C2IMPRESS

D1.1: Analysis of past extreme events, lessons learned ans SoA models V1

WP1

30 July 2023

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Technical References

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5.Acronyms

..Acronym	.1.2. Description
C2IMPRESS	Co-Creative Improved Understanding and Awareness of Multi-Hazard Risk for Disaster Resilient Society
WP	Work Package
CSA	Case Study Area
UIB	University of the Balearic Islands
ES	Spain
LNEC	National Laboratory for Civil Engineering (Portugal)
PT	Portugal
NCSRD	National Centre of Scientific Research "Demokritos"
EGL	Egaleo
GR	Greece
SoA	State of the Art
SoS4MHRIN	System-of-Systems for Multi-Hazard Risk Intelligence Network

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6.Executive Summary

C2IMPRESS is a multi-disciplinary project which aims to enhance understanding and public awareness on multi-hazard risk, based on innovative models, methods, frameworks, tools and technologies to develop decision-making platforms with a fine-grained spatio-temporal data to better assess impacts, vulnerability and resilience on natural hazards. This Report is the Deliverable 1.1 and belongs to Work Package 1, which is mainly addressed to identify the past climate and physical processes that underlie natural disaster events and their consequences

Disaster events, generally, follow a main cycle based on three stages. The pre-disaster stage involves tasks that need to be performed before a disaster occurs and with the goal of protecting population, infrastructures, and services, therefore, getting prepared to face the crisis. In this stage, risk management plans, risk cartography or early warning systems should be developed. The disaster event-response stage occurs when the impact of the disaster is felt and the crisis begins. During this stage, emergency corps and people in charge of disaster management must struggle to deal with the crisis caused by the disaster event and try to apply effectively all the measures planned during the previous stage, in order to save lives. The post-disaster stage comprises all the actions taken once the episode has passed and these actions are addressed to recover from the crisis in the short and long-term, giving assistance to injured people,and addressing damaged buildings or infrastructures, etc. The length of this phase can vary significantly, depending on the effects and consequences of the disaster event. In the worst-case scenarios, a new disaster event can occur before this stage has been completed. During this stage, it is essential to gather knowledge about the impacts and how to deal with them. This information aids in learning from the experience and can be used to improve or validate risk management plans and risk cartography.

Learning from past disaster events should allow risk planners to adequately develop the pre-disaster stage. At this stage, it is critical to gather and assess both quantitative and qualitative data comprehensively. This process allows for a deep understanding of the socio-environmental processes that occurred during the disaster: why it happened, where it happened, the causes and consequences, and how it was managed.

Five forms have been adopted and capitalised from a former Interreg Med Project (Damage) and redesigned to collect data from wildfires, floods, seismic, heatwaves and landslides disaster events. These forms feature general questions that apply to all forms of disasters, and specific questions relating to the idiosyncrasy of each hazard. Finally, questions about the management and lessons learned during each of the three stages of a disaster event are included. These questions are designed to evaluate the preparation, management, and response to the impact of a natural hazard.

These forms have been filled, at least once, by each Case Study Area (CSA). Mallorca (Spain) CSA has filled a form for a wildfire in 2013 and for a flood in 2018. Ordu (Turkey) CSA has input two flood events in 2016 and 2018, and two landslide events in 1984 and 2015. On its side, Centro Region (Portugal) CSA has recorded a wildfire in 2017 and two floods in 2018 and 2019. Finally, Egaleo (Greece) CSA has filled a seismic form with an event of 1999.

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These forms have been used to identify main lessons learned and highlight the most critical points. The next deliverable is expected to deeply analyse all lessons learned derived from each form, and they will mainly structure in two categories: general lessons learned for all disaster events and specific lessons learned for each type of natural hazard, attending to their own characteristics, causes and consequences. Specifically, in Mallorca CSA, maintaining roads and paths in a good conditions and self-protection in front of fire risk is a prevention measure that works properly in case of wildfires, even that, is very important to work on forest management to reduce the amount of fuel and keep increasing public investment in fire prevention and extinction resources. In case of flash floods there is a need for inter-institutional cooperation to develop effective risk management plans with concrete protocols and supported by an early warning system. Otherwise, in Ordu CSA a coordinated management system to face landslides and flash floods would improve the prevention and crisis management, all complemented by an early warning system. Whereas in Centro Region CSA, the main lesson learned lies on an improvement of risk planning, related with emergency planning, therefore, there is a need of improvement to deal with big crises situations, and coordinating different institutions, administrations and emergency corps. Finally, at Egaleo CSA there is a need for risk management plans and social conscientiousness on how to behave in case of an earthquake.

A standardised form for the inventory of catastrophic episodes will be also developed, which in addition to recording disasters in detail, would also include the description of key issues that would help to advance the understanding of the event and assist in its prevention.

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7. Introduction

The overall aim of C2IMPRESS project is to offer an ensemble of innovative revolutionary (albeit mature) models, methods, frameworks, tools and technologies that are holistic and robust enough to provide appropriate fine-grained spatio-temporal qualitative and quantitative data, locally appropriate solutions, better prediction with lower uncertainty on risks of single or multiple hazards stemming from extreme weather events like floods, wildfires, etc. under different climate change scenarios. With these social and technical innovations –as novel processes and products– the C2IMPRESS project will provide better understanding and public awareness on multi-hazard risks, the associated multidimensional impacts, vulnerabilities and resilience of extreme weather events, including their origins and the aftermath. Furthermore, the C2IMPRESS project intends to develop multi-actor decision support microservices and a suite of citizen engagement approaches and tools as key means of improvement of public awareness and understanding together with optimisation of cost, accuracy and efficacy of current practices. The C2IMPRESS project will also embrace a novel co-design and co-creation approach for socio-technical innovations, knowledge production and validation to empower citizens and society with climate actions. This will be achieved taking future resilience in multi-hazard crises into consideration, as well as focusing on inducing an evolution towards new forms of governance to increase the participation of all actors in decision-making for a sustainable transition to a just risk resilient society.

This Deliverable 1.1 is associated with the Work Package 1 (WP1): Understanding multi-hazard risk, its challenges and project specification, lead by the University of the Balearic Islands -UIB. WP1 has the main objectives (1) to analyse and reason historical hazards, (2) to develop calibrated and validated models, (3) to analyse present climatic system and its interaction with the surrounding ecosystem, infrastructure and society, (4) to develop KPIs, and (5) to deliver the specification of the entire project.

WP1 is mainly addressed to achieve the first Research and Innovation Aim of the Project Objectives (POs) which consists in learning from the past (historical events), creating a holistic picture of a customary multi-hazard risk management cycle. Therefore, it aims to identify past climate and physical processes behind natural disaster events and consequences. This enables the understanding of fundamental principles by synthesising historical climatic data and regional weather systems to provide a holistic framework to learn and understand the present drivers and barriers at play.

This deliverable report is focused on the “Analysis of past extreme events, lessons learned and SoA models”, as a result of the work carried out in tasks 1.1, 1.2, and 1.3 during the ten first months of the project, being also scheduled for a second version in the twenty-fourth month of the project. This first version has been structured in different sections in order to provide a clear reasoning behind the research developed. Accordingly, the first section exposes the risk and management cycle as the basis to address the risk comprehension for learning from past events. Under this context, a second section is focused on the results elucidated by the application of disaster events forms. These forms have been capitalised and further developed by UIB to record and assess all the information on disaster events occurring in the Case Study Areas -CSA in order to learn from it. The last section is dedicated to

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analysing how the scientific literature addressed the lessons learned from disaster events by a bibliometric analysis.

8. Disaster events approach

According to the United Nations Office for Disaster Risk Reduction[2], risk is the probability of an outcome having a negative effect on people, systems or assets. Risk is understood as a function of effects of hazards, the elements or people exposed to the hazard, and the vulnerability of those exposed elements. Therefore, these three aspects are discussed in this section, along with risk management, also considering that risk management must be approached as a cycle (Figure 1).

Figure 1: Disaster Management Cycle [3]

8.1. Pre-disaster

The risk management cycle should start at the pre-disaster stage with the risk assessment, where risk plans and vulnerability assessments are developed to prepare the response to the disaster and raise social awareness. Therefore, this stage consists in getting prepared and predicting the hazard events to reduce their impacts and improve society's adaptation capacity.

[2] Sendai Framework For Disaster Risk Reduction 2015-2030. United Nations https://www.undrr.org/quick/11409.

[3] Widyaningrum, Elyta (2009). Tsunami Evacuation Planning using Geoinformation Technology Considering Land Management Aspects Case Study: Cilacap, Central of Java. Technische Universität München. 108 p.

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This stage is crucial to properly face the event and be able to save lives. Also, in this pre-disaster stage, mitigation measures must be taken to reduce the impacts. One of the most effective measures are the early warning systems, enabling the anticipation of the disaster and activating all the mitigation and protection plans, as well as the emergency corps and their coordination centres. In any case, if mitigation and protection plans are not properly implemented, the early warning systems can generate a false safety sense with negative feedback on the risk management cycle.

This stage has an uncertain time length and due to the existence of large periods without any disaster, it may be forgotten or disregarded. In this sense, for C2Impress it is crucial to keep developing risk assessments and disaster awareness so that the pre-disaster stage remains in the mind of all the decision-makers and regional planners. As a result, potential hazards must be identified by analysing historical hazardous events in the region, with the main aim of compiling information from the past to establish a prognosis for the future. Once the main hazards have been identified they must be modelled to predict the behaviour and evolution of the hazards across the territory. This potentially hazardous area is an input to the vulnerability assessment. Vulnerability is calculated using the exposed population and the elements to a determined hazard. In this case, more accurate vulnerability assessments can be developed to find areas with higher vulnerability and identify those zones where prevention measures should be peremptory. This hazard and vulnerability knowledge is essential to develop correct risk plans and manage the emergency effectively to save lives, the final objective of risk assessment and risk plans.

8.2. Disaster event – Response

During the disaster event and its response, all efforts must be focused on dealing with the emergency and saving lives. If the previous stage was correctly developed, these efforts would be more effective and focused on the more vulnerable areas, where the worst effects can be expected. Also, prevention and mitigation actions based on a vulnerability analysis would reduce the risk of those areas where they were applied, reducing or helping the work of emergency corps.

In addition, it is very important to compile, record, and save all the information related with the risk management, such as deployed emergency corps, used resources, activated plans, or severity index of emergency. This information will allow better post-event management and the comprehension of lessons learned from the management.

The separation between the disaster event itself and the post-event stage can be unclear, because at a certain time, some areas can already be in the phase of assistance to affected people and implementation of recovery measures, while -in others- the impact can still be affecting. Therefore, the disaster event section of this report will be only focused on the impact itself; whilst assistance measures will be included in the post-event section.

8.3. Post-disaster

As previously mentioned, this section includes all the activities and assistance measures taken during the immediate post-disaster.
This stage consists in the immediate, short-term and long-term recovery and assistance to injured people, damaged structures, infrastructures, and other goods. The length of this stage

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depends on three main aspects: (a) the severity of the impact, (b) the coordination and mitigation plans developed during the pre-event stage, and (c) the occurrence of a subsequent disaster which can interrupt or limit the post-disaster stage, and start a new pre-disaster stage.

During the post-disaster, different actions must be carried out in different ways, and addressed to many different people and collectives. This involves each event will require adapted solutions and measures to deal with it. The post-disaster management period can last quite long because it should cover the assistance immediately after the event, as well as the restoration and reconstruction of infrastructural services, and the economic and social recovery. It is also essential to keep working on ongoing development activities, and to adapt and improve risk assessment and risk plans in order to learn from the past events and to prevent making the same mistakes again. At this point, once society has recovered, the cycle starts again getting prepared for a new event, or in some cases, a new disaster can occur before the society has recovered from the previous disaster.

9. Disaster events registration

Compiling data from all the events is the best way to learn from them. Registering information of the event and its management allow the assessment of the successes and failures. With the aim of getting the most useful information from disaster events, adapted forms were designed within WP1, also as a result of capitalization of former projects; i.e., Damage (Interreg-SUDOE[4]). These forms have been prepared to obtain useful information to achieve lessons learned from each event, identifying the main errors in all the phases of crisis management and improving them for future events thus contributing to a more resilient society.

Five forms have been developed following a main general structure, but also with specific details for each natural hazard: wildfire, flood, earthquake, seismic and heat wave. In the first section, questions about the contextualization of the event are made. This information is basic to identify the event in time and place, being the time divided at (a) the start and the end of the event itself, (b) the start and end time of the crisis management, and then (c) the recovery time since the end of the event. Related to the location of the event, the affected localities, counties, and countries. Apart from these general issues, there are unique questions such as the ignition point, in the case of wildfires; the epicentre, its depth and the rupture length, in the case of seismic; and rivers' name for floods.

The second section of the form is orientated to the characteristics of the event with questions adapted to each hazard as follows:

- Wildfire:
  - Gravity index
  - Type of wildfire (Domain[5])
  - Morphology (Domain)
  - Perimeter (m)

[4] DAMAGE Project – https://www.uib.cat/secc6/lsig/webdamage/index.en.html

[5] All questions with multiple options have the possibility to write down an answer ('Other')

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- Area (sq m)
- Velocity of propagation
- Wind velocity
- Number of focus

- Heatwave:
  - Gravity index
  - Conditions and thresholds to identify a heatwave in the region
  - How Urban Heat Island effect is considered
  - Maximum temperature during the event (ºC)
  - Maximum temperature at night (ºC)
  - Average temperature during the event (ºC)
  - Number of daily hours above temperature's threshold
  - Number of night hours above temperature's threshold
  - Average relative humidity during the event (%)
  - Minimum relative humidity during the event (%)
  - Maximum relative humidity during the event (%)

- Seismic:
  - Gravity index
  - Magnitude (Richter scale)
  - Intensity (MSK scale)
  - Perimeter (m)
  - Area (sq m)

- Landslide:
  - Gravity index
  - Type (Domain)
  - Average slope (degrees)
  - Type of geology and structure
  - Perimeter (m)
  - Area (sq m)

- Flood:
  - Gravity index
  - Rain volume (mm)
  - Maximum rain intensity (mm h^{-1})
  - Maximum streamflow (m^3 s^{-1})
  - Maximum stream flow velocity (m s^{-1})
  - Type of flood (Domain)
  - Perimeter (m)
  - Area (sq m)

Third, a section with the causes of the event, as well as cascading crises, with the following questions:

- Wildfire, heatwave, seismic, landslide and flood:
  - Causes (Domain)

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- Did it cause another disaster? (Domain)

After analysing the event itself, some sections about the effects on the population, infrastructures and other goods were introduced to analyse the impact of the event.

Regarding population:

- For wildfire, Seismic, Landslide and Flood:
  - People affected
  - People evacuated or rescued
  - People injured
  - Missing people (were they found?)
  - Fatalities

- For heatwave:
  - People affected
  - People evacuated or rescued
  - People injured
  - Fatalities

Regarding dwellings:

- For Wildfire, Seismic, Landslide and Flood:
  - Affected dwellings
  - Destroyed dwellings
  - Dwellings estimated monetary losses

Regarding facilities and infrastructures:

- For Wildfire, Seismic, Landslide and Flood:
  - Affected facilities (Domain)
  - Affected infrastructures (Domain)
  - Quantify the affected infrastructures
  - Patrimonial buildings affected, including monetary losses
  - Estimated monetary losses including facilities, infrastructures, buildings and other goods

The following section is about the impact of the event on land use and land cover.

- For Wildfire, Seismic, Landslide and Flood:
  - Affected artificial surface (ha)
  - Affected forest surface (ha)
  - Affected agricultural surface (ha)
  - Affected wetland surface (ha)

The last section is the most important one and addresses the analytic questions about the management of the disaster. In this section, the details on the crisis management and deployment are asked, considering strengths and weaknesses, being one of the main objectives of these forms. In this section, the vast majority of the questions allow for open answers, giving the user the opportunity to provide detailed descriptions.

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This last section is structured as follows:

1. General information about the corps, units and resources used to face the crisis.
2. Analysis of the pre-event stage management, to know whether there were risk assessment and risk plans or even early warning systems to improve the anticipation, prevention and prevision of the event and thus improve resilience.
3. Third, the activation of the emergency and *in situ* management is assessed, including available resources to protect people and cope with the crisis situation. Finally, the post-event management, recovery programs and assistance to injured people or to damaged buildings and infrastructures are assessed.

- Wildfire, heatwave, seismic, landslide and flood:
  - Activated units and resources
  - Deployed emergency units were… (Domain)
  - Was there a risk assessment in the affected area?
  - Were there risk plans in the affected area? Were they activated during the event?
  - Were there early warning systems? Did they work properly?
  - Assessing numerically the success or failure of early warning systems (0-5)
  - Lessons learned from the prediction and prevention of the event
  - Assessing numerically the success or failure of the prediction and prevention of the event (0-5)
  - Lessons learned from the activation of the emergency
  - Assessing numerically the success or failure of the activation of the emergency (0-5)
  - Lessons learned from the management of the event and available resources to deal with it
  - Assessing numerically the success or failure of the event and available resources to deal with it
  - Lessons learned from the post-event management and recovery programs
  - Assessing numerically the success or failure of the post-event management and recovery programs
  - Scientific research about the event
  - Technical information about the event and measures taken after it
  - Data sources about the event

Finally, the user complete the survey with some additional spatial data, such as the perimeter of the affected area, modelling results or risk maps (to generate the first assessment of the success or failure of the risk assessments in the area), socio-demographic and environmental data (useful to assess the conditions of the area apart from allowing assessing the affected zones), population, buildings, infrastructures, etc. Finally, the user is asked to upload photos and videos that can be useful to show the impacts and the magnitude of the event.

These forms have been sent to the CSA partners; i.e., Mallorca (Spain), Egaleo (Greece), Ordu (Turkey), and Centro Region (Portugal). All of them have provided detailed answers also consulting stakeholders, national and regional databases, and relevant scientific bibliographies. Table 1 summarizes the disaster events assessed at each CSA from the information in the forms.

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Table 1: Disaster events assessed at each CSA

CSA	Flood	Landslide	Wildfire	Seismic
Mallorca (Spain)	Sant Llorenç 2018		Andratx 2013	
Ordu (Turkey)	Ordu Province 2016, Middle/Western Ordu Province 2018	Gölköy District 1984, Aybastı District 2015		
Centro Region (Portugal)	Mondego River 2019, Figueira da Foz 2018		Centro Region 2017	
Egaleo (Grecee)				Athens 1999

4. CSA Mallorca (Balearic Islands, Spain)

The island of Mallorca is a Mediterranean insular region that provides important examples and paradigms of the problems that many Mediterranean areas will probably face in the near future. Mallorca clearly illustrates the transformation of the economy, society, and environment of Mediterranean tourist resorts, undergoing the abandonment of rural activities. Moreover, these hotspots exemplify the need for holistic land use policy and management of natural hazards.

From the flood hazards perspective, the historical distribution patterns of human settlements were related to fluvial systems, but avoided the occupation of floodplains until the increase of urban areas in the 19th century during the Industrial Revolution. However, in the second part of the 20th century this urban expansion became exponential, with many more urban and tourist settlements, often in flood hazard areas.

In terms of wildfire hazard, the forest area in Europe has undergone a process of continuous expansion during the last decades causing an accumulation of forest fuel, increasing the risk of "large forest fires". The proliferation of housing in the wildland urban interface makes them much more dangerous. After a fire, the quality of vegetation, gradient slope, soil type, fire severity, rainfall intensity, the presence of soil conservation structures or the post-fire management, are some of the most important complex variables involved in environmental processes at burned landscapes in Mallorca.

Both hazards are based on the Mediterranean climate, which is mainly characterised by the temporal coincidence, during summer, of dry and hot conditions. Another relevant feature of the climate is the occurrence of heavy thunderstorms in autumn. The coincidence of high sea surface temperatures with cold advections in the mid-levels of the troposphere explains most

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of the heavy rainfall episodes during autumn. These events are characterised by convective storms prone to cause large rainfall totals but also torrential rainfall intensities, sometimes higher than 10 mm in 10 minutes.

As a consequence of these climatic conditions, a Mediterranean pyrophilic forest and shrubs have grown around the island, which implies a vast extension of fire-prone areas. Not only these fire-prone areas have increased their spread due to agricultural abandonment but the development of dwellings in the urban-forest interface, increasing the exposition and thus, vulnerability. On its side, demographic and urban growth have caused the occupation of flood plains during recent decades which, as their name says, are flood-prone areas with high risk in some cases.

Given the combination of natural features and recent changes in vegetation and urban growth, the two most relevant natural hazards in the island are flash floods and wildfires. In the last decade, the island suffered two big events: (1) In August 2013 the largest wildfire occurred since records started in the 1970s and also as a result of forest transition; and (2) in October 2018 an extraordinary flash flood causing 13 fatalities on the municipalities of Sant Llorenç des Cardassar and Artà as a result of unprecedented runoff response as a combination of heavy rainfall, karstic features and land cover disturbances.

Therefore, there is a dangerous combination of a region prone to natural hazards, with occupation of some of the most threatened areas, involving many people living in a context of high vulnerability.

4.1. Wildfire in Andratx-Estellencs-Calvià – July 26th 2013

The large wildfire that burned forest and agricultural areas of Andratx, Estellencs and Calvià from July 26th to August 13th was declared the biggest wildfire in the Balearic Islands since records are available in the 1970s. This wildfire burned 2,335 ha of coniferous forest surface and 71.75 ha of agricultural areas, summing up to 2,406 ha of the Tramuntana Range, a UNESCO Human World Heritage.

In terms of lessons learned, this episode was effectively detected by a watchtower and the response time was below 10 minutes, therefore it confirms the importance of work on warning systems and rapid emergence activation and action. Related to forest management and prevention actions, the importance of maintaining roads and paths in a good condition, and working on self-protection in the case of dwellings in the forest or urban-forest interface was noted. Likewise, it is crucial to develop forest management based on a low fuel load and taking effective prevention measures such as belts and firewalls. After the event, a continuous monitoring of the affected area allows knowing how the fire affected the ecosystem dynamics, the erosion processes and the possibility of landslides to occur. The relative success of the management of this event is partially due to the recurrence of wildfires on the island, which has implied a bigger investment in fire prevention and extinction resources by the Autonomous Government, and the experience and knowledge acquired from past events.

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Table 2: Form response for wildfire event in Mallorca in 2013

Partner	UIB
Event code	IFAndratx_2013
Event name	Incendi forestal sa Coma Calenta (Andratx, Mallorca, 2013)
Start day	26/07/2013
Start time	12:25:00
End time	11:14:00
End day	18/08/2013
Emergency management	
Start day	26/07/2013
Start time	12:30:00
End time	11:14:00
End day	18/08/2013
Recovery time	
End day	
Location	
Locality or region of start	Andratx, Mallorca, Illes Balears
Affected localities or regions	Andratx, Estellencs i Calvià
County of start	Western
Affected counties	Western
Country	Spain
Disaster event	

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Gravity index according to local, regional or national authorities (define the range of the index [e.g. IG1 in a scale from IG0 to IG3])	IG2
Type of wildfire	Underground
Morphology	Irregular
Perimeter (m)	58,971
Area (sq m)	2,335 ha
Speed of propagation (km h^{-1})	1.3
Wind speed (km h^{-1})	18 km/h
Number of focus	1
Causes	
Causes	Anthropogenic negligence
Did it cause another disaster?	Forest fire
Population	
People affected	1,500 approx
People evacuated or rescued	762
People injured	0
Missing people (were they found?)	0
Fatalities	0
Dwellings	
Affected dwellings	25

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Destroyed dwellings	35
Dwellings estimated monetary losses (€)	
Facilities and infrastructures	
Affected facilities	Tourist
Affected infrastructures	Electrical network, Water supply, Roads
Specify the affected infrastructures (e.g. dwellings affected by the electrical network failure, km of roads affected, etc.)	120 houses were affected by the passage of the forest fire, 25 of them suffered slight damage and 35 serious damage. 15 km of regional road were affected, which was completely closed due to the risk of landslides. An undetermined number of power lines and telephone and internet communication lines were affected. Communications towers and water distribution network.
Patrimonial buildings affected (including monetary losses)	0
Estimated monetary losses including facilities, infrastructures, buildings and other goods (e.g. cars, etc.)	an indeterminate number of cars, tractors, motorcycles, and others
Land use and land cover (units in hectares)	
Affected artificial surface	indeterminate
Affected forest surface	2,335 ha
Affected agricultural surface	300 ha aprox
Affected wetland surface	0

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Disaster management	
Activated units and resources	411 people from 10 land brigades (forest firefighters), 86 fire trucks, 34 aerial means of extinguishing forest fires
Deployed emergency units were	Local, Regional, National
Was there risk assessment in the affected area?	yes
Were there risk plans in the affected area? Were they activated during the event?	yes
Were there early warning systems? Did they work properly?	yes (carol towers). Yes
Assess numerically the success or failure of early warning systems	5
Lessons learned from the prevision and prevention of the event	Detection by watchtower worked correctly.
Assess numerically the success or failure of the prevision and prevention of the event	4
Lessons learned from the activation of the emergency	The emergency was activated in accordance with the established protocols. Action was taken with the proper and usual speed for these phenomena.
Assess numerically the success or failure of the activation of the emergency	5

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Lessons learned from the management of the event and available resources to deal with it	The lesson learned is that it is essential to have a well-managed territory in order to respond to an emergency correctly: roads and paths in good condition, houses and self-protected dwellings, and the forest managed with a low fuel load, with prevention measures (belts and firewall).
Assess numerically the success or failure of the event and available resources to deal with it	4
Lessons learned from the post-event management and recovery programs	Very difficult to recover the forest in spaces that have suffered a recurrence of forest fire. These spaces have led to desertification and a significant loss of environmental quality (less biodiversity).
Assess numerically the success or failure of the post-event management and recovery programs	3
Scientific research about the event	Post-forest fire monitoring was carried out with the University of the Blear Islands (geography department for the following 6 years). Numerous scientific reports and publications were produced.
Technical information about the event and measures taken after it	Restoration and management measures of the affected forest biomass were carried out: felling of trees to prevent risks, mulching and log barriers for prevention and erosion. Reconstruction of walls and recovery of roads. Control and prevention of the risk of landslides. Control and monitoring of erosion. Control and monitoring of natural regeneration
Data sources about the event. Include links to national or transnational databases (e.g. EM-DAT, Copernicus, EFAS, etc.)	Regional databases

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4.2. Flood in Sant Llorenç – October 9th 2018

During October 9th 2018 a convective storm grew on the northernmost catchments of Llevant county, which caused heavy rains with an aggregate of up to 240 mm in 10 hours, and a discharge peak of 442 $m^3 s^{-1}$ in 15 minutes, since it started raining. This episode caused 13 casualties and affected up to 433 people.

From this episode, the main lesson learned is the need for early warning systems, which must be complemented with local risk management and regional plans where the protocols of actuation are defined. These two tools would allow emergency corps to confine or evacuate potentially flooded areas, reducing substantially the amount of people exposed to the risk and these actions could have saved human lives. In addition, and purely related to the risk management itself, an active cooperation between public and private services should be compulsory to profit from both resources and knowhow, and thus, achieve a more effective disaster management. Moreover, there must be an improvement in human and structural resources to be able to face big emergency events such as this flood and all the other minor events occurring at the same time. This should include expert technicians in different fields such as cartography, telecommunications, informatics and resources management, and having the adequate tools to develop their work properly.

Table 3: Form response for flash flood event in Mallorca in 2018

Partner	UIB
Event code	
Event name	9 october 2018 in northeastern Mallorca
Start day	09/10/2018
Start time	15:00:00
End time	0:00:00
End day	10/10/2018
Emergency management	
Start day	09/10/2018
Start time	19:00:00
End time	8:00:00
End day	19/10/2018
Recovery time	
End day	

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Location	
River/s	Ca n'Amer and Canyamel rivers
Affected localities or regions	Sant Llorenç, Sa Coma, S'Illot, Son Carrió and Artà
County	Northeastern Mallorca
Affected counties	Northeastern Mallorca
Country	Spain
Disaster event	
Gravity index according to local, regional or national authorities (define the range of the index [e.g. IG1 in a scale from IG0 to IG3])	IG2 (flood) and IG1 (meteo)
Quantity of rain (mm)	240±24 mm
Maximum rain intensity (mm/h)	77
Maximum stream flow ($m^3 s^{-1}$)	442
Maximum stream flow speed (ms^{-1})	
Type of flood	Flash flood
Perimeter (m)	24,737
Area (sq m)	1,175,972
Causes	
Causes	Rainfall
Did it cause another disaster?	
Population	
People affected	433
People evacuated or rescued	342
People injured	4

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Missing people (were they found?)	74 (all found)
Fatalities	13
Dwellings	
Affected dwellings	240
Destroyed dwellings	10
Dwellings estimated monetary losses (€)	3,574,186
Facilities and infrastructures	
Affected facilities	Tourist, Commercial, industrial, sports, store, cultural and religious
Affected infrastructures	Electrical network, Water supply, Sewage network, Roads, Bridges
Specify the affected infrastructures (e.g. dwellings affected by the electrical network failure, km of roads affected, etc.)	4 roads, 8 bridges, all Sant Llorenç village water supply, electrical network: 10,987 people
Patrimonial buildings affected (including monetary losses)	3
Estimated monetary losses including facilities, infrastructures, buildings and other goods (i.e. cars, etc.)	6,842,468
Land use and land cover (units in hectares)	
Affected artificial Surface (ha)	602,855
Affected forest Surface (ha)	23,589,835
Affected agricultural Surface (ha)	2,056,449
Affected wetland Surface (ha)	0
Disaster management	

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Activated units and resources	Emergency Department, Guardia Civil, Policia Nacional, local police, Fire workers, Insular Administration Road Service, SAMU 061, private ambulances, local workers, Red Cross, Endesa, telephone companies, and volunteers. UME, COMGEBAL, Ibanat and Tragsa. Up to 774 people on October 12th
Deployed emergency units were	Local, Regional, National
Was there risk assessment in the affected area?	ARPSI (Significative potential flood risk area)
Were there risk plans in the affected area? Were they activated during the event?	Yes, METEOBAL Plan was activated with level IG1 at 19:12 and INUNBAL Plan was activated at 21:07 with level IG2
Were there early warning systems? Did they work properly?	No
Assess numerically the success or failure of early warning systems	0
Lessons learned from the prevision and prevention of the event	The absence of early warning systems about the atmospheric phenomena and its consequences caused a lack of preparation and conscientiousness about the hazard.
Assess numerically the success or failure of the prevision and prevention of the event	1
Lessons learned from the activation of the emergency	An integration of emergency call centres is needed. Also a unique emergency management centre is needed, instead of 3. The dispersion of the information caused a lack in decision-making. There must be a person specialized in data analysis 24 h every day at the Emergency Service. Some public and private services must be automatically activated when an emergency occurs (university, cartographic service, geologic institute...) Telecommunication services must be prepared for such emergencies.
Assess numerically the success or failure of the activation of the emergency	2

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Lessons learned from the management of the event and available resources to deal with it	A night rescue helicopter would be needed, more employees and with specific formation are needed in the Emergency Service Cartography Service must be integrated in the Emergency Service Lack of formation on big emergency management Advanced Management Centre must be adequately equipped with the material and specialists in telco, GIS, informatic, resources management... Human resources were insufficient to manage with all the impacts around the island and to accomplish daily tasks during these events There must be an automatic procedure to contact other services such as Red Cross and Tragsa (engineering) To organize properly spontaneous volunteers to not disturb the emergency corps Specific places for psychologist attention or first aids were needed at the Advanced Management Center A geolocation system for emergency corps in real time is needed.
Assess numerically the success or failure of the event and available resources to deal with it	3
Lessons learned from the post-event management and recovery programs	This event must imply an inflection point in emergency management and social and administrative conception about public security Still in development
Assess numerically the success or failure of the post-event management and recovery programs	
Scientific research about the event	https://doi.org/10.5194/nhess-20-2195-2020 https://doi.org/10.5194/nhess-20-2195-2020-supplement https://doi.org/10.5194/nhess-19-2597-2019
Technical information about the event and measures taken after it	http://www.caib.es/pidip2front/adjunto?codi=2243620&locale=es http://www.caib.es/pidip2front/adjunto?codi=2243630&locale=es http://www.caib.es/pidip2front/adjunto?codi=2243620&locale=es
Data sources about the event. Include links to national or transnational databases (e.g. EM-DAT, Copernicus, etc.)	https://emergency.copernicus.eu/mapping/list-of-components/EMSR323 https://public.emdat.be/data

5. CSA Ordu (Black Sea region, Turkey)

Ordu is located on the Black Sea Coast in northern Turkey, in the west of the Eastern Black Sea region. The Black Sea Region is the region with the highest rainfall in Turkey. The Eastern Black Sea Region is very rainy. In addition, within this region, daily maximum precipitation can

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significantly contribute to the total annual precipitation, also considering that annual mean precipitation can be >2,500 mm at some places.

The climate of the region is cool in summer and mild in winter. Frontal precipitation is caused by low pressures coming from northwest, west, southwest, and south. Orographic precipitation is also promoted by the effect of mountain ranges and convectional precipitation in the interior of the region. Consequently, the maximum precipitation falling in short time intervals sometimes exceeds the average of one month and often causes severe floods.

Sixty of the 100 km of CSA Ordu's coastline consists of sandy beaches. Ordu has a typical humid Black Sea climate. Precipitation is observed in almost all months of the year. In addition, there are 36 large and small rivers and streams in Ordu. According to the data collected between 1950-2011, the most common natural hazards in the province are landslides (80 %), floods (9 %) and rock falls (8 %).

If the maximum precipitation amounts recorded in the region are analysed, it is understood that large amounts of precipitation fall in short periods of time are frequent throughout the year. As a result, floods and landslides are triggered by the combination of these intense and large amounts of rainfall and also geomorphological features, causing significant loss of life and property.

Ordu has been one of the provinces with the highest number of disasters in the region during the 2010-2021 period. There has been an increase in the number of disasters in the region in the last four years and most disasters occurred in 2021.

As it has been previously explained, floods that occur in Ordu are often related to landslides. While landslides sometimes directly cause flooding, sometimes they occur as a result of flooding. In both cases, they have effects that increase the dimensions of the flood disaster. In recent years, landslides have also occurred with frequent floods and overflows, causing material and moral losses for the people of the region.

In terms of lessons learned, it is necessary to develop an integrated assessment of the synergic and accumulated impacts triggered by different phenomena such as landslides and flash floods in order to improve the prevention and the crisis management, as well as the implementation of early warning systems related with consciousness and emergency planning.

5.1. Landslide in Gölköy District – December 18th 1984

Table 4: Form response for landslide event in Ordu in 1984

Partner	ORDU
Event code	2
Event name	Ordu Province Gölköy District Sarıca-Kuşluvan Neighborhood Landslide Event

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Start day	18/12/1984
Start time	13:00:00
End time	
End day	
Time of the emergency management	
Start day	28/06/2010
Start time	
End time	
End day	
Recovery time since the end of the event itself	
End day	
Location	
Location or region of start	Ordu Province Gölköy District Sarıca-Kuşluvan Neighborhood
Affected localities or regions	Ordu Province Gölköy District Sarıca-Kuşluvan Neighborhood
County	Gölköy
Affected counties	Gölköy
Country	Türkiye
Disaster event	
Gravity index according to local, regional or national authorities (define the range of the index [e.g. IG1 in a scale from IG0 to IG3])	
Type	Rotational landslide
Average slope (degrees)	Low medium slope (17)
Type of geology and structure	It belongs to the Akveren Formation and consists of limestone, sandy limestone, sandstone, marl, siltstone, mudstone, tuffite and conglomerate.

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Perimeter (m)	3,578
Area (sq m)	558
Causes	
Causes	Rainfall
Did it cause another disaster?	No
Population	
People affected	665
People evacuated or rescued	350
People injured	0
Missing people (were they found?)	0
Fatalities	0
Dwellings	
Affected dwellings	69
Destroyed dwellings	69
Dwellings estimated monetary losses (€)	15,000,000
Facilities and infrastructures	
Affected facilities	1 mosque, 1 lodging
Affected infrastructures	Electrical network, Water supply, Sewage network, Roads
Specify the affected infrastructures (e.g. dwellings affected by the electrical network failure, km of roads affected, etc.)	
Patrimonial buildings affected (including monetary losses)	

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Estimated monetary losses including facilities, infrastructures, buildings and other goods (i.e. cars, etc.)	
Land use and land cover (hectares)	
Affected artificial surface	
Affected forest surface	
Affected agricultural surface	
Affected wetland surface	
Affected wetland surface	
Disaster management	
Activated units and resources	Ordu Provincial Directorate of Disaster and Emergency, Law Enforcement Forces (Ordu Provincial Police Department, Ordu Provincial Gendarmerie Command), Local Administrations (Ordu Metropolitan Municipality, District Municipalities)
Deployed emergency units were	Local
Was there previous risk assessment in the affected area?	No
Were there risk plans in the affected area? Were they activated during the event?	Türkiye Disaster Response Plan (TAMP) (2014) Ordu Provincial Disaster Risk Reduction Plan (2021) Türkiye Disaster Response Plan (TAMP) (2014) was activated. Local institutions took action. In the first stages of the landslide, the houses were evacuated and loss of life was prevented.
Were there early warning systems? Did they work properly?	No
Assess numerically the success or failure of early warning systems	0
Lessons learned from the prevision and prevention of the event	*The event is monitored under control. In case of sudden landslides that do not spread over time, there is no loss of life in residential areas. Therefore, the areas with landslide risk throughout the province with a very high landslide risk should be determined and settlement permits should not be given to these areas. It is necessary to evacuate the residences in the areas where settlement permits are granted and to be placed in safe areas. *Landslide risk maps with geographic analysis should be prepared in advance. *Necessary measures should be taken to reduce the risk and/or damage in risky areas by using landslide risk maps.

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	*Remote Sensing data should be integrated more and more accurately into geographic analysis.
Assess numerically the success or failure of the prevision and prevention of the event	5
Lessons learned from the activation of the emergency	Activating inter-institutional coordination during the spread of the landslide and the evacuation of the houses by the law enforcement forces prevented any loss of life in the incident.
Assess numerically the success or failure of the activation of the emergency	5
Lessons learned from the management of the event and available resources to deal with it	Regarding the urgent and prioritised works to be carried out in the Ordu IRAP in 2022-2023: * Completion of digitisation of AMB maps in sketch form *AMB borders are processed in kml / kmz format for the province and made available for common use, *Updating mass movement inventory and sensitivity maps, *Planning awareness trainings on mass movements at local level, *Completion of the new settlement works of the disaster victims whose entitlements have been completed, *Updating the 1/25.000 scale digital geological map covering the whole province, *Pilot applications for surface and shallow drainage measures in hazelnut lands, *Completion of title deed annotation and local announcement procedures of the areas declared as AAMB, *It has been decided to carry out exploration and reclamation works in various areas with rockfall risk. *Landslide risk maps should be prepared in advance by geographical analyses. *Intervention scenarios should be prepared by using landslide risk maps. *The parameters triggering landslides and the correlation and correlation between them should be determined scientifically. *Disaster data sets should be created and the data should be kept up to date continuously.
Assess numerically the success or failure of the event and available resources to deal with it	1
Lessons learned from the post-event management and recovery programs	The basis of disaster management should be preventive measures. Risky areas should be determined in advance with scientific methods, the factors that triggered the landslide and the relation between them should be revealed through field studies. In line with these studies, response scenarios should be prepared, analyzes and scenarios should be continuously improved with new findings obtained from disasters.
Assess numerically the success or failure of the post-event management and recovery programs	

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Scientific research about the event	The Landslides in Aydoğan and its Near Rounds (Ordu-Turkiye) https://dergipark.org.tr/tr/pub/marucog/issue/448/560498
Technical information about the event and measures taken after it	
Data sources about the event. Include links to national or transnational databases (e.g. EM-DAT, Copernicus, etc.)	

5.2. Landslide in Aybastı District – April 28th 2015

Table 5: Form response for landslide event in Ordu in 2015

Partner	ORDU
Event code	1
Event name	Ordu Province Aybastı District Sağlık Neighbourhood Landslide Event
Start day	28/04/2015
Start time	14:00:00
End time	
End day	
Time of the emergency management	
Start day	28/04/2015
Start time	14:00:00
End time	
End day	
Recovery time since the end of the event itself	
End day	
Location	
Location or region of start	Ordu Province Aybastı District Sağlık Neighbourhood Yağcılı Cluster Houses Location

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Affected localities or regions	Ordu Province Aybastı District Sağlık Neighbourhood Yağcılı Cluster Houses Location
County	Aybastı
Affected counties	Aybastı
Country	Türkiye
Disaster event	
Gravity index according to local, regional or national authorities (define the range of the index [e.g. IG1 in a scale from IG0 to IG3])	
Type	Rotational landslide
Average slope (degrees)	Low medium slope (17)
Type of geology and structure	It belongs to the Tekkeköy Formation and consists of sandstone, siltstone, mudstone interbedded andesite, basalt lava and pyroclasts.
Perimeter (m)	3,020 m
Area (sq m)	326,000 m^2
Causes	
Causes	Rainfall
Did it cause another disaster?	No
Population	
People affected	560
People evacuated or rescued	160
People injured	0
Missing people (were they found?)	0
Fatalities	0
Dwellings	
Affected dwellings	80 dwellings (61 buildings)
Destroyed dwellings	31 dwellings (22 buildings), 1 Mosque
Dwellings estimated monetary losses (€)	6.914.433

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Facilities and infrastructures	
Affected facilities	2 mosques 1 lodging house
Affected infrastructures	Electrical network, Water supply, Sewage network, Roads
Specify the affected infrastructures (e.g. dwellings affected by the electrical network failure, km of roads affected, etc.)	Electricity network failure, Water network, 3 km road
Patrimonial buildings affected (including monetary losses)	
Estimated monetary losses including facilities, infrastructures, buildings and other goods (i.e. cars, etc.)	6.914.433 Euro
Land use and land cover (hectares)	
Affected artificial surface	
Affected forest surface	
Affected agricultural surface	8 ha
Affected wetland surface	2 ha
Affected wetland surface	2 ha
Disaster management	
Activated units and resources	Provincial Disaster and Emergency Directorate, Law Enforcement Forces (Ordu Provincial Police Department, Ordu Provincial Gendarmerie Command), Local Administrations (Ordu Metropolitan Municipality, District Municipalities)
Deployed emergency units were	Local
Was there previous risk assessment in the affected area?	There is no local risk assessment. The first study on the landslide incident that occurred in the Health District of Aybastı District was carried out on 28.04.2015 and various cracks were detected in 5 of the 7 houses examined. It was decided to monitor the area in the control studies program.

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Were there risk plans in the affected area? Were they activated during the event?	Türkiye Disaster Response Plan (TAMP) (2014) Ordu Provincial Disaster Risk Reduction Plan (2021) Türkiye Disaster Response Plan (TAMP) (2014) was activated. Local institutions took action. In the first stages of the landslide, the houses were evacuated and loss of life was prevented.
Were there early warning systems? Did they work properly?	No
Assess numerically the success or failure of early warning systems	0
Lessons learned from the prevision and prevention of the event	Thanks to the intervention of the teams at the time of the incident, there were no casualties. No casualties were reported in the collapsed buildings. Türkiye Disaster Response Plan (TAMP) (2014) was activated. Local institutions took action. In the first stages of the landslide, the houses were evacuated and loss of life was prevented. There was no loss of life as the landslide spread over time. However, there is no loss of life in residential areas in sudden landslides that do not spread over time. Therefore, the areas with landslide risk throughout the province with a very high landslide risk should be determined and settlement permits should not be given to these areas. It is necessary to evacuate the residences in the areas where settlement permits are granted and to be placed in safe areas. *Geographic analysis, risk maps and risk models should be prepared before the disaster. * With disaster response scenarios to be created using disaster risk maps, it is necessary to be prepared for disasters in real terms. “Disaster data sets should be created and disaster inventory should be kept up-to-date after disasters. *Remote Sensing Technologies and Weather Forecast models should be integrated more and more accurately into geographical analysis.
Assess numerically the success or failure of the prevision and prevention of the event	5
Lessons learned from the activation of the emergency	Activating inter-institutional coordination during the spread of the landslide and the evacuation of the houses by the law enforcement forces prevented any loss of life in the incident.
Assess numerically the success or failure of the activation of the emergency	5

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Lessons learned from the management of the event and available resources to deal with it	Regarding the urgent and prioritised works to be carried out in the Army IRAP in 2022-2023: * Completion of digitisation of AMB maps in sketch form *AMB borders are processed in kml / kmz format for the province and made available for common use, *Updating mass movement inventory and sensitivity maps, *Planning awareness trainings on mass movements at local level, *Completion of the new settlement works of the disaster victims whose entitlements have been completed, *Updating the 1/25.000 scale digital geological map covering the whole province, *Pilot applications for surface and shallow drainage measures in hazelnut lands, *Completion of title deed annotation and local announcement procedures of the areas declared as AAMB, *It has been decided to carry out exploration and reclamation works in various areas with rockfall risk. *Landslide risk maps should be prepared in advance by geographical analyses. *Intervention scenarios should be prepared by using landslide risk maps. *The parameters triggering landslides and the correlation and correlation between them should be determined scientifically. *Disaster data sets should be created and the data should be kept up to date continuously.
Assess numerically the success or failure of the event and available resources to deal with it	2
Lessons learned from the post-event management and recovery programs	The basis of disaster management should be preventive measures. Risky areas should be determined in advance with scientific methods, the factors that triggered the landslide and the relation between them should be revealed through field studies. In line with these studies, response scenarios should be prepared, analyses and scenarios should be continuously improved with new findings obtained from disasters.
Assess numerically the success or failure of the post-event management and recovery programs	2
Scientific research about the event	Sağlık District Landslide (Ordu, Turkey) https://doi.org/10.46453/jader.811124
Technical information about the event and measures taken after it	
Data sources about the event. Include links to national or transnational databases (e.g. EM-DAT, Copernicus, etc.)	

5.3. Flood in Ordu Province – July 4th 2016

Table 6: Form response for flash flood event in Ordu in 2016

Partner	ORDU

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Event code	2
Event name	Ordu Province Perşembe District Akçaova and Kacali Creeks and Fatsa District Ilıca Creek Floods
Start day	04/07/2016
Start time	23:00:00
End time	5:00:00
End day	05/07/2016
Emergency management	
Start day	04/07/2016
Start time	14:00:00
End time	12:00:00
End day	05/08/2016
Recovery time	
End day	05/08/2017
Location	
River/s	Ordu Province Perşembe District Kacalı, Kırlı, Akçaova Creeks, Altınordu District Civil Creek, Fatsa District Bolaman, Yalıköy and Ilıca Creeks
Affected localities or regions	District centers and rural areas in the middle and east of Ordu Province (Perşembe, Fatsa and Altınordu District centers and rural areas, Gürgentepe, Çatalpınar)
County	District centers and rural areas in the middle and east of Ordu Province (Thursday, Fatsa and Altınordu District centers and rural areas, Gürgentepe, Çatalpınar)
Affected counties	Perşembe, Fatsa ve Altınordu, Gürgentepe, Çatalpınar Districts
Country	Türkiye
Disaster event	
Gravity index according to local, regional or national authorities (define the range of the index [e.g. IG1 in a scale from IG0 to IG3])	IG2 (flood) and IG1 (meteo)
Quantity of rain (mm)	158
Maximum rain intensity (mm h^{-1})	60

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Maximum stream flow ($m^3 s^{-1}$)	
Maximum stream flow speed (m/s)	Data Not Available. (There is no reliable measurement data because objects such as solid matter, litter, tree roots and branches carried along the stream cause immeasurable changes in the stream section.)
Type of flood	Flash flood
Perimeter (m)	68,000
Area (sq m)	241,000,000
Causes	Rainfall
Did it cause another disaster?	Landslide
Population	
People affected	
People evacuated or rescued	
People injured	5
Missing people (were they found?)	2
Fatalities	2
Dwellings	
Affected dwellings	16
Destroyed dwellings	10
Dwellings estimated monetary losses (€)	
Facilities and infrastructures	
Affected facilities	
Affected infrastructures	Electrical network, Water supply, Sewage network, Roads, Bridges
Specify the affected infrastructures (e.g. dwellings affected by the electrical network failure, km of roads affected, etc.)	

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Patrimonial buildings affected (including monetary losses)	
Estimated monetary losses including facilities, infrastructures, buildings and other goods (i.e. cars, etc.)	46,876,000
Land use and land cover (units in hectares)	
Affected artificial Surface (ha)	
Affected forest Surface (ha)	
Affected agricultural Surface (ha)	
Affected wetland Surface (ha)	
Disaster management	
Activated units and resources	Ordu Metropolitan Municipality, District Municipalities, Provincial Disaster and Emergency Directorate, 1st and 2nd Group Support Provinces Provincial Disaster and Emergency Directorates, Ordu Provincial Police Department, Ordu Provincial Revenue Office, Ordu Provincial Gendarmerie Command, Ordu Provincial Directorate of Environment and Urbanization, Ordu Provincial Health Directorate, Ordu Provincial Directorate of Agriculture and Forestry, Ordu Provincial Directorate of Family, Labor and Social Services, Ordu Governorship Social Assistance and Solidarity Foundation Presidency, YEDAŞ Provincial Coordinatorship Information Technologies Institution (BTK) Samsun Regional Directorate, Samsun Highways 7th Regional Directorate, Samsun Transportation and Infrastructure 9th Regional Directorate, Samsun Province Bank Regional Directorate, Erzurum Turkish Red Crescent Northeast Anatolia Regional Disaster Management Directorate
Deployed emergency units were	Local, Regional, National
Was there risk assessment in the affected area?	*Determination of Flood Hazard Areas of Streams within the Borders of Ordu and Sinop Provinces Engineering Services Procurement Final Flood Hazard Report. *Presidential Decree No.4 * Investigation Report of Ordu Province Unye District Cevizderesi dated 16.03.2018 * Eastern Black Sea Basin Flood Management Plan *Türkiye Disaster Response Plan (TAMP) *Ordu Provincial Disaster Risk Reduction Plan

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Were there risk plans in the affected area? Were they activated during the event?	Yes, Ordu Provincial Disaster Response Plan was activated.
Were there early warning systems? Did they work properly?	No
Assess numerically the success or failure of early warning systems	0
Lessons learned from the prevision and prevention of the event	- Preventing the material from all kinds of excavations in the environment from spilling in a way that narrows the stream bed, Areas with landslide risk at local scale should be determined and constructions in these areas should be prevented, -The engineering structures at the highway crossings should be sized according to the 1000-year frequency flood peak flow, and air allowance should be given, -Bridges should be built with single spans as much as possible, middle legs should be avoided, zoning plans should be created according to disaster risk plans, -Stream beds should not be covered, no material that can be dragged by water should be left on the construction sites in the study area, -The trees in the stream beds should be cleaned and more information activities should be carried out in order to raise awareness of the surrounding people in order to avoid any activities that narrow the stream beds, -Agriculture should not be done in the natural beds of rivers, In urban areas, nature should be respected, natural streams should not be closed, they should be rehabilitated, and the design criteria of storm water lines should be updated. -Forests should not be destroyed. -Geographic analysis, risk maps and risk models should be prepared before the disaster. -With disaster response scenarios to be created using disaster risk maps, it is necessary to be prepared for disasters in real terms. -Disaster data sets should be created and disaster inventory should be kept up-to-date after disasters. -Remote Sensing Technologies and Weather Forecast models should be integrated more and more accurately into geographical analysis.
Assess numerically the success or failure of the prevision and prevention of the event	1
Lessons learned from the activation of the emergency	- Coordinating the disaster from a single center by making the hierarchy of authority and definition of responsibility in detail, - Training the personnel in the Disaster Coordination Center and response team, - Digital establishment of a single-center disaster data and information flow network, - Determining the priority of intervention, - Increasing inter-institutional communication/recognition, - Coordinated role of NGOs and private sector in the disaster.

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Assess numerically the success or failure of the activation of the emergency	1
Lessons learned from the management of the event and available resources to deal with it	- Coordinating the disaster from a single center by making the hierarchy of authority and definition of responsibility in detail, - The presence of camera drones, helicopters, special land vehicles for determining the size of the disaster and the risks after it, determining the priority of intervention, search and rescue activities, effective / efficient improvements, - Digital establishment of a single-center disaster data and information flow network, - Increasing inter-institutional communication/recognition, - NGOs and the private sector also take part in the disaster in coordination, - Raising awareness of the people residing in the basin and working in the industrial zone about floods and providing training seminars for this, - Disaster Risk models, maps and scenarios prepared before the disaster should be compared with the disaster experienced, and the models and scenarios should be continuously improved. - Sensors to detect precipitation type (rainstorm or not?), time, location and time should be produced, developed if any, and live data stream should be provided to emergency centers through these sensors. Thus, in the event of a flood/flood, people should be directed to the previously determined assembly centers.
Assess numerically the success or failure of the event and available resources to deal with it	2
Lessons learned from the post-event management and recovery programs	Local, national and international administrations should produce services based on environment friendly principles respectful to nature and realise their technical, technological production and consumption activities based on these principles. The priority is to minimise the disaster risk and not to prepare the ground for disaster. Risky areas should be identified in advance by scientific methods, intervention scenarios should be prepared, analyses and scenarios should be continuously improved with the new findings obtained from the disasters experienced.
Assess numerically the success or failure of the post-event management and recovery programs	1
Scientific research about the event	
Technical information about the event and measures taken after it	- Eastern Black Sea Basin Flood Management Plan - Türkiye Disaster Response Plan (TAMP) - Ordu Provincial Disaster Risk Reduction Plan
Data sources about the event. Include links to national or transnational databases (e.g. EM-DAT, Copernicus, etc.)	

5.4. Flood in Middle/Western Ordu Province – August 7th 2018

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Table 7: Form response for flash flood event in Ordu in 2018

Partner	ORDU
Event code	1
Event name	2018 Middle/Western Ordu Flood
Start day	07/08/2018
Start time	20:00:00
End time	20:20:00
End day	10/08/2018
Emergency management	
Start day	06/08/2018
Start time	16:00:00
End time	18:00:00
End day	29/08/2018
Recovery time	
End day	07/08/2019
Location	
River/s	Ünye Cevizdere Creek, Selviler Creek, Tabakhane Creek, Fatsa Elekçi River, Çaybaşı Kurudere Creek, Persembe Büyükağız Creek, Medreseönü Kalındeğirmen Creek, Yalıköy Cinli Creek and their tributaries.
Affected localities or regions	and Middle and Eastern Black Sea Region, District centres and rural areas in the middle and west of Ordu Province (Çamaş, Çaybaşı, Fatsa, Kumru, Perşembe, İkizce, Ünye Districts)
County	District centres and rural areas in the middle and west of Ordu Province (Çamaş, Çaybaşı, Fatsa, Kumru, Perşembe, İkizce, Ünye Districts).
Affected counties	District centres and rural areas in the middle and west of Ordu Province (Çamaş, Çaybaşı, Fatsa, Kumru, Perşembe, İkizce, Ünye Districts).
Country	Türkiye
Disaster event	

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Gravity index according to local, regional or national authorities (define the range of the index [e.g. IG1 in a scale from IG0 to IG3])	IG2 (flood) and IG1 (meteo)
Quantity of rain (mm)	240-270
Maximum rain intensity (mm h^{-1})	50-70
Maximum stream flow (m^3 s^{-1})	763.32
Maximum stream flow speed (m s^{-1})	Data Not Available. (There is no reliable measurement data because objects such as solid matter, litter, tree roots and branches carried along the stream cause immeasurable changes in the stream section.)
Type of flood	Flash flood
Perimeter (m)	383,792
Area (sq m)	Çamaş (87.783.520 m²), Çaybaşı (103.446.372 m²), Fatsa (363.389.752 m2), Kumru (284.849.931 m²), Perşembe (221.276.984 m2, İkizce (167.539.318 m2), Ünye (571.401.298 m²) Total 1.798 790.000 m²
Causes	Rainfall
Did it cause another disaster?	Landslide
Population	
People affected	7 districts were generally affected directly/indirectly. Çamaş (8211), Çaybaşı (11889), Fatsa (126 775), Kumru (28 436), Perşembe (30 101), İkizce (13 276), Ünye (132 432). Total 351 120 people
People evacuated or rescued	Total 1325 people (930 seasonal agricultural workers, 165 workers in a textile factory in Ünye, 395 local people).
People injured	9
Missing people (were they found?)	
Fatalities	1
Dwellings	
Affected dwellings	77 (due to landslide) 144 (due to flooding) Total: 211
Destroyed dwellings	25
Dwellings estimated monetary losses (€)	3.135.000

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Facilities and infrastructures	
Affected facilities	Ünye Treatment Plant, Ünye Transportation Department Campus, Fatsa Organized Industrial Zone
Affected infrastructures	Electrical network, Water supply, Sewage network, Bridges
Specify the affected infrastructures (e.g. dwellings affected by the electrical network failure, km of roads affected, etc.)	356 workplaces flooded, 99 houses flooded, 123 electricity transformers were damaged, 60 vehicles damaged
Patrimonial buildings affected (including monetary losses)	
Estimated monetary losses including facilities, infrastructures, buildings and other goods (i.e. cars, etc.)	19,590,000 Euro Loss on infrastructure, 3,000,000 Euro Hazelnut crop loss
Land use and land cover (units in hectares)	
Affected artificial Surface (ha)	
Affected forest Surface (ha)	
Affected agricultural Surface (ha)	43,476
Affected wetland Surface (ha)	13,630
Disaster management	

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Activated units and resources	Ordu Metropolitan Municipality, District Municipalities, Provincial Disaster and Emergency Directorate, 1st and 2nd Group Support Provinces Provincial Disaster and Emergency Directorates, Ordu Provincial Police Department, Ordu Provincial Revenue Office, Ordu Provincial Gendarmerie Command, Ordu Provincial Directorate of Environment and Urbanization, Ordu Provincial Health Directorate, Ordu Provincial Directorate of Agriculture and Forestry, Ordu Provincial Directorate of Family, Labor and Social Services, Ordu Governorship Social Assistance and Solidarity Foundation Presidency, YEDAŞ Provincial Coordinatorship Information Technologies Institution (BTK) Samsun Regional Directorate, Samsun Highways 7th Regional Directorate, Samsun Transportation and Infrastructure 9th Regional Directorate, Samsun Province Bank Regional Directorate, Erzurum Turkish Red Crescent Northeast Anatolia Regional Disaster Management Directorate
Deployed emergency units were	Local, Regional
Was there risk assessment in the affected area?	- Determination of Flood Hazard Areas of Streams within the Borders of Ordu and Sinop Provinces Engineering Services Procurement Final Flood Hazard Report. - Presidential Decree No.4 - Investigation Report of Ordu Province Unye District Cevizderesi dated 16.03.2018 - Eastern Black Sea Basin Flood Management Plan - Türkiye Disaster Response Plan (TAMP) - Ordu Provincial Disaster Risk Reduction Plan
Were there risk plans in the affected area? Were they activated during the event?	Yes, Ordu Provincial Disaster Response Plan was activated.
Were there early warning systems? Did they work properly?	No
Assess numerically the success or failure of early warning systems	0

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Lessons learned from the prevision and prevention of the event	- Preventing the material from all kinds of excavations in the environment from spilling in a way that narrows the stream bed, - Ensuring the purchase of licensed materials in accordance with technical specifications for structures built in places such as Cevizdere, - Preventing the shrinkage of the bed section due to the activities of the companies that process industrial raw materials located on the side of Cevizdere, removing the wastes from the stream bed section by purification. - Unye Cevizdere rehabilitation and flood protection (10 x2 = 20 km), which is planned to be prepared and carried out by the 7th Regional Directorate of DSI, with the berm arrangement and creek bed cleaning, a total of L=5 km to the outside of the curves of the banks. stacked-unstacked stone fortifications are urgently needed. - Areas with landslide risk at local scale should be determined and constructions in these areas should be prevented, - The engineering structures at the highway crossings should be sized according to the 1000-year frequency flood peak flow, and air allowance should be given, - Bridges should be built with single spans as much as possible, middle legs should be avoided, zoning plans should be created according to disaster risk plans, - Stream beds should not be covered, no material that can be dragged by water should be left on the construction sites in the study area, - The trees in the stream beds should be cleaned and more information activities should be carried out in order to raise awareness of the surrounding people in order to avoid any activities that narrow the stream beds, - Agriculture should not be done in the natural beds of rivers, In urban areas, nature should be respected, natural streams should not be closed, they should be rehabilitated, and the design criteria of storm water lines should be updated. - Forests should not be destroyed. - Geographic analysis, risk maps and risk models should be prepared before the disaster. -With disaster response scenarios to be created using disaster risk maps, it is necessary to be prepared for disasters in real terms. -Disaster data sets should be created and disaster inventory should be kept up-to-date after disasters. -Remote Sensing Technologies and Weather Forecast models should be integrated more and more accurately into geographical analysis.
Assess numerically the success or failure of the prevision and prevention of the event	1
Lessons learned from the activation of the emergency	-Coordinating the disaster from a single center by making the hierarchy of authority and definition of responsibility in detail, - Training the personnel in the Disaster Coordination Center and response team, - Digital establishment of a single-center disaster data and information flow network, - Determining the priority of intervention, - Increasing inter-institutional communication/recognition, - Coordinated role of NGOs and private sector in the disaster
Assess numerically the success or failure of the activation of the emergency	1

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Lessons learned from the management of the event and available resources to deal with it	- Coordinating the disaster from a single center by making the hierarchy of authority and definition of responsibility in detail, - The presence of camera drones, helicopters, special land vehicles for determining the size of the disaster and the risks after it, determining the priority of intervention, search and rescue activities, effective / efficient improvements, - Digital establishment of a single-center disaster data and information flow network, - Increasing inter-institutional communication/recognition, - NGOs and the private sector also take part in the disaster in coordination, - Raising awareness of the people residing in the basin and working in the industrial zone about floods and providing training seminars for this, - Disaster Risk models, maps and scenarios prepared before the disaster should be compared with the disaster experienced, and the models and scenarios should be continuously improved. -Sensors to detect precipitation type (rainstorm or not?), time, location and time should be produced, developed if any, and live data stream should be provided to emergency centers through these sensors. Thus, in the event of a flood/flood, people should be directed to the previously determined assembly centers.
Assess numerically the success or failure of the event and available resources to deal with it	2
Lessons learned from the post-event management and recovery programs	Local, national and international administrations should produce services based on environment friendly principles respectful to nature and realise their technical, technological production and consumption activities based on these principles. The priority is to minimise the disaster risk and not to prepare the ground for disaster. Risky areas should be identified in advance by scientific methods, intervention scenarios should be prepared, analyses and scenarios should be continuously improved with the new findings obtained from the disasters experienced.
Assess numerically the success or failure of the post-event management and recovery programs	1

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Scientific research about the event	Cevizdere Havzasının Sayısal Modelleme Sistemlerine Dayalı Taşkın Analizi Ve Taşkın Zararlarının Değerlendirilmesi /Neslihan BEDEN http://libra.omu.edu.tr/tezler/125346.pdf https://hdl.handle.net/20.500.12712/26826 Evaluation of Floods and Landslides Triggered by a Meteorological Catastrophe (Ordu, Turkey, August 2018) Using Optical and Radar Data https://doi.org/10.1155/2020/8830661 Flood Mappıng Usıng Sentınel-1 Sar Data: A Case Study Of Ordu 8 August 2018 Flood https://www.tufuab.org.tr/uploads/files/articles/flood-mapping-using-sentinel-1-sar-data-a-case-study-of-ordu-8-august-2018-flood-2202.pdf Örnek Taşkın Risk Modeli Oluşturulması ve Ünye Şehrindeki Derelere Ait Taşkın Risk Analizleri https://jasstudies.com/?mod=tammetin&makaleadi=&makaleurl=459dfd07-2957-4e8a-ba7e-21f1af8b4f0b.pdf&key=43017 Investigation of flood risk areas in Ünye district with Best-Worst method using geographic information systems https://publish.mersin.edu.tr/index.php/alm/article/view/218/240 Estimation of the local financial costs of flood damage with different methodologies in Unye Ordu Turkey https://www.researchgate.net/publication/351903176 8-9 Ağustos 2018 Tarihlerinde Ordu İlçelerinde Meydana Gelen Yağış ve Sel Olayının WRF Modeli ve Uzaktan Algılama Ürünleri ile Analizi https://www.researchgate.net/publication/356962733 Investigation of flood risk areas in Ünye district with Best-Worst method using geographic information systems https://publish.mersin.edu.tr/index.php/alm/article/view/218/240
Technical information about the event and measures taken after it	-Eastern Black Sea Basin Flood Management Plan -Türkiye Disaster Response Plan (TAMP) -Ordu Provincial Disaster Risk Reduction Plan
Data sources about the event. Include links to national or transnational databases (e.g. EM-DAT, Copernicus, etc.)	

6. CSA Centro Region (Portugal)

The lower part of the Mondego River (Portugal) is prone to fluvial flooding due to heavy rains which, associated with the steep slopes of the headwaters of the basin and the discharges of the dams, can cause a rapid rise in the river discharges and the overflow and failure of the dikes of the Mondego River. The most recent floods with severe impacts occurred in 2001, 2016, and 2019. In these events, due to dike failure, the extension of the inundation was very significant, reaching the vast area of the floodplains, where an agricultural activity of great economic importance (area of 12,286 ha) is developed, and where the cities of Coimbra and Montemor-o-Velho and other villages are located. Frequently, some of the villages are

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isolated, with roads cut and significant damage in multiple infrastructures (e.g., water supply systems, including irrigation systems), circulation of trains on the Northern Line, etc. Despite the interventions carried out in the Mondego River basin to control floods during the 1980s, including the construction of dams and the regulation of the river in the lower part, the area is still vulnerable to the occurrence of floods that can lead to significant social and human losses.

The west coast of Portugal, where the Mondego estuary and river mouth, as well as the Figueira da Foz Harbour are located, is affected by a very energetic wave regime.

This area has suffered several interventions, including the construction of the Mondego River mouth jetties, seawalls and groynes, as well as all the works related to the harbour, like dredging and embankments. The coastal stretch south of the jetties, on the southern part of Cova da Gala groyne field, is very vulnerable. This area has a diverse typology of exposed elements to coastal flooding, such as residential areas, a hospital, restaurants, and fishery infrastructures. On the night from the 13th to the 14th October 2018, Leslie storm was responsible for severe coastal flooding that, along with heavy rainfall, caused an estimated amount of €38 million damages (around 5 million only in the Blue Economy sector), the evacuation of 800 people and the injury of a few dozen people. Educational, tourist and port facilities, as well as electrical and road infrastructures were damaged. Near the shoreline, a car was pulverised and a restaurant was reduced to rubble. Although the harbour infrastructures were not affected, the Docapesca facilities, as well as fishing industries and aquaculture facilities were severely affected. The storm left around 324,000 customers without power, highlighting the importance of infrastructure resilience. It is important to invest in infrastructure that is resilient to extreme weather events. Also, if there were proper early warning systems in place, there would be time to accommodate the most fragile assets, so that the total amount of the monetary losses could be reduced.

The Mondego River basin has been affected by wildfires that occurred in large forested areas. Over the past two decades, important wildfires occurred in 2003, 2005, and 2017, and to a lesser extent in 2012 and 2013. The wildfires initiated on the 15th of October 2017 were particularly severe, with 13 different ignitions with different durations, killing a total of 48 people, affecting a total area of 1,638 km^2, with propagation velocities of more than 3 km h^{-1} and up to more than 6 km h^{-1}. A long drought year and the occurrence of storm Ophelia (with very high temperatures and wind velocities) were the major causes of these wildfires. The severity of the fires, the number of different places with ignitions at approximately the same time and the projections of ashes, are some of the causes that justify the dimension of the burnt area.

According to Comissão Técnica Independente (2022)[6] the burnt areas were mainly composed of pinaster and eucalyptus (almost 90 %) and to a lesser extent, oak trees, chestnut trees and

[6] Comissão Técnica Independente (2022). Avaliação dos incêndios ocorridos entre 14 e 16 de outubro de 2017 em Portugal continental – Relatório final. Coord. Guerreiro, J.; Fonseca, C.; Salgueiro, A.; Fernandes, P.; Lopez Iglésias, E.; de Neufville, R.; Mateus, F.; Castellnou Ribau, M.; Sande Silva, J.; Moura, J. M.; Castro Rego, F.; Caldeira, D. N. (2022) Lisboa: Assembleia da República. https://www.parlamento.pt/ArquivoDocumentacao/Documents/Incendios_Outubro_2017_Relatorio.pdf, Last consulted on 27 July 2027.

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others. Urban areas represented only 1.2 % of the burnt areas. The major causes of the fires, considering a larger area than the Mondego river basin, were arson (36%), clearance of ground by fire (33%), and reignition (24%). The major part of the ignitions were fighted in 5 to 10 minutes after warning, but the first intervention took place when the fires were beyond its capacity of extinction.

From the analysis of several wildfires the following lessons were withdrawn (*cf.* Comissão Técnica Independente, 2022): 1) need to correct the poor location of the operational command posts, as they created numerous difficulties in mastering, from a strategic point of view, the expansion of the fire and the respective fight, as well as the rescue actions; 2) organization of a first intervention under the responsibility of duly professionalized forces and placed in a state of alert, soon after the transmission of alert states; 3) definition of a mobilising system of air resources at times when they are most needed, regardless of the time of year; 4) adoption of an efficient communication system, ensuring the necessary redundancies to prevent connection failures between operational forces and command posts; 5) judicious use of alert states, each one accompanied by precise and necessary measures on initiatives to take and preventing the vulgarisation of these warnings; 6) dynamization at the municipal level, through municipal services and local civil protection units, recognising that this has been the main absentee of the fires of October 2017; 7) make operational the municipal emergency plans, involving mobilization and action instruments, and removing the character of an inventory of resources, without operational capacity; 8) raising the awareness of populations for greater citizenship and adoption of a territorial culture that guarantees personal defense preparation against catastrophes and defining local means for combating; 9) design of a robust information system that makes it possible to generically cover the population and effectively disseminate alerts and warnings at critical times.

The impact of these events on water quality and availability, affecting both surface and groundwater resources, will be studied. In section 15, an analysis of the wildfires impacts on groundwater quality using the available historical data is presented.

6.1. Flood of Mondego River – December 23rd 2019

Table 8: Form response for river flood in Centro Region in 2019

Partner	LNEC
Event code	
Event name	2019 floods on the Mondego River
Start day	19/12/2019
Start time	
End time	

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End day	23/12/2019
Emergency management	
Start day	19/12/2019
Start time	
End time	
End day	23/12/2019
Recovery time	
End day	
Location	
River/s	Mondego
Affected localities or regions	Counties of Coimbra, Montemor-o-Velho, Soure, Figueira da Foz
County	District of Coimbra
Affected counties	Counties of Coimbra, Montemor-o-Velho, Soure, Figueira da Foz
Country	Portugal
Disaster event	
Gravity index according to local, regional or national authorities (define the range of the index [e.g. IG1 in a scale from IG0 to IG3])	
Quantity of rain (mm)	160 (in 9 days)
Maximum rain intensity (mm/h)	
Maximum stream flow ($m^3 s^{-1}$)	2,184
Maximum stream flow speed ($m s^{-1}$)	
Type of flood	River flood
Perimeter (m)	
Area (sq m)	94,603,000 (9460.3 ha)
Causes	Rainfall and dike failure

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Did it cause another disaster?	
Population	
People affected	
People evacuated or rescued	352
People injured	
Missing people (were they found?)	
Fatalities	
Dwellings	
Affected dwellings	144
Destroyed dwellings	
Dwellings estimated monetary losses (€)	
Facilities and infrastructures	
Affected facilities	Educational, Agriculture structures
Affected infrastructures	Electrical network, Water supply, Roads, Railway network
Specify the affected infrastructures (e.g. dwellings affected by the electrical network failure, km of roads affected, etc.)	
Patrimonial buildings affected (including monetary losses)	
Estimated monetary losses including facilities, infrastructures, buildings and other goods (i.e. cars, etc.)	
Land use and land cover (units in hectares)	
Affected artificial Surface (ha)	
Affected forest Surface (ha)	

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Affected agricultural Surface (ha)	90%
Affected wetland Surface (ha)	
Disaster management	
Activated units and resources	National Authority for Civil Protection, Regional and local Authorities for Civil Protection
Deployed emergency units were	Local, Regional, National
Was there risk assessment in the affected area?	Not to its full extent
Were there risk plans in the affected area? Were they activated during the event?	
Were there early warning systems? Did they work properly?	There are early warning systems concerning precipitation forecast and river level monitoring, but not an integrated system. Alerts were issued to the population about the possible rise of Mondego river levels and consequent flooding. Authorities monitored the evolution of the flood event.
Assess numerically the success or failure of early warning systems	4
Lessons learned from the prevision and prevention of the event	The authorities and the population in general are aware of the possible floods in river Mondego caused by the rupture of the dikes, based on the experience of recent events. The articulation between different authorities allowed the flood event not to reach major impacts.
Assess numerically the success or failure of the prevision and prevention of the event	4
Lessons learned from the activation of the emergency	Timely evacuation of people in flood-affected areas.
Assess numerically the success or failure of the activation of the emergency	4
Lessons learned from the management of the event and available resources to deal with it	Within the scope of civil protection, resources were mobilized for monitoring and evacuating people. It is considered necessary to implement a duly integrated flood early warning system for the Mondego basin.

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Assess numerically the success or failure of the event and available resources to deal with it	3
Lessons learned from the post-event management and recovery programs	Intervention needs have been identified in the Mondego basin, including structural and non-structural measures (basin management, early-warning systems). However, they have not yet been implemented.
Assess numerically the success or failure of the post-event management and recovery programs	3
Scientific research about the event	Conference papers and a journal article are available in the literature.
Technical information about the event and measures taken after it	
Data sources about the event. Include links to national or transnational databases (e.g. EM-DAT, Copernicus, etc.)	The flood inundation map is available in Copernicus.

6.2. Flood in Figueira da Foz October 14th 2018

Table 9: Form response for coastal flood in Centro Region in 2018

Partner	LNEC
Event code	
Event name	Leslie
Start day	13/10/2018
Start time	22:00:00
End time	2:00:00
End day	14/10/2018
Emergency management	
Start day	

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Start time	
End time	
End day	
Recovery time	
End day	
Location	
River/s	Mondego
Affected localities or regions	Figueira da Foz
County	Região Centro
Affected counties	Região Centro
Country	Portugal
Disaster event	
Gravity index according to local, regional or national authorities (define the range of the index [e.g. IG1 in a scale from IG0 to IG3])	Alert level from 0 to 3
Quantity of rain (mm)	
Maximum rain intensity (mm h^{-1})	
Maximum stream flow (m^3/s^{-1})	
Maximum stream flow speed (m s^{-1})	
Type of flood	Coastal flood
Perimeter (m)	
Area (sq m)	
Causes	
Causes	Sea and rainfall

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Did it cause another disaster?	
Population	
People affected	~30,000
People evacuated or rescued	800
People injured	27
Missing people (were they found?)	
Fatalities	
Dwellings	
Affected dwellings	5,000
Destroyed dwellings	
Dwellings estimated monetary losses (€)	38 million
Facilities and infrastructures	
Affected facilities	Educational, Tourist, Port
Affected infrastructures	Electrical network, Roads
Specify the affected infrastructures (e.g. dwellings affected by the electrical network failure, km of roads affected, etc.)	At least 5,000 homes sustained damage during the storm. Three schools and the Figueira da Foz District Hospital were damaged by the storm.[90] Near the shoreline, a car was pulverized and a restaurant was reduced to rubble Several facilities located in the harbour suffered severe damages (ex: Docapesca, fishing industries, aquaculture) Also, more to the south of Figueira da Foz, the maritime authority facility of Praia da vieira in Leiria was damaged 324,000 customers without power
Patrimonial buildings affected (including monetary losses)	
Estimated monetary losses including facilities, infrastructures, buildings and other goods (i.e. cars, etc.)	38 million (around 5 million in the blue economy)

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Land use and land cover (units in hectares)	
Affected artificial Surface (ha)	
Affected forest Surface (ha)	
Affected agricultural Surface (ha)	
Affected wetland Surface (ha)	
Disaster management	
Activated units and resources	Around 800 people took refuge in a concert hall in Figueira da Foz, more than 2800 operatives were involved
Deployed emergency units were	
Was there risk assessment in the affected area?	
Were there risk plans in the affected area? Were they activated during the event?	
Were there early warning systems? Did they work properly?	
Assess numerically the success or failure of early warning systems	
Lessons learned from the prevision and prevention of the event	
Assess numerically the success or failure of the prevision and prevention of the event	
Lessons learned from the activation of the emergency	
Assess numerically the success or failure of the activation of the emergency	

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Lessons learned from the management of the event and available resources to deal with it	
Assess numerically the success or failure of the event and available resources to deal with it	
Lessons learned from the post-event management and recovery programs	
Assess numerically the success or failure of the post-event management and recovery programs	
Scientific research about the event	
Technical information about the event and measures taken after it	
Data sources about the event. Include links to national or transnational databases (e.g. EM-DAT, Copernicus, etc.)	https://www.nhc.noaa.gov/archive/2018/LESLIE.shtml https://www.ipma.pt/pt/media/noticias/news.detail.jsp?f=/pt/media/noticias/arquivo/2018/leslie.html https://wcd.copernicus.org/articles/2/795/2021/wcd-2-795-2021-discussion.html

6.3. Wildfire in Centro Region, October-November 2017

Table 10: Form response for wildfire event in Centro Region in 2017

Partner	LNEC
Event code	BI1171056, BL2171045, BI1171061, BI2174250, BL2171054, BL2171055, BL4172375, BL2171058, BL2171062, BL1171935, BI1171072, BI1171071, BI1171073 (13 different ignitions with different codes and durations, all starting on 15/Oct/2017)
Event name	Wildfires initiated between 14 and 16 October 2017 in Portugal affecting Mondego river basin
Start day	15/10/2017
Start time	6:03:00
End time	12:22:00
End day	10/11/2017
Emergency management	

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Start day	15/10/2017
Start time	5 to 10 minutes after warning
End time	
End day	
Recovery time	
End day	
Location	
Locality or region of start	Centre and North region of Portugal and Galicia (Spain)
Affected localities or regions	Location (Parish/Municipality – affected area): Prilhão (Vilarinho/Lousã – 679 km^2), Esculca (Coja/Arganil – 472 km^2), Ponte das Portelinhas (Figueiredo/Sertã – 354 km^2, very far to the South of Mondego river basin, where it burnt 73 km^2), Decompras (Sandomil/Seia – 130 km^2), Brejo (Sabugueiro/Seia – 121 km^2)
County of start	Listed in the previous question
Affected counties	Arganil, Carregal do Sal, Fornos de Algodres, Góis, Gouveia, Lousã, Mangualde, Nelas, Oliveira do Hospital, Pampilhosa da Serra, Penacova, Santa Comba Dão, Seia, Tábua, Tondela, Trancoso, Vila Nova de Poiares
Country	Portugal
Disaster event	
Gravity index according to local, regional or national authorities (define the range of the index [e.g. IG1 in a scale from IG0 to IG3])	Extreme and Very high fire severity (cf. report Report_WILDFIRE_2017.pdf)
Type of wildfire	Canopy
Morphology	Irregular
Perimeter (m)	Location (Parish/Municipality – perimeter inside Mondego river basin): Prilhão (Vilarinho/Lousã – 1,306,048 m), Esculca (Coja/Arganil – 402,627 m), Ponte das Portelinhas (Figueiredo/Sertã – 92,007 m), Decompras (Sandomil/Seia – 138,801 m), Brejo (Sabugueiro/Seia – 171,945 m)
Area (sq m)	(area inside Mondego river basin) 1638098103
Speed of propagation (km h^{-1})	>3 everywhere reaching >6 km/h
Wind speed (km h^{-1})	variable, between 4 and 22 km/h
Number of focus	13
Causes	
Causes	Atmospheric conditions + drought
Did it cause another disaster?	There's a chance that these wildfires are responsible for flooding consequences in Dec. 2019.
Population	

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People affected	2,771 (https://public.emdat.be/) [for a larger area]
People evacuated or rescued	2,700 (homeless) (https://public.emdat.be/) [for a larger area]
People injured	71 (https://public.emdat.be/) [for a larger area]
Missing people (were they found?)	
Fatalities	48 (p. 126 Report_WILDFIRE_2017.pdf)
Dwellings	
Affected dwellings	1,712 homes and 768 business infrastructures
Destroyed dwellings	
Dwellings estimated monetary losses (€)	
Facilities and infrastructures	
Affected facilities	
Affected infrastructures	
Specify the affected infrastructures (e.g. dwellings affected by the electrical network failure, km of roads affected, etc.)	
Patrimonial buildings affected (including monetary losses)	
Estimated monetary losses including facilities, infrastructures, buildings and other goods (e.g. cars, etc.)	
Land use and land cover (units in hectares)	
Affected artificial surface	
Affected forest surface	
Affected agricultural surface	
Affected wetland surface	
Disaster management	

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Activated units and resources	
Deployed emergency units were	
Was there risk assessment in the affected area?	
Were there risk plans in the affected area? Were they activated during the event?	
Were there early warning systems? Did they work properly?	
Assess numerically the success or failure of early warning systems	
Lessons learned from the prevision and prevention of the event	
Assess numerically the success or failure of the prevision and prevention of the event	
Lessons learned from the activation of the emergency	
Assess numerically the success or failure of the activation of the emergency	
Lessons learned from the management of the event and available resources to deal with it	
Assess numerically the success or failure of the event and available resources to deal with it	
Lessons learned from the post-event management and recovery programs	

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Assess numerically the success or failure of the post-event management and recovery programs	
Scientific research about the event	
Technical information about the event and measures taken after it	Comissão Técnica Independente (2022)
Data sources about the event. Include links to national or transnational databases (e.g. EM-DAT, Copernicus, EFAS, etc.)	https://emergency.copernicus.eu/mapping/list-of-components/EMSR250, http://si.icnf.pt/geoserverplinia/BDG/ows?service=WFS&version=1.0.0&request=GetFeature&typeName=BDG%3Aardida_2017&output

7. CSA Egaleo (West Athens, Greece)

According to EU wide data (http://www.efehr.org/Earthquake-risk/risk-map/), Athens is one of the most exposed areas to "very high" earthquake risk. Similar areas of risk include major cities include Istanbul and Izmir in Turkey, Catania and Naples in Italy and Bucharest in Romania, many of which have a history of damaging earthquakes. The main drivers for the consequences of this risk include older and poorly maintained buildings and large urban areas.

7.1. Earthquake in Athens – September 7th 1999

The 1999 Athens earthquake occurred on September 7th at 14:56:51 local time near Mount Parnitha in Greece with a moment magnitude of 6.0. The proximity to the Athens metropolitan area resulted in widespread structural damage, mainly to the nearby suburban towns. More than 100 buildings (including three major factories) totally collapsed while approximately 70,000 more were damaged. The death toll of the day was 143 people and up to 1,600 were treated for injuries. Estimated economic damages exceeded 3 billion euros.

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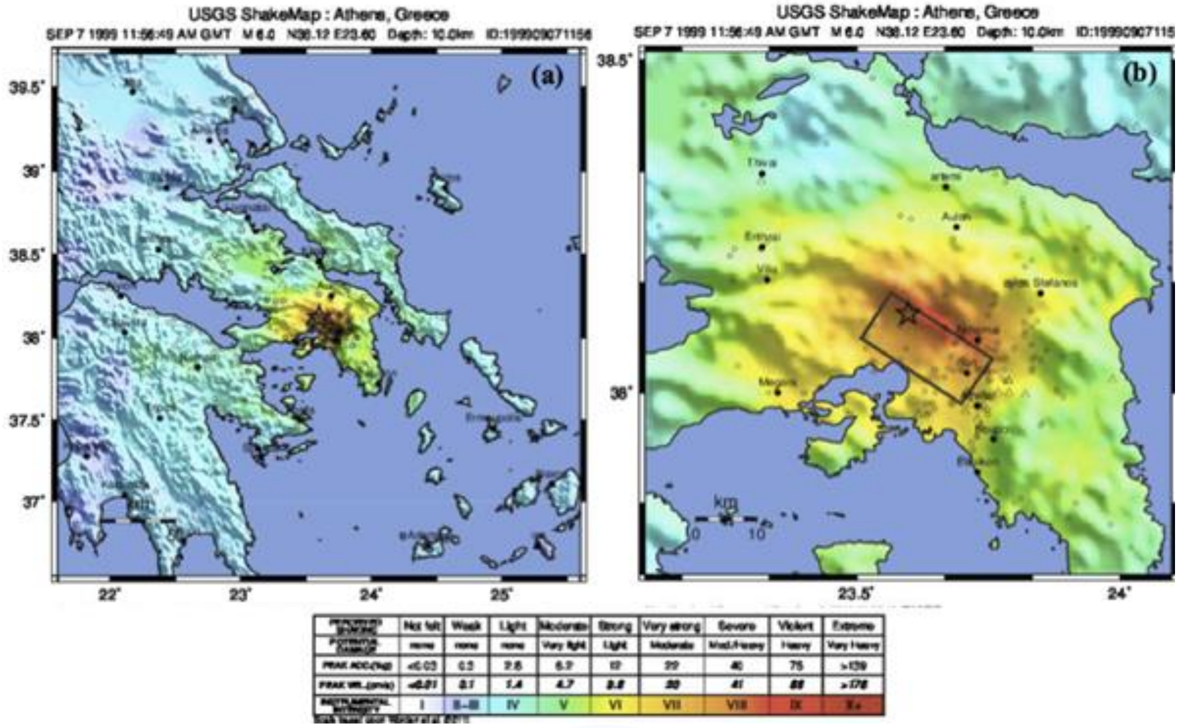

Figure 2. USGS – SHAKEMAPS from the 1999 Athens EQ

Due to the time that the earthquake occurred, many people were at work, which was the reason for the fatalities in the collapsed factories. The earthquake caused traffic jams and failure in infrastructure services. The first response and the relief efforts focussed on search and rescue operations in the collapsed buildings. The operations were done mainly by the special rescue teams and the firefighting service.

The Ministry of Environment, Urban Planning and Public Works organized numerous two-person teams of engineers for a rapid damage assessment of the region. Most of the damages were observed within a distance of 12 km of the epicenter. The damages were identified to be due to the geological site condition, poor foundation conditions (e.g., artificial fill) and/or the local topography played a dominant role

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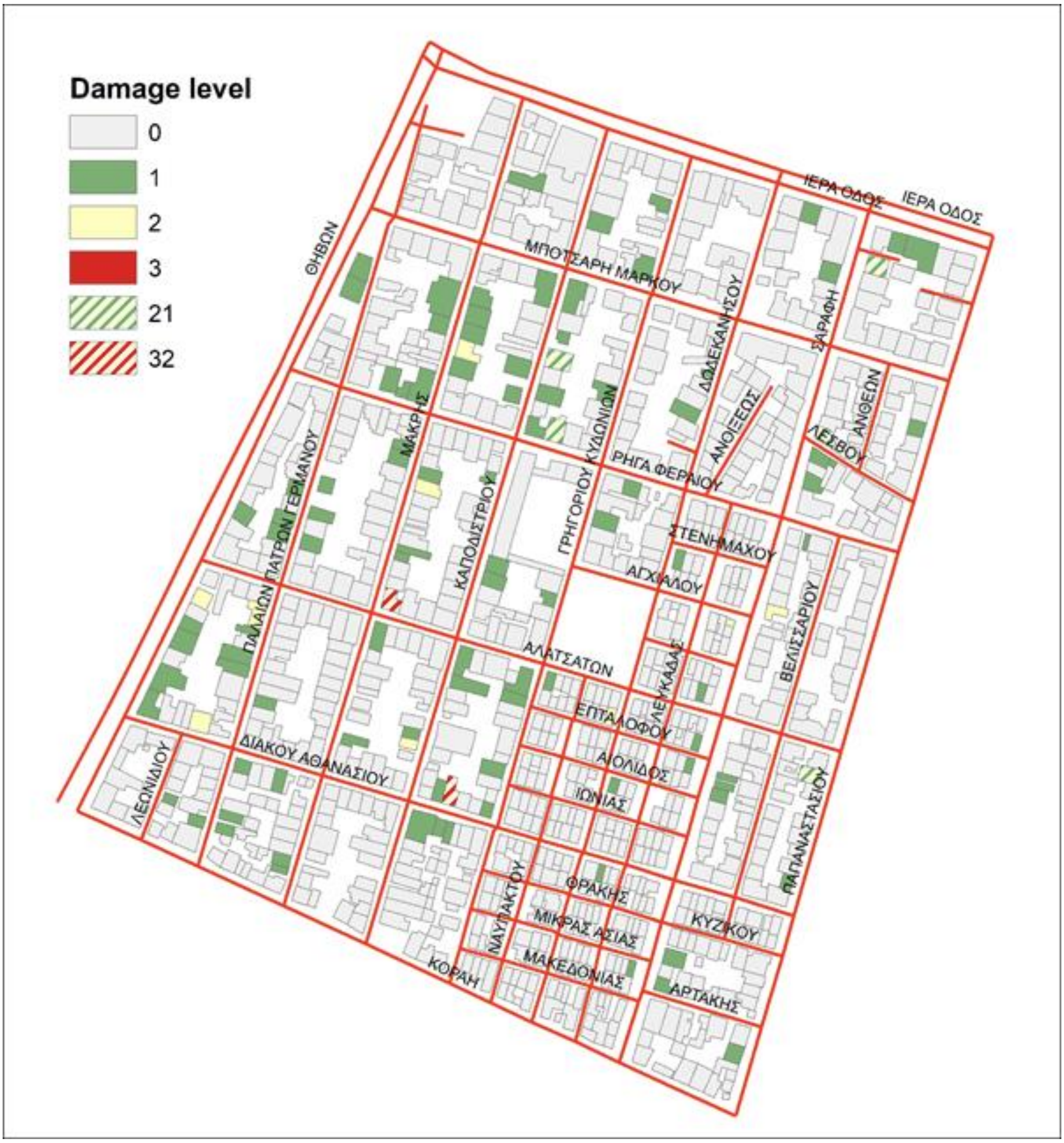

Figure 3. Damage level [1=NO-2=LIGHT-3=HIGH] in the EGL study area (source: EGL records of on site surveys)

Table 11: Form response for earthquake event in Egaleo in 1999

Partner	NCSRD, EGL
Event code	
Event name	1999 Athens Earthquake
Start day	07/09/1999
Start time	14:56:00
End time	14:57:00
End day	07/09/1999
Emergency management	
Start day	07/09/1999
Start time	

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End time	
End day	15/09/1999
Recovery time	
End day	
Location	
Epicenter (include WGS84 coordinates)	Mount Partnitha (38.105◦N, 23.565◦E)
Depth of hypocenter	8 km
Rupture length (km)	dimensions of the fault are 15 km length and 10 km width
Affected localities or regions	All Attica municipalities
County	GR
Affected counties	-
Country	
Disaster event	
Gravity index according to local, regional or national authorities (define the range of the index [e.g. IG1 in a scale from IG0 to IG3])	national
Magnitude (Richter scale)	6
Intensity (MSK scale)	
Perimeter (m)	
Area (sq m)	
Causes	
Causes	Tectonic plates movement
Did it cause another disaster?	
Population	
People affected	approx 4 million
People evacuated or rescued	
People injured	1,600
Missing people (were they found?)	-
Fatalities	143
Dwellings	
Affected dwellings	300
Destroyed dwellings	> 70,000
Dwellings estimated monetary losses	> 3bn euros
Facilities and infrastructures	
Affected facilities	Health, Educational
Affected infrastructures	Electrical network, Water supply, Sewage network, Roads
Specify the affected infrastructures (e.g. dwellings affected by the electrical network failure, km of roads affected, etc.)	
Patrimonial buildings affected (including monetary losses)	minor impacts on all cultural heritage sites
Estimated monetary losses including facilities, infrastructures, buildings and other goods (e.g. cars, etc.)	
Land use and land cover (units in hectares)	
Affected artificial surface	
Affected forest surface	
Affected agricultural surface	
Affected wetland surface	

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Disaster management	
Activated units and resources	
Deployed emergency units were	Local, National
Was there previous risk assessment in the affected area?	Yes
Were there risk plans in the affected area? Were they activated during the event?	yes
Were there early warning systems? Did they work properly?	not applicable in earthquakes
Assess numerically the success or failure of early warning systems	
Lessons learned from the prevision and prevention of the event	
Assess numerically the success or failure of the prevision and prevention of the event	
Lessons learned from the activation of the emergency	Allocation of resources in an important issue
Assess numerically the success or failure of the activation of the emergency	4
Lessons learned from the management of the event and available resources to deal with it	Allocation of resources and cross organizational collaboration
Assess numerically the success or failure of the event and available resources to deal with it	4
Lessons learned from the post-event management and recovery programs	
Assess numerically the success or failure of the post-event management and recovery programs	
Scientific research about the event	> 10 related scientific publications
Technical information about the event and measures taken after it	Changes in National Building Code
Data sources about the event. Include links to national or transnational databases (e.g. EM-DAT, Copernicus, etc.)	

8. Preliminary conclusion remarks and next steps

As the first of the two deliverables within this WP1, preliminary conclusions are provided as general lessons learned from disaster prevention, management and recovery:

a) It is crucial to implement a systematic protocol to collect data after each disaster event because it is the main way to learn from the event management. Under this context, the lack

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of a unique database to collect integrated physical, social and economic data about an event implies that data is collected by different administrations or emergency corps, considering data is not collected in most events.
b) The difficulty to obtain certain data, especially demographic and economic information, is a lack of learning from the past. In this sense, it is crucial to promote inter-institutional cooperation and multi-level governance to get all useful data for risk management and to get lessons learned.
c) In general terms, and common to all kinds of disasters analysed, human and technical resources are clearly needed to deal with large catastrophic events.
d) Fluid cooperation between public and private sector are also mandatory to manage disaster events, as well as inter-institutional cooperation for promoting institutional resilience and multi-level governance Disaster preparedness.
e) An integration of risk management plans with early warning systems and prompt detection systems would minimize damages and injured people, combined with risk cartography and other geographical data, and adaptation of main infrastructures to the risk which they are exposed to.

Therefore, once some of the main lessons learned have been highlighted, a more accurate analysis in the next Report will be developed, in which lessons learned must be stated in two main lines. The first one, referred to lessons learned related to all types of disasters and to all CSA, or most of them, should include the lack of resources or failure in communication flow. Secondly, lessons learned for each specific disaster, or even CSA, which are the tools or management systems to face each disaster. In this sense, an early warning system could be very useful for a flood, but it would be less effective in case of an earthquake. To achieve this task, a deeper analysis on disaster management and cooperation with emergency corps, stakeholders, territorial planners and scientists is mandatory, because an integrated and holistic approach is considered to be the best way to not only analyse the causes and consequences of the disaster event but also its initial response, crisis management and recovery tasks. This inter- and multi disciplinary cooperation based on expertise knowledge will lead to a complete analysis of the disaster event and its crises, management and recovery.

From the first approach developed within this deliverable -focused on historical data acquisition-, the next steps to be developed must address the application of State of the Art Models (SoA), as well as their comparison at the CSA level. Their application should integrated a robust information-theoretic metrics for quantifying the degree of (dis)similarity among outputs (within the SoA and between the SoA and SoS4MHRIN), and the relative merits of each approach with respect to each benchmark ranging from spatiotemporal resolution, lead time and consistency of results.

For the next Deliverable, it is expected to have disaster events from all CSA with more specific and detailed data about the events due to there still are some missing information in some cases, its pre-disaster phase (risk plans availability, risk cartography, etc), and its management (corps and services deployed, consequences, etc), and also the application of SoA Models. All these inputs will allow us to get lessons learned from all catastrophes, not also in each CSA but in a generic way for all CSA and multi-hazard scenarios.

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10.Appendix: Analysis of the wildfires impacts in groundwater quality using the available historical data

1. Introduction

Wildfires have the direct consequence of reducing, or even making disappear, the forest biomass, causing a decrease of the water retention and of the soil infiltration capacity. Soils are exposed to erosion causing the mobilisation of fine matter, namely the ashes of the fire itself, to the nearest water lines or their infiltration into the ground (Neary et al., 2008; Abraham et al., 2017; Stavi, 2019).

The physical erosion processes induce important changes in the soil and water quality, as ashes became a main source of contamination. The amount and composition of the ashes deposited depend on the weight and spatial distribution of burned vegetation, the type and chemical composition of the vegetation, and the degree of combustion. This topic has been widely investigated, namely through laboratory burning, although some of the ashes analysed under these conditions probably have a higher mineral content than that resulting from burning in the field. Bodí et al. (2014) present the results of the chemical composition of various types of ash. Lopes (2006), Lobo Ferreira et al. (2006) and Nunes et al. (2017) present some results of the characterization of soils and fire ashes for different vegetation cover in Portugal.

In general, vegetable ash residues are dominated by carbonates of alkaline and alkaline earth metals, with varying amounts of silica, sesquioxides (oxides in which two atoms of an element are combined with three atoms of oxygen) of alkaline and alkaline earth metals, calcium and magnesium polyphosphates, and small amounts of organic and inorganic nitrogen. The relative concentrations of these components vary according to plant species (Ranalli, 2004; EUFIRELAB, 2006). The amounts of phosphorus, potassium, calcium, and magnesium released by the fire and that accumulate on the surface of the soil and in the ashes are up to ten times higher than the total amounts of these elements in the soil (EUFIRELAB, 2006). Taking these aspects into account, it is possible to consider that the ash deposited on the ground after the fire also improves soil fertility and facilitates the growth of vegetation. The strong increase in pH that occurs at higher temperatures may be due to the loss of OH groups from clays and the formation of oxides of various elements, obtained from the breakdown of carbonates (EUFIRELAB, 2006). Some authors also refer to the presence of some heavy metals after wildfires (e.g., Lobo-Ferreira et al., 2006). In this case it refers to the presence of manganese coming from pine needles burning.

Aiming to support the choices made in this study, a summary of the chemical inputs measured in ashes, soils, and waters in burned areas is presented in Table 1. This table does not intend to be exhaustive, but to bring enough data to support the subject in discussion.

Table 1: Summary of some of the information available on chemical inputs from wildfires in ashes, soil, and water

Reference	Medium	pH	CEC	EC	C	Ca^{2+}	Mg^{2+}	NO_3^-	K^+	Na^+	P	Cl^-	Mn	Cu	Zn	Fe	Pb	PAH

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In: Bitner et al. (2001):																		
Baird *et al.* (1999)	Soil				▼			▼										
Stromgaard (1992)	Soil	↑			↑	▼	↑	↑	↑									
Belillas e Roda (1993)	Surface water	▼								↑								
	Runoff					↑		↑	▼	↑								
DeBano *et al.* (1979)	Soil		▼					↑	↑				↑					
	Surface water									↑								
	Runoff					↑	↑											
Tiedmann *et al.* (1978)	Surface water	↑		↑				↑	↑	↑	↑							
	Runoff					↑	↑											
	Soil												↑					
Wright (1976)	Runoff	↑				↑			↑	↔	↑							
Raison *et al.* (1985)	Ashes					↑	↑				↑							
Austin e Baisinger (1955)	Soil	↑				↑	↑	▼	↑									
Viro (1974)	Soil	↑				↑	↑	↑	▼									
	Ashes					↑					↑							
Stednick *et al.* (1982)	Surface water						↑	↑	↑	↑	↑							
Schindler *et al.* (1980)	Surface water							↑	↑		↑							
Chambers e Attiwill (1994)	Soil							↑					↑					
Adams *et al.* (1994)	Soil				▼			▼										
Auclair (1977)	Soil													↑	↑			
Paliouris *et al.* (1995)	Soil																	
Amiro *et al.* (1996)	Ashes											↑						
Beschta (1900)	Surface water								↑		↑							
In: Ranalli (2004)																		
Soto e Diaz-Fierros (1993)	Ashes	↑																
Kutiel e Inbar (1993)	Soil			↑														
Laranjeira e Leitão (2008)	Groundwater	↑		↑						↑	↑							
Lopes (2006)	Surface water	↑								↑	↑							
Lobo Ferreira et al. (2006)	Ashes and soil												↑					↑
Campos et al. (2012, 2016)	Surface water												↑	↑	↑	↑	↑	↑
Nunes et al. (2017)	Ashes and soil												↑	↑	↑			
Nitzsche et al. (2022)	Surface water							↑			↑							

Legend: ↑ – *increasing values after fire*

▼ – *decreasing values after fire*

CEC – Cation Exchange Capacity

EC – Electrical Conductivity

C – Carbon

PAH – Polycyclic Aromatic Hydrocarbons

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2. Aim and methods

Portugal has experienced several severe wildfires in the past, particularly during the summer months when high temperatures, low humidity and wind conditions increase the risk of fire outbreaks, either naturally or with anthropogenic origin. The central region of Portugal is particularly affected since it reaches these risk conditions often. These wildfires have had various impacts, being the example of the wildfires of 2017, in the region of Mondego watershed, one of the deadliest and with more environmental consequences wildfire events in Portugal's history. The three main impacts were:

1. Loss of lives: these wildfires have tragically resulted in the loss of dozens of human lives, as a direct result of the wildfires.

2. Damages to property and infrastructures, having economic impacts: these wildfires have caused extensive damage to homes (several hundreds), buildings (dozens of industries), infrastructure (such as roads and power lines), and other properties. The destruction of homes and essential facilities lead to long-term displacement and the need for reconstruction. Additionally, wildfires have harmed agriculture, livestock, and forestry, impacting local economies and livelihoods.

3. Environmental aspects: these large-scale wildfires have had a devastating effect on the environment, starting by destroying natural habitats and ecosystems. The loss of vegetation has led to soil erosion and changes in the water cycle, posing a string pressure in the water quality in the area.

The aim of this study is to analyse the possible impact of the last decade wildfires in the groundwater quality of central Portugal, using the affected area of Mondego watershed.

To reach the goal proposed, the following methodology was considered for Mondego watershed:

- Identify the last decade main forest fires periods and the extension of burnt area per year.

- Identify the existing groundwater monitoring wells, within and outside the burned areas.

- Gather the existing historical data obtained by the Portuguese Water Authority (APA) concerning the groundwater quality.

- Analyse possible changes in groundwater quality within burned areas, before and after the wildfire periods, with the following:

    - Analysing the evolution of the concentration in selected parameters (indicators) in the last decades.

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- Calculating the median[7] values in selected parameters (indicators), before and after the wildfire periods.
- Statistically assessing the trends in selected parameters (indicators) using Mann-Kendall (MK) and MK seasonal tests.
- Using Principal Components Analysis (PCA) to help visualizing possible relations between variables, reducing the dimensionality of the data intercorrelations.

In the last decade (2012-2022), the main forest wildfires in Mondego watershed (MAI Mondego) have occurred in the year 2017, followed by the years 2013 and 2015. Figure 1 shows the extension of those fires together with the geographical position of the existing wells with historical water quality data.

[7] Median values were chosen since average values lead to misinterpretations in the cases with extreme values.

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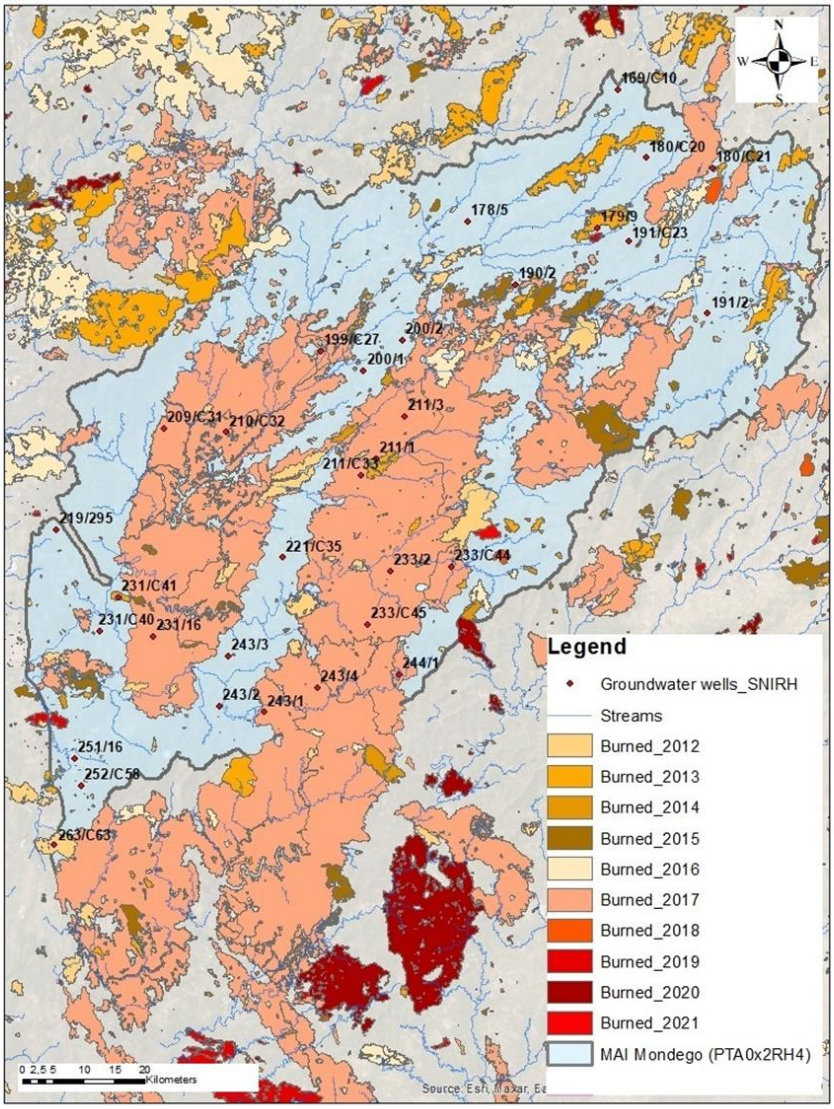

Figure 1: Burned areas in the last decade in Mondego Watershed.

Table 2: Synthesis of the wells reference and the groundwater analysis in burned and non-burned areas.

	Total	Wells in areas not burned	Wells in areas burned	Wells in areas only burned in 2017
Wells	#32	#15 (169/C10, 178/5, 180/C20, 180/C21, 191/2, 191/C23, 200/1, 200/2, 219/295, 221/C35, 231/C40, 243/2, 243/3, 251/16, 252/C58)	#17 (179/9, 190/2, 199/C27, 209/C31, 210/C32, 211/1, 211/3, 211/C33, 231/16, 231/C41, 233/2, 233/C44, 233/C45, 243/1, 243/4, 244/1, 263/C63)	#13 (190/2, 199/C27, 209/C31, 210/C32, 211/3, 211/C33, 231/16, 233/2, 233/C44, 233/C45, 243/1, 243/4, 244/1)
Groundwater analysis	636	319	317	249

Concerning the 17 wells located in a burned area, the existing historical information available in APA database (https://snirh.apambiente.pt/index.php?idMain=2&idItem=1) is summarized in Table 3. From the 17 wells referred, seven have been excluded since the existing data does not cover the respective wildfires period.

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Table 3: Information about the wells located in burned areas, years with wildfires in the last decade, and groundwater quality historical data available.

Well number	Year(s) with wildfires in the last decade	Existing historical data		# groundwater quality samples	Well excluded due to the lack of information
		First sample	Last sample		
179/9	2013	03/02/2004	21/03/2022	26	-
190/2	2017	03/02/2004	03/09/2022	26	-
199/C27	2017	03/09/2004	05/11/2010	12	Yes
209/C31	2017	03/09/2004	29/11/2011	14	Yes
210/C32	2017	03/09/2004	24/10/2006	6	Yes
211/1	2013, 2017	27/04/2010	04/01/2019	9	-
211/3	2017	27/05/2020	03/10/2021	3	Yes
211/C33	2017	16/03/2004	03/10/2015	18	Yes
231/C41	2013, 2017	26/04/2004	13/04/2009	10	Yes
233/2	2017	03/08/2004	15/03/2022	28	-
233/C44	2017	16/03/2004	03/09/2022	25	-
233/C45	2017	16/03/2004	03/09/2022	24	-
231/16	2017	05/04/2004	14/03/2022	22	-
243/1	2017	04/06/2004	15/03/2022	26	-
243/4	2017	03/08/2004	15/03/2022	28	-
244/1	2017	03/08/2004	21/07/2010	17	Yes
263/C63	2012	29/11/2004	31/03/2021	25	-

The 10 wells with relevant information about groundwater quality data are presented in Table 4 (there are 120 pesticides analysis that are not presented in the table since all results were below detection limits; the exception is Methyl Parathion which is included in Table 4).

Table 4: Water quality data available in 10 wells located in the areas burned in the last decade.

Parameter	Unit	No. of results	Non-detects % (No.)	Minimum	Maximum
Temperature	°C	209	0 (0)	9	24
Electrical conductivity (EC)	µS/cm	231	0 (0)	36	820
pH	-	231	0 (0)	5.4	7.9
DO	mg/L	224	0 (0)	1.6	10
BOD	mg/L	9	88.9 (8)	< 3	3
COD	mg/L	9	100 (9)	< 10	< 10
TOC	µg/L	98	38.8 (38)	< 1	42
TSS	mg/L	17	82.4 (14)	< 2	74
Hardness (CaCO3)	mg/L	112	3.6 (4)	< 10	420
Ca^{2+}	mg/L	112	46.4 (52)	< 4	92

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K^+	mg/L	105	4.8 (5)	< 0.1	4.6
Mg^{2+}	mg/L	70	0 (0)	0.1	74
Na^+	mg/L	105	1 (1)	< 0.5	51
Cl^-	mg/L	237	8 (19)	< 5	70
HCO_3^-	mg/L	121	28.1 (34)	< 10	420
SO_4^{2-}	mg/L	234	89.3 (209)	< 10	210
NO_3^-	mg/L	235	48.9 (115)	< 1	18
NO_2^-	mg/L	155	94.2 (146)	< 0.01	0.026
N Kjeldahl	mg/L	7	100 (7)	< 0.5	< 0.5
N total	mg/L	18	50 (9)	< 0.5	2
NH_4^+	mg/L	237	93.3 (221)	< 0.1	1.5
PO_4^{3+}	mg/L	55	0 (0)	< 0.02	0.32
P	mg/L	171	0 (0)	0.005	1.4
Oxidability Permanganate	mg/L	79	83.5 (66)	< 0.51	2.7
P_2O_5	mg/L	200	0 (0)	< 0.05	3.3
Alkalinity $CaCO_3$	mg/L	68	38.2 (26)	< 20	340
Metals and metalloids					
Al total	mg/L	11	27.3 (3)	< 0.005	0.07
As dissolved	mg/L	22	22.7 (5)	< 0.001	0.02
As total	mg/L	33	24.2 (8)	< 0.001	0.061
B	mg/L	2	100 (2)	< 0.021	< 0.021
Ba	mg/L	28	92.9 (26)	< 0.01	0.51
Be	mg/L	17	100 (17)	< 0.01	< 0.01
Cd dissolved	mg/L	22	68.2 (15)	< 0.25	0.46
Cd total	mg/L	33	87.9 (29)	< 0.00025	0.002
CN total	mg/L	69	100 (69)	< 0.02	< 0.02
Cu dissolved	mg/L	29	48.3 (14)	< 0.002	0.04
Cu total	mg/L	103	65.1 (67)	0.01	1.2
Cr dissolved	mg/L	87	83.9 (73)	< 0.0005	0.0039
Cr total	mg/L	14	100 (14)	< 0.001	< 0.005
F	mg/L	26	46.2 (12)	0.2	0.6
Fe dissolved	mg/L	68	86.8 (59)	0.01	6.4
Fe total	mg/L	56	58.9 (33)	< 0.02	12
Hg dissolved	µg/L	22	18.2 (4)	0.01	0.19
Hg total	µg/L	57	68.4 (39)	0.02	0.51
Li	mg/L	2	100 (2)	< 0.0052	< 0.02
Mn dissolved	mg/L	9	55.6 (5)	< 0.005	0.66
Mn total	mg/L	19	36.8 (7)	< 0.005	0.62
Mo total	mg/L	17	94.1 (16)	0.01	0.01
Ni total	mg/L	66	65.2 (43)	< 0.001	0.042
Pb dissolved	mg/L	22	100 (22)	< 1	< 1
Pb total	mg/L	135	86.7 (117)	0.001	0.013
Sb total	mg/L	2	100 (2)	< 0.001	< 0.001
Se dissolved	mg/L	19	89.5 (17)	< 0.001	0.01

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SiO2	mg/L	121	0 (0)	2.4	59
Ti	µg/L	17	100 (17)	< 0.01	< 0.01
Th	mg/L	17	88.2 (15)	< 0.01	0.01
U total	mg/L	6	50 (3)	< 0.03	0.04
V total	mg/L	17	100 (17)	< 0.01	< 0.01
Zn dissolved	mg/L	9	0 (0)	0.01	0.04
Zn total	mg/L	124	54 (67)	< 0.01	1.3
Hydrocarbons					
TPH	mg/L	10	30 (3)	< 1.1	57
Phenol Index	mg/L	16	87.5 (14)	< 0.001	0.001
1,2-Dichloroethane	µg/L	17	100 (17)	< 0.5	< 0.5
TCE	µg/L	48	100 (48)	< 0.5	< 1
PCE	µg/L	48	100 (48)	< 0.5	< 1
BTEX (Benzene, Toluene, Ethylbenzene and Xylenes)					
Benzene	µg/L	30	100 (30)	< 1	< 1
Ethylbenzene	µg/L	30	100 (30)	< 1	< 1
meta- & para-Xylene	µg/L	2	100 (2)	< 1	< 1
ortho-Xylene	µg/L	2	100 (2)	< 1	< 1
Toluene	µg/L	30	100 (30)	< 1	< 1
Xylene	µg/L	30	100 (30)	< 1	< 1
PAH (Polycyclic Aromatic Hydrocarbon)					
Anthracene	µg/L	17	100 (17)	< 0.005	< 0.005
Benzo(a)pyrene	µg/L	17	100 (17)	< 0.005	< 0.005
Benzo(b)fluoranthene	µg/L	17	100 (17)	< 0.005	< 0.005
Benzo(g,h,i)perylene	µg/L	17	100 (17)	< 0.005	< 0.005
Benzo(k)fluoranthene	µg/L	17	100 (17)	< 0.005	< 0.005
Indene(1,2,3-cd)pyrene	µg/L	17	100 (17)	< 0.005	< 0.005
Naphthalene	µg/L	17	11.8 (2)	< 0.005	0.08
Pyrene	µg/L	12	100 (12)	< 0.005	< 0.005
Biologic parameters					
E. Coli	#	106	90.6 (96)	0	8
Enterococcus	NMP/100ml	71	84.5 (60)	0	13
Enterococcus	UFC/100ml	154	28.6 (44)	0	23
Faecal coliforms	#	118	12.7 (15)	0	37
Total Coliforms	#	118	11 (13)	0	66
Pesticide					
Methyl Parathion	µg/L	26	65.4 (17)	< 0.004	0.052

For the 10 wells with information available, an analysis was made to see if there are significant water quality differences before and after the wildfires.

3. Results and discussion

Considering the findings of the authors referred in Table 1 (related to the chemical impacts of wildfires in ash composition, and soil and water quality), the main parameters considered to assess the chemical changes due to wildfires in our study area of Mondego watershed (considering different vegetation burned, fire intensity, geology, etc.) were the following: EC,

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Carbon, hydrocarbons (HC), pH, NO_3^-, P, Ca^+, Mg^{2+}, K^+, Si, Cl^-, SO_4^{2-}, HCO_3^-, Cu, Fe, Mn, Pb, Zn, and PAH. The organic matter content (OM), biological and chemical oxygen demand (BOD, COD), total suspended solids (TSS) and dissolved oxygen (DO) were also initially considered. However, from these set of parameters, several had to be excluded due to very few data available (sometimes because the existing data was mostly below the detection limit) in each well (which is the case of most hydrocarbons, BOD, COD, HC, Fe, Mn, Pb, Zn) or no data available after 2017 (not allowing the comparison before and after the fire, e.g., TSS, Ca^+, Mg^{2+}, K^+, Si, HCO_3^-, Cu).

So, the following six parameters were used to analyse the potential effect of wildfires: NO_3^-, pH, Cl^-, SO_4^{2-}, P, and EC. The variation in their concentration in the last 20 years is presented in Figure 2 to Figure 7 for the 10 wells located in burned areas. Table 5 presents the median values of those six parameters before and after the respective wildfire periods.

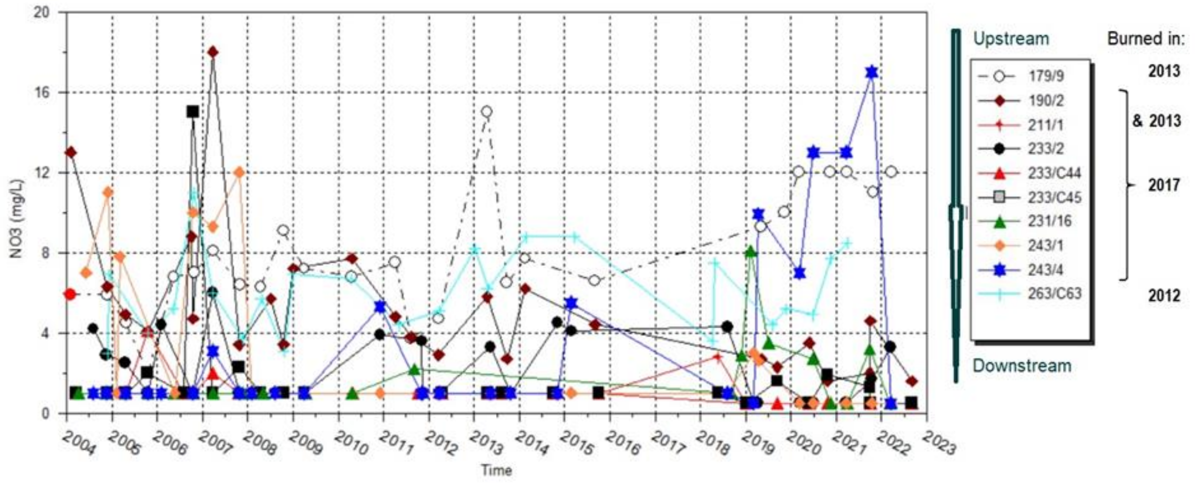

Figure 2: Variation of nitrate (NO_3^-) concentration in the groundwater of 10 wells located in burned areas of Mondego watershed.

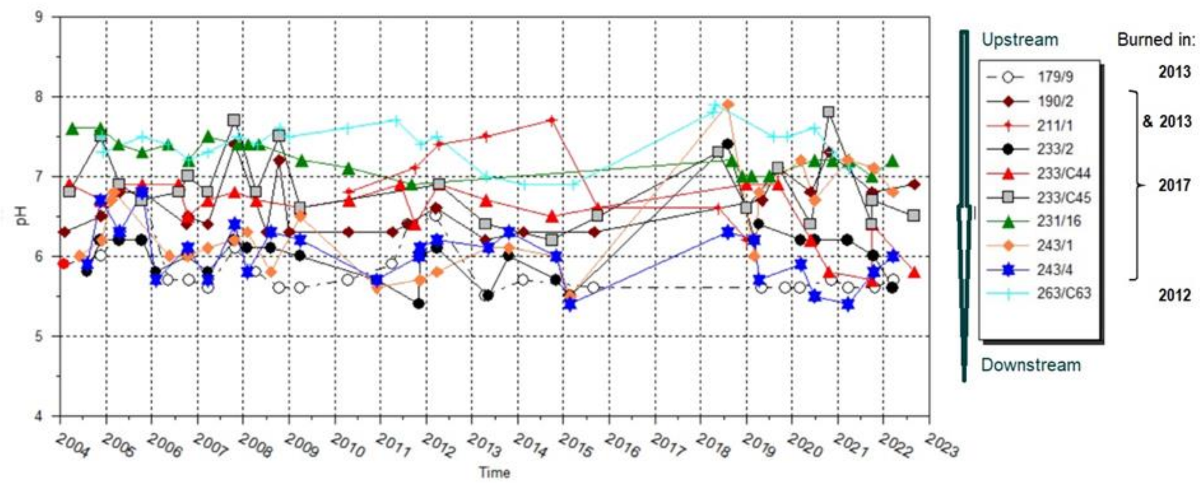

Figure 3: Variation of pH concentration in the groundwater of 10 wells located in burned areas of Mondego watershed.

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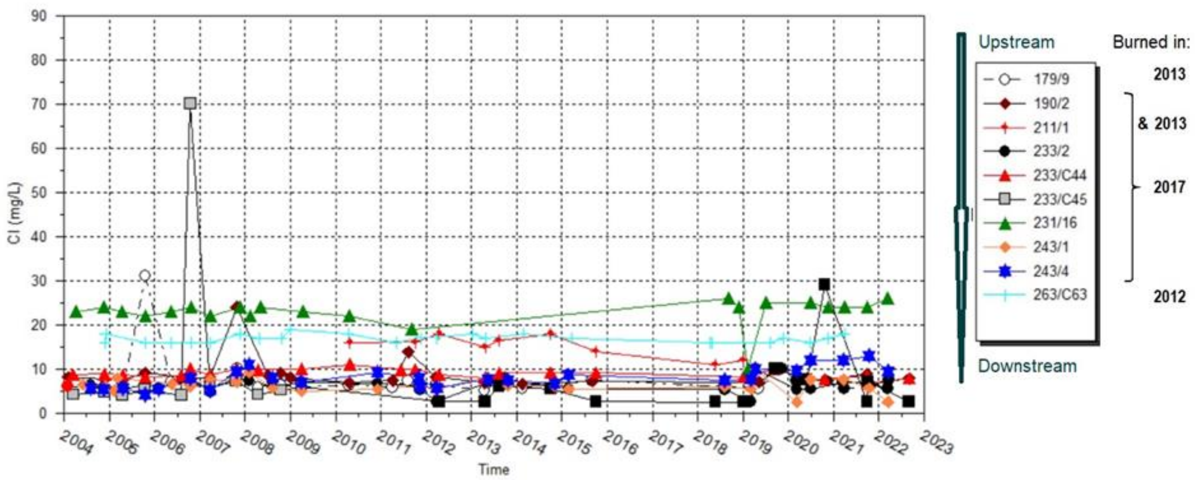

Figure 4: Variation of chloride (Cl^-) concentration in the groundwater of 10 wells located in burned areas of Mondego watershed.

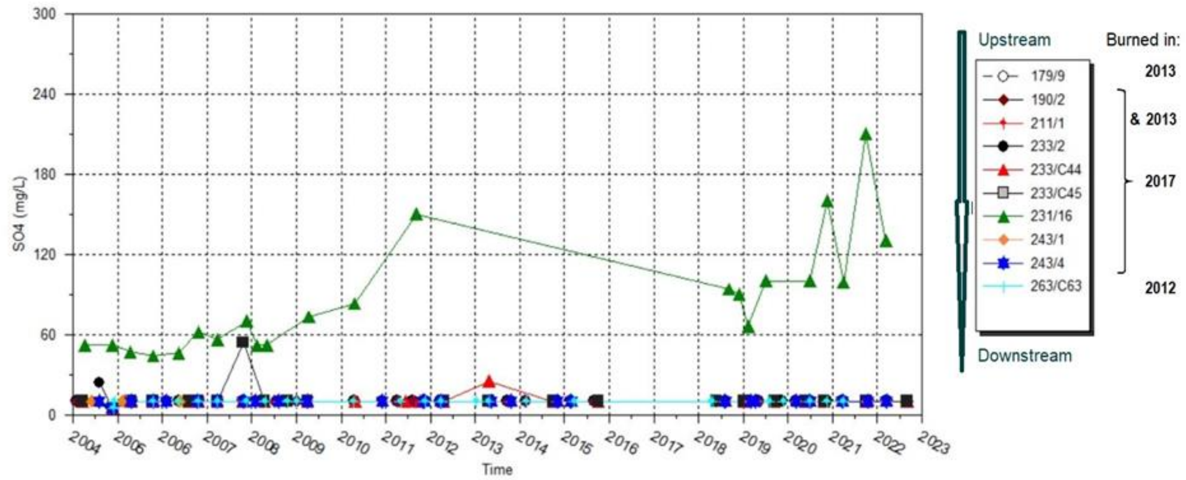

Figure 5: Variation of sulphate (SO_4^{2-}) concentration in the groundwater of 10 wells located in burned areas of Mondego watershed.

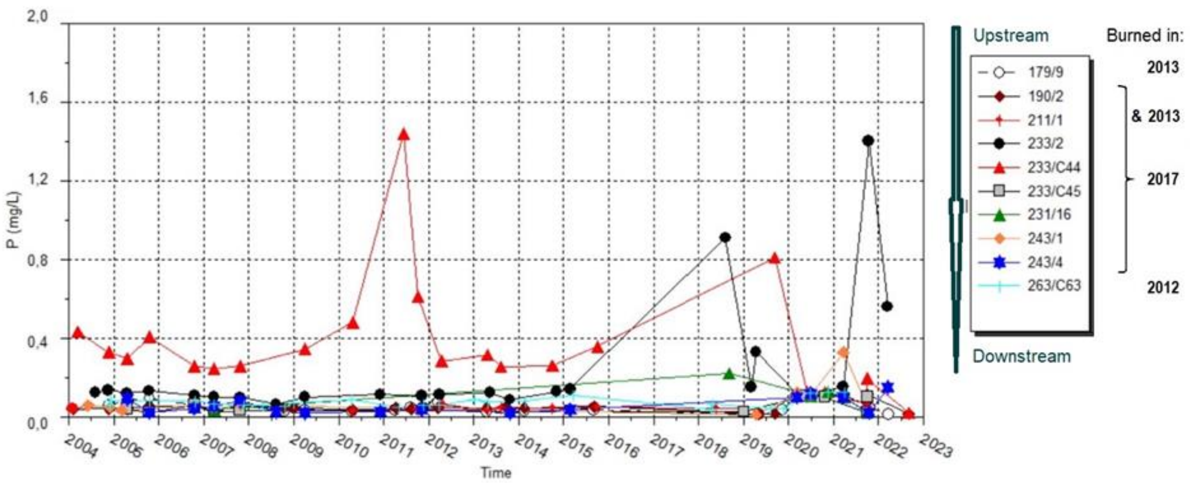

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Figure 6: Variation of phosphate (P) concentration in the groundwater of 10 wells located in burned areas of Mondego watershed.

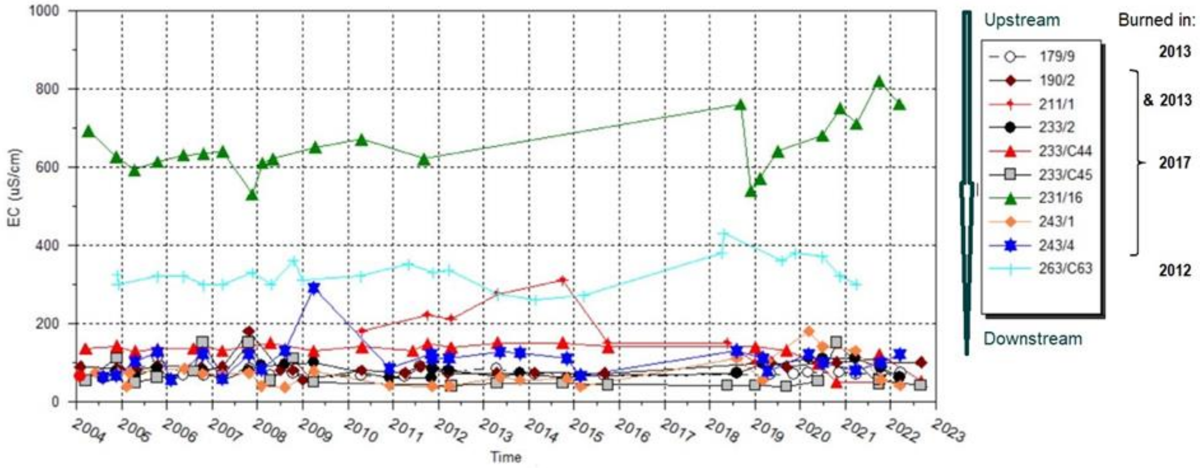

Figure 7: Variation of electrical conductivity (EC) concentration in the groundwater of 10 wells located in burned areas of Mondego watershed.

Table 5: Median values before and after the wildfire periods in the groundwater of 10 wells located in burned areas of Mondego watershed.

Well number from upstream to downstream (fire date)	NO_3^-		pH		Cl^-		SO_4^{2-}		P		EC		Parameters with median values 20% > after fire
	Bf Fire	Aft Fire	Bf Fire	Aft Fire	Bf Fire	Aft Fire	Bf Fire	Aft Fire	Bf Fire	Aft Fire	Bf Fire	Aft Fire	
179/9 (2013)	6.5	11.0	5.9	5.6	6.3	7.2	10	10	0.042	0.035	69	70	NO_3^-
190/2 (2017)	4.9	2.3	6.4	6.8	8.0	7.7	10	10	0.044	0.070	81	100	P; EC
211/1 (2013)	1.0	1.0	7.1	6.7	16.1	8.1	10	10	0.038	0.098	211	110	P
(2017)	1.0	1.0	7.3	6.7	16.5	8.0	10	10	0.044	0.100	216	110	P
233/2 (2017)	2.5	0.5	6.0	6.2	6.2	5.5	10	10	0.113	0.241	72	94	P; EC
233/C44 (2017)	1.0	0.5	6.7	6.2	9.2	7.9	10	10	0.321	0.123	140	97	-
233/C45 (2017)	1.0	0.8	6.8	6.7	5.0	4.9	10	10	0.033	0.100	54	43	P
231/16 (2017)	1.0	2.7	7.4	7.2	23.0	24.0	52	100	0.036	0.108	625	710	NO_3^-; SO_4^{2-}; P
243/1 (2017)	1.0	0.5	6.1	7.0	6.2	5.8	10	10	0.052	0.108	60	107	P; EC
243/4 (2017)	1.0	8.5	6.1	5.9	7.0	9.8	10	10	0.035	0.100	110	105	NO_3^-; Cl^-; P
263/C63 (2012)	5.5	6.9	7.5	7.5	17.0	17.0	10	10	0.063	0.076	320	336	NO_3^-; P

The observation of Figure 2 to Figure 7 and Table 5 allows the following conclusions:

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- NO_3^-: there are four wells that show median values 20% higher after the respective fire period (179/9, 231/16, 243/4, and 263/C63).

- pH: no increase is observed after the fire periods.

- Cl^-: there is one well that shows median values 20% higher after 2017 (243/4).

- SO_4^{2-}: there is one well that shows median values 20% higher after 2017 (231/16). All other wells show concentrations below the detection limit (LOD) (20 mg/L, being considered ½ of the LOD for statistic calculations).

- P: most wells show median values 20% higher after the respective fire period.

- EC: there are three wells that show median values 20% higher after the respective fire period (190/2, 233/2 e 241/1). Wells 231/16 and 263/C63, with clear visibility in Figure 7, have higher values in the last sampling periods, but below 20% median after fire, considering the years 2017 and 2012, respectively.

Nevertheless, there are many wells that show decreasing median values comparing before and after wildfire statistics.

To statistically assess if there is a monotonic upward or downward trend of the variable of interest over time, Mann-Kendall (MK) and MK seasonal tests were performed for the six parameters. A monotonic upward (downward) trend means that the variable consistently increases (decreases) through time, but the trend may or may not be linear (VPS, 2023). The MK test can be computed if there are missing values and values below the one or more limits of detection (LOD). The presence of seasonality implies that the data have different distributions depending on the season. With our data, the quarter of the year was considered. This test compares, for each epoch, the value of each observation with each of the previous observations (from that epoch) and verifies how many cases there are in which the values are greater, equal, or less than each of the previous values.

A trend analysis was done using Mann Kendall (MK) and MK Seasonal trends package from AquaChem 2014.2 software (https://www.waterloohydrogeologic.com/) using four epoch (three month's season) and a significance level of 1% (confidence level for trend test of 99%). The results of the hypothesis of increasing or decreasing trend are shown in Table 6, together with the number of analysis (the minimum number of samples considered in the software is five).

S is MK test statistics. The trend exists when Prob (or p, the probability of the error when expecting that the trend differs from zero) is lower than the significance level (1%), having a trend for increasing when Z (normal approximation statistic) is positive and for decreasing if Z is negative.

Table 6: Trend analysis results for six parameters of 10 wells located in burned areas of Mondego watershed.

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Well number from upstream to downstream	Parameter	ND	No. of samples	Years with Data	Mann Kendall				MK Seasonal				
		#	#	#	S	Z	Prob (%)	Result	S	Z	Prob (%)	Slope	Result
179/9	NO_3^-	0	26	16	171	3.75	0.01	increasing	36	3.35	0.04	2.20	increasing
179/9	pH	0	25	16	-94	-2.18	1.48	no trend	-28	-2.54	0.56	-0.15	decreasing
179/9	Cl	1	26	16	19	0.40	34.58	no trend	24	2.16	1.54	1.60	no trend
179/9	P	0	24	16	-20	-0.47	31.87	no trend	16	1.41	7.94	0.05	no trend
179/9	Cond	0	25	16	37	0.84	20.01	no trend	32	2.91	0.18	4.00	increasing
190/2	NO_3^-	0	26	16	-149	-3.46	0.03	decreasing	-28	-2.54	0.56	-4.48	decreasing
190/2	pH	0	25	16	46	1.12	13.19	no trend	16	1.44	7.57	0.58	no trend
190/2	Cl	1	26	16	-60	-1.38	8.41	no trend	-12	-1.03	15.08	0.38	no trend
190/2	P	0	24	16	49	1.19	11.68	no trend	40	3.66	0.01	0.04	increasing
190/2	Cond	0	25	16	39	0.94	17.27	no trend	4	0.28	38.91	11.50	no trend
211/1	pH	0	8	8	-7	-0.75	22.72	no trend	4	1.50	6.68	0.90	no trend
211/1	Cl	0	9	8	-13	-1.25	10.55	no trend	4	1.50	6.68	0.50	no trend
211/1	P	0	9	8	7	0.63	26.58	no trend	4	1.50	6.68	0.02	no trend
211/1	Cond	0	8	8	-9	-1.00	15.93	no trend	4	1.50	6.68	130.00	no trend
233/2	NO_3^-	14	27	17	-72	-1.57	5.86	no trend	-12	-1.03	15.08	-1.90	no trend
233/2	pH	0	27	17	-7	-0.13	44.74	no trend	4	0.29	38.71	0.35	no trend
233/2	Cl	3	27	17	-37	-0.79	21.38	no trend	20	1.79	3.72	1.45	no trend
233/2	P	0	25	17	97	2.38	0.86	increasing	8	0.66	25.54	-0.40	no trend
233/2	Cond	0	27	17	93	2.03	2.13	no trend	24	2.16	1.54	15.00	no trend
233/C44	pH	0	24	16	-116	-2.85	0.22	decreasing	-48	-4.50	0.00	-0.40	decreasing
233/C44	Cl	1	25	16	-75	-1.73	4.19	no trend	-4	-0.28	38.91	-0.85	no trend
233/C44	P	0	22	15	-80	-2.23	1.30	no trend	-4	-0.28	38.91	-0.40	no trend
233/C44	Cond	0	24	16	-62	-1.52	6.49	no trend	-8	-0.66	25.54	-45.50	no trend
233/C45	NO_3^-	18	24	15	-55	-1.34	8.98	no trend	20	1.82	3.46	0.45	no trend
233/C45	pH	0	23	15	-57	-1.48	6.96	no trend	-36	-3.29	0.05	-0.10	decreasing
233/C45	Cl	8	24	15	-14	-0.32	37.35	no trend	-8	-0.66	25.54	13.15	no trend
233/C45	P	0	10	6	9	0.72	23.72	no trend	-4	-1.50	6.68	-0.01	no trend
233/C45	Cond	0	23	15	-89	-2.33	1.00	no trend	-44	-4.04	0.00	13.00	decreasing
231/16	NO_3^-	16	22	13	26	0.71	23.98	no trend	40	3.80	0.01	-0.15	increasing
231/16	pH	0	22	13	-117	-3.28	0.05	decreasing	-36	-3.35	0.04	-0.10	decreasing

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231/16	Cl	1	22	13	55	1.52	6.38	no trend	8	0.66	25.54	-0.50	no trend
231/16	SO4	0	22	13	158	4.43	0.00	increasing	40	3.73	0.01	52.00	increasing
231/16	P	0	6	4	-5	-0.75	22.62	no trend	4	1.50	6.68	0.06	no trend
231/16	Cond	0	22	13	86	2.40	0.83	increasing	12	1.03	15.08	59.00	no trend
243/1	NO_3^-	18	26	17	-150	-3.49	0.02	decreasing	-40	-3.66	0.01	1.25	decreasing
243/1	pH	0	26	17	77	1.78	3.79	no trend	-12	-1.03	15.08	0.85	no trend
243/1	Cl	3	26	17	-48	-1.10	13.61	no trend	-52	-4.79	0.00	-1.60	decreasing
243/1	P	0	11	7	10	0.70	24.18	no trend	4	0.78	21.67	0.03	no trend
243/1	Cond	0	26	17	13	0.28	38.96	no trend	-4	-0.28	38.91	69.50	no trend
243/4	NO_3^-	19	27	17	81	1.77	3.86	no trend	20	1.85	3.21	4.45	no trend
243/4	pH	0	27	17	-95	-2.07	1.91	no trend	0	0.00	50.00	-0.25	no trend
243/4	Cl	1	27	17	164	3.59	0.02	increasing	20	1.79	3.72	1.50	no trend
243/4	P	0	16	12	24	1.04	15.02	no trend	0	0.00	50.00	0.03	no trend
243/4	Cond	0	27	17	27	0.57	28.33	no trend	20	1.79	3.72	-19.50	no trend
263/C63	NO_3^-	0	24	16	44	1.21	11.26	no trend	28	2.54	0.56	1.60	increasing
263/C63	pH	0	24	16	-1	0.00	50.00	no trend	12	1.03	15.08	-0.33	no trend
263/C63	Cl	0	25	16	21	0.53	29.84	no trend	-12	-1.05	14.64	-1.00	no trend
263/C63	P	0	24	16	33	0.90	18.33	no trend	16	1.44	7.57	0.03	no trend
263/C63	Cond	0	24	16	38	1.04	14.83	no trend	28	2.58	0.49	-48.00	increasing

ND – Non-detects.

Figure 8 to Figure 17 presents the graphic results for the parameters that showed increasing trends in the Mann-Kendall tests. The Sen's slope is basically used to identify the magnitude of trend in a data series.

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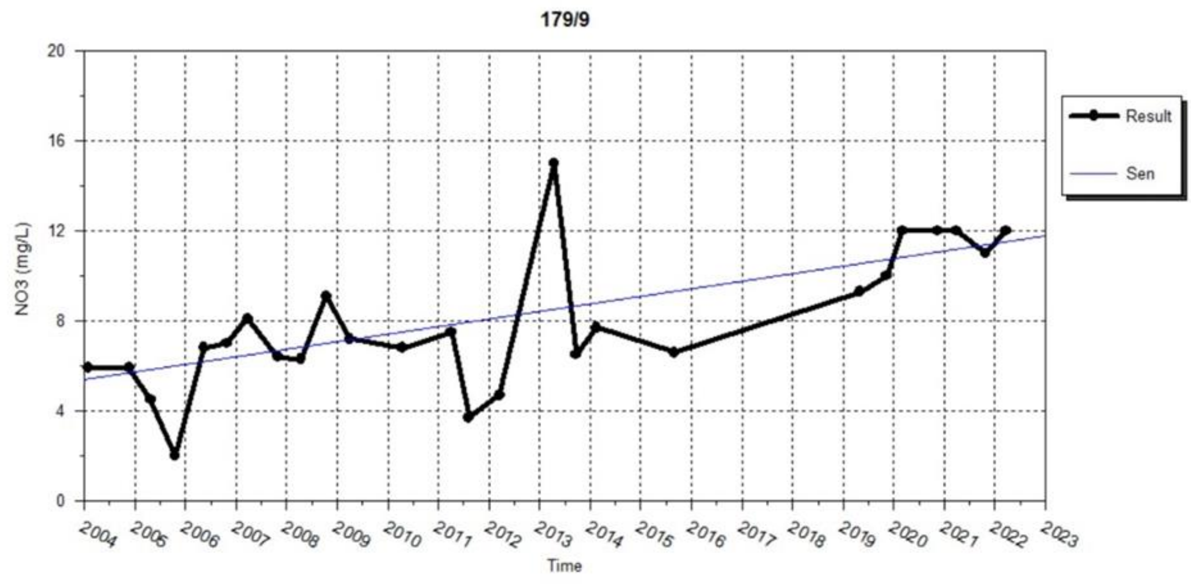

Figure 8: Increasing trend of nitrates in well 179/9 located in burned areas of Mondego watershed.

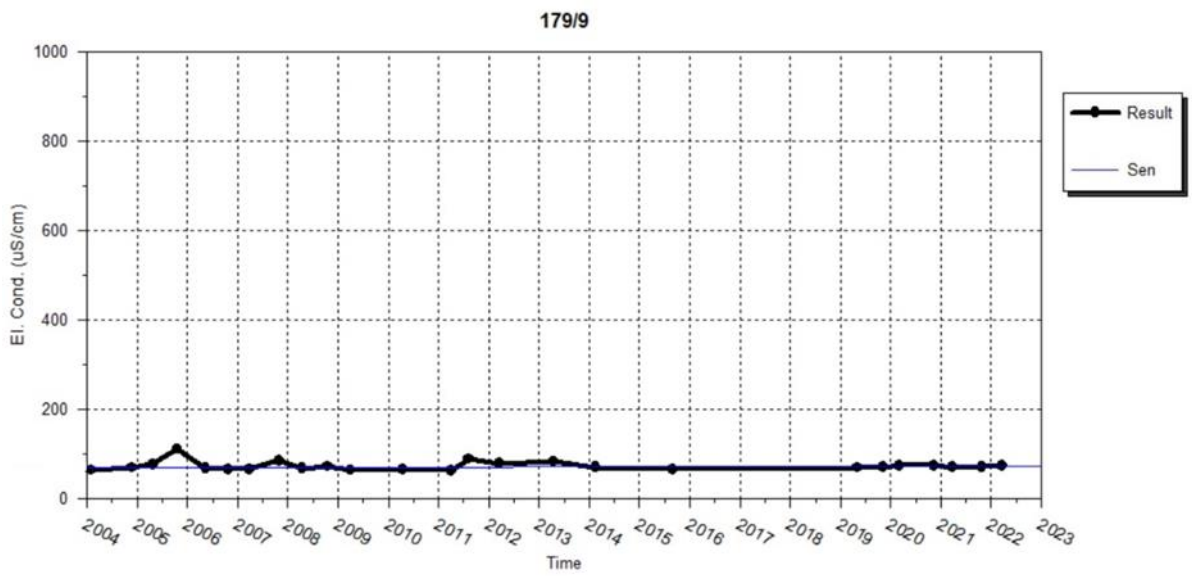

Figure 9: Increasing trend of EC (only MK Seasonal) in well 179/9 located in burned areas of Mondego watershed.

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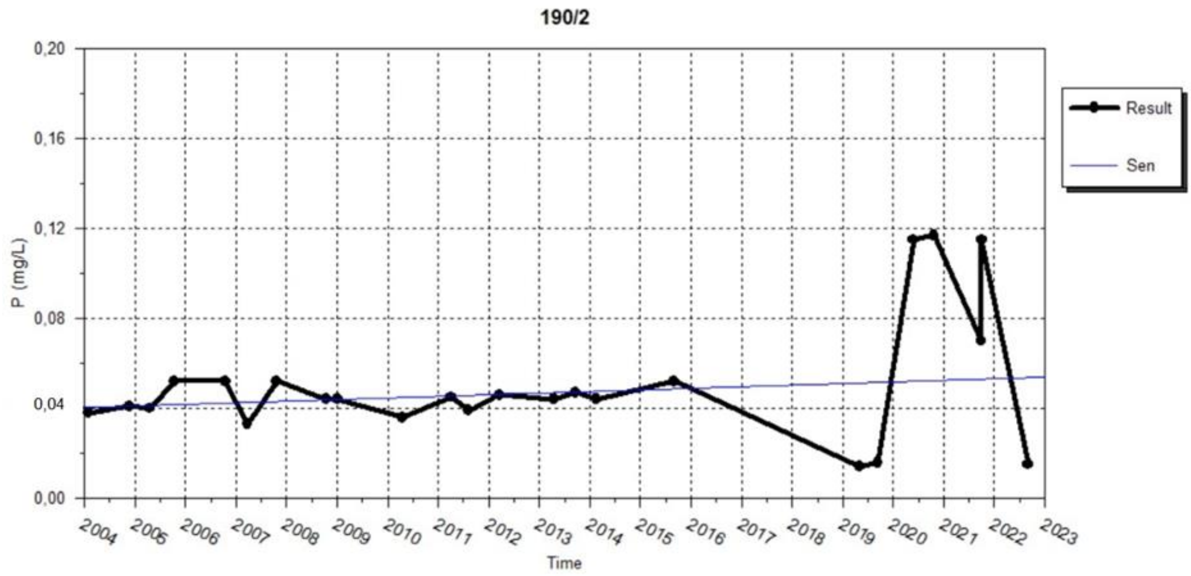

Figure 10: Increasing trend of phosphates (only MK Seasonal) in well 190/2 located in burned areas of Mondego watershed.

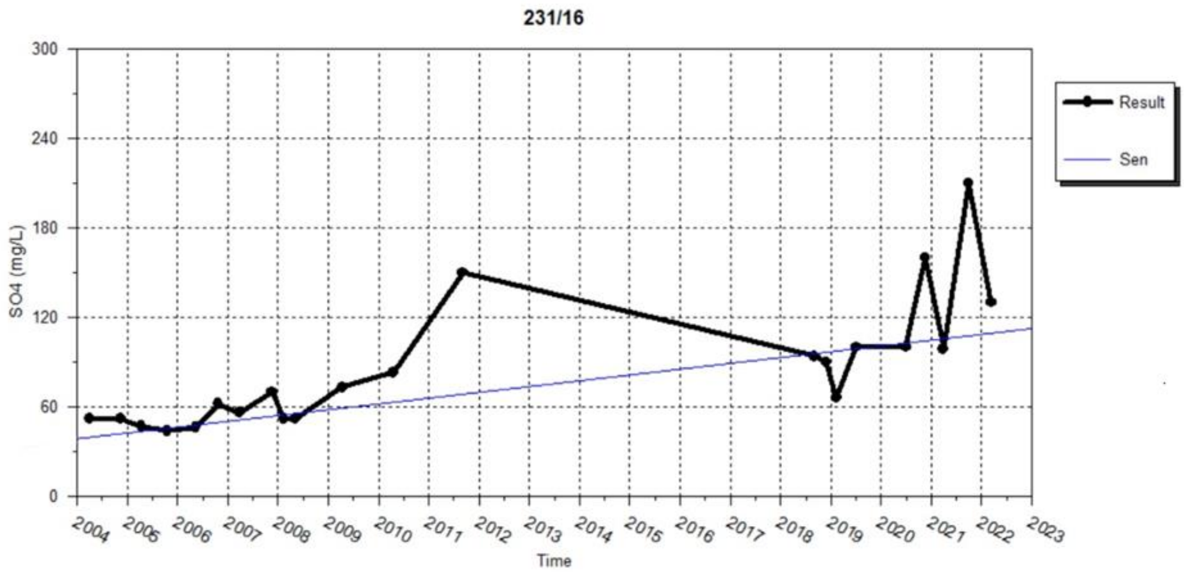

Figure 11: Increasing trend of sulphates in well 231/16 located in burned areas of Mondego watershed.

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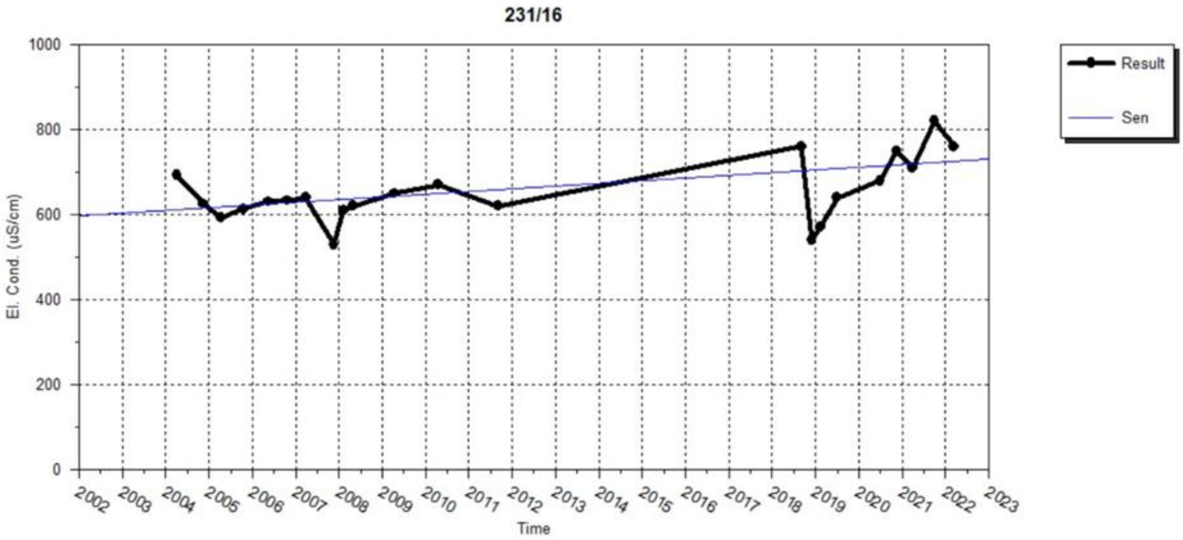

Figure 12: Increasing trend of EC in well 231/16 located in burned areas of Mondego watershed.

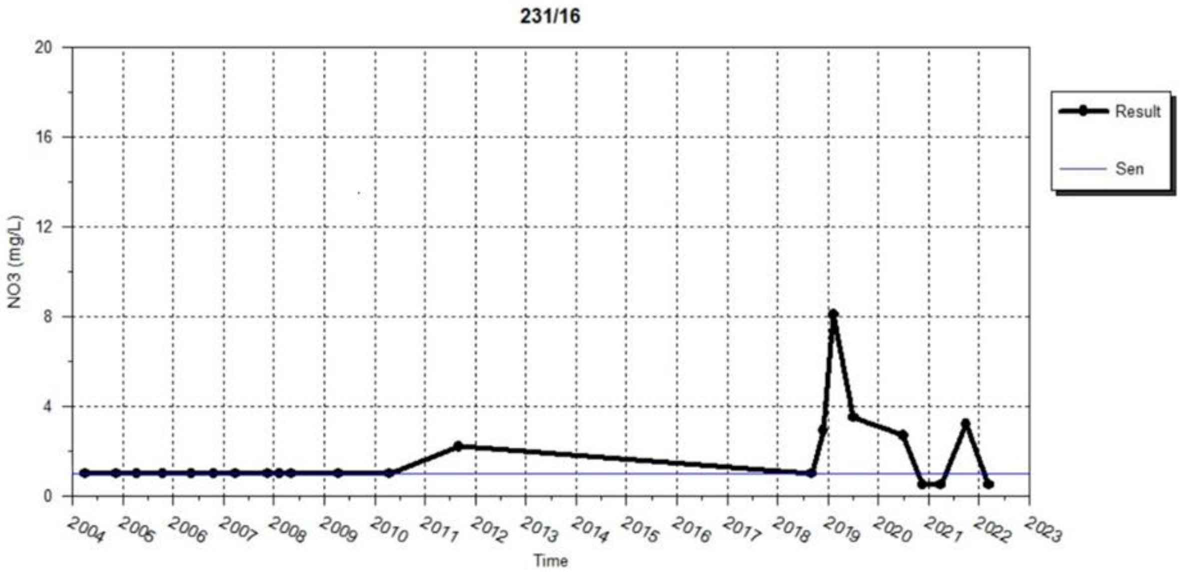

Figure 13: Increasing trend of nitrates (only MK Seasonal) in well 231/16 located in burned areas of Mondego watershed.

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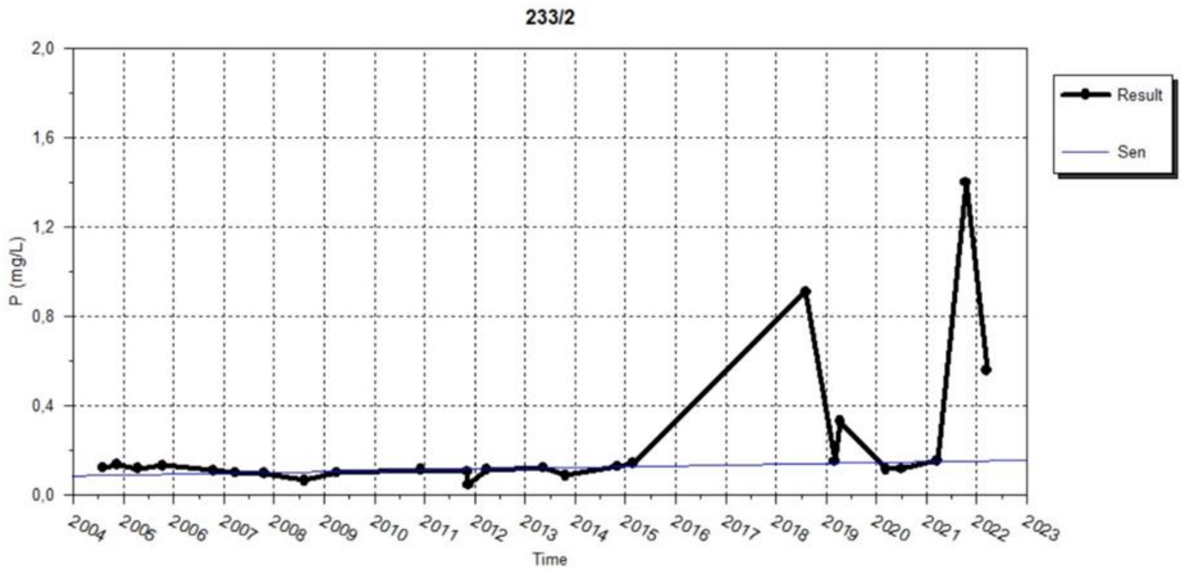

Figure 14: Increasing trend of phosphates in well 233/2 located in burned areas of Mondego watershed.

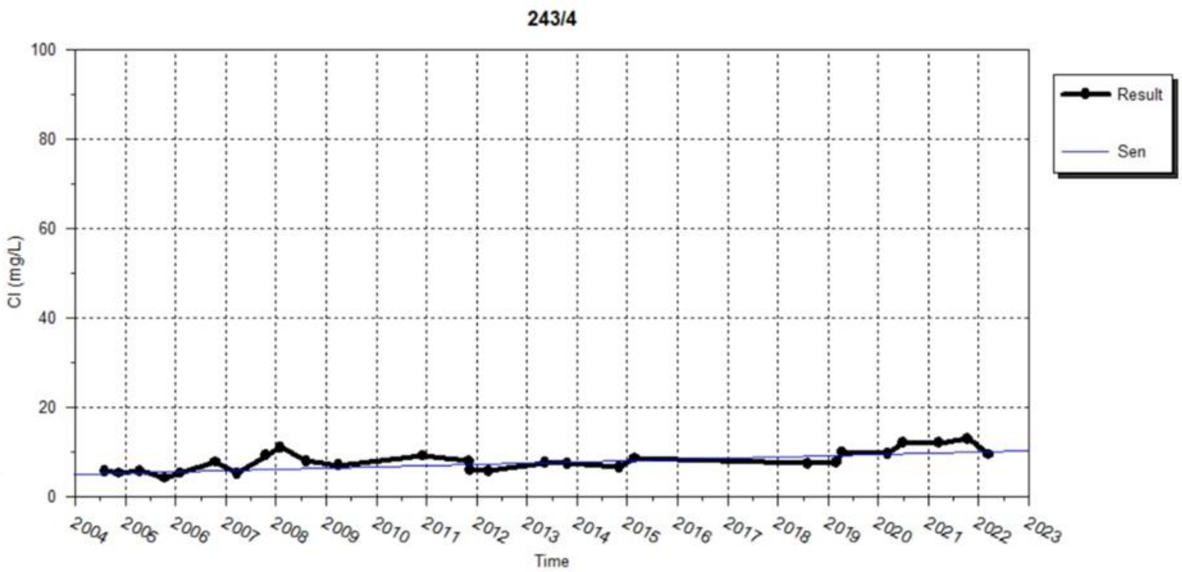

Figure 15: Increasing trend of chloride in well 243/4 located in burned areas of Mondego Watershed

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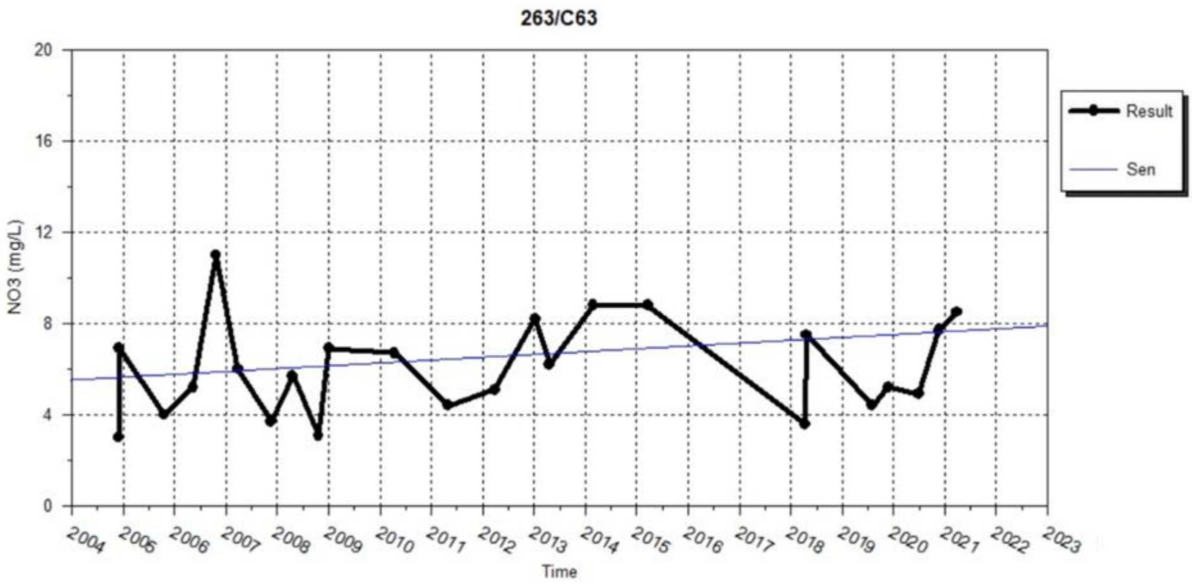

Figure 16: Increasing trend of nitrates (only MK Seasonal) in well 263/C63 located in burned areas of Mondego watershed.

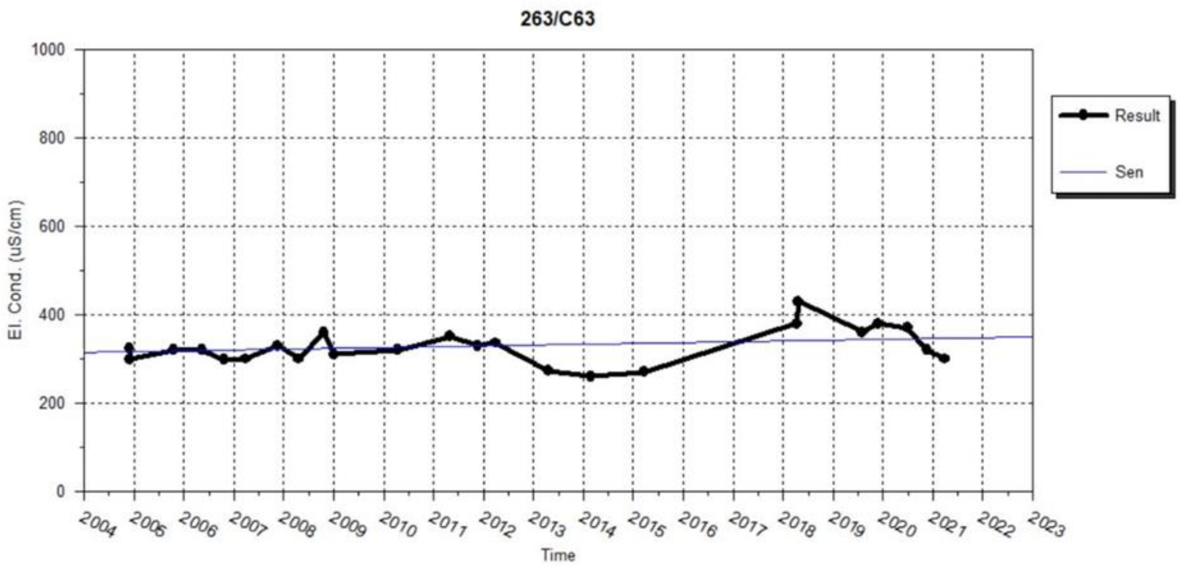

Figure 17: Increasing trend of EC (only MK Seasonal) in well 263/C63 located in burned areas of Mondego watershed.

As can be seen from Table 7, not all the parameters that have median values 20% higher after fire show increasing MK trends. Even for the cases when parameters have median values 20% higher after fire and show increasing MK trends (in red in Table 7), its cause can be diverse.

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Table 7: Trend analysis results for six parameters of 10 wells located in burned areas of Mondego watershed.

Well number from upstream to downstream	Parameters with median values 20% > after fire	Mann-Kendall	Mann-Kendall Seasonal
179/9	NO_3^-	NO_3^-	NO_3^-, EC
190/2	P; EC	-	P
211/1	P	-	-
233/2	P; EC	P	-
233/C44	-	-	-
233/C45	P	-	-
231/16	NO_3^-; SO_4^{2-}; P	SO_4^{2-}; EC	NO_3^-; SO_4^{2-}
243/1	P; EC	-	-
243/4	NO_3^-; Cl^-; P	Cl^-	-
263/C63	NO_3^-; P	-	NO_3^-, EC

To understand better the relationship between variables, correlation and Principal Components Analysis (PCA) was performed using Analyse-IT software (https://analyse-it.com/), with all the groundwater quality data available for the 10 wells located in burned areas. This procedure was attempted to be done for both periods, before and after fire (which data depends on the well), but the results after fire were not sufficient to allow convergence of the models. The results obtained before the wildfires show identical reading if compared to the complete dataset (before and after wildfire). The latter are presented hereinafter.

A Pearson correlation matrix was run to see the possible correlation between variables (with 1 being the perfect positive correlation, -1 a perfect negative correlation and 0 uncorrelated). Table 8 presents the results obtained.

Table 8: Pearson correlation matrix between the parameters analysed for 10 wells located in burned areas of Mondego watershed.

Pearson's r	Alcalinity CaCO3	Ca	Cd	Cl	EC	Cu	DO	HCO3	K	Mn	Na	Ni	NO3	P	Pb	pH	Si	SO4	Mg	Zn
Alcalinity CaCO3	-	0,447	-0,103	-0,093	0,971	-0,118	-0,163	0,993	-0,138	-0,134	0,029	-0,118	-0,149	-0,149	-0,090	-0,154	-0,351	0,058	0,300	-0,129
Ca	0,447	-	0,787	0,788	0,601	0,800	0,742	0,544	0,758	0,802	0,751	0,800	0,793	0,783	0,768	0,747	0,561	0,821	0,918	0,803
Cd	-0,103	0,787	-	0,854	0,042	0,993	0,831	-0,004	0,845	0,970	0,785	0,993	0,967	0,911	0,996	0,831	0,761	0,946	0,735	0,977
Cl	-0,093	0,788	0,854	-	0,114	0,908	0,996	0,024	0,999	0,953	0,955	0,907	0,952	0,991	0,802	0,997	0,898	0,720	0,910	0,944
EC	0,971	0,601	0,042	0,114	-	0,044	0,046	0,989	0,069	0,045	0,221	0,044	0,034	0,049	0,039	0,055	-0,155	0,168	0,491	0,047
Cu	-0,118	0,800	0,993	0,908	0,044	-	0,890	-0,013	0,901	0,992	0,839	1,000	0,988	0,952	0,978	0,890	0,815	0,919	0,787	0,995
DO	-0,163	0,742	0,831	0,996	0,046	0,890	-	-0,047	0,999	0,941	0,940	0,889	0,940	0,987	0,775	1,000	0,911	0,687	0,883	0,930
HCO3	0,993	0,544	-0,004	0,024	0,989	-0,013	-0,047	-	-0,022	-0,023	0,136	-0,013	-0,039	-0,034	0,002	-0,038	-0,245	0,145	0,408	-0,019
K	-0,138	0,758	0,845	0,999	0,069	0,901	0,999	-0,022	-	0,949	0,950	0,900	0,948	0,990	0,791	0,999	0,908	0,702	0,892	0,939
Mn	-0,134	0,802	0,970	0,953	0,045	0,992	0,941	-0,023	0,949	-	0,886	0,992	0,997	0,983	0,943	0,941	0,863	0,876	0,832	1,000
Na	0,029	0,751	0,785	0,955	0,221	0,839	0,940	0,136	0,950	0,886	-	0,839	0,886	0,929	0,733	0,942	0,813	0,630	0,892	0,877
Ni	-0,118	0,800	0,993	0,907	0,044	1,000	0,889	-0,013	0,900	0,992	0,839	-	0,988	0,952	0,978	0,889	0,814	0,920	0,787	0,995
NO3	-0,149	0,793	0,967	0,952	0,034	0,988	0,940	-0,039	0,948	0,997	0,886	0,988	-	0,981	0,939	0,940	0,851	0,865	0,824	0,997
P	-0,149	0,783	0,911	0,991	0,049	0,952	0,987	-0,034	0,990	0,983	0,929	0,952	0,981	-	0,868	0,987	0,904	0,788	0,873	0,978
Pb	-0,090	0,768	0,996	0,802	0,039	0,978	0,775	0,002	0,791	0,943	0,733	0,978	0,939	0,868	-	0,775	0,710	0,959	0,686	0,953
pH	-0,154	0,747	0,831	0,997	0,055	0,890	1,000	-0,038	0,999	0,941	0,942	0,889	0,940	0,987	0,775	-	0,914	0,688	0,887	0,930
Si	-0,351	0,561	0,761	0,898	-0,155	0,815	0,911	-0,245	0,908	0,863	0,813	0,814	0,851	0,904	0,710	0,914	-	0,605	0,714	0,852
SO4	0,058	0,821	0,946	0,720	0,168	0,919	0,687	0,145	0,702	0,876	0,630	0,920	0,865	0,788	0,959	0,688	0,605	-	0,673	0,887
Mg	0,300	0,918	0,735	0,910	0,491	0,787	0,883	0,408	0,892	0,832	0,892	0,787	0,824	0,873	0,686	0,887	0,714	0,673	-	0,823
Zn	-0,129	0,803	0,977	0,944	0,047	0,995	0,930	-0,019	0,939	1,000	0,877	0,995	0,997	0,978	0,953	0,930	0,852	0,887	0,823	-

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Table 8 shows that most variables have strong correlation with each other, except for alkalinity, EC and HCO_3^- and, to some extent, calcium, and magnesium.

A Principal Components Analysis was run to help visualizing possible relations (in a monoplot) between variables, reducing the dimensionality of the data. The results are shown in Table 9, Table 10, and Figure 18.

Table 9: Coefficients correlation between the parameters analysed for 10 wells located in burned areas of Mondego watershed.

Parameter	**Component**		
	1	**2**	**3**
Alcalinity $CaCO_3$	0,017	0,531	-0,026
Ca^{2+}	-0,216	0,272	-0,084
Cd	-0,244	-0,028	-0,297
Cl^-	-0,250	-0,012	0,217
EC (electrical conductivity)	-0,032	0,526	0,074
Cu	-0,251	-0,033	-0,192
DO	-0,247	-0,048	0,251
HCO3	-0,013	0,532	-0,003
K^+	-0,249	-0,036	0,233
Mn	-0,256	-0,039	-0,072
Na^+	-0,236	0,046	0,285
Ni	-0,251	-0,033	-0,193
NO_3^-	-0,255	-0,045	-0,068
P	-0,255	-0,043	0,101
Pb	-0,235	-0,024	-0,380
pH	-0,247	-0,044	0,253
Si	-0,223	-0,157	0,239
SO_4^{2-}	-0,220	0,055	-0,472
Mg	-0,227	0,198	0,246
Zn	-0,255	-0,037	-0,100

Table 10: Variance, proportion and cumulative proportion of the various components of the PCA analysis of groundwater quality data in burned areas of Mondego watershed.

Component	**Variance**	**Proportion**	**Cumulative proportion**
1	15,13	0,757	0,757
2	3,518	0,176	0,933
3	1,069	0,053	0,986
4	0,1387	0,007	0,993
5	0,09514	0,005	0,998
6	0,02238	0,001	0,999
7	0,01441	0,001	1,000

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One can see that the 1st PC explains the majority (75.7%) of the total variance of the dataset, and the second category of water samples contributing 93.3% of the variance cumulatively. The elements belonging to the same PC (cf. Table 9) and with close component quadrant vectors (Figure 18) suggest that the variables are correlated and derive from common processes. All variables have a good representation (cf. high extension of the arrow).

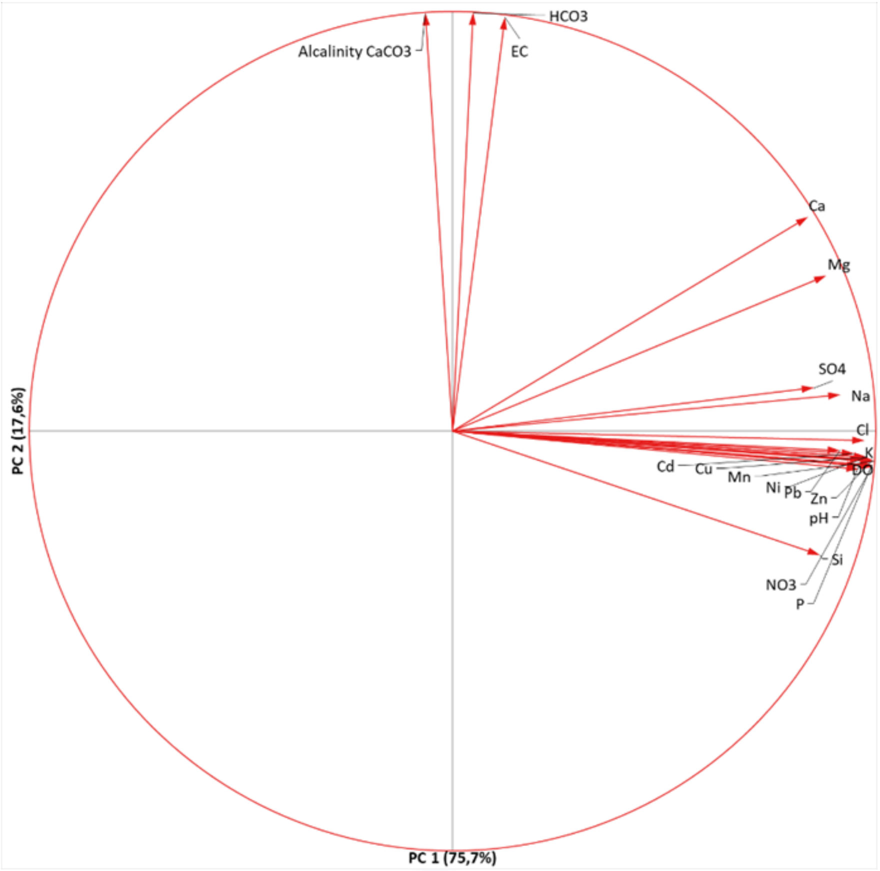

Figure 18: Principal Component Analysis (PCA) correlation monoplot of groundwater quality data in burned areas of Mondego watershed.

PC1 is related to Na^+, Cl^-, SO_4^{2-}, K^+, and several heavy metals, which can be attributed to natural hydrogeochemical characteristics of the groundwater (determined by the water-rock interactions mainly with schists, and with granites in the case of well 233/2), but also to anthropogenic factors such as wildfires, agriculture, or septic tanks (e.g., the contribution of NO_3^-, P, heavy metals). PC2 refers to alkalinity, EC and HCO_3^- and are likely related to the dissolution of rocks rich is carbonates existing in the case of wells 231/16 and 263/63, which are in limestone veins (cf. Figure 19 where groundwater hydrochemical types were dominated by the HCO_3-Ca to mixed). PC1 and PC2 are uncorrelated since a 90° angle existing between the two.

Most parameters present in PC1 are compatible with the analysis conducted in Table 1 concerning the parameters that usually see an increase in concentration after wildfires. However, the large amount of analysis of heavy metals below the detection limit, together with the lack of information in 2017 and 2018 (two years after the major wildfire of 2017), do not allow a clear identification of the underlying processes.

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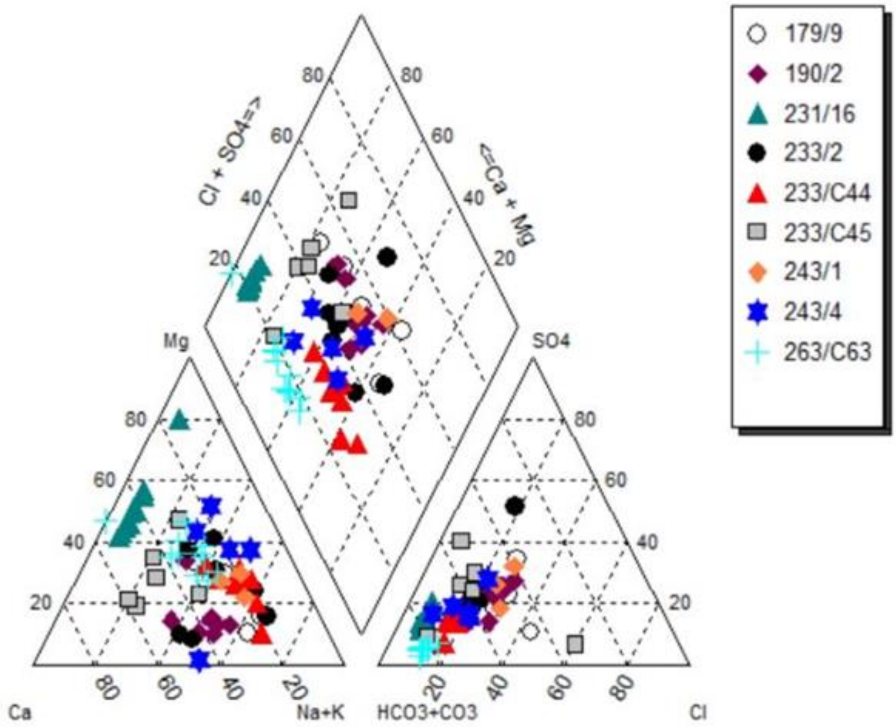

Figure 19: Hydrochemical facies of groundwater quality samples in burned areas of Mondego watershed.

10.1. Conclusions and recommendations

The historical groundwater quality data analysed from 10 wells located in burned areas does not present evidence of a clear impact in the water quality after the wildfire period. In fact, only some of the selected chemical parameters show increasing trends and median values 20% higher after wildfire, e.g., nitrates, while all should have a similar upward trend.

Furthermore, the water quality trends and interrelations observed in selected quality indicators could not be clearly identified as belonging to wildfire pressures.

In future deliverables the subject of water quality changes due to wildfires will be further analysed, including data from surface water in that area.

In future assessments of wildfires impacts in groundwater quality, it is recommended that: (1) most groundwater wells selected are shallow (< 20 m) and (2) at least the following parameters are analysed in all samples[8]: electrical conductivity, pH, major ions (HCO_3^-, Cl^-,

[8] In bold are the parameters that can be directly related to wildfire pressures. All major ions are needed to assess potential changes in the hydrochemical facies.

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SO_4^{2-}, Ca^+, Mg^{2+}, K^+, Na^+), Carbon and organic matter content, heavy metals (**Cu, Fe, Mn, Pb, Zn**) and polycyclic aromatic hydrocarbons (**PAH**), and nutrients (NO_3^-, **P**).

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