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Mapping of the Effects of Climate Change on Water Resources in the Arid Naâma Region-Understanding Past Trends to Plan for Better Future Strategies.

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Abstract— **In the arid agro-pastoral region of Naâma, groundwater is the main source of freshwater. To investigate the effects of climate change on this resource, the Thorthowaite and Penman-Monteith models were used to study the water balance in the region based on monthly and annual remote sensing data of: precipitation, temperature, wind speed, relative humidity and solar radiation from 1990 to 2020. The results show a clear aggravation of aridity in the region, materializing in a decrease of about 50mm of precipitation, an increase of about 1.2 °C in temperature and an increase of about 175mm of potential evapotranspiration from 1990 to 2020. The result also highlight the continuously widening gap between precipitation and evapotranspiration, which has not only led to the deterioration of the wild vegetation cover and favoured desertification, but also significantly increased the agricultural water deficit in irrigated lands, putting even more pressure on groundwater in the region.**

Keywords— **Groundwater, Water Balance, Thorthowaite and Penman-Monteith models, precipitation, temperature, evapotranspiration, water deficit.**

I. INTRODUCTION

Climate change has become a major concern; not only for scientists, but for most people around the world, as it has affected their daily lives to a significant degree. In semi-arid, arid and desert zones, the effects of climate change are even more pronounced [1]. In Algeria, climate change has put more pressure on groundwater, especially in the South, where precipitations are almost inexistent and irregular [2]. This is the case for the arid agro-pastoral region of Naâma, where precipitations rarely reach 250mm/year and temperatures exceed 40°C from July to September [3]. In light of that, the present study focuses on the modelling of the water balance, using the Thorthwaite and Penman-Monteith models, GIS and remote sensing climate data for a 30-year period, from 1990 to 2020. This approach is commonly used to study the components of the hydrologic cycle, especially when in-situ data is poor or lacking [4], [5]. The main objectives of this work are to study the spatiotemporal evolution of climate change and examine its negative effects on groundwater in the region.

II. MATERIAL AND METHODS

A. Study Area & Data Description

The Wilaya of Naâma is trapped between the Tellian and Saharan Atlases and expands over an area of approximately thirty thousand km^2, with most of its surface (75%) represented by a large and flat steppe zone. The region has two main seasons; one, cold and barely humid, with low and erratic precipitations (November to April), the second (May to October), very hot and dry, especially during the months of July and August, where temperatures can exceed 45°C. The main aquifers in the region are the Tertiary filling (Mekmen B-A, A-B Khlil, Kasdir et El Biod), the dolomitic limestone formations of the Bajocian-Bathonian (Mecheria, Naâma and Sfissifa) and the cretaceous sandstones of the Barremian – Albian (Ain Sefra, Tiout and Asla) [6].

The present study was conducted based on monthly and annual remote sensing data (NASA POWER-Data Access Viewer) [7] of five climate parameters; namely: precipitation (P mm), temperature (T °C), wind speed (WS m/s), relative humidity (RH %) and solar radiation (SR MJ/m2/day). The data covers the twelve districts of Naâma for a period of thirty years, from 1990 to 2020 (Figure1).

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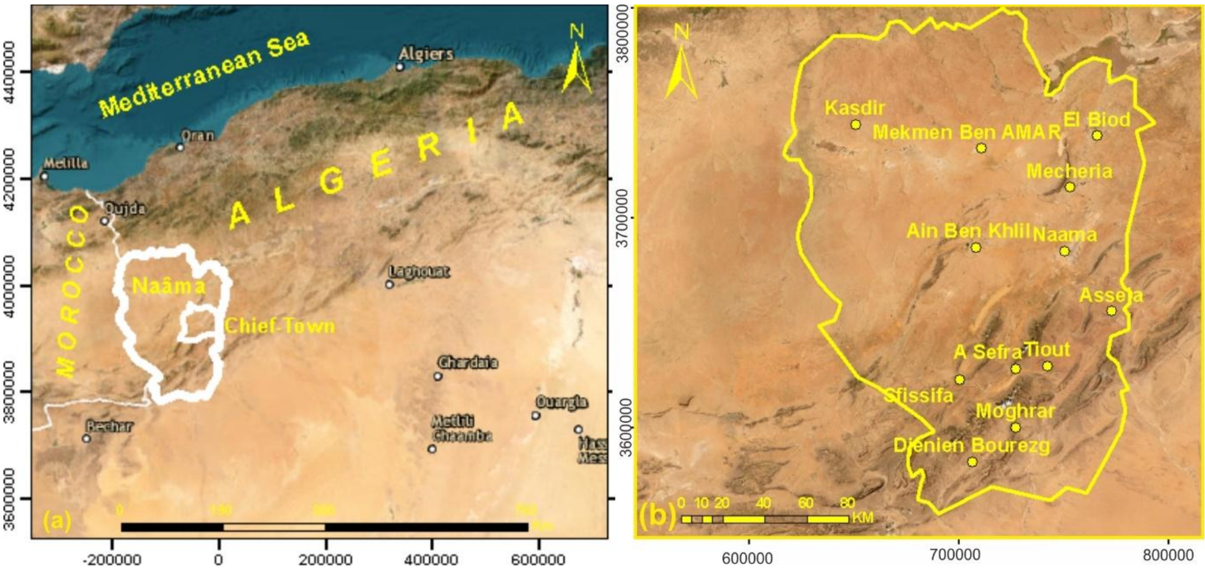

Figure 1. Study area: a) General situation, b) Meteorological stations.

B. *Methodology*

1) Climate Parameters:

First, the temporal evolution from 1990 to 2020 of the aforementioned climate parameters P (mm), T (°C), WS (m/s), RH (%) and SR (MJ/m2/day) is described using simple scatter diagrams (figure 2). Second, the spatiotemporal evolution of Precipitation and Temperature (the two main parameters in the water balance) is examined based on spatiotemporal maps.

2) Water Balance:

The Thornthwaite water balance is a measurement model based on monthly temperature and precipitation data. The model operates according to a measurement procedure that allows the study of the distribution of water resources between the different components of the water cycle. The model has the advantage of not requiring mush data and of calculating several important parameters of the hydrological system, i.e., potential and actual monthly evapotranspiration PET& AET, soil water storage S (max S = the readily usable reserve, RUR), agricultural water deficit AWD and water flow Q [4], [5], [8]. According to Thornthwaite, satisfying PET and RUR by P, takes priority over flow Q; meaning that before there is flow, AET must equal PET and RUR must be full.

For a more realistic representation of the evapotranspiration trends on the ground, the Thornthwaite water balance model was adjusted using the Penman-Monteith formula, derived by the United Nations Food and Agriculture Organization FAO (Penman-FAO), to model the reference evapotranspiration ET0, as it is much more suited for regions affected by aridity [9]. The Penman-FAO equation approximates net evapotranspiration (ET) from meteorological data as a replacement for direct measurement of evapotranspiration. For the present study, ET0 calculations were done using the FAO ET0calculator program. ET0 is used to calculate PET based on a coefficient (Kc) for a given crop: ETP = Kc * ET0. In this study ET0 was adjusted using Kc-mid (growth stages of plants) to account for the period where plants consume the most water [10].

The adjusted Thornthwaite water-balance was first used to determine the monthly and annual differences between inlets (precipitation) and outlets (evapotranspiration) for the twelve districts of Naâma. Second, the AWD (2019-2020) for all irrigated surfaces was calculated based on land occupation (fruit trees and grapes, vegetables and legumes, cereals and forages). Finally, the irrigation water volumes needed to compensate the AWD were estimated.

3) Geo-statistics:

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The spatiotemporal maps of P, T and AWD were constructed using the geographic information system (GIS) program ArcGIS. The maps were created using inverse distance weighting (IDW) interpolation, which estimates parameters values at locations with missing data based on the distance between measured and unmeasured values [11].

III. RESULTS AND DISCUSSION

A. Climate Parameters

Figure 2 reflects the typical irregularity of arid climates. Still, the general trend is towards an increase in aridity. The results show a decrease of about 25 (mm/year) of precipitation and 10% of relative humidity and an increase of about 1°C in temperature, 0.1 (m/s) in wind speed and 1.5 (MJ m^{-2} day^{-1}) in solar radiation.

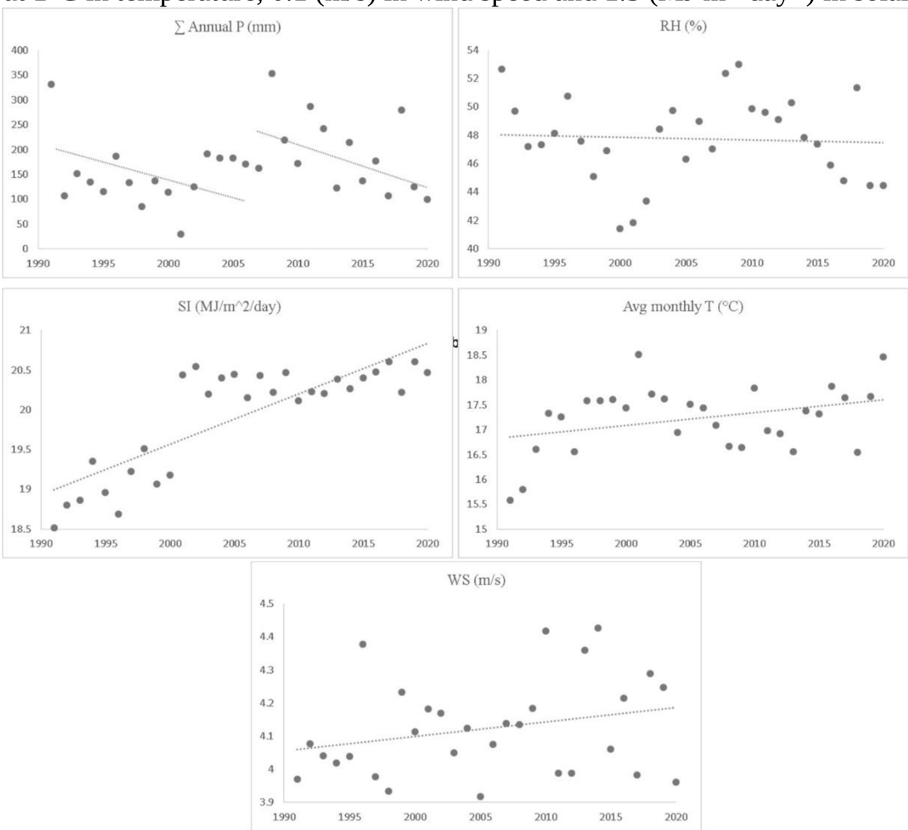

Figure 2. Temporal evolution of P (mm), T (°C), WS (m/s), RH (%) and SR ($MJ/m^2/day$) from 1990 to 2020.

From figure 2, a significant variation at the 5-year mark is observed for all parameters. On this basis and to simplify data interpretation, all spatiotemporal maps were created based on a 5-year time interval (1990-1995, 1995-2000, 2000-2005, 2005-2010, 2010-2015 and 2015-2020).

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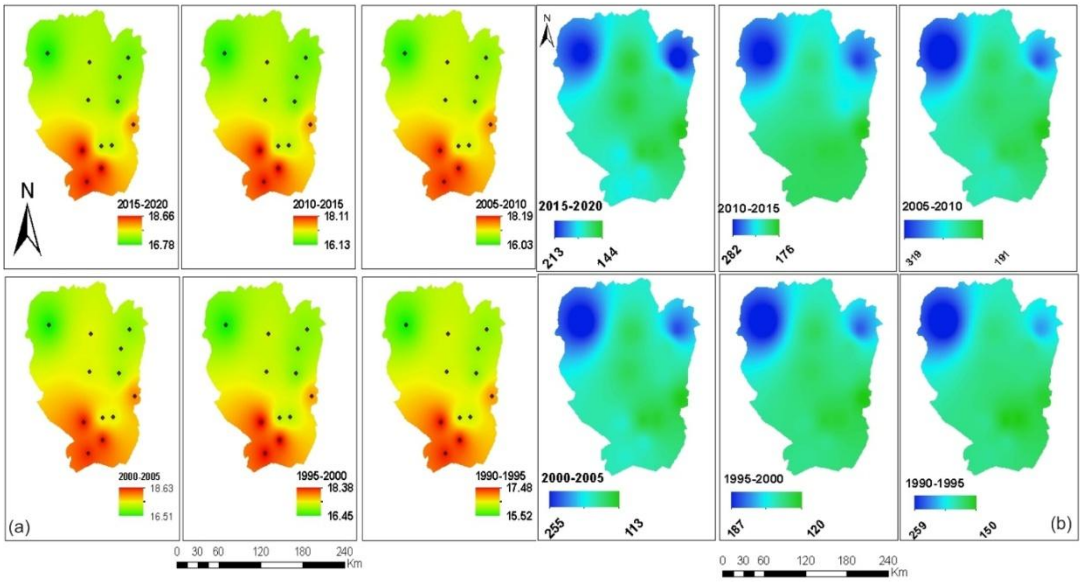

Figure 3. Spatiotemporal evolution of precipitation and temperature in Naâma (1990-2020).

Figure 3 shows that the geographical zoning plays a major role in the distribution of P (mm) and T (°C). The increase in P (mm) and the decrease of T (°C) seems to follow a Southeast-Northwest direction towards the Moroccan border due to the better exposure to humid wind in this area. Figure 3 also shows that the area lost approximately 50mm of rain and gained approximately 1.2 °C in temperature, indicating that the region has become significantly more arid between 1990 and 2020.

B. *Evapotranspiration and Agricultural Water Deficit*

The examination of figure 4 confirms the increasing aridity trend in the area. The temporal evolution of ETP for all twelve districts describes an average increase of about 160-190mm from south to north and from 1990 to 2020. This augmentation in water deficit in the context of an agro-pastoral region like Naâma, has put even more pressure on groundwater.

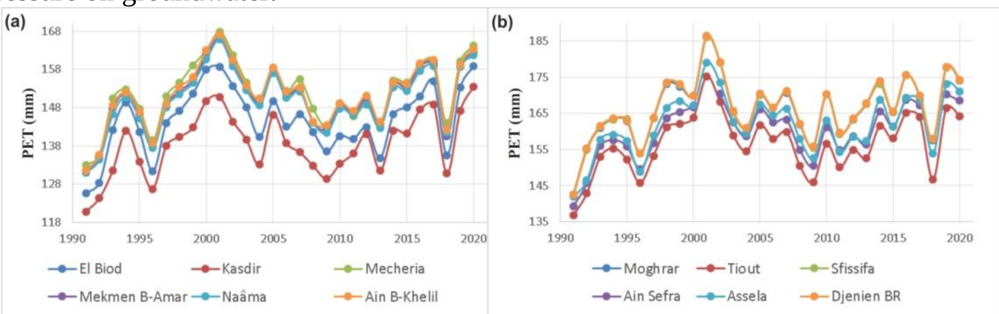

Figure 4. Temporal evolution of monthly ET0 in Naâma (1990-2020).

The water balance results show that the WD between precipitations and ETP has continuously risen, especially in the districts of Mekmen, Assela and Ain Benkhelil, where it has exceeded 185 mm/y from 1990 to 2020. The spatiotemporal mapping of the AWD (figure 5) showed the existence of a clear limit between two domains: extremely arid and arid. The first includes the districts of Djenien, Moghrar, Sfissifa, Ain Sefra, Tiout and Assela and the second the districts of Naâma, Mecheria, Mekmen, Ain Ben Khlil, Kasdir and El Biod.

The AWD Maps (1990-1995 / 1995-2000 / 2000-2005/ 2005-2010 / 2010-2015 / 2015-2020) show a northward migration of the limit separating the two domains of about 0.014° latitude (a shift over an area of approximately 1500km^2), confirming the desertification trends observed in the study area for the past 50 years.

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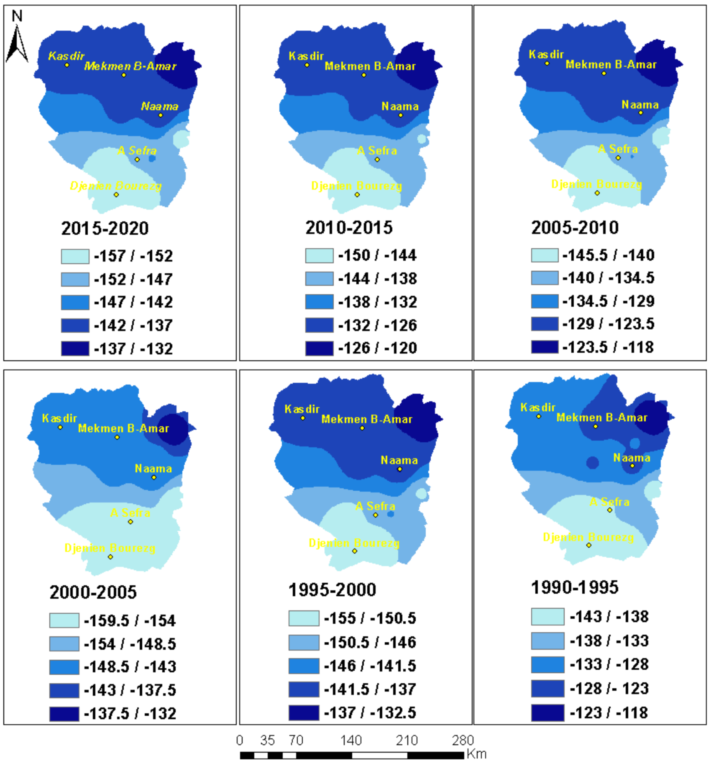

Figure 5. Spatiotemporal evolution of the average monthly water deficit (WD = P-PET) in Naâma (1990-2020).

C. *Irrigation Water Volumes*

Based on land occupation (surface area by crop cultivated) [12], PET averages of irrigated surfaces in all twelve districts were calculated and then used to estimate the volumes of irrigation water needed to compensate the lack of precipitation (table 1).

TABLE 1

IRRIGATION VOLUMES PER LAND OCCUPATION

	Max theoretical irrigation volumes needed in m3 when P = 0 mm*			
irrigated surfaces (ha)	Fruit trees and Grapes	Cereals	Vegetables and Legumes	Forages
723	36015	33673	568781	891603
567	27658	25859	436799	684712
1414	111930	104650	1767675	2770950
953	45611	42645	720331	1129167
1160	53224	49762	8405465	1317614
612	28559	26701	451025	707012
977	52763	49331	833270	1306207
319	15586	14572	246153	385862
1582	70431	65850	1112304	1743612
130	10284	9615	162424	254610
26	8287	7748	130884	205169
1069	44362	41477	700605	1098246

**Volumes should be adjusted according to type of crop, plant cycle stage and amount of precipitation.*

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IV. Conclusion

The present study highlights the extreme vulnerability of arid zones to climate change. The results illustrate the continuous increase of the aridity markers in the region, leading to a bigger reliance on groundwater and consequently, their deterioration due to overexploitation and pollution. In Naâma, signs of soils salinization and contamination by wastewaters are already observed in the districts of Ain Sefra and Tiout. The deterioration of the vegetative cover has also been worsening in areas like El Biod and Mekmen Ben Amar.

The results from this study could be used to inspire future policies aimed at regulating the use and the protection of groundwater both quantitatively and qualitatively. Water efficiency policies such as the generalization of less transpiring plants that can also act as a canopy (artificial microclimates, which are favorable to cultivate other crops, thereby, significantly reducing the evapotranspiration rates) and the generalization of modern irrigation techniques and/or nocturnal irrigation, etc., can significantly reduce the amounts of water needed to produce food and sustain local populations.

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