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Is There a Precipitation Decline in the Mediterranean Region? An Assessment Based on the Scientific Literatured

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ABSTRACT

We have compiled studies published since 1980 on annual precipitation trends in the Mediterranean region. The total number of publications reviewed amounts to 337 papers, sourced from various references, focusing exclusively on studies that have analysed observational series, both from meteorological stations and gridded databases. The goal is to provide a comprehensive overview of the available research and results regarding annual precipitation trends, rather than criticising the quality of the data, methods used, or interpretations made. In this context, we present a compilation of papers in which we select original excerpts from the abstract, main text, or conclusions related to annual precipitation trends, summarising each manuscript. We do not focus on seasonal or monthly trends in detail; however, to offer a broader understanding of the extreme spatial and temporal variability of total annual precipitation, we have included in the Supporting Information file a compendium of papers classified by trends at the monthly and seasonal scales. No generalised significant trends are identified across the entire basin. When a significant signal is found, it greatly depends on the length of the period, the specific selected period, and the region. Finally, we discuss some key unresolved issues that need to be addressed to improve future research.

1 | Introduction

In the Mediterranean region, water is one of the most precious resources for human and ecological uses, and usually, its availability is insufficient to cope with demands. The reasons for the common water deficits are multiple and combine strong summer dryness and high interannual and decadal variability of precipitation. These conditions determine the adaptation of plant species to survive the water scarcity, while human societies have developed strategies adapting crop calendars to the rainfall regime and moving livestock transhumant systems along the year from dry areas to the mountains to guarantee pasture lands. More recently, some Mediterranean countries have generated a very dense network of reservoirs to store water during the humid season to supply irrigated lands, urban, industrial, and tourism uses during the summer.

The recent AR6 IPCC (2021) provides a comprehensive definition of the Mediterranean climate as follows:

> The Mediterranean has a heterogeneous climate that is partly semi-arid, especially along the southern coast of the Mediterranean Sea (...). It is characterized by mild humid winters and dry warm or hot summers, which are associated with

> large scale subsidence that is partly related to the downward branch of the Hadley circulation (...). Seasonal and interannual variability is strongly linked to natural modes of variability. The Mediterranean Sea acts as an evaporation source that dominates the regional hydrological cycle, which is characterized by local cyclogenesis and a separate branch of the mid-latitude storm track (...). Strong storms can develop over the Mediterranean (...). The Mediterranean region is also characterized by strong land-atmosphere coupling and feedbacks (...) generating prolonged droughts and intense heatwaves. Other aspects of Mediterranean climate include regional winds, which can be very strong due to the channelling effect (...) and extreme rainfall during autumn (...).

Given the aforementioned characteristics, the Mediterranean climate areas, particularly around the Mediterranean basin, are considered from years ago a climate hot-spot at a planetary scale (Giorgi 2006; Tuel 2020), a fact which is stressed in the last report of the IPCC (AR6 2021). Furthermore, if we consider that more than 500 million people live around the Mediterranean basin, potential changes in precipitation would have enormous social and environmental effects, and any eventual decline in precipitation, changes in its seasonality, or a combination of both processes would have enormous negative social and environmental consequences in the region (Riedel and Weber 2020).

The assessment of precipitation trends in this region is complex. Added to the strong variability of precipitation, the large number of countries in the basin makes difficult global analyses based on observed data. These reasons could partially explain that the most recent IPCC report (GWI, IPCC 2021) contains partial inconsistencies in different chapters of the document as follows:

- Chapter 8. 'Precipitation has decreased over [...], the Mediterranean region, as simulated by the CMIP5 multi-ensemble mean' (AR6, Cap. 8, p. 1081).
- Chapter 8: 'A number of studies have identified a decline in precipitation since 1960 and attributed this to anthropogenic forcing [...] However, historical trends in precipitation across the Mediterranean are spatially variable and contain substantial decadal variability, such that an anthropogenic influence may not be detectable in all areas' (p. 1087).
- Chapter 10: 'Regarding regional land precipitation changes over the 1901–2010 and 1951–2010 periods, application of the univariate detection method based on CMIP5 models suggests attributable anthropogenic changes at several locations such as [...] and decreases over parts of the Mediterranean region' (p. 1416).
- Chapter 11. 'Other regions do not show substantial trends in long-term meteorological drought or display mixed signals depending on the considered time frame and subregions, such as [...] the Mediterranean display mixed' (p. 1573).
- Chapter 11. 'In the Mediterranean (MED) region, some studies have identified a precipitation decline. [...] and a possible human contribution to these trends. On the contrary, other studies have not identified precipitation and meteorological drought trends in the region from the mid-20th century. [...] internal variability [...] in the region, [...] limits the attribution of human influence on variability and trends of meteorological droughts [...]. In addition, there are important subregional trends showing mixed signals. The evidence thus leads to an assessment of low confidence in the attribution of observed short-term changes in meteorological droughts in the region' (p. 1577).
- Chapter 12: 'Precipitation has generally increased in Northern Europe and decreased in Southern Europe, especially in winter but in the latter precipitation trends are strongly dependent on the examined period. The trend in precipitation increase in the north and decreasing in the south is also represented by global and regional climate simulations and has been attributed to climate change [...]. The Mediterranean region shows evidence of large-scale decreasing precipitation trends over 1901–2010, which are at least partly attributable to anthropogenic forcing according to CMIP5 models. Nevertheless, there is low agreement among studies on observed precipitation trend in the Mediterranean region' (pp. 1822–1823).
- Atlas: 'In the European Mediterranean observed land precipitation trends show pronounced variability within the region, with magnitude and sign of trend in the past century depending on time period and exact study region' (p. 1999).
- Atlas: 'In the European Mediterranean trends in annual mean precipitation contain substantial spatial and temporal variability (medium confidence)' (p. 2003).

The discrepancies underscored in the latest IPCC report emphasise the crucial need for a comprehensive evaluation of the precipitation trends in the region, beyond the effects of diverse databases, analysed periods, and applied methods, and not biased by studies based on regional series, selected short periods, or spatially limited information.

This manuscript presents a compilation of the available published research on precipitation trends in the Mediterranean region, including studies that analyse the basin as a whole, selected areas, countries or particular regions (usually catchments). The review is not constrained to a particular period, but it is focussed on analyses based on observations, including data from meteorological stations and gridded from observed data at stations, not model results or satellite data. The objective of the review is neither to make a critical analysis of the data characteristics, quality and methods used in each study, nor interpretation or conclusions, but to show a global overview of the abundant research done on the topic in recent decades.

The compilation-review has been done by using 'Mediterranean', 'Precipitation' (rainfall) and 'trend' as key in the main scientific tools repertories (Scopus, Clarivate), and also including the name of the different countries in the basin; temporal frame of published studies was between 1980 and 2022.

We know that we do not include all the scientific literature published on the topic, but we believe that the compilation produces a global picture of the research and the results of precipitation available in the study area.

The article is organised as follows: in Section 2 we present a brief global description of the revised studies, then we present the studies detailing by country, and grouped in different geographical sectors (Section 3). In this section we reproduce original paragraphs or sentences from each paper. When we summarise the original paragraph deleting part of the original sentence, we used (…), when we resume previous comments not included in the paragraph, or present the context, we used […]; in any case, we try to avoid any interpretation different from the original source. After the regional studies, we present the studies that analysed the basin as a whole (Section 4). Finally, in Section 5 we introduce a brief discussion of monthly and seasonal trends summarising the extended information included in the Supporting Information S1. In Section 6 we recapitulate the main conclusions.

2 | Brief Description of the Results

The compilation of papers in which annual precipitation trends are specifically quoted and analysed is presented in Table 1. We identified 33 publications focussed on the whole basin and 304 related to national analyses (total 337). In Table 1 the most striking results are those related to national scale where some cases are particularly highlighted, such as Italy, Türkiye, and to a lesser extent Algeria and Spain. In our compilation, when we specify the statistical significance, it must be indicated by authors at least with $p < 0.10$ level.

TABLE 1 | Number of papers including annual trend analyses around Mediterranean basin and countries.

Area	Number of papers	Area	Number of papers
Whole basin	33	Eastern Europe	2
Northern Africa	5	Romania, Moldova, Ukrainia	13
Morocco	17	Bulgaria	8
Algeria	29	Greece	13
Tunisia, Libya	10	Serbia	12
Egypt	4	Albania, Bosnia-Herzegovina, Montenegro	7
Israel, Palestine	13	Croatia, Slovenia	8
Jordan	12	Italy	58
Lebanon	3	Southern France	4
Syria	6	Portugal	11
Cyprus	4	Spain	27
Türkiye	38	Total	337

The evolution in time is shown in Figure 1 in which we count the number of papers per year; the figure shows that after an exponential increase until 2019 the last years seem to be a topic of less interest. A relevant data point is the year of 2003 in which only one paper was found; on the contrary, 2019 was the year in which the highest number of papers were published (32).

Although the compilation is focussed on annual trend, we also included in Section 5 a second compilation of published studies in which trends of monthly and seasonal are noticed in different areas (see Supporting Information). Because some of these studies do not include annual trend, these explain the difference between totals in Table 1 (337) with total amount quoted in the reference list (360).

3 | Regional Studies

The compilation has been done at national scale but grouping nations by geographical areas as follows: North Africa (Morocco, Algeria, Tunisia, Libya and Egypt), Eastern Mediterranean (Israel, the Palestinian territories, Lebanon, Syria, Jordan and Cyprus), Türkiye, European Eastern Mediterranean (Romania, Bulgaria, Moldova and Ukraine), Balkans (Greece, Serbia, Montenegro, the Republic of North Macedonia, Slovenia, Croatia, Albania and Bosnia-Herzegovina) and Western Mediterranean (Italy, South France, Spain, Portugal, Malta and Gibraltar).

3.1 | North Africa (Morocco, Algeria, Tunisia, Libya and Egypt)

- Tramblay et al. (2013). From Morocco to Tunisia, period 1950–2009, 22 stations. Comment: 'Results show a strong tendency toward a decrease of precipitation totals'.
- Donat et al. (2014). From Morocco to Egypt, period 1961 to 2010, 27 stations. Comment: '… in the western part (…), there is a tendency toward wetter conditions…, in the eastern part, there are more drying trends, although, these are of low significance'.
- Nouaceur and Murărescu (2016). From Morocco to Tunisia, period 1970–2013, 35 stations. Comment: '… results show … a gradual return to wetter conditions since the early 2000s in Algeria and Tunisia and from 2008 for Morocco'.
- Benabdelouahab et al. (2020). Morocco and Algeria, also southern Iberian Peninsula period 1987–2016, 25 stations. Comment: 'Overall, an increase of the rainfall amount is observed from east to west in (…) western Mediterranean countries since the second decennial (1997–2006)'.
- Salhi et al. (2022). Morocco, Algeria and Tunisia, period 1970–2021, 45 stations. Comment: 'The Atlas Mountain belt shows a significant negative trend, (…) most of the study area is under a non-significant trend'.

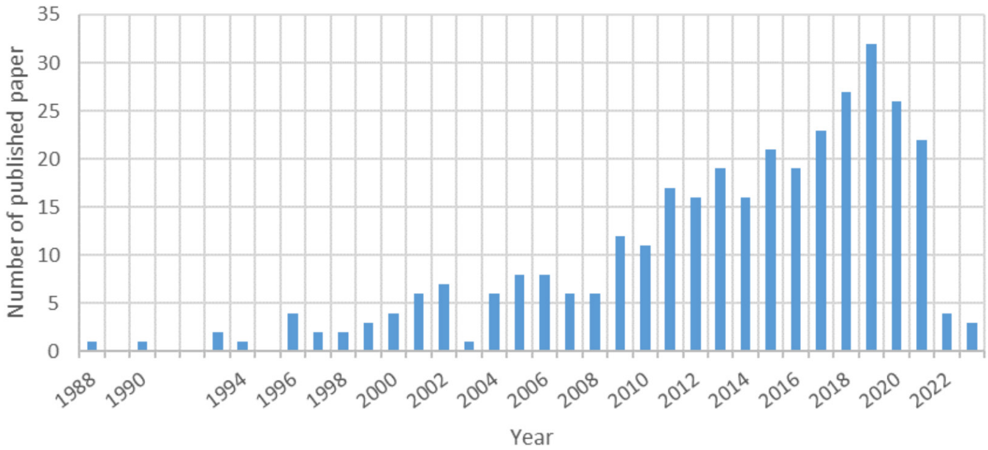

FIGURE 1 | Number of papers published (1985–2024) in which the annual trend of precipitation in the Mediterranean basin is researched. [Colour figure can be viewed at wileyonlinelibrary.com]

3.1.1 | Morocco

3.1.1.1 | Studies With More Than 50 Years.

- Schulz et al. (2008). Upper Drâa basin, southern Atlas, period 1940–2003, 9 stations. Comment: [inconclusive trends] 'It was found that precipitation has a high variability that covers possible trends during the last decades'.
- Ait Brahim et al. (2016) Morocco, period 1961–2017, 29 stations. Comment: '... there is a strong tendency toward a decrease of precipitation totals (...) for Morocco and western Algeria'.
- Fniguire et al. (2017). Central Morocco, period 1929–2010, 7 stations. Comment: [in 2 stations] 'Annual rainfall data series show statistically significant downward trend. For the other stations, the null hypothesis is accepted'.
- Abahous et al. (2018). Western and Anti-Atlas Mountains, period 1932–2010, 19 stations. Comment: '... annual precipitation (...) 1932–2010 shows wet conditions with a maximum between 1963 and 1965 followed by a decrease since 1973'. [from 1970] '... a negative trend is detected in stations located in Western High Atlas and Anti Atlas Mountains, (...) statistically significant in five stations'.
- Echakraoui et al. (2018). Central Morocco, period 1934–2007, 6 stations. Comment: 'On an annual basis, changes in precipitation [negative] were not significant and varied from one region to another'.
- Driouech et al. (2021) Morocco, period 1960–2016, 30 stations. Comment: 'The annual mean precipitation (...) show less spatially consistent tendencies despite the predominance of negative [mostly not significant] trends'.

3.1.1.2 | Whole Country With < 50 Years and Regional Studies, Mostly Small Catchments.

- Singla et al. (2010). Atlas Mountain, period 1970–2008, 27 catchments. Comment: '... generalized rainfall reduction by an abrupt change (...) between 1976 and 1980, except (...) between the Rif and the Mediterranean Sea, where (...) shows a trend toward a relative increase since 1980'.
- Filahi et al. (2016). Morocco, period 1970–2021, 20 stations. Comment: '... decreasing trends are detected for the majority of stations, yet these trends are only significant at a few stations'.
- Khomsi et al. (2016). North and south Morocco, period 1977–2003, 19 stations. Comment: 'When aggregated at the annual scale, some significant trends toward a decrease [i.e., negative trend] have been found'.
- Boudad et al. (2018). Inaouen Basin (Northern Morocco), period 1971–2011, 2 stations. Comment: [using SPI index] 'The results of trends based on Mann-Kendall test showed generally no tendency of the SPI series for time scales of 3, 6 and 12 months'.
- Diani et al. (2019). Central Atlas, 1971–2019, 4 stations. Comment: 'The results showed (...) no significant trend in annual rainfall'.
- Hadri et al. (2021). Chichaoua basin, Western High Atlas, period 1970–2017, 4 stations. Comment: [annual trend] '... is statistically significant'.
- Hadria et al. (2019). Morocco, period 1998–2012, 23 stations. Comment: 'The extreme north eastern of Morocco manifests a positive SPI trends (...) while the extreme south (...) is suffering from a decrease of annual precipitations (...). The negative trend of SPI could be explained by a decrease in rainfall amounts'.
- Salhi et al. (2019). North Morocco, period 1958–2015, 53 stations. Comment: '... annual rainfall increase trend since 1996'.
- Ouatiki et al. (2019). Central Morocco, period 1970–2010, 15 stations. Comment: '... annual rainfall has demonstrated a general [mostly not significant] decreasing tendency'.
- El Harraki et al. (2020). Morocco, period 1961–2007, 29 stations. Comment: 'Comparison of the annual (...) precipitation of the two decades (1971–1980) and (1998–2007) has revealed a tendency (...) to decrease of annual precipitation (...) more pronounced in the northern and central area'.
- Bouizrou et al. (2022). Morocco, Period 1976–2016, 78 stations. Comment: 'The annual precipitation exhibited positive and negative trends where there was no clear evidence of upward or downward trends'.

3.1.2 | Algeria

3.1.2.1 | Studies With More Than 50 Years.

- Hamlaoui-Moulai et al. (2013). Western region, period 1914–2004, 21 stations. Comment: '... significant decreasing trend (...) for 15 stations'.
- Meddi (2013). Northwest, period 1930–2003, 25 stations. Comment: '... increase of rainfall since 1945–1946, which followed by a relatively dry phase and a decrease in precipitation from the 70s'.
- Taibi et al. (2013). Northern country, period 1936–2009, 102 stations. Comment: 'A significant downward trend is observed since the mid-1970s, particularly in the west of the region'.
- Taibi et al. (2017). Northern country, period 1940–2010, 95 stations. Comment: '... there has been a significant decrease in rainfall in northwester Algeria since the middle of the 1970s, while eastern regions show no shift in rainfall patterns'.
- Taibi, Messelmi, Meddi et al (2019). Northern country, period 1950–2017, 9 stations. Comment: 'A decrease of annual rainfall was observed in the western part of the study area'.
- Amer et al. (2021). Central coastland area, period 1927–2012, 26 stations. Comment: '... significant decreasing trend occurred during the period 1927–2012 over the entire central coastal basin' [breakpoint between 1975 and 1981].
- Derdous et al. (2021). Cheliff basin (Northwest), period 1936–2008, 21 stations. Comment: '... a generalized decreasing trend of annual rainfall amounts accompanied by shifts of stationarity observed between 1974 and 1980'.

3.1.2.2 | Whole Country With < 50 Years and Regional Studies Mostly Small Catchments.

- Meddi et al. (2010). Macna and Tafna basins in Northwest, 1950–2004, 5 stations. Comment: '... revealed a significant decline in annual rainfall in the mid-1970s in both basin'.
- Baahmed et al. (2015). Macta basin, period 1975–2005, 68 stations. Comment. 'The results showed no significant trends on annual rainfall in the 1975–2005 period'.
- Taibi et al. (2015). Chéliff basin, 1971–2010, 13 stations. Comment: 'Le test de Mann–Kendall indique une tendance générale à la baisse significative pour les pluies totals'.
- Achite and Ouillon (2016). Wadi Abd sub-basin. period 1970–2010, 6 stations. Comment: '... precipitation decreased with the reduction in rainfall being relatively higher during the rainy season'.
- Elouissi et al. (2016). Macta basin, 1970–2010, 25 stations. Comment: '... decreasing trends [significant] in the northern part close to the Mediterranean Sea coastal area in the Macta basin, whereas at the south, the trends are in the increasing style [significant]'.
- Zeroual et al. (2017). Coastland, period 1972–2013, 7 stations. Comment: '... no significant change in the long-term trend and mean values of the series is observed'.
- Achite et al. (2017). Macta basin, 1970–2010, 80 stations. Comment: 'The Spearman rank coefficient highlighted a remarkable dry tendency in the northern (...), while (...) at higher elevations were dominated by temporal instability'.
- Elouissi et al. (2017). Macta basin, period 1970–2011, 42. Comment: '... annual total rainfall has identified a downward trend'.
- Ghenim and Megnounif (2016). Northern country, period 1970–2011, 35 stations. Comment: '... rainfall undergoes an overall downward trend. (...) decrease in annual rainfall was accompanied by a large temporal irregularity'.
- Taibi, Meddi, and Mahe (2019). Coastland, period 1961–1990, 5 stations. Comment: '...[only] a significant decrease of rainfall since the 1970s at the Tenes and Oran stations, located in the northwest'.
- Khentouche and Dridi (2019). Aures massif, period 1974–2009, 32 stations. Comment: 'Statistical tests reveal breaks around 1991–1994 (...) a significant decrease (1992–2009), particularly on the northern part of the massif'.
- Khedimallah et al. (2020). Cheliff and Medjerda basin (west and east Algeria), period 1968–2013, 48 stations. Comment: 'The Mann–Kendal and Pettitt tests have shown significant downward trends for rainfall'.
- Bouznad et al. (2020). Atlas, period 1985–2014, 11 stations. Comment: 'An increasing trend in precipitation was detected for most of the study area'.
- Aieb et al. (2020). Soummam basin, period 1967–2018, 24 stations. Comment: 'The rainfall was driven by an abrupt change (...) from wet years to (...) dry (...) between 1976 and 2009. Then, an increase in rainfall (...) between 2010 and 2018'.
- Boudiaf et al. (2020). Border with Tunisia, 1982–2017, 6 stations. Comment: 'Positive trends in (...) precipitation records appear in most stations with varying degrees'.
- Kadir et al. (2020). Medjerda basin, period 1981–2012, 1 station. Comment: '... a statistically significant downward trend (significance level 5%) is detected for the mean annual of *P*'.
- Bougara et al. (2020) Tafna basin, period 1979–2011, 9 stations. Comment: '... an increasing trend for annual rainfall after the break detected in 2007 [at 3 stations]. The results of the MK on the annual time scale (...) show no statistically significant trend for all the rainfall stations'.
- Ghorbani et al. (2021). Northern country, period 1980–2013, 44 stations. Comment: 'The MK trend analysis revealed a significant decreasing trend over the central and no trend in north and south of the study area' [break n 1992].
- Bouklikha et al. (2021). Tafna basin, period 1971–2016, 17 stations. Comment: '... stations located in the north, west and central part of the Tafna show a decrease in rainfall' [mostly non-significant].
- Achite et al. (2021). Chéliff basin, period 1970–2018, 150 stations. Comment: '... trend analysis evidenced (...) negative trend of the annual rainfall (22% (...) significant)

involving mainly the northern and the western-central area'.

- Harkat and Kisi (2021) Chéliff basin, period 1959–2019, 28 stations. Comment: '… in [low rainfall class] predominate slightly downward trend … For 'middle' rainfall trends, (…) strongly downward conditions in the centre (…) [and] 'high' [class] precipitation trends show steep downward in the southeast'.
- Bessaklia et al. (2021). North east Algeria, period 1970–2010, 36 stations. Comment: 'The mean annual precipitation (PRCPTOT) is dominated by an increasing trend that appears almost throughout the study region' [only significant in the northwestern].

3.1.3 | Tunisia and Libya

- Kingumbi et al. (2005). Merguellil basin, period 1976–1989, 8 stations. Comment: 'The study of eight rainfall series in central Tunisia has demonstrated a period, between 1976 and 1989, in which annual rain was reduced'.
- Driouech et al. (2013). Whole Tunisia, period 1960–2009, 5 stations. Comment: 'Tunisian precipitation does not exhibit any significant trends'.
- Zeleňáková et al. (2014). In Libya, period 1981–2010, 17 stations. Comment: 'Significant negative trends of annual precipitation were found in four out of seventeen analysed rainfall gauging stations in Libya'.
- Jemai et al. (2018). Bizerta-Ichkeul basin (northern Tunisia), period 1970–2011, 13 stations. Comment '… mixture of increasing and decreasing trends of rainfall is noted (…) from 2002 to 2011, is characterized by an increase of humid'.
- Chargui et al. (2018). Merguelli basin (central Tunisia), period 1961–2013, 15 stations. Comment: 'The annual rainfall has shown increasing trends on the majority of station' [a total of 6].
- Feki et al. (2018). Mellegue basin in the border Tunisia, period 1993–2004, 19 stations. Comment: 'There is a strong evidence of a global drying tendency in most of the stations'.
- Snoussi et al. (2018). In central Tunisia, period 1950–2014, 7 stations. Comment: '… a decrease of annual precipitations in the West Central Tunisia (…) a positive (…) was found in the East central Tunisia (…) but (…) insignificant. These findings prove the irregularity in time and space of rainfall trends'.
- Gader et al. (2020). Medjerda basin, 1973–2012, 41 stations. Comment: '… there is no significant trend in annual rainfall for the majority of the selected stations'.
- Ben Abdelmalek and Nouiri (2020). Whole Tunisia, period 1973–2016, 16 stations. Comment: '… only 30% of stations recorded significant climatic trends, [only 3 stations] had a significant tendency to become more humid, while only one station (…) had a significant tendency to become drier'.
- Jemai et al. (2018). Gabes basin, south-east Tunisia, period 1977–2015, 5 stations. Comment: 'Rainfall (…) was distinguished by three different periods (…) (1970–2011). (…) new climate trends have been registered from 2002 in Tunisia and Algeria (a return to wetter conditions)'.

3.1.4 | Egypt

- Gado et al. (2019). Whole country, different lengths from 1909, 31 stations. Comment: 'Six (19%) out of the 31 stations show significant trends … [f]our negative (…) while only two (…) positive'.
- Mostafa et al. (2019). Northern country period 1980–2017, 8 stations. Comment: '… analysis does not reveal any significant trend of [total precipitation]'.
- El-Geziry (2021). City of Alexandria, period 1980–2009. Comment: 'The mean annual trend of variation reflects an increasing trend in the amount of rainfall'.
- El-Tantawi et al. (2021). Nile Delta, period 1947–2010, 13 stations. Comment: '… the trends (1947–2010) are negative at five stations out of thirteen stations (…) All computed trends were (…) not significant'.

3.1.5 | North Africa Conclusions

Studies analysing precipitation trends in North Africa reveal a complex and spatially heterogeneous pattern over the last decades. Across Morocco, Algeria, Tunisia, Libya, and Egypt, most analyses point to decreasing precipitation trends, especially after the mid to late 20th century, with some regional and temporal variations. For example, in Morocco, studies highlight a significant decline in precipitation since the 1970s, particularly in mountainous regions such as the Atlas and Anti-Atlas. However, a return to wetter conditions has been noted in some areas since the early 2000s. In Algeria, a similar declining trend is evident, with significant decreases reported since the mid-1970s, particularly in the northwest. Some studies, however, identify a mix of trends, including localised increases in rainfall in certain high-altitude regions. Tunisia and Libya exhibit similarly mixed patterns, with significant declines in central Tunisia and sporadic increases in specific basins. Egyptian rainfall trends are generally less pronounced, with studies reporting no significant changes across most stations, although a few regions, such as Alexandria, exhibit slight positive trends.

Overall, while drying trends dominate much of the mid to late 20th century, recent studies suggest emerging signs of recovery in some regions. Temporal irregularity and spatial variability are recurring themes, with western North Africa (Morocco and Algeria) often experiencing stronger downward trends than eastern parts (Tunisia, Libya and Egypt). These findings underscore the influence of localised factors, such as topography and proximity to the Mediterranean, on precipitation patterns. However, the majority of trends detected remain statistically insignificant at smaller scales, indicating the challenges of drawing definitive conclusions from the regional highly variable precipitation dynamics.

3.2 | Eastern Mediterranean (Israel, the Palestinian Territories, Lebanon, Syria, Jordan and Cyprus)

3.2.1 | Israel and the Palestinian Territories

- Ben-Gai et al. (1994). In southern Israel, from 1930s, 30 stations. Comment: '... the annual average rainfall during the period 1961–1990 increased by up to ~30%'.
- Cohen and Stanhill (1996). Jordan valley, different periods from 1930 to 1990, 3 stations. Comment: 'No significant changes in total annual rainfall (...) were found'.
- Steinberger and Gazit-Yaari (1996). In Israel, period 1960–1990, 99 stations. Comment: '... precipitation amounts have decrease in the northern and central coastland areas and in the northern mountain area. In the southern coastal area and western slopes of the central mountain precipitation increased'.
- Ben-Gai et al. (1998). Israel, period 1931–1991, 60 stations. Comment: [after analyse parameter of gamma distribution] '... strongly increasing trend in the shape parameter (...) in the south, can imply a retreat of aridity. The (...) opposite (...) patterns [was found] in the North, (...) [while] an increasing trend in the shape parameter, (...) toward higher annual rainfall values (...) [occurred] in the central part of Israel'.
- Paz and Kutiel (2003). In Northern Israel, period 1976–2001, 2 stations. Comment: [in total precipitation] '... no significant temporal tendency was detected'.
- Kafle and Bruins (2009). Mediterranean coast, period 1970–2002, 12 stations. Comment: 'Precipitation ... increase along or near the Mediterranean coast, ... [while] in the more inland and (...) northern Negev (...) showed a decline. The precipitation trends are not statistically significant'.
- Al-Rimmawi et al. (2010). In the West Bank, 1950–2006, 8 stations. Comment: '... rainfall in the studied area is not decreasing as mentioned in several previous studies'.
- Shohami et al. (2011). In Israel, period 1964–2013, 10 stations. Comment: '... not significant, negative trends in rainfall accumulation (...) were found for nine out of the ten stations'.
- Givati and Rosenfeld (2013). Coastland Israel, period 1950–2010, 121 stations. Comment: '... there is a slight decreasing trend of the rainfall in the north (...), no trend at the centre (...), and a slight increasing trend in the south (...). Although not all the trends are statistically significant'.
- Ziv et al. (2014). In Israel, period 1975–2010, aggregated data from 919 observatories. Comment: 'Negative trend is observed over the majority of Israel, statistically significant only in the super-arid region'.
- Yosef et al. (2019). In Israel, period 1950–2017, 60 stations. Comment: 'A reduction in the total precipitation amount (...) was found. Although all the regional trends of the precipitation indices were not statistically significant'.
- Ajjur and Al-Ghamdi (2021). In Gaza, period 1974–2016, 7 stations. Comment: 'Mann Kendall's analysis showed that annual precipitation had increased at all stations, which does not agree (until now) with climate projections'.
- Drori et al. (2021). In Israel, period 1975–2020, 51 stations. Comment: 'No trend is found for the annual rainfall'.

3.2.2 | Lebanon

- Shaban (2011). Litani basin, period 1967–2009, combination of unspecified observatories and satellite data. Comment: 'The resulted illustrations indicated (...) [non-significant] decline changes in trends of rainfall'.
- Ramadan et al. (2014). Litani basin, period 1921–1960, Ksara station and a combination of CRU TS 2.1 and University Delaware grids at 0.5×0.5 resolution. Comment: '... the Litani Basin has experienced a decrease in annual precipitation significant [1900–2008]. (...) there was no significant trend in precipitation (...) during 1970–2008'.
- Mahfouz et al. (2016). Whole Lebanon, period 1950–2014. Given the absence of reliable data they combine Global Precipitation Climatology Centre database and gridded datasets from E-OBS (v12.0 spatial resolution of 0. 5° ×0. 5°). Comment: [using SPI-12] '... data shows a decreasing trend of SPI-12 for all selected regions'.

3.2.3 | Jordan

- Bani-Domi (2005). Whole Jordan, period 1964–1999, 9 series. Comment: '... trends, however, the slope estimates show negative rates'.
- Smadi and Zghouç (2006). Central Jordan, period 1922–2003, 3 stations. Comment: '... this decreasing trend is not statistically significant' [after change point around the year 1957].
- Dahamsheh and Aksoy (2007). Whole Jordan, period 1953–2000, 13 stations. Comment: 'Results suggest that no station shows evidence of a negative/positive trend in the precipitation'.
- Freiwan and Kadioğlu (2008). Whole Jordan, period 1950–2000, 14 stations. Comment: 'No significant trends have been detected in annual precipitation except a decreasing trend at 95% confidence level in Shoubak station'.
- Ghanem (2011). Central Jordan, period 1956–2000, 11 stations. Comment: 'The trend over the 50-year period shows a small decrease in the areal rainfall (...) not significant'.
- Shakhatreh (2011). Jordan, period 1976–2005, 3 stations. Comment: 'Rainfall trend showed a decrease'.
- Ghanem (2013). Whole country, period 1960–2010, 11 stations. Comment: '... the annual rainfall there were increasing trends in the north-west part of the country, and decreasing trends in the rest of the country'.
- Rahman et al. (2015). Western country, period 1970–2013, 55 stations. Comment: 'In particular, at stations in the northwest portion of the country, the annual rainfall rate (...) have generally increased, whereas at stations primarily

in the south they have generally decreased' [mostly not significant].

- Oroud (2018). Western country, period 1960/70–2013, 6 stations. Comment: '... Whereas the negative precipitation trend is not statistically significant in most stations'.
- Al Qatarneh et al. (2018). Azraq basin, period 1980–2014s, 8 stations. Comment: '... no change in total annual precipitation over the study area during the studied period'.
- Abdulla and Al-Qadami (2019). Whole country, period 1960–2013, 32 stations. Comment: 'A slightly decreasing trend is detected for 15 stations whereas the other 6 stations' trends are increasing'.
- Aladaileh et al. (2019). Whole country, period 1978–2017, 29 stations. Comment: '... annual (...) trend analyses and the Mann–Kendall test indicated significant reduction of precipitation'.

3.2.4 | Syria

- Kelley et al. (2015). Whole Syria, period 1931–2008, using CRU gridded data. Comment: 'The century-long, statistically significant trends in (...) precipitation (...) contributed to the severity of the recent drought'.
- Zeleňáková et al. (2017). Whole Syria, period 1992–2010, 77 stations. Comment: '... rainfall revealed more frequent significant decreasing trends'.
- Mathbout et al. (2018). Whole Syria, period 1961–2012, 20 stations. Comment: [using SPI-12 months] 'For 12-month time scale, 19 stations detected a decreasing trend'.
- Houmsi et al. (2019). Whole Syria, period 1951–2010, using grid data. Comment: 'The significant reduction in precipitation was noticed in the north and northeast'.
- Mohammed et al. (2020). Whole Syria, period 1990–2010, 35 stations. Comment: 'Notably, meteorological drought was more intensified in the early (1999–2001) and late 2000s (2007–2010)'.
- Zeleňáková et al. (2022). Syria, period 1991–2009, 71 stations. Comment: 'The results attained from Mann–Kendall trend analysis revealed decreasing trends at most of the stations'.

3.2.5 | Cyprus

- Pashiardis and Michaelides (2008). Whole island, period 1916–2000, 6 stations. Comment: '... the annual precipitation in Cyprus is decreasing. (...) The non-parametric Mann–Kendall test shows that this trend is highly significant'.
- Michaelides et al. (2009). Southern island, period 1917–2006, period 26 stations. Comment: '... in spite of the changes in the Gamma distribution's characteristics (i.e., in α and $1/\beta$), the variation in the 30-year running averages is not notable and in some stations is even unnoticed'.
- Zaifoğlu et al. (2017). Northern island, period 1970–2015, 37 stations. Comment: 'Generally, it could be concluded that trends were found as non-significant and increasing for annual scale'.
- Gökçekuş et al. (2020). Period 1901–2010, regional series. Comment: '... around 1970, the precipitation values decreased unusually and there is a concern that it will become worse in the future'.
- Lazoglou et al. (2024). Southern Cyprus, period 1981–2018, high resolution grid 1 × 1 km. Comment: 'The annual precipitation trend is negative in all climate regimes (...); however, it is not statistically significant'.

3.2.6 | Eastern Mediterranean Conclusions

The Eastern Mediterranean exhibits diverse and region-specific precipitation trends with considerable spatial and temporal variability. In Israel and the Palestinian territories, studies highlight mixed patterns. Notable findings include regional differences in annual rainfall distributions and a general absence of consistent trends across long-term datasets: while the central and southern regions show occasional increases, northern areas often exhibit declines, underscoring the complexity of climatic influences in this subregion. However, most trends are not statistically significant, with exceptions in localised regions such as the super-arid south. Other parts of the Eastern Mediterranean reveal predominantly declining precipitation trends, but often non-significant, as observed in Lebanon, Jordan, Syria, and Cyprus. Similarly, Jordan and Syria experience slight declines, particularly in the south and northeast. Cyprus exhibits a decrease particularly since the 1970s, with statistically significant trends on an island-wide scale. Despite regional disparities, some of the available studies across the Eastern Mediterranean point to a gradual reduction in precipitation over recent decades although most of them focused on short periods.

3.3 | Türkiye

3.3.1 | Long Term Analyses

- Türkeş (1996). Whole country, period 1930–1993, 91 stations. Comment: '... statistically significant decreasing trends have been found in the annual rainfalls at 15 stations, of which 7 are in the Mediterranean rainfall region'.
- Partal and Kahya (2006). Whole country, period 1929–1993, 96 stations. Comment: 'A noticeable decrease in the annual mean precipitation was observed mostly in western and southern Turkey, as well as along the coasts of the Black Sea'.
- Partal and Küçük (2006 b). Marmara region, period 1929–1993, two long records stations. Comments: 'A significant decreasing tendency starts at the end of 1960s for both stations'.
- Aksoy et al. (2008). European Türkiye, period 1930–2002, 3 stations. Comment: 'The three precipitation time series are found with no trend at annual scale'.

- Türkeş et al. (2009). Whole country, period 1930–2002, 86 stations. Comment: [annual] '... precipitation ... are generally characterized by both decreasing and increasing trends. (...). Decreasing trends (...) are most pronounced for the (...) [Mediterranean coastland]'.
- Yürekli (2015). Upper Euphrates-Tigris Rivers Basin of Southeast Türkiye, different period 1930–2015, 19 stations. Comment: [only 3] '... stations showed [significative] decreasing trend. (...) the positive and negative (...) were scattered in the different parts of the basin'.
- Hadi and Tombul (2018). Whole country, period 1901–2014, based on the CRU TS V3.23 dataset. Comment: '... annual precipitation is decreasing in the southeastern Anatolia and Mediterranean regions and increasing in the Marmara and Black Sea regions, whilst other regions have no specific pattern. (...) insignificance is dominant'.
- Topuz et al. (2021). Whole country, period 1955–2013, 29 stations. Comment: 'No significant trend was found in the annual (...) time series'.

3.3.2 | Whole Country With <50 Years and Regional Studies Mostly Small Catchments

- Tayanç et al. (2009). Western Türkiye (Aegean and Trachea regions), period 1950–2004, 52 observatories. Comment: 'Significant decreases of precipitation (...) in the western parts of Turkey, such as Aegean and Trachea regions, are found. On the other hand, (...) northern stations show increases in precipitation of which some are significant'.
- Cukur (2011). Inner and southern areas, 1975–2006, 40 observatories. Comment: '... annual precipitation (...) positive trends in the Black Sea Region and (...) negative trends southern and inner part of Anatolia'.
- Karabulut (2009). Continental southeastern area, period 1963–2005, 3 stations. Comment: '... there is no statistically significant any trend in the study area, despite of slight precipitation increase'.
- Durdu (2010) Büyük Menderes basin (western Türkiye), period 1960–2013, 4 stations. Comment: 'The long-term trend of annual precipitation demonstrated a decreasing trend; however, it was not found to be statistically significant'.
- Karaburun (2011). Marmara Sea, period 1975–2006, 35 stations. Comment: 'Trends in precipitation were identified in the 1975–2006 period but the test statistic values were not significant'.
- Unal et al. (2012). Whole country, period 1961–2008, 271 stations. Comment: '... decreasing annual precipitation is the dominating trend throughout Anatolia, including west, and southwest sections. Increasing annual precipitation can be observed in only northeast Black Sea region of Turkey' [mostly not significant].
- Yavuz and Erdoğan (2012). Whole country, period 1975–2009, 120 stations. Comment: 'A great number of stations with a statistically significant negative trend were located in the middle regions of Turkey. (...) only the northeast coast showed significantly upward trends'.
- Topaloglu and Ozfidaner (2012). Whole country, period 1968–1997, 52 stations. Comment: '... no evidence of significant change (...) with a general upward (...) in the Black Sea, Mediterranean Sea, Southeastern Anatolia, Eastern Anatolia and partly in the Marmara region compared with the Central Anatolia and Aegean regions [negative]'.
- Toros (2012). Whole country, period 1961–2008, 165 stations. Comment: '... general decrease (...) during the last decades (...) with 34% of the stations having negative trends (...) only 12% (...) significant (...) [mostly in western], whereas 22% of the stations have positive trends with only 4% percentage significance' [mostly in the northeastern].
- Altin and Barak (2014). Antalya district (south coast), period 1970–2011, 7 stations. Comment: '... a non-significant trend (...) are downward, and the increasing trend is determined (...) to the elevation factor'.
- Karabulut (2015). In Antakya-Kahramanmaraş Graben (southeast country), period 1975–2019, 4 stations. Comment: 'From the analyses of SPI [12 months] (...) can be concluded that precipitation (...) is changing and drought events becoming more frequent'.
- Asikoglu and Ciftlik (2015). Aegean Region (Western Anatolia), 1961–2005, 47 stations. Comment: '... a significant decrease [1/3 stations] is apparent (...), especially over the northern half of the Aegean region of Turkey (...); (...) the approximate start years of significant downward trends were in the early 1970s and (...) early 1980s'.
- Ay and Kisi (2015). From northern to southern provinces, period 1970–2011, 6 stations. Comment: 'According to the MK trend test, [two stations to the north] have statistically significant increasing trend. (...) there is no statistically significant trend' [in the rest of series].
- Çiçek and Duman (2015). Whole country, period 1975–2008, 83 stations. Comment: '... a decrease in annual precipitation was observed' [in 6 stations, only 2 significant].
- Yeşilırmak and Atatanir (2016). Western Anatolia, period 1966–2011, 28 stations. Comment: 'The trend analysis showed (...) mostly non-significant decreasing trends'.
- Yurtseven and Serengil (2017). Province of Istanbul, period 1960–2015, 5 stations. Comment: 'The Mann–Kendall test results showed that there is positive statistically significant trend in some meteorology stations'.
- Raja et al. (2017). Whole country, period 1976–2010, 228 stations. Comment: '... pronounced decrease is observed in (...) Central Anatolian (...) and a slight increase (...) for the period 2006–2010 [also noticed in] South East Mediterranean (...) The Eastern Black Sea had (...) increase in annual precipitation after 1996'.
- Abbasnia and Toros (2018). Marmara region, period 1961–2016, 7 stations. Comment: 'Overall, a large proportion of study stations have experienced an increase in annual precipitation (...), although (...) [mostly non] significant'.

- Mengu et al. (2019). Büyük Menderes basin (Aegean Türkiye), period 1975–2014, 6 stations. Comment: 'The trend analysis showed five of the six stations (…) to have an increasing trend, which in three of these five stations was statistically significant'.
- Tongal (2019). Antalya basin (south coast), period 1970–2017, 7 stations. Comment: 'The results of the MK trend analysis show no trend at 95% significance level' [although different sub-periods show different tendencies].
- Gumus (2019). Seyhan-Ceyhan basin (southeastern area), period 1970–2010, 14 stations. Comment: '… a decreasing trend is obtained in the north and the southwest regions of the basins and a positive trend is determined in the rest of the basins [mainly] in the coastal region' [except 1 stations no significant].
- Serencam (2019). Yesilirmak basin (northern inland), period 1970–2013, 5 stations. Comment: 'Based on categorization, precipitation records have significant decreasing trends in low, medium, and high levels'.
- Balov and Altunkaynak (2019). Coastland of Black Sea, period 1971–2000, 9 stations. Comment: '… there were [mostly significant] increasing trends' [of annual precipitation].
- Abbasnia and Toros (2020). Whole country, period 1976–2010, 71 stations. Comment: '… annual [positive] (…) precipitation (…) statistically significant (…) mostly located (…) Black Sea, significant negative trend [7% stations] mostly (…) in the (…) Mediterranean, (…) 79% of the studied stations reported statistically non-significant trends'.
- Ay (2020). Western Black Sea coastland, period 1960–2017, 6 stations. Comment: '… statistically insignificant decreasing trends [3 provinces] according to the MK trend test (…). Only one station (…) had a statistically significant decreasing trend'.
- Yaman and Ertuğrul (2020). Western Black Sea, period 1965–2015, 65 stations. Comment: '… there is no significant trend in (…) annual precipitation'.
- Cengiz et al. (2020). Black sea region, period 1960–2015, 16 stations. Comment: 'The annual rainfall was mainly characterized by [significant] positive trends'.
- Oruc and Yalcin (2021). Thrace region, period 1950–2016, 4 stations. Comment: '… annual total precipitation has an increasing trend [in 2 stations, 1 significant] and a decreasing trend' [in two stations, not significant].
- Koycegiz and Buyukyildiz (2023). Seyhan Basin Türkiye, period 1970–2019, 7 stations. Comment: 'In general, insignificant positive trends were determined in the annual total precipitation (…) at the stations in the south of the basin, while insignificant negative trends were determined in the other regions'.

3.3.3 | Türkiye Conclusions

Studies on precipitation trends in Türkiye reveal a complex spatial and temporal variability, with both increasing and decreasing trends observed across different regions and periods. Long-term analyses generally show decreases in annual precipitation in the Mediterranean and southern regions, with some increases in the Black Sea and Marmara regions. However, these trends are often region-specific, with decreases more pronounced since the 1960s in western areas and Mediterranean coastal zones. Other works using broader datasets suggest mixed trends with a dominance of insignificant changes in most regions. Shorter-term regional studies further emphasise the heterogeneity of trends. In fact, many studies highlight statistically insignificant trends in areas like the Aegean and southeastern Anatolia.

3.4 | Eastern Mediterranean Europe (Romania, Bulgaria, Moldova and Ukrainia)

- Villarini (2012). Bulgaria, Romania and Ukraine, different periods until 2012, 44 stations. Comment: [only] 'Two stations had statistically significant change-points in mean, with the mean after the year of the change-point larger than before it'.
- Croitoru et al. (2013.) Coastland areas from Bulgaria to Ukraine, period 1961–2008, 13 stations. Comment: [found in annual precipitation] '… significant negative trends on the northern Romanian (…), while positive trends are observed (…) on the southern Romanian and Ukrainian coast. (…) the positive slopes were found in more than half of the stations (…) in case of downward trends is also lower compared with those of the upward ones'.

3.4.1 | Romania, Ukrainia and Moldova

- Tomozeiu et al. (2005). Whole Romania, period 1961–1996, 30 stations. Comment: 'A decreasing trend has been found in winter precipitation in Romania, especially in the extra-Carpathian region, during the period 1961–1996'.
- Maftei and Barbulescu (2012). Dobrudja, Southeastern Romania, period 1965–2005, 10 stations. Comment: 'Mann-Kendall test and Sen's slope (…) for the annual (…) precipitation [show that only at one stations] (…) the slope was significant'.
- Dumitrescu et al. (2015). Whole Romania, period 1961–2013, 150 stations. Comment: 'The annual precipitation (…) show mixed signals (…) with the majority of the stations presenting no significant trend'.
- Marin et al. (2014). Whole Romania, period 1963–2013, 149 stations. Comment: 'The annual precipitation amount is rather stable, with increasing trends North-Western Romania and decreasing trends in the Danube Delta (South-East) [but most stations no significant]'.
- Cheval et al. (2014). Carpathian Mountain (different countries), period 1961–2006, 1165 stations. Comment: '… increasing trend characterizes (…) over the whole year (…) P[recipitation] [mostly not significant]'.
- Croitoru and Minea (2014). Northeastern Romania, period 1950–2006, 6 stations. Comment: 'Annual data analysis reveals an increase in precipitation at all weather stations

with high positive slopes (...). Half of them are statistically significant'.

- Croitoru et al. (2016). Whole Romania, period 1961–2013, 34 stations. Comment: 'The amount of [annual] precipitation (...) are (...) increasing (...) especially in northern regions. In the southern half of the Romania, a combination of upward, downward, and no trends was detected [few cases] were significant'.
- Prăvălie and Bandoc (2015). Danube outlet in Romania, period 1961–2009, 8 stations. Comment: '... the last five decades were generally characterized by an upward climatic aridity (...) in the northern part of the Dobrogea region. The situation is slightly different in the central-southern part, where the results indicated (...) an increase of annual precipitation amounts, especially between 1995 and 2009'.
- Arghiuş et al. (2016). South-eastern Romania, period 1961–2005, 5 stations. Comment: '... statistically irrelevant changes in precipitation trends were noted'.
- Potopová et al. (2016). Southern Moldova Republic, period 1951–2012, 15 stations. Comment: 'Though an overall trend toward drying conditions was found since the 1980s, a significant upward shift toward wet conditions was detected for the northern region in 1967'.
- Machidon (2017). Moldova region (Romania), period 1961–2016, 8 stations. Comment: 'In the period 2010–2016, the rainfall was higher in winter, respectively by 17% than during 1961–1990 and by 22% than during 1981–2010'.
- Potopová et al. (2019). Prut River basin shared by Romania and Moldova, periods 1985–2015, 5 stations. Comment: 'The monthly distributions of the slopes show that there is a significant decrease in rainfall (...) in the high-flow months'.
- Micu et al. (2021). Romanian Carpathian Mountain, period 1961–2019, 13 stations. Comment: '[in T]he Southern Carpathians (...) total precipitation amount (...) decreasing at more than 50% of sites. (...) few sites (...) exhibiting significant reductions'.

3.4.2 | Bulgaria

- Alexandrov et al. (2004). Whole Bulgaria, period 1900–2001, 36 stations. Comment: '... annual precipitation in Bulgaria showed an overall decrease' [mostly not significant].
- Grunewald et al. (2009). Pirin Mountains (SW Bulgaria), period 1900–2006, 25 stations. Comment: '... a trend could not be detected for long-term series'.
- Bocheva et al. (2009). Whole Bulgaria period 1961–2005, 26 stations. Comment: 'The Mann–Kendall test shows a slightly negative insignificant trend in the annual precipitation totals'.
- Nojarov (2012). High mountain Bulgaria, period 1947–2009, 3 stations in altitude. Comment: 'The main conclusion is that annual precipitation amounts in high mountainous parts of Bulgaria decrease over the last six decades (...) statistically significant in lower and northern stations'.
- Popova et al. (2014). Whole Bulgaria, period 1951–2004, 8 stations. Comment: '... trend analyses (...) shows no significant trends (...) for most of locations (...), negative trends of precipitation refer to the Thrace plain'.
- Chenkova and Nikolova (2015). North east Bulgaria, period 1981–2010, 4 stations. Comment: '... there are a [negative mostly not significant] tendency in changes of precipitation'.
- Nojarov (2017). Whole Bulgaria, period 1950–2012, 20 stations. Comment: '... precipitation amounts remain the same'.
- Marinova et al. (2017). Whole Bulgaria period 1988–2016, 115 stations. Comment: 'During the last decade however, precipitation totals have increased'.

3.4.3 | Eastern Mediterranean Europe Conclusions

Precipitation trends in the Eastern European Mediterranean region (Romania, Bulgaria, Moldova and Ukraine) exhibit notable spatial and temporal variability, with no consistent long-term patterns. In Romania, studies often report mixed or insignificant trends, with some increasing precipitation in the north and decreases in the southeastern regions, such as the Danube Delta and Dobrogea. Similarly, Moldova shows a shift toward drying conditions since the 1980s but occasional increases in specific sub-regions or periods. The Carpathian Mountains display predominantly stable or slightly decreasing trends, with few stations showing significant reductions. In Bulgaria and Ukraine, most studies reveal predominantly stable or slightly declining trends in precipitation, with rare significant findings. Bulgaria's precipitation generally shows weak downward trends, while increases were observed in recent decades in some areas. Along the coastal regions from Bulgaria to Ukraine, a mix of upward and downward trends was observed, with significant increases more frequent in southern areas. Overall, the region's trends are highly localised, with minimal long-term significance.

3.5 | Balkans, Greece, Serbia, Montenegro, Macedonia, Slovenia, Croatia, Albania and Bosnia-Herzegovina

3.5.1 | Greece

- Maheras and Kolyva-Machera (1990). Balkans, period from 1894 to 1985, 12 stations. Comment: [for precipitation] 'No (...) trend appears [in 6 stations, only one] shows an increase of precipitation from 1935 to 1980, but this is not statistically significant'.
- Amanatidis et al. (1993). Marathon area, period 1926–1990, 11 stations. Comment: '... the annual time series revealed a significant decreasing trend in the precipitation over the area'.
- Kalimeris et al. (2012). Apulia and Ionian Island (West Greece), different period from 1880 to 2008, 6 stations. Comment: 'Significant negative long-term linear trends

in the annual precipitation totals are observed, more pronounced in the southern parts of the studied area'.

- Maheras et al. (2004). Whole Country, period 1958–2000, 22 stations. Comment: 'It is evident (...) the general decreasing tendency of rainfall for almost the whole Greek region'.
- Pnevmatikos and Katsoulis (2006). Whole Country, period 1900–1999, 36 stations. Comment: 'There has been a decline in the annual rainfall during the last 30–35 years (...) The rainfall decline is most pronounced in the west and north (...) and least pronounced but still evident in the east'.
- Feidas et al. (2007). Whole Country, period 1955–2001, 22 stations. Comment: 'An overall decreasing trend (...) in the annual time series of all stations for the period 1955–2001. This is significant (...) with the exception of the central Aegean Sea and Peloponnesus'.
- Kioutsioukis et al. (2010). Whole Country, period 1955–2002, 40 stations. Comment: 'The (...) [annual precipitation] has decreased significantly at almost 44% of the stations'.
- Markonis et al. (2017). Whole Country, period 1940–2012, 136 stations. Comment: 'Most regions show a decline since 1950, an increase since 1980, and remain stable during the last 15 years [highly heterogeneous]'.
- Hatzianastassiou et al. (2008). Whole Country, period 1979–1999, 36 stations. Comment: 'The applied linear regression (...) revealed decreasing precipitation trends in the southernmost part of Greece's mainland and in the southern and southeastern Aegean Sea, (...), against increasing trends in the central and northern part of the region'.
- Pakalidou and Karacosta (2018). Thessalonik city, Period 1931–2015, 1 stations. Comment: 'The annual (...) found (...) positive trend (...). The further analysis (...) did not show any significant trend at the 95% confidence level'.
- Stefanidis and Stathis (2018). Pindus Mountain, central Greece, period 1961–2016, 9 stations. Comment: 'The results showed decreasing trends in annual (...) rainfalls, (...) not statistically significant, for most stations'.
- Agou et al. (2019). Crete island, 1948–2012, 54 stations. Comment: '... we find no statistical evidence for a decrease in the global (over the entire island) annual precipitation during the study period'.
- Varouchakis et al. (2018). Crete island, period 1981–2014, 49 stations. Comment: 'The annual rainfall in Crete shows an upward trend especially toward the end of the time series, between hydrological years 2004 and 2012'.

3.5.2 | Albania, Bosnia-Herzegovina and Montenegro

- Popovska and Bonacci (2007). Lakes Orid and Prespa (between Albania and Greece and Macedonia), period 1961–1990, 15 stations. Comment: '... it is established that the decreasing trend is statistically significant at the Ohrid meteorological station, whereas at the Resen meteorological station (...) not'.
- Burić et al. (2015). Montenegro whole country, period 1951–2010, 23 stations. Comment: 'The annual rainfall trend (...) tends to decrease in south-western parts of the country mostly insignificantly (only two stations ...) showed significant decrease. (...) the northern parts showed positive annual rainfall trends that are also significant at two stations'.
- Burić and Doderovic (2019). Montenegro, period 1951–2018, Podgorica station. Comment: 'In the observed 68-year period (...), the trend of annual and seasonal precipitation amounts is insignificant'.
- Ćulafić et al. (2020). Montenegro whole country, period 1961–2015, 17 stations. Comment: 'A downward tendency in annual precipitation prevails over Montenegro. (...) the majority of estimated trend values was low and statistically insignificant' [none at annual scale].
- Doderović et al. (2020). Mountain North Montenegro, period 1951–2008, Kolašin station. Comment: '... annual precipitation (...) shows a growth trend' [not significant].
- Hadžić and Imamović (2020). Bosnia and Herzegovina, period 1961–2010, 32 stations. Comment: '... on a large part of the BH territory was a slight increase in precipitation at the annual level (...). The largest positive change (...) was recorded in central mountain areas (), while the biggest deficit was recorded in the south of the country'.
- Gnjato et al. (2021). Sava catchment, Bosnia and Herzegovina, period 1961–2016, 11 stations. Comment: 'Insignificant rise in annual precipitation over most of the [Saba River Watershed] was detected'.

3.5.3 | Croatia, Slovenia

- Gajić-Čapka (1993). Croatia whole country, period 1891–1990, 3 stations. Comment: 'A generally decreasing trend is present over the entire interval, but is statistically significant only in the continental lowland'.
- Gajić-Čapka and Cindrić (2011). Croatia whole country, period 1901–2008, 5 stations. Comment: 'The results show a downward trend in annual precipitation amounts since the beginning of the 20th century throughout Croatia'.
- Branković et al. (2013). Croatian coastal zone, period 1951–2010, 13 stations. Comment: 'Annual precipitation anomalies, (...) show (...) no significant trend'.
- de Luis et al. (2014). Slovenia, period 1951–2007, 52 stations from ECA database. Comment: 'Changes in annual precipitation were observed only in the north-western part, where precipitation was decreasing'.
- Tošić et al. (2016). Slovenia, period 1961–2011, 46 stations. Comment: 'A statistically significant decrease of PC1 in annual precipitation (...) was found'.
- Gajić-Čapka et al. (2015). Croatia whole country, whole country, period 1961–2010, 132 stations. Comment: [only] 'A significant trend is detected only for annual amounts (negative) in the mountainous region'.

- Cindrić et al. (2016). Croatia whole country, period 1901, 5 stations. Comment: [SPI analyses detected] '... a shift toward drier conditions in the cold part of year (...) in the easternmost region, the highlands and the northern Adriatic'.

- Bonacci et al. (2021). Croatia whole country, period 1948–2019, 4 stations. Comment: '... there is a trend of increasing precipitation at higher intensities at all four analysed stations' [but no clear trend in totals].

3.5.4 | Serbia

- Unkašević and Tošić (2011). Serbia, period 1949–2007, 10 stations. Comment: '... across Serbia, statistically insignificant increasing trends were found'.

- Gocic and Trajkovic (2013a). Serbia, period 1980–2010, 12 stations. Comment: '... on the annual scale the most of the stations had no significant trends'.

- Gocic and Trajkovic (2013b). Serbia, period 1980–2010, 12 stations. Comment: '... the significant increasing trend in annual precipitation series was detected [only at one stations] (...) while other stations had no significant trends'.

- Gocic and Trajkovic (2014). Serbia, period 1946–2012, 29 stations. Comment: 'The analysis of the linear trend of the mean annual precipitation showed an increasing trend for the stations located in Serbia and three sub-regions'.

- Tošić et al. (2014). Vojvodina Serbia, period 1956–2006, 92. Comment: 'The time series of PC1 revealed decreasing trend in (...) [different seasons] and increasing trend in (...) and annual precipitation'.

- Luković et al. (2014). Serbia, period 1961–2009, 61 stations. Comment: 'Significant trends have not been detected for the whole country at an annual scale'.

- Gocic et al. (2016). Serbia, period 1948–2012, 29 stations. Comment: 'The annual precipitation shows an increasing [positive] trend in Serbia during the period of 1946–2012'.

- Malinovic-Milicevic et al. (2016). Serbia, period 1961–2010, 10 stations. Comment: [annual] 'Precipitation (...) suggest that, in a majority of cases (70%–80%), (...) the amount (...) of precipitation were increasing (...)'.

- Milovanović et al. (2017). Serbia, period 1961–2010, 421 stations. Comment: '... it can be concluded that in most of Serbia, there was a slight increase in the amount of precipitation but without any statistical significance. (...) In the eastern and southeastern (...), there is a reduction (...) while in western Serbia, there are few zones with an appreciable increase in annual precipitation'.

- Tošić et al. (2017). Serbia, period 1961–2014, 16 stations. Comment: 'A non-significant positive trend was found for (...) the total annual precipitation'.

- Gocic et al. (2020). Serbia, 1946–2017, 28 stations. Comment: '... it is evident that the stations in the western part of Serbia have the significant increasing trend in annual precipitation [5 stations]. The significant decreasing trend is not identified'.

- Popov and Svetozarevich (2021). Serbia, period 1991–2019, 15 stations. Comment: [except 1 stations] '... all others stations exhibit a positive lineal trend' [not significant].

3.5.5 | Balkans Conclusions

Precipitation trends across the Balkans show significant spatial and temporal variability, with predominantly weak or insignificant changes at the annual scale. In Greece, the majority of studies report a declining trend in precipitation over the 20th century and early 21st century, particularly in western and northern areas, though these trends are often not statistically significant and precipitation tends to recover in recent decades, particularly in central and northern regions, while areas like Crete show mixed signals, with localised increases in recent years. Similarly, Albania, Bosnia-Herzegovina, and Montenegro exhibit largely stable or slightly declining precipitation trends, with significant findings limited to localised regions, such as positive trends in northern Montenegro and central Bosnia's mountainous areas. In the northern Balkans, Croatia and Slovenia display an overall shift toward drier conditions, though long-term trends are generally weak or insignificant. Serbia shows a slight positive trend in annual precipitation over many stations, but these trends are largely not statistically significant, with some localised increases in western Serbia and reductions in southeastern regions. Overall, precipitation trends in the Balkans are highly heterogeneous, influenced by local geography, and with few consistent trends across the region.

3.6 | Western Mediterranean (Italy, South France, Spain and Portugal)

3.6.1 | Italy

3.6.1.1 | Whole Country Long Term Studies and Recent Decades.

- Buffoni et al. (1999). Whole Italy, period 1833–1996, 32 stations. Comment: 'The results show considerably different trends for different seasons and zones. On a yearly basis a decreasing trend is present over all Italy, but it is statistically significant only in the Central-South'.

- Brunetti, Maugeri, and Nanni (2000). Whole Italy, period 1866–1995, 32 stations. Comment: '... precipitation always has a negative trend'.

- Brunetti, Colacino, et al. (2001). Whole Italy, period 1951–1996, 67 stations. Comment: 'Considering yearly averages, the only significant trend is [southern region], but it is worth noticing that all regions and subregions show a tendency toward a decrease'.

- Brunetti et al. (2004). Whole Italy, period 1880–2003, regional series from 45 stations. Comment: [total precipitation] '... shows no trend in northern regions (...) and a significantly negative trend in southern regions'.

- Cislaghi et al. (2005). Whole Italy, secular series from 1830s–2001, 4 stations. Comment: '... the annual rainfall (...) exhibits a decreasing trend in the first half of the 20th century (...) followed by an increasing trend in northern Italy (...). [in southern Italy t was found a] reduction of annual precipitation (...) from second half of 20th century until today'.

- Brunetti et al. (2006). Whole Italy, period different length 1850–2000, 111 stations. Comment: 'Precipitation trend analysis showed a decreasing tendency, even if the decreases are very low and rarely significant'.
- Colombo et al. (2007). Whole Italy, period 1961–2000, 50 stations. Comment: '... time series do not show a clear trend. (....) show a negative trend detectable during the period 1961–1980, followed by positive trend (...) 1981–2000'.
- Toreti et al. (2009). Whole Italy, period 1961–2006, 59 stations. Comment: 'The annual series of standardized precipitation anomaly (...) do not show a trend'.

3.6.1.2 | Northern Country (Alps, Piedmont, Lombardy and Poo Plain).

- Brunetti, Buffoni, et al. (2000). Poo Plain, period from 1850 until 1990s, 5 stations. Comment: 'Trend analysis confirms (...) [that annual precipitation] (...) ha[s] tendency to decrease'.
- Brunetti, Maugeri, and Nanni (2001). Northeast Italy, period 1920–1998, 7 stations. Comment: [annual precipitation] '... has no significant trend in the 1921–1998 period, even if the general tendency is toward a slow decrease'.
- Ciccarelli et al. (2008). North-western Italy, period 1952–2002, 119 stations. Comment: '... precipitation time series display no significant trend over the last fifty years. (...) The absence of a significant trend in precipitation statistics confirms a general absence of precipitation trends in the Alps'.
- Brugnara et al. (2011). Alps, period 1922–2009, grid from 200 stations. Comment: 'On regional average, we found a weak decrease [not significant] in T[otal] P[recipitation] (...) over the entire studied period'.
- Todeschini (2011). Lombardy, different length period from 1880 to 2005, 6 stations. Comment: 'The annual precipitation height presents a scarcely significant and not generalized negative trend both for the entire series and for the sub-series restricted to the period 1951-2000'.
- Acquaotta and Fratianni (2013). Piedmont (North-West Italy), period 1913–2011, 13 stations. Comment: 'In each location the index analysis shows a decrease in the rainfall' [not significant].
- Baronetti et al. (2018). Piedmont (North-West Italy), period 2004–2016, 211 stations. Comment: '... the (...) area is characterised by an increase in precipitation'.
- Brugnara and Maugeri (2019). Trentino-South Tyrol region (central part of the European Alps), period 1922–2009, 200 series. Comment: '... a weak decrease in [total precipitation] (...) over the entire studied period' [not significant].
- Pavan et al. (2019). North-central Italy, period 1961–2015, 1700 stations. Comment: '... although the time series of area average (...) over north-central Italy does not show significant linear trends, these are present locally. (...), significant negative trends (...) are found in central Italy and in the inner part of northern plains, while significant positive linear trends are present in (...) the Alps and over the Liguria coast'.

3.6.1.3 | Central Italy (Toscana, Umbria, Abruzzo, Macerata, Adriatici and Marca).

- Testa et al. (2006). Lazio, period 1951–2000, 31 stations. Comment: '... it can be concluded that the precipitations over the Roman area in the period 1951–2000 show no significant trend'.
- Fatichi and Caporali (2009). Central Tuscany, period 1916–2003, 60 stations. Comment: [mostly from 1950] 'There is practically an absence of trends in the average precipitation regime (...) in almost all the stations of Tuscany'.
- Romano and Preziosi (2013). Tiber basin, period 1952–2017, 109 stations. Comment: 'The results show a [significant] decreasing trend in annual precipitation'.
- Appiotti et al. (2014). Marca province, Adriatiche, period 1961–2009, 51 stations. Comment: '... the statistical analyses are all negative[s] indicating a widespread decreasing tendency in annual' [mostly statistically significant].
- Bartolini et al. (2014). Tuscany, period 1955–2007, 21 stations. Comment: 'A downward trend in annual rainfall (...) (especially in northwestern Tuscany and northeastern Apennines), (...) was found over the last few decades'.
- Di Lena et al. (2014). Abruzzo (central Italy), period 1951–2009, 69 stations. Comment: 'The results of the single-site trend analysis of SPI (...) shows (...) [that] [i]t is evident that significant trends are mainly negative'.
- Cifrodelli et al. (2015). Central Umbria, period 1923–2012, 3 stations. Comment: '... there is no clear trend in all the observation periods'.
- Conte et al. (2015). Lazio, period 1984–2014, 46 stations. Comment: 'The annual rainfall time series analysis shows significant changes for 28% out of the 46 stations considered, that is: descending to ascending trends or increasing of average values concomitant to the absence of significant trends'.
- D'Oria et al. (2017). Northern Tuscany, period 1916–2012, 18 stations. Comment: 'The historical data highlight a general decrease of the annual rainfall (...) in many cases, the tendencies are not statistically significant'.
- Soldini and Darvini (2017). Marche region, in Central Italy, period 1951–2013, 54 stations. Comment: '... more than 50% of stations have a negative trend for $\alpha = 0.10$'.
- Bartolini et al. (2018). Tuscany, period 1955–2013, 35 stations. Comment: 'Main results, coming from 35 weather stations, did not show statistically significant trends of the PCI on annual basis (...). Concerning annual rainfall, six stations showed statistically significant decreases'.
- Gentilucci et al. (2018). Macerata, period 1931–2014, 55 stations. Comment: 'For precipitation, the decrease is fairly uniform across the study area (...), but with some isolated areas of strong increase (...) and [positive trend in few

stations] (...), mainly in the southern part of the coast, to the south-west and inland'.

- Gentilucci, Barbieri, et al. (2019). Marche province (East Italy), period 1921–2017, 128 series. Comment: '... a strong downward trend in the amount of precipitation from 1921 to 2017 has been identified, with 86% of rain gauges declining and 25% of the total having a significant negative trend'.
- Gentilucci, Materazzi, et al. (2019). Macerata province, central Italy, period 1961–2010, 60 stations. Comment: '... there is a decrease in rainfall'. [from one standard period to the following one (1961–1990, 1981–2010)].
- Scorzini and Leopardi (2019). Abruzzo, period 1951–2012, regional series from 120 stations. Comment: 'The results show a general, although not significant, negative trend in the regionally averaged annual precipitation'.

3.6.1.4 | Southern Continental Provinces (Campania, Pulia, Basilicata and Calabria).

- Piccarreta et al. (2004). Basilicata, period 1923–2000, 50 stations. Comment: 'The results show that the annual total rainfall decreased (...) during the period investigated; the decrease becomes stronger in the last 30 years'.
- Longobardi and Villani (2010). Campania southern Italy, period 1918–1999, 211 stations. Comment: 'Statistical analysis of the database highlight that (...) the trend appears predominantly negative (...) at the annual'.
- Caloiero et al. (2011). Calabria, period 1916–2000, 109 stations. Comment: '... the above mentioned procedures has shown a decreasing trend for annual' [precipitation].
- Buttafuoco et al. (2011). Calabria, period 1921–2000, 173 stations. Comment: 'The results showed that the annual precipitation decreased during the period 1921–2000'.
- Brunetti et al. (2012). South Italy, period 1916–2006, 129 stations. Comment: 'On a yearly basis, (...) [precipitation] shows a significant negative trend in the 1923–2006 period'.
- Capra et al. (2013). Calabria, period 1921–2007, 110 stations. Comment: 'The analysis highlighted a general decrease [mostly significant] in annual precipitation'.
- Buttafuoco et al. (2015) Calabria, period 1916–2006, 129 stations. Comment: '... about 60% (...) of the rain gauges presented a negative trend significant level (SL) of 0.10 for the 12-month [SPI index]'.
- Longobardi et al. (2016). Southern Italy, different series spanning 1917–2006, 559 stations. Comment: '... mainly for the whole area, the (...) series are affected by a negative trend, significant from about the 40%–50% dataset'.
- Ferrari et al. (2018). Calabria, period 1951–2010, 4 stations. Comment: '... main results concern a decreasing trend of (...) the rainfall anomalies'.
- Caloiero, Coscarelli, et al. (2018). Southern country period 1951–2006, 559 stations. Comment: 'With regards to the annual rainfall, a negative trend has been clearly evidenced for almost all the regions, with the exception of Campania'.
- Caloiero, Filice et al. (2020). Calabria, period 1916–2006, 100 series. Comment: 'At the annual scale, results evidenced a decreasing trend mainly in the north-eastern part of the region'.
- Caloiero, Coscarelli et al. (2020). Calabria, period 1951–2006, 129 series. Comment: [in five sub-regions of the Calabria region] '... the MK analysis, [shows] a negative trend of the annual rainfall' [all significant].
- Longobardi et al. (2021). Campania, period 1918–2019, 154 stations. Comment: [rainfall evaluated by SPI_12] 'The negative trend is particularly significant, with a percentage of grid cells of (...) 65%'.
- Caloiero et al. (2021). Calabria, period 1951–2016, grid from 650 stations. Comment: 'Results showed a decreasing trend for the annual' [precipitation].

3.6.1.5 | Sicily and Sardinia.

- Delitala et al. (2000). Sardinia, period 1946–1993, 245 stations. Comment: 'Sardinian precipitation does show a corresponding downward trend (...) significant (...)'.
- Cannarozzo et al. (2006). Sicily, period 1921–2000, 247 stations. Comment: 'The results show the existence of a generalized negative trend for the entire region'.
- Arnone et al. (2013). Sicily, period 1956–2005, 57 stations. Comment: 'Results show a decreasing trend of (...) [annual precipitation] in 75% of the considered stations'.
- Piccarreta et al. (2013). Period 1951–2010, 55 stations. Comment: 'The annual and seasonal total precipitation underwent a general downward trend over the period 1951–2010'.
- Liuzzo et al. (2016). Sicily, period 1921–2012, 245 stations. Comment: 'During the period from 1921 to 2012, a reduction in rainfall occurred at the annual scale. For the period of 1981-2012, an increase in total annual rainfall was detected'.
- Montaldo and Sarigu (2017). Sardinia, period 1975–2010, 10 stations. Comment: 'Although there is a decreasing trend in Py [annual precipitation] for almost all of the Sardinian stations (...), there is a high variability in the Py Mann Kendall [tau]'.
- Boi (2018). Sardinia, period 1951–2000, 13 stations. Comment: 'Trends according to Mann–Kendall test do not present significant results'.
- Corona et al. (2018). Flumendosa basin, Sardinia, period 1922–2007, 31 series. Comment: 'The precipitation trend is significantly negative but with lower values'.
- Montaldo and Oren (2018). Sardinia, period 1922–2010, 206 stations. Comment: 'All 10 basins showed a decreasing trend of yearly precipitation'.
- Caloiero et al. (2019). Sardinia, period 1922–2011, 158 series. Comment: '... negative trend emerged (...) on the Sardinia region (...) throughout the year' [51.3% stations significant].
- Marini et al. (2019). Eastern Apulia, period 1960–2013, 102 stations. Comment: 'For time scales from 6 to 24 months,

many stations exhibit a significant trend. (...) decreasing trends are located in the west zone (...), whereas in the central and east zones many stations show an increasing trend'.

- Caporali et al. (2020). Global review Comment: '... a review of 54 published studies on observed rainfall trend analyses, in the period 1999–2018 (...) [suggest that] there is an agreement about the tendency of a negative trend (although less evident) in total precipitation'.

3.6.2 | France

- Moisselin et al. (2002). In southern coastland, different length from 1880 to 2000. Comment: 'Les Bouches-du-Rhône présentent un ensemble remarquable de baisses (non significatives), mais il manque des séries voisines venant corroborer ce résultat'.
- Chaouche et al. (2010). Western French Mediterranean region, period 1970–2006, 44 stations. Comment: '... annual precipitation has not exhibited any trend'.
- Lespinas et al. (2010). Roussillon, southwestern France, period 1965–2004, 117 stations. Comment: '... annual precipitation did not follow clear trends'.
- Folton et al. (2019). Réal Collobrier catchment, period 1968–2017, 14 stations. Comment: 'At the annual scale, the precipitation trend (...) is not significant according to the Mann–Kendall test'.

3.6.3 | Portugal

- Costa and Soares (2009). South Portugal, period 1955–1999, 106 stations. Comment: 'The trend signals of the wetness indices were not significant at the majority of stations'.
- Mourato et al. (2010). Southern Portugal, period 1931–2006, 35 stations. Comment: '... in the precipitation time series and a significant decreasing trend of precipitation was identified'.
- de Lima et al. (2010). Continental Portugal and island, between 88 and 145 years from 1863 to 2007, 14 stations. Comment: 'Results provide no evidence for rejecting the null hypothesis of no trend in annual precipitation (...). The analyses of partial trends in the time series revealed a sequence of alternating periods of decreasing and increasing trends in annual precipitation'.
- Martins et al. (2012). Continental Portugal, period 1941–2006, 74 stations. Comment: 'A trend analysis (...) was performed using the PC scores [of SPI-12] (...) and, results (...) not show[ing] evidence of a trend for either an increase or decrease'.
- Paulo et al. (2012). Continental Portugal, period 1941–2006, 27 stations. Comment: 'No annual trends were found'.
- de Lima et al. (2013). Continental Portugal, period 1941–2007, 23 stations. Comment: '... annual regional [total precipitation] (...) reveals a decreasing trend (...) over the period 1941–2007. (...) more pronounced in the sub-period 1976–2007 (...), but only (...) 6 stations reveal a statistically significant decrease. (...) increasing tendency is found for the regional [total precipitation] (...) over the earlier 1945–1975 period' [not significant].
- Santos and Fragoso (2013). Northern Portugal, period 1950–2000, 39 stations. Comment: 'The analysis of the (...) [annual precipitation] showed a general decreasing trend' [mostly not significant].
- Nunes and Lourenço (2015). Continental Portugal, period 1960–2011, 42 stations. Comment: 'The results showed that annual precipitation had decreased in all stations and that this trend is statistically significant [$p < 0.1$] for most of the time series (79%)'.
- da Silva et al. (2015). Cobres basin, Southern Portugal, period 1960–2000, 8 stations. Comment: '... there is a decrease in the annual rainfall amount for the period studied (1960–2000). Decreasing trends are dominant for almost all indices; most of the calculated slopes are statistically insignificant'.
- Nunes et al. (2016). South Portugal, period 1950–2008, 90 stations. Comment: '... annual precipitation decreased in around 90% (...) stations of the study area, although this tendency is not statistically significant for the majority of the cases'.
- Portela et al. (2020). Continental Portugal, different periods from 1913 to 2019, 532 stations. Comment: 'The results showed that after the initial sub-period with prevailing increasing rainfall, the trends were almost exclusively decreasing. (...) in the last five decades the rainfall has been markedly decreasing over mainland Portugal'.

3.6.4 | Spain

3.6.4.1 | Whole Country Long Term Studies and Recent Decades.

- Millán (1996). Whole Spain, secular series from 1868 to 1990 (PhD unpublished). Comment: he found a slight increase to the north, a negative trend in the Mediterranean areas (mostly non-significant) and no defined trend in central ones.
- Esteban-Parra et al. (1998). Whole Spain, period 1880–1992, 65 stations. Comment: 'The analysis (...) shows significant long term decreases in precipitation for the Mediterranean and interior regions (...), and an increase in precipitation for the Northern coastal region'.
- Serrano et al. (1999). Whole Spain, period 1921–1995, 40 stations. Comment: 'No significant global trend was found in the annual total precipitation series'.
- González-Rouco et al. (2001). Whole Spain in western Mediterranean basin, period 1899–1989, 66 stations. Comment: 'In most sites the value of trends is negligible [not significant] and there are almost no negative trends left; positive trends in the north of the Iberian Peninsula'.
- Goodess and Jones (2002). Whole Spain, period 1957–1997, 18 stations. Comment: '... the general trend toward

decreasing mean rainfall totals over the Iberian Peninsula and the Mediterranean region as a whole'.

- Saladie et al. (2004). North east mountain areas, period 1901–2000, 33 stations. Comment: 'El resultado en base anual no muestra ninguna tendencia' [significativa], [no significant trend was detected].
- Rodrigo and Trigo (2007). Iberian Peninsula, period 1951–2002, 22 stations. Comment: 'In general terms, most rain gauges show a decrease of the total amount of annual rainfall' [mostly not significant].
- del Rio et al. (2011). Whole Spain, period 1961–2006, 553 stations. Comment: 'On an annual scale, precipitation is decreasing in 11% of the territory, with a significance percentage of 24%'.
- Luna et al. (2012). Whole Spain, period 1951–2008, 66 stations. Comment: 'There is a clear negative trend for the period 1951–2008 (...). The historical precipitation dataset (...) does not exhibit a significant reduction in precipitation amounts'.
- Serrano-Notivoli et al. (2018). Whole Spain, period 1950–2012, grid from 12,858 stations. Comment: '... a significant negative trend in mean and median precipitation when considering all the precipitation days ($p > 0$), especially in the Mediterranean coast'.
- González-Hidalgo et al. (2023). Whole Spain, 1916–2020, grid from 2600 stations. Comment: '... there has been a mostly not significant decrease in annual precipitation in the complete period (1916–2020)'.
- Senent-Aparicio et al. (2023). Peninsular Spain, period 1951–2009, high resolution grid 5 × 5 km from 3236 stations. Comment: 'The results confirm the decreasing trend in annual precipitation in most of the Spanish territory'.

3.6.4.2 | Regional Studies.

- Galán et al. (1999). Southern inland plateau, period 1924–1996, 6 stations. Comment: 'Ninguna de (...) [las estaciones] presenta tendencia significativa (...) en los totales anuales' [translation: no significative trend is observed in anual precipitation].
- Lana and Burgueño (2000). Mediterranean eastern coastland, different periods from 1860 to 1994, 7 stations. Comment: '... temporal trends deduced for annual (...) amounts (...) [positive signal] are considered non-significant from a statistical point of view'.
- Lázaro et al. (2001). SE Spain, period 1967–1997, 15 stations. Comments: 'Results showed neither trends nor abrupt changes in the series'.
- Labajo and Piorno (2001). Duero basin inland north west, period 1945–1996, 44 stations. Comment: 'The results show that at a confidence level of 95% no trends exist (...) [and the analyses suggest] the possible existence in recent decades of a decreasing trend in the total annual'.
- Abaurrea et al. (2002). Ebro basin North East inland, period 1916–2000, 29 stations. Comment: '... si se analiza un largo intervalo temporal, no hay evidencia para establecer la existencia de una tendencia decreciente sostenida de la lluvia de la cuenca del Ebro' [translation: during long period there is no significant trend].
- Chazarra and Almarza (2002). Eastern mainland Spain, period from 1864 to 2000, regional series from 3 centennial stations. Comment: '... la serie en su conjunto no presenta tendencias significativas' [the composite serie has not statistical trend being signal negative].
- Guijarro (2002). Mediterranean coastland, 1964–1993, 410 stations. Comment: [se ha detectado una] '... elevada variabilidad espacio-temporal de las tendencias de la precipitación anual, junto con su escasa significación', [translation: it has been detected high trend variability mostly not significant].
- Saladié et al. (2002). Lower Ebro basin, period 1949–1998, 19 stations. Comment: 'Los resultados muestran un descenso no significativo de la precipitación anual (...) se pueden diferenciar [dos subperiodos] desde 1949 hasta 1971, con una tendencia positiva y [desde] 1972 a la actualidad, de signo contrario', [translation: results show not significant negative trend, and two periods: from 1949 to 1971 positive trend, and from 1972 negative].
- Ceballos et al. (2004). Duero basin, period 1957–2005, 10 stations. Comment: 'Annual rainfall has followed a decreasing trend, although owing to its appreciable interannual variability the trend is not statistically significant'.
- del Rio et al. (2005). Duero basin northwest inland, period 1961–1997, 171 stations. Comment: 'The annual trend (...) decrease (...) although this series was not statistically significant'.
- Ramos and Martínez-Casasnovas (2006). NE Spain, different periods from 1923 to 2000, 5 stations. Comment: 'An increasing trend can be seen, albeit with cyclical variation, but (...) not significant at 95% level of confidence'.
- de Luis et al. (2009). Mediterranean area, period 1951–2000, 1113 stations. Comment: 'The trend analysis of total annual precipitation shows an overall decrease'.
- Valencia et al. (2015). Ebro basin North east inland, period 1931–2009, 132 stations. Comment: '... in the Ebro River Basin (...) [trend show] a slight decrease in the mean annual rainfall over the period 1931–2009, although such a decrease is not statistically significant'.
- Valdes-Abellan et al. (2017). South east Spain, period 1940–2016, 5 stations. Comment: 'The data analysed here revealed a clear (...) rainfall reduction'.
- Miró et al. (2018). Jucar and Segura basin, east-south east, period 1955–2006, 890 stations. Comment: 'Results show significant negative trends for precipitation prevailing in Júcar area (...), especially toward its north interior headwaters'.

3.6.5 | Western Mediterranean Conclusion

Across Western Mediterranean Europe, studies reveal considerable variability in precipitation trends, both spatially and temporally. In Italy, long-term analyses generally show a decrease in annual precipitation, particularly in central and southern regions, but these trends are often not statistically significant. Northern Italy, including areas like the Alps and Po Plain, tends to exhibit weak or absent trends, while southern areas, including Sicily and Sardinia, show more consistent declines in rainfall. Regional analyses further emphasise this variability, with some areas in central Italy experiencing significant decreases, while others show little to no change. Overall, methodological differences complicate the interpretation of these trends. In France, Portugal, and Spain, similar patterns of variability are observed. In France, particularly in the Mediterranean region, precipitation trends are largely inconclusive, with no significant long-term changes noted despite occasional small decreases. Portugal shows a mixed picture, with some southern regions experiencing a decrease in rainfall, but this trend is not universally consistent across the country. In Spain, while some Mediterranean areas show slight decreases in precipitation, these trends are also often not statistically significant, and annual fluctuations are common. These findings suggest that variability in both the data and the regions studied makes it difficult to draw firm conclusions about long-term, countrywide trends.

4 | Large-Scale Studies

Based on large-scale Mediterranean studies, there is a widespread assessment that precipitation has decreased in the Mediterranean basin (Dai 2021) mostly due to winter negative trends. These ideas possibly have originated from the initial studies about the topic by Maheras (1988) in the eastern areas (1901–1985), by Piervitali et al. (1997) in the western basin (1951–1990) and by the influential atlas by Schönwiese and Rapp (1997), in which, with a limited number of observatories, a negative annual precipitation trend was suggested in southern Europe for the period 1891–1990. These conclusions have been repeated through global studies of Mediterranean climate areas around the globe by Deitch et al. (2017) using NOAA-NCDC data (1975–2015), and Seager et al. (2019) using the CRU-TS3.25 datasets for the period 1901–2016, particularly during the winter season.

This assessment has also been supported by different studies published in the last two decades using stations and gridded datasets from which sometimes regional series for the entire Mediterranean region have been calculated. Hoerling et al. (2012) compared five different datasets (1902–2010) and found a negative trend in winter (cold season) precipitation and the increase of dryness from 1970s; similar results were found by Kelley et al. (2012) using observed data from GCOS (1901–2007). Using CRU gridded data, period 1901–2000, Mariotti and Dell'Aquila (2012) detected a negative trend in winter from 1960s, and Mariotti et al. (2015) using the same dataset, period 1850–2005, detected negative trends in annual amounts. Also, Yildrim and Altinsoy (2017) analysed monthly trends from the CRU database in the eastern Mediterranean and Fertile Crescent in the period 1901–2020, finding a generalised decrease and changes between subperiods. Caloiero, Caloiero, and Frustaci (2018) analysed a combined dataset between 1901 and 2009 and found a marked negative trend in the eastern Mediterranean and northern Africa. Finally, Zittis (2018) analysed five observational gridded databases from 1901 to 2014/2015, detecting a negative trend in northern Africa from the Maghreb to the Levant and positive trends in the Balkans and inland Anatolia since the 1970s; this author highlighted the differences between sources and their effects on trends, as seen in the Iberian Peninsula or the Balkans, where the signal changes direction depending on the database and the period studied, a finding consistent with Yildrim and Altinsoy (2017).

Contrary to studies based on gridded databases, long-term studies from series of observed precipitation data at stations highlight strong temporal variability on decadal and interannual scales, with usually no significant long-term trends (Altava-Ortiz et al. 2011; Camuffo et al. 2013). Kostopoulou and Jones (2007) analysed 84 stations (1928–2000) in the eastern part of the basin and detected a positive trend in autumn and a negative in the rest of the seasons. Philandras et al. (2011) analysed 40 stations across the Mediterranean basin and suggested spatial variability of annual precipitation trends between 1900 and 2010, being positive (not significantly) in northern Africa, southern Italy, and western Iberian Peninsula, and negative in the rest of the region; more recently, Peña-Angulo et al. (2020) studying 58 stations from 1850/1870 to 2018 did not detect a significant trend except during summer in the western basin. All of these studies stress again the strong spatial variability in precipitation behaviour and the significant impact of the selected period and length on the final results.

The increase of observed data after World War II probably explains why most of the published studies have focused on the period starting from the mid-20th century; their review shows a great spatial and temporal variability in precipitation trends, nevertheless more homogeneous in the case of grid analyses than station data. Using grids of different resolutions, Mariotti (2010) found decreases in annual totals in the Adriatic and southeastern Mediterranean for the period 1958–2007. A negative but not significant trend in annual rainfall was also described by Tanarhte et al. (2012) between 1960 and 2000 combining different rainfall sources (stations and grids). High spatial variability of trend was also noticed by Raymond et al. (2016) using the E-Obs gridded database for the period 1950–2013. Significant positive trends were noticed in the wet season in parts of the Maghreb, central Italy, Sicily, and northern Balkans, while negative significant trends were only detected in central-northern Italy, southwestern Balkans, and northwestern Anatolia, but without a common generalised pattern and dominant non-statistically significant trends. Finally, studies based on the GPCC grid for the period 1950–2016 (Caloiero, Coscarelli, et al. 2018) and the Watch reanalysis for the period 1958–2014 (Stagge et al. 2017) show very few areas with statistically significant trends.

Studies based on a series of precipitation observatories around the basin show highly heterogeneous trends. Alpert et al. (2002) analysed 265 stations distributed throughout the basin between 1951 and 1995 and detected mostly negative

TABLE 2 | Number of publications according to monthly or seasonal trend signal (see Supporting Information S1).

	Positive	Negative		Positive	Negative
December	3	14	June	—	11
January	4	20	July	11	2
February	7	20	August	14	—
Winter	**13**	**76**	**Summer**	**31**	**20**
March	9	26	September	12	5
April	7	8	October	16	2
May	1	12	November	8	3
Spring	**15**	**54**	**Autumn**	**49**	**22**

Note: Bold values indicate the number of seasonal papers referring trend.

trends in annual totals (but not clearly significant). Similar results were described in winter by Kostopoulou and Jones (2005) in 84 observatories located in the central and eastern sector of the basin between 1958 and 2000, showing differences between the positive signal in the central sector and the negative in the east; Xoplaki et al. (2004) analysed 292 observatories and found a slight increase from the middle 19th century and then a decrease from the 1960s. Zhang et al. (2005), on the contrary, studied 52 stations in a broad region that included areas outside the Eastern Mediterranean and found positive annual trends (1950–2003) although mostly not significant. Norrant and Douguedroit (2005) found a predominantly negative, not significant signal in their study of 63 observatories during the period 1950–2000. This is consistent with Reiser and Kutiel (2011) in their study of 41 observatories for 1931–2006 around the basin, and Nastos (2011) combining different grids and 40 observatories around the Mediterranean basin between 1980 and 2009, suggests positive/negative trends to the west/east during the rainy season and no significant signal in the annual trend.

More recent studies suggest that over the last four decades, there has been an increase in precipitation in the eastern European Mediterranean, but also in the western basin in Morocco and southern Spain (Benabdelouahab et al. 2020). To conclude, the precipitation trends show a large spatial mosaic that makes it very difficult to establish generalisations. This main conclusion has been demonstrated by Vicente-Serrano et al. (2025) using a database of more than 15,000 meteorological stations across the Mediterranean region in an international action. Their results showed that precipitation is stationary for the long-term at the Mediterranean basin scale, and also regionally, and that significant trends are recorded only for particular periods and affecting a low percentage of meteorological stations.

4.1 | General Conclusion

Early global studies on Mediterranean precipitation trends had shown widespread decreases, though results vary across regions and datasets from seminal papers by Maheras (1988) and Piervitali et al. (1997), and recent research supports this with some areas showing negative trends in annual or winter precipitation (e.g., Hoerling et al. 2012). However, long-term station-based studies highlight significant spatial and temporal variability, often without clear long-term trends. In recent decades, some areas like the eastern Mediterranean and parts of Spain and Morocco have seen increased precipitation. Overall, precipitation trends in the Mediterranean are heterogeneous, with no clear generalisation, as confirmed by Vicente-Serrano et al. (2025), who found precipitation trends to be stationary over the long term.

5 | Seasonal or Monthly Dependence?

It is well known that the Mediterranean precipitation regime is characterised by a rainy cold season, the extreme dependence of seasonal totals on the behaviour of a single month, and the highly variable monthly percentage contributions from very few daily events. Then, monthly behaviour sometimes defines the seasonal and annual trend.

In Table 2 we briefly present a global summary of studies that indicate monthly or seasonal trends, and we notice that the numbers are not additive because sometimes in the same studies they are related to different monthly signals or different areas. The table includes signals detected around the Mediterranean basin irrespective of the significance level chosen, with most of this research done with data from 1950 onwards. The compilation tries to express the noticeable seasonal and monthly differences of trend across the basin. This raw information, at present under deep analysis, particularly stressed changes in February, March, September, and October, with regional and subregional studies revealing some common points mostly from 1950 onwards. In Supporting Information S1 we include by month and season the list of studies accordingly signalling trends with specifications of areas.

The conclusion is the absence of a uniform trend; nevertheless, some specific generalised signals emerge: the negative trend of March and positive in October during the last decades of the 20th century, at present under eventual changes (e.g., in Spain, González-Hidalgo et al. 2023), seasonal trends also show a high variability.

As a global conclusion, no generalised change can be detected in the Mediterranean rainfall, and the most probable modification could be a change in the seasonal rainfall regime in some areas of the western basin. Two recent papers show evidence. In the first one, in Italy, Caloiero, Filice, et al. (2020), during 1998–2021, concluded that there was a positive significant trend to the north during winter, and in spring and autumn to the southern land, while a significant negative trend was found in NW in autumn and in central Italy in summer. In a second paper, González-Hidalgo et al. (2024) in the Spanish continental land (Iberian Peninsula) from 1916 to 2015, detected a generalised decrease in the areas under spring rainfall regime from 1990 onwards in favour of autumn ones, a clear seasonal rainfall change in seasonal distribution coupled with non-significant trends along the century.

6 | Conclusions

The compilation of the research published on precipitation trends in the Mediterranean basin during the last decades exhibits significant spatial and temporal variability, with no clear, consistent patterns emerging on a large scale. While many studies suggest a general decrease in precipitation, particularly during the winter months, these trends are often not statistically significant, especially when examined over long periods. Gridded data analyses have highlighted localised negative trends, particularly in southern and eastern regions, but these findings are often accompanied by regions experiencing positive trends or no significant changes at all. This variability is further emphasised by long-term station-based studies, which show that decadal and interannual fluctuations often obscure any clear, long-term trends in precipitation across the region. In recent decades, some studies have indicated localised increases in precipitation in certain areas. However, these trends are not universally observed, and overall, the precipitation patterns across the Mediterranean remain complex and highly variable. The studies consistently underline the challenges in identifying broad, regional trends due to the differences in data sources, the length of the periods, the specific period, and the selection of regions studied. Ultimately, the most significant conclusion is that precipitation in the Mediterranean is largely stationary over the long term, with trends being localised and influenced by specific time periods and regional characteristics. Furthermore, several key aspects stand out indicating unresolved issues in the study of Mediterranean precipitation trends, all of them commented among others by Tanarhte et al. (2012), Yildrim and Altinsoy (2017), Zittis (2018), Sun et al. (2021), El-Kenawy et al. (2019), Gampe et al. (2019), Peña-Angulo et al. (2020); following their conclusions we notice the following.

The first one is the lack of a unified database. One major issue is the absence of a universally accepted high-quality database of surface stations. This lack of standardisation leads to inconsistent results for the same region, depending on the data source used. For example, using the same database (CRU), Seager et al. (2019) showed noticeably different spatial patterns of trends between 1901 and 2016 compared with Philandras et al. (2011) for the period 1901–2009. Also, significant discrepancies between observed data and model outputs have been noted by Barkhordarian et al. (2013), Barrera-Escoda et al. (2014), and Isotta et al. (2015) among many others. The recent action developed by numerous researchers sharing national databases throughout the Mediterranean basin countries has provided the most comprehensive assessment of the precipitation dynamic over the Mediterranean region, and it is an example to be followed in the future (Vicente-Serrano et al. 2025).

As a second point, coupled with the previous one, we would like to highlight that the spatial density of the precipitation information in many of the compiled studies is very low, and also grids usually have been calculated with very low spatial density. This fact suggests great caution when the global trend is attributed to rainfall since regional and subregional studies reveal a high spatial and temporal variability, and spatial extrapolation of precipitation data under such circumstances is highly uncertain. We could say that the precipitation trend in the Mediterranean basin seems to be a complex mixture in which local, regional, and global factors act together with different intensities varying in space and time.

Thirdly, the length and the exact period of analysis is another source of variability, because the signal, significance, and magnitude of any trend depends both on the length of the series and the selection of the period studied; unfortunately, this is a critical point not always considered. The recent change observed in monthly trends in February and March during the cold season, and September and October at the beginning of autumn, quoted in Section 5 are examples that should be in mind.

Last, but not least, any trend should be evaluated considering that under Mediterranean climate conditions annual totals are heavily dependent on the balance between wet-dry season totals, which in turn often depend on the rainfall of a single month or a few daily events. This explains the growing interest in studying these events, but such studies require high-quality and high-spatial resolution daily datasets (as Point 1 and 2 remark), requirements that still are not solved.

Over the century, the prevailing signal in precipitation trends generally lacks statistical significance and is non-monotonic, with considerable spatial and temporal variation uncovered in regional studies, sometimes with a clear sequence of positive–negative–positive signal periods. This highlights the extreme dependence of annual, seasonal, and monthly totals on these variations. Overall, the mosaic of studies underscores the localised nature of precipitation trends and the effect of local factors (vicinity of Sea, relief, etc.), and the risk for generalising precipitation trends in the Mediterranean, emphasising the need for localised, detailed long-term analyses to better understand the dynamics of precipitation in the region. To conclude, our compilation suggests that no significant trend is detected in total annual precipitation around the Mediterranean basin, which contradicts prior assessments of a generalised significant and strong negative trend and obviously without any possibility to be attributed to any clear causal factor.

Author Contributions

José Carlos González-Hidalgo: conceptualization, investigation, writing – original draft, methodology, writing – review and editing, formal analysis, data curation, supervision. **Sergio M. Vicente-Serrano:**

formal analysis, methodology, writing – review and editing, conceptualization, investigation, writing – original draft, data curation, supervision.

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Some portions of this manuscript were edited and translated with the assistance of AI-based language tools to improve clarity and consistency. Final content and interpretations are solely the responsibility of the authors.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section.