TÜBİTAK

UNIfied framework to cope with droughts under MEDiterranean climate change conditions (UNIMED)

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FOREWORD

Our project entitled “UNIfied framework to cope with droughts under MEDiterranean climate change conditions” (UNIMED), which has been accepted for funding by the bilateral call between TUBITAK and Xjenza Malta (former MCST) had a consortium that consisted of Dokuz Eylul University, Türkiye, Integrated Resources Management (IRMCo Co Ltd.), Malta, and Malta College of Arts, Science and Technology (MCAST). The project aimed for an integrated drought index that would not only consider physical, meteorological, and hydrological indicators, but also the socio-economic and environmental indicators for a holistic approach to the fight against drought. The developed index entitled “Survivability of Droughts Index” (SDI) is not a mere combination of any defined indicators, furtherly, SDI has a structure consisting of 4 main sub-indices: Perception, Adaptability, Vulnerability, and Recoverability. Each of the sub-indices is represented by a weighted combination of socio-economic, environmental, and water indicators. The weighting and normalization of the indicators that compose the SDI have been decided by the expert opinions and stakeholder surveys, namely, farmers. temporal and spatial maps of drought survivability, which reflect the capacity of agricultural communities to withstand drought conditions economically and to sustain agricultural activities. To assess the consistency and robustness of the index over time, SDI maps were also produced for a comparatively wet year (1982) and a notably dry period (1991–1992). The outcomes of the project, particularly the SDI, present significant potential for a wide range of end-users. These include individual farmers—who can utilize the index to assess drought risk on their own agricultural plots—as well as governmental agencies and policy-makers, who may employ the index to identify drought-prone areas within the river basin, prioritize investment decisions, and implement preventative measures to mitigate the impacts of future drought events.

TÜBİTAK

CONTENTS

FOREWORD i
CONTENTS ii
LIST OF FIGURES iii
LIST OF TABLES v
ABSTRACT vi
ÖZ vii
1. INTRODUCTION 1
2. LITERATURE REVIEW 3
3. MATERIALS AND METHODS 6
3.1. Study Areas 6
3.1.1. Gediz River Basin, Türkiye 6
3.1.2. Malta 7
3.2. Methods 8
3.2.1. Quantitative Framework 9
3.2.2. Qualitative Assessment 27
4. FINDINGS 33
4.1. Quantitative Findings 33
4.1.1. SDI Findings of Türkiye 33
4.1.2. SDI Findings of Malta 42
4.1.3. Historical Trend Analysis Findings 60
4.2. Qualitative Findings 76
5. DISCUSSION 78
6. CONCLUSIONS AND RECOMMENDATIONS 80

TÜBİTAK

LIST OF FIGURES

Figure 1. Gediz River Basin 6
Figure 2. Island of Malta 7
Figure 3. Flowchart of indicators and sub-indices of SDI 14
Figure 4. Sub-indices weighting survey 21
Figure 5. Adaptability sub-index weighting survey 22
Figure 6. Vulnerability sub-index weighting survey 23
Figure 7. Recoverability sub-index weighting survey 24
Figure 8. VAP survey 28
Figure 9. VAP Survey introduction to the members of Gölmarmara Chamber of Agriculture in the first Turkish CoP meeting (28 July 2023) 30
Figure 10. A photo from the second CoP workshop of the Turkish pilot (5 April 2024) 30
Figure 11. A photo from the third CoP workshop organized as knowledge transfer & training event together with IRMCo and MCAST teams (4 December 2024) .. 30
Figure 12.Empty canvas 31
Figure 13. A graphical representation of the canvas 32
Figure 14. Calculated weighted values of Vulnerability sub-index indicators for the periods of 1991-1992, 1982, and 2023 for Türkiye. 39
Figure 15. Calculated weighted values of Adaptability sub-index indicators for the periods of 1991-1992, 1982, and 2023 for Türkiye. 40
Figure 16. Calculated weighted values of Recoverability sub-index indicators for the periods of 1991-1992, 1982, and 2023 for Türkiye. 40
Figure 17. Calculated weighted values of SDI sub-indices for the periods of 1991-1992, 1982, and 2023 for Türkiye. 41
Figure 18. Generated Gediz River Basin SDI map of 2023 41
Figure 19. Calculated weighted values of Vulnerability sub-index indicators for the periods of 2000, 2010, and 2020 for Malta. 57
Figure 20. Calculated weighted values of Adaptability sub-index indicators for the periods of 2000, 2010, and 2020 for Malta. 58
Figure 21. Calculated weighted values of Recoverability sub-index indicators for the periods of 2000, 2010, and 2020 for Malta. 58
Figure 22. Calculated weighted values of SDI sub-indices for the periods of 2000, 2010, and 2020 for Malta. 59
Figure 23. Generated Malta SDI map of 2020 60
Figure 24. Correlation between the % change in annual rainfall and % change in rainfall during the most pluvial season. 62
Figure 25. Percentage (%) change in annual rainfall over period of analysis 62
Figure 26. Percentage (%) in rainfall during most pluvial season over period of analysis 63
Figure 27. Droughts at 3-month time scale observed in Luqa, Malta (MT-1) 65
Figure 28. Droughts at 3-month time scale observed (from left) in Marseille-Marignane (FR-1), Nice (FR-2), and Perpignan (FR-3) 66
Figure 29. Droughts at 3-month time scale observed (from left) in Vallombrosa, Italy (IT-4), Barcelona (ES-1) and Valencia (ES-3), Spain 66
Figure 30. Droughts at 3-month time scale observed in Venice, Italy (IT-5) 67
Figure 31. Droughts at 3- and 6-month time scale observed in Venice, Italy (IT-5)The average of the SPI outcomes at the 3- and 6-month time scales for the 18 stations included in the present analysis are presented in Table 32. 68
Figure 32. Drought Magnitude vs Return Period 71
Figure 33. Drought Duration vs Return Period 72
Figure 34. Attendees giving their feedback on the asked questions through the provided self-adhesive stickers 76
Figure 35. Final versions of the canvases of the two working groups 77

Figure 36. Outcomes of systems mapping exercise of the two groups of attendees in the 2nd CoP event in Türkiye 77

TÜBİTAK

LIST OF TABLES

Table 1. Initial Indicator List of Perception Index 9
Table 2. Initial Indicator List of Vulnerability Index 10
Table 3. Initial Indicator List of Adaptability Index 10
Table 4. Initial Indicator List of Recoverability Index 11
Table 5. Final Indicator List of Perception Index 12
Table 6. Final Indicator List of Vulnerability Index 12
Table 7. Final Indicator List of Adaptability Index 13
Table 8. Final Indicator List of Recoverability Index 13
Table 9. Metadata of rainfall stations 26
Table 10. Weights of the selected indicators 33
Table 11. Calculated values of indicators, sub-indices, and the SDI for the baseline year of 2023 36
Table 12. Turkish indicator values revised for previous periods 38
Table 13. Calculated values of Vulnerability indicators for the baseline year of 2020 43
Table 14. Calculated values of Adaptability indicators for the baseline year of 2020 44
Table 15. Calculated values of Recoverability indicators for the baseline year of 2020 45
Table 16. Calculated value of Perception indicator for the baseline year of 2020 46
Table 17. Maltese indicator values revised for previous periods 47
Table 18. Calculated values of Vulnerability indicators for the baseline year of 2000 48
Table 19. Calculated values of Adaptability indicators for the baseline year of 2000 49
Table 20. Calculated values of Recoverability indicators for the baseline year of 2000 50
Table 21. Calculated value of Perception indicator for the baseline year of 2000 51
Table 22. Calculated values of Vulnerability indicators for the baseline year of 2010 52
Table 23. Calculated values of Adaptability indicators for the baseline year of 2010 53
Table 24. Calculated values of Recoverability indicators for the baseline year of 2010 54
Table 25. Calculated value of Perception indicator for the baseline year of 2010 55
Table 26. Calculated sub-index and SDI values for 2000 56
Table 27. Calculated sub-index and SDI values for 2010 56
Table 28. Calculated sub-index and SDI values for 2020 57
Table 29. Outcomes of historical trend analysis 61
Table 30. Outcome of historical trend analysis across all rainfall stations 61
Table 31. Variations observed in annual trend within the same catchments 63
Table 32. SPI outcomes at the 3- and 6-month time scales 64
Table 33. Average of SPI outcomes at the 3- and 6-month time scales 68
Table 34. SPI outcomes at the 12- and 24-month time scales 69
Table 35. Average of SPI outcomes at the 12- and 24-month time scales 69
Table 36. RDIstd classification 74
Table 37. Aridity Index classification 74
Table 38. Outcomes of aridity index calculations 75

ABSTRACT

The adverse effects of droughts have been a struggle for humanity from the early ages and still are a truly relevant problem. The efforts to understand, prevent, and mitigate the drought have motivated researchers to develop indicators, indices, and action plans for its management. The presented study suggests a novel index entitled Survivability of Droughts Index (SDI) to evaluate quantitative and qualitative indicators that represent the WEF Nexus system as well as the three pillars of sustainability: economic, social, and environmental aspects. The index consists of four main sub-indices, namely, perception, vulnerability, adaptability, and recoverability; each of which defines the stages when engaging with drought. The SDI encapsulates the economic survivability of the agricultural sector at the scale of a river basin, in the case of the Gediz River Basin, Türkiye. While the results of the study validate the historical droughts, it also indicates that survivability from droughts can be achieved by actions to improve the sub-indices of SDI. The overall framework of SDI demands various data and engagement with stakeholders, but the results represent a strong connection with the analyzed case study. The outcomes of the study are most beneficial to the decision-makers to detect and prioritize their measurements, such as new investments, insurance policies, etc., in drought-vulnerable areas within the analyzed extent.

Keywords: Drought index, risk assessment, WEF nexus, hydrologic modelling, water resources management

ÖZ

Kuraklığın olumsuz etkileri ilk çağlardan beri insanlığın önemli bir mücadelesi olmuş ve halen önemini koruyan bir sorundur. Kuraklığı anlama, önleme ve hafifletme çabaları, araştırmacıları kuraklığın yönetimine yönelik indikatörler, endeksler ve eylem planları geliştirmeye motive etmiştir. Sunulan proje raporunda, WEF Nexus sistemini temsil eden niceliksel ve niteliksel göstergelerin yanı sıra sürdürülebilirliğin üç sütununu (ekonomi, sosyal ve çevresel yönler) değerlendirmek için Kuraklıktan Hayatta Kalma Endeksi (SDI) başlıklı yeni bir endeks önermektedir. Endeks algı, kırılganlık, uyarlanabilirlik ve kurtarılabilirlik olmak üzere 4 ana alt endeksten oluşuyor. Bunların her biri kuraklıkla mücadelenin aşamalarını tanımlamaktadır. SDI, Türkiye'deki Gediz Nehri Havzası örneğinde, tarım sektörünün ekonomik olarak sürdürülebilirliğini bir nehir havzası ölçeğinden özetlemektedir. Çalışmanın sonuçları tarihsel kuraklıkları doğrularken, aynı zamanda SDI alt endekslerinin iyileştirilmesiyle kuraklıktan kurtulmanın sağlanabileceğini de göstermektedir. SDI'nın genel çerçevesi çeşitli veriler ve paydaşların katılımını gerektirmektedir ancak sonuçlar, analiz edilen çalışma alanı ile güçlü bir bağlantıyı temsil etmektedir. Çalışmanın sonuçları, karar vericilerin, analiz edilen kapsamda kuraklığa karşı hassas alanlardaki yeni yatırımlar, sigorta politikaları gibi önlemleri tespit etmeleri ve önceliklendirmeleri açısından son derece faydalıdır.

Anahtar kelimeler: Kuraklık indeksi, risk değerlendirmesi, WEF bağı, hidrolojik modelleme, su kaynakları yönetimi

1. INTRODUCTION

Droughts are among the most devastating environmental hazards, historically affecting more people globally than any other natural disaster (Willhite, Svoboda, and Hayes, 2007). Their increasing frequency, intensity, and duration in recent decades—exacerbated by anthropogenic factors such as climate change, rapid urbanization, and unsustainable water use—have significantly heightened their socio-economic and environmental consequences, particularly in semi-arid regions such as the Mediterranean (Mishra and Singh, 2010). Despite the wide array of drought indices and definitions developed across disciplines (Willhite and Glantz, 1985; Goodrich and Ellis, 2006), cross-disciplinary integration remains limited (Kallis, 2008), posing challenges to formulating effective, comprehensive drought response strategies.

The UNIMED project, titled "UNIfied framework to cope with droughts under MEDiterranean climate change conditions", addresses this critical gap by developing a holistic, stakeholder-informed, indicator-based assessment framework that integrates the water, energy, food, and ecosystem (WEFE) Nexus. Central to this initiative is the development of the Survivability-of-Droughts Index (SDI), which quantifies drought survivability through four interrelated sub-indices: Perception, Vulnerability, Adaptability, and Recoverability. Each sub-index is underpinned by a unique set of social, economic, and environmental indicators, selected and validated through an iterative, participatory process involving Communities of Practice (CoP) in both Malta and Turkey.

The SDI framework aims not only to assess the biophysical impacts of droughts but also to capture the human dimension—perception and attitude toward droughts, institutional preparedness, community adaptability, and the agricultural sector’s capacity to recover economically. These dimensions reflect the stages of drought resilience and survivability, from early awareness to post-drought recovery. The index is grounded in both quantitative data and qualitative insights gathered through surveys and workshops, following the EIT Climate-KIC Challenge-Led System Mapping methodology.

This unified approach enables the identification of drought-vulnerable areas at river basin and national scales, the prioritization of targeted adaptation measures, and the formulation of evidence-based policy recommendations aligned with EU strategies such as the Green Deal, the Common Agricultural Policy, and the Farm to Fork Strategy. Moreover, by building on synergies with the EU-funded Mara-Mediterra project, UNIMED provides practical insights into agro-ecological practices that enhance farmers' capacity to cope with the impacts of droughts.

Ultimately, the SDI serves as a valuable decision-support tool for policymakers, practitioners, and stakeholders, offering a replicable model for drought resilience assessment in Mediterranean and other climate-vulnerable regions.

2. LITERATURE REVIEW

The phenomenon of drought has long captured the attention of both scientists and the public, owing to its widespread and enduring impacts on human societies. From antiquity, arid conditions have been recognized as critical environmental constraints, influencing socio-economic structures, food security, and cultural practices. Historical records, such as those inscribed on bones and tortoise shells in early Chinese civilizations, demonstrate how societies have traditionally sought to understand and respond to drought through early meteorological observations and rituals (Hong et al., 2001). Similar narratives, including the biblical account of Joseph's prediction of seven years of drought and the societal upheaval it caused, are echoed across diverse regions and time periods (Chipman, Avni, and Ellenblum, 2021).

Scientific research on drought has evolved significantly, moving from simple hydrological observations—such as river levels and precipitation records—to complex models and multi-parametric indices. Early studies largely focused on specific hydrological systems, such as river basins or national water supplies (Hurd et al., 1999; Pasini et al., 2012; Al-Saidi et al., 2016; Tatar and Eris, 2022; Volpi et al., 2024). These efforts gave rise to a suite of drought indices designed to monitor and quantify various dimensions of drought. Widely used indices include the Palmer Drought Severity Index (PDSI) (Palmer, 1965), Crop Moisture Index (CMI) (Palmer, 1968), Standardized Precipitation Index (SPI) (McKee et al., 1993), Reconnaissance Drought Index (RDI) (Tsakiris and Vangelis, 2005), and Standardized Precipitation Evapotranspiration Index (SPEI) (Vicente-Serrano et al., 2010; Beguería et al., 2014). These indices combine meteorological variables such as rainfall, temperature, and evapotranspiration to provide more nuanced insights into drought conditions.

Parallel to this hydrological and climatological approach, researchers have increasingly focused on drought-related vulnerability and resilience by integrating socio-economic and environmental indicators. Pioneering works by Gleick (1990), Raskin et al. (1997), and Lane et al. (1999) laid the groundwork for linking water scarcity with socio-economic vulnerability and adaptive capacity. Indicators such as the Water Poverty Index (Sullivan, 2002), Water Stress Index, and Adaptive Capacity Index (Pandey et al., 2011) expanded the analytical framework to

encompass aspects such as institutional capacity, economic resilience, and resource management challenges (Babel and Wahid, 2009; Huang and Cai, 2009; Gain et al., 2012).

Despite this proliferation of indices, scholars have emphasized the need for contextualized assessments that account for local environmental and socio-economic conditions. Comprehensive reviews (Heim, 2002; Keyantash and Dracup, 2002; Zargar et al., 2011; Mishra and Singh, 2010) have catalogued the strengths, limitations, and applicability of various drought indicators, underscoring the importance of selecting fit-for-purpose metrics. Moreover, drought impact monitoring has broadened in scope to include public health (Stanke et al., 2013), aquatic ecosystems (Matthews and Marsh-Matthews, 2003), water quality (Mosley, 2015), and broader socio-economic outcomes (Ding et al., 2011; Stahl et al., 2015).

In recent years, the integration of the Water-Energy-Food-Ecosystem (WEFE) Nexus into drought research has gained traction. This interdisciplinary approach emphasizes the interdependencies between resource systems and supports the development of more comprehensive assessment tools. Notable contributions include scenario modeling (Daher and Mohtar, 2015), diagnostic frameworks (Dargin et al., 2019), and Nexus-aligned indicators (Ferroukhi et al., 2015). However, there remains a critical gap in the literature concerning the fusion of quantitative indicators (e.g., yield loss, groundwater depletion) with qualitative insights (e.g., community perception, institutional response capacity).

Addressing this gap, the UNIMED project introduces an innovative methodological framework for assessing drought impacts under Mediterranean climate change conditions. The proposed Survivability-of-Droughts Index (SDI) distinguishes itself by incorporating four interlinked stages—Perception, Adaptability, Vulnerability, and Recoverability. Each stage is underpinned by a set of mutually exclusive socio-economic and environmental indicators, enabling a multi-dimensional evaluation of drought survivability at both local and regional scales. This structure supports the identification of critical vulnerabilities and facilitates targeted policy interventions.

The participatory design of the SDI, involving stakeholders across the agricultural, policy, and civil society sectors, represents a further advancement. It ensures that the index reflects not only empirical data but also local experiences and adaptive practices, enhancing its utility for decision-makers. In this way, the SDI contributes meaningfully to both academic discourse and practical drought management strategies.

In sum, while existing research has provided a strong foundation for understanding the dynamics of drought, the integration of indicator-based quantitative assessments with stakeholder-driven qualitative insights remains underdeveloped. UNIMED's approach to bridging this gap reinforces the importance of holistic, context-sensitive frameworks for enhancing drought resilience, particularly in vulnerable Mediterranean agricultural communities.

3. MATERIALS AND METHODS

3.1. Study Areas

3.1.1. Gediz River Basin, Türkiye

Gediz River Basin, located in Western Türkiye, has a total drainage area of 17034 km^2(Figure 1). The basin is named after its main river Gediz with its 350 km length. The Gediz River has several tributaries, many of which are dry in summer (Aksoy, 2020). The Marmara, Karagol, Golcuk, and Sazli are the lakes, and Demirkopru, Avsar, and Buldan are the main dams of the basin. The basin has around 578.5 mm of average annual precipitation and has significant importance in the agricultural production of Türkiye.

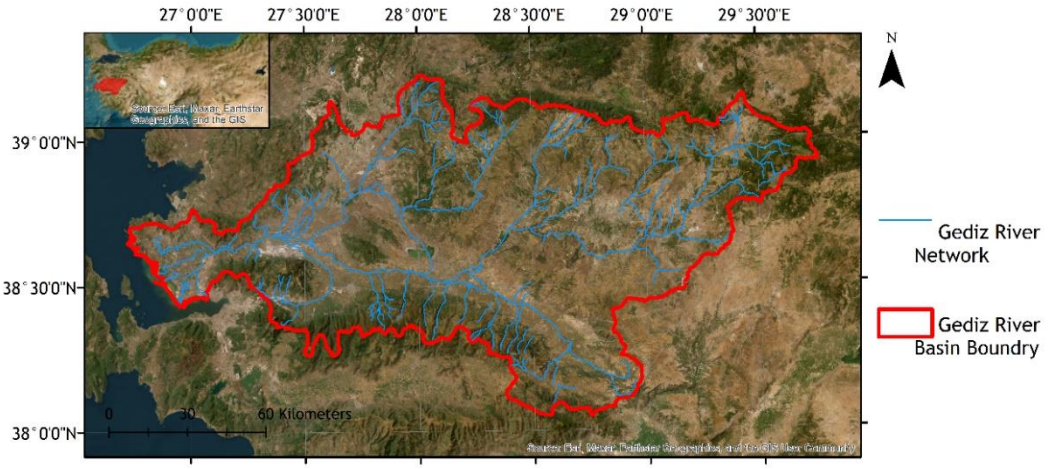

Figure 1. Gediz River Basin

In the 1990s, due to population growth, industrial development, and the climate change effects, the water resources of the basin declined and deteriorated substantially. As a result, the downstream end of the basin, Menemen Plain, is suffering from low water quality and quantity at a notable level. Due to low surface water, the farmers depend heavily on the groundwater resources, hence the groundwater levels decrease, and the seawater intrusion and the soil salinity are experienced often.

On the other hand, investments such as Gordes Dam, which couldn't perform its planned purposes due to leakage losses both in the dam lake and on its

conveyance route to Lake Marmara through Kumcay, have caused one of the major water resources of Gediz River Basin and a wetland of national importance, Lake Marmara to dry completely. Once a hotspot with high social, economic, and environmental assets, Lake Marmara is now struggling for its existence.

Consequently, with one of the major irrigation water resources of Gediz River Basin, the Lake Marmara, was also supplying Menemen Plain for irrigation, its drying condition also affected irrigation sites in Menemen. Thus, Menemen has started to experience water scarcity and vulnerability to drought more than ever. Hence, the Lake Marmara became the case study of this project. The local stakeholders of Menemen Plain and Lake Marmara have played an important role by sharing their opinions and feedback on the qualitative parts of the study.

3.1.2. Malta

The Maltese Islands, located in the central Mediterranean Sea, comprise an archipelago with a total land area of approximately 316 km² (Figure 2). Malta, the largest island, is characterized by its semi-arid climate and highly variable rainfall patterns, with an average annual precipitation of around 550 mm. Given its geographic isolation and absence of surface water bodies such as permanent rivers or lakes, Malta relies heavily on a combination of groundwater extraction and non-conventional water resources, including desalinated water and treated wastewater, to meet its agricultural and domestic needs.

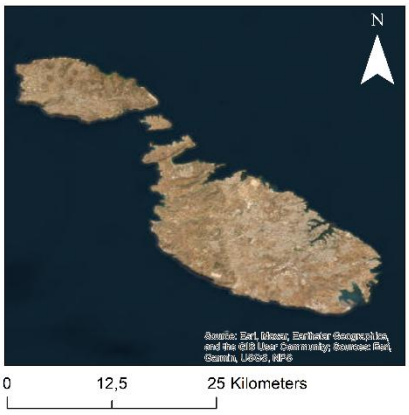

Figure 2. Island of Malta

The agricultural sector in Malta, although limited in scale, holds significant cultural and socio-economic value. Agricultural areas are mostly concentrated in the north-western and central regions of the island, where traditional rain-fed and irrigated farming practices are still maintained. However, due to increasing water demand, urbanization, and the effects of climate change, groundwater over-extraction has become a growing concern, leading to declining water tables, seawater intrusion, and deteriorating water quality, particularly in coastal aquifers.

Among the critical agricultural zones, the rural areas surrounding Rabat and Dingli represent key locations where water stress is particularly pronounced. These zones have been selected as focal points in this study due to their vulnerability to drought and reliance on groundwater for irrigation. Farmers in these regions have been increasingly exposed to the dual pressures of climate variability and resource limitations, which challenge their capacity to sustain agricultural productivity.

Moreover, water policy and governance in Malta have undergone significant transformation in recent years, especially in alignment with EU directives such as the Water Framework Directive and the Common Agricultural Policy. Despite institutional efforts to promote water-use efficiency and encourage the uptake of treated wastewater for irrigation, local stakeholders often face barriers related to infrastructure, financial viability, and public perception.

As part of this research, key stakeholders from Malta's farming community, particularly members of the Young Farmers Association and students at the Malta College of Arts, Science and Technology (MCAST), were actively engaged. Their insights and lived experiences formed an essential component of the study's qualitative methodology, contributing to a more nuanced understanding of water scarcity and drought survivability within Malta's specific socio-environmental context.

3.2. Methods

The methodology employed in the UNIMED project is based on a mixed-methods approach that combines quantitative and qualitative techniques to develop and validate the Survivability-of-Droughts Index (SDI). This index serves as an integrated tool to assess the capacity of agricultural systems to perceive, adapt to,

endure, and recover from droughts under Mediterranean climate change conditions.

3.2.1. Quantitative Framework

The quantitative component of the methodology is rooted in the identification and structuring of indicators across four drought-related domains: Perception, Vulnerability, Adaptability, and Recoverability. Each domain is represented by a mutually exclusive set of economic, social, and environmental indicators. The development process included:

Indicator Selection and Expansion: Initial core indicators were expanded through literature review and feedback gathered during the first round of Community of Practice (CoP) workshops held in Türkiye and Malta (Table 1-4). Stakeholders scrutinized the indicators for data availability and relevance, ensuring no overlap to avoid double-counting, yielding the final list of indicators (Table 5-8).

Table 1. Initial Indicator List of Perception Index

No.	Indicator Name	Nexus Aspect	Definition	Methodology	Unit
P-1	***Perception***	Social	Represents how droughts (in terms of severity) are perceived among the agricultural community	Survey data	'

Table 2. Initial Indicator List of Vulnerability Index

No.	Indicator Name	Nexus Aspect	Definition	Methodology	Unit
V-1	Water Exploitation Index	Economic, Social, Environment	Mean annual total demand for surface/ground water divided by the long-term average surface/ground water resources in the pilot study area	Index (Total freshwater withdrawal in pilot study area / Total available freshwater resource in pilot study area)	-
V-2	Water dependency for food production	Economic, Social, Environment	Total amount of water allocated to food production in agriculture	Observed data	m^3/ha
V-3	Total population density	Economic, Social, Environment	Total population residing in the pilot study area	Observed data	Cap/km^2
V-4	Shannon diversity Index	Environment	Measurement of the diversity of species	Observed data	No.
V-	Benefit to cost ratio	Economic, Social	Average agricultural land benefit to cost ratio	Observed data	%
V-6	Drought Risk	Economic, Social, Environment	Average drought risk of the study area according to Standard Precipitation Index (SPI)	Analysis of observed monthly rainfall data	%

Table 3. Initial Indicator List of Adaptability Index

No.	Indicator Name	Nexus Domain	Definition	Methodology	Unit
A-1	***Attitude***	Social	Extent to which the farming community has adopted measures to mitigate the impact of drought	Survey data	-
A-2	Formal & informal training	Social	Number of events dedicated to training and practical learning on how to adapt to droughts in the agricultural sector	Observed Data, (Survey Data in UNIMED)	-
A-3	Seed variety	Environment	Total number of seed variety cultivated (Cultivating various seeds promotes the biodiversity and ecosystem resilience)	Observed Data	No.
A-4	Rainwater harvesting rate	Economy, Environment	Rate of irrigation water sourced by rainwater harvesting to total amount of water allocated to irrigation	Observed Data	%
A-5	Access to market	Economy, Social	Share of farmers conducting business in local/national/international markets	Observed Data	%

Table 4. Initial Indicator List of Recoverability Index

No.	Indicator Name	Nexus Domain	Definition	Methodology	Unit
R-1	Diversity of source of income	Economy	Number of income sources independent of agricultural activity (termed as ***Value*** in Survey)	Observed Data, (Survey Data in UNIMED)	No.
R-2	Average crop yield	Economy, Environment	Total yield divided by the surface area dedicated to crop production	Observed Data	kg/ha
R-3	Access to credits	Economy, Social	Percentage of agricultural community benefiting from credits	Observed Data	%
R-4	Access to subsidies	Economy, Social	Percentage of agricultural community benefiting from subsidies	Observed Data	%
R-5	Access to relief	Economy, Social	Percentage of agricultural community benefiting from relief funds after a drought	Observed Data	%
R-6	Soil fertility	Environment	Soil fertility promotes ecosystem services, lower irrigation dependence and higher food production	Observed Data: Soil organic matter, soil organic carbon and macronutrients, e.g. (N, P, K)	mg/kg

Table 5. Final Indicator List of Perception Index

	Indicator Name	Definition	Methodology	Unit	Source
Perception	**Perception**	Represents how droughts (in terms of severity) are perceived among the agricultural community	Calculated Data	%	VAP Survey

Table 6. Final Indicator List of Vulnerability Index

	Indicator Name	Definition	Methodology	Unit	Source
Vulnerability	**Supply/Demand Ratio**	The total water supply allocated to demand sites in the analyzed extent divided by the demand for freshwater and/or groundwater resources	Calculated Data	%	Farmers, Water Users Association database
	Water dependency for food production	Total monthly amount of water allocated to food producing agricultural irrigation	Observed Data	m^3/month	Farmers
	Rate of people working in agriculture	Total population of people working in agriculture sector over the total population in the case study area	Observed Data	%	Municipality database
	Species diversity within defined area	Shannon Diversity Index of the pilot study area to measure the diversity of species	Observed Data	Number	Municipality database
	Benefit to cost ratio	Average agricultural land benefit to cost ratio	Calculated Data	%	Farmers
	Drought Risk	Average drought risk of the study area according to Standard Precipitation Index	Calculated Data	%	Meteorological station data

Table 7. Final Indicator List of Adaptability Index

	Indicator Name	Definition	Methodology	Unit	Source
Adaptability	**Attitude**	Extent to which the farming community has adopted measures to mitigate the impact of drought	Calculated	%	VAP Survey
	Formal & informal training	Number of events dedicated to training and practical learning on how to adapt to droughts in the agricultural sector	Observed Data	Number	VAP Survey
	Seed variety	Whether the cultivated crop varieties have more drought-durable alternatives	Observed Data	Yes/No	VAP Survey
	Rainwater harvesting rate	Rate of irrigation water sourced by rainwater harvesting to total amount of water allocated to irrigation	Calculated Data	%	VAP Survey
	Access to market	Percentage of farmers that have access to local/ national/ international markets	Calculated Data	%	Farmers

Table 8. Final Indicator List of Recoverability Index

	Indicator Name	Definition	Methodology	Unit	Source
Recoverability	**Diversity of source of income**	Percentage of income sources independent of agricultural activity (termed as ***Value*** in Survey)	Calculated Data	%	Farmers
	Average crop yield	Total yield divided by the surface area dedicated to crop production	Calculated Data	%	Farmers
	Access to credits	Percentage of the agricultural community benefiting from credits	Calculated Data	%	Farmers
	Access to subsidies	Percentage of the agricultural community benefiting from subsidies	Calculated Data	%	Farmers
	Access to relief	Percentage of the agricultural community benefiting from relief funds after a drought	Calculated Data	%	Farmers
	Soil fertility	Soil fertility promotes ecosystem services, lower irrigation dependence, and higher food production (Soil Organic Carbon Content (SOC) will be observed)	Observed Data	Mg/ha	UTAEM[1]

The Survivability of Drought Index is heavily dependent on the indicators that represent the complex Nexus that defines the drought. Thus, the selection of the indicators is a crucial step in the assessment of the SDI (Figure 3). In the following sub-sections, the definition each sub-index and indicator and their relation to the SDI have been presented.

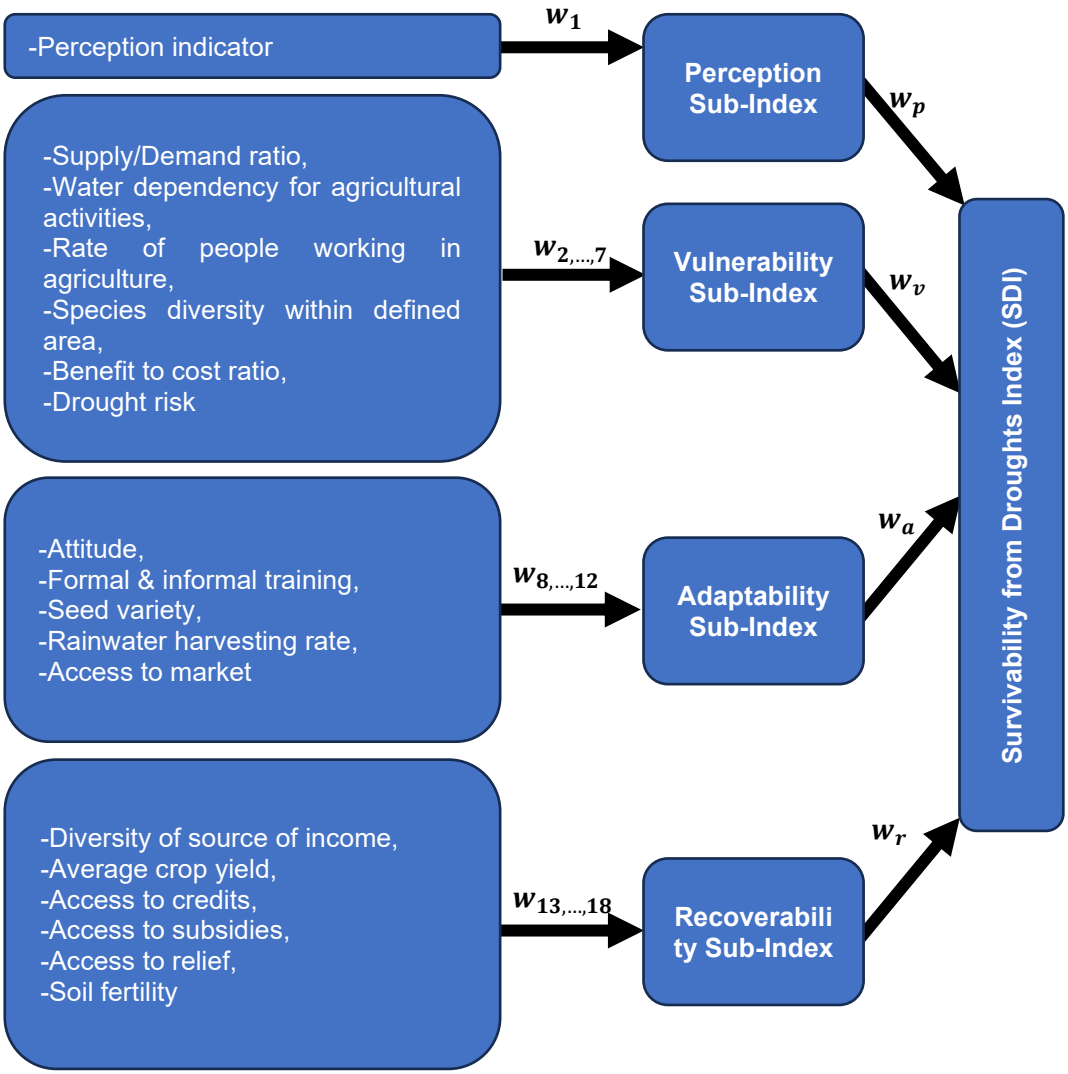

Figure 3. Flowchart of indicators and sub-indices of SDI

- **Perception:** The perception sub-index was determined according to the VAP survey feedback, which included questions to measure the farmers' perception towards the drought. The attendees rate the questions according to their agreement on the given statement between 1 to 5, 1, indicating high agreement and 5, high disagreement. The average value of the feedback is normalized according to the min-max transformation. It is an essential qualitative indicator representing the awareness of the agricultural community towards the drought, how they evaluate themselves

in knowledge-, preparedness-, and resilience-wise. Being aware of the problem is an important step to overcome it. This defines how one avoids, defends, or receives the oncoming threats. The perception indicator integrates social parameters to the SDI. It informs about the priority of challenges that the community faces and how they cope with drought.

- **Vulnerability:** The vulnerability to drought is expressed by various definitions as also stated in the Chapter Two, and it can be summarized as the measured degree of susceptibility to a specific hazard. Thus, the vulnerability can be measured by various indicators. In the case of Gediz River Basin, listed indicators below have been selected according to the data availability other than their strong relevance to the concept of vulnerability. A total of six indicators have been selected to represent the vulnerability sub-index as given below:

- **The supply/demand ratio:** It is a commonly used indicator that takes into account of all agricultural abstractions. This indicator is calculated as the total water supply allocated to agricultural demand sites in the analyzed extent divided by the agricultural demand for freshwater and/or groundwater resources. The calculated value is expressed as a percentage between 0-100, hence no normalization process was needed.

- **The water dependency for food production indicator:** This indicator is selected for the further representation of the agricultural sector needs. Calculated as the abstracted water for agriculture over the long-term maximum value of available water for agriculture sector, the water dependency for food production represents the water and the food aspects of the WEF Nexus. The calculated value is expressed as a percentage between 0-100, hence no normalization process was needed.

- **The rate of people working in agriculture:** The social aspect of the three pillars of sustainability is represented by this indicator. The value for this indicator is collected from the national statistical institution for the pilot area as a percentage, therefore the value was not normalized. A higher rate of

people working in agriculture indicates its profitability and its influence on society and policies.

- **Species diversity within the defined area:** This indicator is an ecosystem (WEFE) and an environment indicator which is determined by the Shannon Diversity Index (H) (Shannon, 1948).

$$H = -\sum_s p_s \times \log(p_s) \quad (1)$$

where, "p_s" is the population of species "s" in the sample. The calculated value of H is then normalized to the "H_{max}" value, which is defined as the logarithm of the total number of species in the sample. The index represents the diversity of species by combining two quantitative measures: the species richness (number of species within the community) and the equitability of species (how even are the numbers of individual species). The indicator also informs about the habitat quality such as effects of pollution effluents.

- **Benefit to cost ratio:** It is a very essential indicator that represents the economic aspect of the system. The value for this indicator calculated as the total benefits over the total costs for agriculture sector. The calculated value is then normalized according to the min-max values observed in the long-term. A higher value of benefit to cost ratio indicates the financial resources of the community to overcome the adverse effects of drought.

- **Drought risk:** This indicator is calculated according to the adapted Kaplan-Meier Estimator method (Cetinkaya and Gunacti, 2024) and is a direct measure indicating the vulnerability of the agricultural community. As the drought risk increases, the community becomes more vulnerable to oncoming droughts.

- **Adaptability:** The preparedness efforts against the effects of drought and available alternative options to current practices capsulates the adaptability sub-index. Adapting to the oncoming drought demands that the members of agricultural community to adopt the mindset that drought is a reality and

the measures to mitigate its effects are essential. According to the data availability, the following indicators are selected in the case of Gediz River Basin to represent its adaptability sub-index. A total of five indicators have been selected for this sub-indicator as presented below:

- **The Attitude:** This indicator summarizes and measures the extent of agricultural community's mindset against the adverse impacts of oncoming droughts and the social aspect of sustainability. The indicator is measured through the "Attitude" section questions of VAP survey (Appendix 3) feedback. The calculated average value of the survey feedback is then normalized according to the min-max transformation.

- **Formal and informal trainings:** The number of events organized by the governmental/institutional/NGO bodies to raise awareness (less water consumption, biodiversity, environmental needs, etc.), build capacity of/educate (new irrigation system technologies, drought resistant seed varieties, Nature Based Solution applications, etc.) the agricultural community and the social aspect of sustainability is represented by this indicator. The total number of events is then normalized according to the maximum value of 12 representing an event each month of the year.

- **The seed variety:** This indicator informs about the availability of drought resistant seed varieties known to the agricultural community and food domain of WEFE. The farmers responding to the first data survey expressed their knowledge of such options. The average value of the feedback to this question (Yes:1, No:0) ranges between 0-1, hence no normalization process was needed.

- **The rainwater harvesting rate:** The alternative source of water and the water domain of WEFE is represented by this indicator. Since other forms of alternative water sources are much more unpopular in the Gediz River Basin, the rainwater harvest rate was measured. This indicator can be replaced by other alternative water sources in other case studies. The value for this indicator was collected in the data survey and since it represents a percentage, normalization step was not needed.

- **Access to market:** The available economic platform alternatives that the agricultural community have is represented by this indicator. It also represents the economy, social and food domains. The indicator is measured by the data survey as a Yes/No question. Since the calculated value ranges between 0-1, normalization process was not needed.

- **Recoverability:** The recoverability sub-index expresses the sources that agricultural community has to minimize the effects of drought in its aftermath. While the income from agriculture might be hindered after a drought, the alternative sources of income would help the community to persevere through this hardship. Postponing the economic losses by credits, supplying relief funds or subsidies are also alternatives to increase the recoverability of the agricultural community. The following six indicators are selected in the case of Gediz River Basin to represent its recoverability sub-index.

- **The diversity of source of income:** This indicator represents the number of income sources independent of the agricultural activities, which increases the recoverability of the community in times of drought where the livelihood acquired from this source might be decreased. This indicator has been measured by the first data survey and VAP survey as a Yes/No question. No normalization process was needed since the calculated average response ranges between 0-1.

- **The average crop yield:** This indicator shows the average crop yield that the agricultural community acquires, represents a magnitude of the drought, and an indicator of recoverability where a high value informs that even through the economic losses, financial survivability might be achieved after all. Since an average value for all the cultivated crops would be an erroneous representation, the dominant crop (grape in the case of Gediz River Basin) cultivated in the analyzed extent has been selected to represent for this indicator. The average yield has been normalized according to the long-term min-max values observed.

- **Access to credits:** It is determined according to the data survey feedback where the farmers asked if they taken credit in the last two years, or not. This indicator represents the economic source availability of the analyzed extent to supply the agricultural community. The calculated average response ranges between 0-1 and needs no normalization process.

- **Access to subsidies:** This indicator represents the local/central governmental policies to support and guide the agricultural community to lower their economic stress and to encourage good agricultural practices. The indicator is calculated according to the data survey responses of the farmers (Yes/No). The results range between 0-1 and needs no normalization process.

- **Access to relief:** This indicator considers the relief funds or insurances that governmental or private sector bodies supply to the agricultural community in a case of economic losses due to a drought event. The indicator is calculated according to the data survey responses of the farmers if they benefited from relief funds or not (Yes/No). The results range between 0-1 and needs no normalization process.

- **The soil fertility:** This indicator is represented by Soil Organic Carbon (SoC) content in the study area for the 2-meter depth profile. The soil fertility promotes ecosystem services, lower irrigation dependence and higher food production. The value for this indicator is determined according to soilgrids database outputs for the extent of Gediz River Basin. The calculated value represents the SoC percentage, hence no normalization process is applied.

Data Sources: Quantitative data were primarily obtained from institutional sources, including the State Hydraulic Works (DSI), Ministry of Agriculture and Forestry (MoAF), the Turkish Statistical Institute (TUIK), and equivalent Maltese agencies. These data were complemented with survey results from farmers, focusing on both measurable parameters (e.g., training exposure, income diversity) and perceptual insights (e.g., severity of drought impacts).

Normalization: A portion of the defined indicators that make up the SDI are the quantitative and qualitative data that have been collected from the farmers such as their perception of drought, their benefit/cost ratio, etc. In order to normalize the data, min–max normalization (range transformation) has been applied according to the equation below,

$$X_i' = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (2)$$

Where X_i represents the i-th value of the respective time series, X_{min} is the minimum value of the timeseries, X_{max} is the maximum value of the timeseries and the X_i' is the normalized value of X_i.

Also, the defined indicators must be weighted in order to calculate the SDI. A survey among the CoP members has been conducted to collect their expert opinions.

Weighting: The budget point allocation method has been chosen as the weighting method. The process of budget point allocation, also known as fixed point allocation, demands the decision-maker to assign relative weights to various criteria by weighing their relative relevance (Gendreau et al., 2019). According to Doyle et al. (1997), the user must allocate a certain budget of points - *typically 100 points because this number is the most easily normalized* - among a set of criteria; thus, the decision-maker can only increase the weight of one criterion by decreasing the weight of another in this way. Since it might be challenging to immediately link one's choices to a numerical number, assigning points can be a cognitively taxing exercise for the decision-maker, where the decision-maker is forced to decide through a holistic way instead of bilateral comparisons (Collewet and Koster, 2023).

In the case of the weighting survey that was conducted in the second CoP meeting, the total points to allocate have been altered in order to: (i) force the survey attendees to avoid allocating equal weights to each indicator/sub-index, (ii) simplify the total points allocated. Usually, the survey attendees tend to give equal weight to the concepts. Each survey section has been designed to have 2 times the amount of concepts plus two points to overcome an equal-weighted result. Hence, the sub-index weighting section which has 4 sub-indices has 10 points to allocate, while the sections where indicators of adaptability, vulnerability, and recoverability

have 12, 14, and 14 points, respectively (Figure 4-7). Since the perception sub-index has only one indicator, no weight assignment was required.

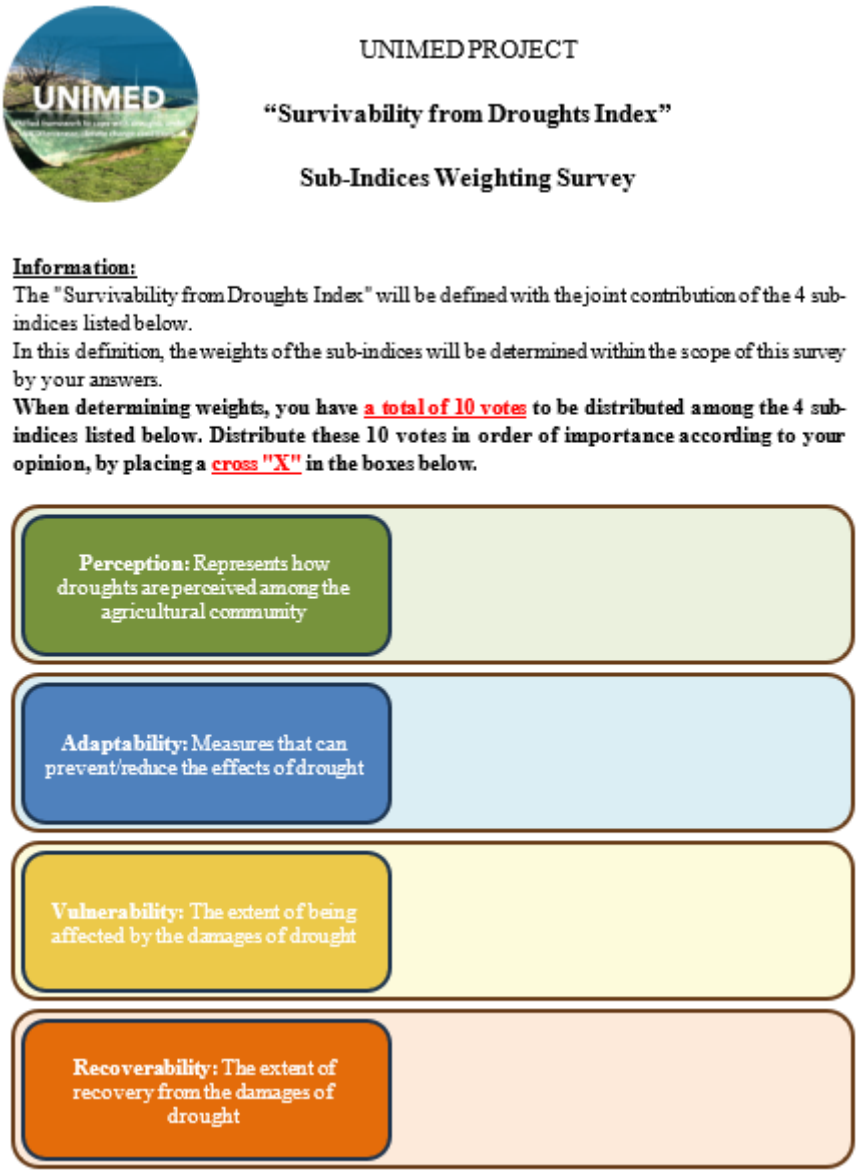

Figure 4. Sub-indices weighting survey

TÜBİTAK



UNIMED PROJECT

"Adaptability"

Sub-Indices Weighting Survey

Information:
You have a total of 12 votes to be distributed among the 5 sub-indices listed below.

Adaptability: Measures that can prevent/reduce the effects of drought

Attitude: Extent to which the farming community has adopted measures to mitigate the impact of drought

Formal & informal training: Number of events dedicated to training and practical learning on how to adapt to droughts in the agricultural sector

Seed variety: Whether the cultivated crop varieties have more drought-durable alternatives

Rainwater harvesting rate: Rate of irrigation water sourced by rainwater harvesting to total amount of water allocated to irrigation

Access to market: Percentage of farmers that have access to local/ national/ international markets

Figure 5. Adaptability sub-index weighting survey



UNIMED PROJECT

"Vulnerability"

Sub-Indices Weighting Survey

Information:
You have a total of 14 votes to be distributed among the 6 sub-indices listed below.

Vulnerability: The extent of being affected by the damages of drought

Supply/Demand Ratio: The total water supply allocated to demand sites in the analyzed extent divided by the demand for freshwater and/or groundwater resources

Water dependency for food production: Total monthly amount of water allocated to food producing agricultural irrigation

Rate of people working in agriculture: Total population of people working in agriculture sector over the total population in the case study area

Species diversity within defined area: Shannon Diversity Index of the pilot study area to measure the diversity of species

Benefit to cost ratio: Average agricultural land benefit to cost ratio

Drought Risk: Average drought risk of the study area according to Standard Precipitation Index

Figure 6. Vulnerability sub-index weighting survey



Figure 7. Recoverability sub-index weighting survey

Validation and Comparison: The SDI and its underlying indices were validated through expert consultation and stakeholder feedback in the third CoP workshops. Additionally, the results were compared against relative wet and dry periods if SDI results were related with historical data. Moreover, historical analysis of drought events was also performed for further validation of the persistent droughts observed in the study areas.

Historical Analysis: As part of the validation process, a historical analysis of drought events was performed using long-term meteorological data (e.g., rainfall

records from Menemen and Luqa stations). In this joint effort, IRMCo and DEU has conducted the calculation of SPI values for 35 stations across the Mediterranean (Table 9), which is a major accomplishment, since the original goal according to the Grant Agreement was to analyse Maltese and Turkish study areas only. Within the second reporting period, the analysis of,

i) Historical trend analysis of monthly rainfall (1960 – 2020),

ii) Comparison of frequency, duration and magnitude of short- and long-term drought events: 1960-1990 vs 1990-2020, based on Standard Precipitation Index (SPI),

iii) Duration, Magnitude vs Return Period relationship based on Gumbel Extreme Value distribution,

iv) Comparison of outcomes of SPI and RDI (which requires Rainfall and Temperature) completed for Malta and 4 other meteorological stations, leading to historical trend analysis of the Aridity Index (AI), has been completed.

Table 9. Metadata of rainfall stations

Station No.	Station name	River basin, Island	Country	Code	Start date of analysed record	End date of analysed record
1	Bouira Coligny	Soummam	Algeria	ALG-1	1.10.1969	30.09.2010
2	Chouly	Tafna	Algeria	ALG-2	1.10.1968	30.09.2013
3	Deux Bassins	Oued El Hamiz	Algeria	ALG-3	1.10.1969	30.09.2020
4	Meurbah	Tafna	Algeria	ALG-4	1.10.1968	30.09.2021
5	Ouled Ali	Oued El Hamiz	Algeria	ALG-5	1.10.1973	30.09.2012
6	Ouled Mimoun	Tafna	Algeria	ALG-6	1.10.1979	30.09.2012
7	Reghaia	Oued El Hamiz	Algeria	ALG-7	1.10.1973	30.09.2020
8	Sidi Bounakhla	Tafna	Algeria	ALG-8	1.10.1973	30.09.2013
9	Touamine	Oued El Hamiz	Algeria	ALG-9	1.10.1978	30.09.2012
10	Athalassa	Pedieos, Cyprus	Cyprus	CY-1	01/01/1960	30.09.2020
11	Larnaca	Cyprus	Cyprus	CY-2	01/10/1960	30/09/2020
12	Troodos Square	Pedieos, Cyprus	Cyprus	CY-3	1.10.1960	30.09.2020
13	Marseille-Marignane	Rhône	France	FR-1	1.10.1960	30.09.2020
14	Nice	Paillon	France	FR-2	1.10.1960	30.09.2020
15	Perpignan	Têt	France	FR-3	1.10.1960	30.09.2020
16	Larissa	Pinios	Greece	GR-2	01/10/1960	30/09/2007
17	Alghero	Cuga, Sardinia	Italy	IT-1	1.10.1960	30.09.2020
18	Civitavecchia	Tevere	Italy	IT-2	1.10.1961	30.09.2016
19	Peretola	Arno	Italy	IT-3	1.10.1960	30.09.2020
20	Vallombrosa	Arno	Italy	IT-4	1.10.1960	30.09.2020
21	Venezia	Po	Italy	IT-5	1.10.1961	30.09.2020
22	American University of Beirut		Lebanon	LB-1A	01/10/1960	30/09/2020
23	Ksara	Bekaa	Lebanon	LB-2A	01/10/1960	30/09/2017
24	Luqa	Wied il-Kbir, Malta	Malta	MT-1	1.10.1960	30.09.2020
25	Barcelona	Llobregat	Spain	SP-1	1.10.1960	30.09.2020
26	Valdivia	Guadiana	Spain	SP-2A	01/10/1962	30/09/2020
27	Valencia	Turia	Spain	SP-3	1.10.2000	30.09.2020
28	Jouggar	Melian	Tunisia	TN-1	1.10.1960	30.09.2019
29	Adana	Seyhan	Turkey	TR-1	1.10.1960	30.09.2019
30	Antakya	Asi	Turkey	TR-2	1.10.1960	30.09.2020
31	Antalya	Antalya	Turkey	TR-3	1.10.1960	30.09.2020
32	Canakkale	Marmara	Turkey	TR-4	1.10.1960	30.09.2017
33	Istanbul	Marmara	Turkey	TR-5	1.10.1960	30.09.2008
34	Izmir	Büyük Menderes	Turkey	TR-6	1.10.1960	30.09.2020
35	Menemen	Gediz	Turkey	TR-7	1.10.1960	30.09.2007

3.2.2. Qualitative Assessment

To complement the quantitative analysis, the project applied a qualitative processes to gather information or interpret the perspective of the stakeholders. The latter process was conducted by knowledge mapping approach based on the EIT Climate-KIC Challenge-Led System Mapping methodology. Additionally, Value-Perception-Attitude, data collection and weighting surveys have been conducted to gather related data.

Value-Perception-Attitude Surveys: Surveys targeting farming communities were conducted to capture changes in perception attributable to project interventions (Figure 8). Respondents included members of agricultural associations in Turkey (Menemen region) and Malta (Young Farmers Association and students at MCAST).

TÜBİTAK



UNIMED PROJECT

VALUE-ATTITUDE-PERCEPTION (VAP) SURVEY

Value Questions:

1) The protection of the environment and of natural resources (soil and water) in farming practices is important:

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

2) My reputation in the community for being a responsible water user is important to me.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

Attitude Questions:

3) I am concerned about drought and its potential impact on my farm.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

4) Your fellow farmers are confident in your ability to cope with drought.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

5) My usage of water on my farm affects neighbouring farmers.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

6) Your fellow farmers are willing to adopt water conservation practices on their farms

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

7) How would you define a drought on your farm? _____

Perception Questions:

8) Droughts occur frequently in my region.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

9) The impact of drought on my farm and the surrounding community is severe.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

10) How would you rate your access to water on your farm.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

11) How would you rate your access to energy on your farm.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

Figure 8. VAP survey

12) Rate the given challenges that you face in dealing with drought below from 1 to 4, 1 being the most significant challenge:

☐ Water Scarcity
☐ Economic and Financial Hardships
☐ Other: _____
☐ Reduced crop productivity
☐ Increased energy costs

Behavioral Questions:

13) Please check from the below options, how have you addressed these challenges in the past?

☐ I adopted a new water management practice (If yes, please specify this practice)
☐ I made infrastructural changes (If yes, please specify its nature)
☐ I received financial support from government (If yes, please specify reason(s))
☐ I started employing diversification of seed varieties (If yes, please specify how many seed varieties and of which crops)
☐ I started employing agricultural practices which help to alleviate the impact of droughts (If yes, please specify which practices)
☐ Other: _____

14) What measures have you taken to conserve water on your farm?

☐ Increasing irrigation efficiency
☐ Water recycling and harvesting
☐ Crop selection and management
☐ Other: _____

15) Have you changed your farming practices in response to past droughts?

○ Yes ○ No

16) How likely are you to take action to prepare for or mitigate the impact of future droughts on your farm?

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

17) Farmers participate regularly in programs or initiatives aimed at promoting water conservation or drought preparedness on their farms.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

18) Farmers are willing to collaborate with neighbouring farms or community organizations in implementing water conservation measures during a drought.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

19) Farms are well prepared for a drought.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

20) Water availability is important for the farm's production and profitability.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

21) Farmers are supportive of government policies and regulations that aim to manage and conserve water resources.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

22) Farmers in my area are satisfied with the current drought response measures.

○ Highly Agree ○ Agree ○ Neutral ○ Disagree ○ Highly Disagree

Figure 8. cont'd.

Community of Practice (CoP) Workshops: A series of three workshops were conducted in both partner countries (Figure 9-11). These involved farmers, policy-makers, civil society actors, and technical experts. Workshops focused on (1) validating and expanding the indicator set, (2) assessing the fitness-for-purpose of the SDI framework, and (3) evaluating the final SDI model against stakeholder experiences and expectations.



Figure 9. VAP Survey introduction to the members of Gölmarmara Chamber of Agriculture in the first Turkish CoP meeting (28 July 2023)



Figure 10. A photo from the second CoP workshop of the Turkish pilot (5 April 2024)



Figure 11. A photo from the third CoP workshop organized as knowledge transfer & training event together with IRMCo and MCAST teams (4 December 2024)

System Mapping: Feedback collected during CoP workshops was codified into a matrix structure to facilitate visualization of stakeholder insights. This was instrumental in translating complex qualitative information into actionable recommendations for drought policy and resilience planning. System mapping is an innovative qualitative research methodology focused on a visual and participatory mapping process that brings together stakeholders relevant to a particular problem devised by the European Institute of Innovation and Technology (EIT) Climate Knowledge and Innovation Community (KIC), which strives for a more climate-resilient Europe (Matti et al., 2020). Data is generated through open roundtable discussions and is mapped using visual tools.

The attendees are asked to use coloured, self-adhesive stickers to jot down the acronym or short title of a planned, ongoing or past project that dealt with the topic at hand, i.e. coping with droughts in agricultural sector. The self-adhesive stickers containing information were posted on the canvas, (Figures 12 and 13). The canvas, the main visual tool used in system mapping, is divided into four quadrants. The sticky notes had to be pegged to the respective quadrant, based on 2 variables – the stage of project completion and whether the project being proposed was of a sector level or a system level.

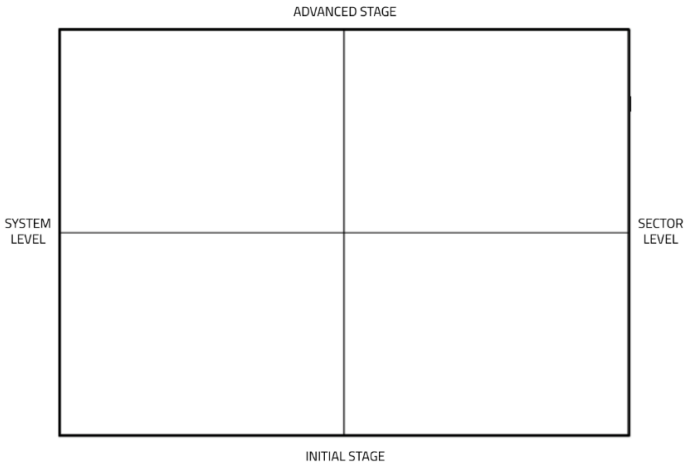

Figure 12.Empty canvas



Figure 13. A graphical representation of the canvas

In a second step, the participants were asked to identify and write on self-adhesive stickers, the primary stakeholders who would be involved in the project, noting those who would welcome the project, or who would hinder it. These were posted around each respective project on the canvas.

In the next step, participants were asked to discuss and write on the self-adhesive stickers, the possible barriers to these projects and to think about solutions to change these barriers into opportunities. These were posted around each project on the canvas. In the final step, potential synergies between the projects were identified.

4. FINDINGS

4.1. Quantitative Findings

4.1.1. SDI Findings of Türkiye

In order to calculate SDI values, gathered data according to the finalized list of indicators had to be weighted. The results of the weighting survey reveal that even though point allocation method have been used, there were no dominant indicators (Table 10).

Table 10. Weights of the selected indicators

Sub-Index	Indicator Name	Indicator Weights
Perception	Perception	1.000*
Vulnerability	Supply/Demand Ratio	0.187
	Water dependency for agricultural activities	0.235
	Rate of people working in Agriculture	0.018
	Species diversity within defined area	0.133
	Benefit to cost ratio	0.143
	Drought Risk	0.194
Adaptability	Attitude	0.258
	Formal & informal training	0.214
	Seed variety	0.224
	Rainwater harvesting rate	0.187
	Access to market	0.151
Recoverability	Diversity of source of income	0.168
	Average crop yield	0.143
	Access to credits	0.136
	Access to subsidies	0.221
	Access to relief	0.154
	Soil fertility	0.201
*Since perception sub-index only has one indicator, its weight is assigned as 1.00		

In the assessment of the SDI for the baseline year of 2023, the data and weighting surveys and the defined official data sources have been used to determine each indicator's value for the Gediz River Basin (Table 11). For the Vulnerability sub-index, the following values have been calculated: Supply/demand ratio has been calculated as 45.00%, the total water supply over the total demand in agriculture sector, according to the data provided by the Water Associations Unions (WUA) of

the Gediz River Basin. The water dependency for agricultural activities has been determined as 66.67%, the analyzed year value over the long-year average of the total agricultural demand. In the context of the study, this value has been inverted as the increase of water dependency is not a factor that would foster the survivability of a system. Hence the inverted value results as 33.33%. The rate of people working in agriculture value for the year 2023 has been collected from the Turkish Statistical Institute (TUIK) as 14.80%. The species diversity within the defined area has been determined according to the normalized Shannon Diversity Index as 86.45% based on the Gediz River Basin bird species records of Izmir Natural Life Park. The benefit-cost ratio has been calculated according to the long-year average value of the farmers' feedback and normalized to the value of 51.37% with this timeseries. The drought risk has been determined according to the adapted Kaplan-Meier method, and the 12-month drought risk value according to the SPI-12 has been selected to represent the annual drought risk as 34.06%.
In the case of the Adaptability sub-index, the attitude indicator has been calculated according to the feedback of the VAP Survey. The questions on the attitude section of the survey were graded between 1-5. The average of the total feedback was then normalized between this range and yielded 55.97%. As for the formal & informal training indicator, the training and capacity-building events that the local chamber of agriculture and International Agricultural Research and Training Center (UTAEM) have organized have been counted and normalized to the maximum number of 12, considering one event a month as an optimal number resulting as 16.67%. The seed variety indicator represents if the farmers have alternative seed varieties as an option to their current crop pattern, determined as 100%. The rainwater harvest rate indicates an important sustainable source of water, representing the percentage of farmers using harvested rainwater, identified as 0.00% for the farmers of the Gediz River Basin. Access to market represents the rate of farmers having access either to any or no markets, resulting as 100%.

The recoverability sub-index has a total of 6 indicators. Diversity of source of income represents the number of income sources that farmers have other than agriculture and normalized to the maximum number observed, calculated as 34.29%. The average crop yield is calculated according to the dominant crop of the case study, grape in the case of Gediz River Basin, normalized according to the maximum and the minimum values observed, resulting as 51.39%. Access to credits, subsidies and relief indicators have been determined according to the data survey conducted among farmers, representing the percentage of farmers who

benefited each service in the last two years, calculated as 82.86%, 85.71%, and 0.00%, respectively. The soil fertility indicator has been represented by the Soil Organic Carbon (SOC) parameter. The SOC average values for the soil layers of 0-5 cm, 5-15 cm, 15-30 cm, 30-60 cm, 60-100 cm, and 100-200 cm for the Gediz River Basin have been accumulated from the Soilgrids database (Poggio et al., 2021) source as the SOC percentage of soil, resulting as 0.0157%.
The perception indicator has been calculated according to the feedback to the questions of the “perception” section. The questions were graded between 1-5 and the average of the total feedback was then normalized between this range and yielded 52.68%.

According to the weight survey, the weights of each indicator and sub-index was determined, normalized to the max votes available for each weighting exercise such as 10 votes for the 4 sub-indices, 12 for adaptability, 14 for vulnerability and recoverability. Since perception consists of just one indicator, no such normalization was necessary. The SDI has been eventually calculated as 49.15% according to the calculated data and defined weights, representing a fairly low-moderate percentage considering the max value of 100% (Table 11).

Table 11. Calculated values of indicators, sub-indices, and the SDI for the baseline year of 2023

	Indicator Name	Definition	Value	Indicator Weights	Weighted Values of Indicators	Sub-index Weights	Weighted Values of Sub-indices	SDI
Perception	**Perception**	Represents how droughts (in terms of severity) are perceived among the agricultural community	0.527	1.000	0.527	0.255	0.1341	0.4915
Vulnerability	**Supply/Demand Ratio**	Annual total supply allocated to agriculture over total demand of agricultural sector.	0.836	0.187	0.031	0.232	0.101	
	Water dependency for agricultural activities	Total amount of water allocated to food production over long-term average of water available for agricultural irrigation (resulting value inverted for the purpose of the study)	0.333	0.235	0.157			
	Rate of people working in Agriculture	Number of people working in agriculture over total population	0.148	0.018	0.004			
	Species diversity within defined area	Shannon Diversity Index of the pilot study area to measure the diversity of species	0.865	0.133	0.115			
	Benefit to cost ratio	Average agricultural land benefit to cost ratio of the case study farmers	0.514	0.143	0.073			
	Drought Risk	Average 12-month drought risk of the study area according to SPI12 calculated by adapted Kaplan-Meier method	0.341	0.194	0.066			

Table 11. cont'd

	Indicator Name	Definition	Value	Indicator Weights	Weighted Values of Indicators	Sub-index Weights	Weighted Values of Sub-indices	SDI
Adaptability	**Attitude**	Extent to which the farming community has adopted measures to mitigate the impact of drought	0.560	0.258	0.144	0.277	0.1537	0.4915
	Formal & informal training	Number of events dedicated to training and practical learning on how to adapt to droughts in the agricultural sector	0.167	0.214	0.036			
	Seed variety	Total number of seed variety cultivated (Cultivating various seeds promotes the biodiversity and ecosystem resilience)	1.000	0.224	0.224			
	Rainwater harvesting rate	Rate of irrigation water sourced by rainwater harvesting to total amount of water allocated to irrigation	0.000	0.187	0.000			
	Access to market	Rate of farmers conducting business in local/national/international markets	1.000	0.151	0.151			
Recoverability	**Diversity of source of income**	Number of income sources independent of agricultural activity	0.343	0.168	0.058	0.236	0.1031	
	Average crop yield	Total yield divided by the surface area dedicated to crop production, normalized to long-term observed min-max values	0.514	0.143	0.073			
	Access to credits	Percentage of agricultural community benefiting from credits	0.829	0.136	0.112			
	Access to subsidies	Percentage of agricultural community benefiting from subsidies	0.857	0.221	0.190			
	Access to relief	Percentage of agricultural community benefiting from relief funds after a drought	0.000	0.154	0.000			
	Soil fertility	The average of Soil Organic Carbon rate in the first 2 meters of soil in the case study extent	0.016	0.201	0.003			

Moreover, to compare the calculated results of the current year with a severely dry period like 1991-1992 and a relatively wet period like 1982, the supply/demand ratio, water dependency for agricultural activities, benefit-to-cost ratio, and drought risk of the 1991-1992 and 1982 period have been determined according to the historical data. Since most of the other indicators cannot be determined for the 1991-1992 period such as the attitude or perception indicators directly, they have been revised according to expert opinion (Table 12). The formal and informal training and seed variety indicators have been revised as 0.00%, the diversity of sources of income and the access to subsidies have been revised as 10.00%, the access to credits has been revised as 50.00%, and the perception indicator has been revised as 30.00% for the 1991-1992 and1982 period. Hence, the drought risk value for the SDI1991-1992 resulted as 31.32%, which is almost 18% lower than the SDI2023, while the SDI1982 was calculated as 38.16%, almost 11% lower than the SDI2023. This result emphasizes that even though the drought risk is an essential indicator, it is not the only component in the goal of survivability from droughts.

Table 12. Turkish indicator values revised for previous periods

Indicator Name	**1982**	**1991-1992**	**2023**
Supply/Demand ratio	**0.96**	**0.49**	0.45
Water dependency for agricultural activities	**0.00**	**0.00**	0.33
Rate of people working in Agriculture	0.15	0.15	0.15
Species diversity within defined area	0.86	0.86	0.86
Benefit to cost ratio	**1.83**	**0.97**	0.51
Drought Risk	**0.82**	**0.61**	0.34
Attitude	0.55	0.55	0.55
Formal & informal training	*0.00*	*0.00*	0.17
Seed variety	*0.00*	*0.00*	1.00
Rainwater harvesting rate	0.00	0.00	0.00
Access to market	1.00	1.00	1.00
Diversity of source of income	*0.10*	*0.10*	0.34
Average crop yield	0.51	0.51	0.51
Access to credits	*0.50*	*0.50*	0.83
Access to subsidies	*0.10*	*0.10*	0.86
Access to relief	*0.00*	*0.00*	0.00
Soil fertility	0.01	0.01	0.01
Perception	*0.30*	*0.30*	0.52
Bold: revised by calculation, Italic: revised by expert opinion			

Furthermore, the weighted values of indicators and sub-indices according to the current period and simulated periods have been presented as radar charts

showcasing the influence of each element that determines the final SDI value (Figure 14-17). In the case of the vulnerability sub-index, the water dependency for agricultural activities is observed to be the least sensitive indicator as it doesn't change much throughout the periods, as the water dependency exceeds the available water amount in most cases.

While rainwater harvest rate, formal & informal training, and access to the market are measured to be the least sensitive indicators of the Adaptability sub-index, it is the access to relief and soil fertility in the case of Recoverability. An overall observation of SDI sub-indices reveals that perception is the least sensitive sub-index among the rest as the relative change in perception is lesser.

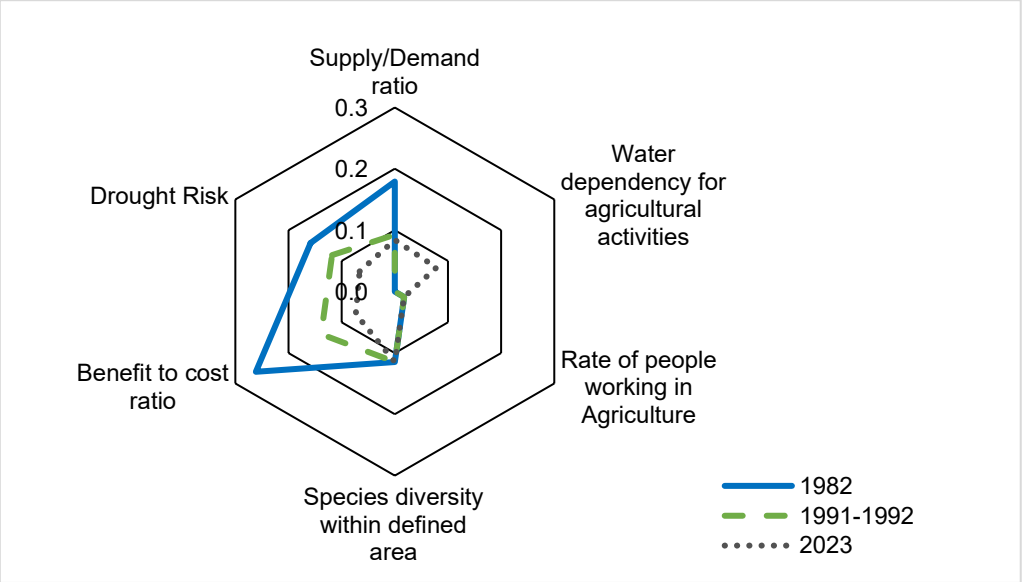

Figure 14. Calculated weighted values of Vulnerability sub-index indicators for the periods of 1991-1992, 1982, and 2023 for Türkiye.

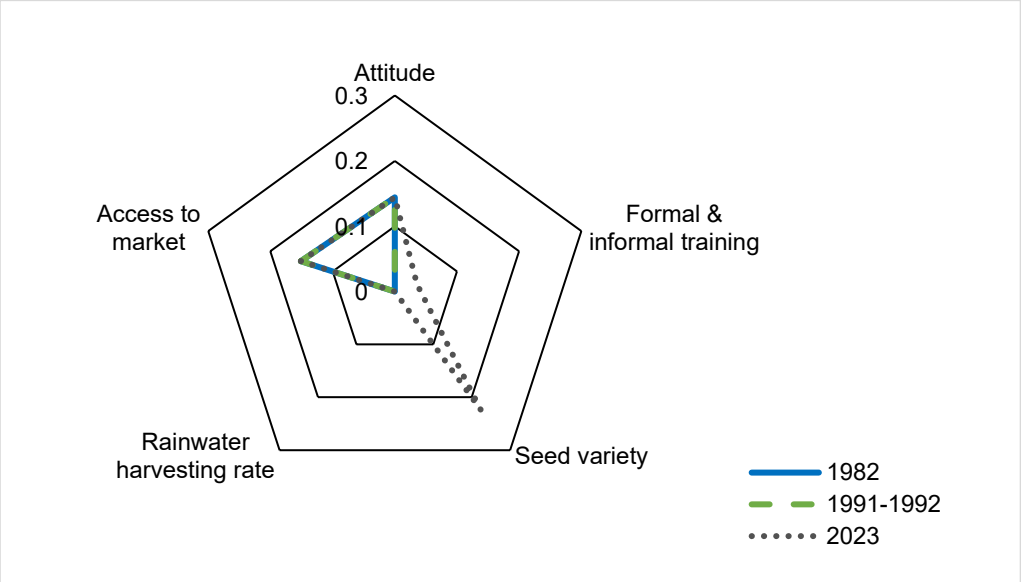

Figure 15. Calculated weighted values of Adaptability sub-index indicators for the periods of 1991-1992, 1982, and 2023 for Türkiye.

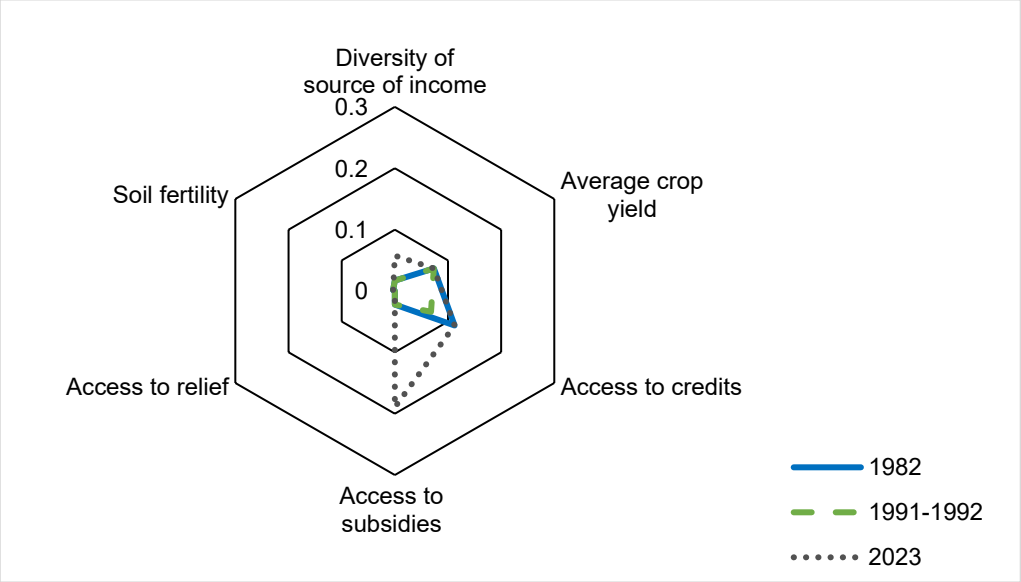

Figure 16. Calculated weighted values of Recoverability sub-index indicators for the periods of 1991-1992, 1982, and 2023 for Türkiye.

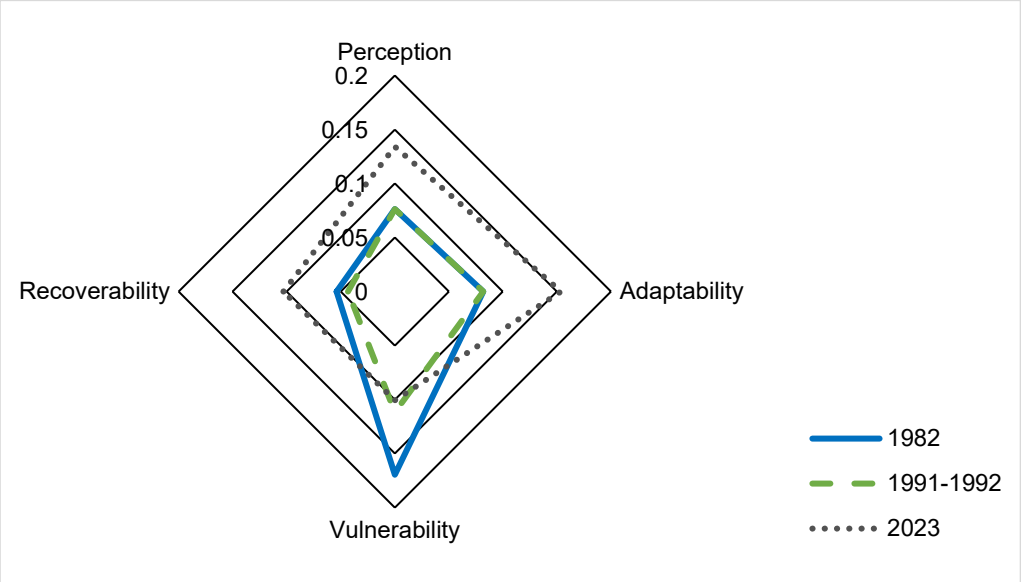

Figure 17. Calculated weighted values of SDI sub-indices for the periods of 1991-1992, 1982, and 2023 for Türkiye.

The generated SDI map of the most recent period, 2023, reveals the distribution of the SDI in the Gediz River Basin (Figure 18). While the SDI values around Lake Marmara indicate relatively moderate magnitudes, the values around Menemen Plain are moderate to slightly higher values, possibly with the influence of coastal humidity. The map also highlights other hotspots of higher and lower SDI regions for the decision-makers to investigate and prioritize while developing action plans. Additionally, the map generation and visualization of the results provide a better understanding of the SDI for the stakeholders.

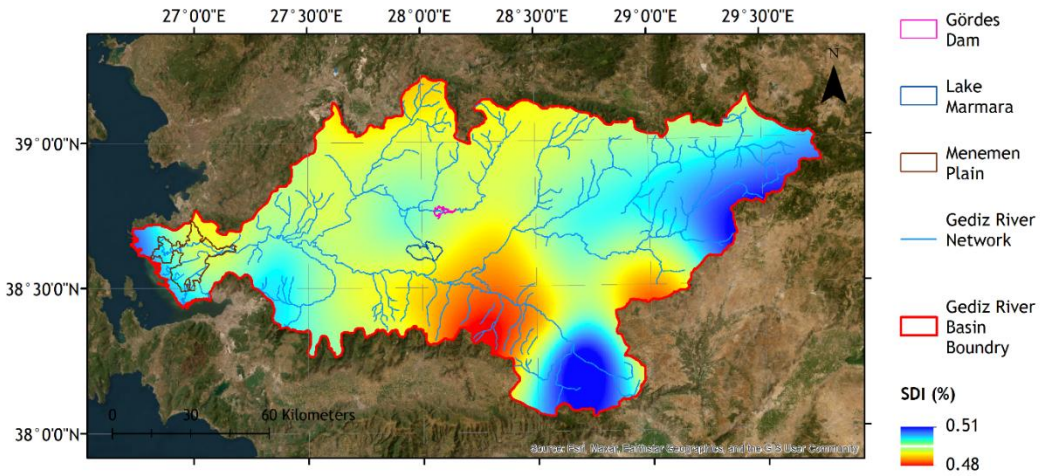

Figure 18. Generated Gediz River Basin SDI map of 2023

4.1.2. SDI Findings of Malta

In the case of Malta, the enlarged indicator set was contrasted with the actual data availability in Malta, which draws mostly from the Agricultural Census Report and through contact with the National Statistics Office in Malta. Consequently, a 'best available' set of indicators was drawn up. However, IRMCo's telecon with Dr. Julian Mamo, Institute of Earth Sciences, UoM on May 16, 2024, guided to the quantification of the Water Exploitation Index for Malta (Second Catchment Management Plan 2015-2021). Furthermore, the analysis of the VAP survey, revealed the potential to extract additional indicators (e.g. Attitude, defined as the extent to which the farming community has adopted measures to mitigate the impact of drought and profitability, defined as the rate of return on expenditures to produce agricultural output). Consequently, an updated version of 'Best available' set of indicators was drawn up in the case of Malta.

IRMCo collected the numerical values of the indicators for respectively a wet (2000), a dry (2010) and an average-rainfall year (2020) in Malta. DEU then computed the SDI values which are presented below (Table 13-16).

Table 13. Calculated values of Vulnerability indicators for the baseline year of 2020

	Indicator Name	Definition	Unit	Value	Weights	Weighted Values
Vulnerability	**Water Exploitation Index**	Mean annual total demand for surface/ground water divided by the long-term average surface/ground water resources in the pilot study area	%	0.780	0.143	0.111
	Total population	Total population residing in the pilot study area	Capita	0.026	0.143	0.004
	Population density	Number of residents per square kilometre	persons/km^2	1.000	0.143	0.143
	Agricultural holdings	Holdings that cultivate agricultural products mainly intended for consumption by the holder and his household (kitchen garden) are also included	units	0.588	0.143	0.084
	Registered labour force	Registered labour force in agricultural sector	-	0.394	0.143	0.056
	Utilised agricultural land	Land area used for farming, including arable land, permanent crops and other utilised agricultural land	ha	0.825	0.143	0.118
	Drought Risk	Average drought risk of the study area according to Standard Precipitation Index	%	0.085	0.143	0.012

Table 14. Calculated values of Adaptability indicators for the baseline year of 2020

Adaptability	**Attitude**	Extent to which the farming community has adopted measures to mitigate the impact of drought	%	0.700	0.200	0.140
	Formal & informal training	Number of events dedicated to training and practical learning on how to adapt to droughts in the agricultural sector	Number	0.900	0.200	0.180
	Access to market	Percentage of farmers that have access to local/ national/ international markets	%	1.000	0.200	0.200
	Profitability	Rate of return on expenditures to produce agricultural output	%	0.360	0.200	0.072
	Standard Output	Average monetary value of the agricultural output at farm-gate price	Euro	0.759	0.200	0.152

Table 15. Calculated values of Recoverability indicators for the baseline year of 2020

Recoverability	**Diversity of source of income**	Percentage of income sources independent of agricultural activity (termed as ***Value*** in Survey)	%	0.531	0.143	0.076
	Livestock population	Headcount of livestock population	-	0.318	0.143	0.045
	Access to subsidies	Percentage of the agricultural community benefiting from subsidies	%	0.760	0.143	0.109
	Access to relief	Percentage of the agricultural community benefiting from relief funds after a drought	%	0.610	0.143	0.087
	Access to water and energy	The extent to which farmers have reliable access to water (weighting coefficient = 0.75) and to energy (weighting coefficient = 0.25) on their farm	%	0.220	0.143	0.031
	Preparedness to take action to mitigate impact of drought in the future	The likelihood as expressed by the agricultural community to take action to mitigate the impact of droughts in the future	%	0.300	0.143	0.043
	Soil fertility	Soil fertility promotes ecosystem services, lower irrigation dependence, and higher food production (Soil Organic Carbon Content (SOC) will be observed)	Mg/ha	0.049	0.143	0.007

Table 16. Calculated value of Perception indicator for the baseline year of 2020

Perception	**Perception**	Represents how droughts (in terms of severity) are perceived among the agricultural community	%	0,440	1,000	0,440

Similar to Turkish case, some of the indicator values in the dry and wet scenario periods have been revised according to expert opnion as depicted in Table 17.

Table 17. Maltese indicator values revised for previous periods

Indicator Name	**2000**	**2010**	**2020**
Water Exploitation Index	0.111	0.111	0.111
Total population	**0.009**	**0.006**	0.004
Population density	**0.030**	**0.047**	0.143
Agricultural holdings	**0.120**	**0.100**	0.084
Registered labour force	**0.105**	**0.077**	0.056
Utilised agricultural land	**0.134**	**0.126**	0.118
Drought Risk	**0.015**	**0.010**	0.012
Attitude	*0.120*	*0.160*	0.140
Formal & informal training	*0.100*	*0.140*	0.180
Access to market	0.200	0.200	0.200
Profitability	**0.096**	**0.056**	0.072
Standard Output	**0.182**	**0.166**	0.152
Diversity of source of income	**0.069**	**0.083**	0.076
Livestock population	**0.078**	**0.060**	0.045
Access to subsidies	**0.094**	**0.123**	0.109
Access to relief	**0.046**	**0.129**	0.087
Access to water and energy	**0.000**	**0.063**	0.031
Preparedness to take action to mitigate impact of drought in the future	**0.030**	**0.056**	0.043
Soil fertility	0.007	0.007	0.007
Perception	*0.420*	*0.460*	0.440
Bold: revised by calculation, Italic: revised by expert opinion			

The calculated values for the 2000 and 2010 period has been presented in the Tables below.

Table 18. Calculated values of Vulnerability indicators for the baseline year of 2000

	Indicator Name	Definition	Unit	Value	Weights	Weighted Values
Vulnerability	**Water Exploitation Index**	Mean annual total demand for surface/ground water divided by the long-term average surface/ground water resources in the pilot study area	%	0.780	0.143	0.111
	Total population	Total population residing in the pilot study area	Capita	0.062	0.143	0.009
	Population density	Number of residents per square kilometre	persons/km^2	0.212	0.143	0.030
	Agricultural holdings	Holdings that cultivate agricultural products mainly intended for consumption by the holder and his household (kitchen garden) are also included	units	0.838	0.143	0.120
	Registered labour force	Registered labour force in agricultural sector	-	0.733	0.143	0.105
	Utilised agricultural land	Land area used for farming. including arable land. permanent crops and other utilised agricultural land	ha	0.938	0.143	0.134
	Drought Risk	Average drought risk of the study area according to Standard Precipitation Index	%	0.102	0.143	0.015

Table 19. Calculated values of Adaptability indicators for the baseline year of 2000

Adaptability	**Attitude**	Extent to which the farming community has adopted measures to mitigate the impact of drought	%	0.600	0.200	0.120
	Formal & informal training	Number of events dedicated to training and practical learning on how to adapt to droughts in the agricultural sector	Number	0.500	0.200	0.100
	Access to market	Percentage of farmers that have access to local/ national/ international markets	%	1.000	0.200	0.200
	Profitability	Rate of return on expenditures to produce agricultural output	%	0.480	0.200	0.096
	Standard Output	Average monetary value of the agricultural output at farm-gate price	Euro	0.910	0.200	0.182

Table 20. Calculated values of Recoverability indicators for the baseline year of 2000

Recoverability	**Diversity of source of income**	Percentage of income sources independent of agricultural activity (termed as ***Value*** in Survey)	%	0.481	0.143	0.069
	Livestock population	Headcount of livestock population	-	0.545	0.143	0.078
	Access to subsidies	Percentage of the agricultural community benefiting from subsidies	%	0.660	0.143	0.094
	Access to relief	Percentage of the agricultural community benefiting from relief funds after a drought	%	0.320	0.143	0.046
	Access to water and energy	The extent to which farmers have reliable access to water (weighting coefficient = 0.75) and to energy (weighting coefficient = 0.25) on their farm	%	0.000	0.143	0.000
	Preparedness to take action to mitigate impact of drought in the future	The likelihood as expressed by the agricultural community to take action to mitigate the impact of droughts in the future	%	0.210	0.143	0.030
	Soil fertility	Soil fertility promotes ecosystem services. lower irrigation dependence. and higher food production (Soil Organic Carbon Content (SOC) will be observed)	Mg/ha	0.049	0.143	0.007

Table 21. Calculated value of Perception indicator for the baseline year of 2000

Perception	**Perception**	Represents how droughts (in terms of severity) are perceived among the agricultural community	%	0.420	1.000	0.420

Table 22. Calculated values of Vulnerability indicators for the baseline year of 2010

	Indicator Name	Definition	Unit	Value	Weights	Weighted Values
Vulnerability	**Water Exploitation Index**	Mean annual total demand for surface/ground water divided by the long-term average surface/ground water resources in the pilot study area	%	0.780	0.143	0.111
	Total population	Total population residing in the pilot study area	Capita	0.044	0.143	0.006
	Population density	Number of residents per square kilometre	persons/km^2	0.326	0.143	0.047
	Agricultural holdings	Holdings that cultivate agricultural products mainly intended for consumption by the holder and his household (kitchen garden) are also included	units	0.702	0.143	0.100
	Registered labour force	Registered labour force in agricultural sector	-	0.537	0.143	0.077
	Utilised agricultural land	Land area used for farming. including arable land. permanent crops and other utilised agricultural land	ha	0.880	0.143	0.126
	Drought Risk	Average drought risk of the study area according to Standard Precipitation Index	%	0.073	0.143	0.010

Table 23. Calculated values of Adaptability indicators for the baseline year of 2010

Adaptability	**Attitude**	Extent to which the farming community has adopted measures to mitigate the impact of drought	%	0.800	0.200	0.160
	Formal & informal training	Number of events dedicated to training and practical learning on how to adapt to droughts in the agricultural sector	Number	0.700	0.200	0.140
	Access to market	Percentage of farmers that have access to local/ national/ international markets	%	1.000	0.200	0.200
	Profitability	Rate of return on expenditures to produce agricultural output	%	0.280	0.200	0.056
	Standard Output	Average monetary value of the agricultural output at farm-gate price	Euro	0.831	0.200	0.166

Table 24. Calculated values of Recoverability indicators for the baseline year of 2010

Recoverability	**Diversity of source of income**	Percentage of income sources independent of agricultural activity (termed as ***Value*** in Survey)	%	0.582	0.143	0.083
	Livestock population	Headcount of livestock population	-	0.417	0.143	0.060
	Access to subsidies	Percentage of the agricultural community benefiting from subsidies	%	0.860	0.143	0.123
	Access to relief	Percentage of the agricultural community benefiting from relief funds after a drought	%	0.900	0.143	0.129
	Access to water and energy	The extent to which farmers have reliable access to water (weighting coefficient = 0.75) and to energy (weighting coefficient = 0.25) on their farm	%	0.440	0.143	0.063
	Preparedness to take action to mitigate impact of drought in the future	The likelihood as expressed by the agricultural community to take action to mitigate the impact of droughts in the future	%	0.390	0.143	0.056
	Soil fertility	Soil fertility promotes ecosystem services. lower irrigation dependence. and higher food production (Soil Organic Carbon Content (SOC) will be observed)	Mg/ha	0.049	0.143	0.007

Table 25. Calculated value of Perception indicator for the baseline year of 2010

Perception	**Perception**	Represents how droughts (in terms of severity) are perceived among the agricultural community	%	0.460	1.000	0.460

The calculated SDI values and sub indices according to given tables are presented below as follows (Table 26-28).

Table 26. Calculated sub-index and SDI values for 2000

Sub-indices	Weights	Weighted Values	SDI
Perception	0.255	0.107	0.498
Adaptability	0.277	0.194	
Vulnerability	0.232	0.121	
Recoverability	0.236	0.076	

Table 27. Calculated sub-index and SDI values for 2010

Sub-indices	Weights	Weighted Values	SDI
Perception	0.255	0.117	0.551
Adaptability	0.277	0.200	
Vulnerability	0.232	0.111	
Recoverability	0.236	0.123	

Table 28. Calculated sub-index and SDI values for 2020

Sub-indices	Weights	Weighted Values	SDI
Perception	0.255	0.112	0.535
Adaptability	0.277	0.206	
Vulnerability	0.232	0.122	
Recoverability	0.236	0.094	

Similar to Turkish case, the radar charts of the sub indices are presented below for visual evaluation (Figure 19-22).

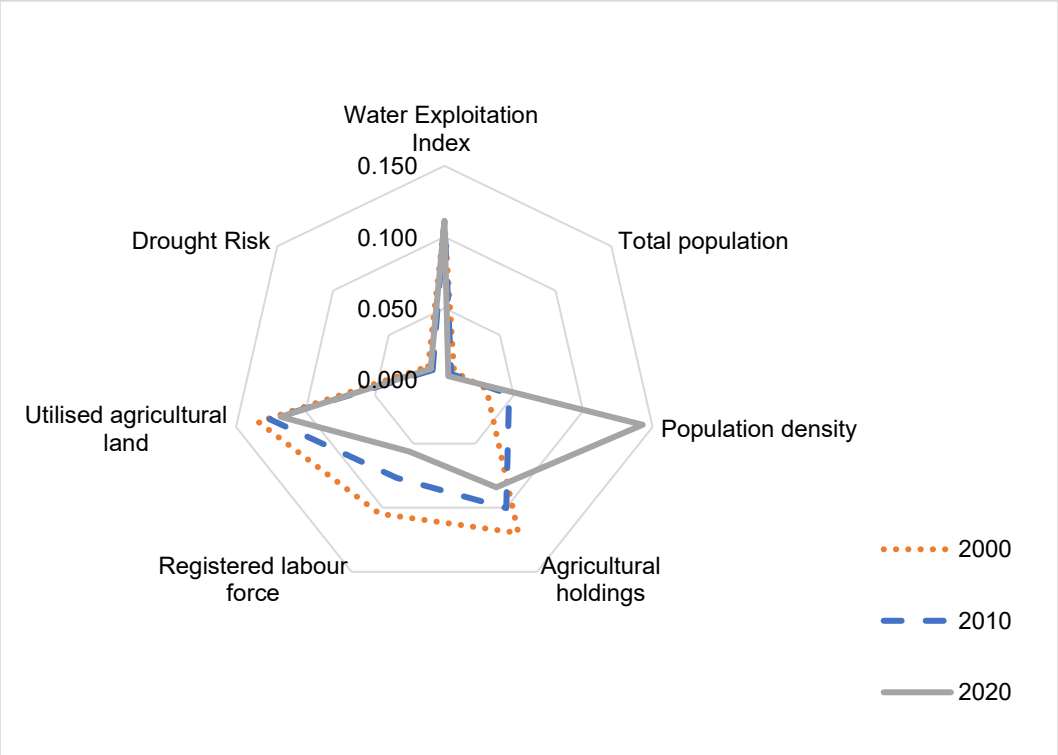

Figure 19. Calculated weighted values of Vulnerability sub-index indicators for the periods of 2000, 2010, and 2020 for Malta.

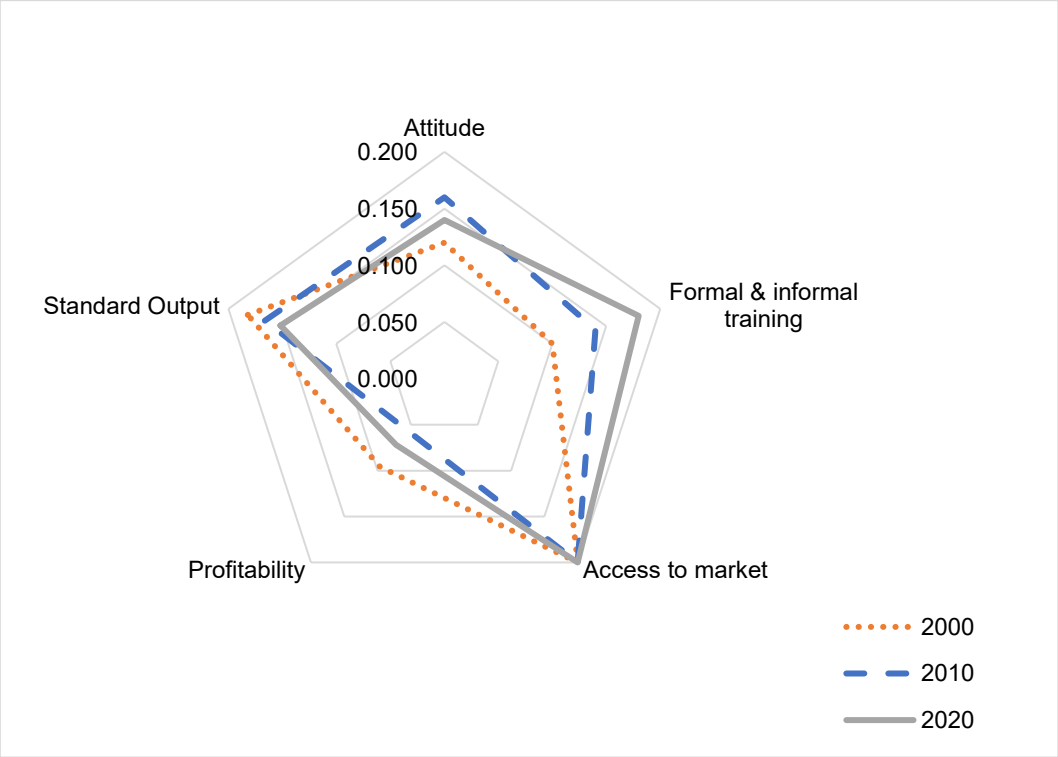

Figure 20. Calculated weighted values of Adaptability sub-index indicators for the periods of 2000, 2010, and 2020 for Malta.

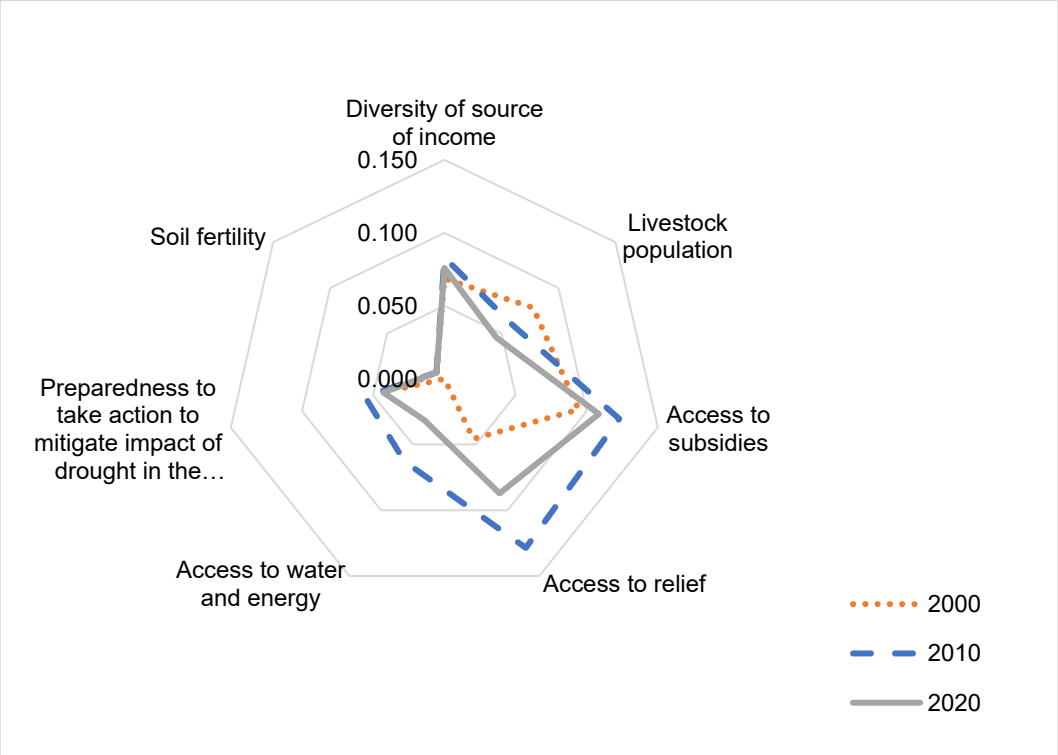

Figure 21. Calculated weighted values of Recoverability sub-index indicators for the periods of 2000, 2010, and 2020 for Malta.

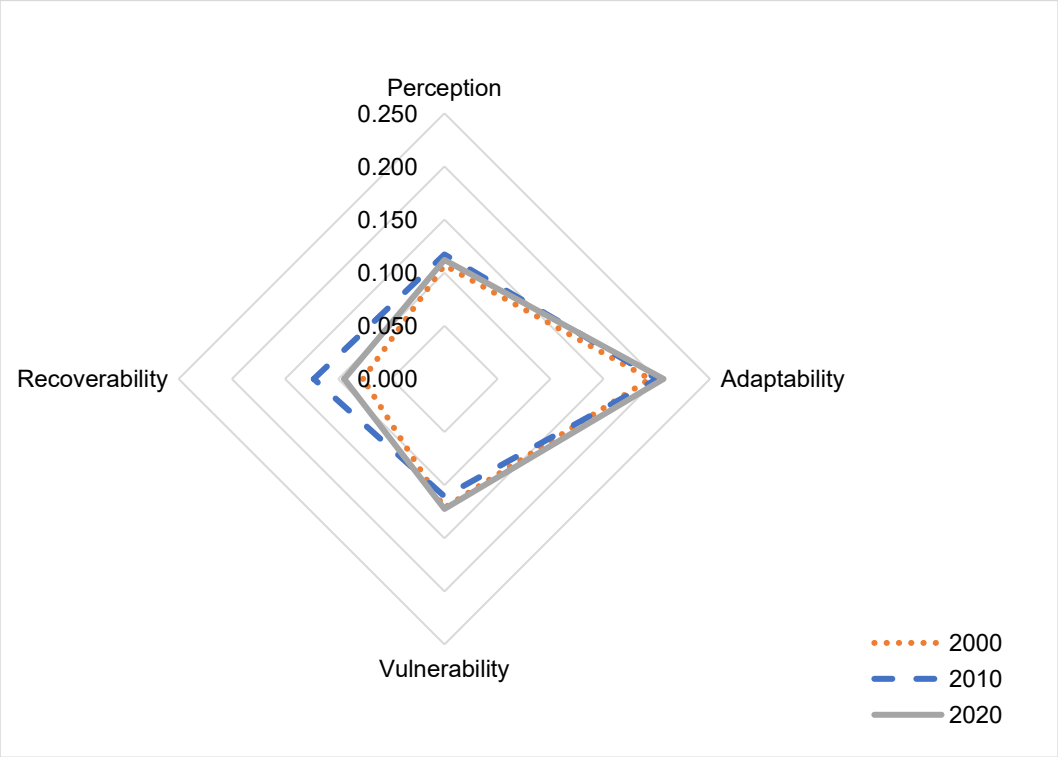

Figure 22. Calculated weighted values of SDI sub-indices for the periods of 2000, 2010, and 2020 for Malta.

In the case of Malta, SDI map of 2020 has been plotted as presented below (Figure 23). According to available data, while the SDI range is low for the Island, inland areas are observed to have slightly lower values.

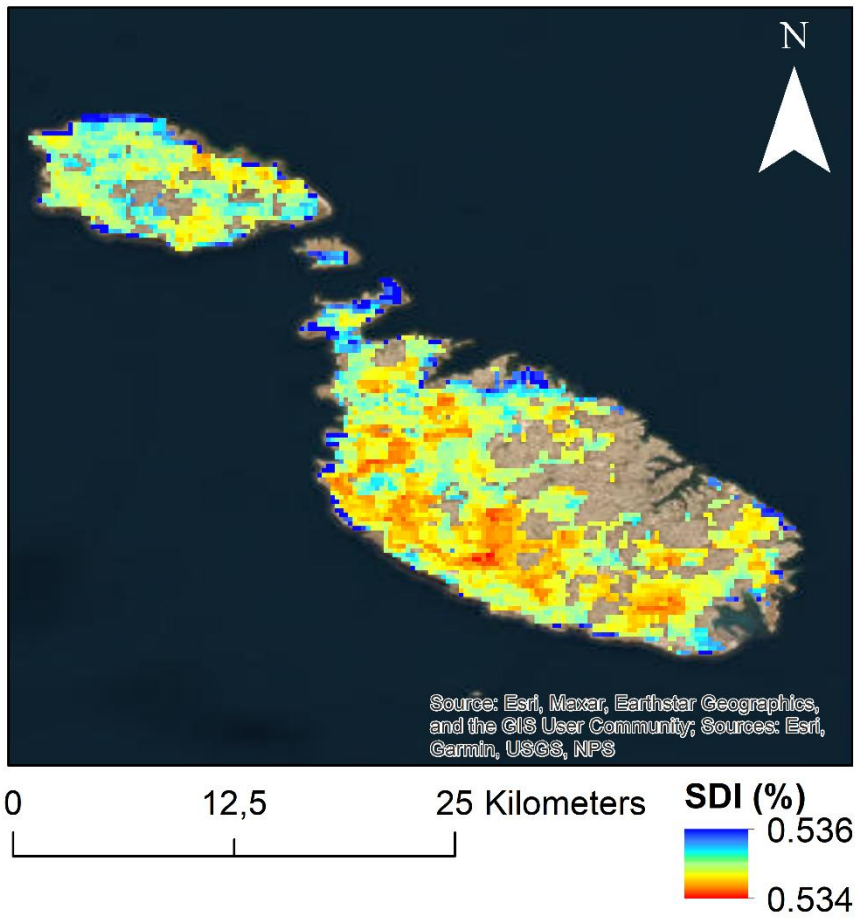

Figure 23. Generated Malta SDI map of 2020

4.1.3. Historical Trend Analysis Findings

As for the historical trend analysis of the rainfalls in Mediterranean region, for two stations in both Cyprus and Lebanon and one station in Spain, the datasets for the respective locations (e.g. CY-1A and CY-1B as shown in Table 29) have been combined so as to cover a maximum duration over the period from 1960 to 2020, and their respective codes have been amalgamated into one code, leading to: CY-1, CY-2, LB-1, LB-2 and SP-2 for the purpose of conducting the historical trend analysis.

Table 28 provides the average annual rainfall, the observed annual trend over the period for which rainfall data were obtained, the observed trend during the most pluvial season, and the projected change in annual rainfall by 2050. The aggregate outcome of the historical trend analysis is presented in Table 30.

Table 29. Outcomes of historical trend analysis

Code	Annual average rainfall (mm)	Observed annual trend over period of analysis	Observed trend during most pluvial season	Projected change in annual rainfall by 2050	Code	Annual average rainfall (mm)	Observed annual trend over period of analysis	Observed trend during most pluvial season	Projected change in annual rainfall by 2050
ALG-1	403.24	-24.0%	-21.2%	-44.0%	IT-3	945.87	-15.8%	3.4%	-29.6%
ALG-2	426.78	-28.9%	-20.4%	-53.8%	IT-4	1278.71	-4.6%	1.3%	-6.9%
ALG-3	735.41	6.4%	-16.3%	10.4%	IT-5	844.72	9.9%	-7.2%	14.8%
ALG-4	388.30	-18.9%	-23.8%	-37.5%	LB-1	898.14	-0.2%	0.2%	-0.5%
ALG-5	598.61	1.0%	6.1%	1.9%	LB-2	651.09	-9.6%	-6.7%	-27.9%
ALG-6	329.91	24.9%	-6.4%	60.0%	MT-1	536.53	-10.7%	-27.7%	-16.1%
ALG-7	626.25	-10.6%	-10.3%	-18.6%	SP-1	600.28	-25.5%	-23.1%	-38.2%
ALG-8	350.92	-0.5%	6.1%	-1.0%	SP-2	477.13	-15.8%	-47.3%	-24.0%
ALG-9	595.14	-25.6%	-19.6%	-55.9%	SP-3	462.55	7.7%	3.2%	11.5%
CY-1	317.70	10.3%	8.0%	15.8%	TN-1	149.56	-14.7%	3.3%	-22.9%
CY-2	339.67	-4.1%	10.4%	-6.3%	TR-1	691.26	-6.4%	-14.1%	-10.4%
CY-3	1076.45	-7.4%	-2.7%	-11.3%	TR-2	1159.32	-2.5%	-2.2%	-3.8%
FR-1	533.21	-6.7%	16.7%	-10.1%	TR-3	1067.87	-18.9%	-32.4%	-28.8%
FR-2	765.10	1.0%	18.8%	1.5%	TR-4	623.67	-2.4%	-14.4%	-3.8%
FR-3	549.15	6.4%	28.5%	9.5%	TR-5	686.54	-10.5%	-31.0%	-20.0%
GR-2	425.59	6.7%	-7.7%	13.0%	TR-6	711.14	9.0%	-8.6%	13.8%
IT-1	565.86	-9.0%	-41.2%	-13.7%	TR-7	528.79	-32.3%	-45.7%	-63.1%
IT-2	841.60	-9.6%	-10.0%	-20.8%					

Table 30. Outcome of historical trend analysis across all rainfall stations

Annual average rainfall (mm)	Observed annual trend over period of analysis	Observed annual trend during the most pluvial season	Projected change in annual rainfall by 2050
633.77	-6.6%	-9.4%	-11.9%

The aggregated outcome informs a decrease of -6.6% was observed across all rainfall stations, with a decrease of 9.4% during the most pluvial season, and a projected decrease of 11.9% by 2050 according to the linear trend calculated in the observed period. As shown in Figure 24, there is a positive correlation between the percentage change in annual rainfall and the percentage change in rainfall during the most pluvial season which alternates between winter (28 stations) and autumn (7 stations).

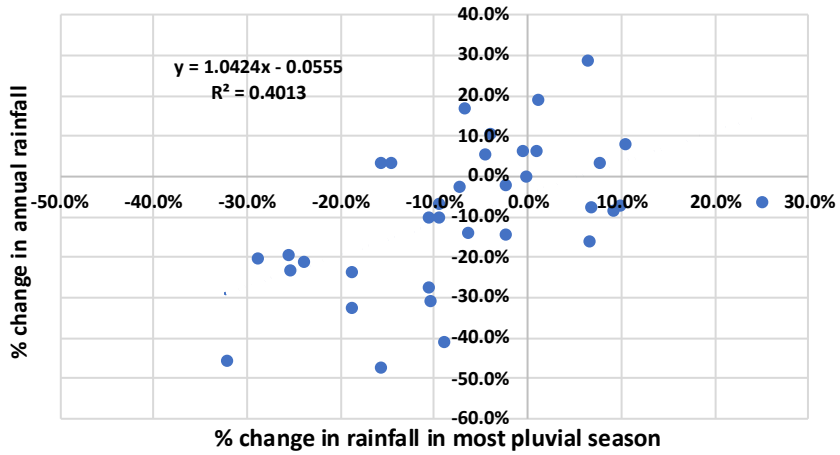

Figure 24. Correlation between the % change in annual rainfall and % change in rainfall during the most pluvial season.

In Figures 25 and 26, the percentage change in the annual rainfall and the most pluvial seasons, have been plotted respectively.

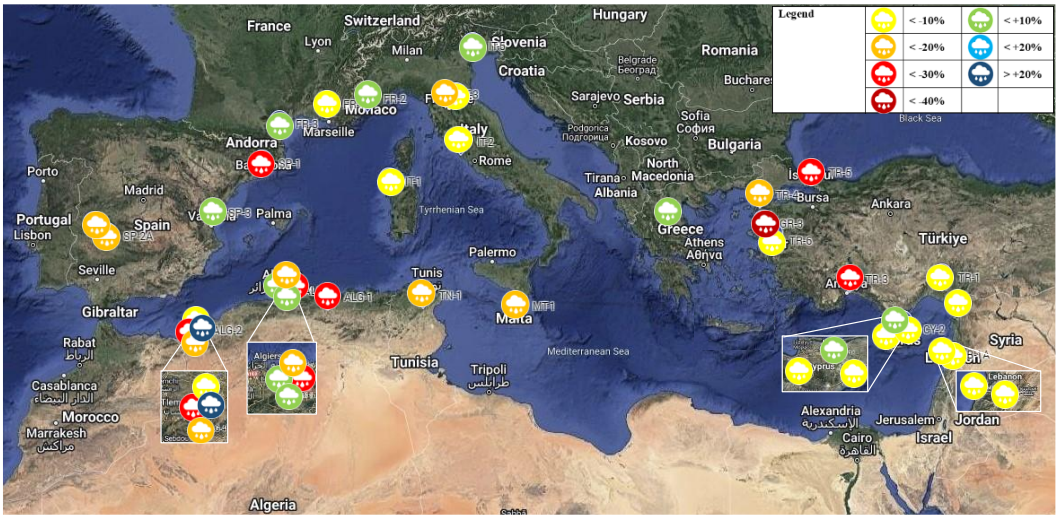

Figure 25. Percentage (%) change in annual rainfall over period of analysis



Figure 26. Percentage (%) in rainfall during most pluvial season over period of analysis

The outcomes presented in Table 29 and in Figure 25 and 26 demonstrate that even within the same catchment area (e.g. Tafna and Oued El Hamiz in Algeria, see insets in Figure 25 and 26), the outcomes show a considerable variation, as recapitulated in Table 31.

Table 31. Variations observed in annual trend within the same catchments

Tafna catchment, Algeria			Oued El Hamiz catchment, Algeria		
Rainfall data set code	**Elevation (meters above mean sea level)**	**Observed annual trend over period of analysis**	**Rainfall data set code**	**Elevation (meters above mean sea level)**	**Observed annual trend over period of analysis**
ALG-2	700	-28.9%	ALG-3	1100	6.4%
ALG-4	1100	-18.9%	ALG-5	67	1.0%
ALG-6	705	24.9%	ALG-7	20	-10.6%
ALG-8	430	-0.5%	ALG-9	570	-25.6%

At the same time, the outcomes point to significant decrease in rainfall in known "*hotspots of land and water degradation"*, such as in Menemen, Turkey (TR-7), where the observed decrease in annual rainfall reaches -32.3%, during the winter season -45.7%, and with a projected decrease of -63.1% by 2050.

The 3- and 6-month time scales are linked to short-term drought conditions which affect the soil moisture conditions and may therefore affect agricultural yield. To analyse this further in the context of the findings of the SPI analysis at these time scales, only those rainfall stations have been considered for which the monthly rainfall data is available throughout (or at least very close to) the full duration from October 1960 to September 2020. This is the case for 18 stations, for which the frequency, average duration and average magnitude of droughts at the 3- and 6-month time scales are presented in Table 32.

Table 32. SPI outcomes at the 3- and 6-month time scales

Station code	Period covered	SPI outcomes at 3-month time scale			SPI outcomes at 6-month time scale		
		Frequency	Average Duration	Average Magnitude	Frequency	Average Duration	Average Magnitude
CY-1	1960-1990	29	6.62	4.97	24	7.04	5.91
	1990-2020	21	7.24	5.62	17	8.65	7.25
CY-2	1960-1990	Nil			25	6.44	4.87
	1990-2020	Nil			24	7.42	6.06
CY-3	1960-1990	21	7.43	4.97	25	7.04	5.21
	1990-2020	17	8.29	6.10	24	7.25	5.82
FR-1	1960-1990	16	7.25	5.63	9	13.11	10.82
	1990-2020	28	5.61	4.64	13	11.08	9.55
FR-2	1960-1990	18	8.22	5.92	16	10.56	6.93
	1990-2020	22	7.09	4.91	17	8.59	8.24
FR-3	1960-1990	16	7.50	5.27	13	12.31	8.88
	1990-2020	25	6.68	4.98	15	9.33	7.75
IT-1	1960-1990	26	6.08	4.62	21	6.81	5.34
	1990-2020	23	7.00	5.73	13	12.46	10.59
IT-4	1960-1990	18	5.89	4.55	14	8.14	5.52
	1990-2020	23	6.09	5.66	13	11.00	11.28
IT-5	1961-1990	12	7.67	4.24	6	18.33	10.16
	1990-2020	14	11.29	8.03	7	26.14	19.92
MT-1	1960-1990	26	7.15	4.89	26	7.00	5.25
	1990-2020	23	6.83	5.09	23	8.26	6.13
SP-1	1960-1990	15	7.93	5.33	14	9.86	6.99
	1990-2020	21	8.29	5.97	16	11.81	8.88
SP-2	1962-1990	22	5.27	3.78	13	7.15	5.12
	1990-2020	26	7.38	5.53	16	11.25	9.10
SP-3	1960-1990	14	7.50	5.40	13	11.62	9.41
	1990-2020	14	8.36	5.68	13	10.31	8.24
TN-1	1960-1990	24	6.29	5.02	16	8.56	7.08
	1990-2019	26	6.27	5.13	16	10.81	8.60
TR-1	1960-1990	23	7.61	5.22	21	8.14	6.10
	1990-2019	20	6.40	4.87	16	7.06	6.43
TR-2	1960-1990	28	6.57	4.87	24	7.04	5.55
	1990-2020	27	6.78	5.22	20	8.35	6.92
TR-3	1960-1990	Nil			25	6.96	5.24
	1990-2020	Nil			20	8.85	6.60
TR-6	1960-1990	26	7.12	5.01	28	6.50	5.36
	1990-2020	24	6.92	5.10	21	7.33	6.04

Across the 18 rainfall stations included in Table 31, the frequency of observed droughts at the 3-month time scale was typically found to approach the number of years of monthly rainfall data recorded at a given location. As an example, in Luqa, Malta (MT-1), 49 droughts were observed both at the 3- and 6-month time scales over the period 1960-2020. By plotting the findings at the 3-month time scale for Luqa, Malta (MT-1) as shown in Figure 27, it can be derived that all moderate to severe droughts correspond to the summer season.

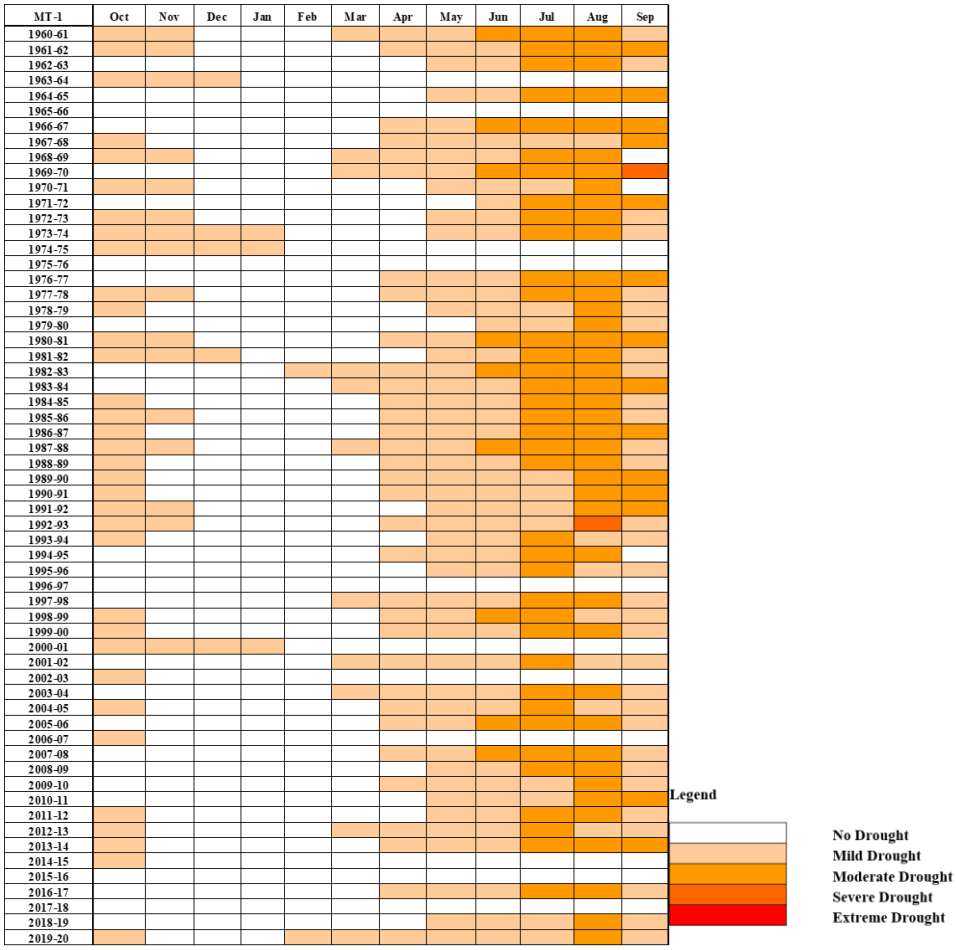

Figure 27. Droughts at 3-month time scale observed in Luqa, Malta (MT-1)

The same conclusion holds true for the three stations in Cyprus: Athalassa (CY-1), Larnaca (CY-2) and Troodos Square (CY-3); Alghero, Italy (IT-1); Valdivia-Villagonzalo, Spain (SP-2); Jouggar, Tunisia, (TN-1); and for three stations in Turkey: Adana (TR-1), Antalya (TR-2) and Izmir (TR-6). Thus, for 10 out of 18 stations, it is unlikely that droughts observed at the 3-month time scale would have impacted on agricultural yield. It is noteworthy that in Antalya, Turkey (TR-3), no droughts were observed at the 3-month time scale.

However, for the three rainfall locations in France, moderate to severe droughts at the 3-month time scale are observed not only during the summer season but throughout the year, as shown in Figure 28. This points to the likelihood that droughts (outside of the summer season) could have impacted on agricultural yield.

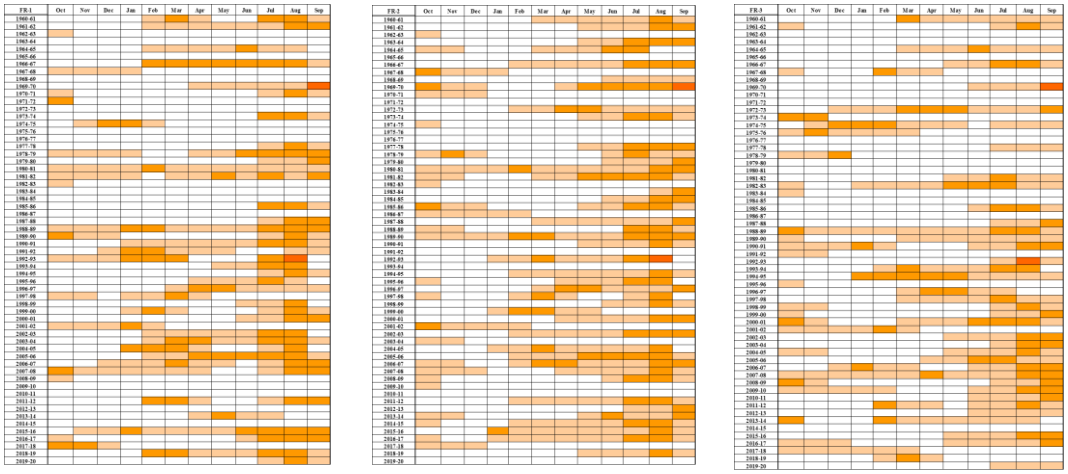

Figure 28. Droughts at 3-month time scale observed (from left) in Marseille-Marignane (FR-1), Nice (FR-2), and Perpignan (FR-3)

The observation for the three stations in France applies also to the observed droughts in Vallombrosa, Italy (IT-4), as well as to Barcelona (SP-1) and Valencia (SP-3), Spain as shown in Figure 29.

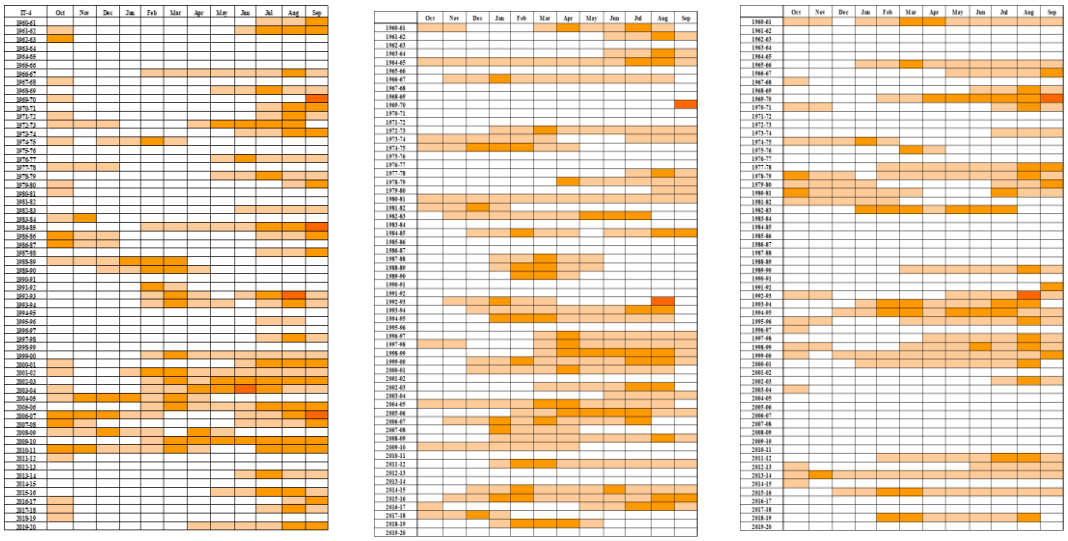

Figure 29. Droughts at 3-month time scale observed (from left) in Vallombrosa, Italy (IT-4), Barcelona (ES-1) and Valencia (ES-3), Spain

However, the pattern of droughts at the 3-month time scale in Venice, Italy (IT-5), as shown in Figure 30, follows a rather different regime from the other stations considered in this analysis, which merits further investigation.

The observed droughts in Venice, Italy (IT-5), both at the 3- and 6-month time scales are further illustrated in Figure 31, demonstrating that these droughts are typically longer and of a higher magnitude as compared to the other rainfall station locations considered in the present analysis. Thus, the impact on agricultural yield

of droughts is likely to be high in the region of Venice. This different pattern of droughts observed in Venice can be attributed to the Dinaric Alps, running parallel to the Adriatic coast, which are known to have a profound impact on precipitation. They act as a barrier, forcing moist air to rise and cool, leading to increased rainfall on the Adriatic side. This phenomenon is known as the often-cited effect of orography in the scientific literature. In turn, this phenomenon leads to less rainfall further inland.

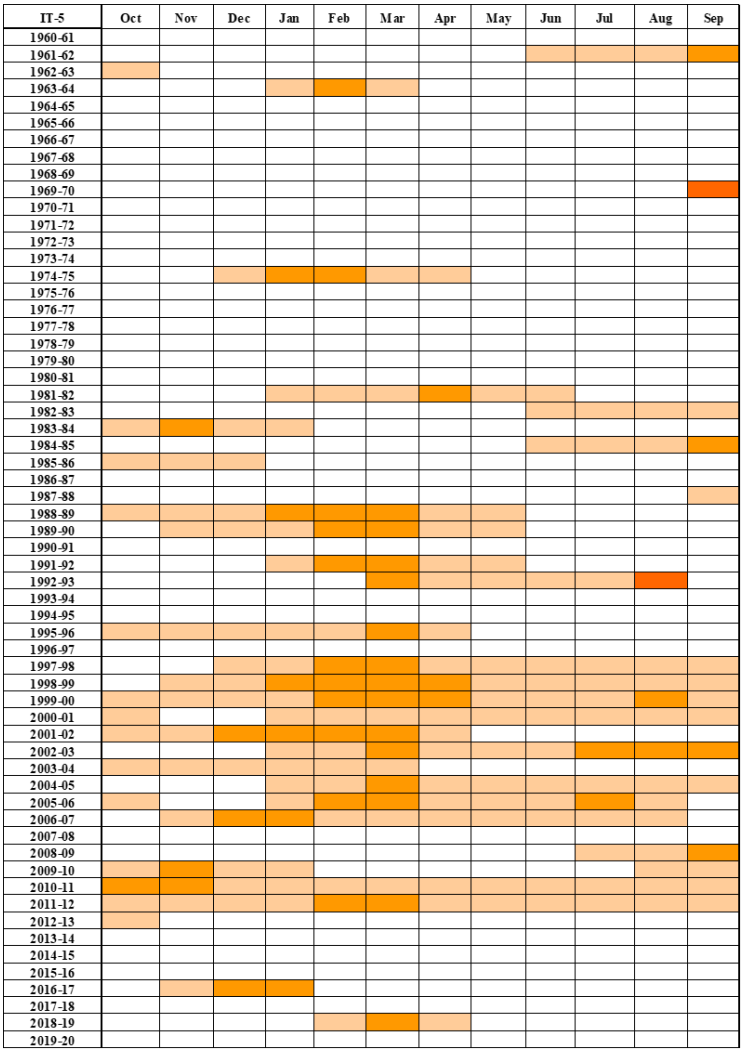

Figure 30. Droughts at 3-month time scale observed in Venice, Italy (IT-5)

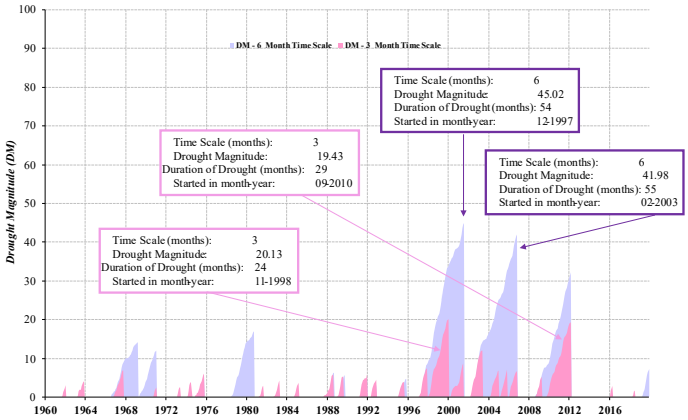

Figure 31. Droughts at 3- and 6-month time scale observed in Venice, Italy (IT-5)The average of the SPI outcomes at the 3- and 6-month time scales for the 18 stations included in the present analysis are presented in Table 32.

Table 33. Average of SPI outcomes at the 3- and 6-month time scales

All stations	Period covered	SPI outcomes at 3-month time scale			SPI outcomes at 6-month time scale		
		Frequency	Average Duration	Average Magnitude	Frequency	Average Duration	Average Magnitude
Average	1960-1990	21	7.01	4.98	19	9.03	6.65
	1990-2020	22	7.28	5.52	17	10.33	8.52

At the 3-month time scale, the frequency, average duration and average magnitude marginally increased when comparing the period 1990-2020 with the previous 30 years. At the 6-month time scale the frequency is marginally less while the average duration and magnitude show a moderate increase.

The 12- and 24-month time scales are linked to long-term drought conditions which affect river flows and groundwater storage. Similar to the analysis at the 3- and 6-month time scales our analysis focuses on those stations for which the monthly rainfall data is available throughout (or at least very close to) the full duration of the period from October 1960 to September 2020. The frequency, average duration and average magnitude at the 12- and 24-month time scales of the 18 rainfall stations retained for the purpose of the present analysis are provided in Table 34. The average frequency, duration and magnitude of the long-term droughts observed across these 18 stations is presented in Table 35.

Table 34. SPI outcomes at the 12- and 24-month time scales

Station code	Period covered	SPI outcomes at 12-month time scale			SPI outcomes at 24-month time scale		
		Frequency	Average Duration	Average Magnitude	Frequency	Average Duration	Average Magnitude
CY-1	1960-1990	9	15.44	14.00	6	21.33	20.31
	1990-2020	6	22.33	22.82	4	31.00	29.68
CY-2	1960-1990	7	19.86	14.65	5	19.60	22.81
	1990-2020	5	38.20	32.58	4	46.00	41.21
CY-3	1960-1990	5	17.80	16.68	3	22.00	29.46
	1990-2020	7	28.00	24.68	4	48.75	37.91
FR-1	1960-1990	7	18.43	13.26	4	30.75	24.94
	1990-2020	5	30.00	34.17	2	64.00	76.50
FR-2	1960-1990	10	16.90	12.84	5	28.20	23.94
	1990-2020	4	31.50	36.70	2	63.50	72.61
FR-3	1960-1990	8	19.63	16.95	6	28.17	24.74
	1990-2020	7	21.00	17.12	5	24.40	21.53
IT-1	1960-1990	5	19.40	10.56	3	24.33	21.04
	1990-2020	6	32.50	34.61	3	75.33	69.78
IT-4	1960-1990	5	24.40	18.58	3	37.00	38.51
	1990-2020	5	23.00	30.96	3	36.00	46.11
IT-5	1961-1990	4	28.00	17.94	2	26.50	27.04
	1990-2020	3	60.00	50.45	4	46.00	38.49
MT-1	1960-1990	8	16.88	16.92	5	20.40	26.20
	1990-2020	8	18.00	17.28	5	22.80	21.06
SP-1	1960-1990	5	18.60	13.52	3	24.33	23.43
	1990-2020	5	35.20	27.07	3	64.00	50.27
SP-2	1962-1990	3	25.67	22.19	2	51.00	42.19
	1990-2020	8	23.00	21.29	5	33.00	23.34
SP-3	1962-1990	9	17.00	14.13	5	29.20	26.93
	1990-2020	6	24.33	19.87	2	78.00	64.64
TN-1	1960-1990	4	35.75	29.68	3	47.33	23.75
	1990-2019	5	31.60	29.59	4	36.25	46.56
TR-1	1960-1990	8	20.00	17.12	4	32.50	34.35
	1990-2019	7	20.00	18.29	3	48.67	35.41
TR-2	1960-1990	5	26.00	20.40	4	38.25	35.79
	1990-2020	7	23.43	20.98	3	45.00	35.88
TR-3	1960-1990	5	19.40	13.67	4	34.00	19.05
	1990-2020	4	40.50	42.38	3	63.33	66.89
TR-6	1960-1990	9	16.78	12.05	5	28.40	22.69
	1990-2020	4	30.50	37.19	3	29.67	45.60

Table 35. Average of SPI outcomes at the 12- and 24-month time scales

All stations	Period covered	SPI outcomes at 12-month time scale			SPI outcomes at 24-month time scale		
		Frequency	Average Duration	Average Magnitude	Frequency	Average Duration	Average Magnitude
Average	1960-1990	6.44	20.88	16.40	4.00	30.18	27.06
	1990-2020	5.67	29.62	28.78	3.44	47.54	45.75

While on average the frequency of long-term drought events largely remained the same when comparing the period 1990 until 2020 with the previous 30 years, the average duration and magnitude of the drought events increased significantly. The drought events at the 12-and 24-time scales are further illustrated in Appendix 4. To enable a direct visual comparison between the different station locations, the drought magnitude axis ranges up to 100 months, except for two stations in Italy, Alghero (IT-1) and Vallombrosa (IT-4), where the drought magnitude axis ranges up to 200 months.

The observed increase in drought duration and drought magnitude during the period 1990-2020 as compared to the previous thirty years, suggests the Mediterranean Region is becoming more arid. This has been investigated further through the computation of the aridity index for selected locations.

The 12-month time scale permits to establish a relationship between duration (D), magnitude (DM) and return period (T) of long-term drought events. To establish this relationship, the magnitude of the drought events has been fitted to the Gumbel Extreme Value distribution:

$$F(X) = \exp\left[-e^{-b(X-a)}\right] \tag{3}$$

where $F(X)$ is the probability of a drought magnitude $DM \leq X$ and *a* and *b* are two parameters related to the moments of the population of DM values, i.e.

$$a = \mu_Q - \frac{0.5772}{b} \tag{4}$$

$$b = \frac{\pi}{\sigma_Q \sqrt{6}} \tag{5}$$

Substituting the parameters with the mean $\overline{DM}$ and standard deviation s_{DM} of the observed (historical) drought events as estimates of the population values μ_{DM} and σ_{DM}, then estimates of X may be obtained from:

$$X_{estimated} = \bar{Q} + K(T)s_Q \tag{6}$$

$$DM_{T,estimated} = \overline{DM} + K(T)s_{DM} \tag{7}$$

where,

$$K(T) = -\frac{\sqrt{6}}{\pi}\left(0.5772 + \ln\left(-\ln\left[\frac{T(X)-1}{T(X)}\right]\right)\right) \tag{8}$$

$K(T)$ is called the frequency factor and is a function only of the Return Period T, which is specific to the Gumbel Extreme Value distribution.

Based on this assumption that the probability distribution of droughts matches the Gumbel Extreme Value distribution, the SPI values obtained at the 12-month time scale have been used to derive the duration-magnitude-return period relationship, as shown in Figures 32 and 33. Two locations in Turkey, TR-6 (Izmir) and TR-6 (Antalya) are associated with the highest expected drought magnitude and duration for a given return period, with the reverse finding for the station FR-3 (Perpignan) in France.

As can be derived from Figures. 32 and 33, the stations do not follow the exact same sequence in terms of drought severity and drought duration, rendering it unfeasible to e.g. group the station locations in sets of different categories. From Figures 32 and 33, it can only be derived that e.g. over a period of 100 years, the drought magnitude at the 12-month time scale reaches an average of 53 months, with a minimum of 33 months and an expected maximum of 86 months. Similarly, the drought duration reaches and average 58 months, with a minimum of 38 months and a maximum of 105 months.

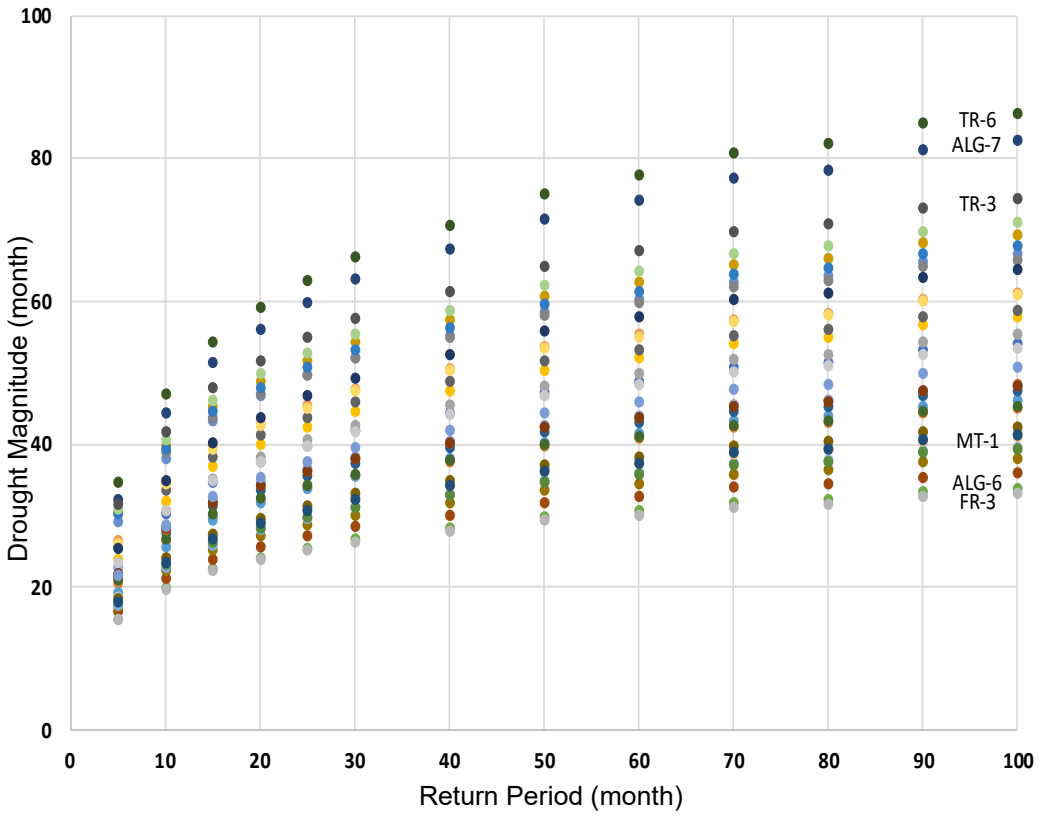

Figure 32. Drought Magnitude vs Return Period

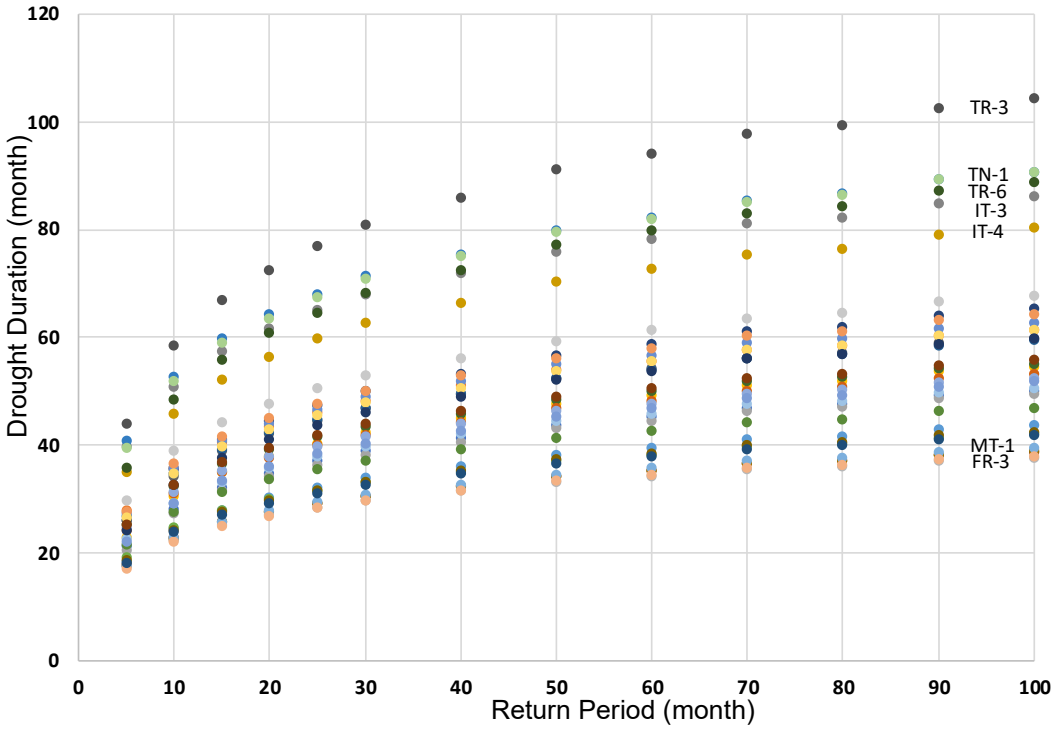

Figure 33. Drought Duration vs Return Period

Despite its advantages, SPI has limitations. It solely focuses on precipitation, neglecting other factors like temperature and wind that influence drought severity (Mishra and Singh, 2011). For selected locations where both the temperature and the rainfall data sets were obtained, the Reconnaissance Drought Index (RDI) has been computed. This enabled, on the one hand, to gain insights to what extent the outcomes of the RDI-based analysis differ from those obtained using the SPI. It also enabled to calculate a potential shift in the Aridity Index.

Reconnaissance Drought Index (RDI): The RDI takes also the temperature, and hence the evapotranspiration into account (Tsakiris and Vangelis, 2005). The initial value of the index for a certain period, indicated by a certain month (k) during a year, is calculated by the equation below.

$$a_k = \frac{\sum_{j=1}^{j=k} P_j}{\sum_{j=1}^{j=k} PET_j} \tag{9}$$

where, P_j and PET_j are the precipitation and the potential evapotranspiration of month j. By choosing a_1 to coincide with the starting month of the hydrological year,

a_{12} represents the aggregated value obtained at the end of the hydrological year at a given rainfall gauge location.

An estimate of the potential evapotranspiration is obtained using the empirical formula developed by Thornthwaite:

$$PET_j = 16\alpha_j \left(\frac{10\overline{T}_j}{I} \right)^a \tag{10}$$

Where $\overline{T}_j$ is the monthly mean temperature in °C, and *I* is the heat index for the year, given by:

$$I = \sum i_j = \sum \left(\frac{\overline{T}_j}{5} \right)^{1.5} \tag{11}$$

and

$$a = 6.7x10^{-7}I^3 - 7.7x10^{-5}I^2 + 1.8x10^{-2}I + 0.49 \text{ for j = 1, 2, …, 12} \tag{12}$$

and where α_j is the monthly adjustment factor related to hours of daylight N_j for the appropriate latitude, and the number of days d_j in a given month j:

$$\alpha_j = \frac{N_j}{12} \times \frac{d_j}{30} \tag{13}$$

The RDI has two expressions, i.e. Normalised RDI (RDI_n) and Standardised RDI (RDI_{std}). The Normalised RDI and the Standardised RDI are computed by respectively:

$$RDI_n(k) = \frac{a_k}{\overline{a}_k} - 1 \tag{14}$$

$$RDI_{std}(k) = \frac{y_k - \overline{y}_k}{\hat{\sigma}_k} \tag{15}$$

where, a_k is the initial value for each month, $\overline{a}_k$ is the average value of a_k, y_k is the lognormal value of a_k [$\ln(a_k)$], $\overline{y}_k$ is its arithmetic mean and $\hat{\sigma}_k$ is its standard deviation.

For the present analysis, the RDI_{std} has been computed and interpreted according to the classification provided in Table 36.

Table 36. RDIstd classification

Drought Classes	RDI Values
Extremely Wet	>2.00
Very Wet	1.50 to 1.99
Moderately Wet	1.00 to 1.49
Near Normal	-0.99 to 0.99
Moderately Dry	-1.00 to -1.49
Severely Dry	-1.50 to -1.99
Extremely Dry	<-2.00

Aridity Index (AI): It can be noted that the RDI_{std} values allow for a direct comparison with the SPI values when using a 12-month time scale for both the SPI approach and for the computation of RDI_{std} ($\ln a_k = \ln a_{12}$). Furthermore, the average value $\overline{a}_{12}$ is comparable to the Aridity Index (AI) as defined in World Atlas of Desertification (UNEP, 1992).

$$AI = \frac{P}{PET} \tag{16}$$

where, P is the average annual precipitation and PET is the average annual potential evapotranspiration, leading to the classification shown in Table 37.

Table 37. Aridity Index classification

Classification	Aridity Index
Hyperarid	AI<0.05
Arid	0.05<AI<0.20
Semi-arid	0.20<AI<0.50
Dry sub-humid	0.50<AI<0.65

For the analysis, the Aridity Index has been calculated using the annual rainfall and potential evapotranspiration, to obtain AI values for each year *i* from:

$$AI_i = \frac{P_i}{PET_i} \tag{17}$$

The findings for 5 locations for which also the monthly temperature over the period from 1960 to 2020 was collected have been summarized in Table 38. At each of these 5 locations, a downward trend in the Aridity Index values is observed. As mentioned, the standardized Reconnaissance Drought Index approach enables a

direct comparison with the Aridity Index (AI) at the 12-month time scale as defined in World Atlas of Desertification (UNEP, 1992).

A more dramatic change is observed in Barcelona (SP-1), Spain where the Aridity Index dropped from 0.91 to 0.60. At the same time, the temperature increased by 2.5 degrees Celsius over the period from 1960 to 2020. A continuation of these trends into the future would imply that Barcelona will be classified as 'semi-arid' by 2038 as the Aridity Index would decrease to 0.5. Similarly, a continuation of the observed trend in Menemen (TR-7), Turkey, is set to render the area being classified as 'arid' by 2056, i.e. the Aridity Index reaching the value of 0.2.

Table 38. Outcomes of aridity index calculations

Rainfall station code	Average annual temperature (T) (°C)	Change in temperature over period analysed (°C)	Average annual rainfall (P) (mm)	Average annual potential evapotranspiration (PET) (mm)	Average Annual Aridity Index (AI)	Change in AI over period analysed
SP-1	16.04	+2.5	600.28	815.52	0.74	0.91 => 0.60
SP-3	18.08	+2.1	462.55	903.04	0.51	0.54 => 0.49
MT-1	18.92	+1.3	536.53	949.41	0.57	0.62 => 0.53
TR-6	17.96	+1.3	711.14	956.31	0.74	0.75 => 0.73
TR-7	17.29	+0.6	528.79	931.03	0.57	0.69 => 0.39

4.2. Qualitative Findings

In the Systems Mapping implementation section in the second Turkish CoP workshop, first, the attendees were divided into two working groups and asked to fill in their feedback on the developed “Survivability from Drought Index” to the self-adhesive stickers and peg them on the corresponding part of the canvases according to their opinion as follows (Figure 34),



Figure 34. Attendees giving their feedback on the asked questions through the provided self-adhesive stickers

Quadrant 1 - System/advanced: if the participant is already aware of some similar index and if the participant thinks that SDI can be applied to other sectors and not just to the farming sector. If so participant to write down on the note the other sector(s).

Quadrant 2 – Sector/advanced: if the participant is aware of some similar index and if the participant thinks that SDI can be applied only to the farming sector.

Quadrant 3 – System/initial: if the participant is unaware of some similar index and if the participant thinks that SDI can be applied to other sectors and not just to the farming sector. If so participant to write down on the note the other sector(s).

Quadrant 4 – Sector/initial: if the participant is unaware of some similar index and if the participant thinks that SDI can be applied only to the farming sector.

Second, the attendees were asked to fill in their feedback on what the possible stakeholders might be to the stickers. In the third step, the attendees were asked to express their feedback on the usefulness of the developed “Survivability from

Drought Index" lastly on the final step, the final version of the canvases was discussed with the participants to find similarities/linkages between stakeholders or linkages between opportunities (Figure 35).

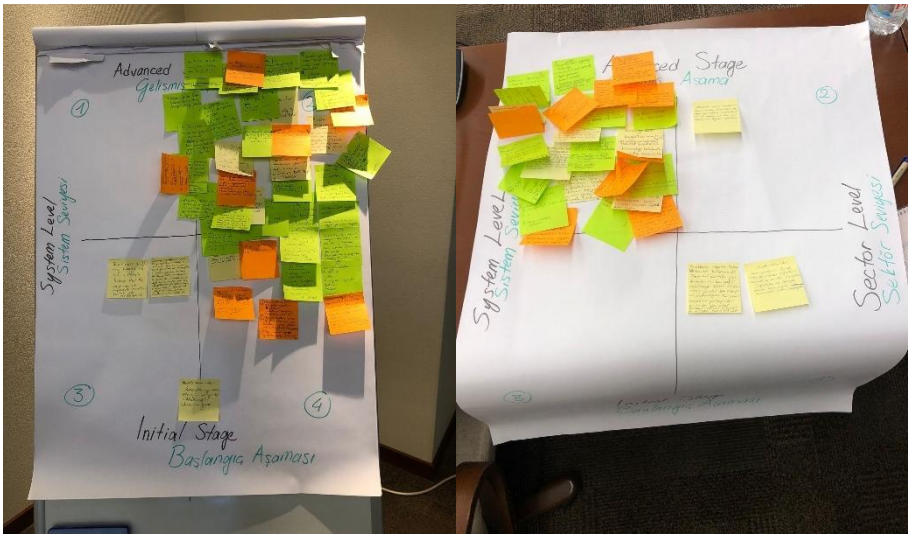

Figure 35. Final versions of the canvases of the two working groups

The exercise results (Figure 36) shows that the group 1 considers that the SDI can only be applied to the farming sector where the group 2 evaluates that the SDI can be applied to other sectors and not just to the farming sector. Both groups agree that the SDI is an advanced stage concept. Moreover, the sticky notes feedback indicates that the SDI will be most beneficial as it is an integrated tool for the farmers, researchers, decision-makers, and the general public in the scope of drought management plans, action plans, and prioritization of drought-prone areas.

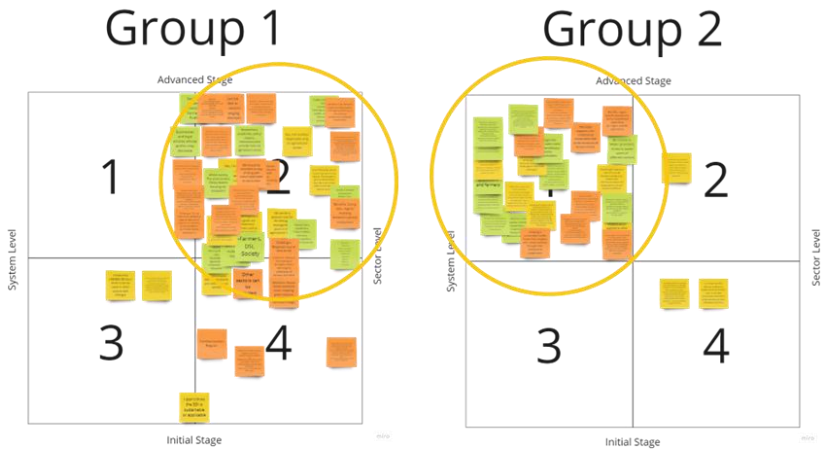

Figure 36. Outcomes of systems mapping exercise of the two groups of attendees in the 2nd CoP event in Türkiye

5. DISCUSSION

The UNIMED project has successfully developed and validated a novel, integrative framework—the Survivability of Droughts Index (SDI)—designed to assess the resilience of agricultural systems under Mediterranean climate change conditions. By incorporating a wide range of socio-economic, environmental, and hydrological indicators, the SDI advances the current discourse on drought risk assessment, moving beyond conventional meteorological indices to include perception, adaptability, vulnerability, and recoverability dimensions. This multidimensional approach not only captures the complex interdependencies within the Water-Energy-Food-Ecosystem (WEFE) nexus but also reflects the lived experiences and capacities of local stakeholders through participatory methods.

The implementation of the SDI in the Gediz River Basin (Türkiye) and key agricultural regions in Malta revealed significant spatial and temporal variations in drought survivability. In Türkiye, the SDI score of 49.15% for the base year of 2023 indicated a moderate level of resilience, with notable deficiencies in the Adaptability and Recoverability sub-indices—particularly in indicators such as rainwater harvesting, access to relief, and soil fertility. Historical comparisons with wetter (1982) and drier (1991–1992) periods affirmed the SDI's capacity to distinguish variations in drought conditions, with corresponding index values demonstrating lower resilience in the past. Importantly, these findings underscore that drought survivability is not solely determined by climatic parameters such as precipitation deficits or SPI-based drought risk, but also by systemic social and economic factors that shape adaptive capacity and post-drought recovery.

In Malta, data limitations were more pronounced; however, the application of a tailored "best available" set of indicators enabled the derivation of SDI scores for representative years (2000, 2010, 2020). Results revealed modest improvement over time in key indicators such as training exposure, institutional preparedness, and stakeholder engagement. Nonetheless, persistent structural vulnerabilities remain, particularly regarding water exploitation, limited diversification of income, and constrained access to financial relief and alternative water sources. These observations highlight the need for targeted policy interventions that promote integrated water resource management and resilience-building investments, especially in small island contexts where ecological and infrastructural constraints are more severe.

A notable strength of the UNIMED approach lies in its rigorous stakeholder engagement methodology. The use of Communities of Practice (CoP), Value-Attitude-Perception (VAP) surveys, and EIT Climate-KIC system mapping allowed for the integration of qualitative insights into the quantitative assessment framework. This hybrid methodology ensured that the SDI was context-sensitive, reflecting local priorities, and enhancing its relevance and usability for both policy-makers and agricultural communities. The iterative weighting process—via budget point allocation—further emphasized the participatory essence of the framework, while reducing expert bias through collective decision-making.

Despite these achievements, some limitations must be acknowledged. The reliance on self-reported data for several indicators, while invaluable for capturing subjective dimensions such as perception and attitude, introduces potential biases that may affect the robustness of the results. Additionally, the limited temporal scope of certain indicators and the use of expert-based estimations for historical periods may constrain the precision of longitudinal comparisons. Moreover, the extrapolation of SDI findings to regions beyond the pilot areas must be approached with caution, given the specificity of data sources and regional environmental dynamics.

In conclusion, the SDI offers a replicable, flexible, and policy-relevant tool for assessing drought survivability across diverse Mediterranean agro-ecological contexts. By synthesizing environmental, economic, and social data within a coherent index structure, the UNIMED framework not only provides actionable intelligence for adaptive drought governance but also lays the groundwork for future research aimed at refining and expanding resilience metrics in response to evolving climate risks.

6. CONCLUSIONS AND RECOMMENDATIONS

The UNIMED project has addressed a critical gap in drought resilience research by developing and operationalizing the Survivability of Droughts Index (SDI), a holistic and multi-dimensional framework that integrates physical, ecological, and socio-economic indicators to assess agricultural resilience in Mediterranean regions. The application of SDI in two distinct case studies—Türkiye's Gediz River Basin and agricultural areas in Malta—demonstrated its versatility, diagnostic power, and relevance to both local and regional drought management strategies.

The SDI results for the Gediz River Basin reveal a moderate level of drought survivability (49.15%), with distinct weaknesses observed in the dimensions of adaptability and recoverability. Notably, limited rainwater harvesting, inadequate access to relief mechanisms, and low soil fertility stand out as major impediments to resilience. The temporal assessment further confirmed that improvements in institutional support, knowledge dissemination, and diversification of agricultural practices over recent decades have positively influenced the capacity to withstand drought, though significant vulnerabilities persist.

In Malta, while the availability of detailed data posed constraints, the adapted SDI model provided meaningful insights into the structural challenges faced by the agricultural sector. The findings highlighted the importance of increasing training opportunities, enhancing water-use efficiency, and expanding economic support mechanisms such as subsidies and relief funds.

Drawing on these insights, the following recommendations are proposed to enhance drought resilience across Mediterranean agricultural systems:

Institutionalize the SDI Framework: Integrate the SDI into national and regional drought monitoring systems to support evidence-based planning and resource allocation. This will enable authorities to identify and prioritize drought-prone areas with precision.

Strengthen Data Infrastructure: Improve the collection, accessibility, and consistency of data related to social, environmental, and economic indicators—particularly those concerning smallholder farmers and marginalized rural communities.

Enhance Stakeholder Engagement: Institutionalize participatory approaches such as Communities of Practice (CoP) and VAP surveys as integral components of drought policy design and implementation, ensuring that local knowledge informs adaptive strategies.

Invest in Nature-Based Solutions and Water Alternatives: Promote the adoption of sustainable water management practices, including rainwater harvesting, treated wastewater reuse, and soil restoration measures that enhance both water retention and agricultural productivity.

Support Adaptive Capacity: Expand access to drought-resistant seed varieties, technical training, and climate-smart agricultural technologies that bolster the adaptability of farming systems.

Develop Financial Safeguards: Improve access to credit, insurance schemes, and emergency relief funds to support post-drought recovery and reduce long-term economic stress on agricultural communities.

Policy Alignment and Scaling: Align SDI-related recommendations with broader policy frameworks, such as the European Green Deal, Farm to Fork Strategy, and Common Agricultural Policy, to enable strategic funding and scalable interventions.

In summary, the UNIMED project demonstrates that effective drought resilience cannot rely solely on hydrological metrics or infrastructure investment. Rather, a systems-based, stakeholder-informed approach—anchored in data, participatory processes, and institutional commitment—is essential to ensuring the long-term sustainability of agriculture in drought-prone Mediterranean regions. The SDI presents a replicable foundation for such efforts, offering a pathway toward climate-resilient, socially inclusive, and ecologically sound agricultural development.

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