International Conference on Geospatial Technologies
LibyaGeotec3
Tripoli - Libya - Dhat Alemad Complex 19-21 Dec 2017

Statistical and Geographical Analysis of Evapotranspiration in Libya

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KEY WORDS
Evapotranspiration, Mann_Kendall, Trend, Penman-Monteith, Climate

ABSTRACT
Evapotranspiration is an important climatic parameter controlling surface energy exchange, energy transport and transformation in the global atmospheric system, with increases in global warming leading to get higher surface temperatures, which may generate more evaporation. The main objective of this paper is to identify the temporal and spatial changes in potential evapotranspiration and to analyze the characteristics and trends of evapotranspiration across Libya, based on long monthly climatic parameters observed from 16 stations for 50 years (1961-2010). The trends of evapotranspiration are estimated by the Mann-Kendall test. In additional the relationship between potential evapotranspiration (PET) and climate variables that used to estimate the (PET) was determined using person correlation coefficient. The mean annual potential evapotranspiration of stations across Libya during the period 1961-2010 ranges between1703.5- 2052.5 mm/year at coastal stations and 2501.1 mm/year for the inland station, with the highest estimated PET of 3026.3 mm/year at Sabha. The mean monthly PET during the period 1961-2010 ranges from 71.4 mm/month (January) to 212.1 mm/month (July) at the coastal stations and between 96.2 mm/month (January) to 318.8 mm/month (July) at inland stations; where July represents approximately 12.4% of the annual PET at both coastal and inland regions. Time trend of Evapotranspiration were analyzed and the results from geographical analysis are also presented.

1. Introduction

Evapotranspiration is the second largest flux in the water cycle thus any changes, would affect the whole water cycle. Feng et al. (2016) indicated that, potential evapotranspiration (PET) as well as temperature, solar radiation, wind speed and direction and precipitation are the most important climatic factors affecting agricultural production. Evapotranspiration is the most difficult and complicated component of the water cycle (Xu and Singh, 2005) and also a very important indicator for climate change (Peterson et al., 1995; Brutsaert and Parlange, 1998). In the surface water balance, approximately 60-80% of the precipitation on the terrestrial surface returns back into the atmosphere, where it becomes the source of future precipitation (Tateishi and Ahn, 1996). Evapotranspiration is an important climatic parameter controlling surface energy exchange, energy transport and transformation in the global atmospheric system, with increases in global warming leading to get higher surface temperatures, which may generate more evaporation. The fluctuations in temperature and precipitation trends resulting from changes of climate are expected to have a strong effect on the spatial and temporal distribution of water resources (IPCC, 2007) and thus impact on patterns of evaporation.

2. Data and Methodology

The climate of Libya is characterized by wet winters and hot dry summers. The area is characterized by dry and hot winds blowing from the Sahara Desert, which are dominate in the spring and summer months, with the mean annual average temperature across Libya ranging between 14.2 °C to 23.4 °C (Ageena et al. 2014). Therefore, the climate of Libya shows notable variability, with mean annual maximum temperature ranges between 24.7 °C and 29.7 °C and means annual precipitation ranges between 279.3 mm to 22.8 mm for coastal and inland regions respectively, (Ageena 2014). The initial division of Libya into two geographical regions (coastal and inland: Figure1) will permit further analysis into the potential mechanisms responsible for changes in potential evapotranspiration (PET). The coastal region includes nine stations; Zwarah, Tripoli Airport, Nalut, Musratah, Sirt, Ajdabyia, Binina, Shahat and Darnah, where the inland region includes seven stations: Ghadames, Hon, Jalo, Al-Jaghbub, Sabha, Tazerbou and Al-Kufrah Climatic data for 16 synoptic stations during the period (1961-2010) across Libya were collected from the Libyan National Meteorological Centre (LNMC).

In this paper, spatial and temporal characteristics of PET are analyzed across Libya based on the Penman-Monteith (PET_{P-M}) methods which is recommended by the Food and Agricultural Organisation of the United Nations (FAO). The Penman-Monteith method (Jensen et al., 1990) requires data for the following variables for calculation: sunshine duration (hours), humidity (percentage) and wind speed (km), minimum and maximum temperature (°C); unfortunately, several of these are not recorded before 1961 at majority of meteorological stations across Libya. Therefore, the geographic density of stations allowing for PET calculation is restricted to the limited number of 16 synoptic stations distributed across Libya during the period of study (1961-2010).

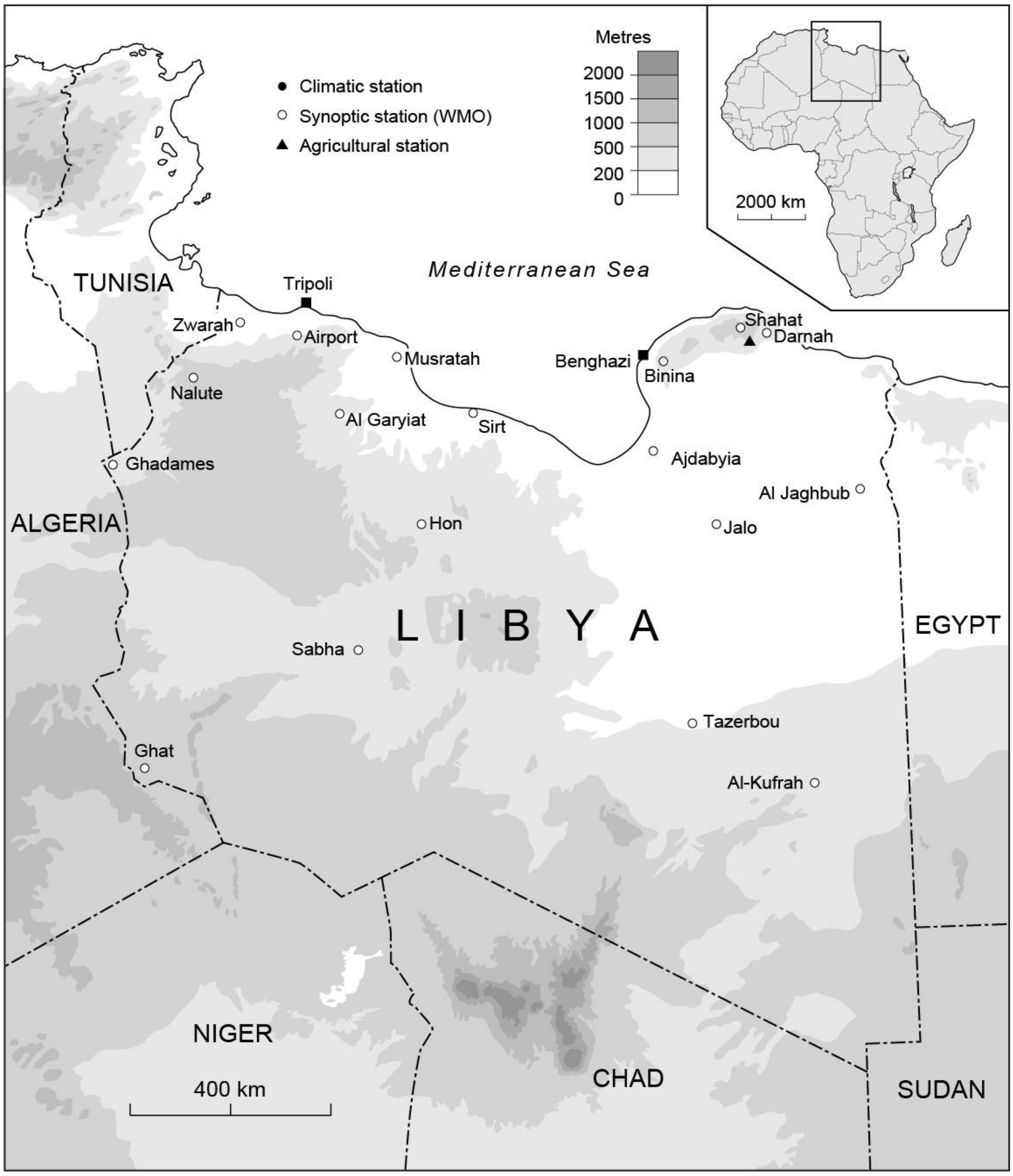

Figure 1: *The distribution of synoptic stations within this study.*

The Mann-Kendall test (MK; (Mann, 1945; Kendall, 1975), was applied to detect the significance of trends in evapotranspiration data; with the MK test, more suitable where monotonic trends are found in data series of 1945-2010; (e.g. Zhou and Ren 2011; Ageena 2013; Feng et al. 2016). The study focuses on climatic data: temperature, wind speed, relative humidity and sunshine duration. Inverse Distance Weighted (IDW) tool in ArcMap was used as Interpolation tool to predict the Evapotranspiration trend values of cells at locations that lack sampled points. It involves using known z values and weights determined as a function of distances between the unknown and known points. As such in IDW points that are far away have far less influence than points that are close (Childs, 2004).

2.1. Potential Evapotranspiration (PET)

Potential evapotranspiration (PET) is defined as the maximum amount of water removed from surface through the processes of evaporation and transpiration, when water availability is not limited. There are about 50 methods or models available for the estimation of PET, but these methods and models can give conflicting values and give different trends.

Thomas (2000), identified that negative trends can occur over large areas and are more pronounced than positive trends over China (1954-1993). According to the IPCC (2007), decreasing trends during recent decades are found in pan-evaporation over the USA (Peterson et al., 1995; Golubev et al., 2001; Hobbins et al., 2004), India (Chattopadhyay and Hulme, 1997), Australia (Roderick and Farquhar, 2004) and China (Liu et al., 2004a; Qian et al., 2006) and over smaller regions e.g. the significant increasing trends in PET identified by Abtew et al. (2011) over South Florida during the period 1948-2009.

1. Results and discussion

3.1. Observation, changes and trends of potential evapotranspiration (PET_{P-M})

The mean annual and seasonal of potential evapotranspiration based on the Penman-Monteith equation (using the CropWat 8.0 software program based on Allen et al. 1998; Raja 2010) was estimated for 16 stations for the period 1961-2010 (Figure 2). The mean annual potential evapotranspiration (PET) at the meteorological stations across Libya during the period 1961-2010 ranges between 1509.4 (Darnah) and 2054.1 (Nalut) mm a^{-1} at coastal stations. And from 2128.2 (Al-Jaghbub) to 3026.3 mm a^{-1} (Sabha) for the inland station, with the mean average of PET_{P-M} estimated by 1703.5 mm a^{-1} and 2501.3 mm a^{-1} at the coastal and inland stations, respectively (Table 1).

Table 1 shows that, the highest seasonal of PET_{P-M} in summer, with an average rate ranges between 33% and 39% of annual total evapotranspiration with the lowest in winter (13%). The mean seasonal PET_{P-M} of spring (28%) and autumn (23%) are almost similar.

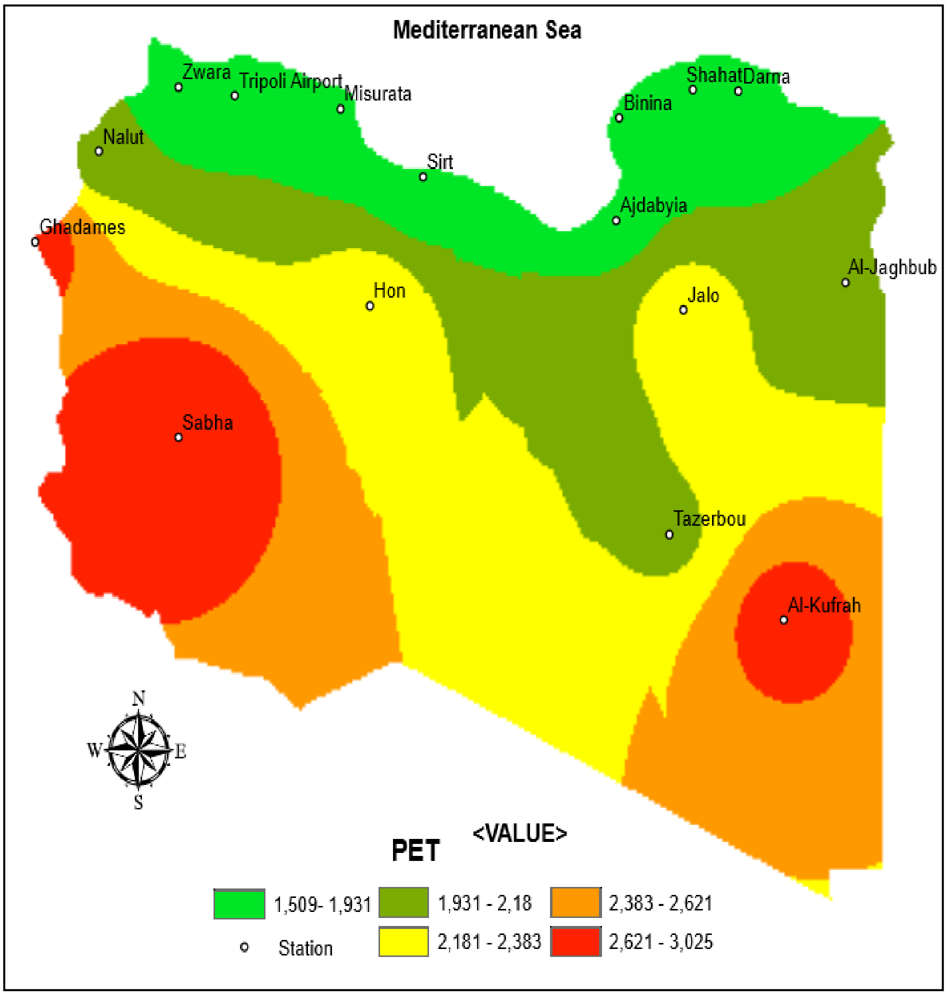

Figure 2: *The mean annual Evapotranspiration (1961-2010)*

Table 1: *Absolute values of annual and seasonal PETP-M (mm a^{-1}) for the 16 stations and Trend rate, with significant (95% confidence level) for the period (1961-2010)*

Time series	Trend rate	Annual	Autumn	Winter	Spring	Summer
Zwarah	2.867 *	1512.4	373.8	245.4	380.5	512.7
T. Airport	-0.448	1851.3	416.7	219.3	493.0	722.2
Nalut	-5.555 *	2054.1	462.3	264.1	547.2	781.2
Musratah	2.899 *	1585.6	381.1	240.6	412.2	551.7
Sirt	-0.131	1599.5	389.9	251.7	424.8	533.2
Ajdabyia	3.655 *	1813.1	412.2	217.3	520.3	663.3
Binina	1.511	1865.3	443.4	217.2	517.3	687.3
Shahat	-2.960 *	1541.0	343.8	181.1	407.6	608.5
Darnah	-0.223	1509.4	365.2	245.9	399.3	519.0
Ghadames	-6.834 *	2757.0	619.8	304.1	763.2	1069.9
Hon	3.400	2375.3	529.4	301.6	684.4	860.0
Jalo	-1.636	2332.4	513.0	306.0	665.6	847.8
AL-Jaghbub	-8.759 *	2128.2	453.4	257.7	612.4	804.7
Sabha	3.640	3026.3	697.2	363.6	868.5	1096.9
Tazerbou	-11.173 *	2133.1	479.4	285.8	636.0	731.9
Al-Kufrah	1.598	2756.5	641.1	363.3	779.6	972.5

Linear regression of PETP-M (1961-2010) was performed on monthly and annual estimates. For coastal and inland regions, a spatially averaged time series was analyzed from all stations (Figure 3). Increases trends (Table 1) are identified at four coastal stations as average (2.733 mm a^{-1}), with significant (95% confidence level) trends at Zwarah, Musratah, Binina and Ajdabyia. The mean linear trends for the inland region illustrate decreases (-7.101 mm a^{-1}) in annual PETP-M at four stations, with highest value (-11.173 mm a^{-1}) at Tazerbou, with significant (95% confidence level) decreases at Al-Jaghbub, Ghadmes, Jalo and Tazerbou. Increasing trends are identified at three inland stations (2.879 mm a^{-1}), with no positive significant trend at any inland stations. Several studies have shown that the development of irrigation in arid zone oasis agriculture has resulted in a reduction in wind speed and an increase in relative humidity. As a consequence of these changes, reference crop evapotranspiration in this region has decreased (Han et al, 2010).

With the purpose to define the behaviour of both parameters of relative humidity and wind speed in the stations that gave negative trends for PET; The Mann-Kendall test was applied to detect the significance of trends in those weather parameters that contribute to changes in PET rates. The results showed a significant negative trend for wind speed and a significant positive trend for relative humidity which was in agreement with the decreasing trend in PET at the stations of Nalut, Shahat, Ghadames, AL-Jaghbub and Tazerbou (Table 2).

Table 2: *Absolute annual values of (WS, RH, and SSD) and Trend rate for the period (1961-2010)*

	Wind speed (m/s)			Relative humidity (%)			Sun-shine duration (h/d)		
Stations	Mean annual	Sig	Q	Mean annual	Sig	Q	Mean annual	Sig	Q
Zwarah	4.5	+	-0.007	73.0		0.035	8.11	***	0.019
T. Airport	3.8		0.001	61.5	***	0.208	8.82		-0.002
Nalute	4.5	**	-0.029	49.8	**	0.114	9.05	***	0.018
Musratah	4.4	*	0.023	70.0	*	0.050	8.58	**	0.012
Sirt	4.4	**	-0.023	70.3		0.021	8.77		-0.003
Ajdabyia	3.2		0.004	60.2	**	-0.081	9.18	+	0.004
Binina	5.2	**	0.013	64.6		0.042	8.87	*	0.009
Shahat	4.5	***	-0.047	68.7		0.017	8.03		0.006
Darnah	6.2	***	-0.024	71.6	*	-0.092	7.98	***	0.039
Ghadames	4.4	***	-0.022	34.7	***	0.266	9.50		0.002
Hon	4.1		0.005	46.6		0.030	9.43	***	0.016
Jalo	3.6		-0.005	44.5	*	-0.116	9.64		0.005
Al-Jaghbub	3.1	***	-0.026	49.1	***	0.177	9.74	**	0.015
Sabha	4.8		0.012	33.3		-0.060	9.90	+	0.008
Tazerbou	2.3	***	-0.028	36.7		-0.046	10.29		0.003
Al-Kufrah	4.3		0.007	28.5		0.021	10.62	***	0.014

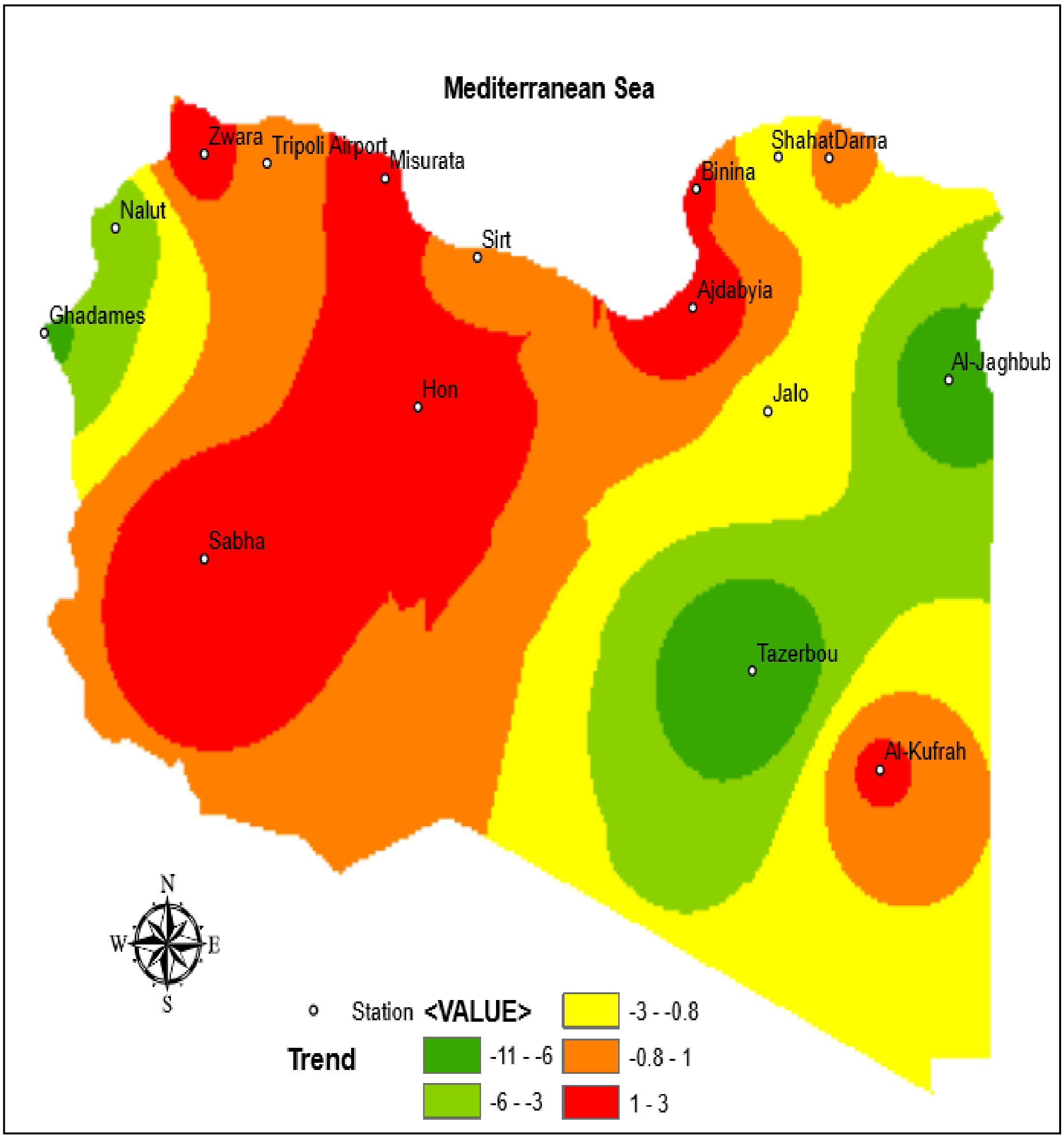

Figure 3: *The trend values of annual Evapotranspiration (1961-2010)*

3.2. Changes and trends of monthly potential evapotranspiration

The mean monthly PETP-M during the period 1961-2010 ranges between 71.4 mm M^{-1} (January) to 212.1 mm M^{-1} (July) at the coastal stations and between 96.2 mm M^{-1} (January) to 3118.8 mm M^{-1} (July) at inland stations; where July represents approximately 12.4% of the annual PETP-M at both coastal and inland regions (Table 3). Negative trends in PETP-M (0.150 mm M^{-1}) are found November-June, with the exception for April at coastal stations (Figure 4), with the highest value (-0.263 mm M^{-1}) in February. Significant decreases (95% confidence level) are found in February, June and December. Positive trends (0.120 mm M^{-1}) are identified during the warm months July-October and in April, with the highest value (0.233 mm M^{-1}) in October (not significant). Positive trends in monthly PETP-M prevail at inland stations during the period April- November (0.257 mm M^{-1}; Figure5), with the highest rates (0.543 mm M^{-1}) in September (*). Negative trends (-0.163 mm M^{-1}) are found in the coldest months (December-March), with significant (95% confidence level) decreases in (February and December) and at inland stations in February, September and December.

Table 3: *Values of the trend rate for mean monthly PETP-M, with statistically significant levels (mm/month) in coastal and inland regions for the period 1961-2010*

	Coastal region			Inland region		
	Mean monthly (mm)	Trend rate (mm/M)	Sig.	Mean monthly (mm)	Trend rate (mm/M)	Sig.
January	71.4	-0.123		96.8	-0.118	
February	83.6	-0.263	*	118.7	-0.248	*
March	117.5	-0.116		183.6	-0.121	
April	150.4	0.024		239.2	0.114	
May	187.9	-0.061		292.8	0.201	
June	206.7	0.193	*	308.0	0.108	
July	212.1	0. 29		311.8	0.249	
August	202.4	0.054		292.2	0.438	
September	168.1	0.170		246.4	0.534	*
October	134.7	0.233		190.8	0.286	
November	95.9	-0.069		124.7	0.129	
December	76.4	-0.180	*	96.2	-0.162	*

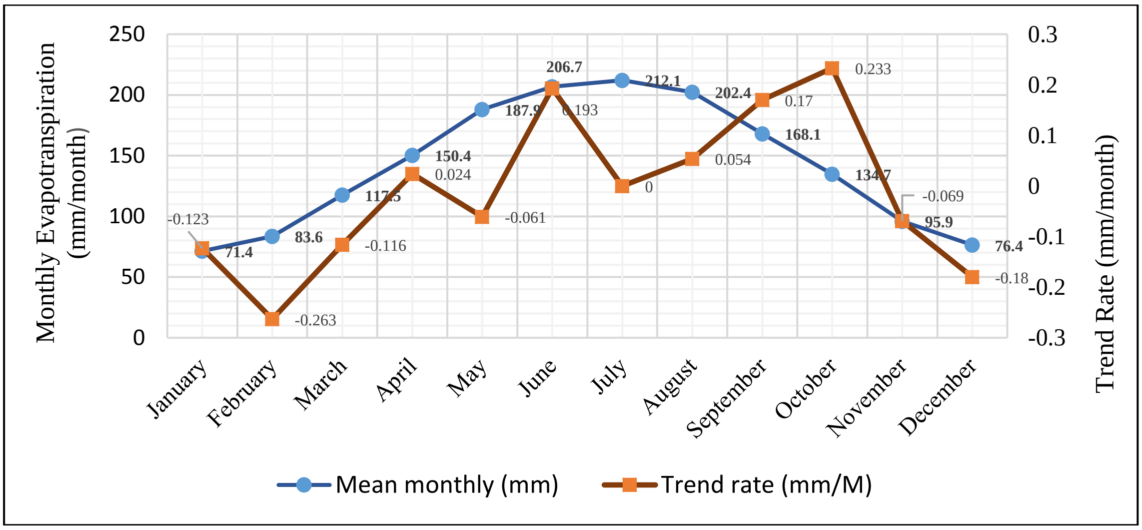

Figure 4: *Mean monthly PETP-M, with values of trend rate values at coastal region across Libya (1961-2010)*

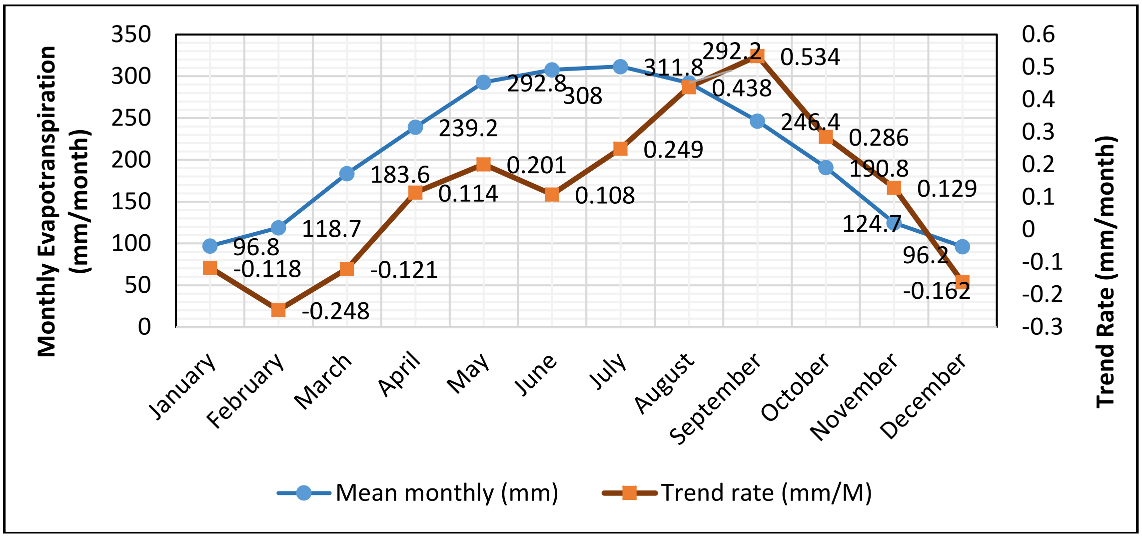

Figure 5: *Mean monthly PETP-M, with values of trend rate values at inland region across Libya (1961-2010)*

Relationships between PETP-M and climate variables

The meteorological factors which determine evapotranspiration (ET) are weather parameters which provide energy for vaporization and removal of water vapor from the surface. The principal weather parameters that contribute to changes in PET rates are: temperature, wind speed, relative humidity, sunshine duration and precipitation which are assessed for the 16 synoptic stations (1961-2010). A change in ET is mainly dependent on moisture supply, energy availability and wind speed and direction (IPCC, 2007).

3.4. Annual correlations

To analyze the meteorological parameters that contributed most to the observed reduction of PETP-M rates across Libya, correlations between seasonal and annual PETP-M and mean meteorological variables used to estimate PETP-M were calculated for the last 50-years 1961-2010. The annual PETP-M is strongly positively correlated with the annual mean wind speed (WS) at inland stations, (r = 0.72; Table 4). The mean annual relative humidity (RH) is negatively correlated with the annual PETP-M in the inland region (Table 4). The mean annual maximum temperature (T. Max) is strongly correlated (positively) with annual PETP-M (r=0.58) in the coastal region; while strongly negatively correlated with annual mean relative humidity (RH) at coastal stations (r = 0.56; Table 3). The results show little relationship between PETP-M and sun-shine duration (SSD). The results indicate that RH and T. Max are the most important factors influencing annual PETP-M at coastal stations and WS at inland regions. The increasing trend in PETP-M was likely caused by an increase in T. Max and a decrease in the RH for the coastal region (Northern-Libya). Analysis of the impacts of meteorological variables indicates that the increase in PETP-M most likely results from an increase in WS for inland region (southern-Libya).

Table 4: *Correlation coefficient (r) between PETP-M and meteorological parameters*

Stations	WS	RH	SSD	PPT	T.min	T. max
	Coastal regions					
Annual	-0.01	-0.56	0.14	-0.08	0.11	0.58
Autumn	0.07	-0.70	0.03	-0.51	0.50	0.78
Winter	-0.25	-0.65	0.05	-0.06	0.06	0.51
Spring	-0.18	-0.68	0.22	-0.31	-0.12	0.76
Summer	-0.07	-0.66	0.01	-0.10	-0.04	0.70
	Inland regions					
Annual	0.72	-0.33	0.29	-0.17	-0.17	0.04
Autumn	0.51	0.23	0.17	-0.25	0.07	0.32
Winter	0.24	-0.13	0.04	-0.35	-0.35	0.52
Spring	0.25	-0.27	0.21	-0.03	-0.13	0.46
Summer	0.59	0.04	-0.05	-0.09	-0.06	0.18

3.5. Seasonal correlations

Correlations between seasonal PETP-M and meteorological variables used to estimate PETP-M were analyzed for the last 50-years (1961-2010). In the coastal region, seasonal PETP-M is strongly negatively correlated with the all mean seasonal RH, particularly, in autumn (-0.70; Fig. 11c) and strongly positive correlated with T.max, particularly, in spring (0.76) and summer (0.70; Table 4). Strongly correlations are noted in autumn precipitation (PPT) (negative) and T. min (positive) relative to the other months (Table 4). At the inland region; while strongly positively correlated with WS, *r* of 0.59 (summer) and 0.51 (autumn). In general, PETP-M is less responsiveness to SSD and SW in the coastal region relative to the inland region (Table 3). The results of seasonal correlations indicate that the seasonal SW is more effectiveness in inland stations, with the RH is in coastal stations, where the climate variables of SSD, T. min and T. max having the same effect.

Conclusion

Annual PET (1961-2010) calculated from meteorological data for 16 meteorological stations across Libya shows decreasing trends at nine stations (an average rate of - 4.191 mm a^{-1}) with the highest trend (-11.173 mm a^{-1}) at Tazerbou, with significant decreases (95% confidence level) at five coastal and inland stations. Increasing trends in annual PETP-M, are lower (an average increasing rate of 2.796 mm a^{-1}) compared to the decreasing trends found at the remaining seven stations, with significant increases (95% confidence level) identified at only three coastal stations. In general, trends in potential evapotranspiration follow a high/low transect from the north (coastal) to the south (Sahara), reflecting the trends in the weather parameters that affect the rate of evaporation. The period of November-June (with exception for April) presents negative trends (0.150 mm M^{-1}) at most coastal stations; with significant decreases (95% confidence level) identified in February, June and December. Positive trends in monthly PETP-M (0.257 mm M^{-1}) are found during the period between April-November for the inland region, with significant increase in September. Analyses of the relationships between PETP-M and the weather parameters indicate a strong positive correlation with SW, RH and SSD in the inland region and a strong negative correlation with RH at the coastal stations.

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