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International Journal Water Sciences and Environment Technologies
Vol. (viii), Issue. 2, December 2023, pp. 72-76
ISSN Online: 1737-9350; ISSN Print: 1737-6688, Open Access
www.jiste.org
Scientific Press International Limited
Received: 12 November 2023 / Revised: 25 November 2023 / Accepted: November 2023 / Published: December 2023

Study of the spatio-temporal variation of climatic variables in the CSM basin - Eastern Algeria

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Abstract

Due to climate change, Algeria has experienced frequent droughts in most of its regions in recent years, including the Constantinois-Seybouse-Mellegue (CSM) basin, which is the subject of our study and spans across 14 provinces of the national territory. Due to rapid population growth, increased air temperature, and decreased precipitation in the CSM hydrographic basin, there has been a decrease in static water table levels and the drying up of several wadis, especially during the summer period. Therefore, Algerian authorities are resorting to the search for the best water management strategies in the face of climate change. That is why it is necessary to understand the spatio-temporal evolution of meteorological variables in order to assess climate-induced changes and develop appropriate strategies. In the present work, a spatio-temporal study of the evolution of aridity in the CSM basin was conducted using monthly data of precipitation and temperatures recorded at 10 meteorological stations during the period 1960/61-2019/20. The analyses of time series data were conducted based on the De-Martonne Aridity Index (IADM), the Emberger Aridity Index (IAE), and the FAO Aridity Index (IAFAO). The values of the three indicators IADM, IAE and IAFAO were studied at two time scales; seasonal and annual. Furthermore, the statistical tests of Pettitt and Buishand were performed to assess the homogeneity of the data series, and the Mann-Kendall test was used to identify trends in the variables at the selected stations. In the majority of the stations studied, the statistical tests for trends revealed significant trends towards increasing air temperatures and decreasing annual precipitation during the study period. In general, the evolution of the three considered aridity indices (IADM, IAE and IAFAO) shows a clear upward trend regarding aridity in the CSM basin. These results reflecting the negative effects of recent climate change on water availability must be taken into consideration in the planning and management of water resources in northeastern Algeria.

Key Words*:* Climate change, CSM Basin, Aridity Index, Statistical tests

Étude de la variation spatio-temporelle des variables climatiques dans le bassin versant CSM - Algérie orientale

Résumé

Suite aux changements climatiques, l'Algérie a connu ces dernières années des sécheresses fréquentes dans la majorité de ses régions, y compris le bassin Constantinois-Seybouse-Mellegue (CSM) objet de notre étude qui s'étend sur 14 wilayas du territoire national. A l'essor démographique rapide, l'augmentation de la température de l'air et la diminution de la précipitation dans le bassin hydrographique CSM ont provoqué une baisse des niveaux statiques des nappes d'eau et l'assèchement de plusieurs oueds notamment en période estivale. Par conséquent, les autorités algériennes ont recours à la recherche des meilleures stratégies de gestion de l'eau face aux changements climatiques. C'est pourquoi il est nécessaire de comprendre l'évolution du régime spatio-temporel des variables météorologiques afin d'évaluer les changements induits par le climat et de parvenir à des stratégies appropriées. Dans le présent travail, une étude spatio-temporelle de l'évolution de l'aridité dans le bassin CSM a été faite à l'aide de données mensuelles des précipitations et des températures enregistrées dans 10 stations météorologiques durant la période 1960/61-2019/20. Les analyses des séries chronologiques de données ont été effectuées en se basant sur l'Indice d'Aridité de De-Martonne (IA_{DM}), l'Indice d'Aridité d'Emberger (IA_E) et l'Indice d'Aridité FAO (IA_{FAO}). Les valeurs des trois indicateurs IA_{DM}, IA_E et IA_{FAO}, ont été étudiées à deux échelles de temps ; saisonnière et annuelle. De plus, les tests statistiques de Pettitt et Buishand ont été réalisées pour évaluer l'homogénéité des séries de données et le test de Mann-Kendal a été utilisé pour identifier les tendances des variables dans les stations sélectionnées. Dans la plupart des stations étudiées, les tests statistiques des tendances ont révélé des tendances significatives à l'augmentation des températures de l'air et la diminution des précipitations annuelles au cours de la période d'étude. En général, l'évolution des trois indices d'aridité considérés (IA_{DM}, IA_E et IA_{FAO}) montre une nette tendance à la hausse quant à l'aridité dans le bassin CSM. Ces résultats reflétant les effets négatifs du récent changement climatique sur la disponibilité en eau doivent être pris en considération dans la planification et la gestion des ressources en eau dans le nord-est algérien.

Mots clés : Changements climatiques, bassin CSM, Indice d'Aridité, tests statistiques.

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1. INTRODUCTION

Climate variations, such as alterations in local rain patterns, have altered hydrologic processes and will persistently remodel the hydrology [1]. Rainfall holds significance as a meteorological factor and plays a crucial role in regional hydrologic processes [2,3]. Aridity has emerged as a significant environmental concern in numerous regions across the globe, presenting potential risks to human populations. Arid regions accommodate more than 38% of the world's population and stand out as some of the most vulnerable areas to climate change and anthropogenic activities [4-6]. According to Milly and Dunne [7], Huang et al. [8], Lickley and Solomon [9], and Islam et al. [10], global warming-induced simultaneous decrease in precipitation, coupled with a sharp increase in temperature and potential evapotranspiration (PET), leads to drier conditions in arid and semi-arid regions worldwide [6]. Aridity is a intricate and multifaceted occurrence caused by the interplay between various atmospheric, surface, vegetation, and human-related elements [6,11].

As per the Oxford Advanced Learner's Dictionary, a drought refers to an extended duration lacking significant rainfall, while arid pertains to land or a climate exhibiting minimal or no rainfall. To clarify, drought characterizes the juxtaposition of various historical periods, whereas aridity pertains to the comparison of different geographical regions [12]. For this, a great number of aridity indices, mostly based on the combination of temperature and precipitation data, have been proposed so far. Donat et al. [13] highlighted that the Aridity Index (AI) can be employed in arid regions. However, the results' uncertainty is considerable due to limited observed coverage in most arid regions worldwide. The previous research findings mentioned above demonstrate significant variations in the impacts of global climate change on dry-wet climate changes across different regions. The interactions are intricate, and numerous uncertainties persist concerning the mechanisms driving regional-scale impacts. Therefore, investigating aridity at a regional scale necessitates the use of an appropriate aridity index, which accurately represents the measure of water deficiency in a specific location [14].

In the present study, the De-Martonne index, the Emberger index, and the FAO index are used for aridity classification in northeastern Algeria, across five basins. The main objectives of this study were to (1) generate accurate aridity classification maps in the northeastern part of Algeria according to each index, and (2) compare the spatial patterns of the three aridity indices.

2. MATÉRIELS ET MÉTHODES

2.1. *Study area*

This study concerns the Constantinois-Seybouse-Mellegue hydrologic unit located in the northeastern part of Algeria, which covers an area of 44,438 km² between the latitudes 35°12'08"N and 37°05'06"N and the longitudes 4°58'19"E and 8°40'43"E. It is limited to the north by the Mediterranean Sea, to the west by Chott El Hodna and Soumam Basins, to the east by Tunisia, and to the south by Chott Melrhir Basin (Figure 1).

Fig. 1 - Location map of the study area.

The study area is mostly dominated by a Mediterranean climate, which is a temperate climate characterized by a cold and humid season and a hot and dry season. The main crops cultivated in the study area are cereals, vegetable crops, and arboriculture.

2.2. *Methodology*

Among the climatic parameters, rainfall, air temperature, and potential evapotranspiration were obtained from ten meteorological stations. Therefore, in this study, we used three aridity indices based on their popularity in the literature and the ability to calculate them with the available data from the National Office of Meteorology. These indices are: (1) De-Martonne's aridity index [15], (2) Emberger's aridity index [16], and (3) FAO aridity index [17]. All these aridity indices have subtle differences; thus, their consideration has introduced substantial diversity into this study. The following indices are presented in the table 1.

Table 1 - Methods of calculating aridity indices used in this study.

Index formula	Description	Value	Climate
$AI_{DM} = \frac{P_a}{T_a + 10}$	AI_{DM}: De-Martonne aridity index P_a: annual precipitation in mm T_a: mean annual air temperature in °C	$AI_{DM} < 10$	Dry
		$10 \leq AI_{DM} < 20$	Semi-dry
		$20 \leq AI_{DM} < 24$	Mediterranean
		$24 \leq AI_{DM} < 28$	Semi-humid
		$28 \leq AI_{DM} < 35$	Humid
		$35 \leq AI_{DM} < 55$	Very-humid
		$AI_{DM} > 55$	Extremely-humid
$AI_E = \frac{2000 * P_a}{M^2 - m^2}$	AI_E : Emberger's aridity index P_a: annual precipitation in mm M: average temperature of the warmest month in K m: average temperature of the coldest month in K 1K = T°C + 273	$AI_E < 10$	Per-arid
		$AI_E < 30$	Arid
		$30 \leq AI_E < 65$	Semi-arid
		$65 \leq AI_E < 120$	Sub-humid
		$120 \leq AI_E$ 170	Humid
		$AI_E >170$	Per-humid
$AI_{FAO} = \frac{P_a}{ET_0}$	AI_{FAO}: FAO aridity index P_a: annual precipitation in mm ET_0: reference evapotranspiration in mm	$AI_{FAO} <0.05$	Hyper-arid
		$0.05 \leq AI_{FAO} <0.20$	Arid
		$0.20 \leq AI_{FAO} <0.50$	Semi-arid
		$0.50 \leq AI_{FAO} <0.65$	Dry sub-humid
		$0.65 \leq AI_{FAO} <0.75$	Wet sub-humid
		$AI_{FAO} \geq 0.75$	Humid

Homogeneity tests of the climatic parameters, including Rainfall, Temperature, and Reference Evapotranspiration, were performed to define the change points and trends at the annual scale using the following methods: (i) the Pettitt test, (ii) Mann-Kendall test, and (iii) Sen's slope.

3. RÉSULTATS ET DISCUSSION

The results obtained by the three aridity indices showed that the De-Martonne aridity index varies between 16.04 at the Cheikh Larbi Tebessi station and 28.09 at the Skikda station, indicating a variation in climate from semi-dry to humid in the CSM basin (Table 2). The meteorological stations of Annaba, Constantine, and Guelma are characterized by a Mediterranean climate. The stations of Bejaia airport, Jijel, and Cheffia Dam are classified as Semi-humid, while the station of Batna indicates a Semi-dry climate. While the Emberger aridity index varies between 68.97 at the Batna station and 189.20 at the Bejaia airport station, the results indicate a variation in climate between Sub-humid and Per-humid in the studied area. The results obtained by the FAO aridity index indicate only two climatic classes in the presented area, namely: Semi-arid and Dry sub-humid (Table 2).

Table 2 - Annual precipitation, mean temperature, reference evapotranspiration and aridity indices during the following period 1960/61-2019/20.

Station name	P (mm/year)	T_{mean} (°C)	ET_0 (mm/year)	AI_{DM} (Climate)	AI_E (Climate)	AI_{FAO} (Climate)
Annaba	638.24	17.55	1270.20	23.12 (Mediterranean)	152.95 (Humid)	0.50 (Dry sub-humid)
Constantine	509.55	15.38	1257.07	20.06 (Mediterranean)	93.39 (Sub-humid)	0.41 (Semi-arid)
Skikda	734.18	16.11	1285.28	28.09 (Humid)	161.91 (Humid)	0.57 (Dry sub-humid)
Bejaia airport	764.06	17.61	1211.49	27.56 (Semi-humid)	189.20 (Per-humid)	0.63 (Dry sub-humid)
Batna	410.70	14.43	1450.90	16.78 (Semi-dry)	68.97 (Sub-humid)	0.32 (Semi-arid)
Cheikh Larbi Tebessi	402.70	15.12	1532.80	16.04 (Semi-dry)	69.63 (Sub-humid)	0.28 (Semi-arid)
Setif Ain Arnat	432.87	15.06	1332.00	17.22 (Semi-dry)	73.40 (Sub-humid)	0.33 (Semi-arid)
Guelma	592.15	16.05	1474.90	22.69 (Mediterranean)	115.77 (Sub-humid)	0.43 (Semi-arid)
Jijel	739.81	16.67	1592.70	27.41 (Semi-humid)	164.87 (Humid)	0.54 (Dry sub-humid)
Cheffia Dam	717.92	20.00	1290.10	24.12 (Semi-humid)	137.04 (Humid)	0.58 (Dry sub-humid)

The results of the Pettit test show that the annual precipitation of Annaba, Batna, Jijel, and Cheffia Dam stations has significant change points that occurred during 1978/79, 2004/05, 2001/02, and 1977/78, respectively (Table 3). The hypothesis of homogeneity is rejected for these stations at the 5% level of significance. On the other hand, the test also indicated that the hypothesis of homogeneity is valid in the other stations, as non-significant change points were detected in their rainfall series (p value ≥ 0.05). Moreover, the results of the Pettit test indicate that the temperature of all stations, except the Setif Ain Arnat station, has significant change points (Table 3).

Table 3 - Results of Pettitt's and Mann-Kendall's statistical tests at the weather stations studied.

	Station name	Pettitt	Mann-Kendall (P-value < 5%)	Sen's slope	Average before rupture	Average after rupture	Difference
Precipitation (P)	Annaba	1978/79	S (0.0206)	2.5300	555.31	676.67	121.36
	Constantine	-	NS (1.0000)	-0.0054	-	-	-
	Skikda	-	NS (0.6123)	0.4950	-	-	-
	Bejaia airport	-	NS (0.8134)	0.3803	-	-	-
	Batna	2004/05	S (0.0008)	-2.4893	445.09	307.53	-137.56
	Cheikh Larbi Tebessi	-	NS (0.1152)	-1.1803	-	-	-
	Setif Ain Arnat	-	S (0.0206)	-1.3448	-	-	-
	Guelma	-	NS (0.5790)	0.5387	-	-	-
	Jijel	2001/02	S (< 0.0001)	9.4191	606.15	1052.00	445.85
	Cheffia Dam	1977/78	NS (0.0794)	2.5938	609.30	764.47	155.17
Temperature (T_{mean})	Annaba	1981/82	S (< 0.0001)	0.0164	17.06	17.83	0.77
	Constantine	1993/94	S (< 0.0001)	0.0194	15.03	15.83	0.80
	Skikda	1986/87	S (< 0.0001)	0.0569	15.06	16.98	1.92
	Bejaia airport	1982/83	S (< 0.0001)	0.0199	17.15	17.90	0.75
	Batna	1993/94	S (< 0.0001)	0.0422	13.82	15.24	1.42
	Cheikh Larbi Tebessi	1992/93	S (< 0.0001)	0.0546	14.21	16.22	2.01
	Setif Ain Arnat	-	NS (1.0000)	-0.0001	-	-	-
	Guelma	1986/87	S (< 0.0001)	0.0832	14.10	17.64	3.54
	Jijel	1993/94	S (< 0.0001)	0.0661	15.77	17.84	2.07
	Cheffia Dam	1979/80	S (0.0002)	0.1351	14.54	22.73	8.20
Reference evapotranspiration (ET_0)	Annaba	1993/94	S (< 0.0001)	2.6920	1224	1331	107
	Constantine	1992/93	S (< 0.0001)	3.1300	1204	1321	117
	Skikda	1992/93	S (< 0.0001)	4.0885	1221	1363	142
	Bejaia airport	1992/93	S (< 0.0001)	5.2374	1121	1322	201
	Batna	1993/94	S (< 0.0001)	3.9000	1247	1387	140
	Cheikh Larbi Tebessi	1992/93	S (< 0.0001)	4.2614	1374	1530	156
	Setif Ain Arnat	-	NS (0.9288)	0.0482	-	-	-
	Guelma	1986/87	S (< 0.0001)	7.8885	1219	1538	319
	Jijel	1992/93	S (< 0.0001)	5.2483	1282	1446	164
	Cheffia Dam	1992/93	S (< 0.0001)	2.0780	1198	1279	81

The results of the Mann-Kendall test indicated that the null hypothesis Ho is accepted for Constantine, Skikda, Bejaia airport, Cheikh Larbi Tebessi, Guelma, and Cheffia Dam stations (p-value > 0.05), with magnitudes of trends equal to 1.0000, 0.6123, 0.8134, 0.1152, 0.5790, and 0.0794, respectively (Table 3). The mentioned stations present certain homogeneity of annual precipitation data at the 5% level of significance.

On the other hand, the probability of the null hypothesis is rejected for Annaba, Batna, Setif Ain Arnat, and Jijel stations, with magnitudes of trends equal to 0.0206, 0.0008, 0.0206, and 0.00001, respectively. According to Sen's slope estimates at the 5% level of significance, it can be noticed that the stations of Constantine, Batna, and Setif Ain Arnat are indicating negative trends with -0.0054, -2.4893, and -1.3448, respectively. The Jijel station showed a highly significant positive trend of 9.4191 (Table 3).

CONCLUSION

In this study, we aimed to assess the spatio-temporal evolution of the climate in the CSM basin (northeastern Algeria), a region of great importance for managing water resources and other activities affected by climate change. To achieve this, we conducted an analysis of the variability and homogeneity of precipitation, temperature, and reference evapotranspiration data on an annual scale using statistical tests. Subsequently, we calculated three aridity indices based on the data collected from the meteorological stations in the study area. The results of the three aridity indices clearly indicate a noticeable trend towards increased aridity in the CSM basin. These findings underscore the negative impact of recent climate change on water availability in the region. As such, it is imperative to consider these results in the planning and management of water resources in northeastern Algeria. Proper management strategies and mitigation measures need to be implemented to address the challenges posed by the changing climate and ensure sustainable water availability for the region's diverse needs.

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