Drought : science, tools and trends

Takumi Therville
University of Antwerp

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Definition of drought

"Droughts refer to periods of time with substantially below-average moisture conditions, usually covering large areas, during which limitations in water availability result in negative impacts for various components of natural systems and economic sectors.

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What?

Droughts refer to periods of time with substantially below-average moisture conditions, usually covering large areas, during which **limitations in water availability** result in negative impacts for various components of natural systems and economic sectors.

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When?

From a few days and weeks,

Through a few months,

to several years.

> Droughts refer to **periods of time** with substantially below-average moisture conditions, usually covering large areas, during which limitations in water availability result in negative impacts for various components of natural systems and economic sectors.

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When/where?

Droughts refer to periods of time with substantially **below-average moisture conditions**, usually covering large areas, during which limitations in water availability result in negative impacts for various components of natural systems and economic sectors.

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Drought vs Aridity

Drought : temporary abnormally dry

Aridity : permanent* climate feature

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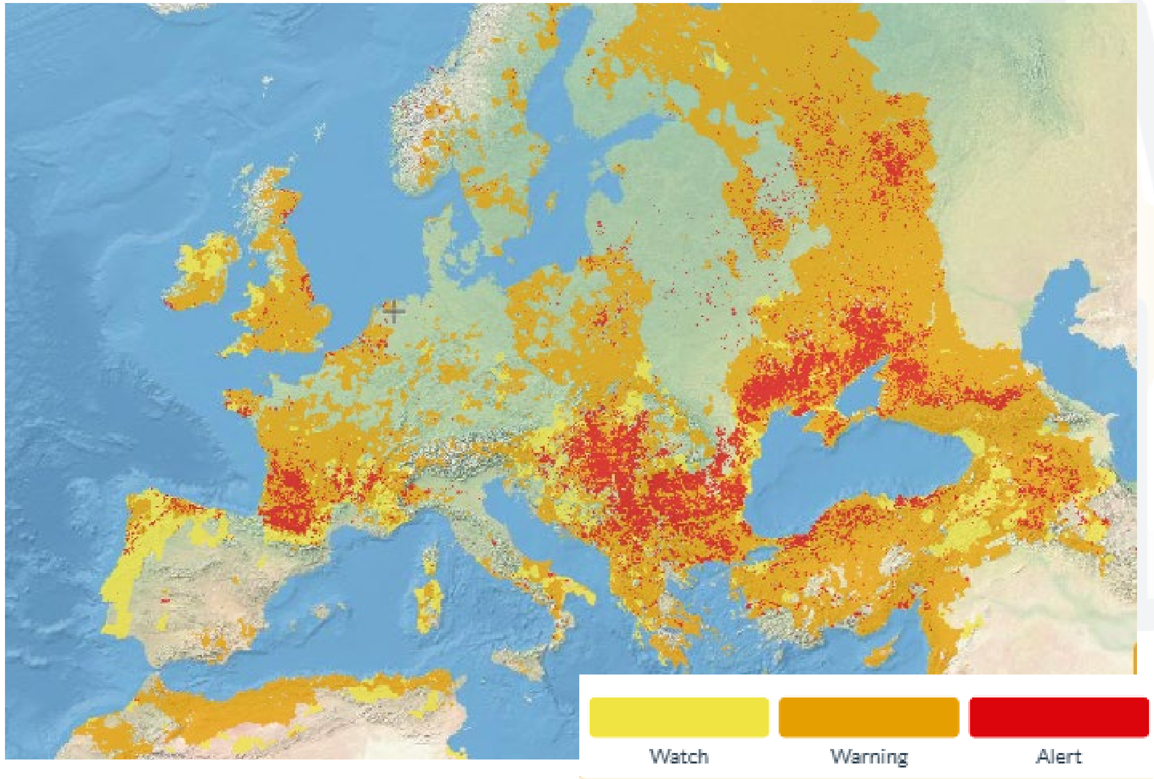
Drought vs Aridity

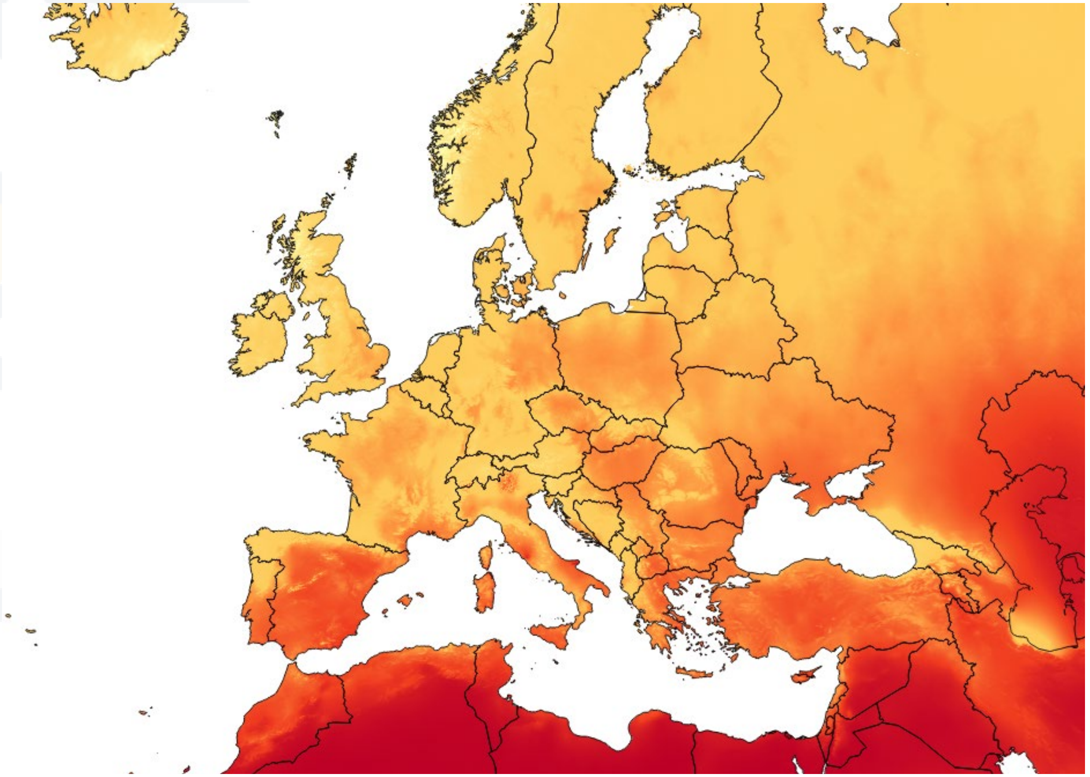
Drought

Situation 2025-09-01 European drought observatory (EDO)



Aridity

(Zomer, R.J., Xu, J. & Trabucco, A, 2022)



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What is drought

Droughts refer to periods of time with substantially below-average moisture conditions, usually covering large areas, during which limitations in water availability result in **negative impacts for various components of natural systems and economic sectors.**

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Impacts of droughts

Ecosystem

Vegetation stress and loss
(Powers et al., 2020)

Satellite images of drought impact on vegetation cover
(Cappucci, 2022)

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Impacts of droughts

Wildfires (Littell et al., 2016; JRC 2023)

Ecosystem

European Commission

The Joint Research Centre: EU Science Hub

Home > JRC news and updates > The EU 2022 wildfire season was the second worst on

NEWS ANNOUNCEMENT | 2 May 2023 | Joint Research Centre | 3 min read

The EU 2022 wildfire season was the second worst on record

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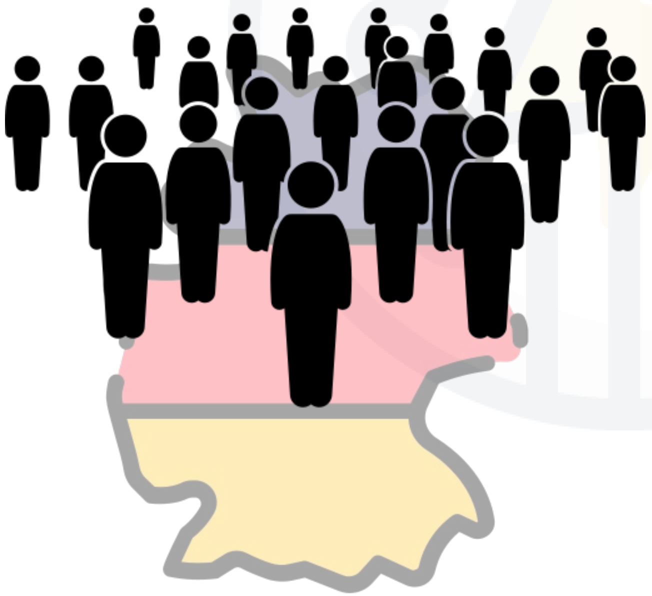
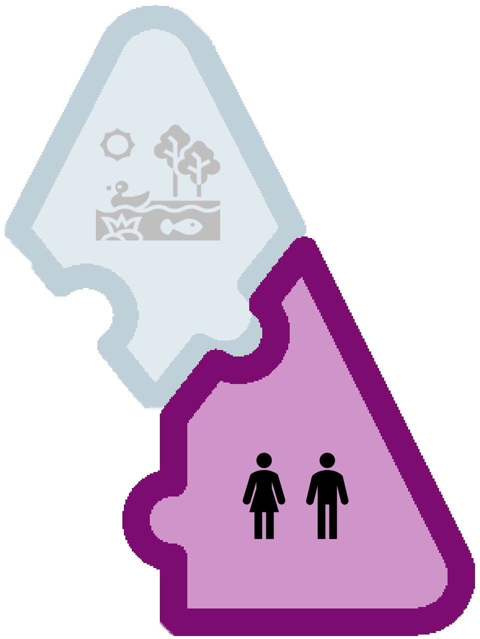
Impacts of droughts

Social

Every year, enough calories to feed the population of Germany are lost to droughts (World Bank 2017)





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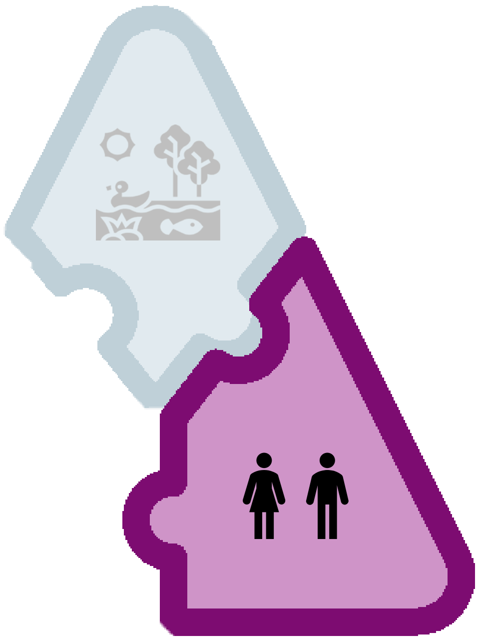
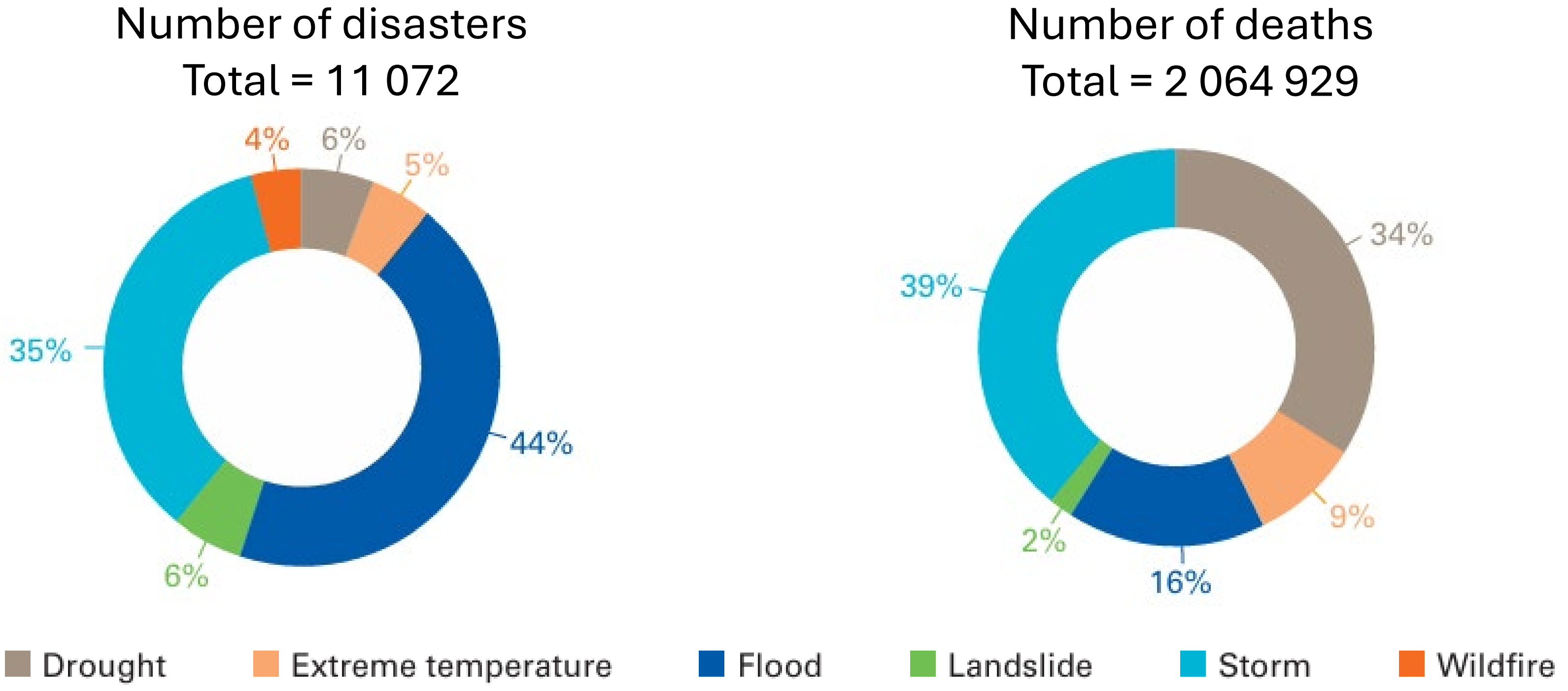
Impacts of droughts

Social



Number of reported disasters and deaths from 1970-2019 (WMO 2021)



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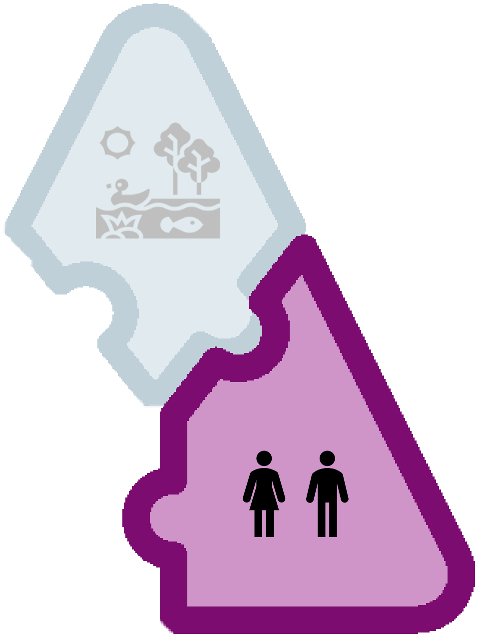
Impacts of droughts

Social

Conflicts, social unrest and breakdown
(Lucchetti, 2017)



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Im

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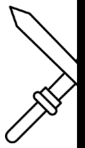
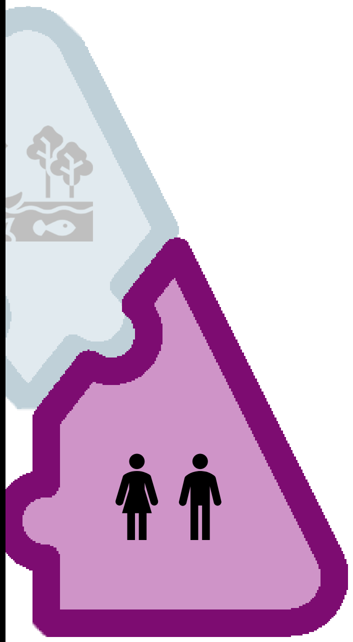
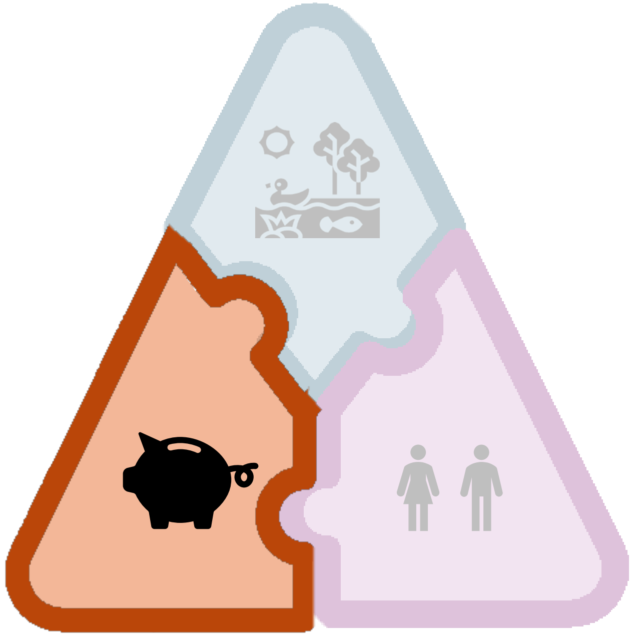




Impacts of droughts

Economic



Transportation and supply chain disruptions

Industrial and energetic water restrictions

The New York Times

European Heat Wave | What to Know | Maps | Wildfires | Paris Braces for the Future | Spain's Old Ways of Coping | Managing Extreme Heat

Europe's Scorching Summer Puts Unexpected Strain on Energy Supply

The dry summer has reduced hydropower in Norway, threatened nuclear reactors in France and crimped coal transport in Germany. And that's on top of Russian gas cuts.

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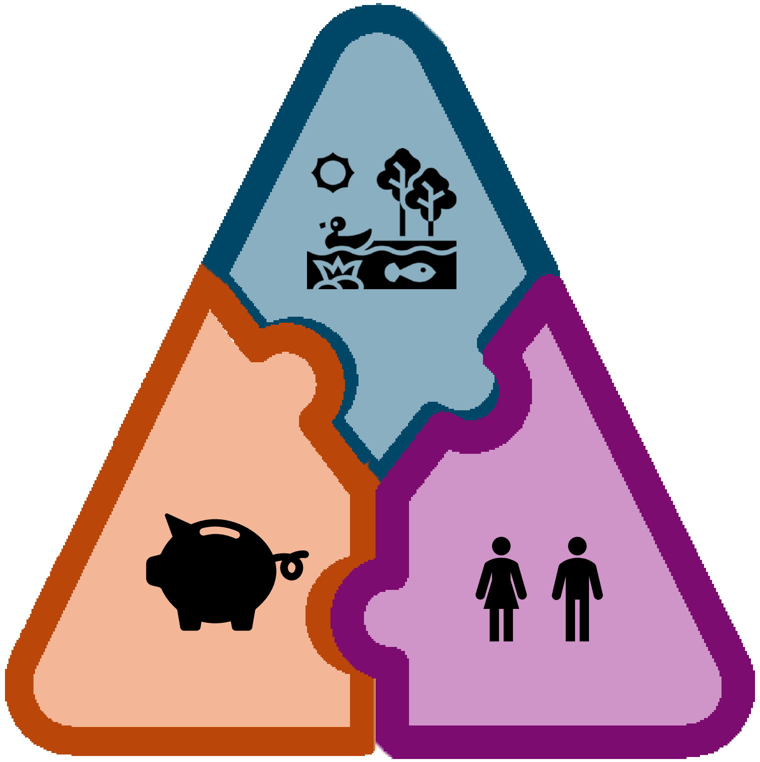
What is drought?

Drought isn't just a lack of rain — it's a complex hazard, defined **relative to normal conditions**, with impacts that **ripple through** systems. And crucially — ***no region is immune***.



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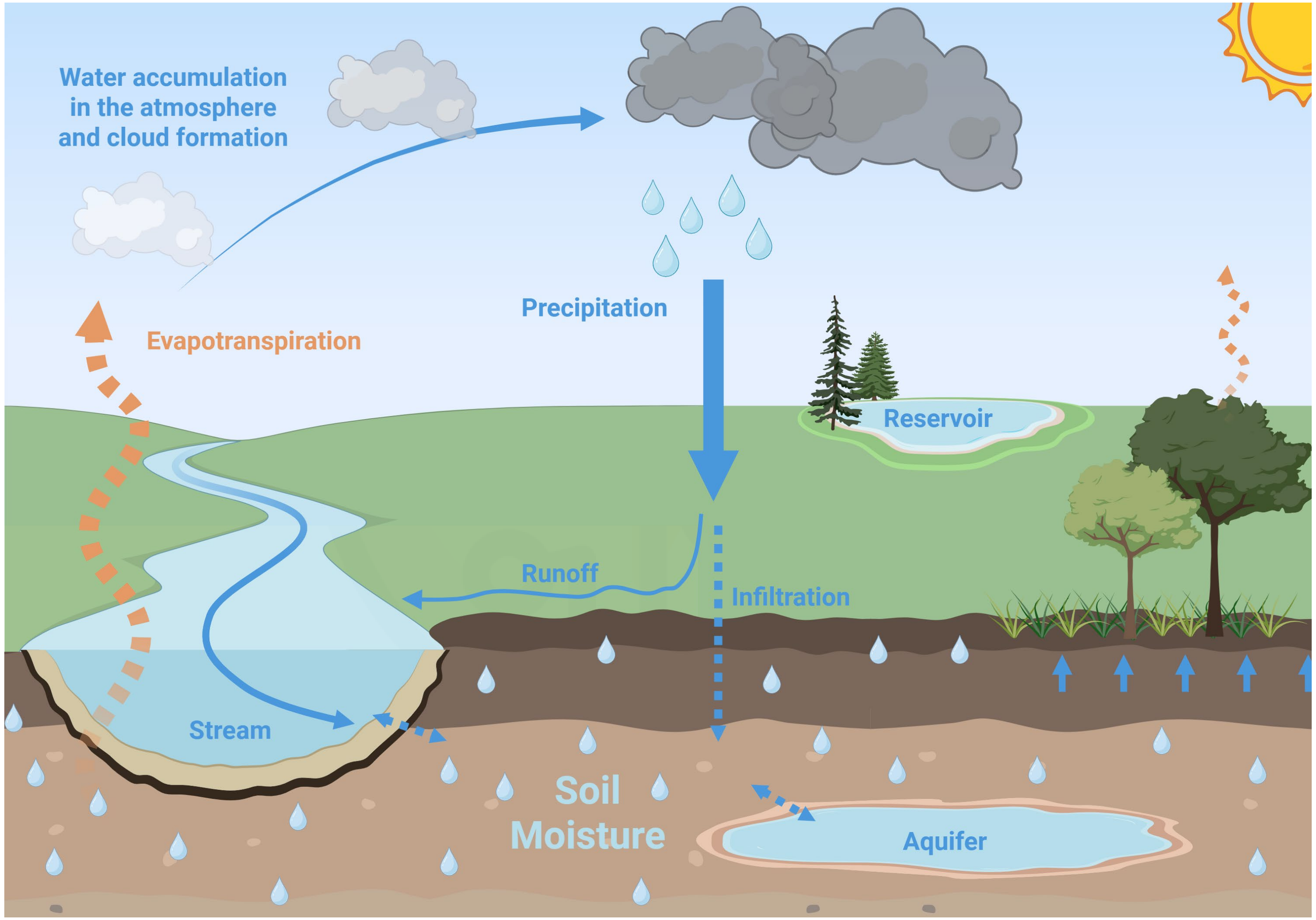
Physical mechanisms



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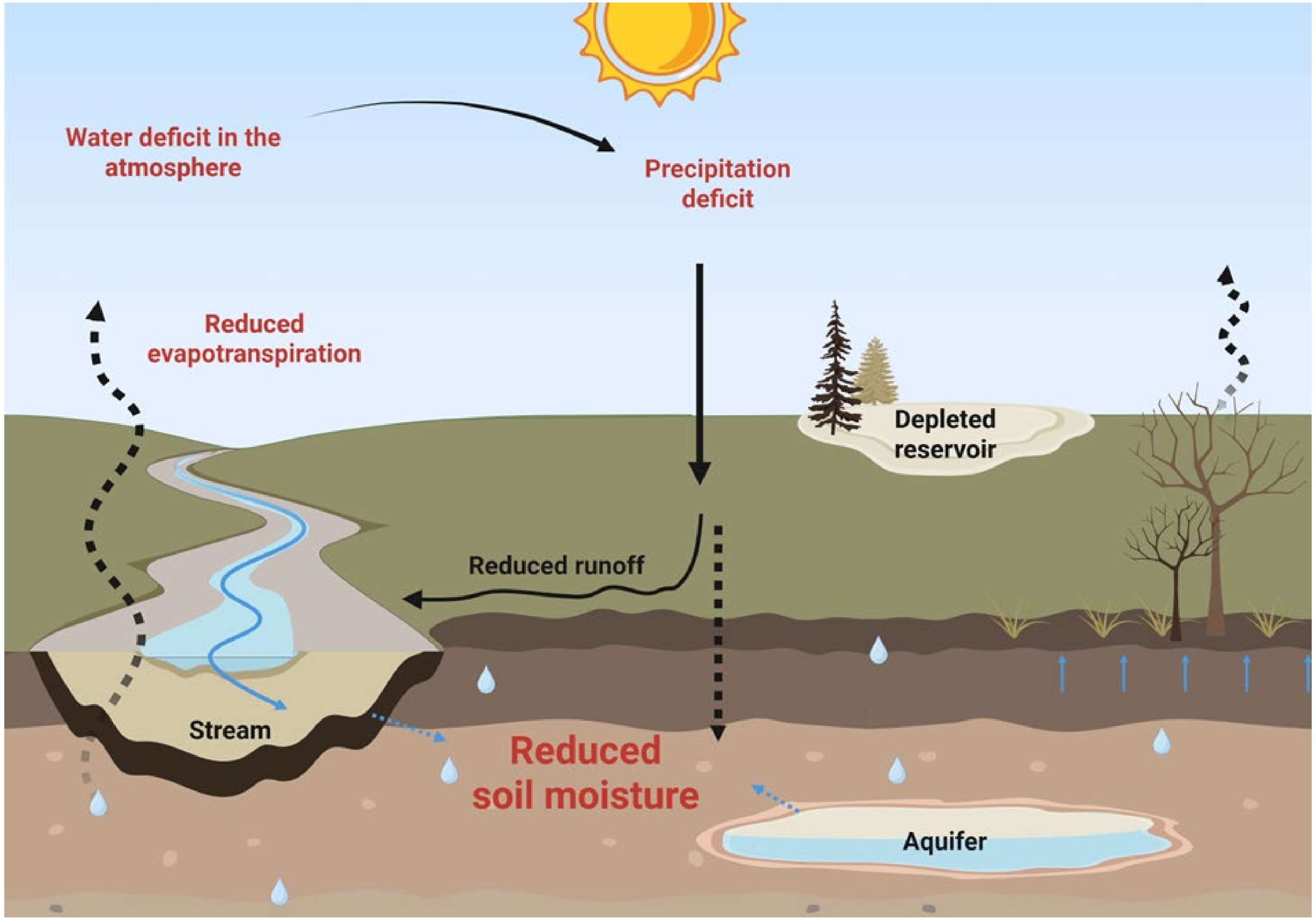
Physical mechanisms



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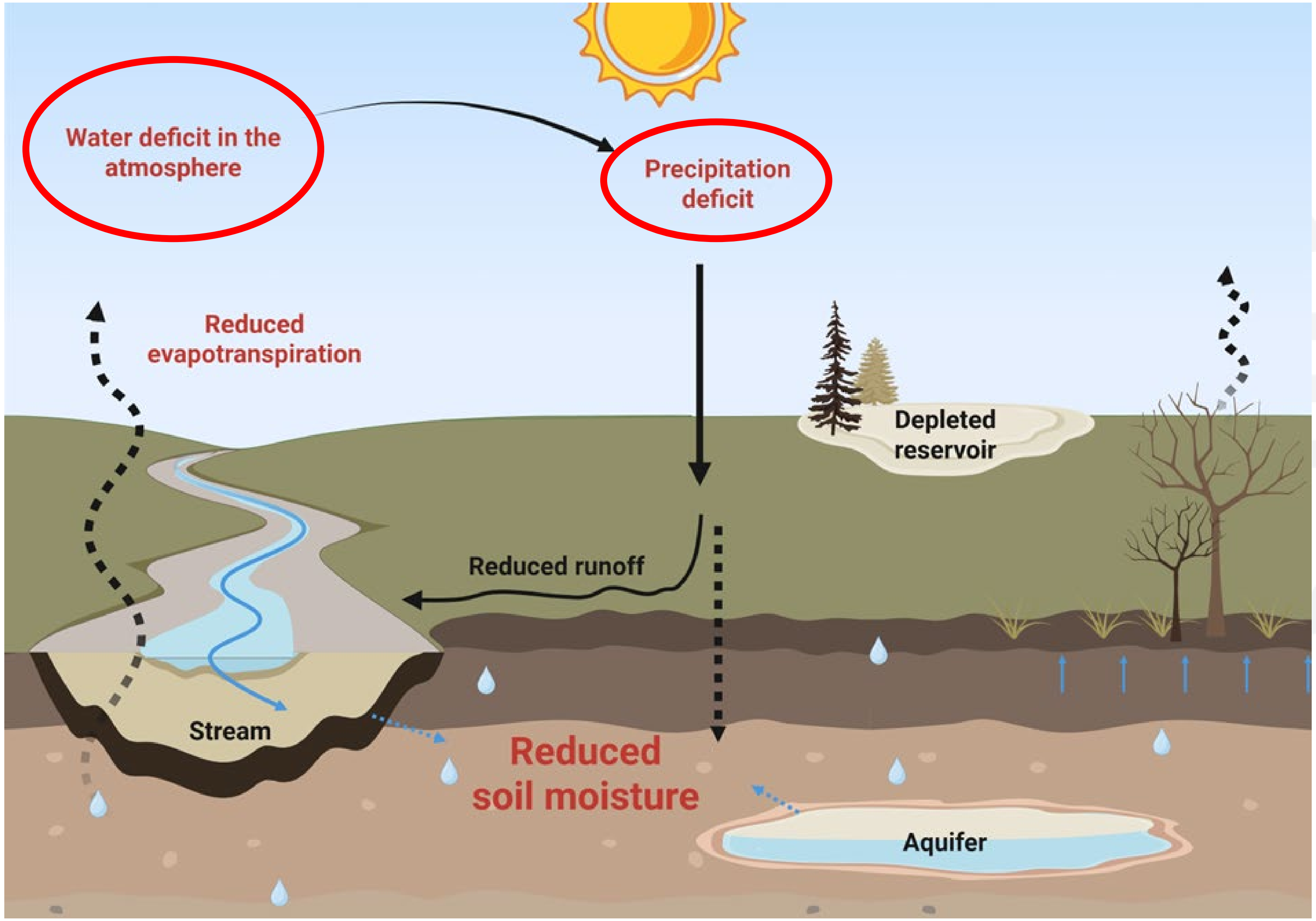
Different drought types



Meteorological drought

- Rainfall deficit
- Water vapor deficit

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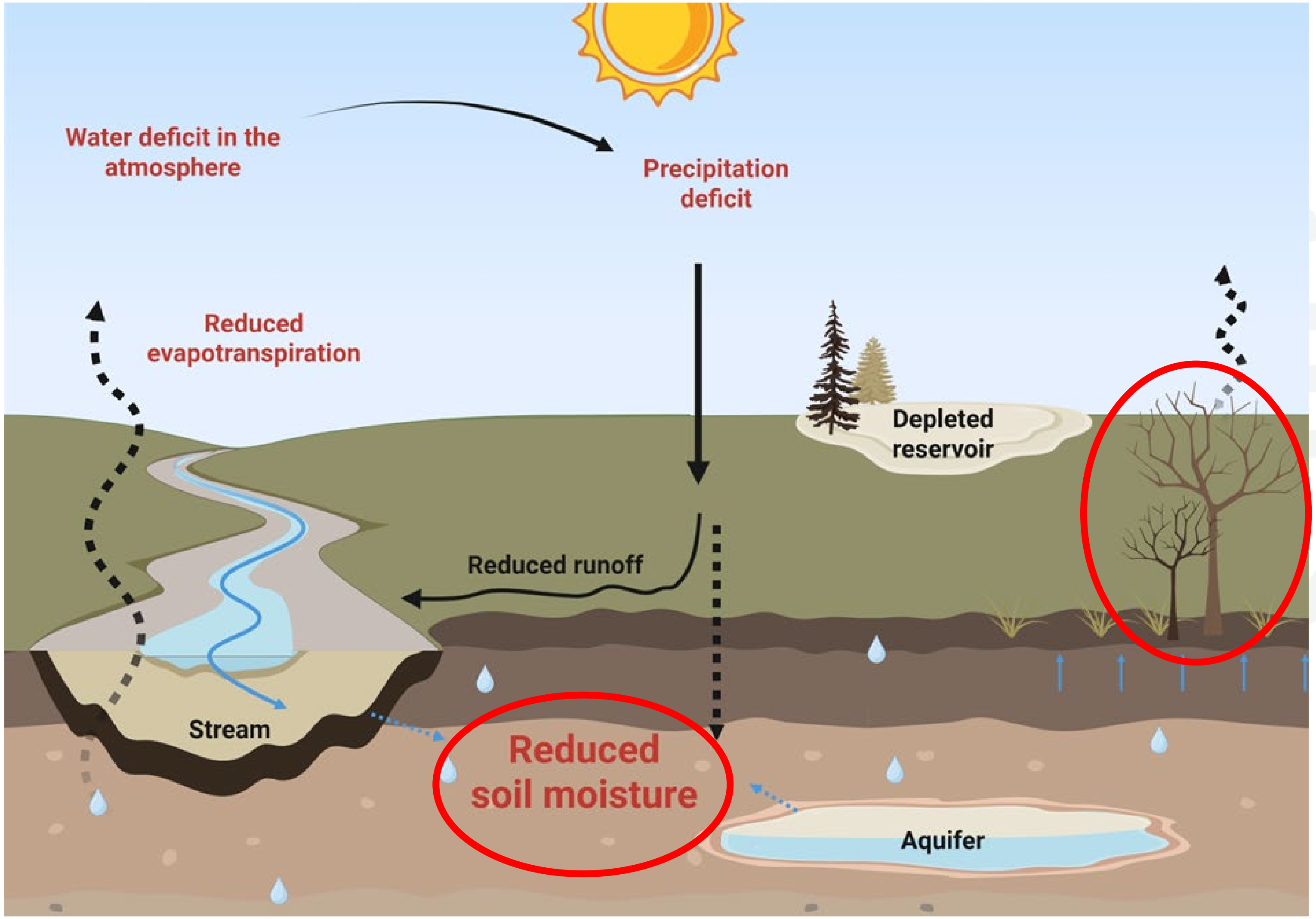
Different drought types



Time (duration)

Meteorological drought

Agricultural drought

- Soil moisture depletion
- Vegetation stress
- Crop yield reduction

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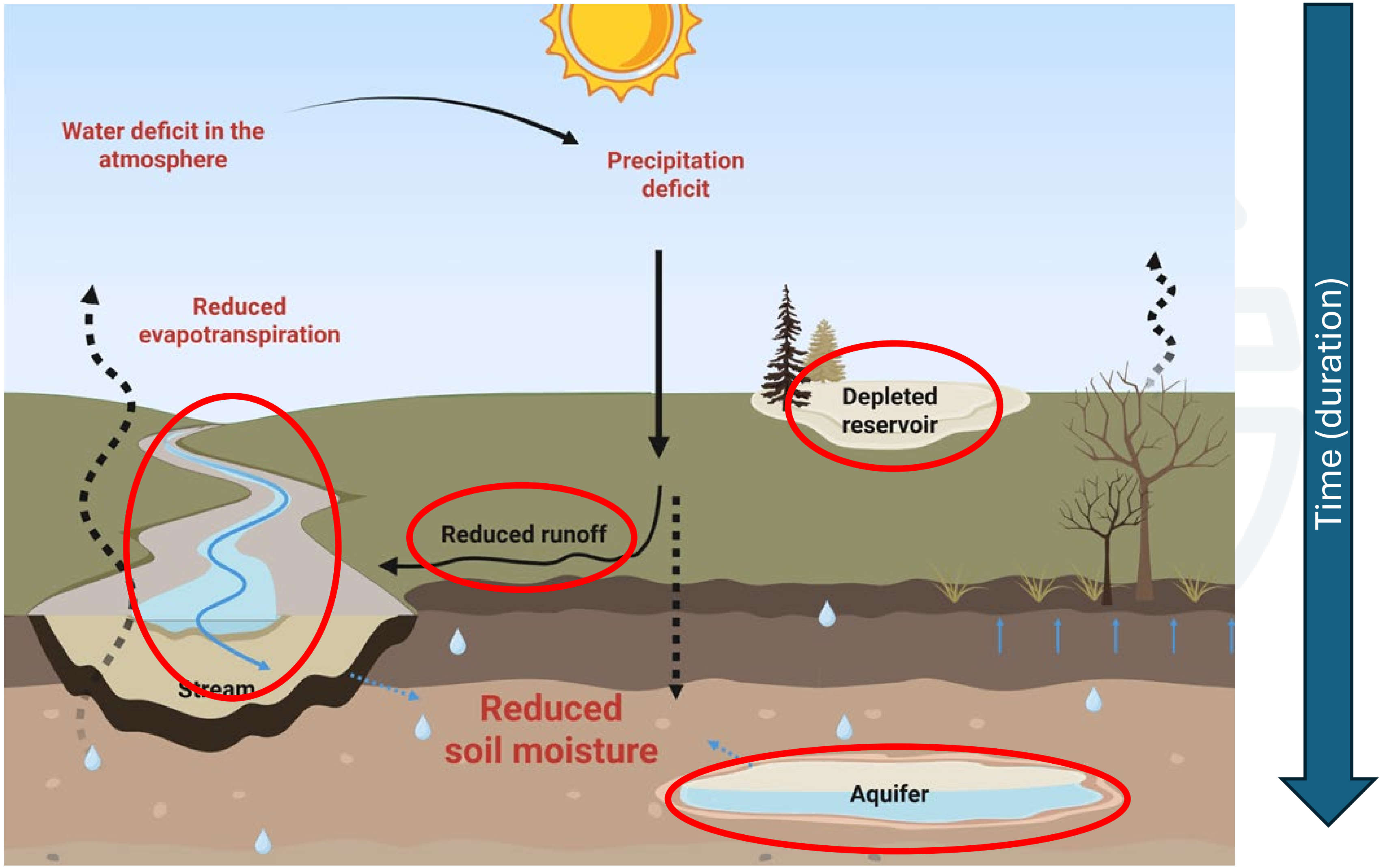
Different drought types



Meteorological drought

Agricultural drought

Hydrological drought

- Reduced streamflow and runoff
- Decreased groundwater/res-ervoir/lake/... levels

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Different drought types *(UNISDR, 2009)*

Time (duration)

- Several weeks – a few months
- A few months – several months
- Months to years

Meteorological drought → **Agricultural drought** → **Hydrological drought** → **Socio-economic Drought**

Socio-economic Drought

- Demand-supply mismatch of a specific water commodity
- Population and urbanization trends impact demand
- Drought impact supply

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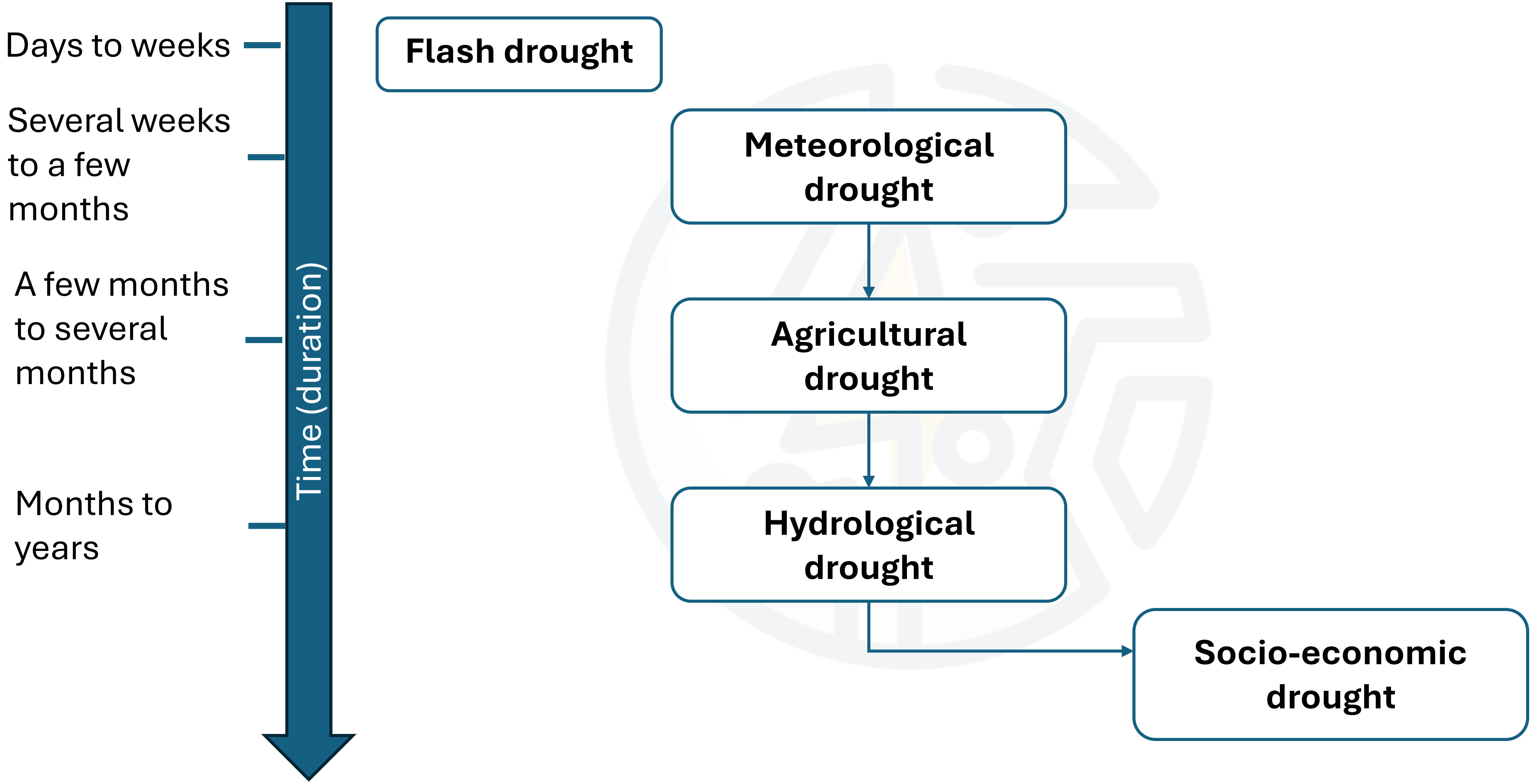
Different drought types



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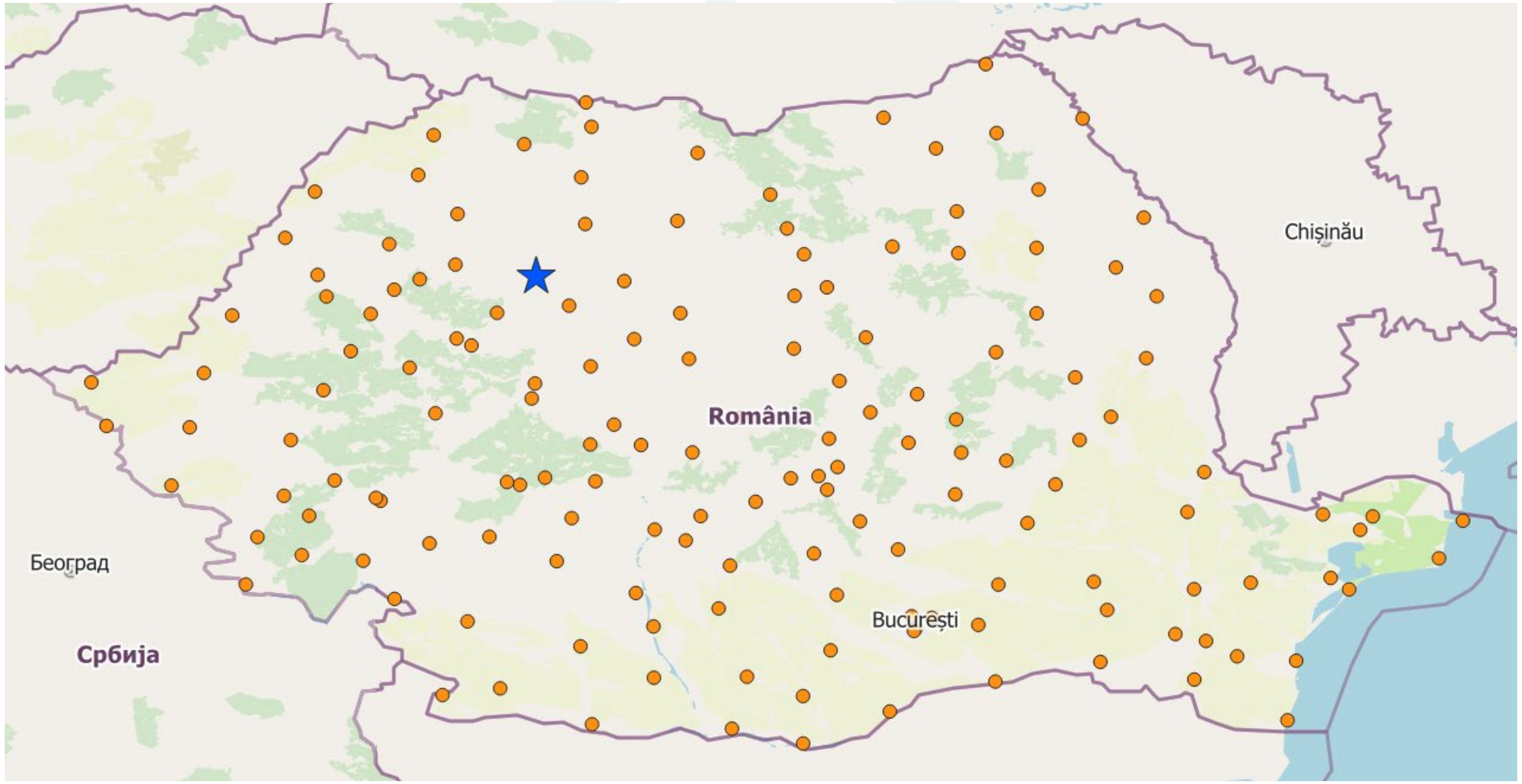
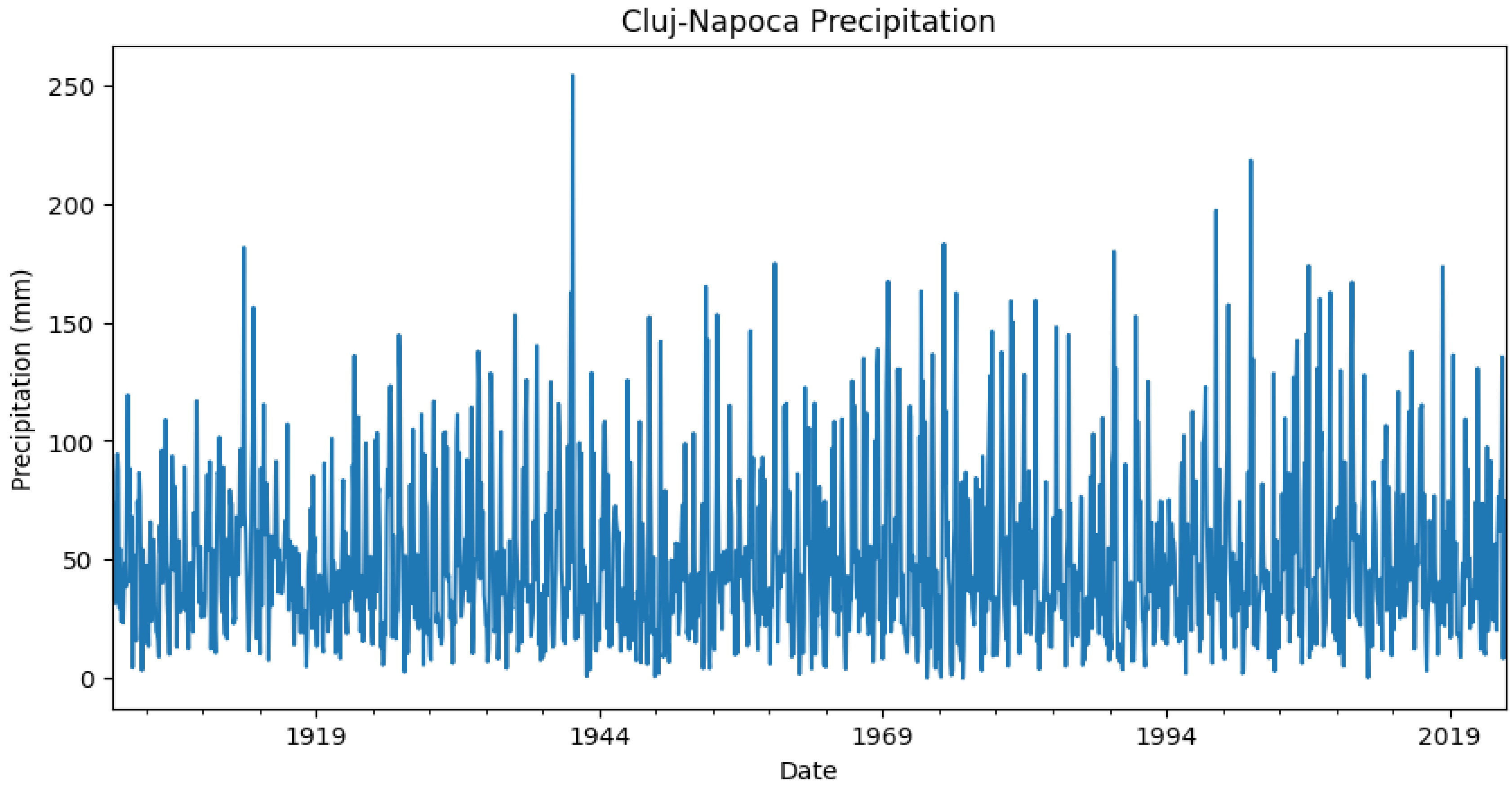
Why do we need drought indices?



Data from Dumitrescu, A. et al. (2025)

Why do we need drought indices?



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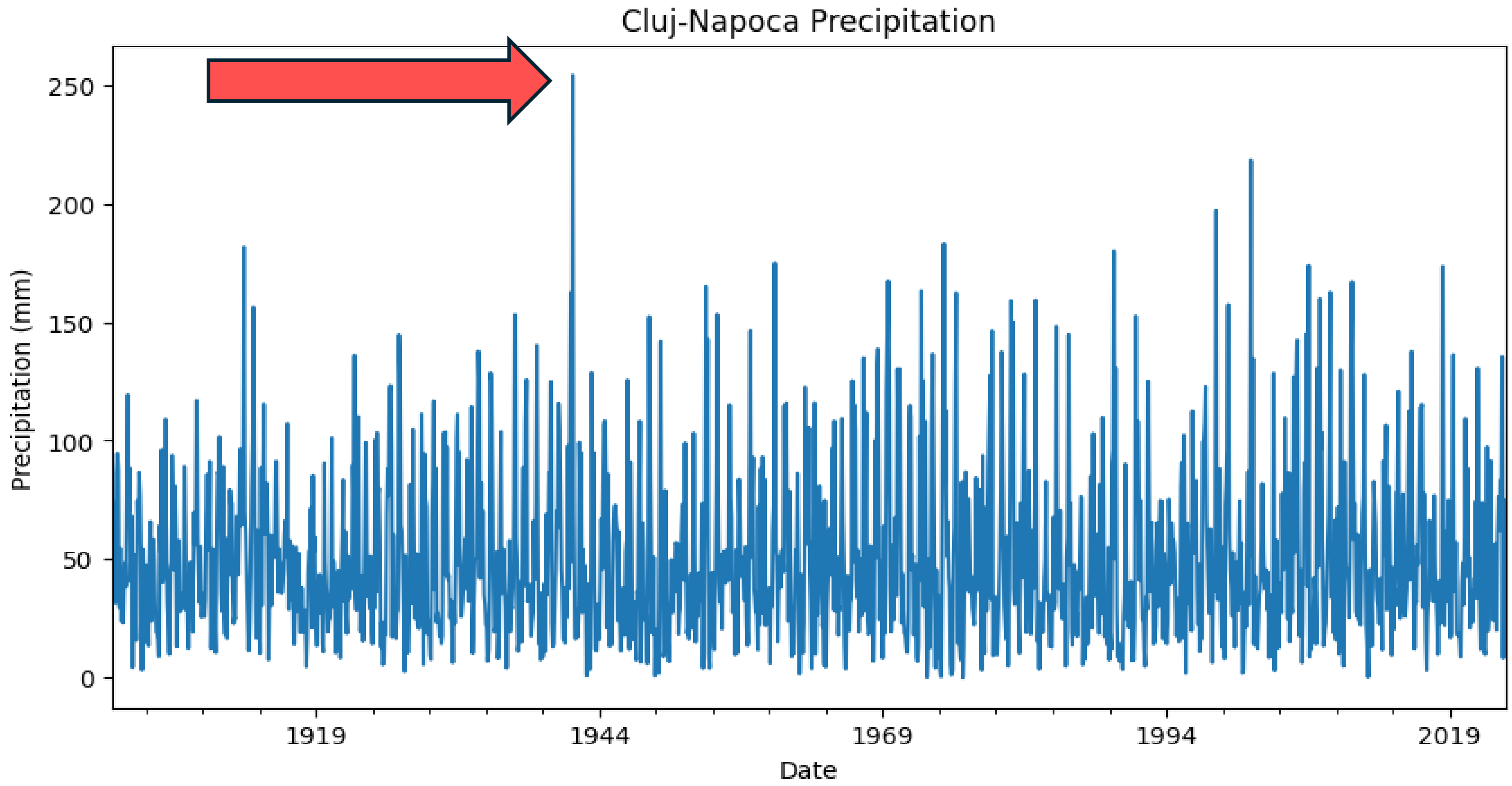
Why do we need drought indices?



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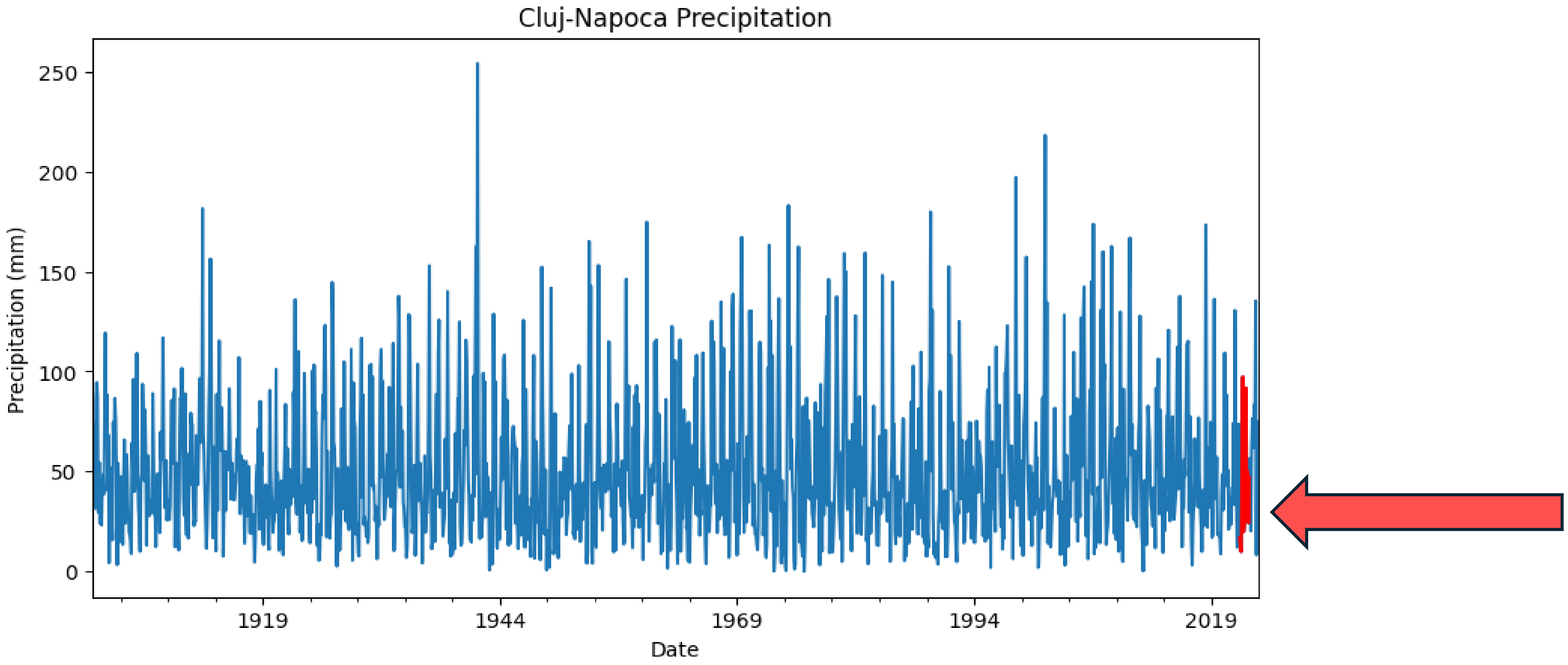
Why do we need drought indices?



Drought Indices

Multi-scale	Works at different temporal scales
Comparable	Provides comparable values across climate regions
Interpretable	Easy to relate to observed impacts (thresholds, severity)
Accessible	Can be calculated from available data
Sensitive	Reacts clearly to water deficits

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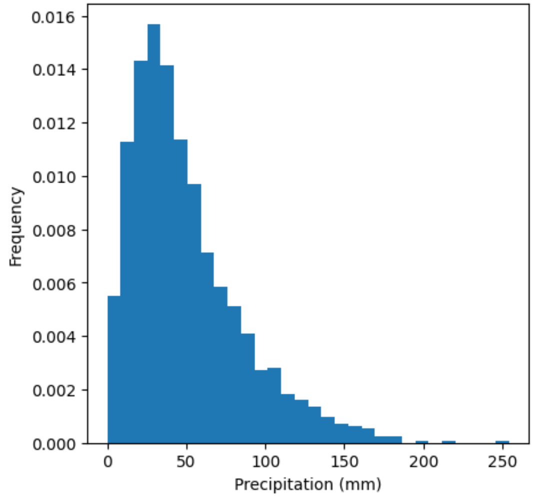
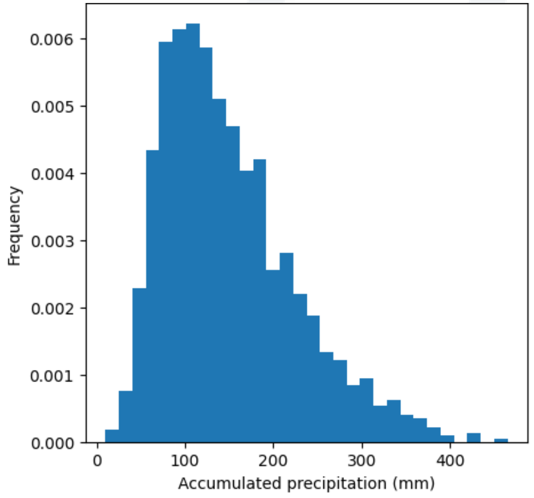
The Standardized Precipitation Index (SPI)

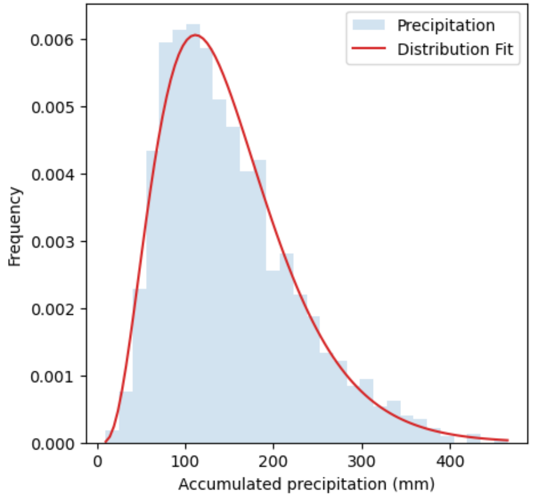
(McKee et al., 1993)



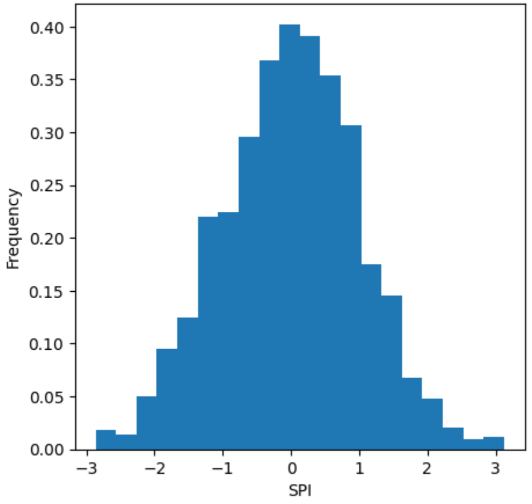
Raw precipitation data



Accumulate precipitations over a chosen period



Obtain probability of precipitation amount over chosen period



Transform into Standard normal

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SPI : Standardized Precipitation Index

Multi-scale	Works at different temporal scales	✓
Comparable	Provides comparable values across climate regions	✓
Interpretable	Easy to relate to observed impacts (thresholds, severity)	
Accessible	Can be calculated from available data	✓
Sensitive	Reacts clearly to water deficits	

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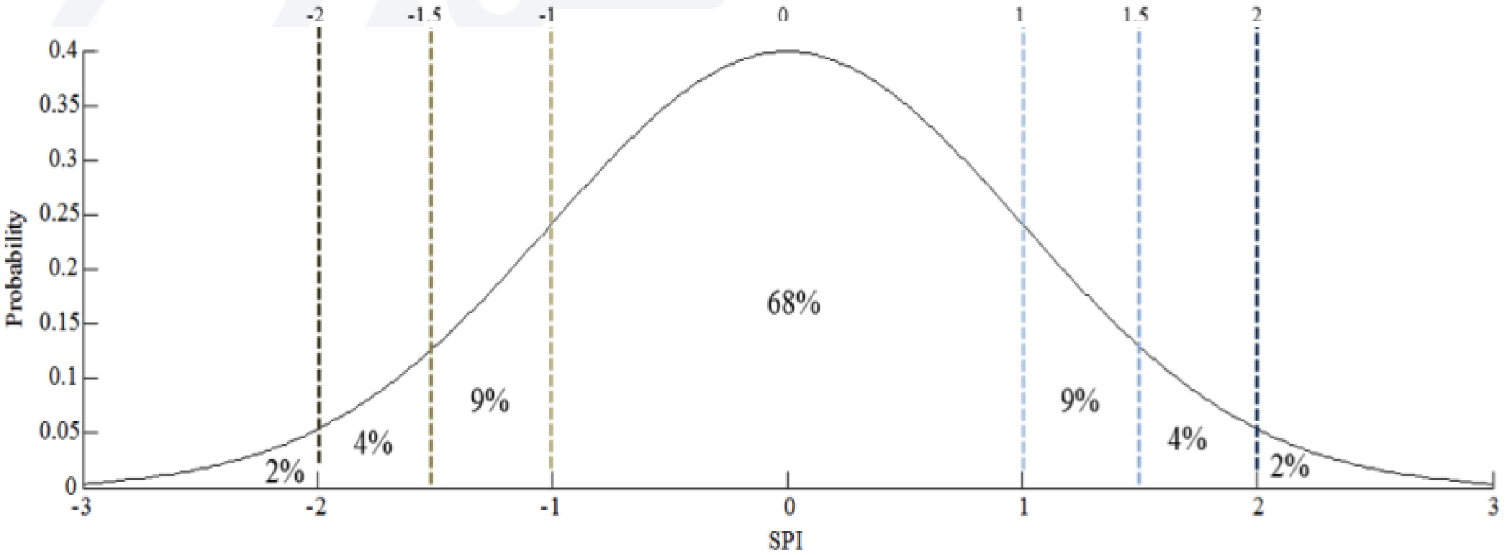
SPI drought definition

SPI range	Condition
$SPI \geq 2$	Extremely wet
$1.5 \geq SPI > 2$	Severely wet
$1 \geq SPI > 1.5$	Moderately wet
$1 > SPI > -1$	Normal
$-1 \geq SPI > -1.5$	Moderately dry
$-1.5 \geq SPI > -2$	Severely dry
$-2 \geq SPI$	Extremely dry



(Keyantash & National Center for Atmospheric Research Staff (Eds)., 2025)

SPI : Standardized Precipitation Index

Multi-scale	Works at different temporal scales	✓
Comparable	Provides comparable values across climate regions	✓
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Accessible	Can be calculated from available data	✓
Sensitive	Reacts clearly to water deficits	

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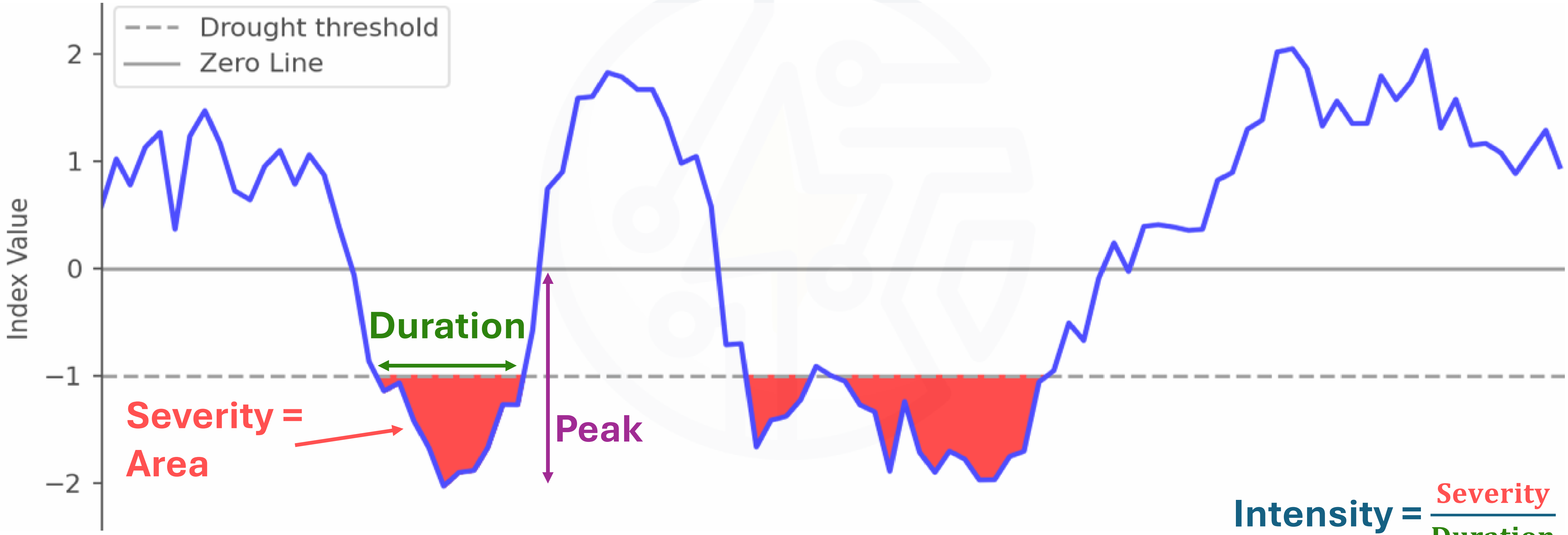
Drought detection with run theory



$$\text{Intensity} = \frac{\text{Severity}}{\text{Duration}}$$

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SPI : Standardized Precipitation Index

Multi-scale	Works at different temporal scales	✓
Comparable	Provides comparable values across climate regions	✓
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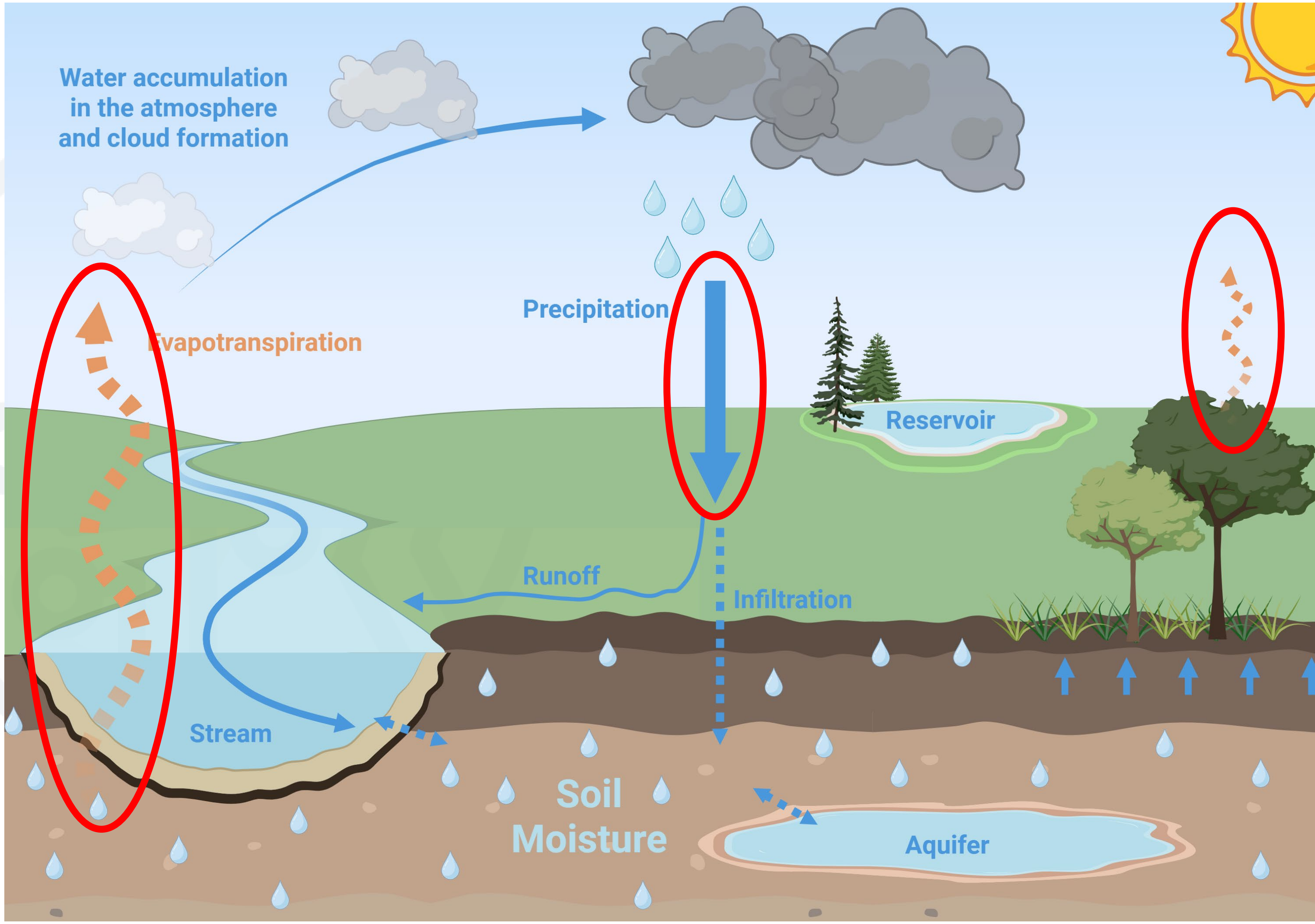
SPEI

(Vicente-Serrano et al., 2010)

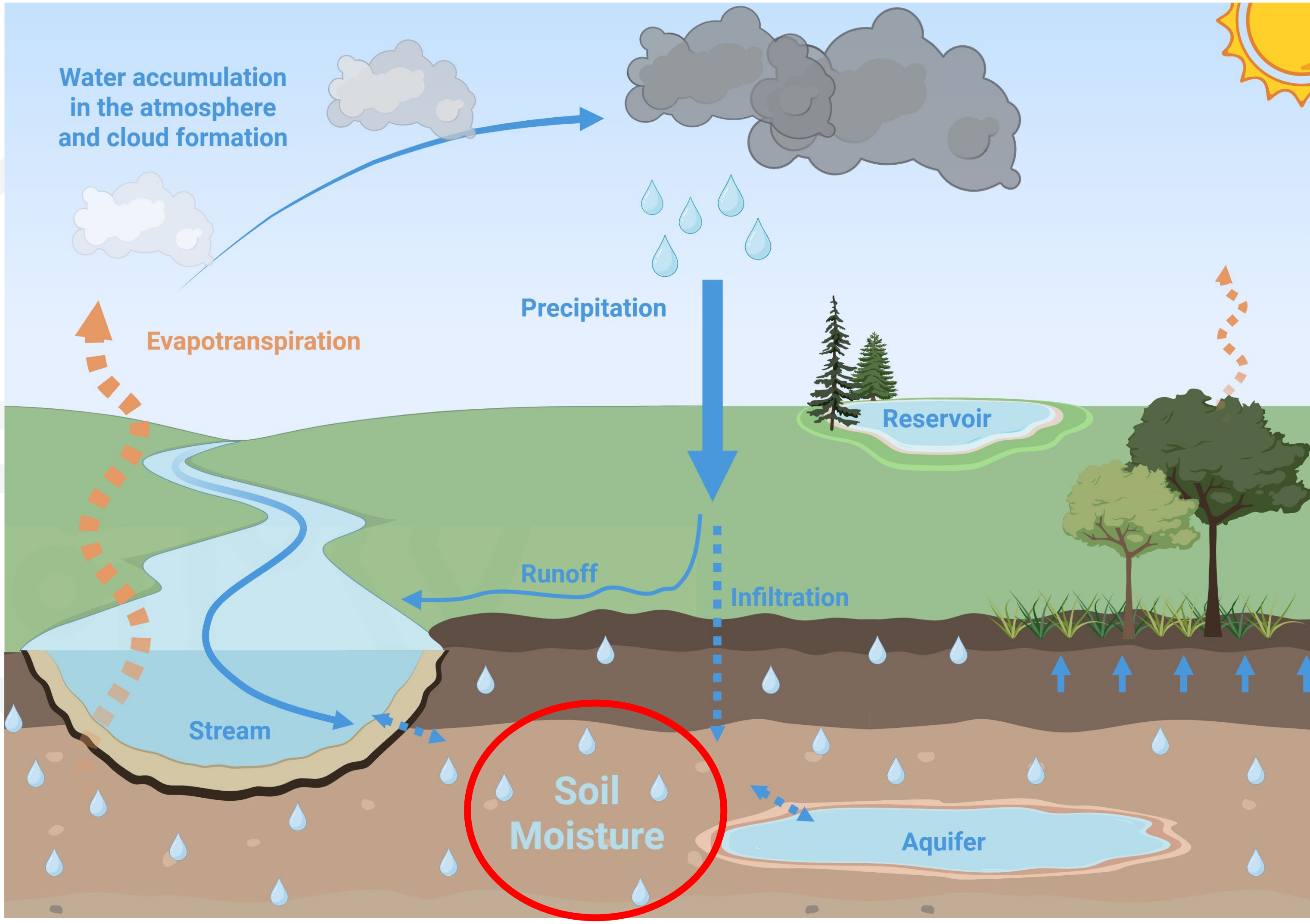
- Apply standardization process to $D = precip - PET$ where PET is the potential evapotranspiration
- Considers temperature's effect on the water cycle



Agricultural drought SSI

(Sheffield, J. & Wood, E.F., 2008)

- Apply standardization process to soil moisture
  - At a certain depth
  - In the total soil column
- Different plants use different soil moisture depths
- Data scarcity and model assumption dependent



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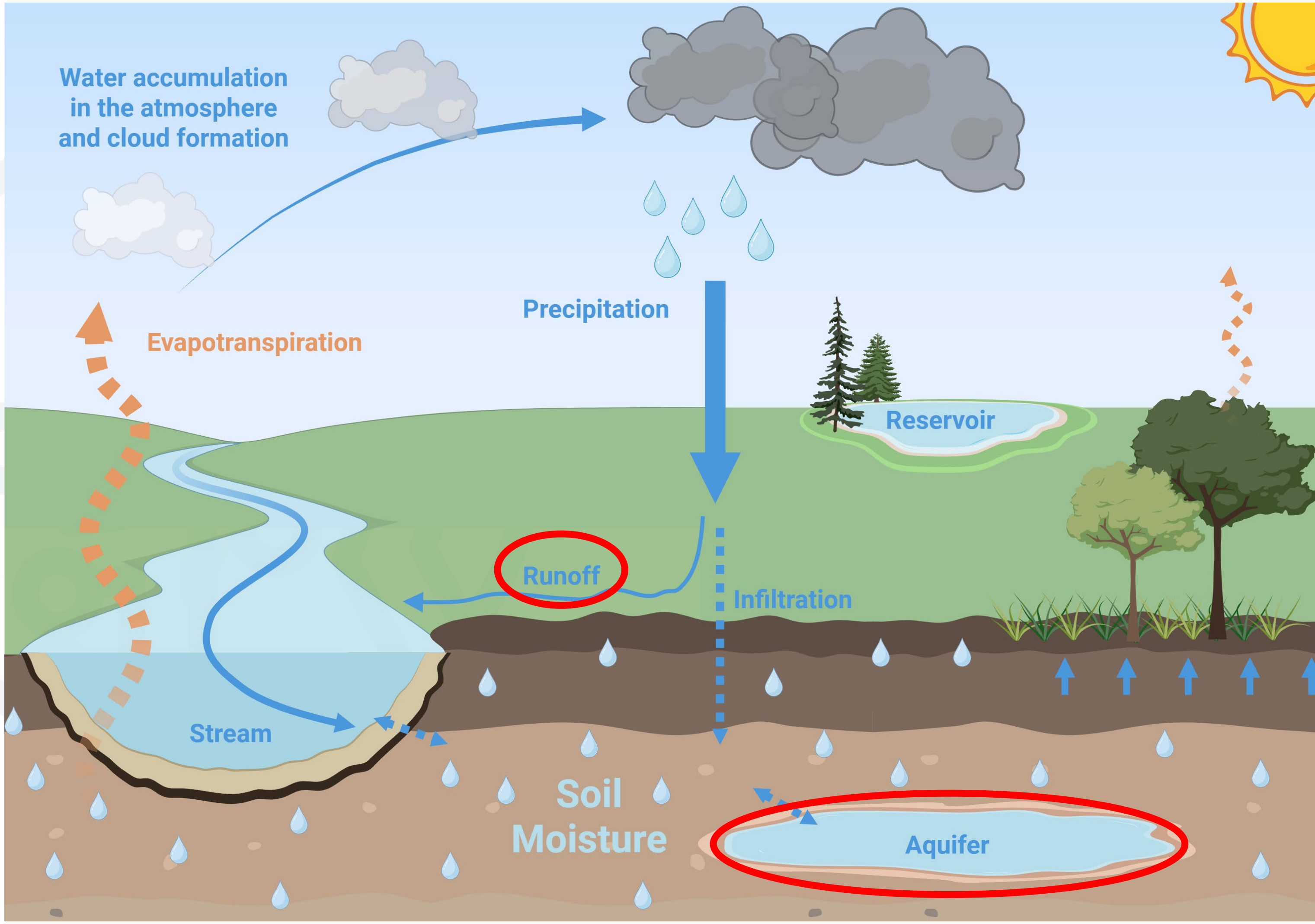
Hydrological drought SRI and SGI

(Shukla, S. & A. W. Wood, 2008; Bloomfield, J. P. & Marchant, B. P., 2013)

- Apply standardization process to
  - Runoff
  - Groundwater level
- Data difficulties
- Highly localized process



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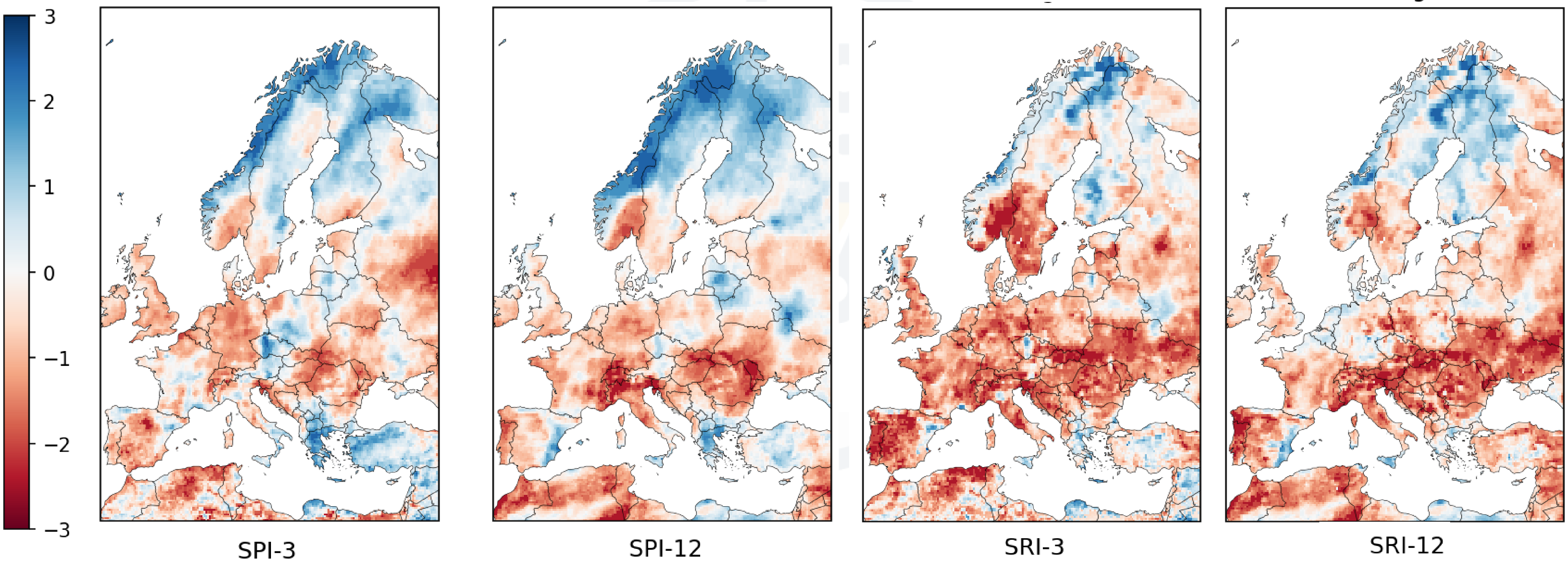
Drought Monitoring in Practice: A 2022 Example



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Online drought monitoring tools and resources

UNU

Sustainability Nexus Analytics, Informatics, and Data (AID) Programme

HOME ABOUT AID MODULES

https://www.sustainabilityaid.net/drought

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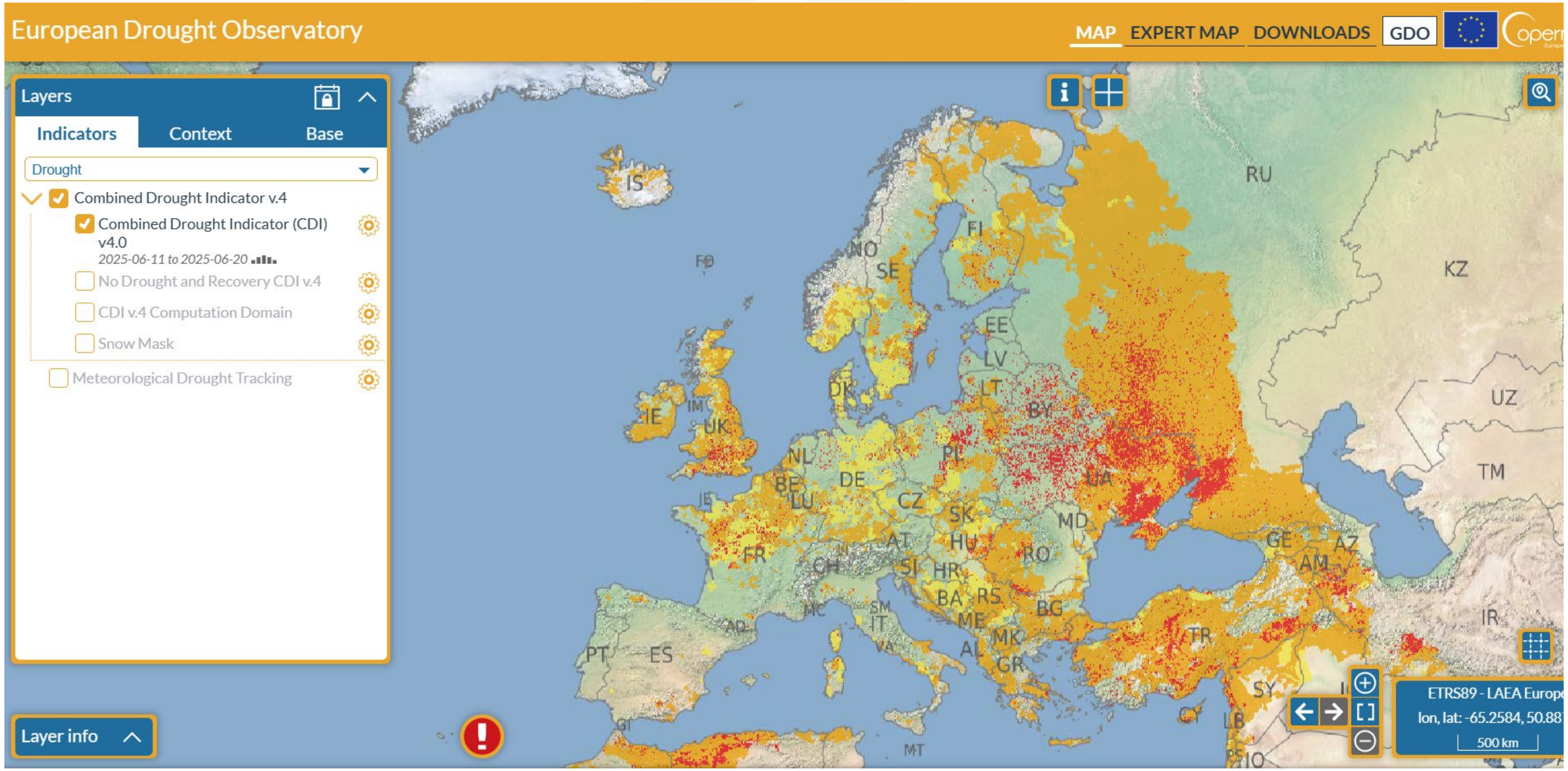
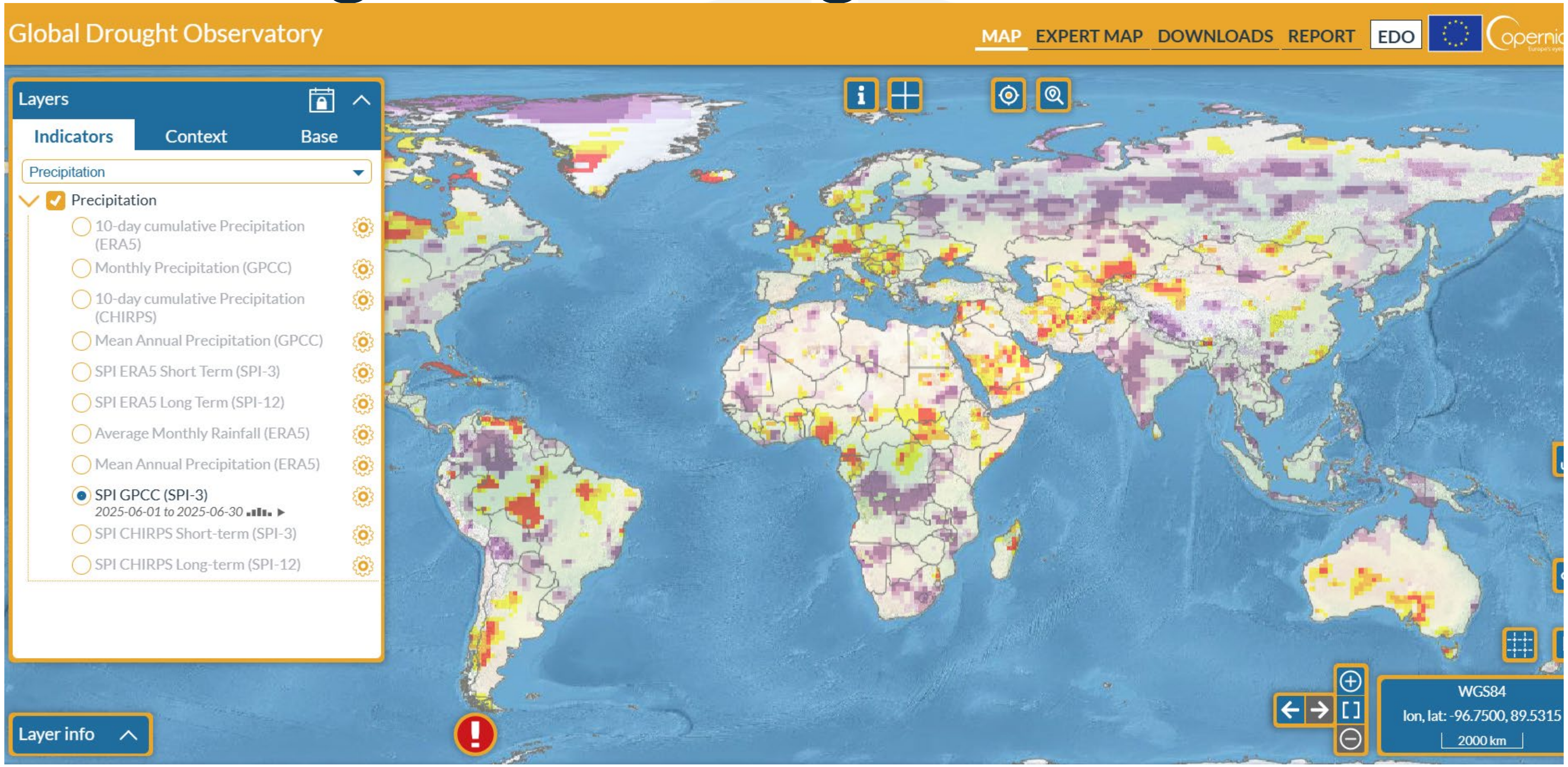
Online drought monitoring tools and resources



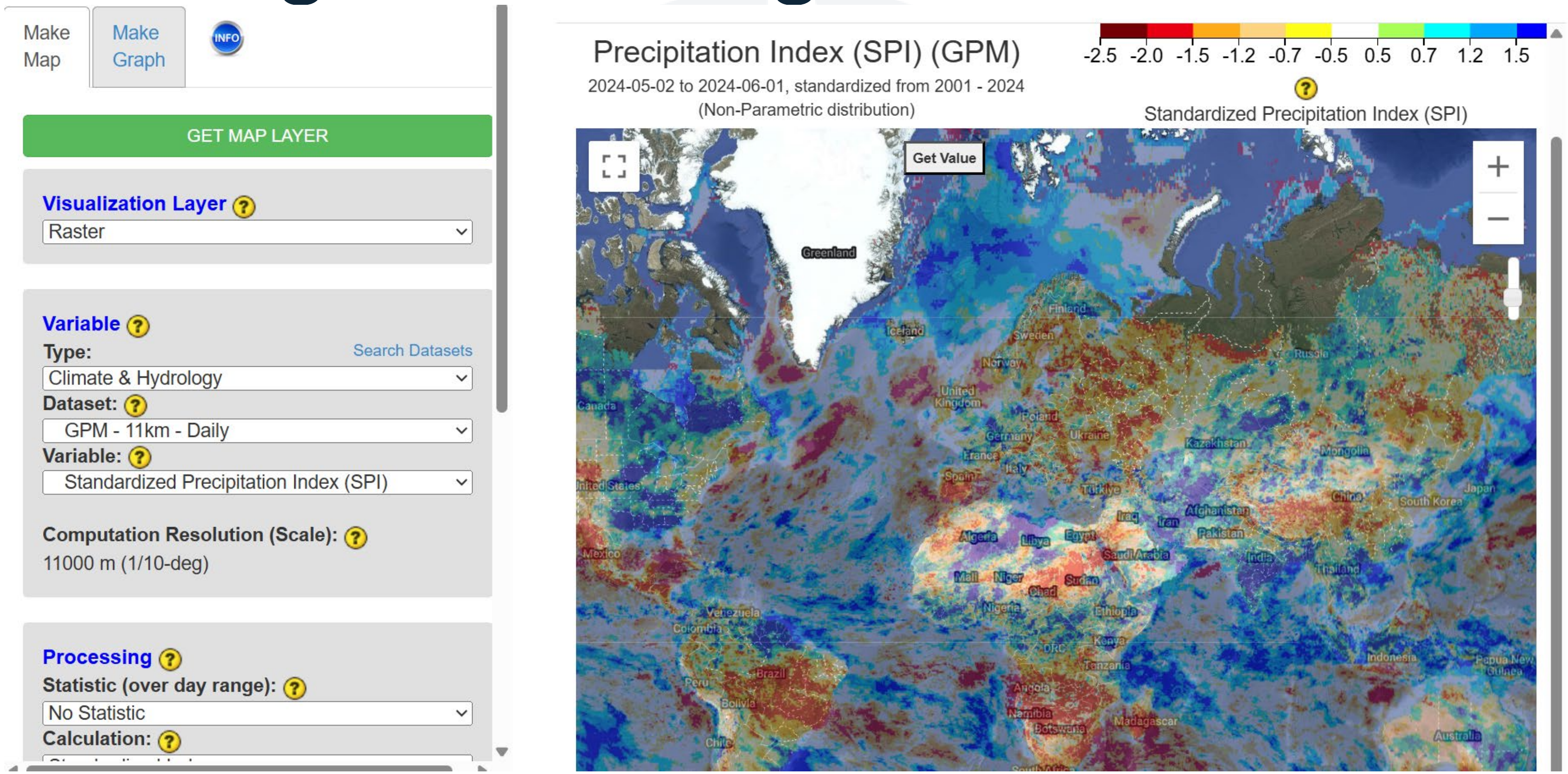
https://drought.emergency.copernicus.eu/tumbo/edo/map/

Online drought monitoring tools and resources



https://drought.emergency.copernicus.eu/tumbo/gdo/map/

Online drought monitoring tools and resources



https://app.climateengine.org/climateEngine

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Online drought monitoring tools and resources

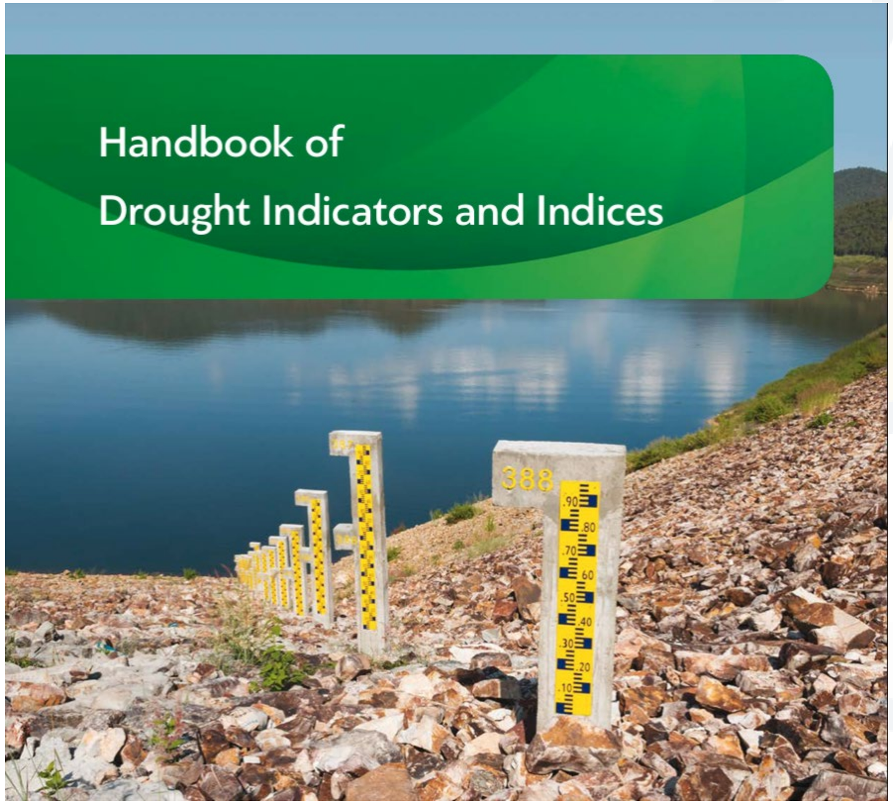

Table 1. Indicators and indices listed in this handbook

Meteorology	*Page*	*Ease of use*	*Input parameters*	*Additional information*
Aridity Anomaly Index (AAI)	11	Green	P, T, PET, ET	Operationally available for India
Deciles	11	Green	P	Easy to calculate; examples from Australia are useful
Keetch–Byram Drought Index (KBDI)	12	Green	P, T	Calculations are based upon the climate of the area of interest
Percent of Normal Precipitation	12	Green	P	Simple calculations
Standardized Precipitation Index (SPI)	13	Green	P	Highlighted by the World Meteorological Organization as a starting point for meteorological drought monitoring
Weighted Anomaly Standardized Precipitation (WASP)	15	Green	P, T	Uses gridded data for monitoring drought in tropical regions
Aridity Index (AI)	15	Yellow	P, T	Can also be used in climate classifications
China Z Index (CZI)	16	Yellow	P	Intended to improve upon SPI data
Crop Moisture Index (CMI)	16	Yellow	P, T	Weekly values are required
Drought Area Index (DAI)	17	Yellow	P	Gives an indication of monsoon season performance
Drought Reconnaissance Index (DRI)	17	Yellow	P, T	Monthly temperature and precipitation are required
Effective Drought Index (EDI)	18	Yellow	P	Program available through direct contact with originator
Hydro-thermal Coefficient of Selyaninov (HTC)	19	Yellow	P, T	Easy calculations and several examples in the Russian Federation

https://www.drought.gov/documents/handbook-drought-indicators-and-indices

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Online drought monitoring tools and resources

Index name: Standardized Precipitation Evapotranspiration Index (SPEI).

Ease of use: Yellow.

Origins: Developed by Vicente-Serrano et al. at the Instituto Pirenaico de Ecologia in Zaragoza, Spain.

Characteristics: As a relatively new drought index, SPEI uses the basis of SPI but includes a temperature component, allowing the index to account for the effect of temperature on drought development through a basic water balance calculation. SPEI has an intensity scale in which both positive and negative values are calculated, identifying wet and dry events. It can be calculated for time steps of as little as 1 month up to 48 months or more. Monthly updates allow it to be used operationally, and the longer the time series of data available, the more robust the results will be.

Input parameters: Monthly precipitation and temperature data. A serially complete record of data is required with no missing months.

Applications: With the same versatility as that of SPI, SPEI can be used to identify and monitor conditions associated with a variety of drought impacts.

Strengths: The inclusion of temperature along with precipitation data allows SPEI to account for the impact of temperature on a drought situation. The output is applicable for all climate regimes, with the results being comparable because they are standardized. With the use of temperature data, SPEI is an ideal index when looking at the impact of climate change in model output under various future scenarios.

Weaknesses: The requirement for a serially complete dataset for both temperature and precipitation may limit its use due to insufficient data being available. Being a monthly index, rapidly developing drought situations may not be identified quickly.

Resources: SPEI code is freely available and the calculations are also described in the literature, http://sac.csic.es/spei/.

Reference: Vicente-Serrano, S.M., S. Begueria and J.I. Lopez-Moreno, 2010: A multi-scalar drought index sensitive to global warming: the Standardized Precipitation Evapotranspiration Index. *Journal of Climate*, 23:1696–1718.

https://www.drought.gov/documents/handbook-drought-indicators-and-indices

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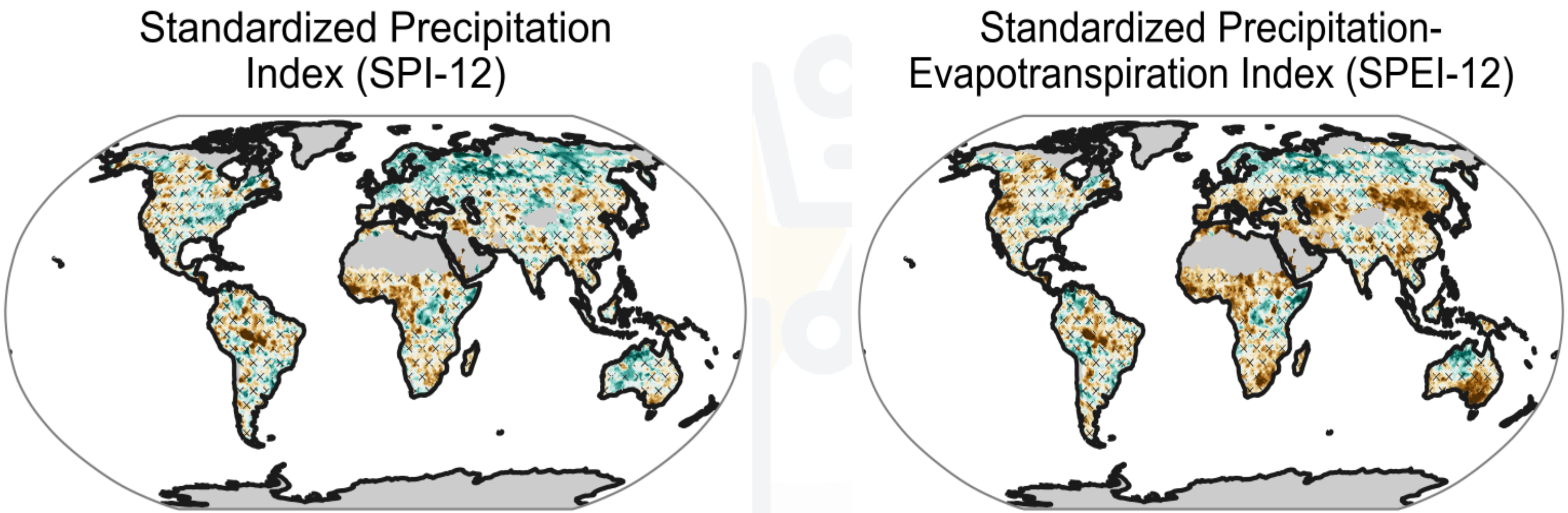
Trends of drought - historical



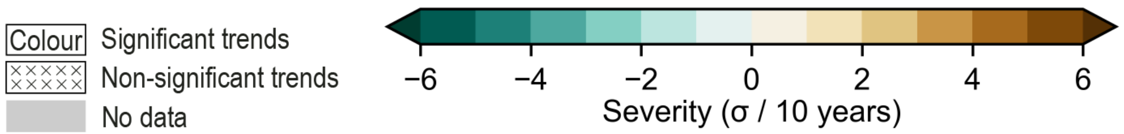


Figure 11.17 in IPCC, 2021: Chapter 11. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change

Trends of drought – future climate

We can also look at drought **event characteristics**… like **duration**

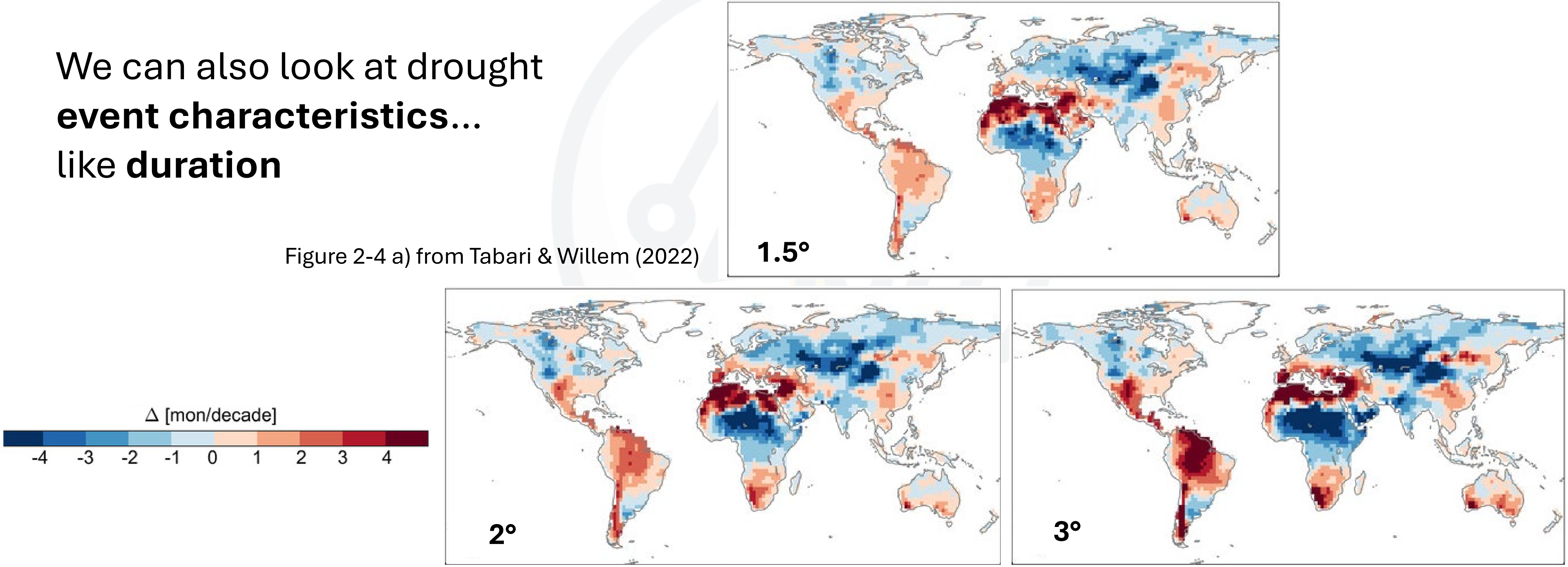


Figure 2-4 a) from Tabari & Willem (2022)

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Trends of drought – future climate

We can also look at drought **event characteristics…** like duration or **frequency**

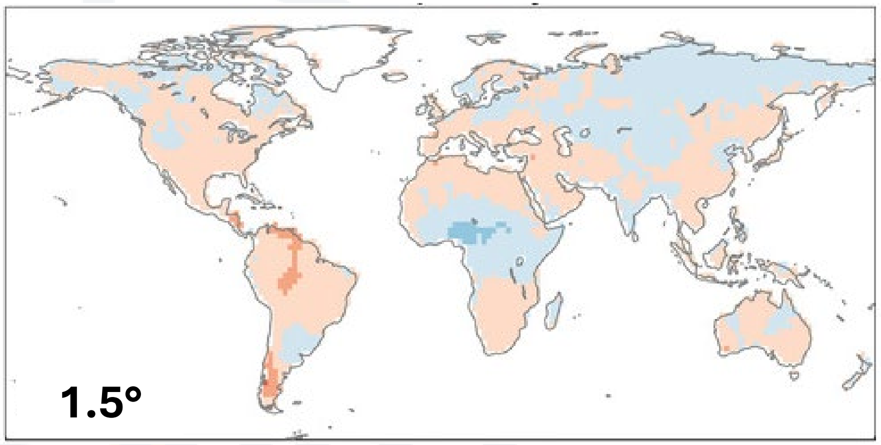
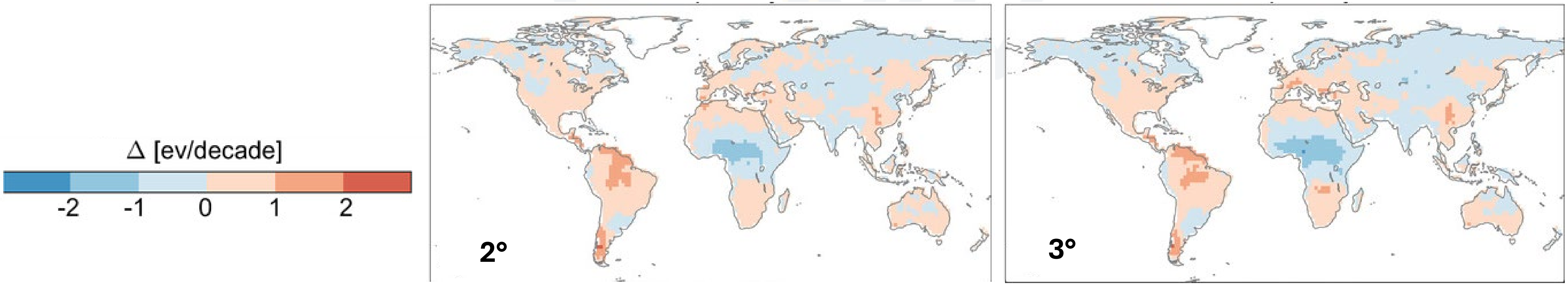
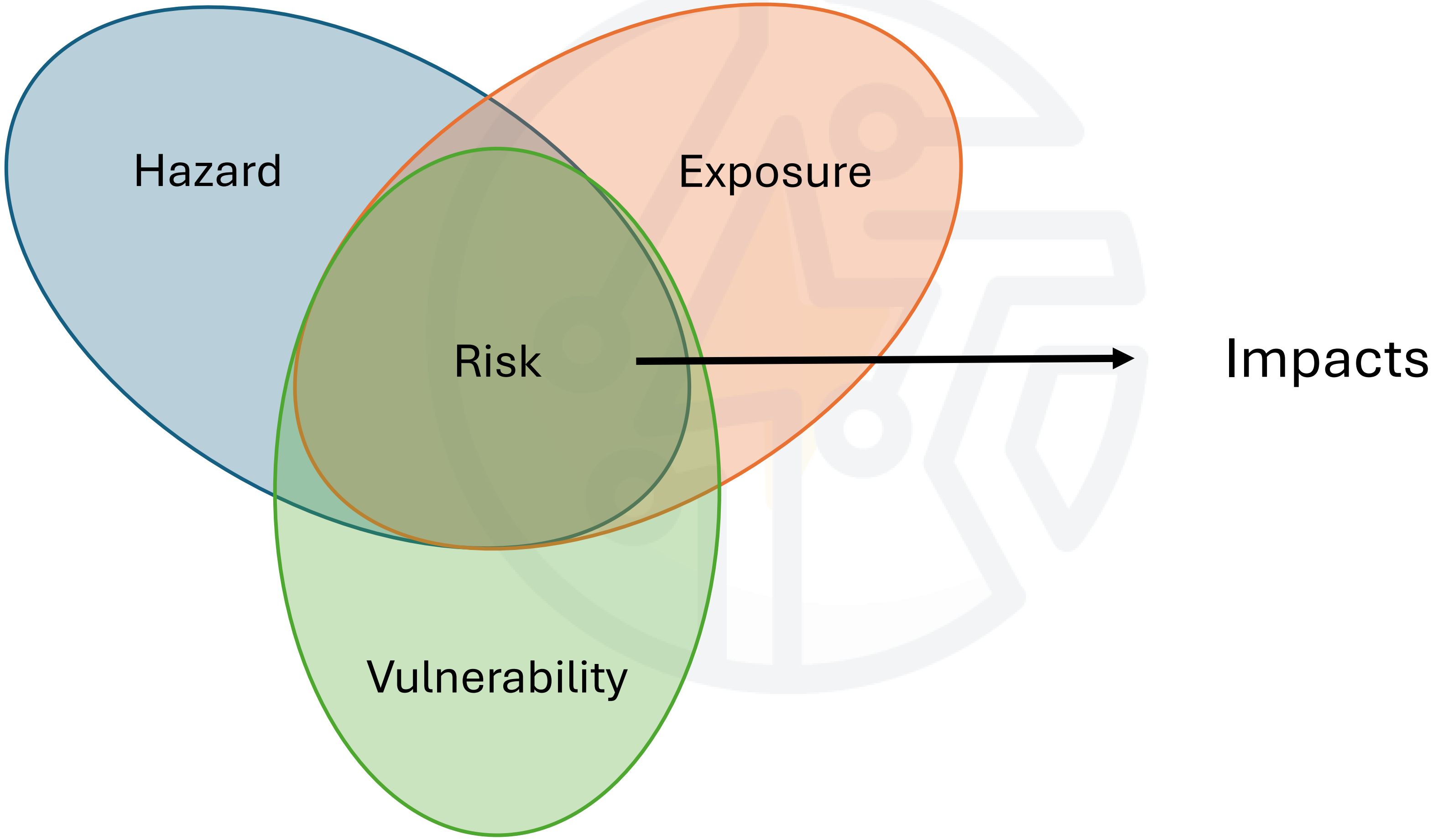


Figure 2-4 b) from Tabari & Willem (2022)



Impacts and risk (IPCC AR5)



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Trends of drought – future risk

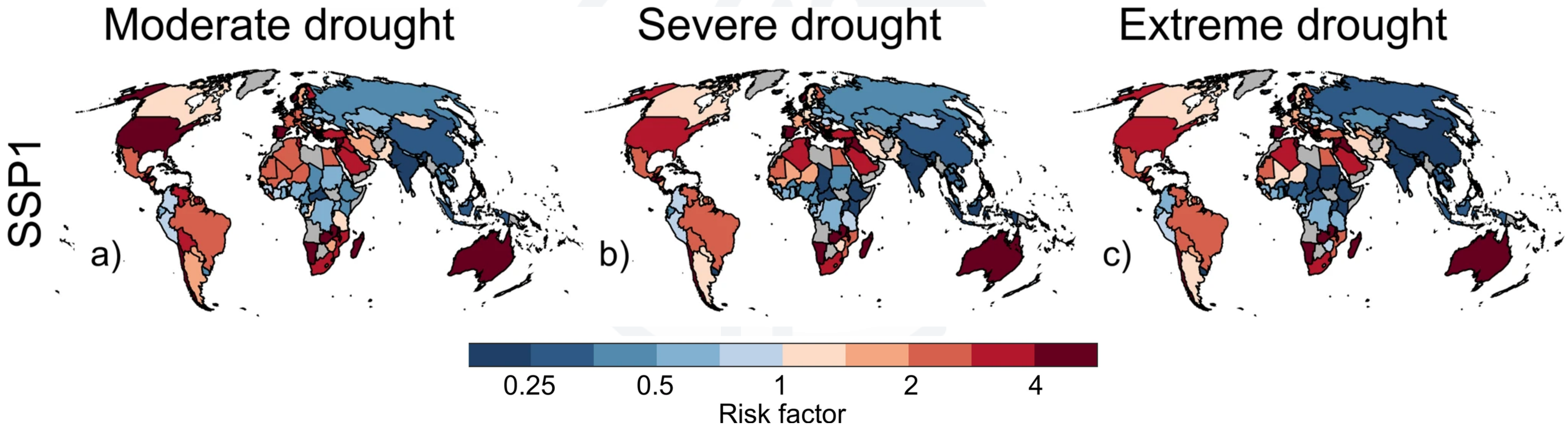


Figure 4 in Tabari, H. & Willems, P., 2023 : Sustainable development substantially reduces the risk of future drought impacts

Trends of drought – future risk

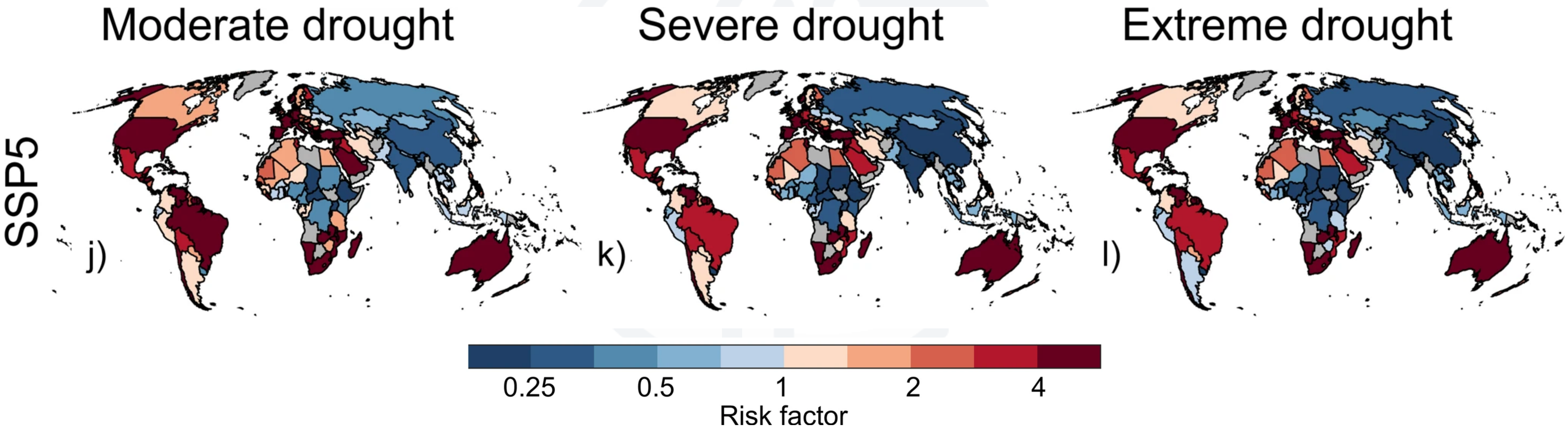


Figure 4 in Tabari, H. & Willems, P., 2023 : Sustainable development substantially reduces the risk of future drought impacts

Trends of drought – future risk in Romania

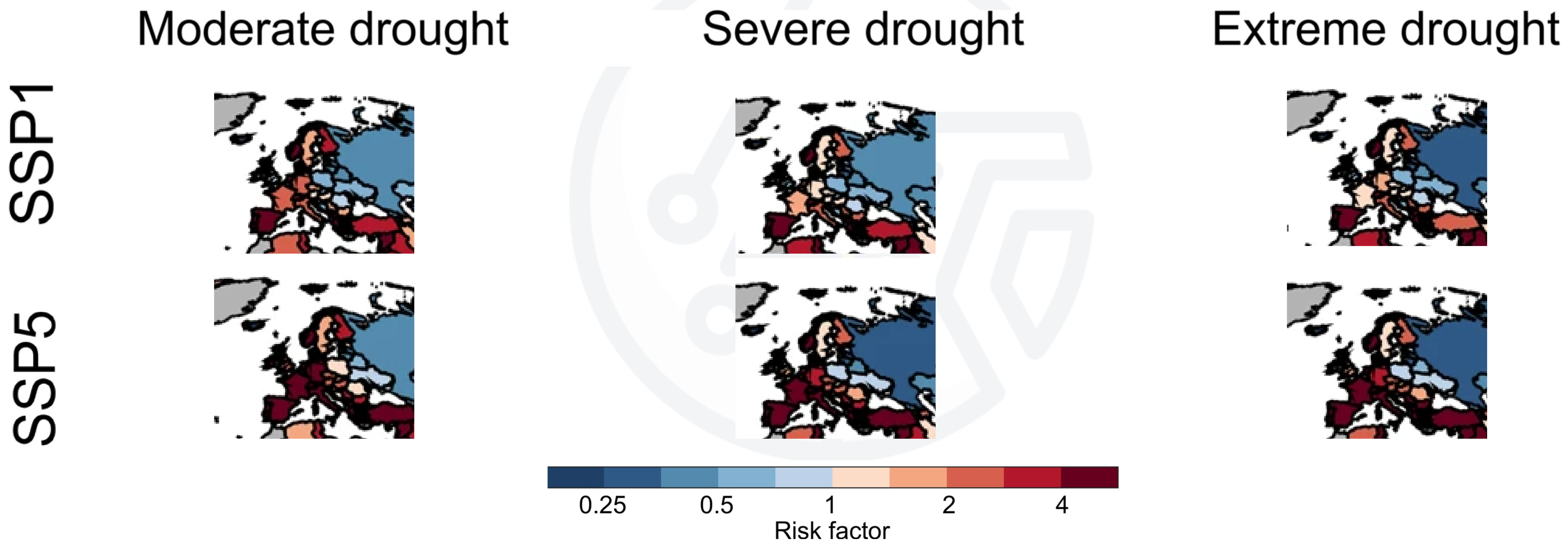
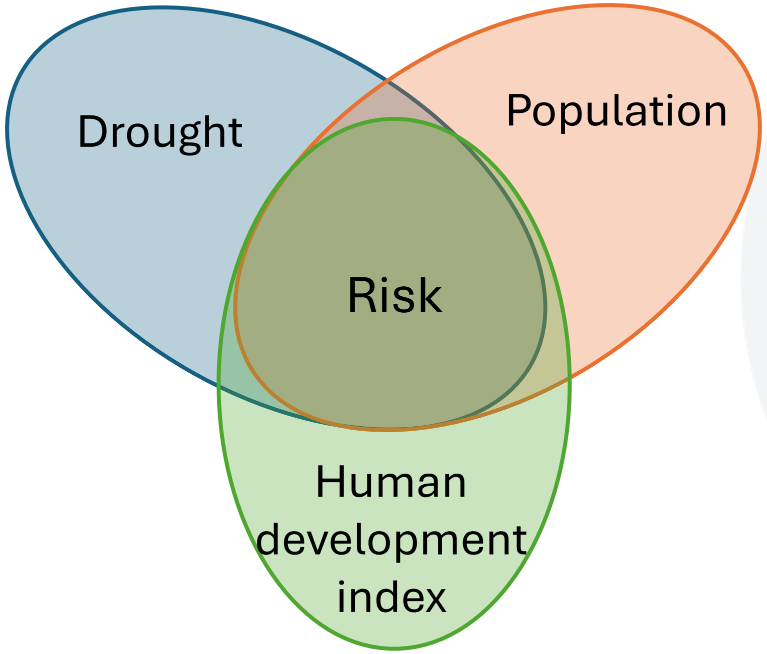


Figure 4 in Tabari, H. & Willems, P., 2023 : Sustainable development substantially reduces the risk of future drought impacts

Future risk



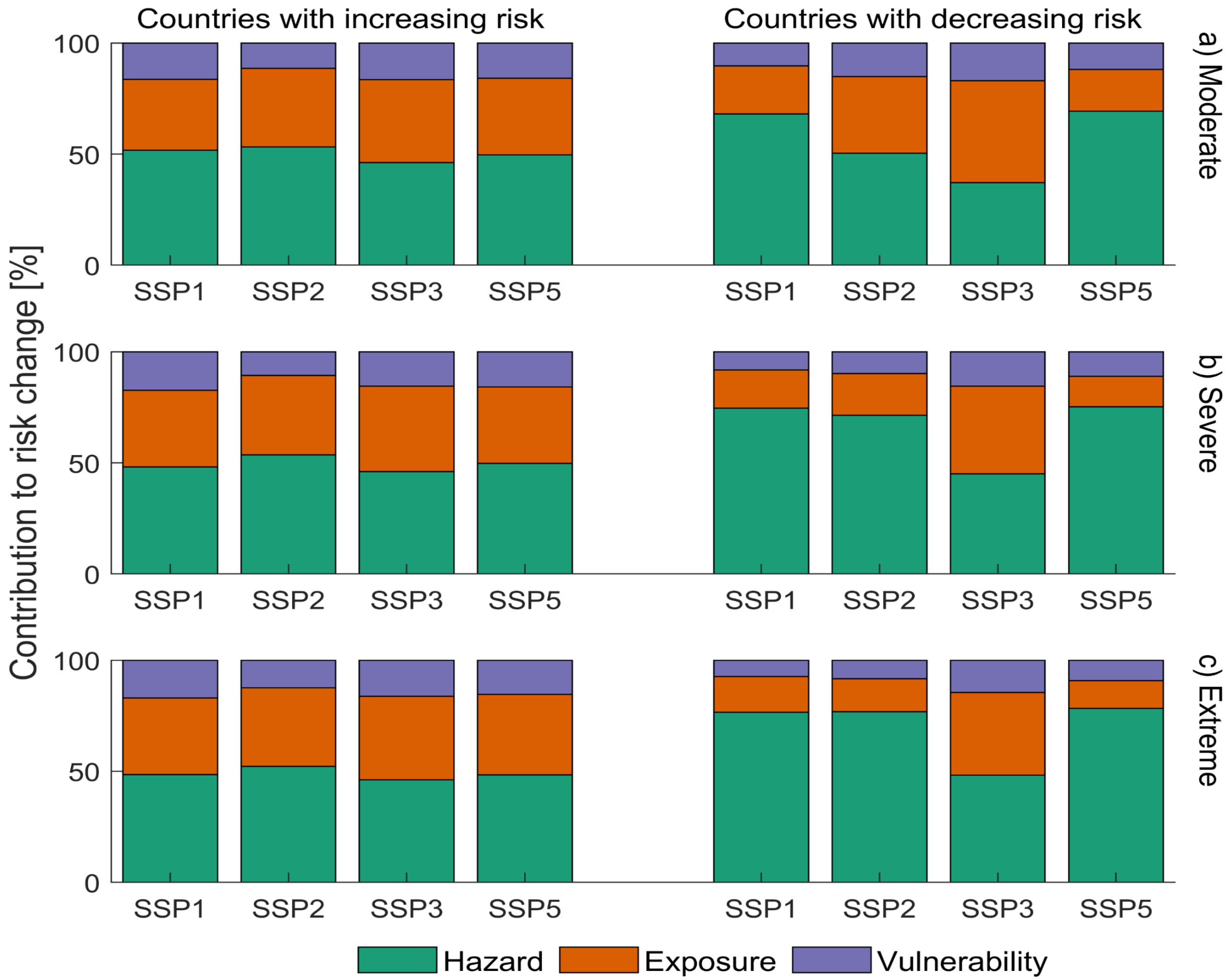


Figure 5 in Tabari, H. & Willems, P., 2023 : Sustainable development substantially reduces the risk of future drought impacts

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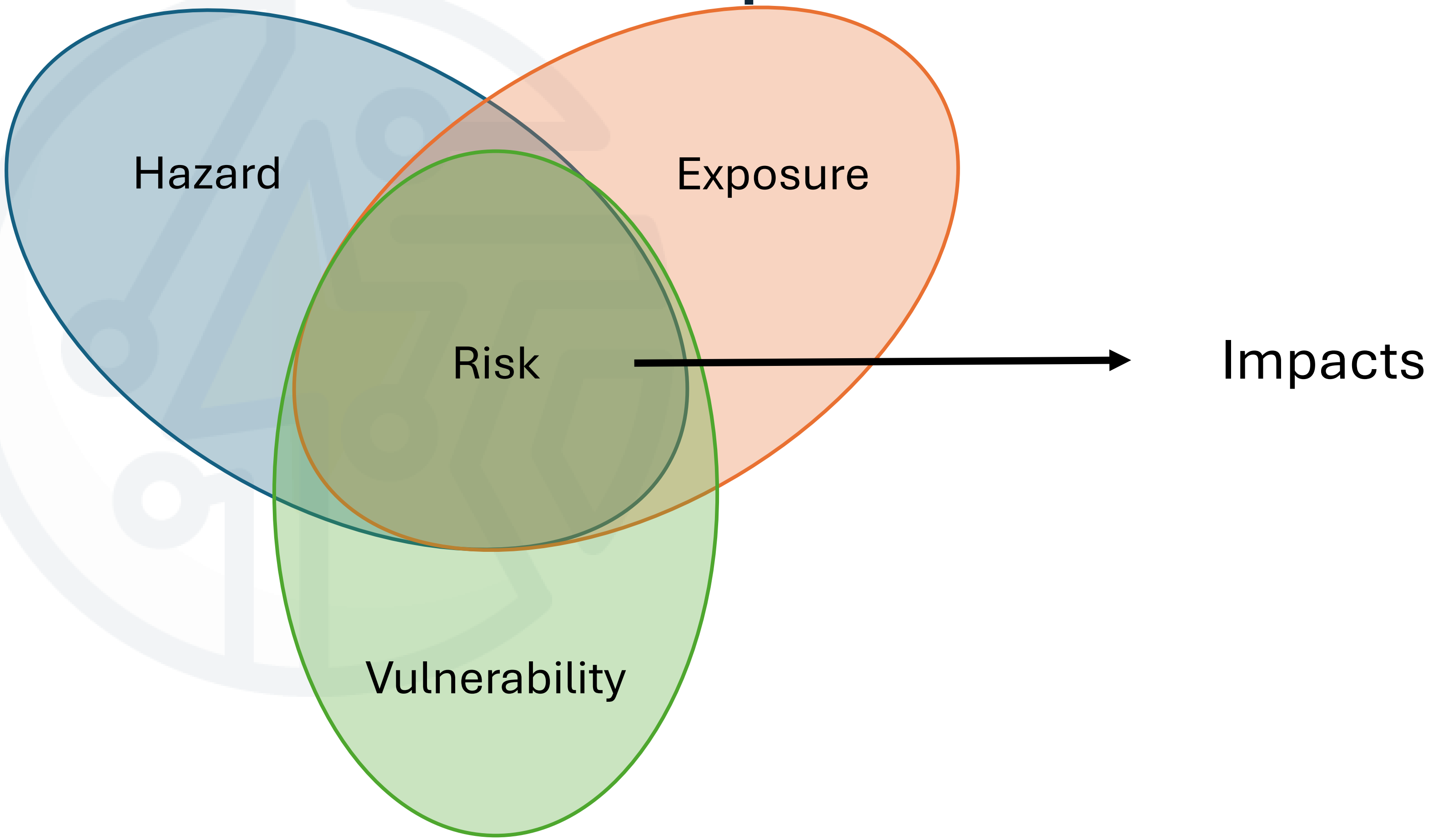

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Thank you for your attention !

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