JJEES

Volume 9, (Number 1), April, 2018
ISSN 1995-6681
Pages 67 - 74

Jordan Journal of Earth and Environmental Sciences

Analyses of Climate Variability in Jordan using Topographic Auxiliary Variables by the Cokriging Technique

Mohammed I. Al-Qinna

Department of Land Management and Environment, Faculty of Natural Resources and Environment, The Hashemite University, Zarqa, Jordan

Received 13 December, 2017; Accepted 18 April, 2018

Abstract

Climatic variability in Jordan is unequivocal resulting from various atmospheric circulations that have complex site-specific characteristics. Trends of change in daily and monthly precipitation, mean air temperature, maximum air temperature, minimum air temperature, relative air humidity, and potential evapotranspiration across the country were investigated by the Mann-Kendall rank and linear regression trend tests using long-term historical meteorological data collected on daily and monthly bases from about 143 stational points. Trend tests indicated significant changes at both national and station levels, where the mean annual precipitation tended to decrease significantly by time at a rate of 1.2 mm per year. Mean air temperature, maximum air temperature, minimum air temperature, relative humidity, and mean annual potential evapotranspiration all tended to increase significantly by 0.02°C/year, 0.01°C/year, 0.03°C/year, 0.08%/year, and 17mm/year, respectively.

The Integrated Geographic Information System (GIS), and a geostatistic approach were used for spatial interpolation of selected climatic variables. Cokriging fine resolution maps were generated from integrating climatic variables with elevations obtained from digital elevation maps. The cross validations indicated the efficient use of auxiliary information to aid the interpolation with a very high coefficient of determination and low root mean square errors. The cokriging with elevation as an auxiliary variable is a very flexible and robust interpolation method that exhibited great improvement for estimating several climatic variables in the country.

Keywords: Cokriging, digital elevation model, climatic variability, Jordan

1. Introduction

Warming of the climate system is unequivocal. Since the 1950s, many of the observed changes are unprecedented over decades to millennia (IPCC, 2007). The increase in concentrations of greenhouse gases (GHGs) was detected to be mainly responsible for the atmosphere and ocean warming, changes in the global water cycle, reductions in snow and ice, global mean sea level rise, and changes in some climate extremes. It is *extremely likely* that human influence has been the dominant cause of the observed warming since the mid-twentieth century (IPCC, 2013).

The globally-averaged land and ocean surface temperature has risen from 0.85 [0.65 to 1.06] °C over the period from 1880 to 2012. Continued emissions of GHGs will cause further warming and changes in all components of the climate system. Climatologists project that the tempreture may rise another 0.3 and 4.8 **°C** over the next century depending on the world's ability to reduce emissions (IPCC, 2014).

Many of the world countries, including the Hashemite Kingdom of Jordan, already struggle under various pressures such as water scarcity, food insecurity, ecological, economical and social development (MoEnv, 2012). These pressures will be significantly exacerbated by the climate change creating several hazards for many regions such as reduced rainfall, increased temperatures, increased frequency and intensity of floods, increased chances of the occurrences of weather extreme events (e.g. flash floods and warm waves), intensified erosion, reductions in snow cover, sea-level rise, and damage to water quality and ecosystems (MoEnv, 2013; UN, 2009). In order to improve climate change resilience, proper understanding of the current and future climate changes are acquired.

Several investigations of the variability of the meteorological parameters in Jordan were conducted over the last decade (Abandeh, 1999; Al-Ansari et al., 1999; Al-Houri, 2014; Al-Qinna et al., 2011; Bani-Domi, 2005, Dahamsheh and Aksoy, 2007; Freiwan and Kadioglu, 2006; Freiwana, and Kadioğlu, 2008; Ghanem, 2010; Ghanem, 2011; Ghanem, 2013; Matouqa, et al., 2013; Ragab and Prudhomme, 2002; Smadi and Zghoul, 2006; Tarawneh and Kadioğlu, 2002)

Most of the literature indicated the existence of huge spatial and temporal variability especially in precipitation with unclear and/or insignificant trends of increase or decrease at station levels (MoEnv, 1999; MoEnv, 2006; MoEnv, 2009; MoEnv, 2012; MoEnv, 2013; MoEnv, 2014a; MoEnv, 2014b). However, researchers were able to conclude that the reliability of data in terms of availability, accuracy, and precision play an important role in the final results. The spatial and temporal meteorological trends vary by data source, measurement techniques, and accuracy assessment, especially when dealing with missing values. Limited data and the lack of models and tools specifically designed for local conditions result in high uncertainty regarding the impact of climate change on Jordan (MoEnv, 2013).

* Corresponding author. e-mail: qinna@hu.edu.jo

Up to now, there is a lack of understanding of the consequences of climate change at the local level due to imprecise status analyses of the historic and current climatic variability As a consequence, decision-makers are unable to link the regional and national conditions with the global conditions, which hampers their ability to take the most appropriate planning decisions regarding vulnerability and adaptation. One of the best methods used to reduce the prediction errors is the cokriging technique with well-defined auxiliary variables such as elevation (Goovaerts, 2000; Diodato, 2005). The multivariate geostatistical incorporating of the digital elevation model into the spatial prediction of climatic variables such as precipitation yields more accurate predictions (Wang et al., 2011; Adhikary et al., 20017). The objective of this paper is to investigate the climatic variability through the trend analyses of many long reliable historical climatic data across the country, and to generate detailed climatic spatial interpolation maps through integrating the geographic information system and the geostatistic approach of cokriging with elevation as an auxiliary variable.

2. Methodology

2.1. Study Area

Jordan is located about 80 km to the East of the Mediterranean Sea between 29º 11´ to 23º 22´ North, and 34º 19´ to 39º 18´ East. Its predominant Mediterranean climate is characterized hot dry summers and wet cool winters.

Jordan is divided into three main climatic regions (FAO, 2012); the Ghor Region (lowlands), the Highlands, and the Badia or Desert region (Figure 1). The Lowlands region is part of the Great Rift Valley with elevation ranging from 197 m below MSL in the north to 417 at the Dead Sea. The lowlands consist of three parts; the Jordan River, the Dead Sea, and Wadi Araba. The Highlands and the Marginal Steeps Region extend north-south to the east of the Ghor, i.e. from the Yarmouk River in the north to Ras El-Naqab in the south. The mountain peaks' elevation varies from 1150 m above MSL in Ras Muneef to 1365 m above MSL in Al–Shoubak, and exceeds 1500 m above MSL at El-Qurain. The Desert Region extends north to south from the eastward foot of the Highlands with elevation ranging from 600 to 750 above MSL.

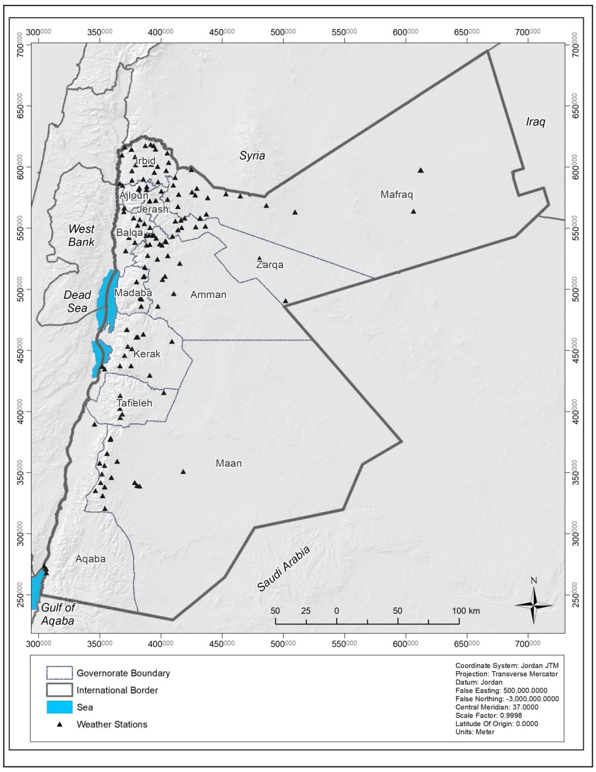

Figure 1. Meteorological stations locations within the Jordan study area.

2.2. Data Sources and Description

Although there are many stational points available within the country, reliable and continuous local daily meteorological data sets were selectively obtained from both the Jordanian Meteorological Department (JMD) and the Ministry of Water and Irrigation (MWI) for the period between (1961-2012). For precipitation, a total of 143 station points (twenty-four station points from JMD and 119 station points from MWI) were implemented in this study. On the other hand, only forty meteorological stational points (twenty-four station points from JMD and sixteen station points from MWI) were selected for the following climatic variables: mean temperature, maximum temperature, minimum temperature, relative humidity, and Class A-Evaporation Pan (Figure 1).

Weather data quality-assessment, including outlier detection and filling missing values, was achieved using the Quality Control (QC) tool to assess the validity of weather data of long-term stations. Both threshold and step-change tests were conducted using JMP statistical software (Guttman et al., 1988; Fiebrich et al., 2010; Shulski et al., 2014). On the other hand, missing values were treated in four different manners depending on the range of the gap; mean substitution, simple regression, multiple regressions, and spatial distribution based on the nearest station (Kotsiantis et al., 2006; Grzymala-Busse Hu, 2001).

2.3. Trend Analyses

The climatic trend of a monotonic increase or decrease in the average meteorological values between the beginning and the end of an available time series was detected using two methods: (1) the linear regression trends, and (2) the nonparametric "Mann-Kendall rank trend test" (Kendall, 1975; Mann, 1945; Nelsen, 2001). The trend analyses were cnducted on both monthly and yearly bases to assess monotonic changes dominancy over the historical period using the JMP statistical software (version 11) (JMP, 2014).

2.4. Spatial Variability

Before commencing the modeling analysis, it was useful to identify the strength of the relationships between the climatic variables and the auxiliary variables such as altitude. This was achieved by creating a Pearson's product moment correlation matrix using Equation (1).

$$r = \frac{\sum_{1}^{n}\left(Z_i - \overline{Z}\right)\left(A_i - \overline{A}\right)}{\sqrt{\sum_{1}^{n}\left(Z_i - \overline{Z}\right)^2}\sqrt{\sum_{1}^{n}\left(A_i - \overline{A}\right)^2}} \quad \text{..(1)}$$

where n is the number of observations, Z_i is the selected climatic variable, A_i is the auxiliary variable, is the mean of the first selected climatic variable, and is the mean of the auxiliary variable. The strength of the correlation was classified into three levels: weak correlation when $0 \leq |r| < 0.3$, moderate correlation when $0.3 \leq |r| < 0.6$, and strong correlation when $0.6 \leq |r| \leq 1.0$.

In order to have a fine resolution map for the climatic variables across the country (i.e. down to 30m pixel range), spatial interpolation was achieved using the ordinary Co-kriging technique between the climatic variable and the altitude, taking into account the existing huge variability of the altitudes within the country.

Cokriging is a method for interpolation that minimizes the variance of the estimation error by exploiting the cross-correlation between several variables, thus the cross-correlated information contained in the auxiliary variable will help reduce the variance of the estimation errors (Wackernagel, 1995; Journel, 1986; Journel, 1989; Isaaks and Srivastava, 1989). The digital elevation map (DEM) including altitude, orientation, slope, roughness, and encasement was obtained from the Royal Jordanian Geographic Center on a 30 m interval.

A multiple regression technique was adopted to interpolate the climatic variable of magnitude at an unknown pixel (i.e. between the climatic variable and DEM data). The cross-correlation was achieved using geostatistical tools within Arc Map (ArcGIS 10.3, ESRI, 2017). The ordiniary cokriging assumes the following two equations (2) and (3):

$$Z(x) = \mu_1 + \varepsilon_1(x) \quad \text{.. (2)}$$

$$A(x) = \mu_2 + \varepsilon_2(x) \quad \text{.. (3)}$$

where Z(x) is the climatic variable of interest at location x, A(x) is the covariate/auxiliary at location x, μ_1 and μ_2 are unknown constants, $\varepsilon_1(x)$ and $\varepsilon_2(x)$ are random errors representing autocorrelation of Z variable and cross-correlation between Z and A, respectively.

The unknown value Z_0 at any pixel is then a linear combination of N values of two regionalized variables. The general equation for a two-variable cokriging was estimated locally within each set of the neighborhood control points using Equation (4) (Goovaerts, 2000).

$$Z_0 = \sum_{i=1}^{n} W_i Z_i + \sum_{j=1}^{n} \varsigma_j A_j + \varsigma_0 A_0 \quad \text{........................ (4)}$$

where Z_0 = the estimate at the unknown location, W_i = the undetermined weight assigned to Zi varying between 0 and 100 %, Zi = the regionalized variable at a given location, with the same units as for the regionalized variable, Ai = the auxiliary regionalized variable co-located with Zi, with the same units as for the secondary regionalized variable, β_j = the undetermined weight assigned to Ai varying between 0 and 100 %, A_0 = the auxillary variable located at the target location, with the same units as for the secondary variable, and β_0 = the undetermined weights assigned to A_0 varying between 0 and 100 %.

$$(_{za} = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z_i(x) - Z_i(x+h)] \times [A_i(x) - A_i(x+h)] \quad \text{..... (5)}$$

The cokriging accuracy were investigated using cross-validation between actual measured values and predicted climatic variables at the same pixel using the root mean square error (RMSE) and the coefficient of determination (r) performance indicators as indicated by Equations (5) and (6) respectively.

$$\mathrm{RMSE} = \frac{1}{n} \sum_{i=1}^{n} [Z_i(x) - Z_i(x)] \quad \text{.. (6)}$$

$$r = \frac{\{\sum_{i=1}^{n} [Z_i(x) - Z_i(x)] \times [Z_i(x) - Z_i(x)]^2\}}{\sum_{i=1}^{n} [Z_i(x) - Z_i(x)]^2 \times \sum_{i=1}^{n} [Z_i(x) - Z_i(x)]^2} \quad \text{...... (7)}$$

where (x) is the predicted climatic variable at location x using the cokriging technique.

3. Results and Discussion

3.1. Trend Analyses

According to the preliminary statistical description of all the tested climatic variables, there exist clear trends either decreasing or increasing with time as indicated by both Mann-Kendall and linear trends (Table 1). The resulted trends are a clear evidence of climate change in Jordan over the last fifty years.

According to the historic climatic linear analyses, the annual precipitation tends to decrease significantly ($P<0.0021$) by time with an average rate of 1.2 mm/year (ranging from 0.5 to 2.2 mm/year regarding the stational point). On the contrary, the mean, maximum and minimum air temperatures tend to increase significantly by 0.02, 0.01, and 0.03 °C/year, respectively. On the other hand, the relative humidity and mean annual potential evapotranspiration tend to increase significantly by an average of 0.08 %/year and 17mm/year.

Table 1. Mann-Kendall trend statistics of climatological time series for selected climate variables for all of Jordan.

	Mann-Kendall τ	Prob>|τ|	R	RMSE	Linear Model	P value
Precipitation	-0.0590	0.0044*	-0.0964	184.1829	= 2632.01 - 1.214*YEAR	0.0021*
Mean Temp	0.0930	<.0001**	0.0933	3.282705	= -24.31 + 0.022*YEAR	0.0039*
Max Temp	0.0424	0.0463*	0.0463	3.583504	= 2.02 + 0.012*YEAR	0.1425
Min Temp	0.1104	<.0001**	0.1098	3.430952	= -41.07 + 0.027*YEAR	0.0005**
Relative Humidity	0.0663	0.0056*	0.1125	7.678434	= -102.14 + 0.080*YEAR	0.0015*
Evapotranspiration	0.1501	<.0001**	0.2357	189.5767	= 16370.75 + 17.052*YEAR	<.0001**

** sign indicates significant trends at the 5 percent confidence level, and ** sign indicates significant trends at the 1 percent confidence level.*

The trend statistics of precipitation on a monthly basis indicated that the reduction is highly significant during the whole rainy season (which extends from October to May of the next year) except for January where it increases by time (Table 2). The maximum rate of decrease was during March followed by January, while the maximum increase was found to be associated with February with a rate of 0.245mm/year. Coinciding with (Salahat and Qinna, 2015), the trends show a clear shift in the rainy season with significant narrowing of precipitation magnitudes; however, the rate of decrease in rainfall seems to be affecting not only the quantities but also the number of rainy days.

Table 2. Historic Trend Analyses of Average Monthly Precipitation across the country.

	Month	Linear Model	Mann-Kendall τ	Prob>|τ|	R^2	RMSE	Prob > F
Precipitation	JAN	= 567.57 - 0.259 * Year	-0.0179	0.3848	0.0047	55.273	0.0241*
	FEB	= -440.65 + 0.245 * Year	0.0581	0.0047*	0.0043	54.712	0.0313*
	MAR	= 861.15 - 0.416 * Year	-0.124	<.0001**	0.0217	40.839	<.0001**
	APR	= 435.65 - 0.213 * Year	-0.1272	<.0001**	0.0176	23.300	<.0001**
	MAY	= 79.96 - 0.039 * Year	-0.005	0.8214	0.0070	6.754	0.0062*
	JUN	= -4.89 + 0.003 * Year	0.0005	0.9834	0.0007	1.463	0.4013
	JUL	= -0.26 + 0.0001 * Year	0.0156	0.532	0.0001	0.168	0.6995
	AUG	= -0.66 + 0.0003 * Year	0.0067	0.7889	0.0008	0.181	0.3676
	SEP	= -13.38 + 0.007 * Year	0.1123	<.0001**	0.0063	1.265	0.0089*
	OCT	= 60.53 - 0.027 * Year	-0.0301	0.1603	0.0011	11.799	0.2769
	NOV	= 149.46 - 0.064 * Year	-0.0704	0.0007**	0.0008	33.249	0.3551
	DEC	= 1066.97 - 0.516 * Year	-0.0678	0.001**	0.0208	51.935	<.0001**
Mean air temperature	JAN	= -9.09 + 0.009 * Year	0.0776	0.017*	0.0014	3.421	0.2447
	FEB	= 4.88 + 0.003 * Year	0.0339	0.2973	0.0001	3.474	0.7335
	MAR	= -11.06 + 0.012 * Year	0.0579	0.0749	0.0024	3.558	0.1325
	APR	= -23.85 + 0.021 * Year	0.1032	0.0015**	0.0075	3.428	0.0078**
	MAY	= -20.71 + 0.021 * Year	0.0947	0.0036**	0.0077	3.454	0.0070**
	JUN	= -10.74 + 0.018 * Year	0.0855	0.0085**	0.0052	3.506	0.0258*
	JUL	= -43.08 + 0.035 * Year	0.1459	<.0001**	0.0188	3.601	<.0001**
	AUG	= -37.16 + 0.032 * Year	0.1376	<.0001**	0.0155	3.648	0.0001**
	SEPT	= -19.401 + 0.022 * Year	0.1023	0.0016**	0.0084	3.435	0.0046**
	OCT	= -27.88 + 0.025 * Year	0.1324	<.0001**	0.0105	3.417	0.0016**
	NOV	= 5.47 + 0.005 * Year	0.0508	0.118	0.0004	3.575	0.5406
	DEC	= -25.41 + 0.018 * Year	0.1197	0.0002**	0.0060	3.350	0.0173*
Maximum air temperature	JAN	= 1.85 + 0.006 * Year	0.0299	0.1648	0.0005	3.800	0.4644
	FEB	= 33.87 - 0.009 * Year	-0.0114	0.5974	0.0010	3.945	0.3095
	MAR	= 3.59 + 0.008 * Year	0.0231	0.2833	0.0008	4.019	0.3751
	APR	= -10.25 + 0.018 * Year	0.047	0.0288*	0.0043	3.815	0.0400**
	MAY	= 11.35 + 0.009 * Year	0.0266	0.2172	0.0012	3.785	0.2836
	JUN	= 24.54 + 0.004 * Year	0.0208	0.3327	0.0002	3.864	0.6316
	JUL	= -6.24 + 0.020 * Year	0.0537	0.0125*	0.0052	4.007	0.0238*
	AUG	= -1.96 + 0.018 * Year	0.0514	0.0166*	0.0043	3.932	0.0387*
	SEPT	= 22.03 + 0.005 * Year	0.0179	0.4049	0.0004	3.550	0.5119
	OCT	= 16.57 + 0.006 * Year	0.0255	0.2348	0.0006	3.509	0.4511
	NOV	= 26.71 - 0.003 * Year	0.0028	0.8962	0.0001	3.784	0.7674
	DEC	= -30.55 + 0.024 * Year	0.0739	0.0006**	0.0085	3.600	0.0035**
Minimum air temperature	JAN	= -16.18 + 0.010 * Year	0.0464	0.0314*	0.0017	3.482	0.1960
	FEB	= -15.47 + 0.010 * Year	0.0491	0.0228*	0.0018	3.386	0.1791
	MAR	= -19.04 + 0.013 * Year	0.0445	0.0391*	0.0030	3.424	0.0869
	APR	= -32.06 + 0.022 * Year	0.0803	0.0002**	0.0081	3.373	0.0046*
	MAY	= -44.39 + 0.030 * Year	0.0825	0.0001**	0.0143	3.476	0.0002**
	JUN	= -39.71 + 0.029 * Year	0.0867	<.0001**	0.0129	3.540	0.0003**
	JUL	= -73.75 + 0.047 * Year	0.1296	<.0001**	0.0331	3.585	<.0001**
	AUG	= -69.37 + 0.045 * Year	0.1257	<.0001**	0.0272	3.788	<.0001**
	SEPT	= -51.59 + 0.035 * Year	0.1072	<.0001**	0.0162	3.842	<.0001**
	OCT	= -62.03 + 0.038 * Year	0.1118	<.0001**	0.0196	3.847	<.0001**
	NOV	= -7.23 + 0.008 * Year	0.0401	0.0616	0.0009	3.882	0.3355
	DEC	= -16.84 + 0.011 * Year	0.0476	0.0264*	0.0019	3.630	0.1668

** sign indicates significant trends at the 5 percent confidence level, and ** sign indicates significant trends at the 1 percent confidence level.*

Although the lack of data on the rainfall intensity hinders the investigation of the potentials of extreme events in the country, it was found through the exploration of the number of rainy days within each month at the station level that there exists a high potential of increase in rainfall intensity with time. The significant decrease in the number of rainy days with time supports the increase postulation of intensity with the assumption of keeping the precipitation quantity around the same annual average. On the other hand, it was clear that the precipitation quantity varies spatially and temporally across the country, thus the rainfall intensity and, therefore, extreme events are likely to appear with spatial and temporal dependents as well. This justifies the increase in flooding events at some locations in Jordan during the last decade.

On the other hand, the statistical trends of mean, maximum and minimum temperatures on daily and monthly bases indicated significant increasing for most of the months and within the majority of the stational points. The climate change trends are clearer and more affective at the minimum air temperature as shown by the probability of significance compared to mean and maximum temperatures. The increase trends in maximum air temperatures were detected to be insignificant; however, they are spatial-dependent rather than being temporal-dependent. This coincide with Freiwan and Kadioğlu (2008a and 2008b) where warming climate trends were recognized in two spells in the time series of the early 1970s and beyond the year 1992, when maximum temperature was less statistically-significant compared to the minimum temperature. The minimum air temperature increase was detected to be more sever in the dry season (May to September) compared to the wet season (October to April) as indicated by the rate of change and the trend tests' significance.

3.2. Spatial Cokriging Mapping

The strength of the relationships between the climatic variables and auxiliary variables were ranging between moderate to strong. Pearson correlation matrix indicated that the auxiliary variable correlation with precipitation, maximum air temperature, mean air temperature, minimum air temperature, relative air humidity, and potential evapotranspiration were 0.56, 0.67, 0.71, 0.78, 0.81, and 0.75, respectively.

The cross-variogram model indicates the anisotropical behavior of all climatic variables with a logarithmic behavior of change for most of the climatic variables, except for relative air humidity where the best fit model is Gaussian. The cross-validation between the auxiliary variable and the climatic variables were very satisfactory. The coefficients of determination of the final cokriging map were 0.92, 0.80, 0.84, 0.91, 0.86, and 0.74 for precipitation, mean air temperature, maximum air temperature, minimum air temperature, relative air humidity, and potential evapotranspiration, respectively. The root low magnitudes of residuals are indicative of the improvement of the accuracy of prediction compared to the general kriging technique; therefore, the cokriging technique for the generation of precipitation maps especially in regions with high spatial variation of rainfall as well as elevation was employed.

Table 3. Cross-validation statistics of cokriging spatial interpolation.

Climatic Variable	R^2	RMSE
Precipitation	92	31.2
Mean Air Temperature	0.80	2.3
Maximum Air Temperature	0.84	1.9
Minimum Air Temperature	0.91	1.5
Relative Air Humidity	0.86	5.4
Potential Evapotranspiration	0.74	55.4

Based on the generated cokriging precipitation map, the long mean annual precipitation appears to be spatially and temporally dependent (Figure 2)t. The minimum rainfall was recorded at the southern Badia region with an average value of less than 30 mm similar to Al–Jafr and Aqaba. The cokriging precipitation map was able to show the detailed variation in precipitation especially along the Ghor region, starting from 280 mm at the highest point in the north, declining towards the south until reaching 71 mm in Ghor Safi. The high average annual precipitation in the mountains was found to vary from 298 mm in Tafeeleh and 270 mm in Al–Shoubak to 540 mm at Bulqa mount and 615 mm in Ras Muneef.

On the other hand, the generated cokriging temperature maps indicated that the average mean temperature across the country varies from 13 C in the southern Badia region to 28 C at Aqaba with a mean of 18.6 C all over the country (Figure 3). The variability in the mean air temperature is attributed to the existing variability in the minimum temperature ranging from 5.6 in the eastern region to 19.8 C in the western region (Figure 4), while the maximum temperature is almost distributed uniformly with an average of 25.3 C varying from 18.7 to 31.3 C (Figure 5).

The country seems to have an oriented spatial distribution of both potential evapotranspiration and relative humidity. The average annual potential evapotranspiration was estimated at about 2502 mm varying from 1460 mm in the northern highlands of Ras Muneef to 3886 mm in the eastern region, especially in Aqaba (Figure 6). Similarly, the relative humidity was about 57% varying from 76.2% in the northern highlands of Ras Muneef to 48.8 % in the northern Badia region and to 47.6 % in Aqaba (Figure 7f).

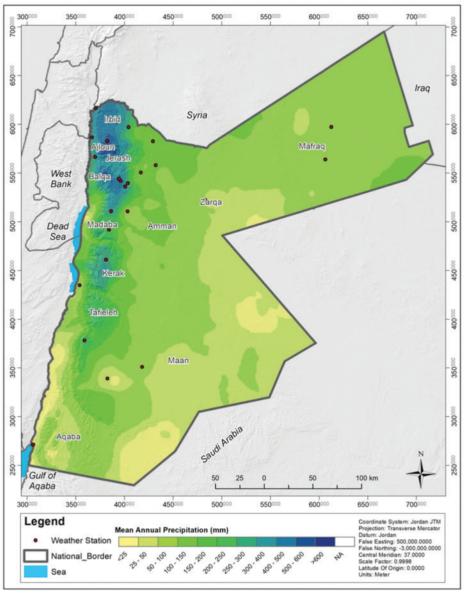

Figure 2. Generated gokriging precipitation map

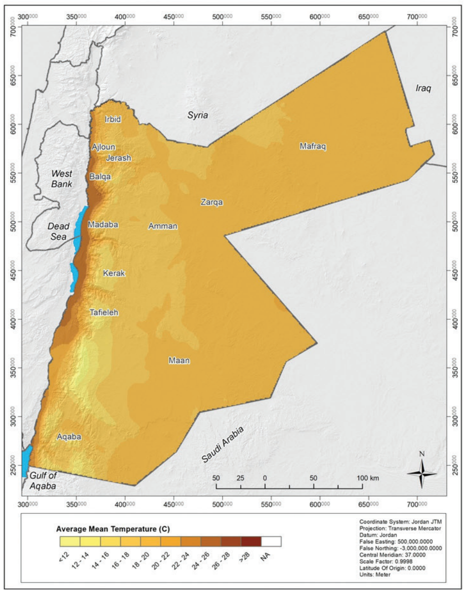

Figure 3. Generated cokriging average mean air temperature map

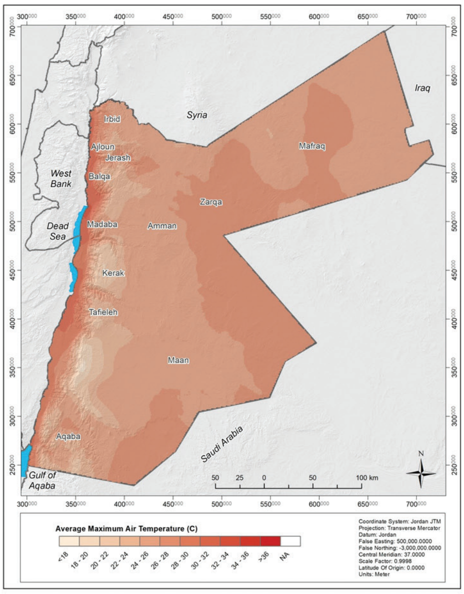

Figure 4. Generated cokriging maximum air temperature map

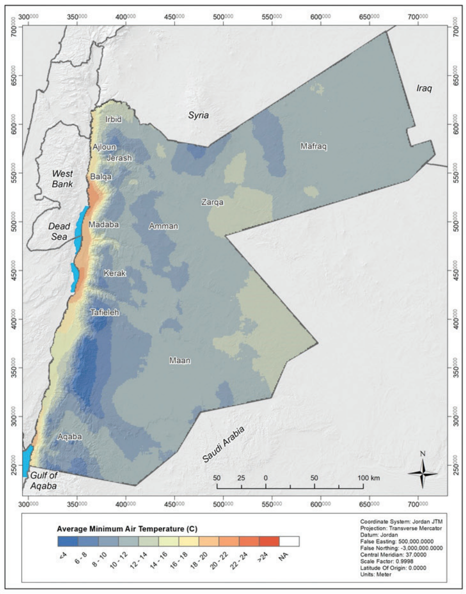

Figure 5. Generated cokriging maximum air temperature map

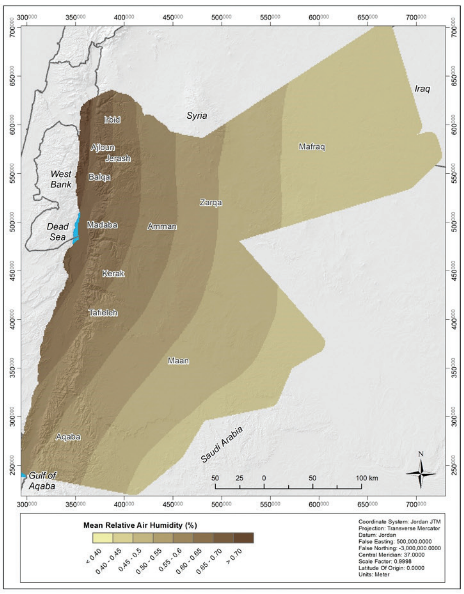

Figure 6. Generated cokriging mean relative air humidity map

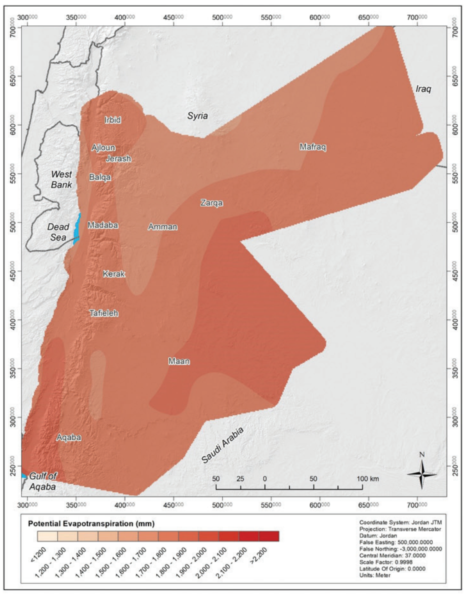

Figure 7. Generated cokriging potential evapotranspiration map

Conclusions

Climatic variability in Jordan is spatially and temporally dependent, varying at both national and local micro-climatic levels. Understanding the spatial variation of climatic factors is very important for a better future planning and management. Also, increasing the accuracy of the spatial predictions of the climatic variables with the aid of the available ancillary data is quite helpful, especially in complex terrains like Jordan.

Mann-Kendall rank and linear regression trend tests for long historical data about 143 stational points indicated that the climatic variability in Jordan has specific site-base trends which confirm the warming generated by the impacts of climate change. Annual precipitation decreasing trends vary by space with an average rate of 1.2 mm/year. On the contrary, maximum air temperature tends more likely to increase by 0.01°C/year, while the minimum air temperature is very likely to increase by 0.03 °C/year, respectively. As a result, the potential evapotraspiration will eventually increase by an estimated rate of 17mm/year threatening the water availability which is already exerbated by the growing needs for crop-water.

Integrating the Geographic Information System and a geostatistic approach for the spatial interpolation of selected climatic variables was promising through generating cokriging fine resolution maps by integrating climatic variables with elevation as an auxiliary variable. Cross-validations between the auxiliary variable and the climatic variables were very satisfactory, and provided good advantages that enabled the reduction of significant prediction errors, therefore, improving the prediction accuracy as indicated by the high coefficients of determination and the low root mean square errors.

References

[1] Abandeh, A. 1999. Climate trends and climate change scenarios, vulnerability and Adaptation to Climate Change in Jordan, Project No. JOR/95/G31/IG/99, 1, Al-Shamil Engineering: Amman, Jordan.

[2] Adhikary S.K., Muttil N., Yilmaz A.G. 2017. Cokriging for enhanced spatial interpolation of rainfall in two Australian catchments. Hydrological Processes. 31:2143–2161.

[3] Al-Ansari, N., Salameh, E., and Al-Omari, H. 1999. Analysis of rainfall in the Badia region, Jordan, Research Paper, 1. Al-al-Bayt University, Jordan.

[4] Al-Houri Z. 2014. Detecting Variability and Trends in Daily Rainfall Characteristics in Amman-Zarqa Basin, Jordan. International Journal of Applied Science and Technology, 4(6):11-23.

[5] Al-Qinna M., Hammouri N., Obeidat M., Ahmad F. 2011. Drought Analysis in Jordan under Current and Future Climates. Journal of Climatic Change, 106(3):421-440.

[6] Bani-Domi, M. 2005. Trend analysis of temperatures and precipitation in Jordan, Umm Al-Qura University Journal of Educational, Social Sciences & Humanities, 17(1), 15-36.

[7] Dahamsheh, A., and Aksoy H. 2007. Structural characteristics of annual precipitation data in Jordan. Theoretical Applied Climatology, 88, 201–212.

[8] Diodato N. 2005. The Influence of Topographic Co-Variables on the Spatial Variability of Precipitation Over Small Regions of Complex Terrain. Int. J. Climatol. 25: 351–363.

[9] ESRI. 2017. ArcGIS software version 10.3. ESRI Inc., Redlands, California, USA

[10] FAO (Food and Agricultural Organization). 2012. Assessment of the risks from climate change and water scarcity on food productivity in Jordan.

[11] Fiebrich, C.A., Morgan, C.R., McCombs, A.G., Hall, P.K., Jr., and McPherson, R.A. 2010. Quality assurance procedures for mesoscale meteorological data. Journal of Atmospheric and Oceanic Technology 27(10):1565 – 1582.

[12] Freiwan M. and Kadioğlu M. 2008a. Spatial and temporal analysis of climatology in Jordan. Int. J. Climatol., 28:521 – 535.

[13] Freiwan, M. and Kadioğlu, M. 2008b. Climate variability in Jordan. Int. J. Climatol. 28: 69 – 89.

[14] Freiwan, M. and Kadioğlu, M. 2006. Contemporary Climate Change in Jordan. 1st International Conference on Climate Change and the Middle East: Past, Present and Future 20-23 November 2006, Istanbul Technical University, Istanbul, Turkey.

[15] Ghanem A. 2013. Case Study: Trends and Early Prediction of Rainfall in Jordan. American Journal of Climate Change, 2013, 2, 203-208.

[16] Ghanem, A. 2010. Climatology of the areal precipitation in Amman/Jordan, International Journal of Climatology, 31(9), 1328-1333.

[17] Ghanem, A. 2011. Trends in mean seasonal and annual rainfall amounts over Jordan. Dirasat, University of Jordan, Vol. 8, 2011, pp. 1041-1049.

[18] Goovaerts P. 1997. Geostatistics for natural resources evaluation. Oxford University Press, New York

[19] Goovaerts, P. 2000. Geostatistical approaches for incorporating elevation into the spatial interpolation of rainfall, J Hydrol. 228, 113—129.

[20] Grzymala-Busse J.W. and Hu M. 2001. A Comparison of Several Approaches to Missing Attribute Values in Data Mining, RSCTC 2000, LNAI 2005, pp. 378−385, 2001.

[21] Guttman, N., Karl, C., Reek, T., and Shuler, V. 1988. Measuring the performance of data validators. Bulletin of the American Meteorological Society 69(12):1448 – 1452.

[22] IPCC (Intergovernmental Panel on Climate Change). 2007: Technical Summary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[23] IPCC (Intergovernmental Panel on Climate Change). 2013. Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, 1535 pp.

[24] IPCC (Intergovernmental Panel on Climate Change). 2014. Summary for Policymakers. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. http://doi.org/10.1017/CBO9781107415324

[25] Isaaks, E.H. and Srivastava, R.M. 1989. An Introduction to Applied Geostatistics. Oxford, UK: Oxford University Press.

[26] JMP. 2014. JMP statistical Software Guide Book, SAS Institute Inc., Cary, NC, USA.

[27] Journel, A.G. 1986. Geostatistics: Models and Tools for Earth Sciences. Math. Geol. 18: 119.

[28] Journel, A.G. 1989. Fundamentals of Geostatistics in Five Lessons. Short Course in Geology, AGU, Washington, DC, 8, 40.

[29] Kendall, M. 1975. Rank correlation methods, 4th edition, Charles Griffin, London.

[30] Kotsiantis S., A. Kostoulas, S. Lykoudis, A. Argiriou, K. Menagias. 2006. Filling Missing Temperature Values In Weather Data Banks. 2nd IEE International Conference on Intelligent Environments, 5-6 July, 2006, Athens, Greece, 1:327-334.

[31] Mann, H. 1945. Non-parametric tests against trend, Econometrica, 13, 163-171.

[32] Matouqa, M., El-Hasan,T., Al-Bilbisi, H., Abdelhadi, M., Hindiyeh, M., Eslamian, S., and Duheisat, S. 2013. The climate change implication on Jordan: A case study using GIS and Artificial Neural Networks for weather forecasting, Journal of Taibah University for Science, 7, 44–55.

[33] MoEnv (Ministry of Environment). 1999. Jordan's First National Communication to the UNFCCC. Ministry of Environment, Amman, Jordan.

[34] MoEnv (Ministry of Environment). 2006. National Capacity Self Assessment for Global Environmental Management (NCSA) - Jordan National Capacity: Assessment Report and Action Plan, GEF and UNDP project, Amman, Jordan.

[35] MoEnv (Ministry of Environment). 2009. Jordan's Second National Communication to the UNFCCC. Ministry of Environment, Amman, Jordan.

[36] MoEnv (Ministry of Environment). 2012. Climate Change Adaptation in the Zarqa River Basin: Assessment of Direct and Indirect Impacts of Climate Change Scenarios, (Water Resources Study, Vol. l). Ministry of Environment, Funded by UNDP, Amman, Jordan.

[37] MoEnv (Ministry of Environment). 2013. The National Climate Change Policy of the Hashemite Kingdom of Jordan 2013-2020. Sector Strategic Guidance Framework. Supported by Global Environment Facility (GEF) and the United Nations Development Programme (UNDP), Amman, Jordan.

[38] MoEnv (Ministry of Environment). 2014a. Intended Nationally Determined Contribution (INDC) submitted by the Hashemite Kingdom of Jordan to UNFCCC, Amman, Jordan.

[39] MoEnv (Ministry of Environment). 2014b. Jordan's Third National Communication on Climate Change Submitted to The united nations Framework Convention on Climate Change (UNFCCC). Ministry of Environment, Amman, Jordan.

[40] Nelsen, R. 2001. Kendall tau metric, Hazewinkel, Michiel, Encyclopedia of Mathematics, Springer.

[41] Ragab, R. and Prudhomme, C. 2002. Climate change and water resources management in arid and semi arid regions: prospective and challenges of the 21st century. Biosystem Engineering, 81(1): 3- 34.

[42] Salahat M.A. and Al-Qinna M.I. 2015. Rainfall Fluctuation for Exploring Desertification and Climate Change: New Aridity Classification. Jordan Journal of Earth and Environmental Sciences. 7(1): 27-35.

[43] Scott H.D. 2000. Soil physics: agricultural and environmental applications. Iowa State University Press, Iowa, USA.

[44] Selker J.S., Keller C.K., McCord J.T. 1999. Vadose zone processes. Lewis Publishers/CRC Press LLC, Florida, USA.

[45] Shulski, M.D., J. You, J.R. Krieger, W. Baule, J. Zhang, X. Zhang and W. Horowitz. 2014. Quality Assessment of Meteorological Data for the Beaufort and Chukchi Sea Coastal Region using Automated Routines. ARCTIC, 67(1):104–112.

[46] Smadi, M., and Zghoul, A. 2006. A sudden change in rainfall characteristics in Amman, Jordan during the mid 1950s, American Journal of Environmental Sciences, 2 (3), 84-91.

[47] Tarawneh Q. and Kadioğlu M. 2002. An analysis of precipitation climatology in Jordan. Theoretical and Applied Climatology. 74: 123-136.

[48] UN (United Nation). 2009. Guidance on Water and Adaptation to Climate Change. Economic Commission for Europe Convention on the Protection and Use of Transboundary Watercourses and International Lakes.

[49] Wackernagel, H. 1995. Multivariate Geostatistics: An Introduction with Applications. Berlin, Germany: Springer-Verlag.

[50] Wang X., Lv J., Wei C., Xie D. 2011. Modeling Spatial Pattern of Precipitation with GIS and Multivariate Geostatistical Methods in Chongqing Tobacco Planting Region, China. In: Li D., Liu Y., Chen Y. (eds) Computer and Computing Technologies in Agriculture IV. CCTA 2010. IFIP Advances in Information and Communication Technology, vol 346. Springer, Berlin, Heidelberg.