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Spatio-Temporal Changes of Aridity in the Province of Naâma (Western Algeria)

Miloud Oubadi and Mohammed Faci*

Centre for Scientific and Technical Research on Arid Regions (CRSTRA), Biskra, Algeria

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Abstract: Arid regions are characterized by the fragility of their ecosystems, which are highly vulnerable to climate change. The increase in aridity in these regions makes them more exposed to droughts. This article analyses the trend in aridity and the expansion of drylands in the Wilaya (province) of Naâma, which is an arid region in south-western Algeria, over the period of 1951 to 2020. Monthly rainfall data from the Global Precipitation Climatology Centre (GPCC), as well as monthly mean temperature and potential evapotranspiration (PET) data from the Climatic Research Unit (CRU), characterized by a spatial resolution in grid points of 0.5º, were used. The results showed an increase in annual aridity, leading to transformation of drylands in to arid lands. As a result of these changes an additional 10% area of semi-arid land to converted to arid zone.

Key words: Arid regions, Algeria, drought, Mann-Kendall, trends, spatial analysis.

***Correspondence**
Mohammed Faci
fm_alg@yahoo.fr

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Climate change has become a pervasive global phenomenon, fundamentally altering atmospheric conditions and precipitation patterns across the globe (Khan *et al.*, 2018). These shifts in air temperature and rainfall have profound implications, notably impacting evapotranspiration rates and atmospheric water storage. Consequently, there is potential for significant modifications in precipitation characteristics, including magnitude, frequency, intensity, and geographical distribution (Wang *et al.*, 2013). The cumulative effect of these changes is reflected in the expansion of drylands, increase in soil degradation and the degradation of natural ecosystems. Between 1980 and 2008, the world's drylands expanded by 3.1% compared to the preceding decades, with projections indicating a continuous trend towards global drying throughout the 21st century (Wu and Chen, 2019). Estimates suggest drylands could escalate by up to 7% to 10% by 2100, potentially leading to a 24% increase in the population inhabiting arid environments (Koutroulis, 2019). Arid regions, characterized by fragile ecosystems, are particularly susceptible to the adverse impacts of increasing aridity, exacerbating environmental risks and vulnerabilities.

Algeria, predominantly arid and desertic, epitomizes the broader global trend of aridity expansion. The Algerian steppe zone, deeply rooted in pastoral traditions, faces significant challenges due to the encroaching spread of aridity. This expansion, coupled with intensive land use practices, has led to pronounced ecosystem degradation, jeopardizing ecological and socio-economic equilibrium. Amidst these challenges, the situation in the steppe region, notably the Wilaya of Naâma, stands out as particularly concerning, with discernible signs of degradation permeating the landscape (Oubadi *et al.*, 2024).

Despite the clear implications, research into the evolution of aridity in Algeria remains limited. Hence, it is imperative to assess spatial changes in aridity within the Wilaya of Naâma, which represents a focal point for understanding the impacts of aridity expansion in Algeria. By delving into this specific context, this study aims to address the gap in knowledge concerning aridity dynamics, offering valuable insights into the region's vulnerability to climate change and informing sustainable resource management strategies.

Materials and Methods

Data Sources and Period

Precipitation, temperature, and potential evapotranspiration (PET) data for the period 1951-2020 were obtained from the Global Precipitation Climatology Centre (GPCC) and the Climate Research Unit (CRU) (Becker *et al.*, 2013; Harris *et al.*, 2014). These datasets have a spatial resolution of 0.5°×0.5° and are widely used to their accuracy (Dinku *et al.*, 2008; Yang *et al.*, 2014; Merabti *et al.*, 2023). GPCC and CRU data publicly available in NetCDF file form, AgriMetSoft-NetCDF-Extractor V2.1 software (https://agrimetsoft.com/netcdf) was used to extract climate data for the study area.

Study area

The Wilaya of Naâma, situated on the western Algerian high plateaus bordering Morocco, covers an expanse of 29,514 km^2. Its geographical diversity is notable, characterized by a gradient in precipitation and temperature across the region. The dominant land uses and topography and relief of The Wilaya of Naâma are described in Fig. 1 and Fig. 2, respectively. Annual rainfall varies significantly, ranging from less than 150 mm in the southern regions to over 350 mm in the north (Fig. 3). This climatic variability is accompanied by pronounced temperature fluctuations, with hot summers and cold winters. January stands as the coldest month, while July records the highest temperatures, with distinctions becoming more pronounced from north to south (Fig. 3).

Naâma's landscape can be broadly categorized into three main geographical areas

Steppe Zone: Encompassing 74% of the Wilaya's territory, this vast plain ascends sharply in altitude towards the south (1,000 to 1,300 m). The steppe zone is characterized by grasslands, plains, and semi-arid climates, making it suitable primarily for pastoral activities. It extends from the Algerian-Moroccan border to the western edge of the Wilaya of El-Bayadh.

Mountainous area: Covering 12% of the total land area, this region features the southern foothills of the Tellian Atlas, with elevations ranging from 900 to 1,200 m. Mountainous areas are characterized by high landforms such as mountains and hills, providing diverse habitats and ecosystems. The Ksour Mountains, a segment of the Saharan Atlas, stretch diagonally from southwest to northeast, boasting altitudes exceeding 2,000 m (e.g., Djebel Aissa at 2,250 m) (Fig. 2).

Pre-Saharan zone: This zone covers approximately 14% of the Wilaya's total surface area, contributing to the region's diverse landscape and environmental characteristics. The pre-Saharan zone serves as a transitional region between the Sahara Desert and more fertile lands to the south, experiencing a semi-arid climate with limited rainfall and vegetation.

Aridity index

The aridity index (AI), adopted from the United Nations Environment Program (UNEP, 1997), quantifies the aridity level relative to atmospheric evaporative demand. It is calculated as the ratio of average annual precipitation (P) to average annual potential evapotranspiration (PET).

The aridity index (AI) (UNEP, 1997) is an indicator of the degree of aridity of the climate in a given location in relation to the evaporative demand of the atmosphere. It is defined as follows:

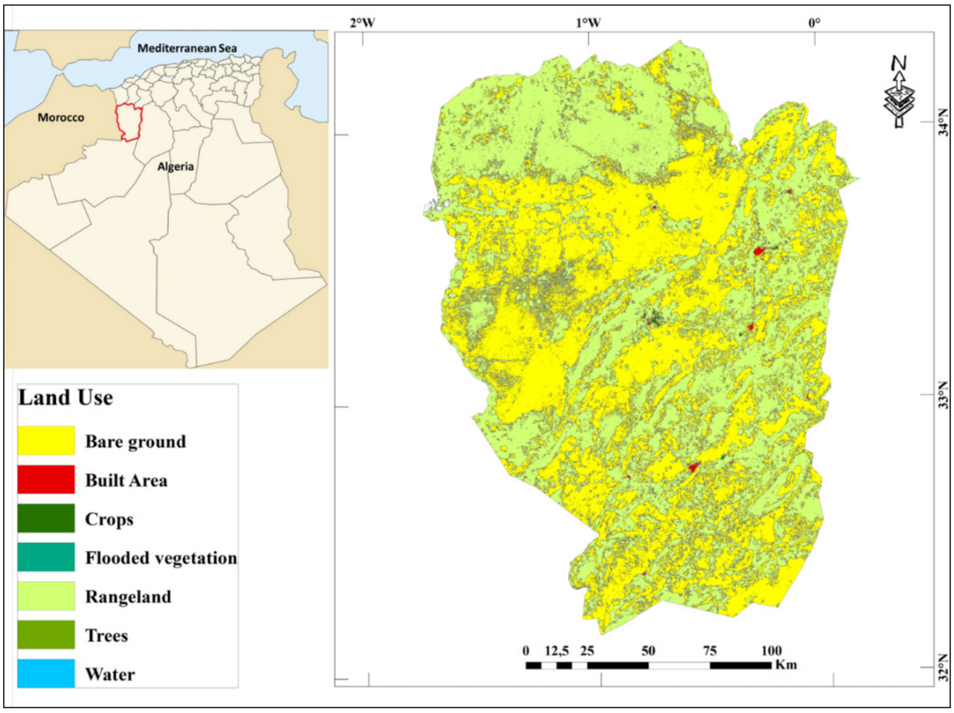

Fig. 1. Map of land use in Naâma, showing the geographical distribution of different types of agricultural land. Source: Esri, Microsoft, Impact Observatory. Source: https://www.arcgis.com/apps/instant/media/index.html?appid=fc92d38533d440078f17678ebc20e8e2

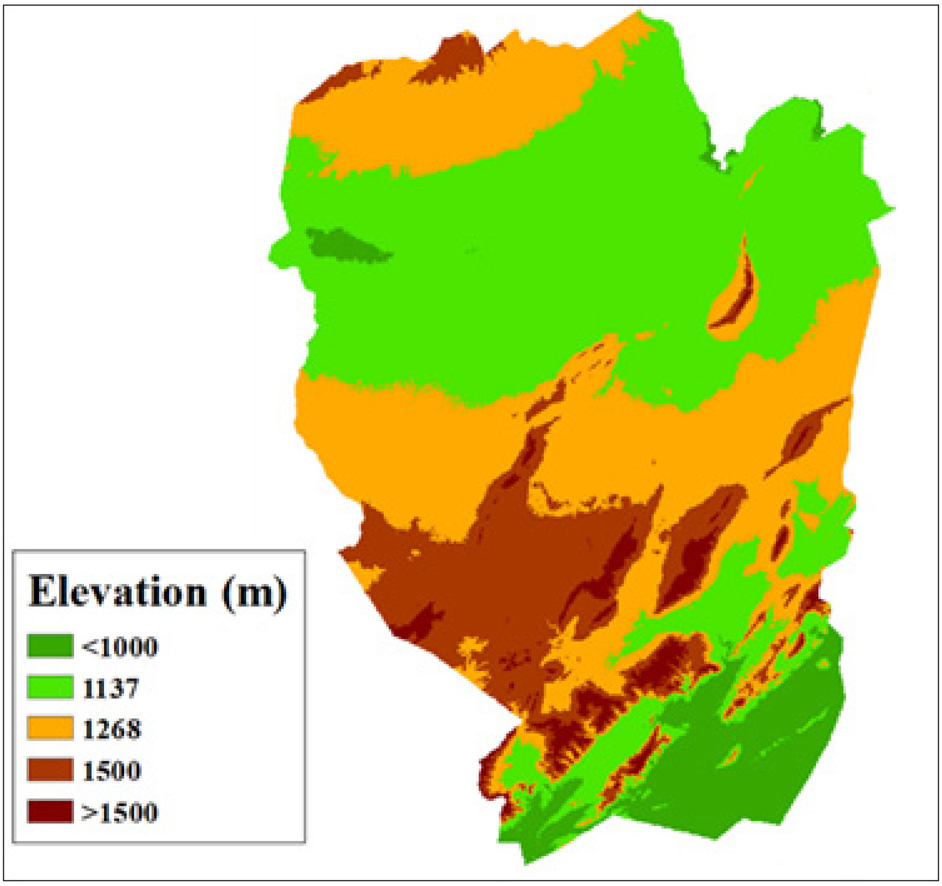

Fig. 2. Topography and relief of Naâma. Source: https://lta.cr.usgs.gov/citation.

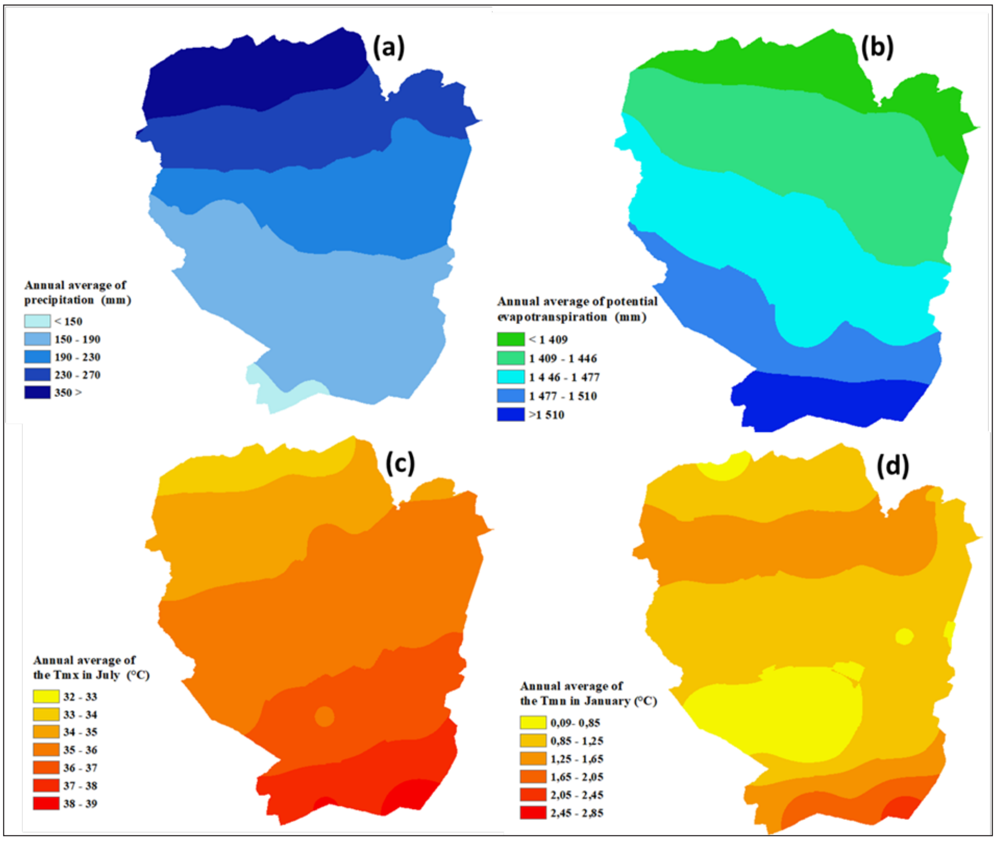

Fig. 3. Spatial distribution over the period 1951-2020 of (a) mean annual precipitation (mm) (Source: GPCC); (b) mean annual potential evapotranspiration (mm) (Source: CRU); (c) mean annual maximum air temperature (°C) in July (Source: CRU) and (d) mean annual minimum air temperature (°C) in January (Source: CRU).

$$AI = \frac{P}{PET} \quad \ldots(1)$$

where,

P: Average annual precipitation in mm,

PET: Average annual potential evapotranspiration in mm.

This index is widely used to assess the quality of the climate; it reflects the annual deficit between the amount of precipitation received (P) compared with the evaporative demand of the atmosphere (PET). AI values categorize climates from hyper-arid to humid, with thresholds defined as follows: hyper-arid (AI < 0.05), arid (0.05 ≤ AI < 0.20), semi-arid (0.20 ≤ AI < 0.50), sub-humid (0.50 ≤ AI < 0.65), and humid (AI ≥ 0.65).

Trend test

The non-parametric Mann Kendall test or MK (Mann, 1945; Kendall, 1975) is adopted to determine the presence or absence of a linear trend in time series (Pohlert, 2016). Let X_1, X_2 ...X_n be a data series where X_j is the corresponding data at time t_j. The MK statisticis defined by:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn(X_j - X_i) \quad \ldots(2)$$

where

$$\begin{cases} sgn(X_j - X_i) = 1, & if(X_j - X_i) > 0 \\ sgn(X_j - X_i) = 0, & if(X_j - X_i) = 0 \\ sgn(X_j - X_i) = -1, & if(X_j - X_i) < 0 \end{cases} \quad \ldots(3)$$

Assuming that the data are independent and identically distributed, Kendall (1975) gives E(S) = 0.

$$Var(S) = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} t_i\,(t_i-1)(2t_i+5)\right] \quad \ldots(4)$$

Where n is the number of data in the series, m is the number of linked groups and t_i is the number of data in the group of order $_i$. If the sample contains ten or more data, the distribution of the test statistic Z below will be approximated by a centred reduced Gaussian.

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & if\ S > 0 \\ 0, & if\ S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & if\ S > 0 \end{cases} \qquad ...(5)$$

The null hypothesis H_0 (no trend) is rejected when the significance level or eigenvalue (*p*-value) is greater than 5%.

A positive value of Z indicates an increasing trend. Otherwise, it indicates a downward trend.

Estimation of the slope of Sen

When the alternative hypothesis H1 is accepted, the slope of the trend (called Sen's slope) is estimated using Sen's method (Sen, 1968), where the slope is the median of all the slopes calculated between each pair of points.

For the set of peers (i, X_i) where X_i is a time series. The slope of Sen is defined as:

$$Sen's\ Slope = Median\left\{\frac{X_j - X_i}{j-i}; i<j\right\} \qquad ...(6)$$

The robustness of the test was validated by several comparison tests (Lubes-Niel *et al.*, 1998; Yue and Wang, 2004). Sen's Slope has an advantage compared to the linear regression were the test is not affected by the number of outliers and data errors.

The PET CRU grid was calculated using equation FAO 56-PM (Allen *et al.*, 1998), using the CRU gridded values of mean temperature, vapor pressure, cloud cover and static (temporally invariant except for the annual cycle) 1961–90 average wind field values.

Results and Discussion

Applying the Mann-Kendall test at the 5% threshold to all the points on the grid shows a significant upward trend in the maximum temperature in July (Fig. 4a). There is an upward trend in the minimum temperature in January in the north of the Wilaya and a downward trend in the center and south, although this is not significant (Fig. 4b). Changes in maximum July temperature estimated by the Sen slope vary between 0.19°C per decade in the north of the Wilaya and 0.22°C per decade in the south.

Figure 5a shows the geographical distribution of rainfall trends over the Wilaya of Naâma, obtained using the MK test. A significant decrease in rainfall was recorded in the north, where annual rainfall is generally higher compared to other parts of the Wilaya. The decrease in rainfall in the region varies between -15.78 and -6.83 mm decade^{-1}, which is very high compared with the annual rates recorded in the region (250 to 400 mm). However, there was a significant increase in the south of the Wilaya. This increase of around 6.6 mm decade^{-1}, on average, is very low compared with the annual average, which does not exceed 150 mm. On the other hand, rainfall has increased in the

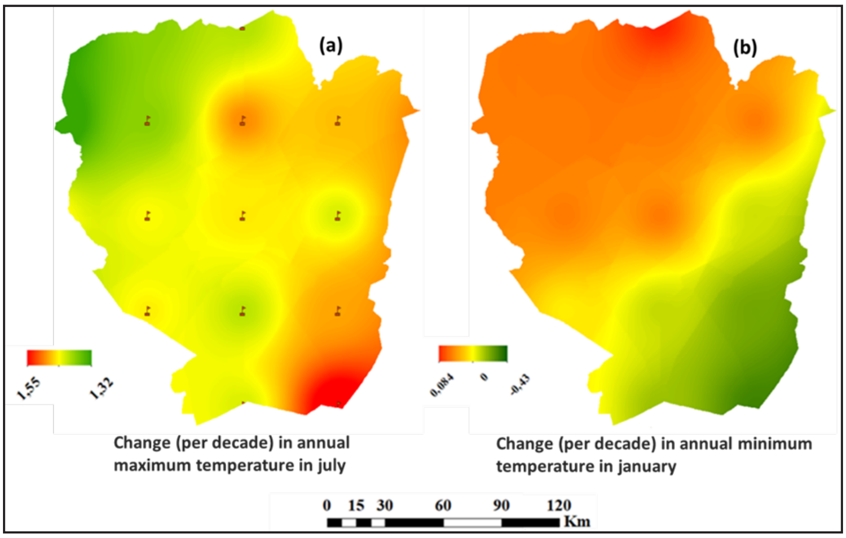

Fig. 4. Spatial distribution of trends in (a) annual mean maximum air temperature in July; and (b) annual mean minimum air temperature in January (trends significant at the 5% threshold are indicated by a flag).

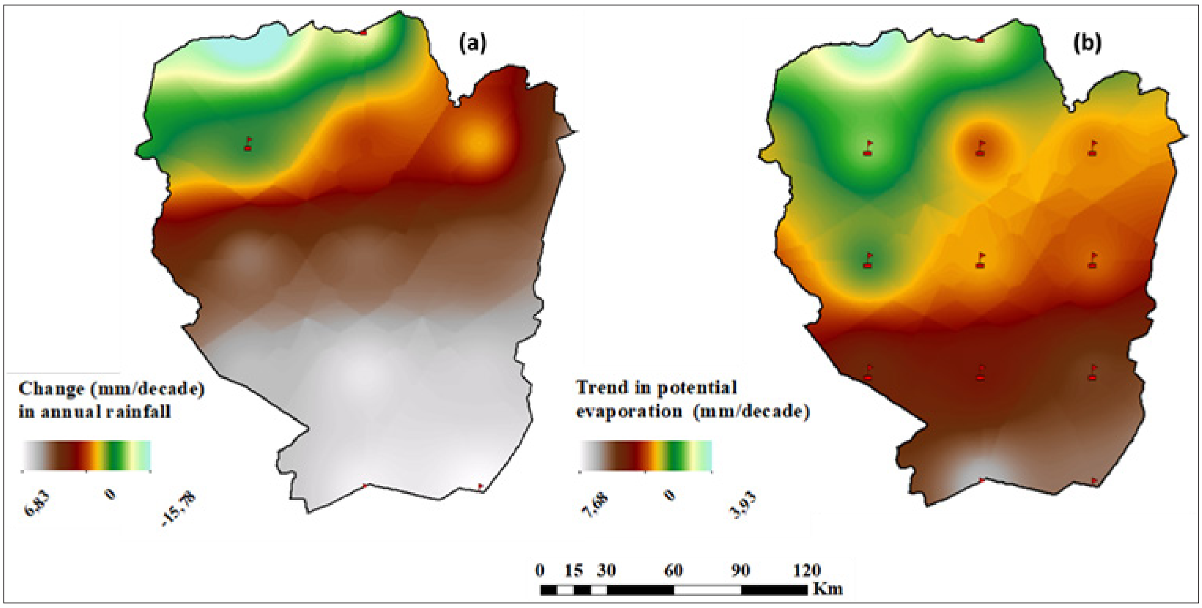

Fig. 5. Spatial distribution of (a) the trend in mean annual precipitation (in mm) (Source: GPCC) and (b) potential evapotranspiration (in mm) (Source: CRU) over the period 1951-2020 (Significant trends at the 5% threshold are indicated by a flag).

center of the Wilaya, but this increase is not statistically significant. PET has increased significantly throughout the Wilaya (Fig. 5b). The increase is around 3.9 mm decade^{-1} in the north, then gradually increases towards the south, reaching 7.7 mm decade^{-1}.

The spatial distribution of annual aridity index trends is shown in Fig. 6, where changes in annual AI north of Naâma range from -0.01221 to -0.0024 per decade. The color ramp on the map represents the change in AI per decade. The flag symbol is used to indicate the significant aridity trend at the 5% threshold. The annual AI decreases (increases in aridity) significantly in the north of the Wilaya, where AI values are generally high, due to higher rainfall and lower temperatures compared to

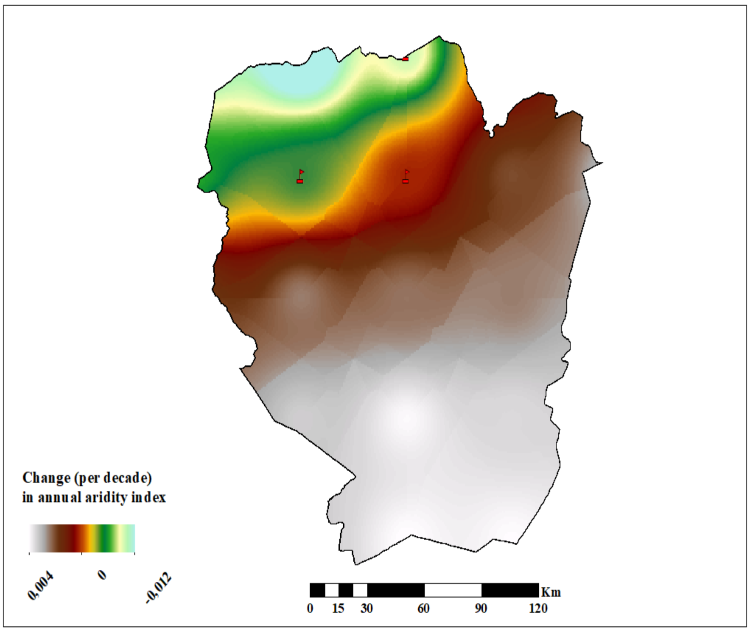

Fig. 6. Spatial distribution of the aridity trend according to the UNEP (1997) method; estimation of aridity using CRU potential evapotranspiration and GPCC rainfall data, for the period 1951-2020 (Significant trends at the 5% threshold are indicated by a flag).

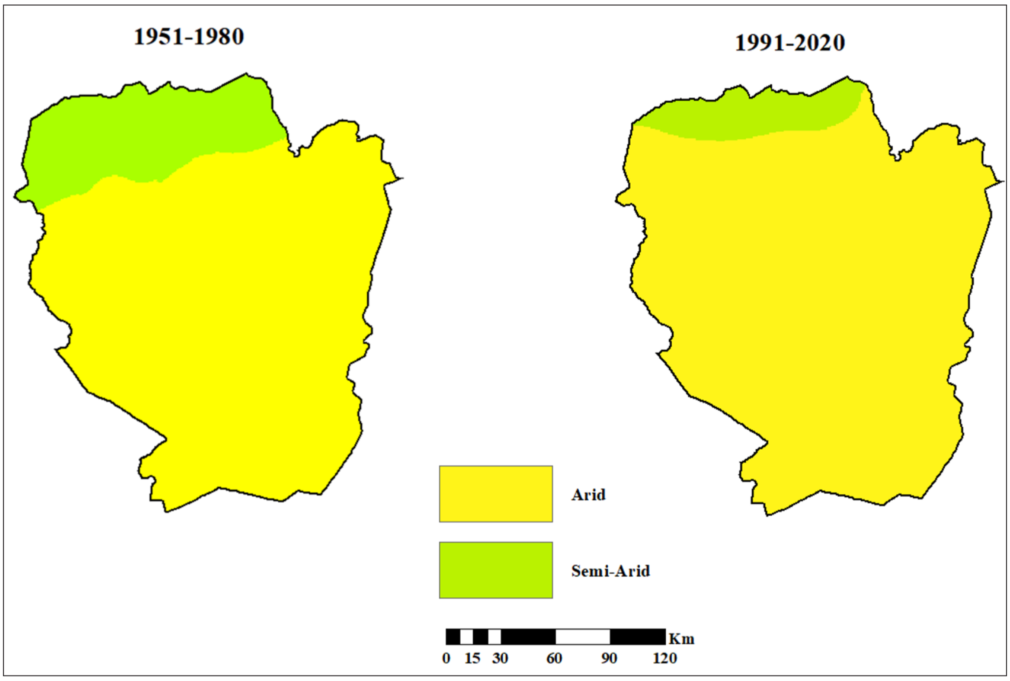

Fig. 7. Temporal changes in annual aridity in Naâma between the periods 1951-1980 and 1991-2020.

the south of the region. No significant trends were detected in the centre and south of the Wilaya.

A comparison of the results obtained (Fig. 7) for the two periods 1951-1980 and 1991-2020 shows that arid land has expanded at the expense of semi-arid land. Arid land represented 80% of the territory of the Wilaya of Naâma during the first period, rising to 90% of the territory during the second period, i.e., the transformation of 10% of semi-arid land into arid land.

Aridity presents a multitude of complex challenges as it encompasses various detrimental factors affecting the environment. These include soil degradation and desertification, which have serious repercussions on vegetation and pose significant threats to agriculture, especially in irrigated areas. Aridity plays a negative role in environmental evolution, leading to significant water deficits due to limited rainfall and runoff, alongside rising temperatures and increased evapotranspiration.

The results obtained show an upward trend in annual aridity (decrease in the aridity index) in Naâma, which is in line with the conclusions of several authors around the world, who report that drier regions would dry out more intensively and to a greater extent than wet regions (Feng and Zhang, 2015; Lickley and Solomon, 2018). The Wilaya of Naâma, characterized by two bioclimatic stages (arid and semi-arid), has experienced an expansion of arid territory at the expense of semi-arid areas. This confirms the findings of previous studies on aridity trends in other regions of Algeria. Derdous *et al.* (2020) assessed aridity trends over northern Algeria between 1980 and 2018 and found a trend towards increasing aridity in the driest regions. This study indicated that the majority of stations experienced a non-significant decrease in rainfall and a significant increase in air temperatures. By studying the evolution of minimum and maximum temperatures over the period 1951-2010 at the Bechar station, a region bordering Naâma, Oubadi *et al.* (2021) detected a significant upward trend from the 1990s onwards. Benyettou and Bouklikha (2017) revealed significantly positive rainfall trends at the Tiaret and Saïda stations (north-western Algeria) over the period 1982-2016. Similar results were obtained by Merniz *et al.* (2019), over north-eastern Algeria, but with a non-significant decrease in annual precipitation. The studies by Taibi *et al.* (2015) and Zeroual *et al.* (2017) showed pessimistic precipitation projections, with all scenarios predicting a decrease in precipitation. Indeed, the persistence of precipitation decline in these regions, even with non-significant trends, could lead to a significant increase in aridity in a short period of time, especially in light of the significant global warming trend. These results underline the complex trends in precipitation and potential evapotranspiration in the steppe, highlighting significant variations that have important implications for water resource management and adaptation to climate change in this region.

The aridity index (AI) serves as a valuable indicator of climate aridity by comparing atmospheric evaporative demand to precipitation levels in a given location. However, its utility is limited by several constraints. These include sensitivity to temperature variations, dependence on data availability for precipitation and potential evapotranspiration, and the assumption of constant potential evapotranspiration, which may not hold true in regions experiencing climate or land use changes. Moreover, the index may not directly consider variations in soil moisture or capture fine-scale aridity nuances within a region. Extreme events such as droughts or heatwaves can also challenge its accuracy, potentially leading to underestimations of aridity. Ultimately, while the aridity index offers valuable insights, its interpretation should be contextualized with local environmental, socio-economic factors, and supplemented with other indicators for a comprehensive understanding of aridity dynamics.

Conclusion

The Wilaya of Naâma, like the other Wilayas of the Algerian steppe, has suffered remarkable degradation of its rangelands. The causes most often cited are overgrazing, due to the rapid growth in sheep numbers, and recurrent droughts. This contribution has studied another parameter influencing the evolution of the environment, namely aridity; the variation of this parameter is dependent on rainfall and air temperature, and has placed it in its historical context. The results of statistical trend tests showed the expansion of arid land, from 80% to 90% of the Wilaya's territory; this is the consequence of increase in potential evapotranspiration, caused by the rise in temperature. On the other hand, statistical analyses revealed a downward trend in rainfall in the north of the Wilaya, but no trend was recorded in the other areas of Naâma.

The expansion of drylands will have significant implications for agriculture, water availability, and biodiversity. Decreased rainfall and increased evaporation rates can diminish soil moisture, leading to reduced crop yields and agricultural productivity. To address this, implementing water-efficient irrigation techniques, diversification of crop varieties, and investment in soil conservation measures are crucial. Water scarcity caused by increased aridity can strain water resources, necessitating water conservation measures, alternative water sources development, and infrastructure improvements for water storage and distribution. In terms of biodiversity, alterations in aridity can disrupt habitats and species distributions, highlighting the importance of protecting and restoring natural habitats, managing invasive species, and promoting ecosystem-based adaptation strategies. Overall, addressing the impacts of aridification requires proactive measures, including sustainable land and water management practices, infrastructure investments, and collaborative efforts among stakeholders. The escalating aridification demands urgent action to safeguard the region's environment and well-being. It is imperative to advocate for sustainable land management practices, promote conservation efforts, and call for further research and monitoring to better understand and respond to environmental changes.

References

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. 1998. *Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements*. 56, FAO, Rome, Italy, 300 p.

Becker, A., Finger, P., Meyer-Christoffer, A., Rudolf, B., Schamm, K., Schneider, U. and Ziese, M. 2013. A description of the global land-surface precipitation data products of the Global Precipitation Climatology Centre with sample applications including centennial (trend) analysis from 1901–present. *Earth System Science Data* 5: 71-99 ; https://doi.org/10.5194/essd-5-71-2013

Benyettou, M.A. and Bouklikha, A. 2017.Variations et tendances des températures et des précipitations journalières en Algérie. Thesis, Abou Bekr Belkaid University, Tlemcen, Algeria.

Derdous, O., Tachi, S.E. and Bouguerra, H. 2020. Spatial distribution and evaluation of aridity indices in Northern Algeria, *Arid Land Research and Management* 1-14; https://doi.org/10.1080/15324982.2020.1796841

Dinku, T., Connor, S.J., Ceccato, P. and Ropelewski, C.F. 2008. Comparison of global gridded precipitation products over a mountainous region of Africa. *International Journal of Climatology* 28: 1627-1638; https://doi.org/10.1002/joc.1669

Feng, H. and Zhang, M. 2015. Global land moisture trends: drier in dry and wetter in wet over land. *Scientific Reports* 5: 18018; https://doi.org/10.1038/srep18018

Harris, I., Jones, P.D., Osborn, T.J. and Lister, D.H. 2014. Updated high-resolution grids of monthly climatic observations – the CRU TS3.10 Dataset. *International Journal of Climatology* 34: 623-642; https://doi.org/10.1002/joc.3711

Kendall, M.G.1975. *Rank Correlation Methods*. 4th edition. Charles Griffin, London.

Khan, N., Shahid, S., Ahmed, K., Ismail, T., Nawaz, N. and Son, M. 2018. Performance Assessment of General Circulation Model in Simulating Daily Precipitation and Temperature Using Multiple Gridded Datasets. *Water* 10(12): 1793; https://doi.org/10.3390/w10121793

Koutroulis, A.G. 2019. Dryland changes under different levels of global warming. *Science of the Total Environ* 655: 482-511; https://doi.org/10.1016/j.scitotenv.2018.11.215

Lickley, M. and Solomon, S. 2018. Drivers, timing and some impacts of global aridity change. *Environmental Research Letters* 13: 104010; https://doi.org/10.1088/1748-9326/aae013

Lubes-Niel, H., Masson, J.M., Paturel, J.L. and Servat, E. 1998. Variabilité climatique et statistique. Étude par simulation de la puissance et de la robustesse de quelques tests utilisés pour vérifier l'homogénéité de chroniques. *Journal of Water Science* 11: 383-408.

Mann, H.B. 1945. Nonparametric Tests Against Trend. *Econometrica* 13: 245-259; https://doi.org/10.2307/1907187

Merabti, A., Darouich, H., Paredes, P., Meddi, M. and Pereira, L.S. 2023. Assessing Spatial Variability and Trends of Droughts in Eastern Algeria Using SPI, RDI, PDSI, and Med PDSI—A Novel Drought Index Using the FAO 56 Evapotranspiration Method. *Water* 15: 626; https://doi.org/10.3390/w15040626

Merniz, N., Tahar, A. and Benmehaia, M.A. 2019. Statistical assessment of rainfall variability and trends in northeastern Algeria. *Journal of Water and Land Development* 40(I–III): 87-96; https://doi.org/10.2478/jwld-2019-0009

Oubadi, M., Hamou, A. and Tedim, F. 2021. The rising temperature trend and elongation of the warm period in summer in the Algerian south-west, 1951–2010. *Acta Geographica Lodziensia* 3: 203-21; https://czasopisma.ltn.lodz.pl/index.php/Acta-Geographica-Lodziensia/article/view/1594

Oubadi, M., Faci, M. and Pham, Q.B. 2024. Drought and aridity trends on the Algerian steppe. *Theoretical and Applied Climatology* 155: 1541-1551; https://doi.org/10.1007/s00704-024-04865-2

Pohlert, T. 2016. Non-parametric trend tests and change-point detection. *CC BY-ND* 4: 1-18; https://brieger.esalq.usp.br/CRAN/web/packages/trend/vignettes/trend.pdf

Sen, P.K. 1968. Estimates of the regression coefficient based on Kendall's Tau. *Journal of the American Statistical Association* 63: 1379-1389. https://doi.org/10.1080/01621459.1968.10480934

Taibi, S., Meddi, M., Mahé, G. and Assani, A. 2015. Relationships between atmospheric circulation indices and rainfall in northern Algeria and comparison of observed and RCM-generated rainfall. *Theoretical and Applied Climatology* 127(1-2): 241-257.

UNEP 1997. *World Atlas of Desertification*. Nick Middleton and Davis Thomas, London, Arnold, 182 p.

Wang, X.J., Zhang, J.Y., Yang, Z.F., Shamsuddin S, He R-M and Xia X-H and Liu H-W 2013. Historic water consumptions and future management strategies for Haihe River basin of Northern China. *Mitigation and Adaptation Strategies for Global Change* 20: 371-387; https://doi.org/10.1007/s11027-013-9496-5

Wu, J. and Chen, X. 2019. Spatiotemporal trends of dryness/wetness duration and severity: The respective contribution of precipitation and temperature. *Atmospheric Research* 216: 176-185; https://doi.org/10.1016/j.atmosres.2018.10.005

Yang, Y., Wang, G., Wang, L., Yu, J. and Xu, Z. 2014. Evaluation of Gridded Precipitation Data for Driving SWAT Model in Area Upstream of Three Gorges Reservoir. *PLoS One*, 9(11): e112725; https://doi.org/10.1371/journal.pone.0112725

Yue, S. and Wang, C. 2004. The Mann-Kendall test modified by effective sample size to detect trend in serially correlated hydrological series. *Water Resource Management* 18: 201-218.

Zeroual, A., Assani, A.A. and Meddi, M. 2017. Combined analysis of temperature and rainfall varia-bility as they relate to climate indices in Northern Algeria over the 1972-2013 period. *Hydrology Reseach* 48(2): 584-595; https://doi.org/10.2166/nh.2016.244

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