© by PSP Volume 29 – No. 12A/2020 pages 11565-11572 Fresenius Environmental Bulletin

SPATIAL AND TEMPORAL MAPS IN REFERENCE EVAPOTRANSPIRATION IN CHAD

Cihan Karaca, Hisseine Mahamat Allamine*, Dursun Buyuktas

Department of Agricultural Structures and Irrigation, Faculty of Agriculture, Akdeniz University, Antalya, Turkey

ABSTRACT

Millions of people living in Chad are affected by food insecurity, malnutrition and water scarcity. For this reason, diversification of agricultural cultivation and existing water should be used more efficiently. Irrigation is one of the most important cultural practices in agricultural cultivation. Determination of the evapotranspiration values of crops is important in irrigation system planning and irrigation scheduling. Estimation of evapotranspiration with meteorological data is the most widely used method. However, in the least developed countries such as Chad, climate data is not always available. For this reason, in this study, it was aimed to create temporal and spatial maps in order to determine reference evapotranspiration values, which is an important parameter in estimating crop evapotranspiration values, more easily. These maps showed that the reference evapotranspiration increases from the Sudanese savannah zone to Sahara (desert) zone. It is thought that temporal and spatial maps will be beneficial for regional farmers as diversification of agricultural production and the use of irrigation systems are expected to increase in the future.

KEYWORDS:
ETo, ETc, GIS, Semi-Arid Region

INTRODUCTION

United Nations (UN) population projections show that the Sub-Saharan Africa population, which is 1 066 million, is expected to be 1400 million in 2050 and 3 775 million in 2100 [1]. Sub-Saharan Africa's population is growing at 2.7% per year, which is faster than South Asia 1.2% and Latin America 0.9%. These data show that the demographic trends in Africa face a major population explosion in the near future. If the current growth rate continues, Africa's population is expected to double by 2050 [1]. That would be 2.5 billion people, meaning more than a quarter of the world's population would be in Africa.

Chad is one of the poorest countries in the world. Chad's major problems include a high risk of floods and droughts, widespread poverty, frequent civil war and the rapid population growth [2]. Chad is facing interconnected humanitarian crises in the context of chronic poverty and low economic development. The security situation in neighboring countries has led to large population movements into Chad, as well as an internal displacement for several years. Millions of people are affected by food insecurity and malnutrition, especially in the Sahel belt, and this situation is likely to worsen during the lean season (June- September). Due to lack of funding, 212,000 people in crisis-affected areas do not have access to safe drinking water and adequate sanitation. This situation increases the risk of waterborne diseases and malnutrition [3].

Agricultural production is based on rain since there is insufficient funding in Chad. However, irrigation systems have become mandatory to feed the growing population, to use water resources more effectively and to ensure diversity in agricultural production. Evapotranspiration values are required for the selection of the correct irrigation system and irrigation scheduling. FAO 56 model, which is based on reference evapotranspiration (ET_o) and crop coefficient (kc) in order to determine crop evapotranspiration ($ETc= ET_o$ x kc), is accepted by the authorities as the standard and most accurate model. The major limitation of the FAO-56 PM model is that it requires many meteorological inputs, thereby limiting its utility in data-sparse areas. Moreover, it is expensive to equip meteorology stations to measure these climate data, especially in developing countries [4].

Computer models, e.g. hydrological models, are one of the key components in determining effective policy and estimating the impact of water management. Many of these models require gridded information on meteorological variables such as evaporation and precipitation [5]. Arc GIS software provides geostatistical tools to create surfaces from sample data (TCI value of stations) using interpolation methods such as inverse weighted distance, radial-based functions, global and local polynomials, kriging, co-kriging, and isotropic or anisotropic models. Kriging is known as the best linear unbiased estimator amongst all interpolation methods [6]. In a spatial context, interpolation is the process of estimating a variable at unmeasured locations using surrounding locations that do have a

measurement of that variable [5]. Previous researches have demonstrated that kriging is a better interpolation method with high accuracy and low bias compared to other methods [7–9].

In this study, it was aimed to determine ET_o with climatic data obtained from different regions of Chad and to create temporal and spatial maps using these data.

MATERIALS AND METHODS

Chad is in north-central Africa, lying between latitudes 7° and 24°N, and longitudes 13° and 24°E. The country is bounded to the east by Sudan, to the west by Niger, Nigeria and Cameroon, to the north by Libya and to the south by the Central African Republic (Figure 1(a)). Chad is divided into three regions: a Sahara (desert) zone in the north, an arid Sahelian belt zone in the center and a more fertile Sudanese savannah zone in the south (Figure 1(b)). In general, the country weather is always hot, each year a tropical weather system known as the intertropical front crosses Chad from south to north, bringing a wet season that lasts from May to October in the south, and from June to September in the Sahel.

The long-term average climate data required in the study were obtained from the CLIMWAT 2.0 software. CLIMWAT provides long-term monthly mean values of seven climatic parameters, namely: mean daily maximum temperature, minimum temperature, relative humidity, wind speed, sunshine hours per day, solar radiation and rainfall [10]. CropWAT software developed by FAO [11] was used to calculate ET_o values in the study. These ET_o values from measurement points in different locations were used to create a continuous surface by using the Kriging tool of the ArcGIS Spatial Analyst module. Spatial ET_o maps for each month were created using this method. In order to prepare spatial maps with high accuracy, data from 12 meteorological stations belonging to Chad and 20 different meteorological stations belonging to 6 different countries neighbor to Chad were used and the information on these stations was given in Table 1.

A GIS software package ArcGIS (Pro 2.5.2) Spatial Analyst Tools-Ordinary Kriging extension was used to map, query, and analyze the data in this study. The spherical model was used among the variogram models for kriging applications.

Kriging assumes that the distance or direction between sample points reflects a spatial correlation that can be used to explain variation in the surface. Kriging is most appropriate when you know there is a spatially correlated distance or directional bias in the data. It is often used in soil science and geology [12]. The formula for the Kriging model is given in Equation 1.

$$\hat{Z}(s_o) = \sum_{i=1}^{N} \lambda_i Z(s_i) \quad (1)$$

Where; $Z(_{si})$ is the measured value at the i^{th} location, λ_i is an unknown weight for the measured value at the i^{th} location, s_o is the prediction location and N is the number of measured values.

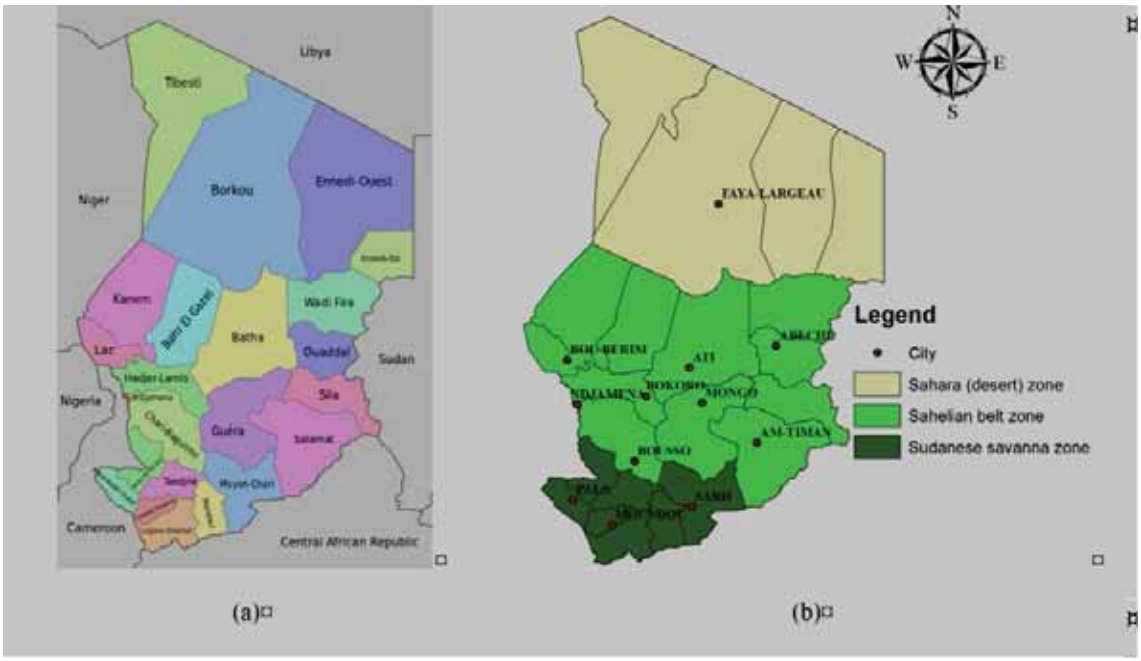
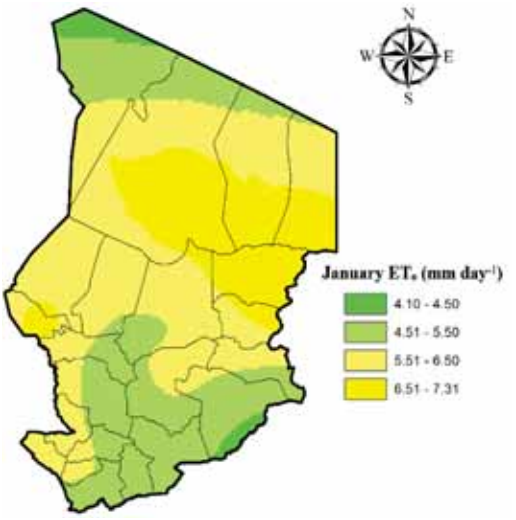


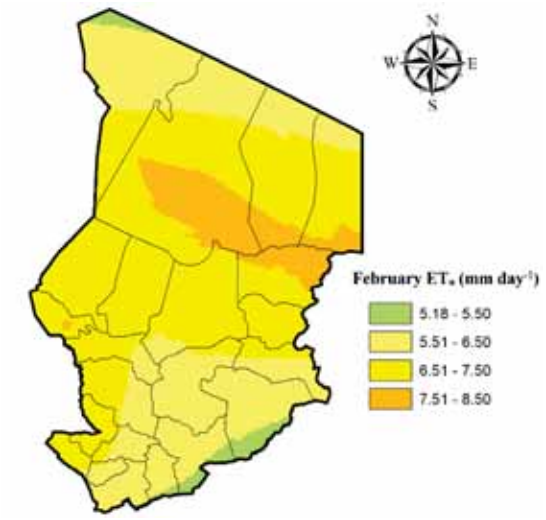
FIGURE 1
Administrative regions and different climatic zones of Chad

TABLE 1
Locations of meteorological stations in Chad and neighboring cities and ET_o values calculated by climatic data at these stations

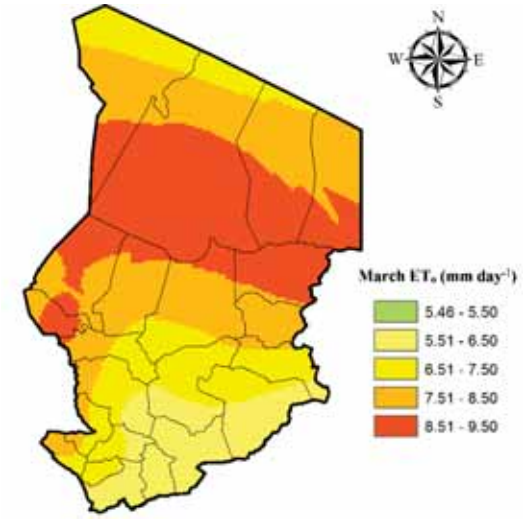
Country	Stations	Latitude	Longitude	ET_o (mm day^{-1}) Months 1	2	3	4	5	6	7	8	9	10	11	12
Chad	Abeche	13.85 ºN	20.85º E	6.5	7.3	8.3	8.7	8.1	6.9	5.5	4.3	5.3	6.7	6.9	6.5
	Am-Timan	11.03 ºN	20.28 ºE	5.0	5.9	6.6	6.7	6.2	5.3	4.2	3.9	4.0	4.4	4.7	4.5
	Ati	13.21 ºN	18.31 ºE	5.3	6.3	7.3	7.3	7.0	6.5	5.6	4.3	5.0	5.8	5.7	5.3
	Bokoro	12.38 ºN	17.05 ºE	4.9	5.6	6.5	6.4	6.6	5.7	4.7	3.9	4.3	4.8	5.0	5.0
	Bol-Berim	13.43 ºN	14.73 ºE	6.9	8.4	9.4	9.1	8.1	7.6	6.2	4.8	5.4	7.2	8.1	7.1
	Bousso	10.48 ºN	16.71 ºE	4.9	5.6	5.8	6.6	6.1	5.0	4.0	3.6	4.0	4.5	5.1	4.9
	Faya	18.00 ºN	19.16 ºE	7.1	8.1	9.5	9.8	9.8	9.5	8.4	8.0	9.2	8.7	7.5	6.6
	Mongo	12.18 ºN	18.68 ºE	6.1	6.9	7.3	6.8	6.5	5.7	4.5	3.7	4.2	5.0	5.5	5.7
	Moundou	8.61 ºN	16.06 ºE	5.6	6.7	6.7	6.0	5.2	4.2	3.8	3.6	3.8	4.0	4.7	4.8
	Ndjamena	12.13 ºN	15.03 ºE	5.9	7.3	8.1	7.5	7.6	6.6	5.0	4.1	4.7	5.6	6.0	5.5
	Pala	9.36 ºN	14.91 ºE	6.3	7.6	7.9	7.2	6.3	4.9	4.0	3.6	4.0	4.6	5.4	5.8
	Sarh	9.15 ºN	18.38 ºE	5.2	6.1	6.2	5.9	5.3	4.4	3.7	3.6	3.9	4.2	4.6	4.7
Cameron	Garoua	9.33 ºN	13.38 ºE	4.7	5.9	7.3	7.2	6.5	4.9	4.1	3.8	4.1	4.8	5.1	4.6
	Maroua-Salak	10.45 ºN	14.25 ºE	7.0	8.6	9.2	8.7	7.5	6.1	4.7	4.0	4.4	5.6	6.9	6.8
	Ngaoundere	7.35 ºN	13.56 ºE	4.4	5.0	4.9	4.1	3.7	3.2	2.9	3.0	3.1	3.5	4.2	4.4
Central Africa	Birao	10.28 ºN	22.78 ºE	3.9	4.4	4.9	4.8	4.8	4.3	3.8	3.6	3.8	4.1	4.2	3.9
	Bossangoa	6.48 ºN	17.43 ºE	4.0	4.1	5.0	4.7	4.4	3.9	3.7	3.6	3.8	3.9	4.1	3.7
	N_Dele	8.40 ºN	20.65 ºE	4.0	4.5	4.9	4.8	4.4	3.9	3.5	3.5	3.6	3.8	4.3	4.0
Libya	Kufra	24.21 ºN	23.30 ºE	2.7	3.4	4.6	5.9	7.0	7.8	7.8	7.5	6.3	4.9	3.5	2.8
	Sebha	27.01 ºN	14.43 ºE	2.8	4.1	5.9	7.6	8.8	10.1	9.4	8.6	7.6	6.1	4.4	2.8
	Tazerbo	25.80 ºN	21.13 ºE	2.5	4.1	4.9	6.0	7.0	7.7	7.4	7.0	5.8	4.5	3.1	2.6
Niger	Bilma	18.68 ºN	12.91 ºE	5.7	6.9	8.8	9.4	9.4	9.4	8.7	8.0	8.3	8.1	6.3	5.7
	N_Guigmi	14.25 ºN	13.11 ºE	5.9	6.8	7.6	7.9	7.6	7.3	6.6	5.6	6.0	7.0	6.6	6.0
Nigeria	Maiduguri	11.85 ºN	13.08 ºE	6.0	7.5	8.3	8.5	7.9	6.5	5.1	4.2	4.9	6.3	6.7	6.2
Sudan	Dereisa	12.68 ºN	22.76 ºE	5.4	5.9	7.1	6.9	6.4	5.9	4.6	3.8	4.5	5.6	5.6	5.4
	Geneina	19.16 ºN	30.48 ºE	7.1	8.4	8.7	8.0	8.0	6.8	5.1	4.2	4.9	6.9	7.5	7.0
	Mukgur	14.00 ºN	32.33 ºE	6.2	6.7	6.8	7.2	6.7	5.4	4.0	3.5	3.9	5.6	6.0	5.8
	Dongola	12.7 ºN	28.43 ºE	5.9	7.0	8.7	10.3	11.5	12.1	10.3	10.7	11.3	10.1	7.5	5.8
	En-Nahud	13.48 ºN	22.45 ºE	6.6	7.0	8.3	8.4	7.5	6.5	5.3	4.6	5.0	6.3	7.3	7.1
	Ed-Dueim	11.95 ºN	23.28 ºE	6.7	8.0	9.3	10.3	9.8	8.9	7.3	6.2	6.9	7.1	7.8	6.8
	Shambat	15.66 ºN	32.53 ºE	6.2	7.1	8.3	8.7	9.6	9.3	8.7	7.6	7.1	7.1	7.1	6.3
	Shendi	16.7 ºN	33.43 ºE	5.0	5.9	7.7	7.9	8.2	9.6	8.6	7.0	7.2	7.0	6.0	5.6



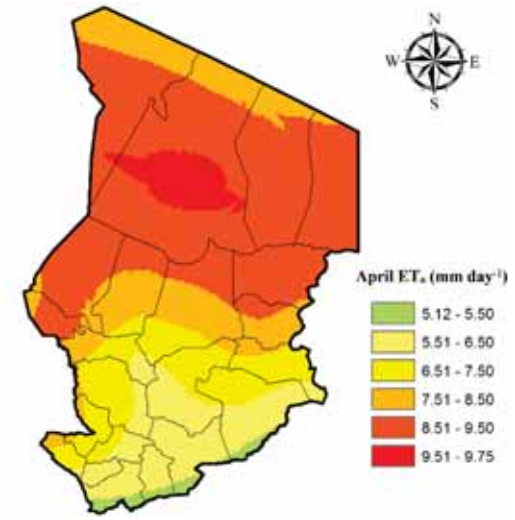
January



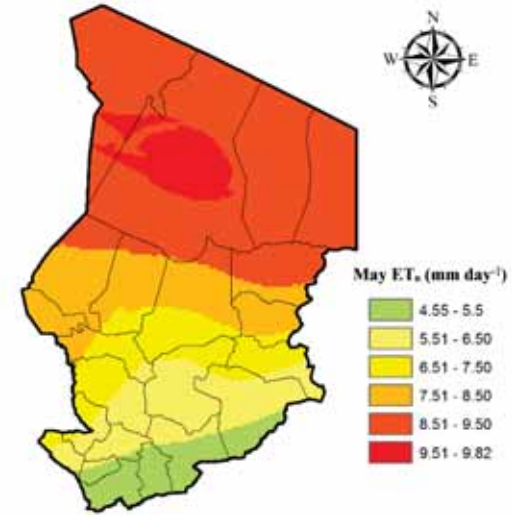
(b) February



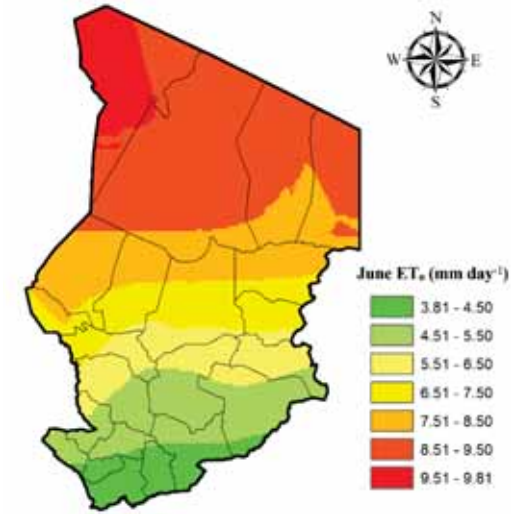
March



(d) April

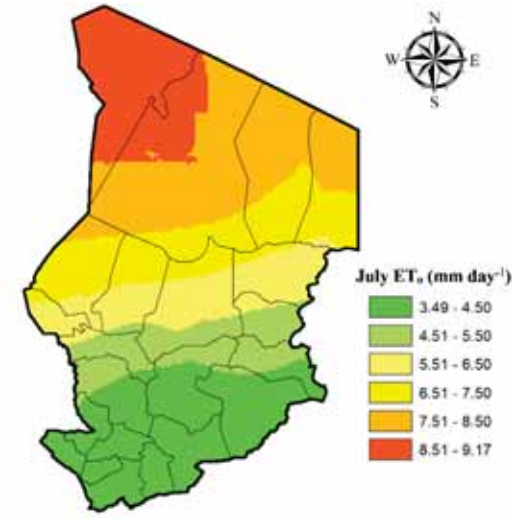


(e) May

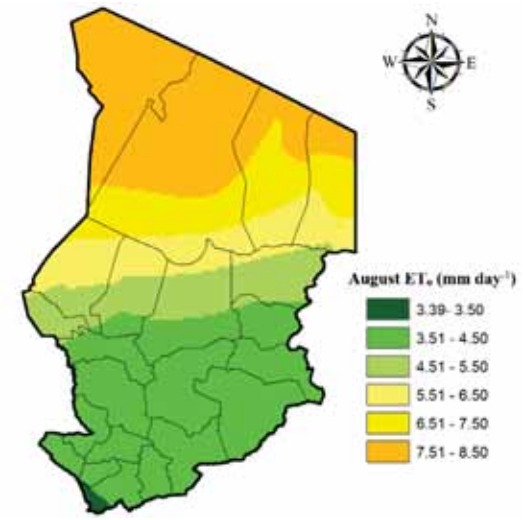


(f) June

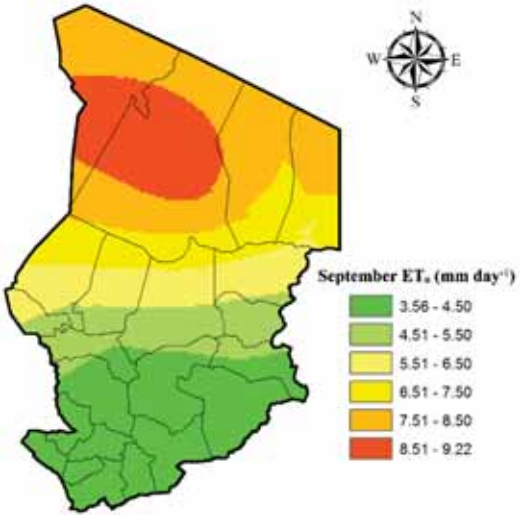
FIGURE 2
Spatial and Temporal Maps in Reference Evapotranspiration in Chad



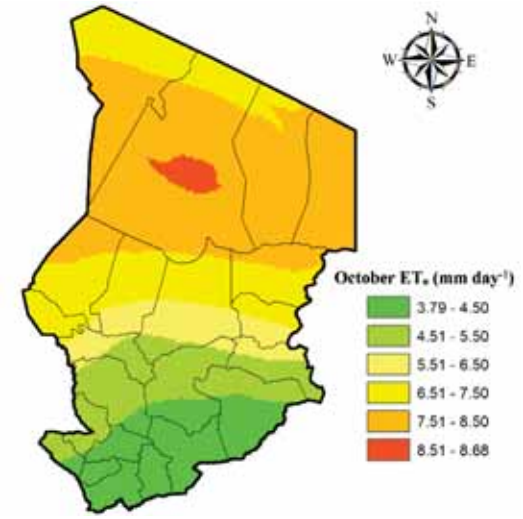
(g) July



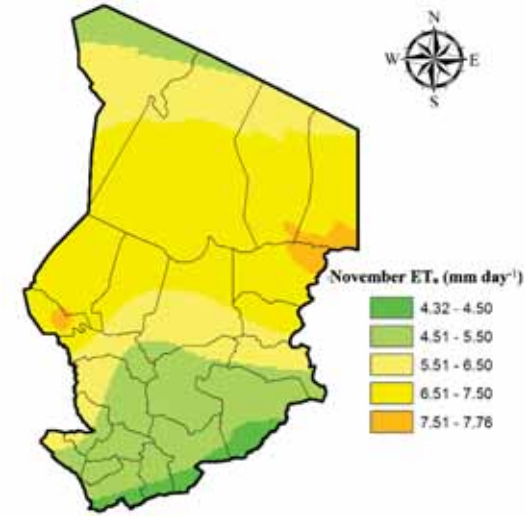
(h) August



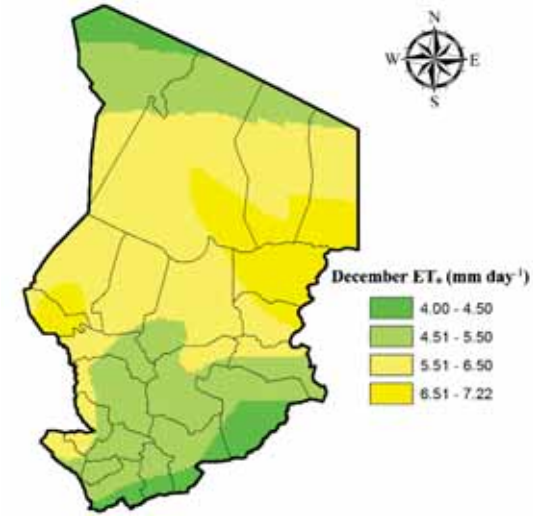
September



October



November



December

FIGURE 2
Spatial and Temporal Maps in Reference Evapotranspiration in Chad (Continued)

RESULTS

The ET_o values calculated using the climate data obtained from 32 different meteorology stations are given in Table 1, and the temporal and spatial maps calculated from these values are given in Figure 2.

There are very few studies on evapotranspiration in Chad. The first evapotranspiration studies in Chad were carried out by ORSTOM (The French Overseas Office for Scientific Research) in the early 1950s. They used Piche evaporimeter for this purpose. In later years, the Colorado sunken pan and Penman model were used by the same research agency. In these studies, the pan overestimated the open water evaporation in the winter months and gave a better or closer estimate in the summer months [13]. Evapotranspiration studies in Chad were done only in the Chad Lake basin. In these studies, the annual total evapotranspiration values in Chad Lake changed as 2,166-2,239 mm y^{-1} [13]. In this study, the annual total ET_o value in the same region was 2247 mm y^{-1}. Therefore, the results were compatible with previous studies.

Structural factors that affect food security in Sahelian regions even in normal years include degraded land and soil, low agricultural production, poverty and limited access to safe drinking water and sanitation [14]. Hssaine et al. [15] stated that it would never be possible to determine actual ET_o levels across the country in Africa. However, ET and biomass mapping would be of great benefit in African countries, especially in the (semi) arid region.

Karaca et al. [4,16] recommended using climate data from the nearest meteorological station to accurately calculate the ET_o values used as basic data to determine irrigation scheduling and crop water requirements. However, he stated that if there is no meteorological station in the region where the agricultural production will be made, the temporal and spatial ET_o maps will provide ease of use in the calculation of the crop water requirements and thus the available water can be used effectively.

For these reasons, the analysis of the distribution of reference evapotranspiration in Chad was made spatially and temporally. When the regions with different climates in Chad were examined, the evapotranspiration map of Chad can be divided into three distinct regions namely: the southern region characterized by low evapotranspiration, the central region with medium evapotranspiration and the northern region characterized by high evapotranspiration. The highest ET_o values were found in the Sahara (desert) zone and the lowest ET_o values were found in the Sudanese savannah zone. These results showed that ET_o values increased from the Sudanese savannah zone to Sahara (desert) zone. These results corroborate with those of Nilsson et al. [17], WFP [18] and Pattnayak et al. [19] on the agro-ecological classification of Chad. They reported that the agro-ecological map of Chad can be subdivided into three main agro-climatic zones: the Sudanese zone in the south, the Sahelian agro-ecological zone in the center and the Saharan agro-ecological zone in the north.

When the ET_o values of Chad in Table 2 and Figure 2 are analyzed, the lowest ET_o values occurred in August, which is in the middle of the rainy season, while the highest ET_o values occurred in March and April, in the middle of the dry season.

The lowest levels of evapotranspiration were observed in the Sudanese agro-ecological zone. In the Sudanese savannah zone, the lowest ET_o value was determined in Sarh city in August (3.6 mm d^{-1}), while the highest ET_o was determined in March in Pala city (6.3 mm d^{-1}). Annual precipitation of around 1000 mm and an average temperature of 27 ^oC [19] characterize this region. In view of the monthly distribution of evapotranspiration in the Sudanian agro-ecological zone, two farming systems can be practiced during the year as rain-fed agriculture between June and October and irrigated agriculture between October and June.

The Sahelian region is one of the most vulnerable areas to climate variability and change due to the scarcity of water resources, associated with high evaporative demand and low and irregular rainfall [15]. According to WFP [18], the Sahelian agro-ecological zone corresponds to all of the Sahelian climatological zones with rainfall of the order of 400-600 mm and Sahelo-Saharan (transition zone between Sahelian and Sahara zone) with rainfall of 100-400 mm. Ludwig et al. [20] evaluated the relationship between precipitation and evaporation in this region. He reported that until the middle of the 21st century, evaporation would increase as precipitation increased, but only in 2050 and afterward only evaporation would continue to increase, however, the increase becomes smaller. In this agro-ecological zone, characterized by average evapotranspiration and low annual precipitation, it is mainly possible to practice irrigated agriculture between May and December. Although rain-fed agriculture can be made in the south of this region, cultivation can be diversified by investing in an appropriate irrigation system. For this purpose, the selection of crops with low water requirements and tolerant to high temperatures should be considered.

The Saharan agro-ecological zone, which presents high evapotranspiration and a scorching temperature throughout the year, does not offer the possibility of practicing a precise agricultural system without great human intervention (lowering temperatures, irrigating, etc.). However, with regard to evapotranspiration and average precipitation, the exception can be made in its north-western part where it is possible to practice irrigated agriculture between October and March.

CONCLUSION

The results showed that ET_o values increased from the Sudanese Savannah zone to the Sahara (desert) zone. Moreover, the lowest ET_o in all regions occurred in August, which was in the middle of the rainy season, and the highest ET_o occurred in March and April in the dry season. The results obtained are very important for Chad since there is no study on evapotranspiration other than Chad lake basin. Today, although agricultural production is made based on rain, it is expected that agricultural production will be diversified with future irrigation systems. For this reason, it is thought that temporal and spatial maps prepared for Chad will be beneficial for the regional farmers.

REFERENCES

[1] UN (2019) World Population Prospects 2019: Highlights. World Population Prospect. Department of Economic and Social Affairs. 2.

[2] UNICEF (2020) Humanitarian Action for Children 2020, Overview. UNICEF, 1-16.

[3] WFP (2019) Logistics Capacity Assessment-Chad, 193.

[4] Karaca, C., Buyuktas, D., Ruhi, B., Aydinsaki, K. and Buyuktas, K. (2018) Comparing Seven Different Reference Evapotranspiration Equations with Penman-Monteith for Antalya. Fresen. Environ. Bull. 27, 9500–8.

[5] Hiemstra, P. and Sluiter, R. (2011) Interpolation of Makkink Evaporation in the Netherlands. Royal Netherlands Meteorological Institute Ministry of Infrastructure and the environment. De Bilt. Technical Report. TR-327, 1-78.

[6] Olya, H.G.T. and Alipour, H. (2015) Developing a Climate-Based Recreation Management System for a Mediterranean Island. Fresen. Environ. Bull. 24, 4125–41.

[7] Li, X., Cheng, G. and Lu, L. (2005) Spatial Analysis of Air Temperature in the Qinghai-Tibet Plateau. Arctic, Antarctic, and Alpine Research. 37, 246–52.

[8] Mahdian, M.H., Bandarabady, S.R., Sokouti, R. and Banis, Y.N. (2009) Appraisal of the Geostatistical Methods to Estimate Monthly and Annual Temperature. Journal of Applied Sciences. 9, 128–34.

[9] Wu, T. and Li, Y. (2013) Spatial Interpolation of Temperature in the United States Using Residual Kriging. Applied Geography. 44, 112–20.

[10] Grieser, J. (2006) Climwat 2.0. Water Resources Development and Management. Serv. FAO. Rome, Italy. Available online: http://www.fao.org/ land-water/databases-and-software/ climwat- for-cropwat/en/ (assessed on 21 July 2020)

[11] Smith, M. (1992) CROPWAT: A Computer Program for Irrigation Planning and Management. FAO Irrigation and Drainage Paper Rome. 46, 126. ISBN:92-5-103106-1

[12] ESRI. (2016) How Kriging works. ArcGIS Desktop Available online: https://desktop.arcgis. com/ en/arcmap/10.3/tools/3d-analyst-toolbox/how-kriging-works.htm#:~:text=Kriging%20is%20a%20multistep%20process,directional%20bias%20in%20the%20data (assessed on 21 July 2020).

[13] Shahin, M. (2002) Hydrology and Water Resources of Africa. Kluwer Academic Publishers. 587.

[14] FSIN. (2019) Global Report on Food Crises. 194.

[15] Hssaine, B.A., Ezzahar, J., Jarlan, L., Merlin, O., Khabba, S., Brut, A., Er-Raki, S., Elfarkh, J., Capelaere, B., Chehbouni, G. (2018) Combining a Two Source Energy Balance Model Driven by MODIS and MSG-SEVIRI Products with an Aggregation Approach to Estimate Turbulent Fluxes over Sparse and Heterogeneous Vegetation In Sahel Region (Niger). Remote Sensing. 10, 1–29.

[16] Karaca, C., Büyüktaş, D., Baştuğ, R., Aydinşakir, K. and Tekelioğlu, B. (2017) Spatial and temporal distribution of reference crop evapotranspiration in Antalya conditions. Derim. 2017, 158–71. (in Turkish).

[17] Nilsson, E., Uvo, C.B., Becker, P. and Persson, M. (2020) Drivers of Regional Crop Variability in Chad. Journal of Arid Environments. 175, 1–13.

[18] WFP. (2012) National post-harvest survey on food security of Chad rural households. United Nation World Food Program (WFP) headquarters, Rome. pp. 71. (in French)

[19] Pattnayak, K.C., Abdel-Lathif, A.Y., Rathakrishnan, K. V., Singh, M., Dash, R. and Maharana, P. (2019) Changing Climate over Chad: Is the Rainfall over the Major Cities Recovering? Earth and Space Science. 6, 1149–60.

[20] Ludwig, F., Franssen, W., Jans, W., Kruijt, B. and Supit, I. (2013) Climate Change Impacts on the Congo Basin Region. In: Haensler A, Jacob D, Kabat P, and Ludwig F, editors. Climate Change Scenarios for the Congo Basin, Climate Service Centre, Hamburg, 1-53.

Received: **25.07.2020**
Accepted: **06.10.2020**

CORRESPONDING AUTHOR

Hisseine Mahamat Allamine
Department of Agricultural Structures and Irrigation
Faculty of Agriculture
Akdeniz University
Antalya 07058 – Turkey

e-mail: hisseineallamine@yahoo.com