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Comparison of temporal changes in aridity in European and African regions

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Research Question

Recurring droughts under climate variability pose increasing challenges for drinking-water supply and irrigation. Regions that share similar aridity levels may differ dramatically in their ability to cope with water stress, due to differences in water infrastructure and adaptive capacity.

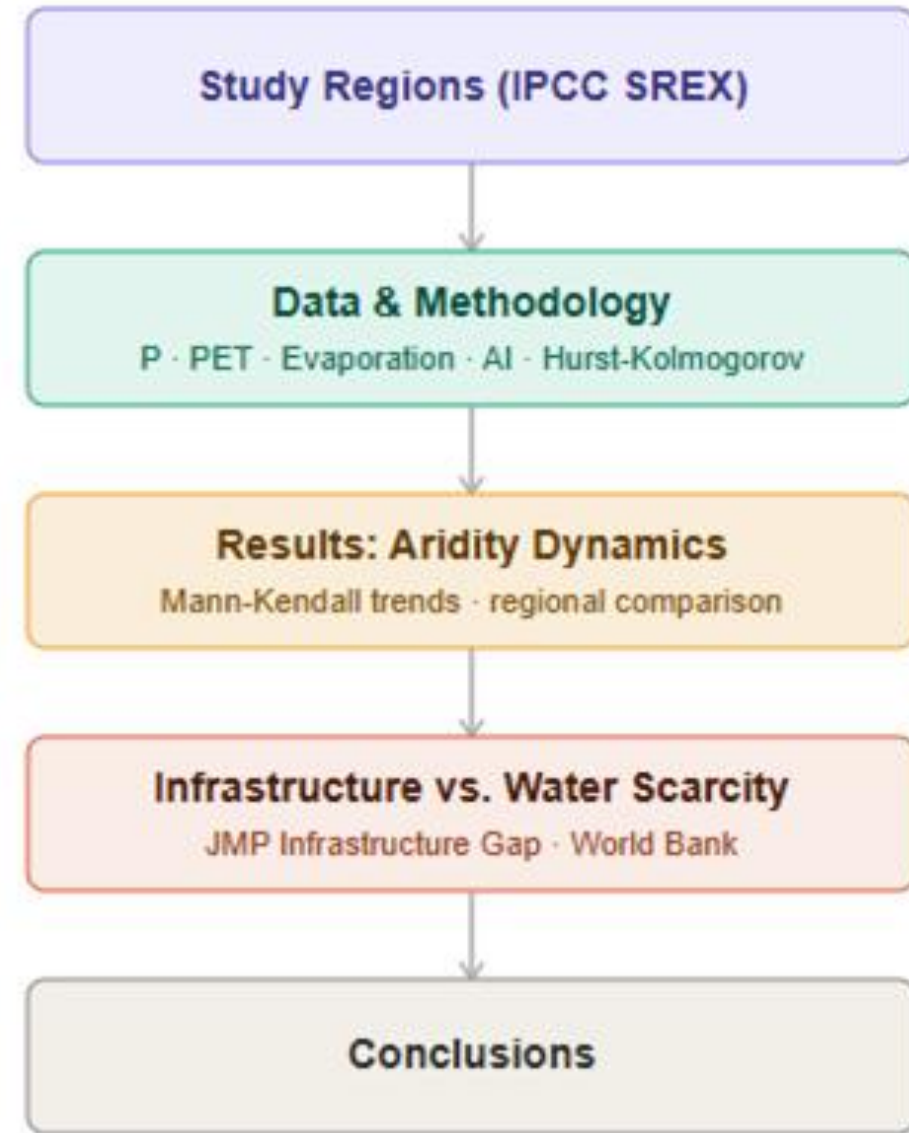
1. This study compares the temporal dynamics of **aridity** in selected **European** and **African** IPCC SREX regions, using long-term hydroclimatic datasets spanning 77 years of monthly **precipitation** and **potential evapotranspiration**.
1. **Aridity** is assessed via the **Aridity Index** ($AI = P/PET$) and the **Hurst-Kolmogorov** stochastic framework.

Finally, for regions sharing similar aridity levels, World Bank **water infrastructure indicators** are used to explore whether observed **water scarcity** is driven by **climate** or by **infrastructure deficits**.

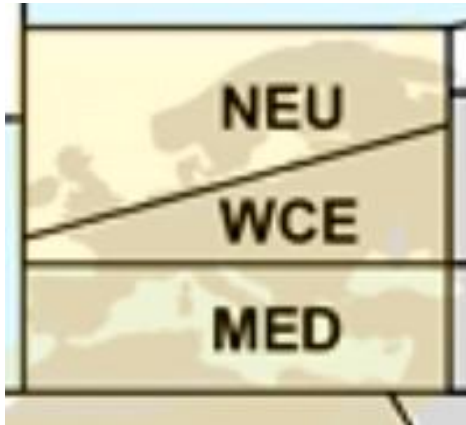


Work flow

- Study Regions (IPCC SREX)
- Data & Methodology
 - Hydroclimatic variables (P, PET, Evaporation)
 - Aridity Index ($AI = P/PET$) & Hurst-Kolmogorov framework
- Results: Aridity Dynamics
- Infrastructure vs. Water scarcity (World Bank Analysis)
- Conclusions



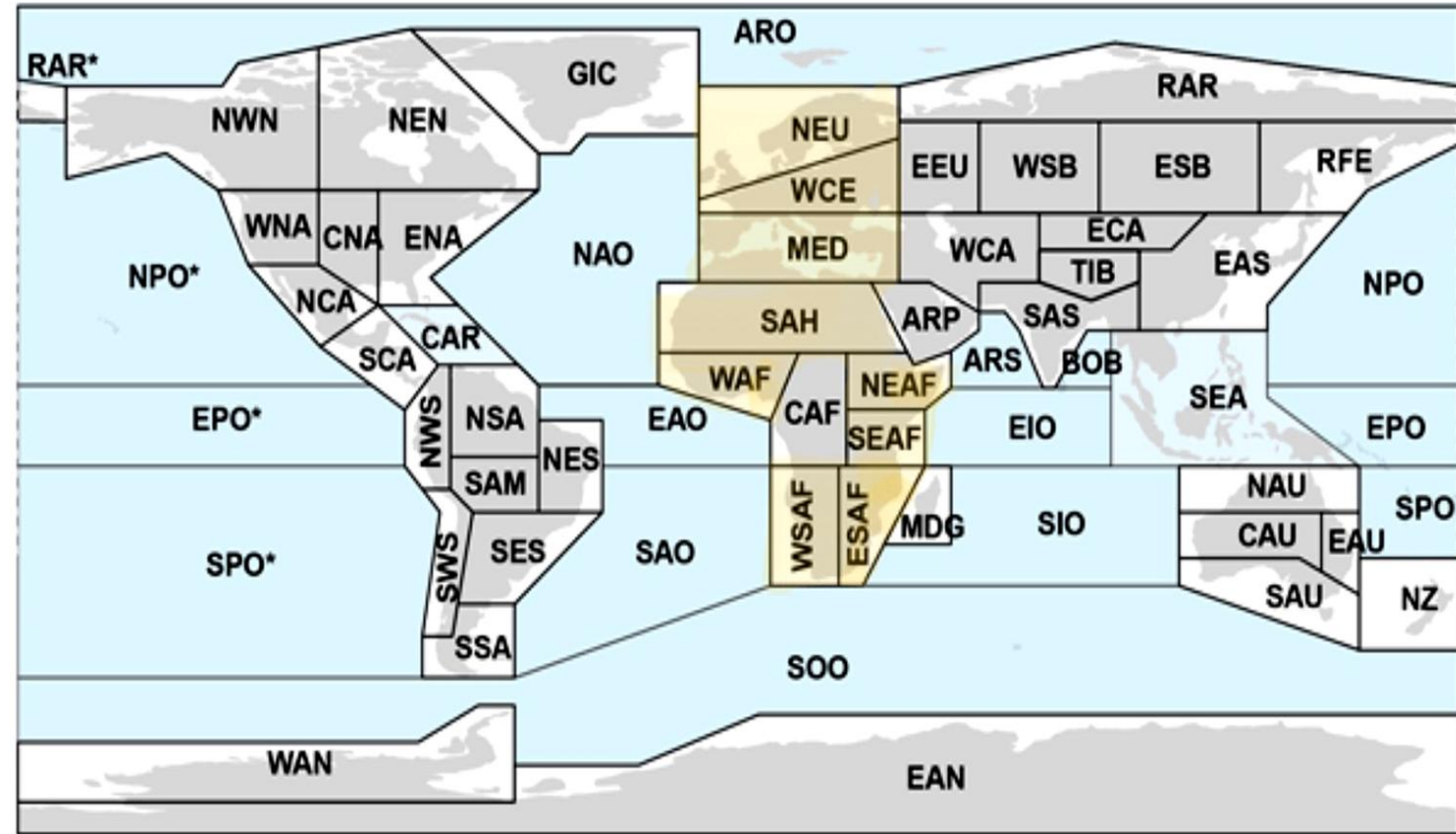
Study Regions: IPCC SREX Classification



EUROPE REGION



AFRICAN REGION



For this analysis presented, the CAF region was excluded due to concerns about data reliability. Specifically, recent findings by Kaicun Wang et al. indicate that the ERA5 dataset significantly overestimates the land drying trend from 1980 to 2023—by more than 100% in some areas. Given these uncertainties, we chose not to include CAF in order **to ensure the robustness and credibility of our results.**

Methodology

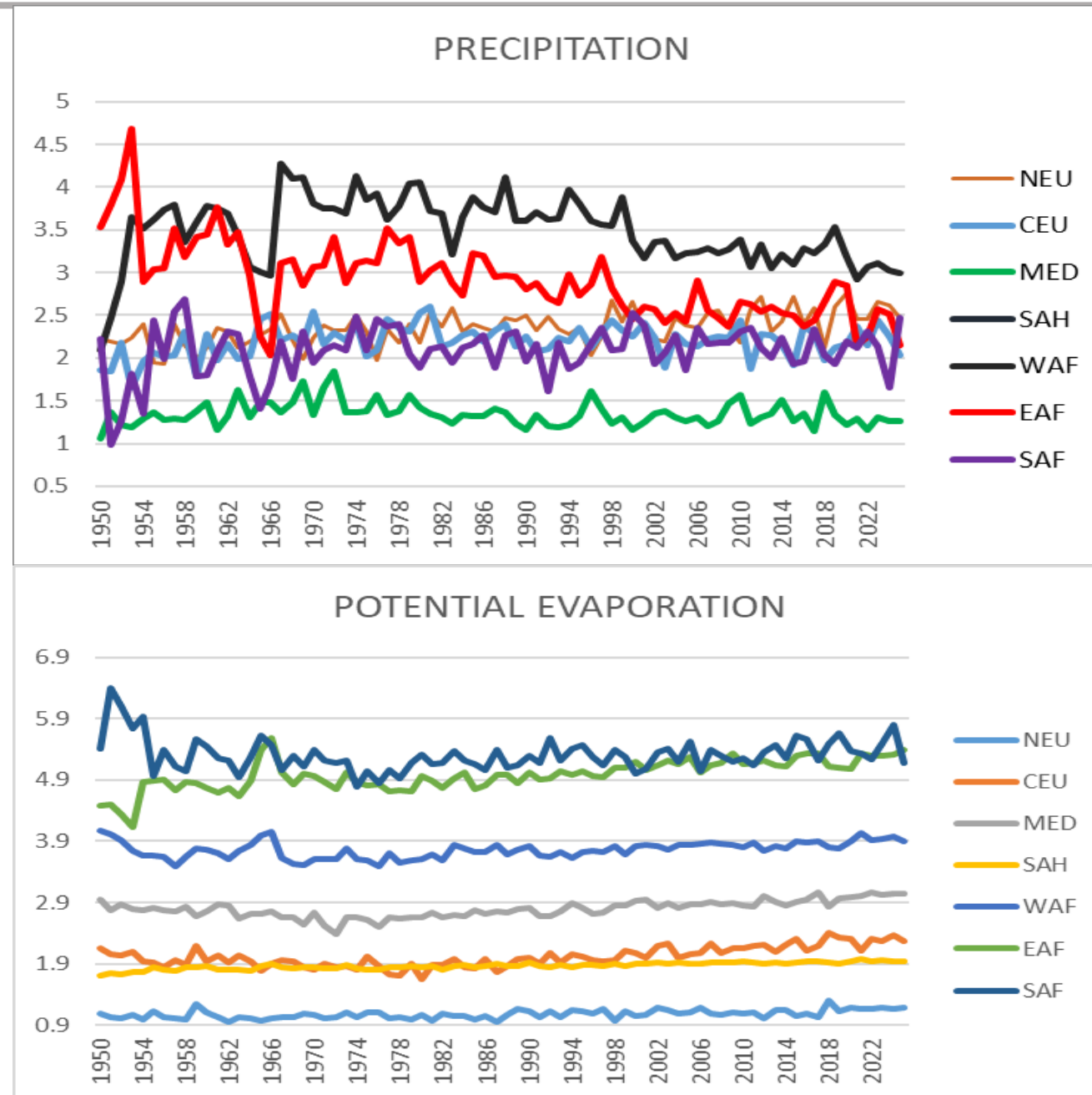
Hydroclimatic Data

Monthly time series spanning the period **1950–2025** were retrieved from the **KNMI Climate Explorer** (climexp.knmi.nl) for a total of **7 IPCC SREX regions** — 3 European (NEU, CEU, MED) and 4 African (SAH, WAF, EAF, SAF) — covering a wide latitudinal range from temperate Northern Europe to sub-Saharan Africa.

Two variables were extracted:

- **Precipitation (P)** — mm/month
- **Potential Evaporation (PET)** — mm/month

The **Aridity Index** ($AI = P / PET$) was computed per region and year to assess long-term hydroclimatic trends.

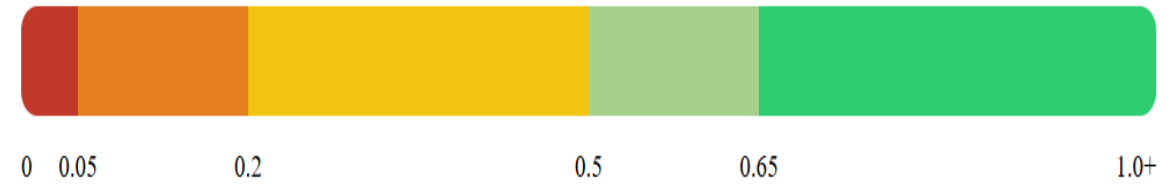


Aridity Index: $AI = P / PET$

The **Aridity Index** ($AI = P / PET$) was adopted as the core metric of this study, following the methodology of the **UNEP (1992)** framework, which defines aridity as the ratio of mean annual **precipitation** to mean annual **potential evapotranspiration**.

AI values close to **0** indicate extreme water deficit, while values **above 0.65** reflect humid conditions where precipitation consistently exceeds evaporative demand.

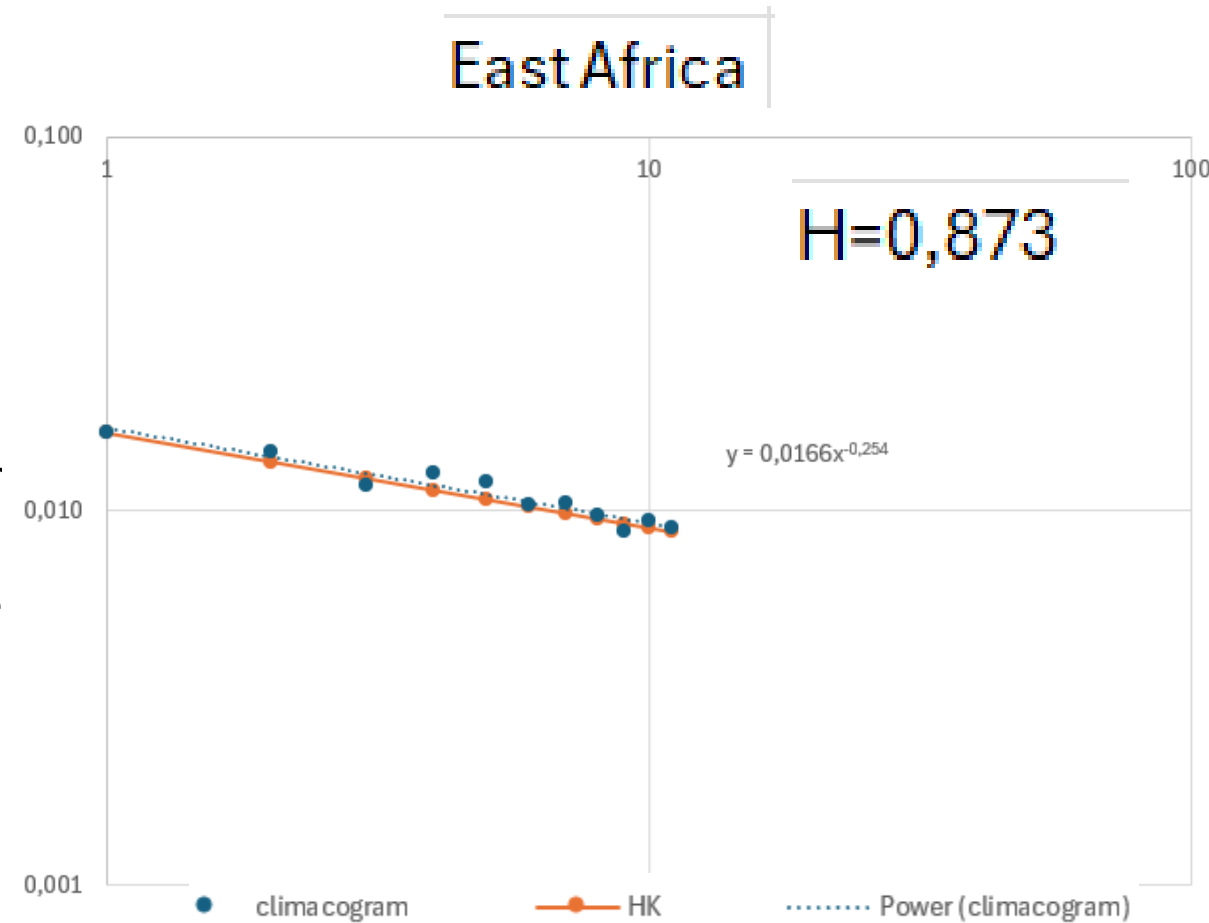
The **classification thresholds** shown (Hyperarid, Arid, Semi-arid, Dry sub-humid, Humid) are drawn directly from the **UNEP (1992) World Atlas of Desertification**, as subsequently adopted by the **FAO** and referenced in IPCC assessment reports, and represent the internationally accepted standard for dryland classification.



UNEP (1992) — Climate classification based on the Aridity Index ($AI = P / PET$)

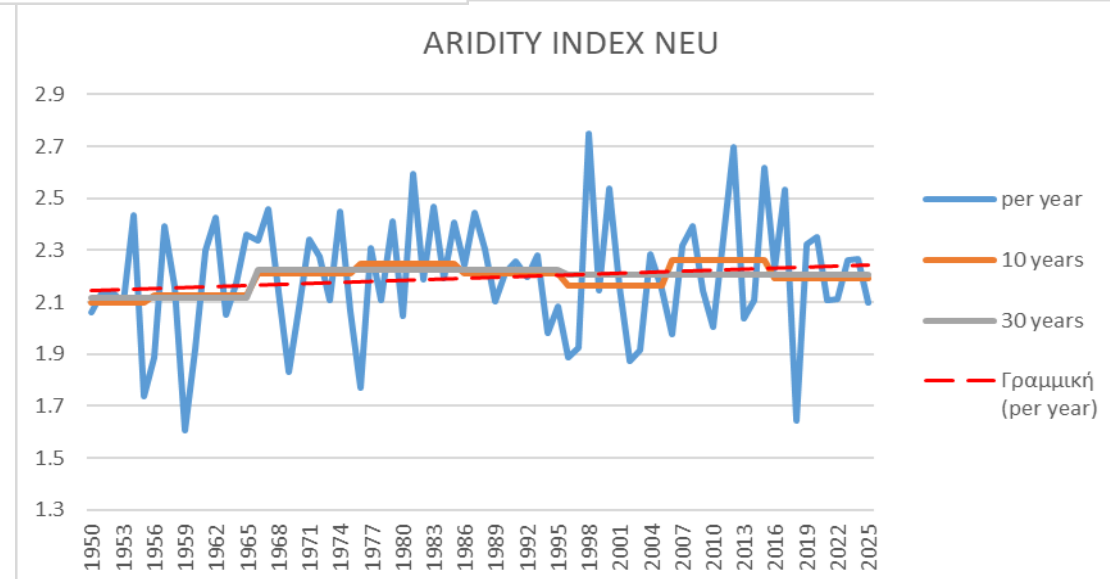
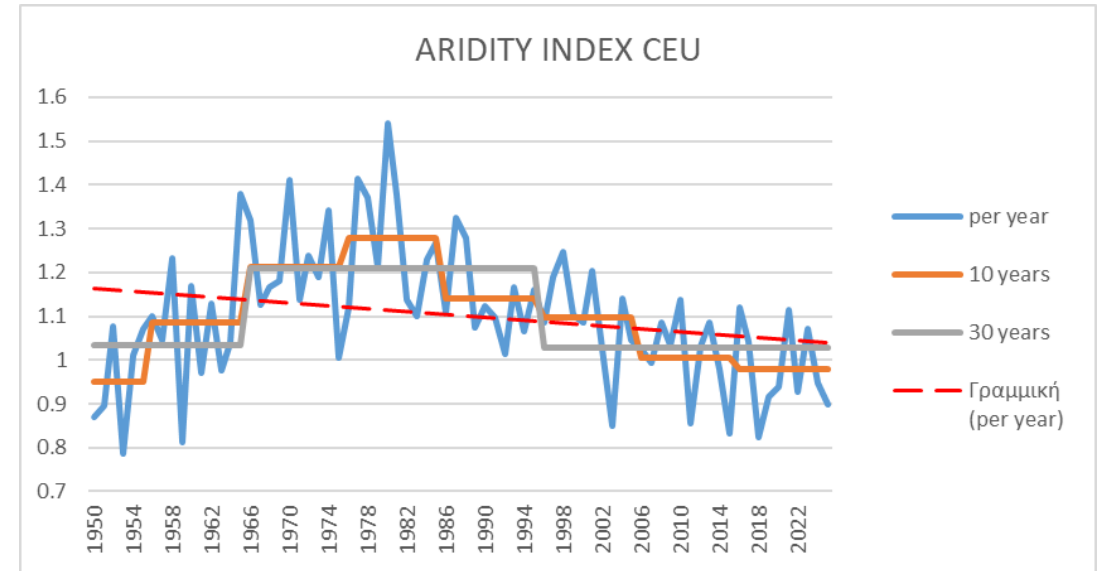
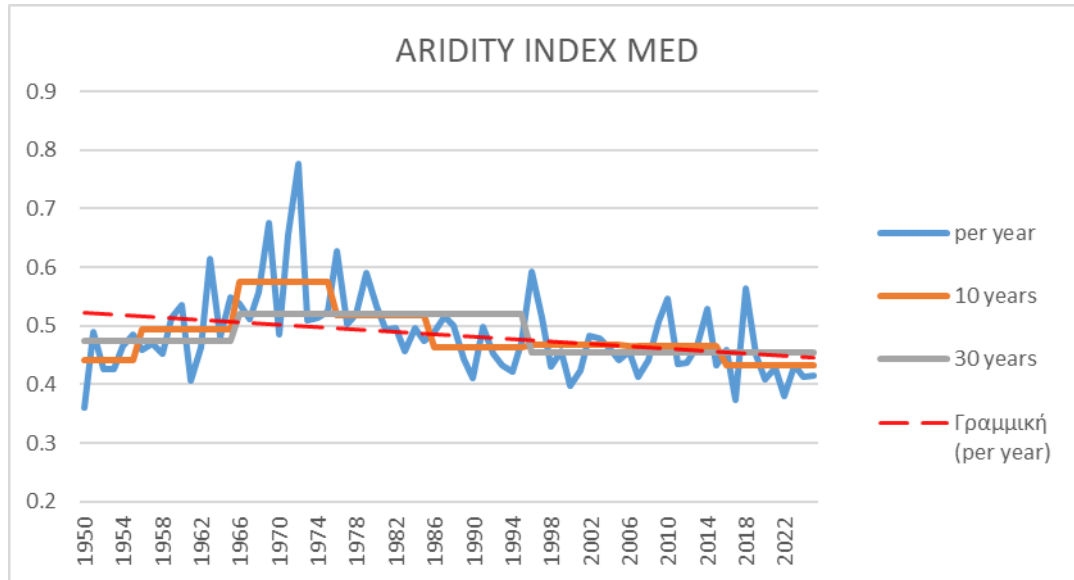
Stochastic Framework

The Hurst-Kolmogorov (HK) stochastic framework describes the long range memory and persistence of aridity. H values approaching 0,5 indicate more random behaviour, whereas H values approaching 1 indicate strong aridity persistence, conditions tend to continue over time.

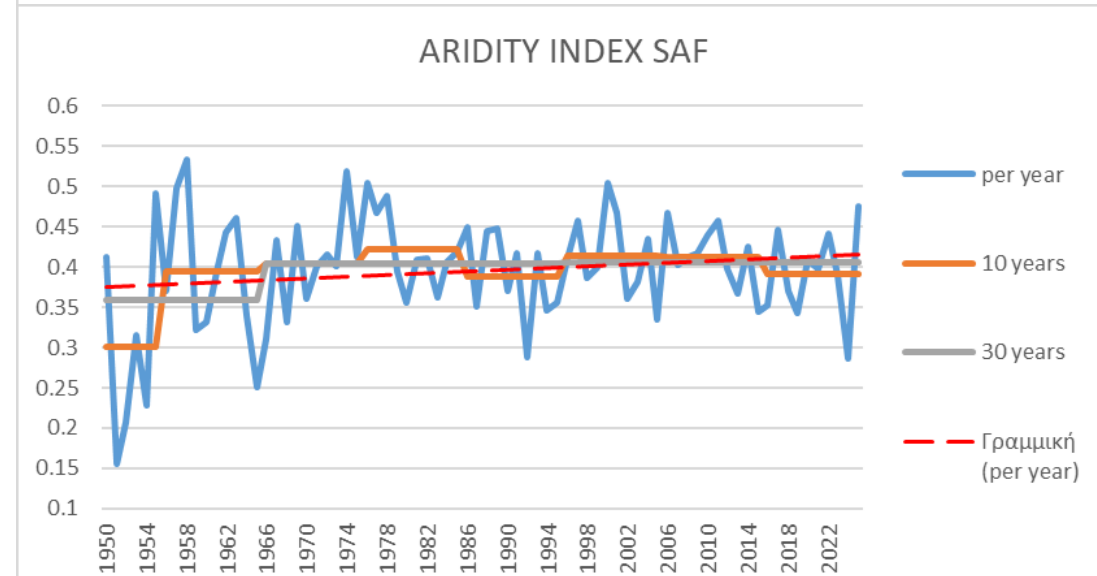
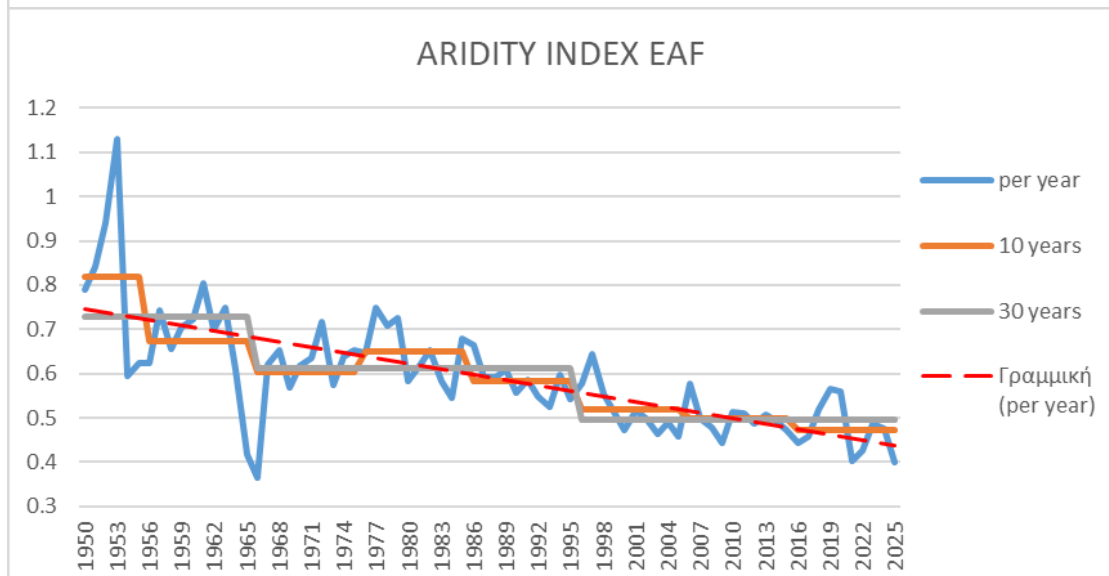
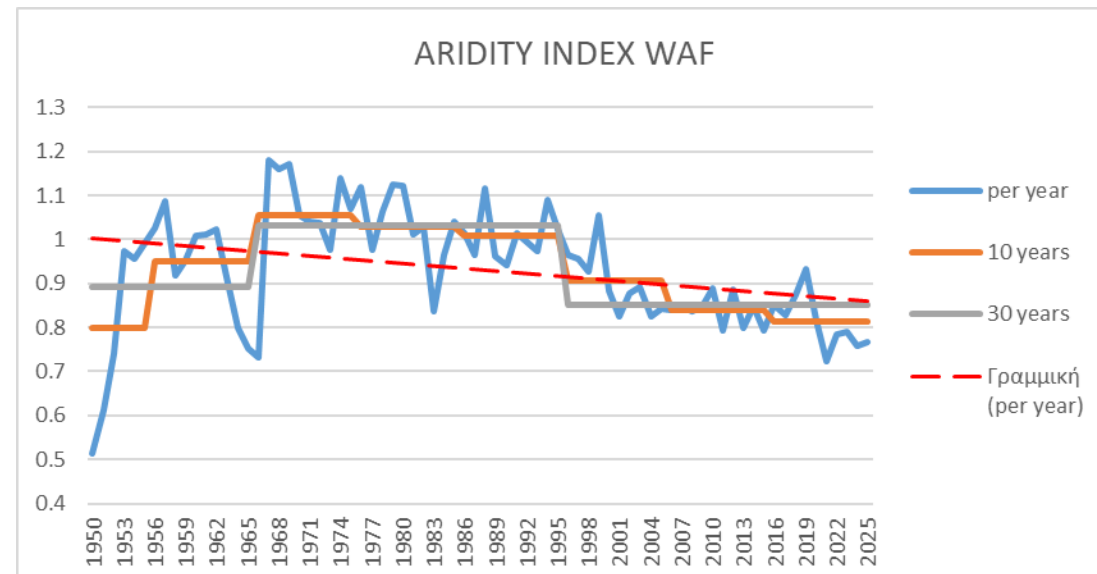
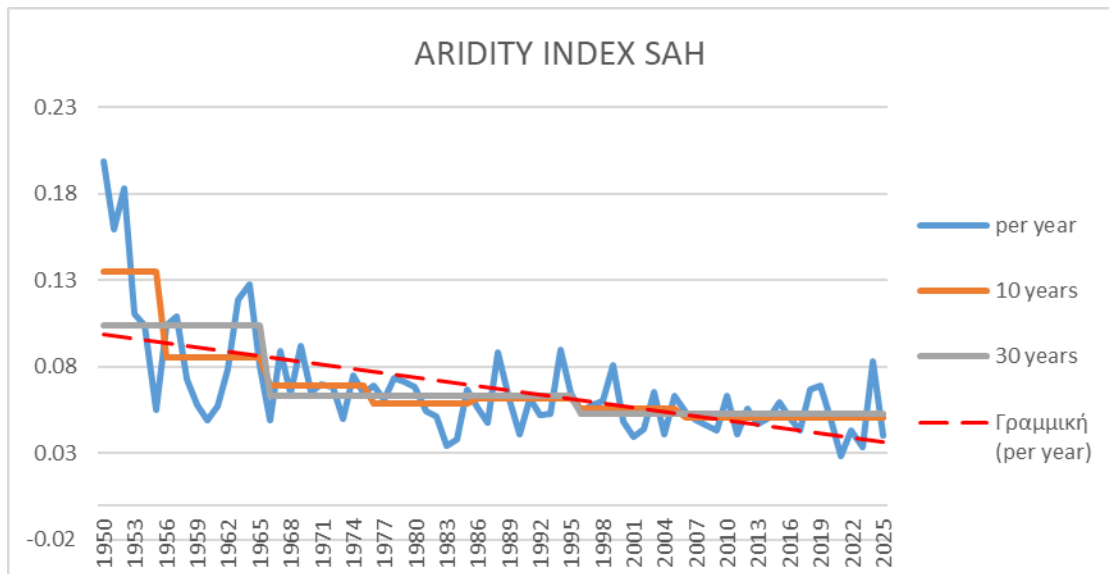


Results

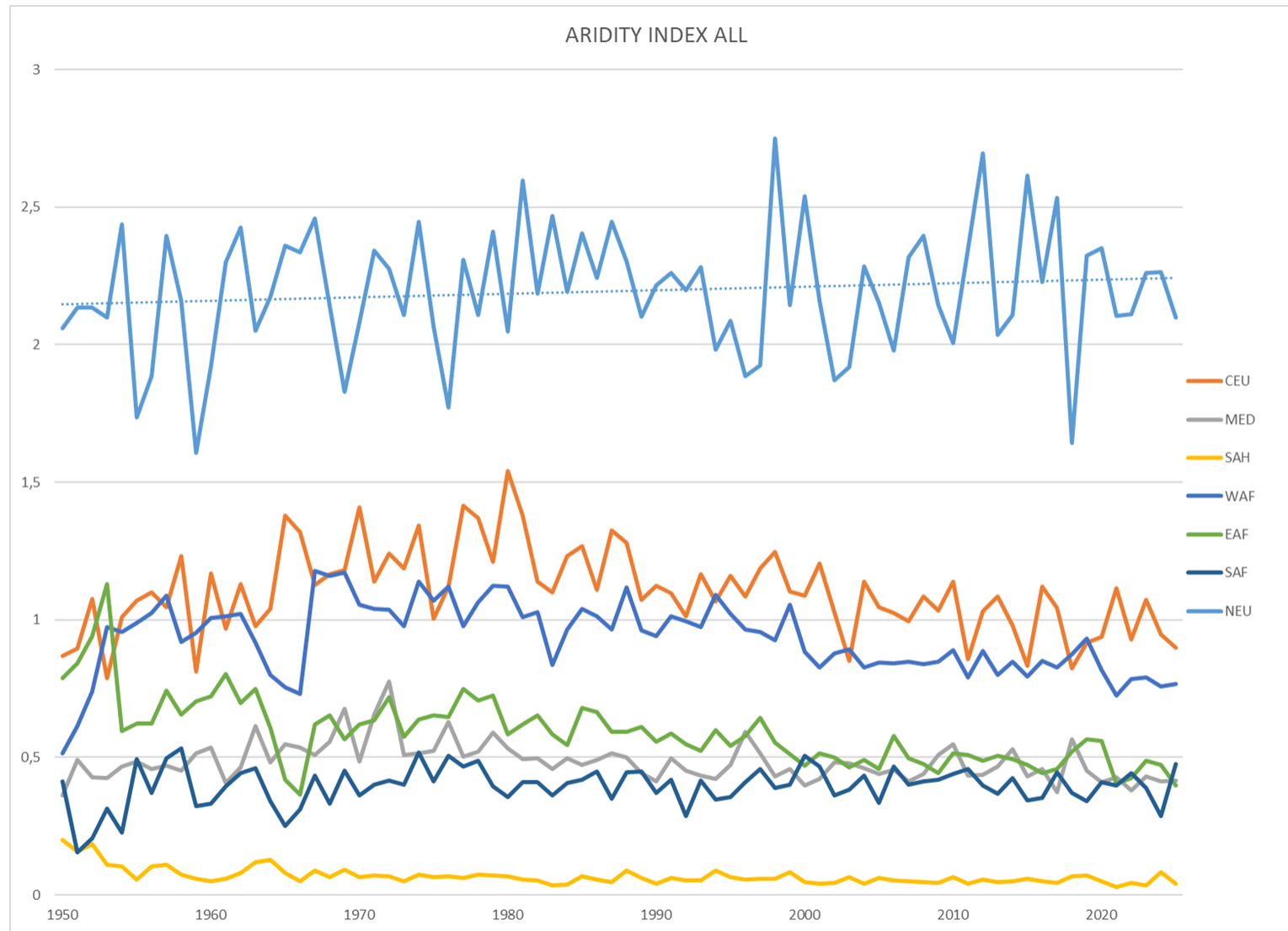
Aridity Trends: European Regions



Aridity Trends: African Regions

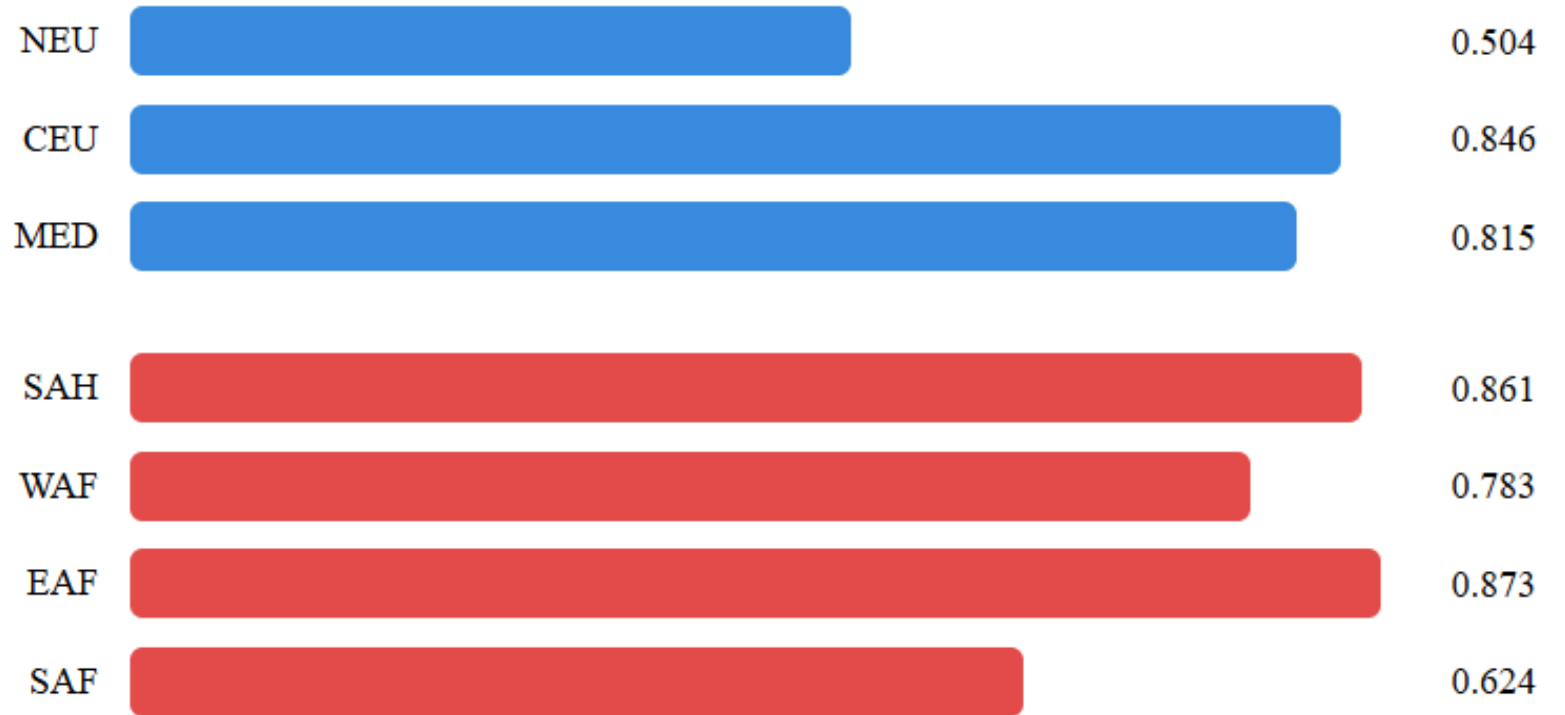


Aridity Trends



Arridity Persistence-Estimation of the Hurst component

$H > 0.5$ — persistent behaviour in all regions



■ European regions ■ African regions

Hurst exponent H

The MED, EAF and SAF regions are frequently affected by semi arid conditions. However Med and EAF show a decreasing trend in the Aridity Index over time and are characterised by higher H values, which suggests not only a shift towards drier conditions but also strong long-term persistence.

Infrastructure vs. Water scarcity

Key Finding - Water scarcity

Renewable internal freshwater resources per capita m³/capita (2022)

EAF	Ethiopia	973
	Tanzania	1,298
	Uganda	834
	Average	1035
MED	Tunisia	346
	Greece	5,557
	Italy	3,093
	Spain	2,327
	Average	2831
SAF	South Africa	718
	Zimbabwe	763
	Mozambique	3,071
	Average	1517

Indicators for Water scarcity

Absolute Scarcity: < 500 m³

Water Scarcity: 500 - 1.000 m³

Water Stress: 1.000 - 1.700 m³

Key Finding - JMP Infrastructure Gap: Safely Managed Drinking Water - At Least Basic Drinking Water

		People using safely managed drinking water drinking services (%) (2024)	People using at least basic drinking water services (%)	Infrastructure Gap (%)
EAF	Ethiopia	14	56	42
	Tanzania	31	65	34
	Uganda	18	63	45
	Average	21	61	40
MED	Tunisia	65	97	32
	Greece	97	100	3
	Italy	97	100	3
	Spain	99	100	1
	Average	89.5	99	10
SAF	South Africa	68	90	22
	Zimbabwe	25	67	42
	Mozambique	28	67	39
	Average	40	75	34

JMP Infrastructure Gap

To isolate the effect of water infrastructure from climate-driven water scarcity, we introduce the **JMP Infrastructure Gap**, defined as:

Infrastructure Gap (%) =

At Least Basic (%) – Safely Managed (%)

Countries with a large gap — such as **Ethiopia** (42%) or **Uganda** (45%) — have populations that can reach a water source, yet the network infrastructure is insufficient to guarantee quality and reliability.

In contrast, countries like **Spain** (1%) or **Italy** (3%) show near-complete infrastructure coverage.

Conclusions

1. **Aridity trends differ significantly between continents.** MED and SAF regions show statistically significant long-term drying trends, while NEU exhibits slight moistening. African regions (EAF, SAF) display higher Hurst exponents, indicating stronger persistence — meaning drying conditions are self-reinforcing and likely to continue.
2. **For regions with similar aridity, infrastructure is the decisive factor.** EAF and SAF share comparable Aridity Index values with MED, yet their JMP Infrastructure Gaps exceed 40% versus near-zero in Mediterranean countries. This directly answers the core research question: **water scarcity in sub-Saharan Africa is primarily infrastructure-driven, not climate-driven.**
3. **The Hurst-Kolmogorov framework adds value beyond trend detection.** High H values in MED and EAF reveal that aridity changes are not random but persistent — a critical distinction for long-term water resource planning that standard trend analysis alone cannot capture.
4. **A multi-dimensional approach is needed.** The Aridity Index alone cannot explain water access disparities. Combining AI with infrastructure indicators (JMP Gap) provides a more complete diagnostic framework for distinguishing climate-driven from infrastructure-driven water scarcity.

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<https://data.worldbank.org/indicator/ER.H2O.INTR.PC?end=2022&start=1961&view=map>

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ERA5 overestimates land drying trend from 1980 to 2023 by more than 100%

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