Long term trends in the Bologna daily rainfall time series

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Introduction

The **rainfall time series observed in Bologna** (Italy) is one of the longest daily precipitation records available.

Dating back to 1813 with no missing values, the time series spans over 208 years.

As such, it provides a valuable opportunity to **evaluate long term trends of rainfall statistics**, thus offering information on **past and recent precipitation changes** and **long term** (more than 3 years) **droughts.**

Data

Rainfall observation in Bologna at daily time scale dates back to 1714. Since 1813 the series is continuous.

A **fascinating history** of the time series and the methods used to find and fix apparent inconsistencies are provided by Brunetti et al. (2001).

In order to correct the apparent underestimation of rainfall during the periods 1813–1858, 1900–1928, and 1813–1978, Brunetti et al. (2001) proposed **monthly correction factors**, which were estimated by making a comparison with other monthly series. To avoid introducing spurious bias, **we analyse the raw data** that are available in the European Climate Assessment Daily Database (ECA & D) (https://climexp.knmi.nl/). The time series is extended up to 2022. Results are evaluated by considering the correction factors proposed by Brunetti et al. (2001).

Visual inspection

Figure 1 shows the time series from 1813 to 2022 with the average value plotted in black. The **lower and upper extreme values** occurred in the 1820s and in the decade ending in 1902, respectively. In red we show the 50-year average for the periods 1813-1863 and 1972-2022.

The shift in average values already noticed by Brunetti et al. (2001) is clearly visible. For comparison, **Figure 2 shows the daily rainfall time series in Milan** (Italy) for the period 1813-1991. One notices that **the general pattern of the two time series is comparable**, and shows the occurrence of **severe long term droughts** during the XIX century and the period 1930-1950. It seems that rainfall in Bologna is indeed underestimated from 1813 to 1857, but actually a similar drought pattern is observed in the first half of the XX century. These long term droughts look consistently more severe in Bologna with respect to Milan, thus **highlighting a significant and concerning climatic feature**.

We point out that droughts in Northern Italy, while being of a large scale atmospheric process, may exhibit **small spatial scale behaviours** that may reflect local environmental conditions.

Whether the data are corrected or not, it looks like long term droughts are a concerning threat for the Bologna region.

Trend and drought analysis

Figure 1

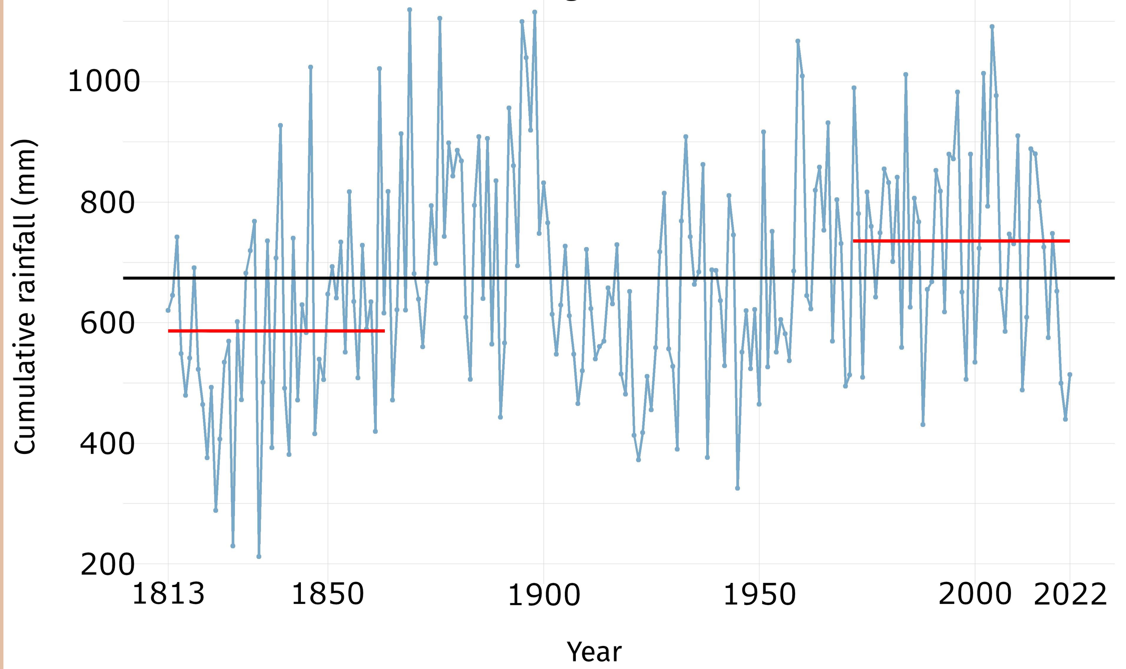

Figure 2

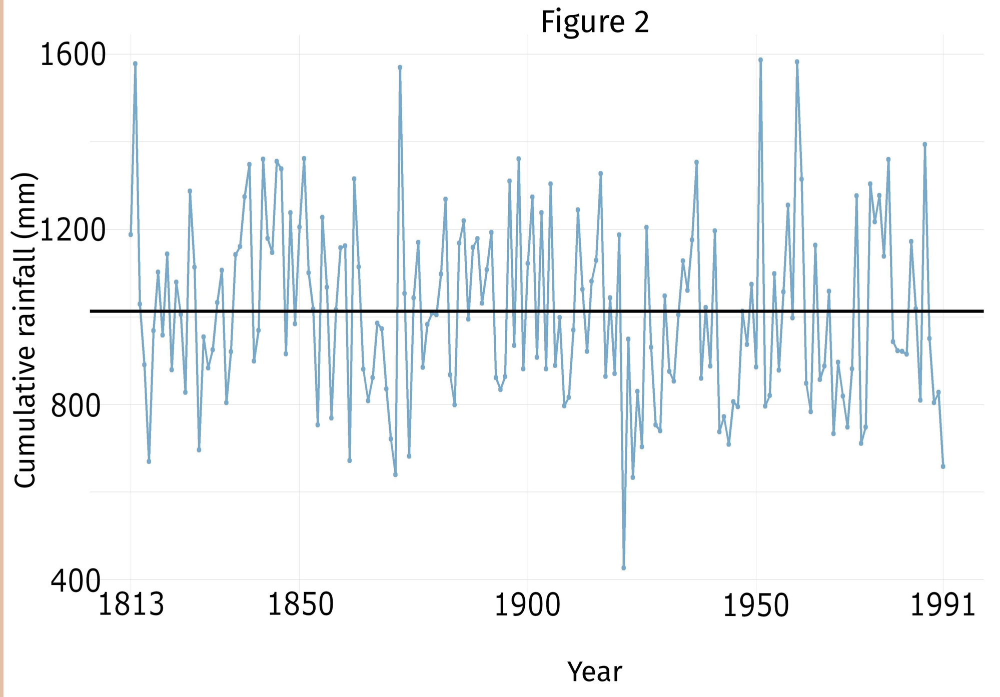

Figure 3

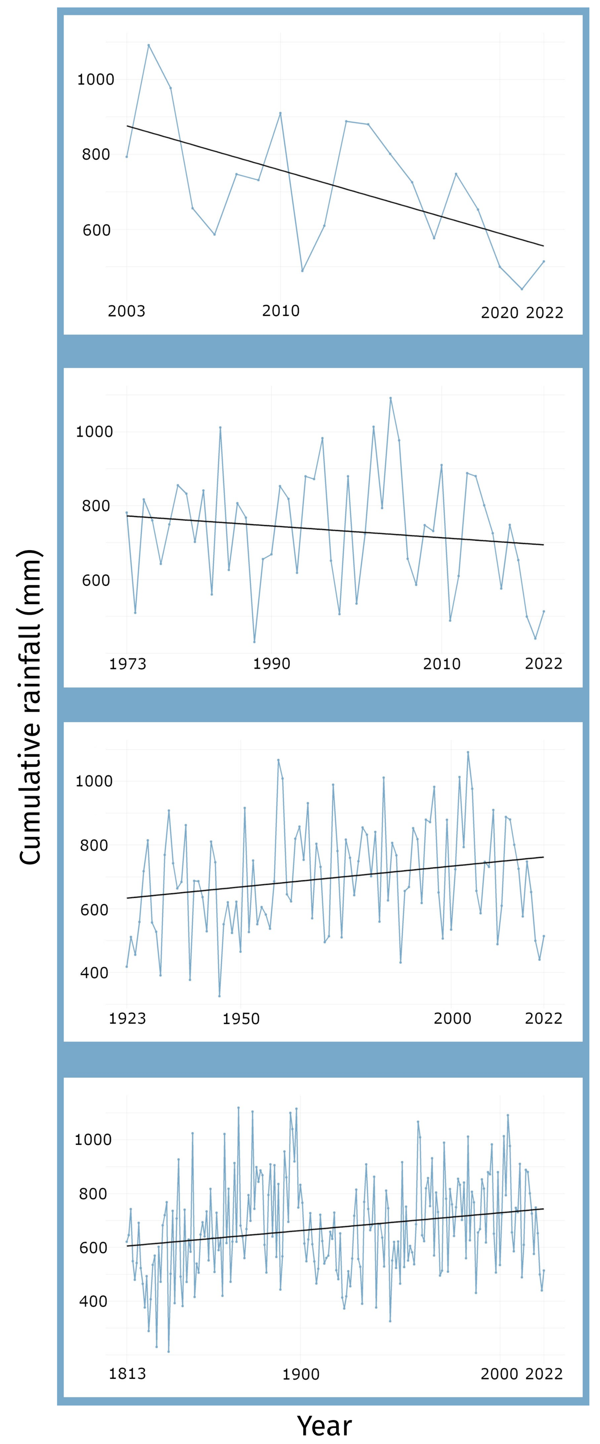

Figure 1 shows the presence of an increasing trend in the raw data during the whole observation period.

In particular, the 1813-1863 mean value is **almost 150mm/year smaller** than the 1973-2022 one.

Independently of the introduction or not of a correction factor (which we did not use) one notices that several long droughts (expression of a long term cycle which may be attributed to the **Hurst (1951) effect**) occurred up to 1950. After that time several seasonal droughts occurred with less persistence in time.

The drought that occurred between 1945 and 1950 was a **particularly severe** one, which is still well remembered in Northern Italy.

Figure 3 and Table 1 report the trends estimated over the periods **2003-2022, 1973-2022, 1923-2022** and **1813-2022.** Trends were estimated with the **Mann-Kendall test** and the **Sen's Slope method.**

Results show **downward trends** in the last 20 and 50 years but **upward trends** over the last 100 years and over the complete time series.

While the above mentioned uncertainty may affect the estimation of the overall increase, the reliability of the data collected in the past 20 years allows to conclude that a **decreasing trend is being observed during the global warming period.**

Regarding the recent past, precipitation in 2022 was higher than 2021 and 2020. Rainfall so far observed in 2023 is rather lower than the respective seasonal average, thus raising concerns **on the overall duration of the current drought**.

Table 1

Period	Slope (mm/year)	P-value
2003-2022	-18.94	0.010
1973-2022	-1.65	0.349
1923-2022	1.38	0.036
1813-2022	0.67	0.001

Review of climatic projections

To inspect whether **climate change may increase the drought frequency in the future** we refer to Guo and Montanari (2022) who recently presented a **drought frequency study for Bologna** by using climatic scenarios provided by 13 General Circulation Models. They applied **run theory (Yevjevich, 1967)** to annual rainfall to characterise drought events in terms of drought frequency, duration, severity and intensity.

In their application of run theory, the long term mean rainfall R_{LT} is adopted as the threshold to identify positive or negative runs (see Fig. 4). If rainfall in a given year is below an assigned threshold $T_{lower} < R_{LT}$ a negative run is started. An annual rainfall higher than R_{LT} fixes the closure of the run. If the interval between two negative runs is only one year and rainfall in that year is below a selected threshold $T_{upper} > R_{LT}$ the two runs are combined. Finally, only runs which have a duration of at least 3 years are determined as multiyear drought events. Guo and Montanari (2022) adopted 20% more and 10% less than RLT as T_{upper} T_{lower}.

Results are presented in Table 2 for SSP2.6 and SSP8.5 emission scenarios, for observed data, multi-model ensemble and each considered model. For more details see **Guo and Montanari (2022).**

Figure 4 (from Guo and Montanari, 2022)

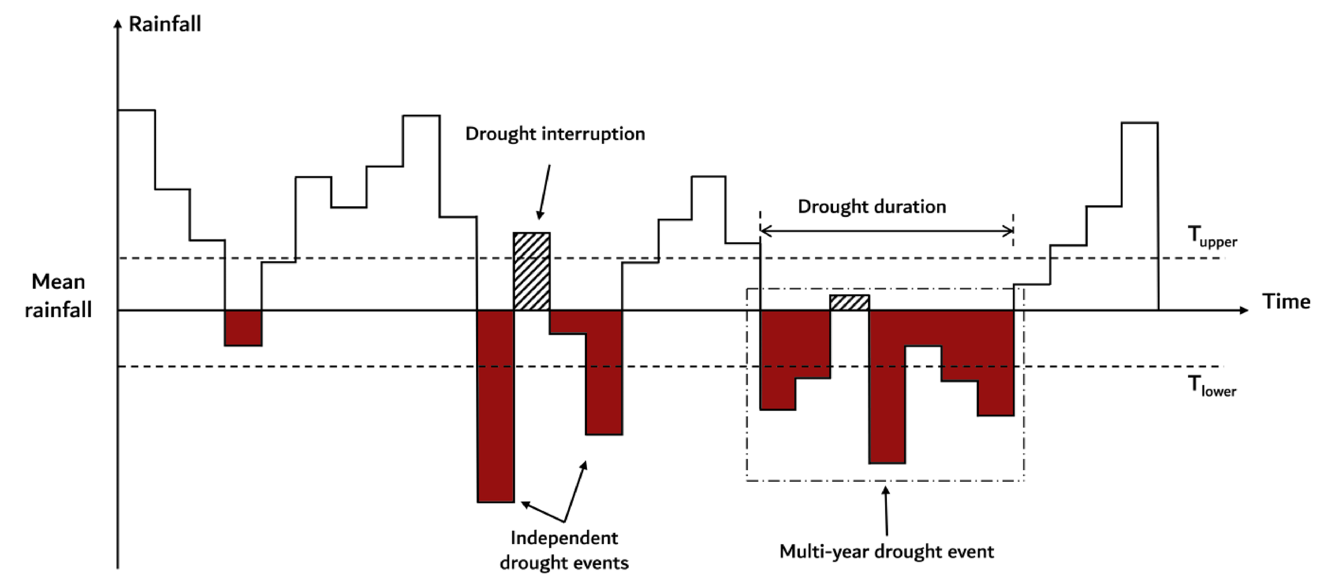

Table 2 (from Guo and Montanari, 2022)

Models	Drought Frequency			Drought Duration			Drought Intensity			Max Deficit		
	HIS	SSP2.6	SSP8.5	HIS	SSP2.6	SSP8.5	HIS	SSP2.6	SSP8.5	HIS	SSP2.6	SSP8.5
OBS	0.055	-	-	4.80	-	-	0.205	-	-	36.70%	-	-
MME	0.053	0.056	0.050	3.96	4.02	4.75	0.153	0.168	0.184	26.40%	27.87%	32.24%
1	0.030	0.070	0.058	4.20	3.83	4.20	0.134	0.184	0.202	27.05%	33.23%	39.55%
2	0.042	0.035	0.035	3.86	4.00	4.00	0.167	0.154	0.192	23.13%	27.05%	31.84%
3	0.042	0.047	0.058	4.14	3.75	4.20	0.155	0.188	0.210	29.89%	28.32%	36.45%
4	0.079	0.081	0.058	4.23	3.71	4.60	0.140	0.171	0.203	24.60%	28.18%	34.16%
5	0.055	0.035	0.035	4.11	3.00	3.67	0.130	0.110	0.091	22.03%	18.29%	19.21%
6	0.048	0.035	0.047	3.63	6.33	4.50	0.162	0.152	0.173	28.76%	25.12%	26.90%
7	0.048	0.070	0.070	4.25	4.00	3.83	0.167	0.155	0.177	27.27%	23.55%	29.40%
8	0.055	0.058	0.058	4.33	3.60	4.60	0.131	0.189	0.189	21.66%	30.67%	34.00%
9	0.048	0.081	0.023	4.25	3.57	9.00	0.132	0.177	0.246	26.86%	28.29%	48.37%
10	0.055	0.070	0.047	3.44	3.67	5.75	0.163	0.147	0.138	26.55%	24.34%	21.95%
11	0.079	0.047	0.047	3.54	3.75	5.00	0.173	0.226	0.184	29.03%	37.97%	34.04%
12	0.055	0.035	0.058	3.89	5.67	4.40	0.173	0.161	0.191	28.75%	26.34%	28.02%
13	0.055	0.070	0.058	3.56	3.33	4.00	0.158	0.165	0.194	27.63%	30.93%	35.23%

The unit of drought frequency is (times/year) and the unit of drought duration is (years). OBS and HIS are observed data and historical simulation. MME is multi-model ensemble mean and different numbers indicate different models: 1. ACCESS-CM2; 2. CMCC-ESM2; 3.CanESM5; 4.EC-Earth3-Veg-LR; 5. FGOALS-g3; 6. GFDL-ESM4; 7. INM-CM4-8; 8. INM-CM5-0; 9. IPSL-CM6A-LR; 10. MIROC6; 11. MPI-ESM1-2-LR; 12. MRI-ESM2-0; 13. NorESM2-MM.

The results show the **limited capability of models and the multi-model ensemble to reproduce drought frequency for Bologna**. In fact, observed data provide a more critical picture in terms of long term droughts.

Overall, we conclude that the occurrence of past severe droughts in Bologna and the decreasing trend of annual rainfall that was observed in the recent past point out a **relevant drought risk for the region**. In fact there is no reason to exclude that past drought events may occur again, if one also considers the impact of climate change.

Water supply in the Bologna region heavily relies on **groundwater resources**, which however may be severely impacted by a long term drought. In fact, the presence of a **multi-layered aquifer** with possibly long recharge (and recovery) time may imply that the impact of drought events **may last well beyond the duration of the drought itself**.

Conclusions

The rainfall time series in Bologna is a unique opportunity to study the impact of climate change and long term climatic behaviours in the region.

We found that overall, **no relevant change of annual rainfall is found** during the observation period.

However:

- There is compelling evidence in the data of the presence of long term cycles, originating multi-year droughts.
- The prediction of future features of long term droughts is affected by relevant uncertainty (Guo and Montanari, 2022).
- Under global warming, droughts are expected to occur more frequently in the future.
- There is a consistent decreasing trend in annual rainfall in the past 20 years.
- The years 2020, 2021, 2022 and (so far) 2023 are characterized by very low annual rainfall.
- Are we experiencing another long term drought?

Therefore:

- In view of the key role of groundwater resources during (and their potential to recover from) long term droughts, it is compelling to better inspect the sustainability of water uses in the region to avoid amplification of the impact of climate change.

References

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The tower of the Specola observatory in Bologna where the first rain gauge was located (By Paolo Monti - Available in the BEIC digital library, CC BY-SA 4.0).

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