), climate modeling input (RCM: CMCC, CNRM, GUF), climate change scenario (RCP: 4.5, 8.5), and study period (STF, LTF). Thirty-six cases are given in total for the two 30-year periods of the twenty-first century

serve as axes of differentiation for the manifold interpretations of "participation" [78, 79]:

1. Who participates in the decision-making process?
2. To what extent are participants allowed to interfere with the decisions?
3. How does the process take place?
4. What is the purpose of the participatory process?

Veraart et al. [80] underline the vital role of experts' involvement in participatory approaches on regional and sectoral adaptation strategies. Generally, the main point is to identify in each specific situation, who the stakeholders really are (rather than relying on generic stakeholder lists, that create a lot of questionable assumptions flowing into who counts as a stakeholder). Another important goal is to explore the impact of stakeholder dynamics [81, 82]. In the present study, only public stakeholders (public authorities, institutions, organizations, associations) have been chosen to participate. Koutrakis et al. [72] followed the same philosophy to assess the public stakeholders' perception of Integrated Coastal Zone Management (ICZM) and Coastal Erosion in the Mediterranean (including the Nestos Delta area).

To explore the dimension of stakeholders' participation/involvement, preliminary interviews and questionnaires were adopted. Useful conclusions can be extracted regarding the current role and responsibilities of stakeholders as well as their actual level of knowledge and awareness on the issues (hazards) under investigation. Our results demonstrate a rather low level of knowledge and awareness about climate change impacts. This could be attributed to the lack of information on the specific thematic from the competent organizations/institutions and/or to the lack or poor collaboration between the stakeholders. This result is in line with the findings of a study about climate change adaptation in a water-scarce basin by Esteve et al. [83], who highlighted the lack of awareness and absence of a common understanding among the different stakeholders as preeminent barriers to adaptation. Similarly, Eisenack et al. [84] mentioned the relatively limited knowledge about actors and institutions that support adaptation to climate change. Finally, concerning the purpose of stakeholder participation and in accordance with relevant literature [85–89], our stakeholder analysis aimed to assess the positions and engagement of actors relevant to policy, through a multi-criteria decision method [90, 91].

Regarding the multi-parametric analysis for the Nestos Delta the first SPmRI approach, namely, $SPmRI_A$, where all stakeholders' opinions and answers are equally taken into consideration, is a common practice in literature [92, 93]. However, in some cases, it can lead to erroneous results and conclusions, as the different attributes (characteristics) of the stakeholders are not evaluated. The results of the first approach (Fig. 7a) demonstrate a slight downgrade of the index scores when compared to the IDRI matrix (Fig. 7b), because the stakeholders of the study area attach almost similar weights to each hazard (see Sect. 5.2.1). Particularly, $SPmRI_A$ matrix demonstrates that the identified risks are smoothed and no managerial practices arise, due to low-leveled index scores, in the cases of CNRM and CMCC climatic data. It should be noted that the similarity in IDRI and $SPmRI_A$ patterns should not be generalized beyond the findings of this study, as these results refer to the specific study area. In other cases, with different risk values and stakeholder weights, greater differences may emerge.

The second approach ($SPmRI_B$), which evaluates the subjective stakeholders' assessments through a multi-criteria analysis, results in more noticeable differentiations of index scores along the discrete combinations of timeframes, models, and scenarios, compared to the initial approaches ($SPmRI_A$ and IDRI). $SPmRI_A$ and $SPmRI_B$ matrices demonstrate almost similar patterns when CMCC and CNRM climate input datasets are considered. On the contrary, in the case of GUF-driven produced datasets, $SPmRI_B$ reaches higher values more pronounced under the RCP8.5 LTF scenario. To sum up, the values of the $SPmRI_B$ seem to be higher than those of $SPmRI_A$ and of IDRI, because stakeholder groups with greater interest and role in the study area attribute higher weights to the individual perceived risks, as shown in Fig. 8. Translating the latter into policy, according to $SPmRI_B$, stricter measures need to be taken for risk mitigation particularly if the GUF climatic scenario conditions are to be realized towards the end of the twenty-first century. Hence, in the case of extreme climatic conditions, a decision-making process that considers the stakeholders' opinion according to the second approach is rather linked with more ambitious and demanding environmental policies.

5.2 Participatory Multi-risk Indexes Benefits and Limitations

Adaptation to climate change necessitates the implementation of measures and actions. The experience acquired through the application of the proposed methodology supports the implementation of risk mitigation measures in the study area and could therefore contribute to the establishment of integrated management strategies. Considering the relative infancy of integrated approaches for risk assessment in deltaic areas, especially in the Mediterranean region, there is a great opportunity to verify and potentially raise the involvement of the local institutional players, especially regional and local policy-makers and officers.

Within the methodology used in the present study (preliminary interviews, structured questionnaire survey, PCA of results in PROMETHEE, GAIA-plane graph approach), apart from the SG involvement, the informational briefing,

awareness, and active participation of individual stakeholders were also achieved. Hence, any management decision will be easier implemented, as it has emerged from stakeholders' own evaluation. In this context, our study attempts to obtain meaningful stakeholder input for the evaluation and enhancement of local integrated deltaic area management projects. In addition, the discussion with all interested parties about heat stress, coastal floods, and water scarcity threats managed, in several cases, to sensitize stakeholders on issues, not strictly related to their responsibilities, and on risks that have been ignored, overlooked, or poorly evaluated. The process followed and improved both their level of knowledge on the related environmental issues and their ability to reach consensual solution. However, it should be highlighted that through this process, no attempt has been made to manipulate the stakeholders and influence their opinion. During the preliminary interviews and meetings, no reference was ever made to the perception and opinion of the other stakeholders, nor to the physically-based modeling outputs of our previous research [70]. The reasoning behind this decision is that any kind of information regarding other stakeholders, results, and indexes would affect the answers. On the other hand, our purpose was to explore the level of knowledge and awareness of stakeholders on current and future hazards and risks. Hence, a key element of the survey was to unbiasedly capture the views of each group and to avoid guiding stakeholders' responses by presenting them extracted physically-based model results.

The proposed methodology initially examines separately the numerically modeled hazards and the related risks perceived by the stakeholders and afterwards combines them in a common modeling approach. The methodology can be applied in various deltaic coastal areas both in Greece and the Mediterranean (or even worldwide, mainly in microtidal estuary environments). Especially in cases where outputs of risk assessment relied on physically based models do exist, the consideration of stakeholders' knowledge is a state-of-the-art thematic in water resources management processes.

A possible limitation of our study is that stakeholders are solely public authorities without considering the private sector who may have different perceptions/prioritization of impacts and associated risks. Moreover, the paper proposes the estimation of an elementary risk index; nevertheless, it could be further appointed to meet the demands of the EU Floods Directive (EU 2007), where "risk" is defined as the product of hazard, exposure, and vulnerability. Particularly, although the presented methodology of hazards' estimation is identical to the one of the Directive, the "exposure" is introduced in spatial terms without investigating (and further expressing in monetary values) the types of elements, e.g., building stock, essential facilities, and critical infrastructures, within the exposed area. Finally, the vulnerability, i.e., "the characteristics of a community, system or asset that make it susceptible to the damaging effects of a hazard" was not considered, but it could be a thematic of further development. Nevertheless, the possible impacts of examined hazards were implicitly included in our analysis via the quantification of the stakeholders' perception of impacts and risk. Similarly, the proposed methodology could be enhanced to include several other components such as hydropower generation and environmental protection through maintenance of the ecological flow. The associated exposure could also be further redefined based on the latest Shared Socioeconomic Pathways (SSPs) climate change scenarios to feed the model processing. Socio-economic issues could also be included in the analysis and the interaction with engaged stakeholders within the participatory concept. To this end, stakeholders from local NGOs, the farming and fisheries communities, the touristic professional agencies, the urban utilities sector, etc. should be included in future investigations. This should be followed by proper quantification of damages, losses, and generally measurable impacts of elements-at-risk in order to define a fact-based projected vulnerability of the study area in the twenty-first century.

6 Conclusions

Decisions related to risk assessment and water resources management under the effects of climate change should be participative (shared) and dynamic. To this end, stakeholders representing users, policy-makers, and civil society may need to establish negotiation relationships with each other. Especially in the case of regional problems and case studies, stakeholders' participation, consultation, and active engagement deliver local knowledge on horizontal derived policies and measures applied by large-scale management plans.

The research, through the form of indexes, attempts to integrate stakeholders' perceptions on hazards and risks coming from numerical modeling of coastal floods, water scarcity, and heat stress on a deltaic environment. The public participation involvement was conducted thought stakeholders' analysis and mapping, while a structured questionnaire attributed their perception on the specific hazards. The two developed methods for coupling the stakeholders' opinion and the numerical simulations' outputs on the case study region revealed the following:

- For the cases that the IDRI identifies very low-to-low risks (e.g., CMCC and CNRM climate models for both RCPs and for all climate change and water consumption scenarios), both SPmRI approaches slightly downgrade the calculated risks.
- For the cases that IDRI identifies moderate risks (e.g., GUF climate model under the RCP4.5 scenario and

for all WCS) both SPmRI approaches retain the same risk classification when the stakeholders' perception is inserted in the decision-making problem.

- For those cases that IDRI identifies moderate-to-very high risks (e.g., GUF climate model under the RCP8.5 scenario and all consumption scenarios): (a) The $SpmRI_A$ approach (that equally accounts for all stakeholders' preferences) results to similar risk classification(s) due to the attribution of similar weights to each hazard, and (b) the $SpmRI_B$ approach (where stakeholders are classified into groups, weighed according to their relevance, and multi-criteria analysis is applied) results to higher (than IDRI) risk values.

In conclusion, participatory processes in water resources management and risk assessment should be promoted as cornerstones in integrated deltaic management, because optimal decision-making is fostered by the combination of physically based numerical modeling and stakeholder-based perception modeling.

Appendix

Table 3 Questionnaire form

Question groups	Questions
Irrigation water supply	Question 1: Did you observe any reduction in irrigation water supply due to the decrease in Nestos river flow?
	Question 2: In which extent has the agricultural production been affected due to the supply reduction?
	Question 3: How important is for you the (future) risk of agricultural production decrease due to a possible reduction of river Nestos flow caused by climate change?
Agriculture and temperature	Question 4: Did you observe a temperature increase (due to climate change), with a potential risk for the production of specific crops (agricultural production decrease)?
	Question 5: In which extent has the agricultural production been affected due to the temperature increase?
	Question 6: How important is for you the (future) risk of agricultural production decrease due to a possible temperature increase caused by climate change?
Environmental services of the delta	Question 7: Has there been a reduction in river flow in the past with a potential risk to the ecological status of the Nestos?
	Question 8: In which extent has the ecological status of Nestos been affected?
	Question 9: How important is for you the (future) risk of the river Nestos ecological status degradation due to a possible reduction(s) in river flow?
Upstream hydropower production	Question 10: How important is for you the (future) risk of electricity production decrease due to a possible reduction in river flow?
	Question 11: Do you consider dam operation and irrigated agriculture in Nestos Delta to be competitive uses of water?
Coastal inundation	Question 12: Did you observe coastal inundation in Nestos Delta, with an impact on economic activities in the coastal area (e.g., lagoon activity, tourism activities)?
	Question 13: In which extent have economic activities in the coastal area been affected by coastal inundation?
	Question 14: How important is for you the (future) risk of coastal inundation?

Author Contribution MK was responsible for the conceptualization of the research, the development of the methodology regarding stakeholders' participation methods and their coupling with the physical based models, the formal analysis and investigation, as well as highly contributed to the writing-original draft preparation and the writing-review and final editing. CH was the main responsible for the conceptualization of the research, the development of the methodology focusing on the integration of the physical-based models with the stakeholders modelling, the formal analysis and investigation, the supervision of the research, as well as responsible for the writing-original draft preparation and the writing-review and final editing. CM has important contribution in the conceptualization of the research, the development of the methodology and evaluation of the methods, the formal analysis and investigation, and the writing-review and final editing. VB contributed in the formal analysis and investigation and the writing-review and final editing. DL was also responsible for the conceptualization of the research, the development of the methodology regarding stakeholders' participation methods, the evaluation of the equations used, as well as highly contributed to the writing-review and final editing. YK was the project supervisor and contributed in the conceptualization of the research. All authors read and approved the final manuscript.

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Declarations

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