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Perspective

Human-environmental interaction with extreme hydrological events and climate change scenarios as background

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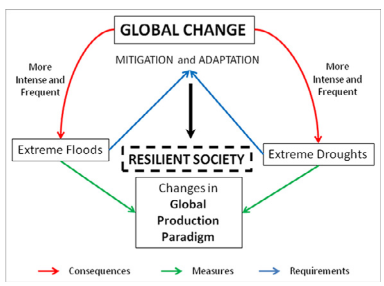
HIGHLIGHTS

- Global change impacts people's life.
- Climate change strongly affects the Mediterranean area.
- Extreme floods and droughts will be more intense and frequent.
- Adapting to future climate conditions will construct a resilient society.
- Human adaptation to global change is a necessity to decrease natural hazards risk.

GRAPHICAL ABSTRACT



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ABSTRACT

Climate change significantly impacts the lives of all people. Global change is composed of multiple factors that affect the population differently, having a very significant impact in the Mediterranean area. Human beings, through their actions, try to mitigate this impact and thus generate a more resilient society. Extreme hydrological events are affected by this climate change, with torrential rainfall events and severe droughts becoming frequent. Understanding these trends will allow us to better adapt to future conditions. This study aims to analyse catastrophic floods and severe droughts from paleo studies to studies that focus on future projections. For this purpose, a search for information has been carried out through other studies over the last five years to have a current perspective of this situation. Studies point to changes in the dynamics of floods and droughts, not only worsening the extremes but also affecting the average values of the records of each. In addition, the studies point out that anthropic action is accelerating the changes, with human beings and their capacity to adapt being inferior to the velocity of this global change. It is necessary to generate a paradigm shift in terms of global production by trying to adapt to future extreme flood and drought hazards.

1. Introduction

Climate change is a global phenomenon that affects more people globally at an economic, social and political level. After the Paris agreement during the 21st Conference of Parties (COP21), the objective of not exceeding 2°C of increase in the global annual average temperature was reaffirmed in Glasgow during the 26th Conference of Parties (COP26), with a target to not exceed 1.5°C since pre-industrial times. It was also agreed to increase spending in the fight against climate change, investing more and more in renewable energy and less in non-renewable energy from fossil fuels, such as coal or oil (COP26 Agreements, https://www.un.org/es/climatechange/cop26). One of the consequences of climate change that has the greatest impact on society is the increase in extreme hydrological events (Tabari, 2021).

Extreme hydrological events are the natural risks that affect most people in the world, according to the latest IPCC Report (2021). The current global climate change affects the global hydrological cycle in general and, specifically, the amount of evaporation, water available in

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the soil, synoptic patterns, types of precipitation or levels of river flows (Milly et al., 2005; Wanders and Wada, 2015; Sánchez-García et al., 2019; Blöschl et al., 2020; IPCC, 2021; Benestad et al., 2022). The changes not only affect the averages but also the extreme hydrological events, which are altered in such a way that torrential precipitation events, severe droughts or changes in the occurrence of floods are becoming more frequent (Prudhomme et al., 2014; Schulte et al., 2019; Kam et al., 2021). These extreme events can impact society, the economy and even politics. Some examples could be Hurricane Katrina in the USA (Petterson et al., 2006) or the drought in Central Africa in the 1990s (Masih et al., 2014), which forced entire populations to migrate from their areas of origin (Kundzewicz and Matczak, 2015).

At the European level, several works have been carried out in which the impacts of climate change on river dynamics are addressed (Papadimitriou et al., 2016; Blöschl et al., 2020; Gudmundsson et al., 2021; Shamir et al., 2021). Papadimitriou et al. (2016) showed how the changes in the flow dynamics were quite similar between the rivers of central and southern Europe and the rivers of Scandinavia. In this study, the rivers evolved to have more days with less flow on average. However, in the same study, the authors showed that although the average annual flow tended to be lower, the extreme values tended to be more severe, with higher flow floods and more extended droughts throughout the Mediterranean basin. In Europe, more than 75% of the population lives in urban environments, and it is expected that by 2050 this figure will increase to 82% (UN HABITAT, 2011). Urban environments are susceptible to more extreme heat waves than rural areas due to the urban heat island effect (Guerreiro et al., 2018). Therefore, urban policies will take on paramount importance in the coming years in adapting to the increase in the average annual temperature.

This paper aims to compile the latest studies on the different reconstruction techniques for extreme hydrological events in European Mediterranean basins. Two main objectives are established: 1) analyse the evolution of studies on catastrophic floods from paleo studies to studies that focus on future projection, and 2) analyse the evolution of droughts in the same context as the previous one.

2. Flood hazards in a climate change context

One of the direct consequences of climate change is the impact on precipitation regimes, increasing torrentiality and the frequency of extreme floods (IPCC, 2021). This change in flooding dynamics in areas prone to this natural risk makes it challenging to identify how the new environmental reality will affect it shortly. For this, it is necessary to study the floods in the past (Romppainen-Martius et al., 2020) and to project the environmental conditions that were similar to those that may exist in the future (Alfieri et al., 2018).

The prediction of flood scenarios in urban areas has taken on considerable importance in Europe, taking into account the urbanisation of the population (Bui et al., 2019; Hosseini et al., 2020; Zounemat-Kermani et al., 2020; Speight et al., 2021). For this, new quantitative and predictive methodological analysis have been applied. Mosavi et al. (2018) conducted a literature review of Machine Learning models used for flood prediction. The authors emphasised the importance of transferring this knowledge to society through binding policies in their work.

In many cases, understanding floods as a local or regional phenomenon depends on geomorphological, social, economic and climatological characteristics. It is crucial for making predictions (Alfieri et al., 2018). Therefore, a database with the largest number of floods is necessary to perform the analysis with the greatest possible likelihood. However, the uncertainties inherent in applying climate models will provide a series of calculation errors that must be considered as acceptable (Alfieri et al., 2018; Mosavi et al., 2018). These uncertainties can be minimised if historical data and paleo series of floods are obtained in climatic periods more similar to those projected for 2050–2100 (Blöschl et al., 2020). Other studies provide knowledge of how societies have adapted throughout history to successive climatic changes through changes in land use (De Souza et al., 2019), migrations (Beine and Jeusette, 2021) or they did not adapt and ended up disappearing (Cook et al., 2018; Kahn, 2020).

The works focused on historical floods and paleofloods can be from specific study areas (e.g., Sánchez-García et al., 2019; Balasch et al., 2019; Barriendos et al., 2019; Peña and Schulte, 2020 ; Bravo-Paredes et al., 2021), of specific extreme events (Stucki et al., 2018; González-Cao et al., 2021), or compendiums of other works where joint analyses or a reanalysis are made (e.g. Blöschl et al., 2020; Paprotny et al., 2018; Bertola et al., 2020; Bellos et al., 2020; Alcoforado et al., 2021). Blöschl et al. (2020) carried out a meta-analysis of the historic floods in Europe in the last 500 years and analysed the trends that were translated from the historical series of the different rivers. Another work that performed a meta-analysis with a more up-to-date approach is the work carried out by Paprotny et al. (2018). In this paper, authors analysed the human losses resulting from the floods that have occurred in Europe in the last 150 years. On the other hand, Bertola et al. (2020) also performed a reanalysis, modelling flood trends in Europe. In this case, the authors analysed how the trends changed depending on whether they were more severe or less severe floods.

Flood reconstruction can be divided into two data sources: 1) direct data, such as primary and secondary information sources and historical archives, and 2) indirect data or proxies as indirect data could be the tree rings, sediments (both fluvial and lacustrine), pollen records and through the dating of both organic elements with radiocarbon and inorganic elements with OSL (optical sensity luminescence) (Fig. 1). Each of the sources of information allows us to identify floods at different times in history. In contrast, most direct data is limited to the last 1,000 years (Schulte et al., 2019). Indirect sources allow the reconstruction of floods throughout the Holocene (Benito et al., 2008).

Ribas et al. (2020) analysed the evolution of floods on a much more current time scale. They explained how there has been a significant increase in urban floods in recent decades, because they were produced by intense precipitation in a short period and generated surface runoff in urban areas, causing severe material damage in a few minutes. Following this case, a flooding trend can be identified in some areas of the Iberian Mediterranean coast. Serrano-Notivoli (2017) analysed the precipitation regimes in Spain and showed how there was a decreasing trend in the amount of average annual precipitation but that extreme episodes were becoming more extreme and more frequent, both in terms of extreme precipitation, as in periods of drought. Criado et al. (2019) carried out a study on urban flooding in the city of Salamanca (Spain) and modelled how the Tormes river would behave according to floods with a 5,100 and 500 year return period.

From all the studies on historical floods, paleofloods and modelling of future floods, it can be seen how their dynamics have changed in recent decades. In most study areas, the leading cause is land-use change. There is a transition from traditional or agricultural use to urban, increasing soil sealing (Sánchez-García et al., 2019) and shifting flooding from the riverbed to urban areas that were once never subject to catastrophic flooding (Ribas et al., 2020; Blöschl et al., 2020).

3. Droughts in Europe

Droughts are another consequence of the impacts of climate change on hydrological cycles. The impact is reflected in more significant uncertainty in rainfall (Naumann et al., 2021), greater irregularity (Grillakis, 2019) and greater torrentiality, as explained in the previous section. Adaptation to climate change by societies will change land use in the contexts in which hydrological changes are more extreme (Jacobs et al., 2019).

For a better adaptation, incorporating scientific knowledge into politics is once again essential and urgently applicable. In the last four years, a series of work have been carried out focusing on drought in a climate change context. Naumann et al. (2018) treated the subject from an ac-

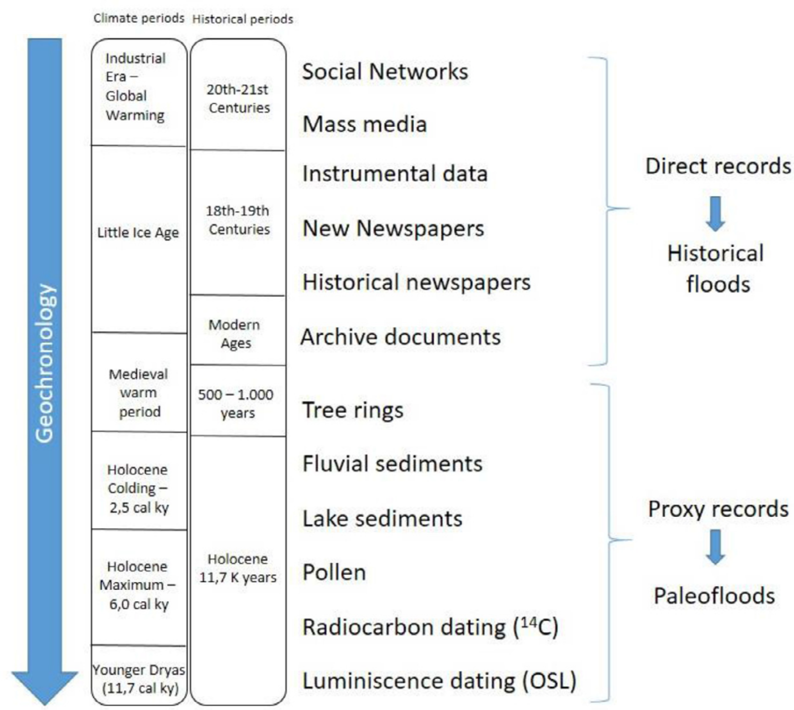

Fig. 1. Different recording techniques for the reconstruction of historical floods and paleofloods (Schulte et al., 2019).

tualist perspective, focusing on the economic consequences due to the droughts caused by the -called by the authors- anthropogenic warming. The term anthropogenic warming is supported by temperature data from the last 500 years. Hanel et al. (2018) analysed droughts in Europe from a long-term perspective. Their work showed that 2006–2007 were the hottest in the last 500 years due to human activity. Subsequently, it has been verified that 2020–2021 have had the highest temperatures (Ionita and Nagavciuc, 2021).

In this case, droughts directly affect land uses, impacting the development of agriculture, livestock and forest plantations (Jacobs et al., 2019). Adaptation goes through the change of land use in many cases, as highlighted by Teuling et al. (2019). Water availability for soils will be one of the adaptation challenges in the coming decades in areas such as the Mediterranean basins (Bach et al., 2018).

As in the case of floods, historical droughts and paleo-droughts obtained from written documents and proxies provide information on what hydrological conditions will be like in the future. In the case of historical droughts, we have worked from the documentation of diaries of people interested especially in meteorological processes; writings related to accounting; local economic administration; observations and comments on religious liturgies; letters; and even evidence in popular songs, as shown by Brázdil et al. (2020). Garnier (2018) pointed out the difficulty of finding own records of droughts. Being a gradual phenomenon and not punctual like floods, it makes the record in historical documents more diluted in account records, prayers for rain or municipal minutes books. In Europe, most of the historical records begin to be constant from the end of the 15th century. It is from then on that most of the series of historical droughts on the continent were generated (García-Valdecasas et al., 2021; Almendra-Martín et al., 2021; Fragoso et al., 2018; Pulido-Calvo et al., 2020; Caporali et al., 2021; Baronetti et al., 2020; Glaser and Kahle, 2020; Ionita et al., 2021). Works focused on historical droughts and paleosechics topics on other occasions on the reconstruction of rainfall, assuming periods with less rainfall as periods of drought (Brázdil et al., 2018; Cook et al., 2018; Caporali et al., 2021). The same thing happens in the case of paleoequies. Most of the works focus on the reconstruction of precipitation indices and, in this way, estimate the possible droughts that have occurred before the documentary evidence (Sampériz et al., 2019; Castro et al., 2020; Schirrmacher et al., 2020; Rozas-Davila et al., 2021). Paleosequies works include a large number of methodologies. Some are climatological reconstruction from tree rings (Ljungqvist et al., 2020). Others are based on geoarchaeological records (Büntgen et al., 2021) and record pollen (Roces-Díaz et al., 2018; Altolaguirre et al., 2020; Revelles et al., 2022). Regarding pollen records, a differentiated speciality is anthropology. In this sense, forest fires or fire processes (also anthropic) are related to paleoenvironments. In this way, the climatic dynamics in paleo times can be reconstructed (Vidal-Matutano, 2018). In addition, anthracology makes it possible to distinguish between climatic droughts and forest soil losses since the human-forest interaction is reflected in the anthracological analysis (Mas et al., 2022).

4. Human-environmental interactions

As shown in various studies, humans have already had to adapt to previous climatic changes during the Last Glacial Maximum. Through methods such as anthropology, carbon dating and paleoclimatic reconstruction from sedimentary records (lacustrine and marine), it has been possible to know how humans adapted to the last glaciation and successive climate changes (Cascalheira et al., 2021). Most of the paleoenvironmental reconstruction work use pollen records, from which the authors can reconstruct the life forms of humans and plant communities (Clark et al., 2019; Gil-García et al., 2019).

During the Little Ice Age (LIA), characterised by a succession of climatic extremes, floods and droughts occurred during the centuries. In the Iberian Peninsula, it has been extensively studied thanks to many documentaries and sedimentary records that can be found throughout the geography. In some cases, two or more disciplines focus on specific extreme events, such as archaeology and physical geography (Fernández et al., 2019). From fluvial and lacustrine sediments, it has been possible to reconstruct the environment during the LIA. In the second half of this time, the first documentary records begin to be found, which shows us records of cultivated land, purchase and sale of land, or pro-rain prayers to stop the rains (Santisteban et al., 2021).

However, we currently find ourselves in a different situation from all those described above. Current climate change is accelerated by anthropic action, and the rate of change is higher than at any time in the past (Catullo et al., 2019). Extreme hydrological events are becoming more common and more extreme (Sánchez-García et al., 2019). However, other studies show less number of floods in the last century but more severe (Blösch et al., 2020). The way we adapt to the new climate background will be essential in economic, social and cultural incomes.

Also, other natural risks, such as forest fires, are increasingly in more anthropised landscapes and have been more severe (Kirchmeier-Young et al., 2019). That is why, on this occasion, human adaptation to global change is more pressing and necessary (Malhi et al., 2020). We have seen in summer 2022 how political background can impact to economic situation of the countries in Europe. The extreme drought in central and south Europe with the political situation have shown that European society should adopt new clean energies soon. In this case, human interaction with climate change is not just in the environmental way but also political, economic, social and cultural.

5. Conclusions

The IPCC projections are illuminating regarding the consequences of rising temperatures if business as usual continues. Humans have gradually adapted to past climatic changes, migrating to areas more conducive to development or applying new adaptation techniques. Currently, we are at crossroads since the current climate change is being much faster than previous as a consequence of human activities, as practically all the scientific works show. Adapting to current changes involves a change in the global production paradigm that reduces gas emissions in a short time. This work demonstrates that climatic changes have been extensively studied in previous years and that it is well known what caused them and how the process has been. If we know how it has been in the past, we should learn to manage how we want it to be in the future.

Declaration of Competing Interest

The authors declare no competing interests.

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