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ENHANCING CLIMATE INFORMATION SERVICES

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SUMMARY

Although many Weather and Climate Information Services (WCIS) are available in Southeast Europe (SEE), their contribution to enhancing long-term climate resilience remains unclear. This first version of the deliverable focuses on heat and drought extremes, given their complexity and relevance across multiple sectors. While extreme precipitation and flooding are equally critical, their analysis will be addressed in the second version to ensure adequate depth and clarity. This phased approach allows us to give due attention to the specific characteristics, impacts, and adaptation needs associated with each type of climate extreme. The current study evaluates the role of WCIS in supporting climate change adaptation in SEE to extreme heat and drought events and identifies key gaps. The performance of WCIS was investigated using a mixed-methods approach that combines bibliometric and market analysis, surveys, and semi-structured interviews. The results highlight a key challenge in WCIS user engagement, stemming from gaps in their design and communication. Many services in SEE contain top-down approaches with limited user involvement and inadequate educational support. Strengthening community involvement and promoting transparency in information dissemination are therefore crucial. This can be complemented by tailoring WCIS to specific sectors, such as agriculture, public health, or water management, ensuring that they meet the local information needs of their respective audiences. Lastly, technical challenges remain regarding the reliability, trustworthiness and performance of WCIS with regards to the climate extremes associated with heat and drought events. This study concludes with five key recommendations for WCIS in SEE: 1) improve cross-scales community engagements, 2) ensure transparent information delivery, 3) address sector-specific needs, 4) improve user-friendliness, and 5) increase reliability and trust.

1. INTRODUCTION

In the Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC), it was unequivocally stated, for the first time, that specific regions in Southern Europe are notably susceptible to heightened risks such as extreme heatwaves, severe droughts, and other extreme weather events (IPCC, 2014). The Sixth Assessment Report (AR6), released in 2023, reinforces these findings, highlighting the increasing vulnerability of Southern Europe to these climatic challenges (IPCC, 2023). While Europe as a whole is vulnerable to climate-related risks, certain regions have been more extensively studied, with their vulnerabilities and adaptation needs better understood (Sutanto et al. 2020). In contrast, the Balkan region of Southeastern Europe (SEE) has increasingly been identified as a high-risk area for droughts and heatwave events but lacks comprehensive, targeted research on effective adaptation strategies (Paparrizos & Matzarakis, 2016; Klimavičius & Rimkus, 2023).

In SEE, models predict that by the end of this century, the occurrence of extreme heat and drought events will continue to increase in both frequency and intensity (Sutanto et al., 2020; Douville et al., 2023). These extreme drought and heat events can directly cause significant damage, while their indirect consequences trigger social tension arising from food and water insecurity, along with health problems due to increased heatwaves (Bezak & Mikoš, 2020; Arsenovic et al., 2023; Đurđević et al., 2023; Martinez et al., 2016), prolonged droughts (Stahl et al. 2016; Paparrizos et al. 2018; Sutanto and Van Lanen, 2020; Toreti et al. 2022), compounded events (Mukherjee & Mishra, 2021; Zhang et al., 2022; Wu et al., 2019), possible wildfires occurrence, and loss of biodiversity (Giannaros et al. 2022; Giannaros and Papavasileiou 2023). The risk of drought in eastern and SEE regions have been perceived by water managers increasing, with the highest increase felt in Serbia and small increase felt in Romania (Biella et al., 2024). For instance, European drought 2022 was deemed as having severe impacts on terrestrial ecosystem and wildfires in southeast Europe due to the occurrence of long drought and its compounding events.

Climate adaptation and resilience strategies are vital response to the challenges posed by extreme events and other climate-related risks. These strategies aim to enhance the capacity of communities, ecosystems, and economies to withstand and recover from the impacts of climate change (IPCC, 2023). Climate adaptation strategies are already widely implemented globally to address the impacts of climate change. Within these adaptation strategies, Weather and Climate Information Services (hereafter WCIS or Climate services) are being increasingly recognized as playing a crucial role (Paparrizos et al. 2021). Climate Services provide decision-makers with reliable climate information, tools, and methodologies to support climate-sensitive decision-making. By making climate-relevant information accessible, usable, and useful, climate services can significantly improve the quality of decisions (Findlater et al., 2021). Within the context of climate services, two different types can be distinguished: First-generation climate services consist of technologies that support scientific knowledge creation and target scientific audiences. This generation of WCIS is created by and caters to a scientific audience and is provided through a top-down approach (Karpouzoglou et al., 2016). In recent years, a more user-oriented, bottom-up approach has

been advocated. This interactive approach includes stakeholder engagement and knowledge co-production to ensure that the provided services are tailored to the needs of societal users (Vincent et al. 2018; Weichselgartner and Arheimer 2019; Norström et al. 2020). Second-generation climate services enhance the quality of information by making it more accurate, context-specific, and aligned with the needs of both users and providers (Di Fant et al. 2024; Paparrizos et al., 2024). This approach helps to better understand the priorities and practical requirements that the services must meet to address specific user needs (Georgeson et al., 2017).

Although Climate Services are used as an adaptation strategy to enhance climate-smart decision-making in many European areas, Southeastern Europe, particularly the Balkans, lag behind (Cortekar et al., 2020). This gap is usually due to a combination of factors, including limited access to modern technology, restricted financial resources for infrastructure development, lower awareness of the importance of weather information for agriculture and water management, historical challenges such as political instability, and the geographic complexity of the region (Cortekar et al. 2020).

The aim of this research is to assess the current status and potential of Climate Services to address the impacts of extreme drought and heat in Southeastern Europe (SEE). Specifically, this study examines three interconnected aspects: (1) the status of Weather and Climate Information Services (WCIS) in the region, reflecting the current awareness, accessibility, and level of trust in these services; (2) the potential of WCIS, defined as their capacity to strengthen climate resilience by making climate information more actionable, accessible, and user-centered; and (3) the barriers and opportunities influencing the effectiveness of WCIS. Barriers may stem from limited resources, knowledge gaps, or infrastructural challenges, while opportunities focus on ways to enhance service uptake—such as through improved communication, targeted educational initiatives, and tailored hazard warnings. Understanding these interrelated factors will provide insights into how WCIS should be implemented to better support adaptation and resilience strategies in SEE, addressing regional needs amid increasing climate risks.

2. STUDY AREA, METHODS AND DATA

The focus of this study is on ten countries in Southeastern Europe, including the countries of Slovenia (SI), Bosnia and Herzegovina (BA), Croatia (HR), Serbia (RS), Montenegro (ME), Albania (AL), North Macedonia (MK), Romania (RO), Bulgaria (BG), and Greece (GR) (Figure 1).

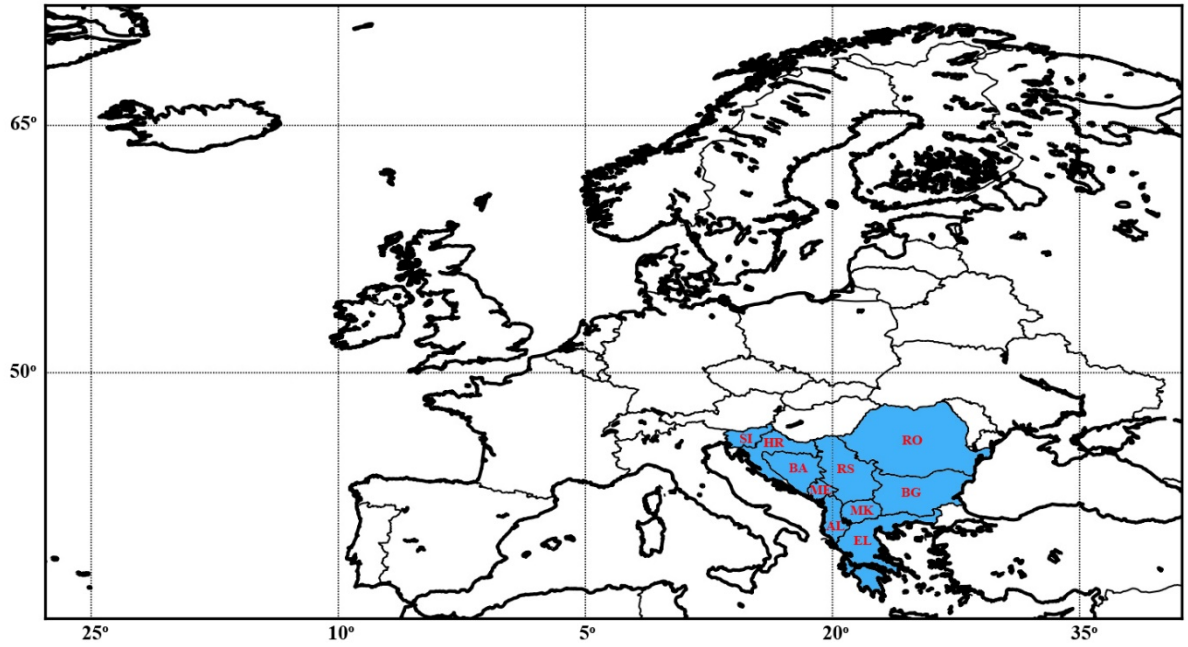

Figure 1. Geographic Locations of the study area in Southeastern Europe: Slovenia (SI), Croatia (HR), Bosnia and Herzegovina (BA), Serbia (RS), Montenegro (ME), North Macedonia (MK), Albania (AL), Greece (EL), Bulgaria (BG), and Romania (RO).

The research design was based on a mixed-methods approach, combining qualitative and quantitative methods. Firstly, a bibliometric analysis was conducted to quantitatively evaluate current research areas in the domain of WCIS in Europe on heat and drought. Additionally, it was used to highlight the research gap in Southeast Europe relative to other regions in Europe. In addressing Southeastern Europe's status as a climate change hotspot, the methodology involves prioritizing the development of accessible and scientifically rigorous WCIS. This approach aims to enhance comprehension of the scientific dimensions of climate change within the region and deepen the understanding of the scientific aspects of climate change. Secondly, market research was performed to identify the current WCIS providers, as well as the current and potential demand for WCIS in SEE. Thirdly, a survey was developed, to collect insights from the general public around the theme of WCIS for heat and drought adaptation. This was complemented with semi-structured interviews with key informants of heat and drought extremes. The research design for this study was structured to provide a comprehensive and multifaceted analysis of WCIS in SEE. By combining quantitative surveys and qualitative interviews, the study seeks to gather diverse data sources and perspectives. This holistic approach aims to offer valuable insights into the current state

of WCIS utilization, barriers to implementation, and opportunities for improvement. The findings from this research will contribute to inform efforts to design WCIS that can provide actionable recommendations to enhance resilience and climate adaptation in the face of droughts and heatwaves affecting the SEE region. The following sections provide more information on the various research approaches adopted in the current study.

2.1. Bibliometric analysis on heat and drought extremes and Climate Services in SEE

To better understand the research gap in WCIS development in SEE a bibliometric analysis was performed, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA, Moher et al., 2016, Figure 2). The search focused on climate extremes related topics, specifically heat and drought events (Figure 2a) and the WCIS status in SEE (Figure 2b). PRISMA approach was selected due to its completeness and usefulness in assessing the literature in relation to climate change (e.g. Paparrizos et al. 2023; Lindawati & Meiryani, 2024). PRISMA, originally intended for systematic reviews in medical and health sciences, offers a structured framework that prioritizes transparency and methodological rigor. This framework can be effectively applied to bibliometric analysis and literature reviews across various disciplines. By following PRISMA guidelines, researchers can systematically and rigorously synthesize bibliometric data, thereby bolstering the reliability and credibility of their research outcomes (Baidya, Saha, 2024).

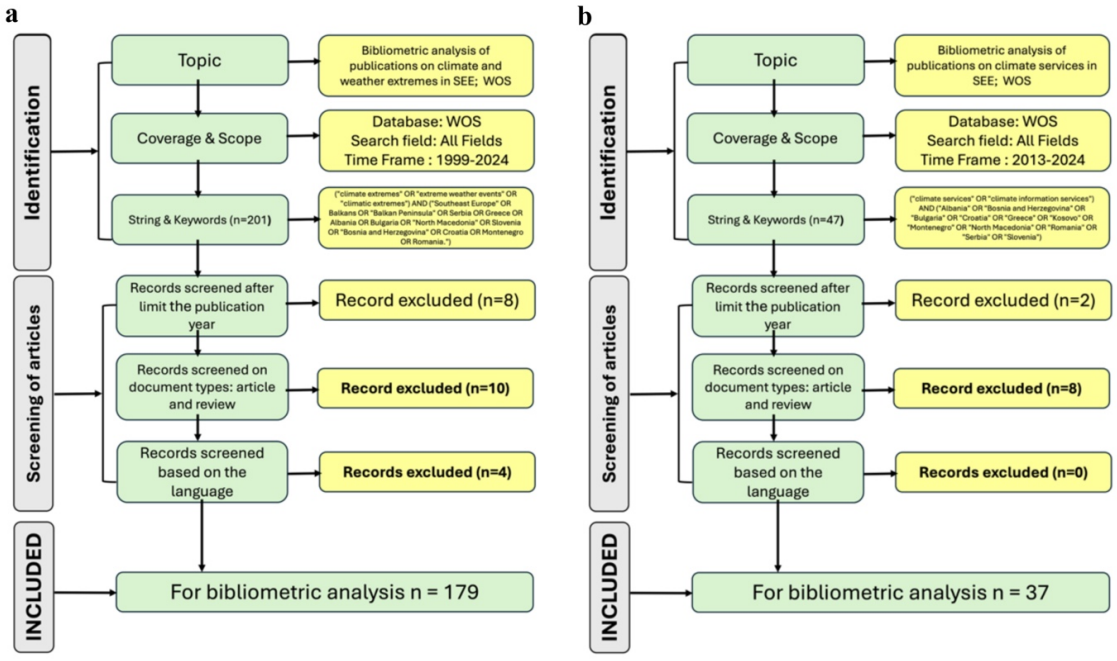

Figure 2. PRISMA framework shows literature search criteria for climate extremes in Southeastern Europe of the current study. a) Search focus on climate extremes, specially droughts and heatwaves and b) focus on the WCIS in SEE

The Web of Science platform (WOS) was used to perform the search with the terms ("*climate extremes" OR "extreme weather events" OR "climatic extremes"*) AND *("Southeast Europe" OR Balkans OR "Balkan Peninsula" OR Serbia OR Greece OR Albania OR Bulgaria OR "North*

Macedonia" OR "Slovenia" OR "Bosnia and Herzegovina" OR "Croatia" OR "Montenegro" OR "Romania"). The search yielded 201 documents for the period 1999-2024 (Figure 2a). After screening, 22 articles were excluded due to publication year (which was older than 1999), language (not written in English), and document type (only articles and reviews were included in the current search). Similarly, the bibliometric review was conducted using the keywords " (*"climate services" OR "climate information services")* AND *("Albania" OR "Bosnia and Herzegovina" OR "Bulgaria" OR "Croatia" OR "Greece" OR "Kosovo" OR "Montenegro" OR "North Macedonia" OR "Romania" OR "Serbia" OR "Slovenia"*) to assess the current state of research in the field of climate information services in Europe. The search gave the result of 47 documents that were further filtered based using the same criteria as for the weather and climate extremes (Figure 2b). To manipulate the data more efficiently, the complete bibliographic data for both searches, were exported in the BibTeX (.bib) file format. Biblioshiny R software packages have been used as bibliometric analysis tools for summarising the results (Aria & Cuccurullo, 2017). Biblioshiny is highly recommended for scientific mapping, offering comprehensive research capabilities in bibliometrics and scientometrics. It features an intuitive interface along with a diverse array of functions, analyses, and graphical representations (Aria & Cuccurullo, 2017).

2.2. Market research on Climate Service providers in SEE

The focus of the market analysis was on collecting and analyzing market data to determine the current and potential demand for Climate Services in SEE. The market research involved identifying the types of WCIS services and providers available in the region and assessing their effectiveness to assist with climate-smart decision making. This is a necessary step since not much research has been focusing on SEE so far. While working on this task, we have identified 37 important CIS providers in SEE. The CIS providers were recognized in each country of SEE. Furthermore, sectors for which they provide their services were recognized. In addition, we have obtained information about relevant stakeholders, including local communities, government agencies, and industry groups in SEE.

2.3. Survey description

To explore public awareness, experiences, and needs related to weather and climate information services (WCIS) for heat and drought adaptation in Southeast Europe (SEE), we conducted a qualitative study based on an online survey targeting citizens in the region. The questionnaire was open from January to March 2024 and was disseminated through email lists, social media platforms, and the ClearClimate project network (https://cordis.europa.eu/project/id/101131220). Given the diverse dissemination channels, the total number of individuals reached could not be determined, and therefore no response rate is reported. To enhance accessibility, the survey was made available in English, Serbian, and Greek. Its structure and process was adapted from existing studies on climate services (Lambrechts et al., 2024) and tailored to capture citizen-level perspectives. The survey aimed to assess general awareness and current use of WCIS, understand how these services are

perceived in relation to recent extreme heat and drought events, identify barriers to their uptake, and gather suggestions for improving their accessibility and relevance. A total of 60 responses were collected, and further details on the survey design and respondent characteristics are provided in Annex 1.

2.4. Semi-structured interviews

Semi-structured interviews were conducted with nine (9) academic experts from Southeastern Europe. These experts, identified through the ClearClimate project network (but not directly related to the project) and using a snowball effect approach, have various fields of expertise related to hydrology, physical geography, meteorology, and climatology. The interviews were designed to gather more in-depth perspectives on several key areas concerning experiences with heat and drought, impact on local communities and perceptions about weather and climate information services now and in the future. The respondents' extensive experience and profound understanding of these subjects allowed them to significantly contribute to the current research. The interviews, conducted online via MS Teams, gathered in-depth information on their experiences with extreme heat and drought events, the impacts on local communities and societal sectors, and their perceptions about the future of Climate Services for heat and drought adaptation in SEE.

3. RESULTS

3.1. Bibliometric analysis on heat and drought events in SEE

The number of publications about extreme events, especially drought and heat, are rising. The sharpest rise is seen from the 2017 and the highest number is observed in 2022. A detailed overview of the bibliometric analysis results can be found in Annex 2.

The 179 articles in our collection include 1582 authors from 20 countries. There are 5 single authored articles. The annual growth rate in the number of articles in 10.5%. A co-authors ratio per document is 9.9, with international co-authorship of 42.6%. These numbers indicate trends towards multi-authored articles, and inter- and transdisciplinary collaborations. Even though the trends suggest rise in the internationalisation, the majority of articles come from the region of SEE.

The analysis identified 678 unique keywords with *precipitation, variability, trends, climate extremes and temperature* being among the most frequent (Fig. 3). Furthermore, as shown in Figure 3, keywords evolved over time. The co-occurrence of terms indicates instances where two keywords often appear together in multiple manuscripts (Fig. 4a). By analysing these co-occurrences, we can identify emerging trends and key areas of focus during different research periods, which highlight shifts in the popularity of various research topics (Radhakrishnan et al., 2017). Additionally, co-occurrence analysis of the keywords structure was utilized to uncover major thematic clusters. The co-occurrence network and word cloud analysis indicate that research on extremes in SEE predominantly focuses on trends in indices and physical drivers, rather than on adaptation and climate change mitigation strategies. According to Li

et al. (2021), climate and environmental sciences dominated as the primary research areas. Additionally, keyword burst analysis (Fig. 4b) highlighted emerging research directions, including changes in atmospheric rivers, the effects of global nitrogen content on extreme weather, and the interconnections between water quality, soil moisture, and extreme weather events. Similarly, Ng (2024) showed that the field has expanded significantly over the past two decades, with five major research themes emerging: *global impacts and policy, agricultural adaptation, extreme weather and prediction, risk management, and heat waves and human health*. Additionally, six international collaboration clusters were recognized, encompassing the Asia-Pacific group, central and southern European group, northern European group, low-latitude countries, small countries, and African countries.

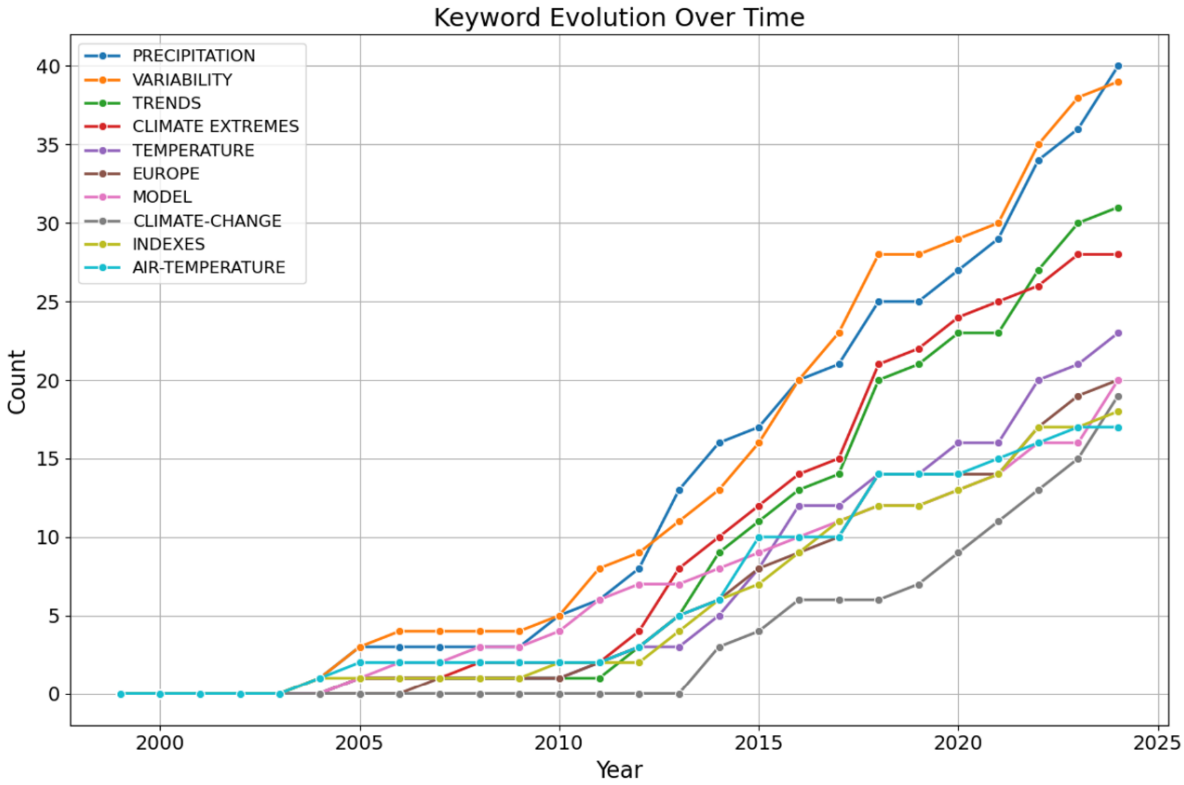

Figure 3. Keywords evolution over time. Results from the bibliometric analysis on heat and drought extremes and Climate Services in SEE of the current study.

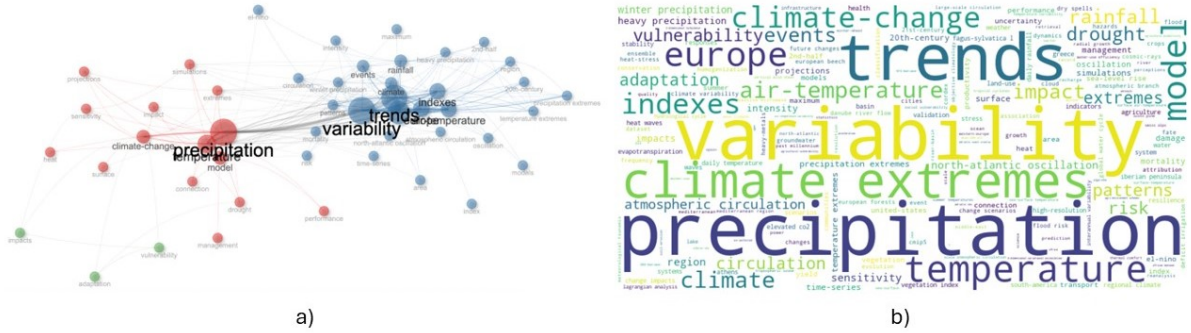

Figure 4. a) Keywords evolution over time and b) their co-occurrences found in the bibliometric analysis of the current study.

3.2. Market analysis of Climate Service providers in Southeast Europe

Following the market analysis, 37 WCIS providers in SEE were identified. These providers are recognized in each country of SEE. Figure 5 summarizes the countries in Southeast Europe (SEE) where these services are provided (a) and their respective status (b). By status, we mean whether the provision of these services is fully covered by public funds, a mix of public and other partners, or developed, provided, and sustained through collaboration with private partners, EU or in-country funding and other sources. This distinction helps to clarify the various mechanisms and partnerships involved in delivering these services.

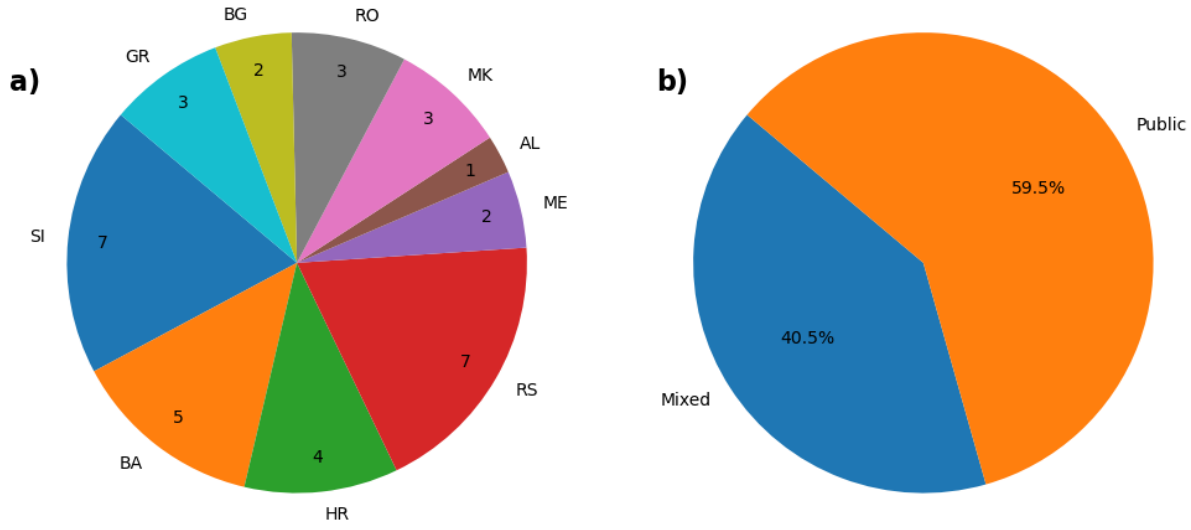

Figure 5. The number of (a) Weather and Climate Information Service providers, and (b) their provision status in southeast Europe.

Serbia and Slovenia were found to have the highest number of WCIS providers related to extremes (seven each), followed by Bosnia and Herzegovina (five) and Croatia (four) (Figure 5a). In total, 37 providers were identified in SEE. In contrast to the findings of Cortekar et al. (2020), which identified only a very limited number of WCIS providers in Southeast Europe (SEE), our market analysis revealed a more diverse landscape of WCIS providers in the region. Pure public funding remains the predominant model for providing WCIS, with 59.5% services being operated or financed through this type of funding (Figure 5b). The remaining 40.5% of WCIS providers operate through joint funding scheme between public, private, or other sources. While it is encouraging to see an increase in the number of providers, it is important to note that only a small subset explicitly offers information on extreme heat and drought events. National meteorological and hydrological services (NMHS) play a pivotal role as the primary issuing authorities for warnings related to these extreme weather events. These services are crucial for mitigating the impacts of extreme weather on communities and economies. The warnings issued by NMHS are disseminated through various channels, including their official portals and social media platforms, ensuring timely and widespread access to critical information. Additionally, these warnings are often picked up and further communicated by third parties, such as news media, to ensure they reach the general public effectively. Despite the presence of multiple WCIS providers, the specialized focus on extreme heat and drought remains limited, highlighting a gap that needs to be addressed to enhance climate resilience in SEE.

Figure 6 highlights the range of weather and climate information available from WCIS providers in SEE, showcasing their diverse temporal coverage and broad applicability across multiple sectors. Note that many of the identified services do not explicitly target a specific sector but offer general information that might be useful for multiple sectors. Information is mainly focused on agriculture, water management, energy, transportation, and health (Figure 6a). While these services primarily focus on general meteorological and climatological information, rather than specifically targeting heat and drought extremes, their provided information supports both immediate weather concerns and long-term climate trends, including aspects related to heatwaves and droughts. WCIS providers thus play a crucial role in enhancing regional resilience against climate impacts. However, this range of information can also present challenges. End-users seeking specific details on heat and drought extremes may need to navigate through broad datasets to find relevant information.

Similarly, these providers offer a range of weather and climate information across various temporal scales. Some WCIS providers utilize historical data to derive information on climate extremes (29.3%), short-term weather forecasts ranging from daily to weekly (22.4%), and long-term climate predictions spanning from season to decadal scales (48.3%) (Figure 6b). These findings indicate that almost half of the WCIS providers deliver information for future climate conditions, often with a focus on climate change. Interestingly, seasonal forecasts are used in 27.6% of WCIS providers in SEE, strongly linked to drought. On the other hand, short-term forecasts are primarily implemented in WCIS related to heatwaves.

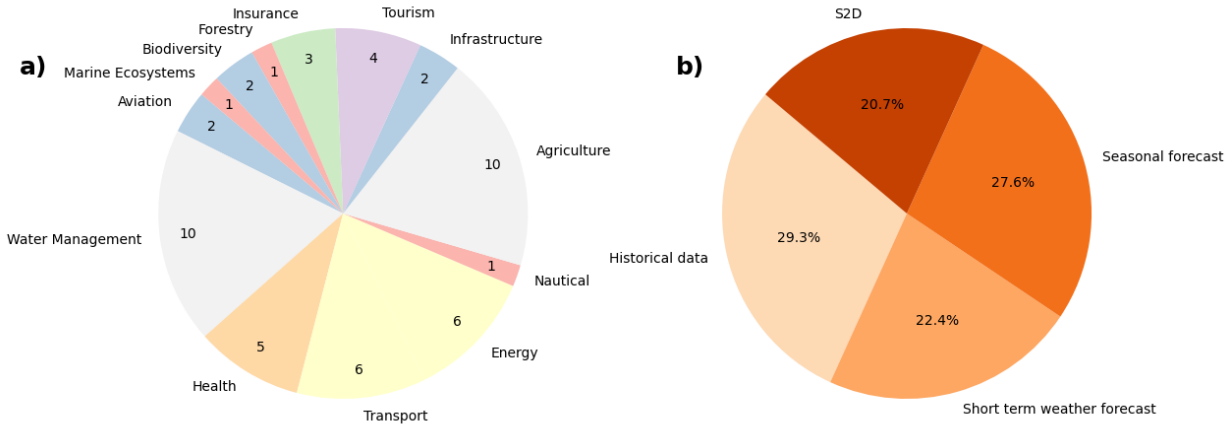

Figure 6. Sectors for which the identified services provide information (a), and temporal scale of weather and climate services (b) in Southeast Europe (SEE). S2D stands for seasonal to decadal predictions.

3.3. Perceptions and Responses to Extreme Heat and Drought Events in SEE

3.3.1. Participant Demographics and Interview Overview

A total of 60 online survey responses were obtained from January to March 2024 through Google forms. Due to the option to skip certain questions, some answers had fewer responses. Additionally, some participants with original nationality outside the selected study area, but who work with the countries of interest, were included in the survey. The participant demographics revealed a majority of women (55%) compared to men (45%), spanning various age categories from under 20 to over 60, with the largest cohorts in the 20-30 (30%) and 30-40 (28%) age brackets (Appendix Figure 3.1 and 3.2). Most participants were from Greece (66.6%), representing a diverse range of occupations, with Research and Science constituting the largest group (31%), closely followed by students (25%) (Appendix Figure 3.3 and 3.4). A comprehensive overview of the demographic profiles of the respondents is available in Annex 3. The survey results were complemented by semi-structured interviews with a total of nine academics from various Southeast European countries and diverse research fields. Most of the participants were from Serbia (six), followed by Hungary but working in Serbia (two), and Greece (one). Annex 4 provides details on the interviews conducted, including the country of origin, title, and working fields of the participants. The remaining information, such as names and contact details, has been anonymized for privacy reasons. The results and narratives presented in the following sections are a combination of the survey data and insights from the key informant interviews, graphical representations of survey results and quotes and key points from the interviews.

3.3.2. Severity perception, concern, experience and preparedness on heat and drought extremes

In line with observations and model projections that indicate an increase in extreme heat and drought events in SEE, survey participants and expert interviewees also anticipate an increase in the frequency and intensity of these events. Figure 7 depicts the perception of severity of extreme heat and drought events among the survey participants, which is confirmed by a large part of interviewees (>80%) who assessed the severity of extreme heat and drought as "significant" or "extremely severe". Heat was more frequently considered as "extremely severe" compared to drought (Figure 6). Interestingly, responses across different countries – such as Greece and Serbia- show similar severity ratings for heat and drought, suggesting a regionally shared concern about these extremes. This similarity indicates that, although the survey data may not be fully representative across SEE, perceptions of climate severity appear consistent, possibly reflecting common experiences or awareness of these growing climate risks across the region.

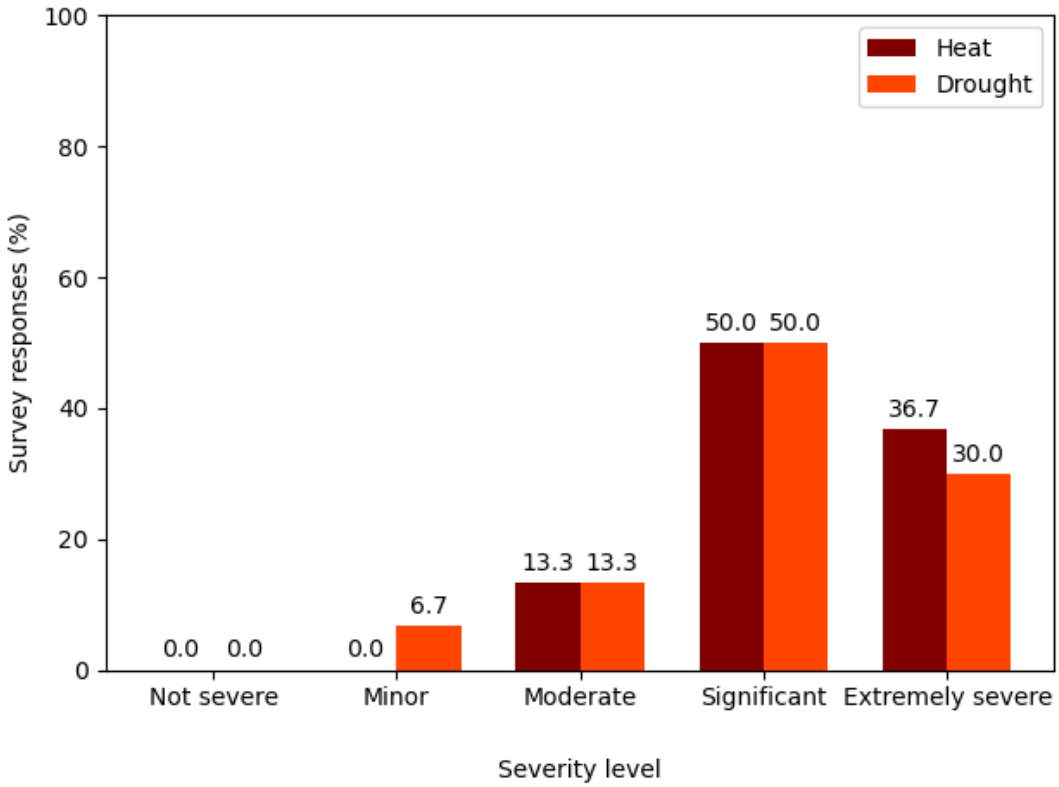

Figure 7. Severity assessment (in percentage) of extreme heat and drought events in SEE (results from the survey, n=60).

Survey participants were asked to indicate on a Likert scale ranging from 1 to 5 the level of concern about heat and drought extremes, whether they have had prior experience with these events, as well as how prepared they currently feel against future heat and drought extreme events. Figure 8 presents their responses.

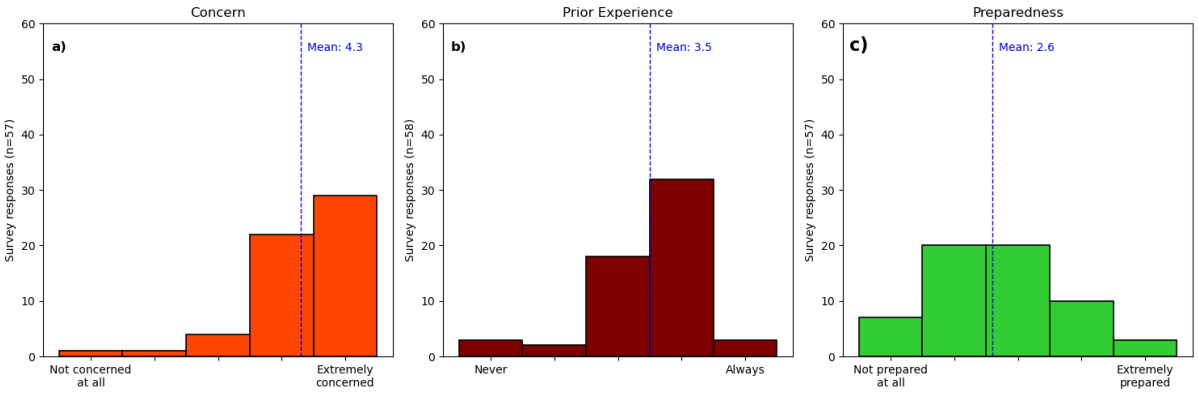

Figure 8. Level of concern (a), prior experience (b), and level of preparedness (c) about heat and drought extreme events of survey participants. Results were calculated on a Likert scale from 1 to 5.

Figure 8a indicates that respondents feel "very much" to "extremely concerned" about occurring heat and drought extremes affecting their respective regions and communities. Many respondents also have prior experience on extreme drought and heatwave events (Figure 8b). Although they have a high concern and experience in extreme droughts and heatwaves, only a few of them are prepared and extremely prepared (Figure 8c). Most respondents indicated that they personally have a very low level of perceived preparedness (average= 2.6).

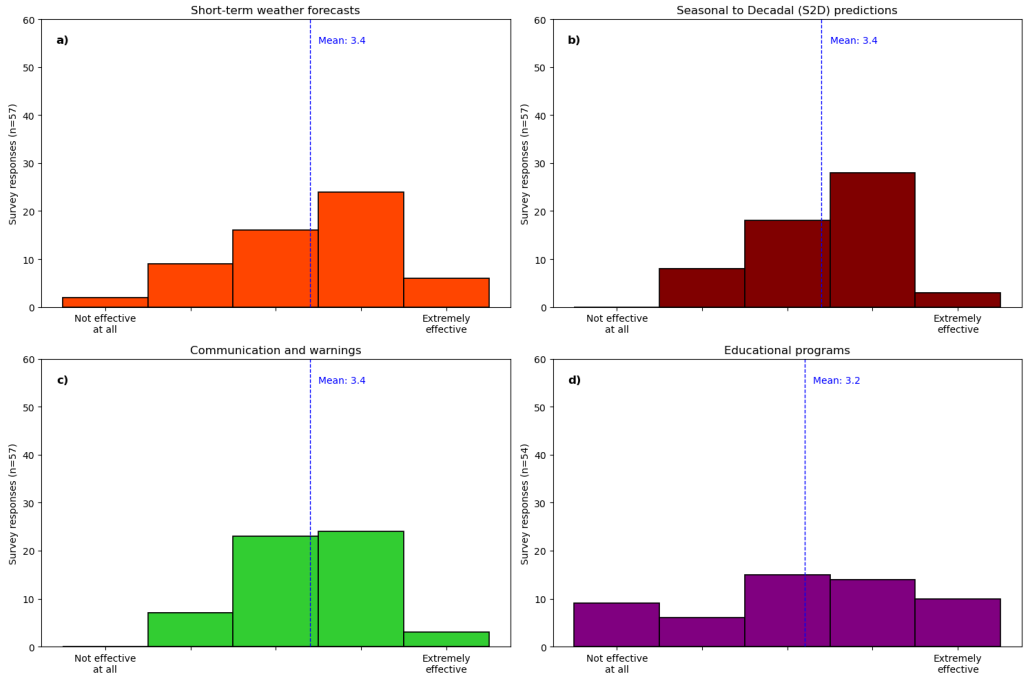

Figure 9. Perceived effectiveness of various Weather and Climate Information Service elements towards heat and drought adaptation: short-term weather forecasts (a), seasonal to decadal (S2D) predictions, communication and warnings (c), and educational programs (d). Results were calculated on a Likert scale from 1 to 5.

Next, respondents were asked to indicate the effectiveness of various WCIS elements coping with future heat and drought extreme events. Figure 9 illustrates the respondents' perceived effectiveness of short-term weather forecasts (a), seasonal to decadal (S2D) predictions (b), communication and warnings (c), and educational programs around heat and drought extremes (d).

Based on the results, study participants find short-term weather forecasts, seasonal to decadal predictions, and prior communication and warnings very effective (mean 3.4) for adapting to extreme heat and drought events (Figure 9a, b, and c, respectively). However, perceptions of educational programs on heat and drought adaptation differ. With a lower average response (mean 3.2) and greater variation (Figure 9d), participants expressed uncertainty about their usefulness, noting that while educational programs might be helpful for specific groups—like farmers or elderly citizens—most people feel they already know what actions to take during extreme events. Instead, they prioritize receiving timely forecasts and alerts on when these events will occur. Interviews further revealed that educational programs in Southeastern Europe, which are often delivered through a top-down governmental approach, face trust issues among the public. Many respondents expressed limited confidence in their government's handling of climate-related information, stating that these programs are sometimes perceived as disconnected from the immediate needs of communities. Some interviewees also pointed out that governmental media regulations often limit the availability and neutrality of information, with climate adaptation topics receiving lower priority in public agendas. As a result, educational programs may lack appeal and effectiveness. To better support communities, these programs should focus on building trust by delivering reliable, actionable information that addresses local concerns and offers practical steps for adaptation.

3.4. Mapping the effects of extreme heat and drought on socio-economic and environmental systems

Based on the results from the surveys and interviews, it is perceived that heatwaves and droughts have significant consequences across all SEE countries. Agriculture is profoundly impacted, with issues such as the spread of exotic or invasive species, increased water demand, and soil degradation being prominent (Fiala et al., 2014; Fabri et al., 2022). Immediate threats include yield reductions and crop losses due to escalating heat and drought extremes (Sutanto et al., 2024). Indirect consequences, such as reduced production and lower yields, exacerbate food insecurity, leading to elevated food prices and economic instability, particularly affecting small-scale farmers and vulnerable populations in SEE. Given that droughts and heatwaves have tremendous impacts on agriculture, many WCIS in SEE are aimed to cope with these issues (see Fig. 6a). Changing climate patterns also affect water sources and infrastructure. Prolonged hydro-meteorological droughts resulting from decreased precipitation and increased evaporation lead to water shortages (Van Loon, 2015). This situation is critical in SEE, where water is essential for hydropower production, impacting energy generation, especially during peak electricity demand for cooling. Excessive energy consumption during heatwaves can trigger power blackouts, as it was mentioned by several

study participants. Furthermore, heat and drought can degrade water quality, affecting both ecological habitats like lakes and rivers and the safety of drinking water (Wright et al., 2014). These challenges underscore the need for sustainable water management and resilient infrastructure. Additionally, heatwaves and droughts pose significant health risks, particularly for vulnerable groups such as the elderly, children, and outdoor workers (Di Napoli et al., 2018). Health issues including heatstroke, dehydration, respiratory illnesses, and vector-borne diseases are exacerbated during prolonged periods of extreme heat and water scarcity. Previous studies have already shown increased mortality and hospitalization in Serbia during hot summer months (Arsenović et al., 2023; Savić et al., 2023) and several participants also noted a notable increase in mortality rates during these periods. Following insights from interviews and surveys, a mind map (Figure 10) has been developed to visually represent the effects of heat and drought in SEE across various sectors and their associated consequences.

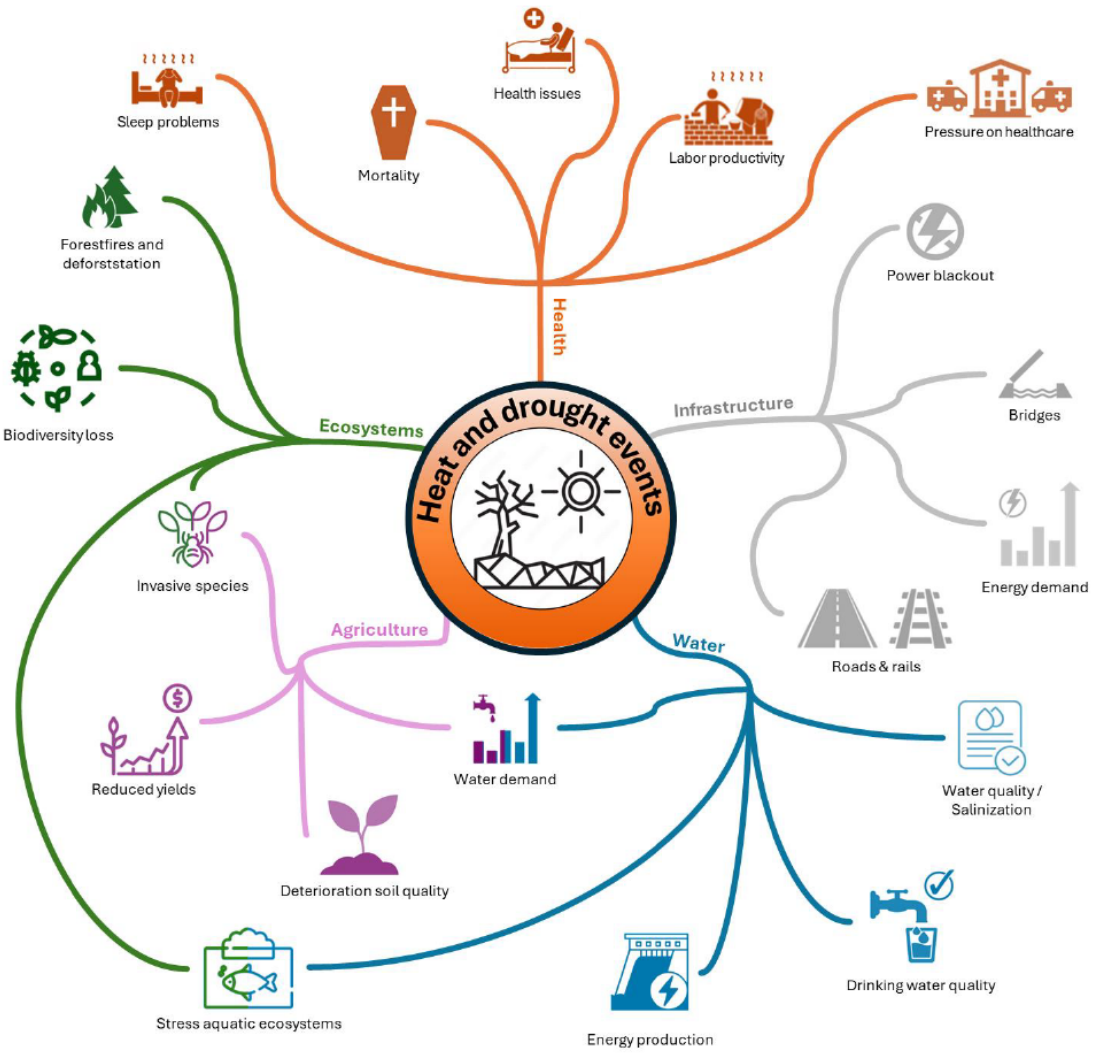

Figure 10. Mind map depicting the effects and consequences of extreme heat and drought events in SEE based on the results of the current study

4. PRINCIPLES FOR ENHANCING THE USE OF CLIMATE SERVICES FOR HEAT AND DROUGHT ADAPTATION IN SEE

The results of the current study emphasise the crucial role of Weather and Climate Information Services (WCIS) to adapt and forged resilience to the increased heat and drought extremes and make more climate-smart decisions in the various sectors of society. Currently, although many climate services exist in SEE (see Fig. 5a), they primarily operate in a top-down manner, often excluding potential users from the design and provision of information. The evidence we recompiled by surveying WCIS users and climate extreme experts suggests the need to step up efforts to improve coverage, accuracy, and user-tailoring of services in the region. To improve the effectiveness and user engagement of Climate Services and enhance their use towards adaptation to extreme heat and drought events, we propose some key principles that are visualized in Figure 11 and are described afterwards.

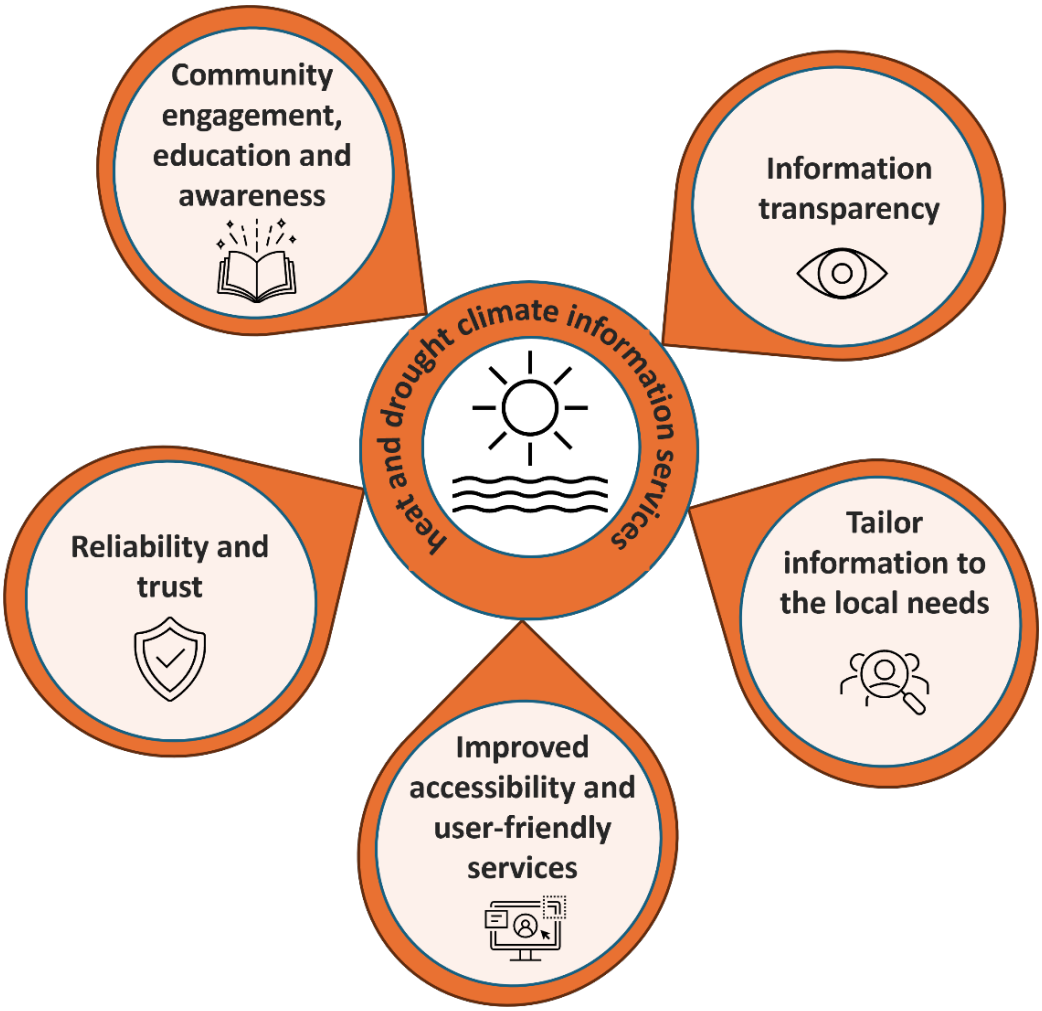

Figure 11. Key principles for enhancing and fostering the further development and provision of WCIS in SEE for adaptation to extreme heat and drought events

4.1. Community engagement, education, and awareness

The first point that emerged from the results is the mixed interest in educational programs for adaptation to heat and drought extremes, generally due to limited awareness of climate change and its associated implications. Community engagement and developing education and awareness around WCIS are essential to foster a more proactive approach to climate resilience against heat and drought extremes (Baiardi and Morana 2021). Education and awareness on this topic lay the foundation and ensure that citizens understand the significance of WCIS and how they can help address heat and drought challenges. There is a need to increase the general public's knowledge of climate change and its causes, as well as the importance of WCIS in this regard (Pekez et al. 2024). One suggestion is to include these educational programs in the school curriculum to build awareness from a young age as the study by Leščešen et al. (2024) pointed out that there is a significant knowledge gap among primary school students in Serbia on the topic of climate change which is barely covered in the curriculum. Effective cooperation with in-country educational authorities through bottom-up driven initiatives as there is mistrust in government authorities as mentioned above is essential for this. Field trips and practical exercises can help students understand the real-world applications of WCIS. Moreover, to reach the broader population, public awareness campaigns can help bridge the gap among adults and emphasize the importance of understanding climate change and utilizing WCIS to mitigate the impacts of extreme heat and drought.

4.2. Transparency of information

The second principle emphasizes promoting transparency in the development and dissemination of the information, specifically for heatwaves and droughts. Disclosing data sources, methodologies used to estimate these extreme events, and any potential uncertainties associated with the provided information is crucial for establishing the credibility of the services and enhancing user confidence. For instance, clearly explaining how temperature thresholds for heatwaves or precipitation deficits for droughts are determined helps users grasp the severity and potential impacts of these events. Transparent disclosure of data sources and methodologies enables users to understand both the strengths and limitations of the information provided, such as the reliability of heatwave forecasts or the accuracy of drought predictions (Sutanto and Van Lanen, 2021). This empowers them to make informed decisions about preparation and response strategies. Moreover, fostering open communication channels between WCIS providers and users facilitates feedback mechanisms and continuous service improvements, ensuring that the services remain relevant and effective. This approach aligns with principles of co-production, where stakeholders are actively involved in discussions about data sources, methodologies, and forecast uncertainties specific to heatwaves and droughts (Vincent et al. 2018; Norström et al. 2020). By engaging with stakeholders in these discussions, WCIS providers can build trust and credibility, thereby enhancing transparency and bolstering user confidence in the services offered for managing extreme heat and drought events.

4.3. Tailoring information to the local needs

The third principle focuses on tailoring Climate Services to address the unique contextual needs of local communities and users. Recognizing that the impacts of heatwaves and droughts can vary significantly across different regions (Biella et al., 2024), it is essential to provide information that is relevant and actionable at the local level. Hence, there is a necessity to customize WCIS to meet the diverse user needs, as one size does not fit all. Various sectors, such as agriculture, water management, and public health, for example, require different information to make informed and climate-smart decisions. In agriculture, farmers and agricultural experts provide valuable insights into how weather conditions impact crop growth, livestock health, and overall farm operations. Their practical knowledge helps determine critical thresholds for temperature and drought, which are crucial for maintaining agricultural productivity and sustainability. Similarly, users related to public health could help identify thermal comfort conditions, temperature thresholds, and heat indices (Xu et al., 2016). This practical knowledge guides the development of essential information needed by the public, including recommended strategies and measures for different vulnerable groups. By involving end-users to tailoring information, WCIS providers can ensure that the information delivered to them is not only scientifically accurate but also practical and actionable for enhancing agricultural resilience and addressing public health challenges related to heatwaves and droughts.

4.4. Improved accessibility through user-friendly services

The fourth principle emphasizes improving accessibility to WCIS, specifically for heat and drought extremes, ensuring these services are user-friendly and cater to the diverse needs and circumstances of various users, including those who are illiterate or not technically proficient. Enhancing accessibility involves simplifying the presentation of information on heatwaves and droughts, using clear and comprehensible language, and employing visual aids or audio formats where necessary (e.g., see Kumar et al., 2021). The results of the current study highlight that while information on heat and drought extremes may be available, it is often too complex for end-users to interpret, thus limiting its usability. There is a need to convey heat and drought information in a manner that various end users can understand and act upon. This approach should include localized outreach efforts, such as providing information in local languages and targeting specific regions and communities affected by heatwaves and droughts. Additionally, it is crucial to develop multi-channel dissemination strategies that encompass both digital platforms and non-electronic means, such as community radio broadcasts or printed materials, to reach wider audiences. By leveraging multiple communication channels, WCIS can effectively disseminate contextual information on heat and drought extremes to all segments of society. Making WCIS more inclusive and easily understandable, enables users to adapt effectively to heatwaves and drought events, regardless of their literacy levels or technical skills.

4.5. Reliability and trust

The implementation of WCIS in Southeast Europe is influenced by various institutional barriers, which have direct implications for the effectiveness and acceptance of these services in the region. These barriers are forming crucial considerations for policymakers and researchers aiming to understand why WCIS adoption lags behind and how policy measures can help overcome these hurdles (Wanner & Pröbstl-Haider, 2019; Cortekar et al., 2020). Ensuring the reliability and trustworthiness of WCIS is essential for building user confidence and increasing the uptake of information, particularly in the context of heat and drought extremes. Study participants expressed specific concerns about the reliability of forecasts during heatwaves and droughts, highlighting the need for continuous improvement and rigorous quality assurance measures tailored to these conditions. Transparent communication about the methodologies used and the limitations of WCIS, as discussed in previous sections, is vital for maintaining trust. By providing clear, accurate, and timely information about heatwaves and droughts, governments and institutions can enhance their credibility and foster public cooperation. Building trust in WCIS also involves demonstrating the tangible benefits of these services through case studies and success stories, showing how accurate forecasts and timely information have helped mitigate the impacts of extreme weather events (Sutanto and Van Lanen, 2024). Engaging with local communities to gather feedback and address their concerns can further strengthen the relationship between WCIS providers and users. Adaptation to climate change is fundamentally a matter of governance (Termeer et al., 2014). Therefore, a coordinated effort involving governments, institutions, and local communities is crucial to overcoming institutional barriers and enhancing the effectiveness of WCIS. By fostering a collaborative environment and ensuring the reliability and trustworthiness of WCIS, Southeast Europe can better prepare for and respond to the challenges posed by heatwaves and droughts.

5. CONCLUSIONS

This study highlights the critical importance of WCIS in enhancing climate resilience and adaptation to extreme heat and drought events in SEE. Through a comprehensive mixed-methods approach, combining bibliometric analysis, market research, surveys, and semi-structured interviews, the research provides significant insights into the current state and potential of WCIS in the region. The bibliometric analysis and market research highlight a diverse landscape of WCIS providers across SEE; while emphasizing a notable gap in the specialized focus on extreme heat and drought events. Although there is an increasing number of providers, many services lack targeted information for these extreme conditions. National meteorological and hydrological services play a pivotal role, but their warnings are often general and not always effectively communicated to the public. Survey results and interviews reveal that the general public and academic experts perceive extreme heat and drought as severe and growing concerns. Despite frequent personal experiences with these events, there is a widespread feeling of inadequate preparedness. This underscores the need for more tailored and accessible information that addresses local needs and specific sectoral requirements. The perceived effectiveness of short-term forecasts and seasonal predictions

is acknowledged, but there is room for improvement in educational programs about climate extremes. To address these challenges, several key principles for enhancing the use of WCIS have been proposed. These include increasing community engagement and education, promoting transparency, tailoring information to local needs, improving accessibility, and building reliability and trust. By implementing these principles, WCIS can become more effective in supporting adaptation strategies and decision-making processes, thereby contributing to enhanced climate resilience in SEE. While progress has been made in expanding WCIS in SEE, targeted efforts are needed to improve their relevance and usability in addressing extreme heat and drought. A collaborative approach involving stakeholders at all levels can facilitate the development of more effective climate services, ultimately fostering greater resilience and adaptive capacity in the face of a changing climate.

6. REFERENCES

Aria, M., & Cuccurullo, C., 2017. bibliometrix: An R-tool for comprehensive science mapping analysis. Journal of Informetrics , 11(4), 959-975

Arsenović, D., Lužanin, Z., Milošević, D., Dunjić, J., Nikitović, V., & Savić, S., 2023. The effects of summer ambient temperature on total mortality in Serbia. International Journal of Biometeorology, 67(10), 1581-1589.

Baidya, A., & Saha, A. K., 2024. Exploring the research trends in climate change and sustainable development: A bibliometric study. Cleaner Engineering and Technology, 100720.

Baiardi, D., and Morana, C., 2021. Climate change awareness: Empirical evidence for the European Union. Energy Economics, 96, 105163, https://doi.org/10.1016/j.eneco.2021.105163

Bezak, N., & Mikoš, M., 2020. Changes in the compound drought and extreme heat occurrence in the 1961–2018 period at the European scale. Water, 12(12), 3543. https://doi.org/10.3390/w12123543

Biella, R., Shyrokaya, A., Ionita, M., & co-authors. (2024). The 2022 drought needs to be a turning point for European drought risk management. Egusphere. https://doi.org/10.5194/egusphere-2024-2069

Cortekar, J., Themeßl, M., & Lamich, K., 2020. Systematic analysis of EU-based climate service providers. Climate Services, 17, 100125. https://doi.org/10.1016/j.cliser.2019.100125

Di Fant, V, del Pozo, M., Gulikers, J., & Paparrizos, S., 2024. Conceptualizations and implementation of user engagement in Weather and climate services: A climate services providers' perspective. Heliyon, 10, e22940, https://doi.org/10.1016/j.heliyon.2023.e22940

Di Napoli, C., Pappenberger, F., & Cloke, H. L. (2018). Assessing heat-related health risk in Europe via the Universal Thermal Climate Index (UTCI). International Journal of Biometeorology, 62, 1155–1165. https://doi.org/10.1007/s00484-018-1518-2

Douville, H., Raghavan, K., Renwick, J., Allan, R. R., Arias, P. A., Barlow, M., Cerezo-Mota, R., Cherchi, A., Gan, T. Y., Gergis, J., Jiang, D., Khan, A. M. S., Pokam, W. M., Rosenfeld, D., Tierney, J. E., & Zolina, O. (2023). Weather and Climate Extreme Events in a Changing Climate. In IPCC Sixth Assessment Report Working Group 1: The Physical Science Basis (pp. 1513–1766). https://doi.org/10.1017/9781009157896.013

Đurđević, D., Vasić, M., Ogrin, M., Savić, S., Milošević, D., Dunjić, J., ... & Mitrović, L. (2023). Long-Term Assessment of Bioclimatic Conditions at Micro and Local Scales in the Cities of the Western Part of the Balkan Peninsula during the 21st Century. Sustainability, 15(21), 15286.

Fabri, C., Moretti, M., Van Passel, S., 2022. On the (ir)relevance of heatwaves in climate change impacts on European agriculture. Climatic Change 174, 16. https://doi.org/10.1007/s10584-022-03438-4

Fiala, K., Blanka, V., Ladányi, Z. et al., 2014. Drought severity and its effect on agricultural production in the Hungarian-Serbian cross-border area. Journal of Environmental Geography 7(3-4), 43-51. https://doi.org/10.2478/jengeo-2014-0011

Findlater, K., Webber, S., Kandlikar, M. et al., 2021. Climate services promise better decisions but mainly focus on better data. Nat. Clim. Chang. 11, 731–737. https://doi.org/10.1038/s41558-021-01125-3

Georgeson, L., Maslin, M., Poessinouw, M., 2017. Global disparity in the supply of commercial weather and climate information services. Sci. Adv. 3 (5), e1602632.

Giannaros, T.M., Papavasileiou, G., Lagouvardos, K., Kotroni, V., Dafis, S., Karagiannidis, A., Dragozi, E., 2022. Meteorological Analysis of the 2021 Extreme Wildfires in Greece: Lessons Learned and Implications for Early Warning of the Potential for Pyroconvection. Atmosphere, 13, 475. https://doi.org/10.3390/atmos13030475

Giannaros, T.M. and Papavasileiou, G., 2023. Changes in European fire weather extremes and related atmospheric drivers, Agricultural and Forest Meteorology, 342,109749, https://doi.org/10.1016/j.agrformet.2023.109749

IPCC, 2014. Climate change 2014 - synthesis report. Contribution of working groups i, ii and iii to the fifth assessment report of the intergovernmental panel on climate change. Geneva, Switzerland. Retrieved from: https://www.ipcc.ch/report/ar5/syr/

IPCC, 2023. Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 35-115, doi: 10.59327/IPCC/AR6-9789291691647

Karpouzoglou, T., Zulkafli, Z., Grainger, S., Dewulf, A., Buytaert, W., Hannah, D.M., 2016. Environmental virtual observatories (evos): Prospects for knowledge cocreation and resilience in the information age. Curr. Opin. Environ. Sustain. 18,40–48.

Klimavičius, L., & Rimkus, E., 2023. Compound drought and heatwave events in the eastern part of the Baltic Sea region. Oceanologia. https://doi.org/10.1016/j.oceano.2023.06.010

Kumar, U., Werners, S. E., Paparrizos, S., Datta, D. K., & Ludwig, F., 2021. Co-producing climate information services with smallholder farmers in the Lower Bengal Delta: How forecast visualization and communication support farmers' decision-making. Climate Risk Management, 33, 100346.

Lambrechts, H.A., Stoof, C.R., del Pozo, M., Ludwig, F., & Paparrizos, S. (2024). The role of weather and climate information services to support in wildfire management in Northwestern Europe. Clim. Risk. Manag., 46, 100672.

Leščešen, I., Basarin, B., & Vujičić, M. (2024). What do they know? Is climate change education necessary in primary schools in Serbia. Geographica Pannonica, 28(2).

Li, Z., Guo, L., Sha, Y., & Yang, K. (2021). Knowledge map and global trends in extreme weather research from 1980 to 2019: a bibliometric analysis. Environmental Science and Pollution Research, 28(36), 49755-49773.

Lindawati, A. S. L., & Meiryani., 2024. A bibliometric analysis on the research trends of global climate change and future directions. Cogent Business & Management, 11(1), 2325112.

Martinez, G. S., Baccini, M., De Ridder, K., Hooyberghs, H., Lefebvre, W., Kendrovski, V., ... & Spasenovska, M., 2016. Projected heat-related mortality under climate change in the metropolitan area of Skopje. BMC Public Health, 16, 1-12.

Moher, D., Stewart, L., & Shekelle, P., 2016. Implementing PRISMA-P: recommendations for prospective authors. Systematic reviews, 5, 1-2.

Mukherjee, S., & Mishra, A. K., 2021. Increase in compound drought and heatwaves in a warming world. Geophysical Research Letters, 48(1). https://doi.org/10.1029/2020gl090617

Ng, S. L. (2024). Bibliometric analysis of climate change and extreme weather adaptation based on Scopus. Journal of Environmental Studies and Sciences, 1-20.

Norström, A.V., Cvitanovic, C., Löf, M.F. et al. 2020. Principles for knowledge co-production in sustainability research. Nat Sustain 3, 182–190. https://doi.org/10.1038/s41893-019-0448-2

Paparrizos, S., & Matzarakis, A., 2016. Assessment of future climate change impacts on the hydrological regime of selected Greek areas with different climate conditions. Hydrology Research, 48(5), 1327–1342. https://doi.org/10.2166/nh.2016.018

Paparrizos, S., Maris, F., Weiler, M., & Matzarakis, A., 2018. Analysis and mapping of present and future drought conditions over Greek areas with different climate conditions. Theoretical and Applied Climatology, 131 (102), 259-270.

Paparrizos, S., Kumar, U., Amjath-Babu, T., Ludwig, F., 2021. Are farmers willing to pay for participatory climate information services? Insights from a case study in periurban Khulna, Bangladesh. Clim. Serv., 23, 100241.

Paparrizos, S., Attoh, E.M.N.A.N., Sutanto, S.J., Snoeren, N. & Ludwig, F., 2023. Local rainfall forecast knowledge across the globe used for agricultural decision-making. Science of the Total Environment, 899, 165539.

Paparrizos, S., Vignola, R. & Sutanto, S. J., 2024. Integrating user- and data-driven weather forecasts to develop legitimate, credible, and salient information services for smallholders in the Global South. Scientific Reports, 14, 22841. https://doi.org/10.1038/s41598-024-73539-w

Pekez, J., Stojanov, J., Mihajlovic, V. et al. 2024. The impact analysis of education on raising awareness towards climate change and energy efficiency. Int J Technol Des Educ. https://doi.org/10.1007/s10798-024-09904-7

Radhakrishnan S, Erbis S, Isaacs J A and Kamarthi S 2017. Novel keyword co-occurrence network-based methods to foster systematic reviews of scientific literature PLoS One 12 e0172778.

Savić, S., Arsenović, D., Lužanin, Z., Milošević, D., Dunjić, J., Šećerov, I., ... & Arsić, M. (2023). Hospital admission tendencies caused by day-to-day temperature changes during summer: a case study for the city of Novi Sad (Serbia). International Journal of Biometeorology, 67(4), 695-704.

Stahl, K., Kohn, I., Blauhut, V., Urquijo, J., De Stefano, L., Acácio, V., Dias, S., Stagge, J. H., Tallaksen, L. M., Kampragou, E., Van Loon, A. F., Barker, L., Melsen, L., Bifulco, C., Musolino, D., De Carli, A., Massarutto, A., Assimacopoulos, D., & Van Lanen, H. (2016). Impacts of European drought events: insights from an international database of text-based reports. Natural Hazards and Earth System Sciences (Print), 16(3), 801–819. https://doi.org/10.5194/nhess-16-801-2016

Sutanto, S. J., Zarzoza M, S. B., Supit, I., & Wang, M. (2024). Compound and cascading droughts and heatwaves decrease maize yields by nearly half in Sinaloa, Mexico. npj Nat. Hazards 1, 26 (2024). https://doi.org/10.1038/s44304-024-00026-7

Sutanto, S. J., & Van Lanen, H. A. J. (2024). Hydrometeorological drought forecasts: Lessons learned from ANYWHERE and next steps to improve drought management.

Responding to extreme weather events, edited by Sempere-Torres, D., Karakostas, A., Rossi, C., & Quevauviller, P., Wiley, ISBN: 9781119741589, 23-48

Sutanto, S. J., & Van Lanen, H. A. J. (2021). Streamflow drought: implication of drought definitions and its application for drought forecasting. Hydrol. Earth Syst. Sci., 25, 3991–4023. https://doi.org/10.5194/hess-25-3991-2021

Sutanto, S. J., & Van Lanen, H. A. J. (2020). Hydrological drought characteristics based on groundwater and runoff across Europe. Proc. IAHS, 383, 281–290. https://doi.org/10.5194/piahs-383-281-2020

Sutanto, S. J., Vitolo, C., Di Napoli, C., D'Andrea, M., & Van Lanen, H. A. J. (2020). Heatwaves, droughts, and fires: Exploring compound and cascading dry hazards at the pan-European scale. Environment International, 134, 105276. https://doi.org/10.1016/j.envint.2019.105276

Termeer, C.J.A.M., Van Buuren, A., Dewulf, A. R. P. J., Huitema, D., Mees, H. L. P., Meijerink, S., & Rijswick, H. F. M. W. The Oxford Research Encyclopedia of Climate Science Oxford University Press (2017) https://doi.org/10.1093/acrefore/9780190228620.013.600

Toreti, A., Masante, D., Acosta Navarro, J., Bavera, D., Cammalleri, C., De Jager, A., Di Ciollo, C., Hrast Essenfelder, A., Maetens, W., Magni, D., Mazzeschi, M., Spinoni, J., & De Felice, M., 2022. Drought in Europe: July 2022 : GDO Analytical Report.

Van Loon, A. F. (2015). Hydrological drought explained. WIREs Water, 2(4), 359-392. https://doi. org/10.1002/wat2.1085

Vincent, K., Danly, M., Scanell, C. & Leathes, B., 2018. What can climate services learn from theory and practice of co-production? Clim. Serv. 12, 48–58. https://doi.org/10.1016/j.cliser.2018.11.001

Wanner, A., & Pröbstl-Haider, U., 2019. Barriers to Stakeholder Involvement in Sustainable Rural Tourism Development—Experiences from Southeast Europe. Sustainability, 11(12), 3372. https://doi.org/10.3390/su11123372

Weichselgartner, J., & Arheimer, B., 2019. Evolving Climate Services into Knowledge–Action Systems. Wea. Climate Soc., 11, 385–399, https://doi.org/10.1175/WCAS-D-18-0087.1

Wright, B., Stanford, B. D., Reinert, A., Routt, J. C., Khan, S. J., & Debroux, J. F. (2014). Managing water quality impacts from drought on drinking water supplies. Journal of Water Supply: Research and Technology-Aqua, 63 (3), 179–188. https://doi.org/10.2166/aqua.2013.123

Wu, X., Hao, Z., Hao, F., Singh, V. P., & Zhang, X., 2019. Dry-hot magnitude index: a joint indicator for compound event analysis. Environmental Research Letters, 14(6), 064017. https://doi.org/10.1088/1748-9326/ab1ec7

Xu, Z., FitzGerald, G., Guo, Y., Jalaludin, B., & Tong, S. (2016). Impact of heatwave on mortality under different heatwave definitions: A systematic review and meta-analysis. Environment International, 89-90, 193-203. http://dx.doi.org/10.1016/j.envint.2016.02.007

Zhang, Q., She, D., Zhang, L., Wang, G., Troin, M., & Hao, Z., 2022. High sensitivity of compound drought and heatwave events to global warming in the future. Earth's Future, 10(11). https://doi.org/10.1029/2022ef002833

ANNEXES

ANNEX 1 – Survey for heat and drought extreme events in Southeast Europe

Annex 1 presents the questionnaire that was utilized to collect answer from the general public (English version). Google forms were used to distribute the questionnaire and collect the answers.

Climate Services for adaptation to heat and drought events

This questionnaire is designed to provide insights into the integration and optimization of Weather and Climate Information Services (WCIS) for citizens in Southeast Europe, addressing the impacts of extreme drought and/or extreme heat. The primary focus is on identifying opportunities to more effectively utilize WCIS to mitigate the impact of these weather extremes.
This study serves an academic purpose, and your input is highly valued for its contribution. Your responses will solely be utilized for research purposes, devoid of any financial or commercial agenda. I assure you that there are no risks involved in participating in this survey, and there are no direct personal benefits for your involvement. The data gathered from this questionnaire is expected to enhance our research endeavours. You have the autonomy to abstain from answering any questions you prefer not to disclose. Additionally, you retain the freedom to discontinue your participation if any question makes you uncomfortable. Rest assured, your identity will remain anonymous, and your name will not be linked to any research materials or reports, ensuring confidentiality and privacy.

The questionnaire consists of 21 questions, almost all (19) of which are multiple-choice. It should take approximately 6 minutes to complete the questionnaire.

Do you agree to participate in the Questionnaire? YES - NO

Choose your language: English - Serbian - Greek

1. Introduction

1.1 Your gender?

- M
- F

1.2 Your age?

- <20
- 20-30
- 30-40
- 40-50
- 50-60
- 60>

1.3 Your working field/sector?

- Information Technology (IT)
- Healthcare
- Education
- Business and Finance
- Engineering
- Creative Arts and Media
- Science and Research
- Government and Public Administration
- Student
- Other,……

1.4 Your country?

- Greece
- Serbia
- Slovenia
- Croatia
- Romania
- North Macedonia
- Bulgaria
- Bosnia-Herzegovina
- Montenegro
- Albania
- Other: ……

2. Own knowledge & experiences about Climate Change

2.1 On a scale of 1 to 5, to what extent are you familiar with the basic principles of climate change?

1. Not Familiar at All
2. Somewhat Familiar
3. Moderately Familiar
4. Quite Familiar
5. Very Familiar

2.2 On a scale of 1 to 5, how do you assess your own knowledge of climate change compared to the average level of knowledge in your country?

1. Much Lower Than Average
2. Lower Than Average
3. Average
4. Higher Than Average
5. Much Higher Than Average

2.3 On a scale of 1 to 5, how severe do you consider the consequences of extreme drought in your country?

1. Not severe
2. Minor
3. Moderate
4. Significant
5. Extremely severe

2.4 On a scale of 1 to 5, how severe do you consider the consequences of extreme heat in your country?

1. Not severe
2. Minor
3. Moderate
4. Significant
5. Severe

2.5 On a scale of 1 to 5, how concerned are you about the potential future impact of extreme heat and drought climate-related events on your community?

1. Not Concerned At All
2. Slightly Concerned
3. Moderately Concerned
4. Quite Concerned
5. Extremely Concerned

2.6 On a scale of 1 to 5, how often have you personally experienced extreme heat and drought events in your region?

1. Never
2. Rarely
3. Sometimes
4. Very often
5. Always

3. Confidence current situation

3.1 On a scale of 1 to 5, how much confidence do you have in the scientific community when it comes to climate change?

1. No Confidence
2. Low Confidence
3. Moderate Confidence
4. High Confidence
5. Very High Confidence

3.2 On a scale of 1 to 5, how much confidence do you have in the government when it comes to climate change?

1. No Confidence
2. Low Confidence
3. Moderate Confidence
4. High Confidence
5. Very High Confidence

3.3 On a scale of 1 to 5, to what extent do you feel personally prepared for extreme heat and drought events?

1. Not Prepared at all
2. Somewhat Prepared
3. Adequately Prepared
4. Very Well Prepared
5. Extremely Prepared

4. Effectiveness Weather and Climate Information Services

4.1 On a scale of 1 to 5, to what extent are you familiar with the basic principles of Weather and Climate Information Services (the availability and provision of weather and climate information)?

1. Not Familiar At All
2. Somewhat Familiar
3. Moderately Familiar
4. Quite Familiar
5. Very Familiar

4.2 On a scale of 1 to 5, have you ever used any of the following examples of WCIS, tick which ones?

- Weather forecasts
- Weather-related hazard warnings
- Seasonal-to-decadal predictions (S2D)
- Educational programs (for increased understanding in promoting resilience and adaptability)
- No, I didn't use any of these

4.3 On a scale of 1 to 5, how effective do you find short-term weather forecasts regarding extreme heat and drought?

1. Not Effective At All
2. Slightly Effective
3. Moderately Effective
4. Quite Effective
5. Extremely Effective

4.4 On a scale of 1 to 5, how effective do you find the Seasonal information and/or decadal predictions (S2D) regarding extreme heat and drought?

1. Not Effective At All
2. Slightly Effective
3. Moderately Effective
4. Quite Effective
5. Extremely Effective

4.5 On a scale of 1 to 5, how effective do you find communication and warnings regarding extreme heat and drought?

1. Not Effective At All
2. Slightly Effective
3. Moderately Effective
4. Quite Effective
5. Extremely Effective

4.6 On a scale of 1 to 5, how effective do you find Educational programs (for increased understanding in promoting resilience and adaptability) regarding extreme heat and drought?

1. Not Effective At All
2. Slightly Effective
3. Moderately Effective
4. Quite Effective
5. Extremely Effective

5. Future needs regarding Climate Information services for heat and drought adaptation

5.1 Which of the WCIS examples do you think are useful to make more easily accessible in the future? Put the numbers in order from most important (1) to least important (5).

Weather forecasts	1 - 2 - 3 - 4 - 5
Weather-related hazard warnings	1 - 2 - 3 - 4 - 5
Climate Information	1 - 2 - 3 - 4 - 5
Educational programs	1 - 2 - 3 - 4 - 5
None of the above (if so, fill in question 5.2)	1 - 2 - 3 - 4 - 5

5.2 If you have any other suggestions for question 5.1 fill them in here, please. (*Open question*)

……

5.3 What do you need to make more effective use of Weather and Climate Information Services in the future? (*Open question*)

……

5.4 Do you have any other questions or additions? (*Open question*)

……

ANNEX 2 – Detailed bibliometric analysis on heat and drought events in SEE

When combined with the most relevant sources, it could be concluded that most papers are published in journals related to sustainable development (*Sustainability*), climatology (*International Journal of Climatology, Atmosphere, Climate Research, Theoretical and Applied Climatology, Agricultural and Forest Meteorology, Atmospheric Research, Climatic Change*), water management (*Water*) and natural hazards (*Natural Hazards and Earth System Sciences*). These journals have been identified as the most impactful based on the number of research papers they published in the investigated period.

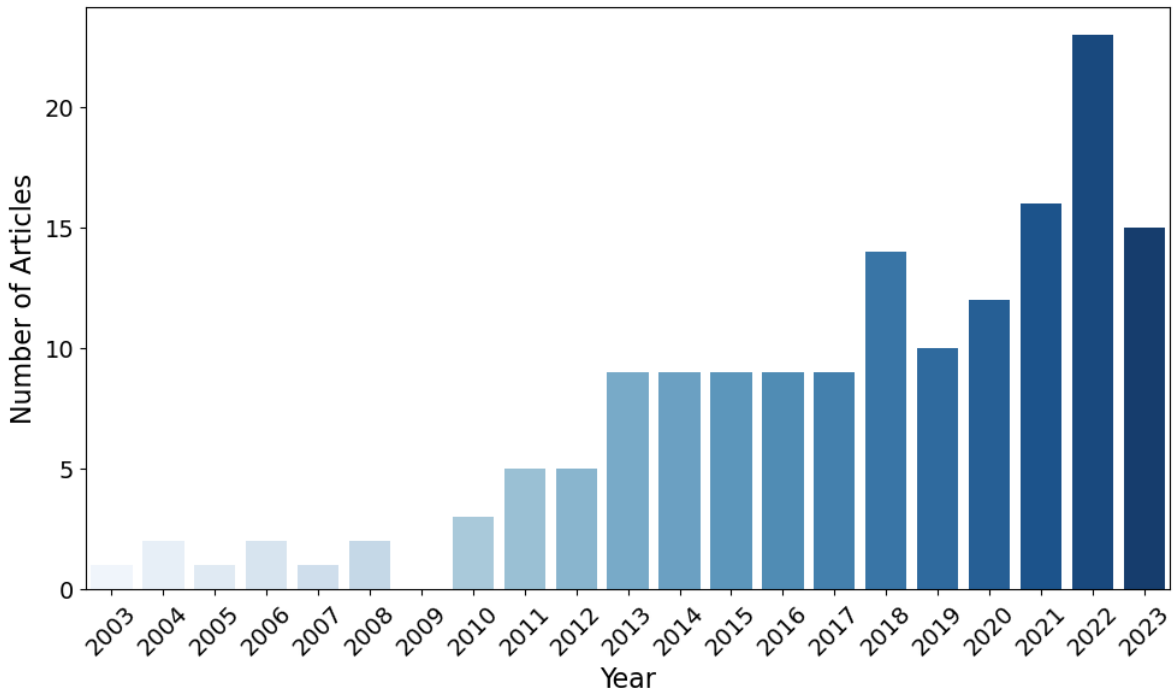

Figure 2.1: Number of scientific publications on extreme events in SEE that were revealed through the bibliometric analysis of the current study

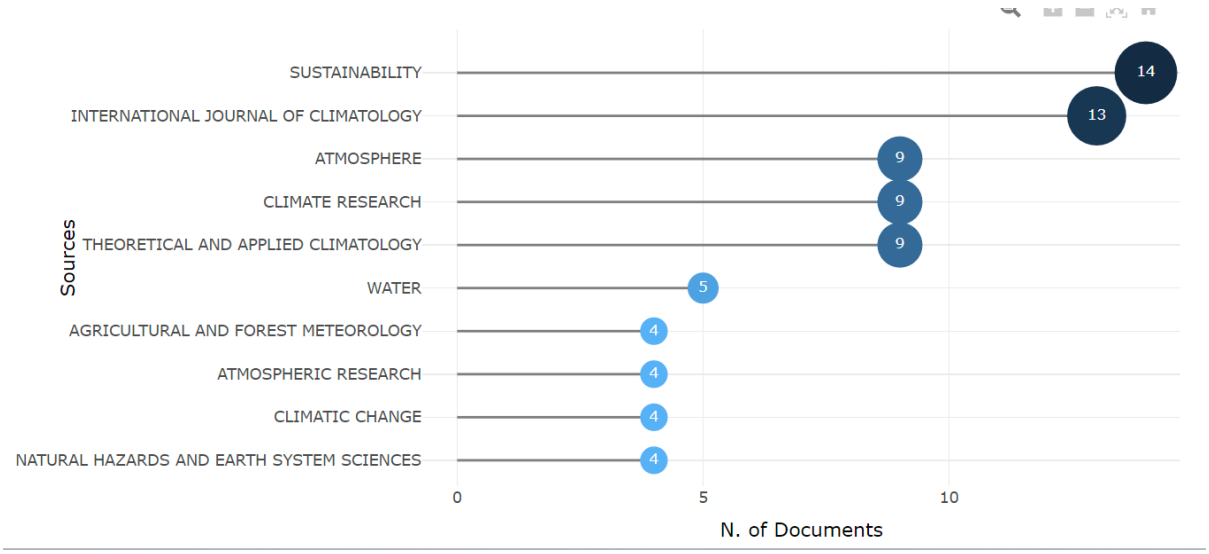

Figure 2.2: Top 10 journals based on the number of publications

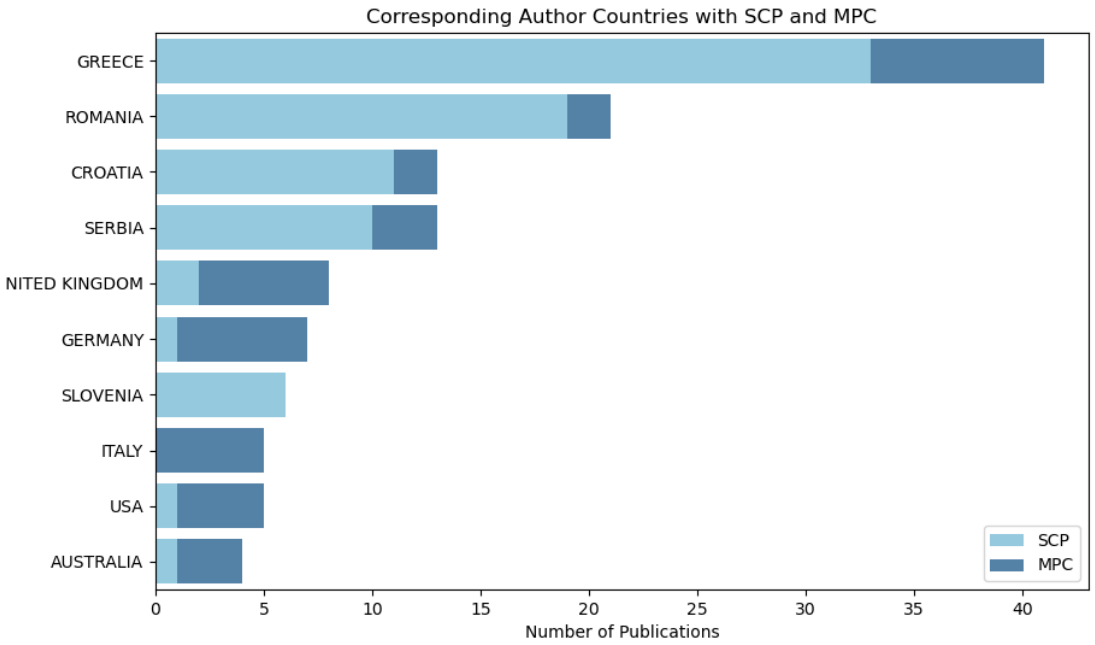

Figure 2.3: Corresponding authors from most relevant countries

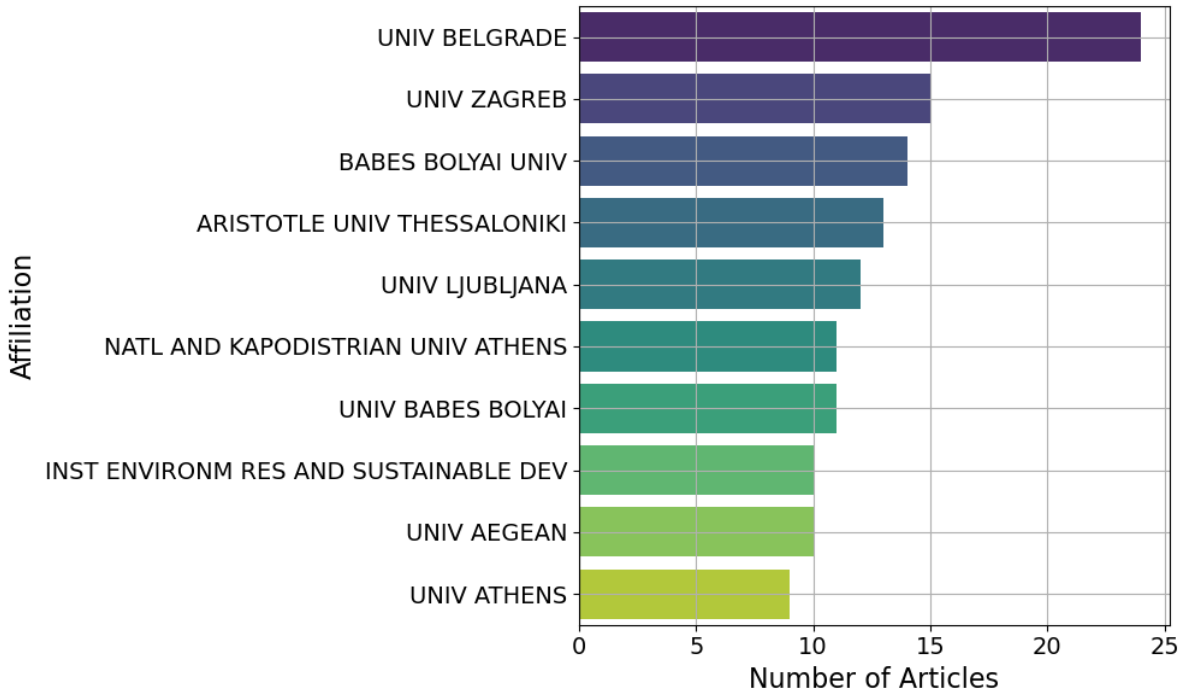

Figure 2.4: Authors affiliations

ANNEX 3 – Demographic profile of the survey participants

Annex 3 below presents a comprehensive overview of the demographics of the study participants such as Gender, Age range, country of origin and working field of the participants. Overall, 60 people participated in the current study.

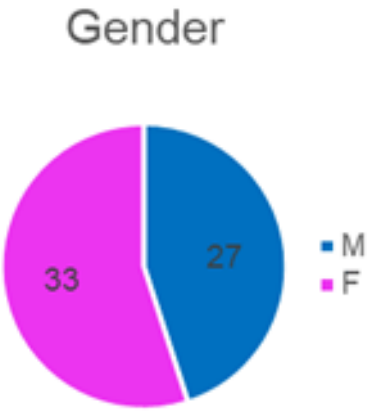

Figure 3.1: Gender of the participants of the current study

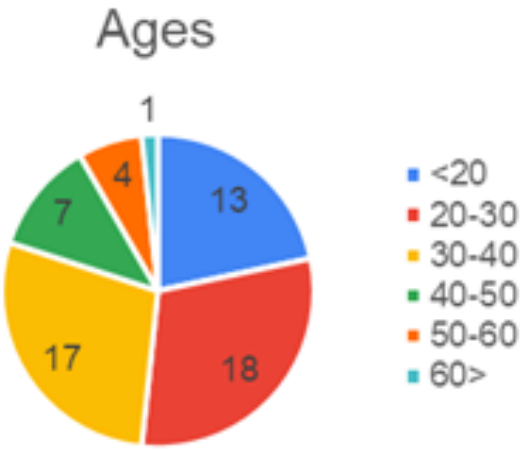

Figure 3.2: Age range of the participants of the current study

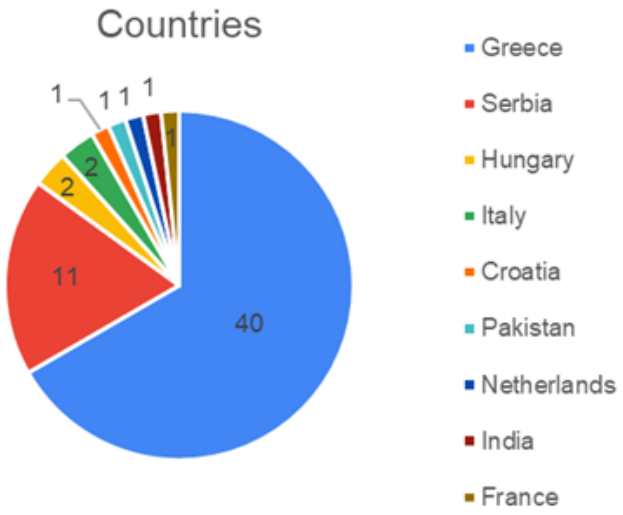

Figure 3.3: Country of origin of the participants of the current study

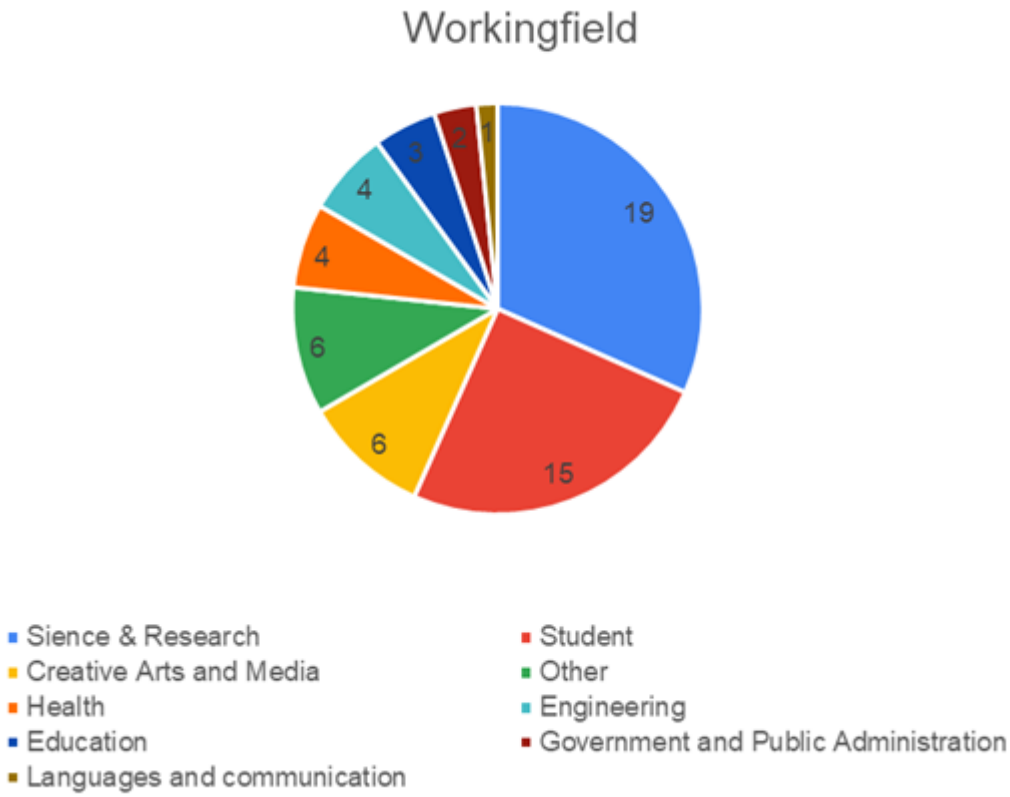

Figure 3.4: Working field of the participants of the current study

ANNEX 4 – of the interviewee participants of the current study

Annex 4 below provides details on the semi-structured interviews conducted with academic experts from or working in SEE. All interviews were transcribed after obtaining approval.

Nr.	Country of origin (country of work)	Scientific field
1	Hungary (Serbia)	Biotechnology agriculture
2	Serbia	Physical geography & Hydrology
3	Serbia	Biotechnology & Agricultural Plant Science
4	Serbia	Natural/mathematical sciences - meteorology
5	Serbia	Hydrology
6	Serbia	Natural resources management
7	Hungary (Serbia)	GIS, remote sensing & hydrology
8	Serbia	Hydrology
9	Greece	Atmospheric physics & regional climate modelling