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# Production of Digital Climatic Maps Using Geostatistical Techniques (Ordinary Kriging) Case Study from Libya

*Abdussalam Ahmed Mohamed Ibrahim*

Nasser University, Tarhuna, Libya

**Abstract:** Lack of accurate climate data is a problem that facing many Arab countries including Libya. This problem affects integrated planning on the environment and the agriculture. There is an increasing demand for gridded datasets of climate variables from fields such as hydrology, ecology, agriculture, climate change research and climate model verification. Consequently this paper attempted to make at spatial interpolation, of main climatic parameters using spatial geostatistics tools. This paper gave a brief overview of how to produce accurate climatic maps by producing a consistent series of climatic statistics which enables comparisons to be made across space and time using contemporary techniques that are inherent in the Science of Geographic Information Systems (GIS) and Genstat (Ordinary Kriging). The maps were created using Ordinary Kriging with accuracy of estimates for each 1000 m x 1000 m pixel. The kriged map for rainfall shows a rapid increase in mean annual rainfall from the south to north and there are also "wet rainfall spots" prevalent throughout the line up to the mountains and a gradual decrease to the south and west parts of the study area. Temperature and evaporation trend to decrease from the west to east and most of northern and western parts in the region experienced the warmer with highest daily rates of evaporation than the eastern parts. The highest humid values are found in the coast line and it decreases regularly to warding south due to effecting of the Mediterranean Sea. The spatial distribution of moisture availability index in agreement with the spatial distribution of rainfall, temperature and evaporation.

**Key words:** GIS geographic information system · Geostatistical · Ordinary kriging · Genstat · SV semivariogram

## INTRODUCTION

Geostatistics is the name given to a range of methods for spatial data analysis that were originally developed by mining engineers for the estimation of the mineral resources in a region, based on the values measured at a sample of locations [1].

Environmental data are likely to vary throughout a region and such variation takes place in space and time. This is referred to as spatial variation. Relatively large variation within small distances indicates that the variable is subject to very local influences. On the other hand, very gradual changes in a variable indicate an influence at a more global scale.

Geostatistics allows to quantitatively dealing with such spatial variation in large sets of data. This is carried out in many stages such as an analysis of the spatial dependence, creating of computerised maps, determination of the probabilities of exceeding a threshold value and determination of sampling schemes which are optimal in some predefined sense [1].

The main distinction with statistics is that in Geostatistics the variables used are linked to locations. Observations in space are linked to their co-ordinates and each observation has its specific place in space.

GIS have been successfully used for spatial prediction [2-5] by providing, integrating and, analysing a wide variety of spatial data.

Climate information is valuable in understanding the ecology of systems affecting our life. This information is often unavailable at the local scale. This study evaluated the applicability of several climate factor estimates at

**Corresponding Author:** Abdussalam Ahmed Mohamed Ibrahim, Nasser University, Tarhuna, Libya.

the local scale-scale and illustrated the usefulness of estimated climate factors in localized environmental investigations.

The most important and common tool of geostatistics is local estimation and prediction. There are a number of interpolation methods available but the most commonly used method in GIS is Kriging. Kriging is a moderately quick interpolator that can be exact or smoothed depending on the measurement error model. It is very flexible and allows you to investigate graphs of spatial autocorrelation [4].

Kriging uses statistical models that allow a variety of map outputs including predictions, prediction standard errors, probability, etc. The flexibility of kriging can require a lot of decision-making. Kriging assumes the data come from a stationary stochastic process constant mean throughout the region, or variance of differences between any two samples is independent of position, but depends on separated distance) and some methods assume normally-distributed data [5, 4].

Ordinary Kriging is based on the model of assuming that there is no trend in the data is mathematically equivalent to assuming that the data have a constant mean value. If the mean is a simple constant, such as $\mu(s) = \mu$ (i.e., no trend) for all locations s and if $\mu$ is unknown (you do not have prior knowledge of the mean value) [5].

Based on the above and with a lack of accurate climate data covering all regions is a problem that facing many Arab countries including Libya. This problem affects integrated planning on the environment and the agriculture.

The overall general goal of this paper is to study the pattern of a spatial distribution of rainfall, temperature, humidity and evaporation and moisture availability index levels in the North West area of Libya using contemporary techniques that are inherent in the Science of Geographic Information Systems (GIS) and Genstat.

**Methodology**

**Study Area:** The study area, as shown in Figure 1, is located on the north west of Libya, which represents the area range along the coast of the Mediterranean Sea from Misratah in the east to Tunisian bounders in the west , it included all Jifara Plain and the mountain of Tarhuna.

The study area lies approximately between latitudes 32° N. to 33°10' N. and between longitudes 11° E and 15° E, (Figure 1), with areal extent about 54,000 km$^2$ [6, 7].

The study region is part of the eastern section of the vast arc-shaped of plain and plateau that extends from extreme southern Tunisia to the Tripolitania coast. The topography consists mainly of fertile coastal lowlands along the Mediterranean coast which is vast plain in the west to narrow coastal plain in the east and it rises

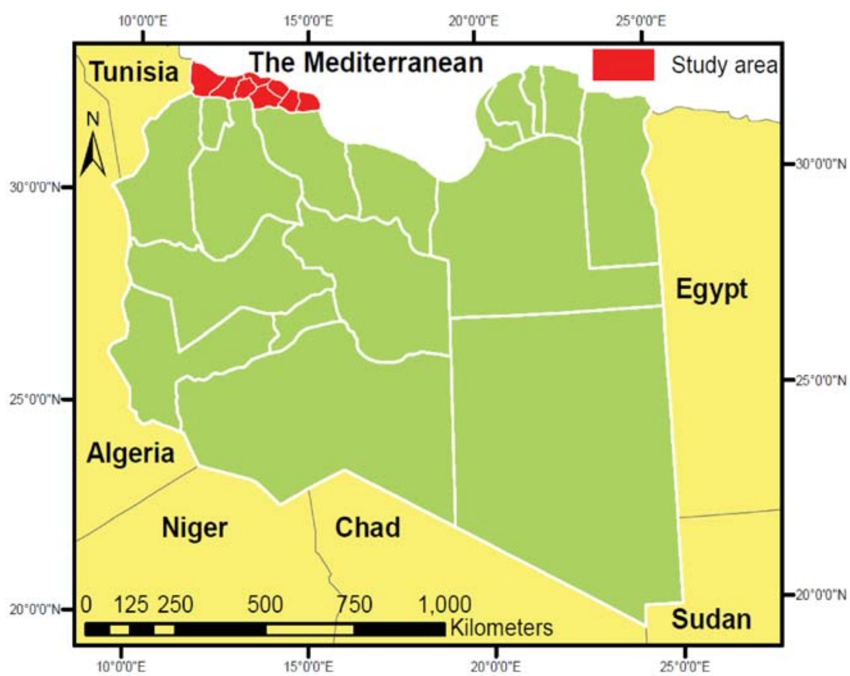


Fig. 1: Location of the study area
Source: prepared by the researcher from ESRI world map.

Table 1: Summary statistics for climate data used in the study

| Parameters | Rainfall | Temperature | Humid | Evaporation | Moisture Availability Index |
|---|---|---|---|---|---|
| Number of values | 94.0 | 94.00 | 94.00 | 94.000 | 94 |
| Number of missing values | 0.0 | 0.00 | 0.00 | 0.000 | 0 |
| Mean | 157.8 | 20.04 | 64.14 | 4.519 | 0.0672 |
| Median | 170.9 | 20.35 | 64.90 | 4.500 | 0.0737 |
| Minimum | 23.5 | 18.10 | 59.30 | 4.300 | 0.005 |
| Maximum | 216.0 | 21.10 | 66.50 | 5.000 | 0.1117 |
| Standard deviation | 44.9 | 0.75 | 1.84 | 0.145 | 0.028 |
| Skewness | 0.9 | 0.80 | 0.80 | 0.90 | 0.9 |

towards to the south until it reaches the vast expanse of Tarhuna plateau with a dissected northern edge [6].

The coastal region has a Mediterranean climate, (hot, dry summers and cold, wet winters) with average monthly temperatures in Tripoli from more 35°C in summer to 5°C in winter. However, climate in the area is greatly influenced by the Mediterranean Sea to the north and the desert to the south where the wind called the "Gibli " (a hot, very dry, sand laden wind) can raise the temperatures in a matter of hours to between 40 °C and 50°C. The highest temperature ever recorded on earth (58°C) was in this area in El Azizia city in September 13, 1922 [8, 9].

Rainfall in the study area is the main parameter of climate which may control the socio-economic prospects. It begins usually in autumn to winter which is the rainiest season and end in spring, while a negligible rainfall occurs in summer. High rainfall variabilities and severe rainfall intensities over the study area may cause severe moisture stress on cultivated crops and reduce yields. As a common rule, rainfall in semi-arid areas has in most cases negative effects. Due to high temperatures, most water evaporates without any benefit to agriculture, whereas a small percentage of rainfall only infiltrates to groundwater [8, 9].

The population of the study area is about 3063757. Because more than 90% of the country is desert or semi desert, most of the population is focused along the Mediterranean coast; this is the country's most densely populated area. In 2006, 54.2% of the Libyan population lived in the western coastal area (Jifara plain and Misurata area). This means that more than half of the Libyan population is concentrated on 3% of the total area of the country [10].

**Spatial Data Analysis:** Spatial Analysis is the process of examining the locations, attributes and relationships of features in spatial data through overlay and other analytical techniques in order to address a question or gain useful knowledge [11].

Genstat software is designed to support a range of different kinds of analysis of temporary and spatial analysis techniques to examine and explore data from a geographic perspective, to develop and test models and to present data in ways that lead to greater insight and understanding. A linkage between Genstat software and spatial data analysis is considered to be an important aspect in the development a research tool to explore and analyze spatial relationships.

The following basic statistical stages Webster and Oliver [11] have been undertaken in GenStat with the climate data to identity the best Kriging.

- Data summary statistics and transformation (Table 1), Skewness is defined formally from the third moment. As ordinary kriging equation requires the normality of data, these must be transformed. Keeping the transformation parameters, the back transformation might be done after kriging (or other analysis) straightforwardly.
- Multiple linear regression analysis was used to detect climatic trends over time series at all stations; When significant trends were identified, the data were detrended following the guidelines of Webster and Oliver [11].
- Analyse histogram to determine if the data are normally distributed. Figure 2 shows an ex ambles of Moisture Availability Index data.
- Normalise the data, if necessary, to overcome the difficulties arising from departures from the Normal distribution. The measured values were transformed to a new scale on which the distribution is more nearly Normal. (Logarithmic used with evaporation data and Square root used with rainfall data).
- Construct a variogram of the data.
- Fit an approved model to the variogram, using the best-fit criteria outlined by Webster and Oliver [11]. Figure 4 shows
- Extract model parameters from GenStat (sill, lag and nugget).
- Apply this model in Arc GIS 9.1 to produce the maps of estimated values and their prediction standard error.

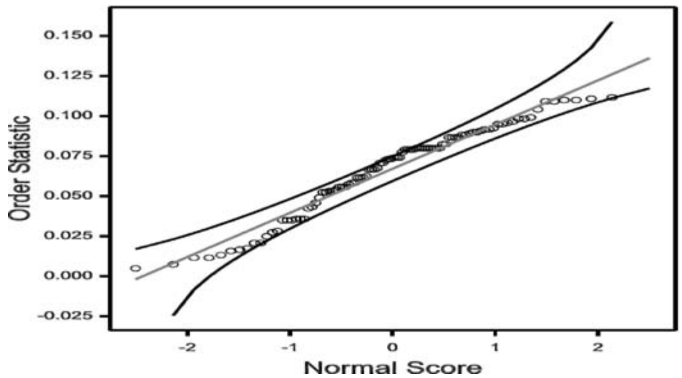


Fig. 2: Normal plot for moisture availability index data

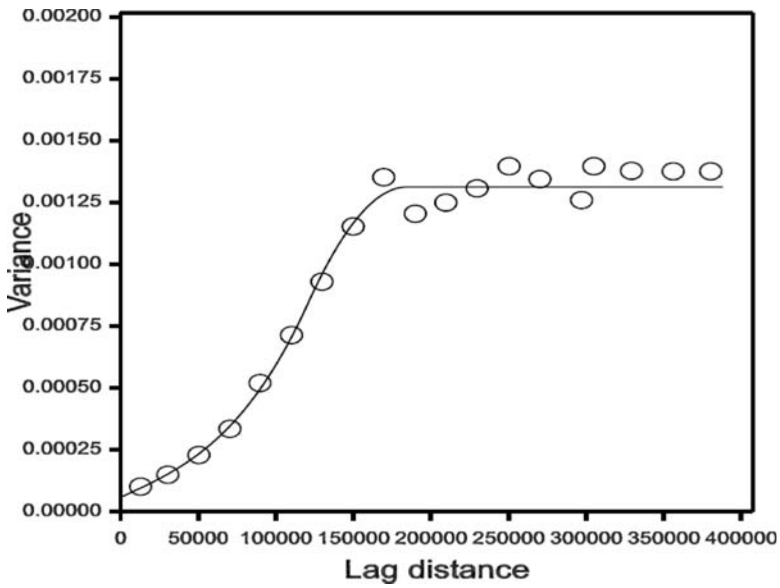


Fig. 3: Experimental and fitted SV model for moisture availability index data

Figure 3 presents an ex ambles of the best variogram model fit criteria moisture availability index data that fitted in Genstat with using double spherical model with small nugget and sill , it is represents the continuity structure quite well. Also a Gaussian model provided the best fit to the variogram for mean annual rainfall, a Spherical model provided the best fit to the variogram for evaporation and Circular model provided the best fit to the variogram for Temperature and Humid. Predicted models variogram were produced using GenStat. The cross validation supports selection of models and their parameters. For Kriging estimation and variance, the back-transformed values are applied for all climatic data.

**Spatial Data Interpolation:** A climate element varies both in time and in space; and its sampling is based on measurement stations' configuration. In many practical applications measured data are seldom available at the point of interest and consequently the only way to transfer the climate elements data from the measurement sites to the estimation point is through regional interpolation techniques using powerful models.

The spatial variability is measured in the most common way through the recorded climate elements time series at individual points.

The relative variability between the stations (the difference of simultaneous values between each pair of stations) is treated commonly by spatial autocorrelation function, which is used for inter-station dependence based on a set of restrictions Frei and Schar [12], Goovaerts [13].

Spatial variability is the main feature of regionalized variables, which are very common in climate elements. In practical applications, the spatial variation rates of the phenomenon concerned is of great significance in fields such as climate elements, agriculture, remote sensing and other earth and planetary sciences. A set of measurement stations during a fixed time interval (hour, day, month, etc.) provides records of the regionalized variable at irregular sites and there are few methodologies to deal with this type of scattered data. There are various difficulties in making spatial estimations originating not only from the regionalized random behavior but also from the irregular site configuration, Goovaerts [13].

Optimum interpolation modeling technique is presented for spatio-temporal prediction of regionalized variable with application to stations of climate data from North West of Libya. Ordinary Kriging method is explained in detail with simple basic concepts and graphics for the spatial data modeling. Finally, diagrams, mapping is presented with applications at about 100 different climate stations locations.

In order to create and develop the spatial model, the researcher needs to create a general climatic map to compare the relationship spatially, because temporal model can not do it.

Geostatistic techniques were applied to estimate values of climate elements such as rainfall and temperature at locations where climate data were not available, using Arc GIS 9.1 geostatistical tools.

Kriging is a method of calculating estimates of a regionalized variable at a point over the study area. Kriging weights the surrounding measured values to derive a prediction for an unmeasured location [11].

The general Kriging formula (equation 1) is a weighted sum of the observed data:

$$\hat{Z}(S_0) = \sum_{i=1}^{N} \lambda_i Z(S_i) \quad (1)$$

Where:

$Z(s_i)$ = The measured value at the $i^{th}$ location.

$\lambda_i$ = An unknown weight for the measured value at the $i^{th}$ location.

$s_0$ = The prediction location.

N = The number of measured values.

Ordinary Kriging is a geostatistical method used for regionalization of point data in space (equation 2). Because it is similar to multiple linear regressions and interpolates values based on point estimates, it is the most general, widely used of the Kriging methods. It assumes the constant mean is unknown. In this project, it was used to produce gridded maps of climate variables from point (meteorological station) observations.

$$F(x,y) = \sum_{i-1}^{n} w_i f_i \quad (2)$$

N = Is the number of scatter points in the set.

Fi = Are the values of the scatter points.

Wi = Are weights assigned to each scatter point.

The weights used in kriging are based on the model variogram.

For example, to interpolate at a point P based on the surrounding points P1, P2 and P3, the weights w1, w2 and w3 must be found.

Spatial stationarity, mainly second-order stationarity, is a common assumption in spatial analysis [14].

Therefore, weights are found through the solution of the simultaneous equations, a second-order stationarity was used as assumption method in this practical application, because it can be relaxed slightly when you are using the semivariogram.

Description of theoretical background of geostatistical modelling goes beyond the scope of this paper. The book by Webster and Oliver, [11] provides fundamental information on this topic.

The reliability of the experimental variogram is affected by the distribution, the size of the sample (or its inverse, the density of data) and the configuration or design of the sample. The larger the sample from which the variogram is computed, the more precisely is it estimated [11].

In order to spatially distribute data from climate stations Ordinary Kriging (OK) was applied using Genstat software and the method outlined by Webster and Oliver [11]. The technique is based on fitting an approved model to the variogram describing semi-variance and a large number of data points are needed to produce a stable variogram; at least 100 points is recommended [11]. Typically, 100-200 data points are needed to produce a stable variogram. Spatial stationarity, mainly second-order stationarity, is a common assumption in spatial analysis [14].

A major issue in Kriging is the choice of the most appropriate model to fit to the observed variogram. An experimental variogram was computed and fitted with all permitted models for each date set using GenStat see an example Figure 3. The model selected in each case was the one with the lowest prediction error.

**Spatial Data Application:** Measurements of mean rainfall, temperature, humidity and evaporation and moisture availability index record at about 100 stations from 1970 to 2000 are selected for the Kriging application (Figure 4).

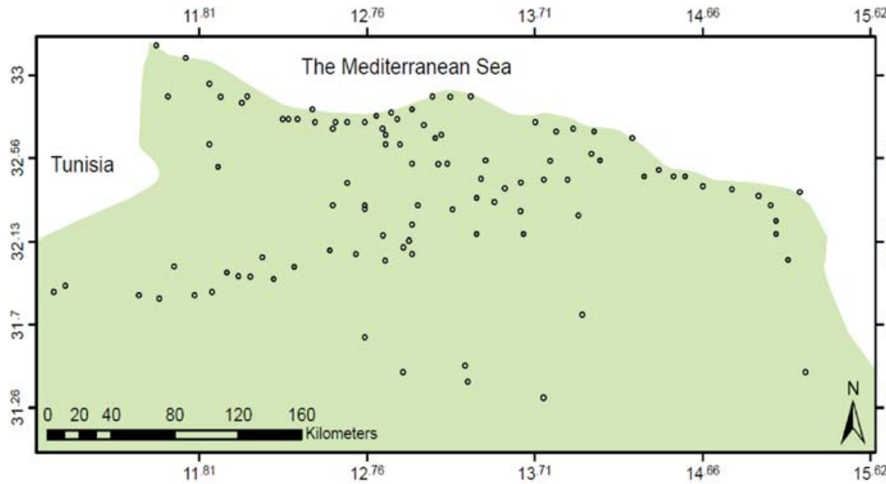


Fig. 4: Climate Stations in Northwest Libya
Source: prepared by the researcher

The region of application is North West of Libya, The grid for this analysis is into UTM projection, zone 33 N and: WGS84 Datum. The data employed in this research paper are the Measurements of mean annual rainfall, temperature, humidity and evaporation and moisture availability index collected from the statistics published of the Mapping of Natural Resources for Agricultural Use and Planning - LIB/00/004 Project [15]; with additional data collected from the World Water and Climate Atlas and supplemented by personal collection from individual Libyan meteorological stations by the researcher.

According to the definition of the World Meteorological Organisation [16], data for a 30-year period are recommended because they provide stable and reproducible .Therefore; a bout one hundred stations are selected with measurements of mean annual rainfall, temperature, humidity, evaporation and moisture availability index covering the period from 1970 to 2000.

However, climatic data histogram in arid regions, as stated behaves as lognormal distribution, Hevesi and Dehon [17]. Hence, the transformation as $Y = \ln Z(x)$ is applied for determining approximately normal annual data. Problems in the data, such as non-normality, trend and outliers, should be fixed before developing any kind of model. Normality of the sample data distribution is known to improve the results from Kriging. Further investigation can be done by visually observing the normal probability plots and most of the data lies on a straight line for the transformed values for example see Figure 4.

In addition, the Skewness coefficients are reduced close to zero. Transformation is very important to make the data more symmetric, linear and constant in variance. Since annual data are considered, it is pragmatic to find one transformation, which works reasonably well for all.

There was spatial scatter distribution of these measurement sites which shows an irregular pattern. In general, the transfer of information from the measurement sites to krig maps alike In practical applications of the optimum interpolation here each site of mean annual rainfall, temperature, humidity, evaporation and moisture availability index time series by using the climatological mean as the first guess value. The square root transformation is widely used and can be easily managed so that the Skewness of transformed data $Z(x,t)$ becomes close to zero. Table 2 shows the summary statistics for the climatic data in the region.

The most important and common tool of geostatistics is local estimation and prediction. There are a number of interpolation methods available but the most commonly used method in GIS is Kriging.

Mean annual rainfall, temperature, humidity, evaporation and moisture availability index maps were created using Ordinary Kriging applied to data from 100 climate stations.

## RESULTS

Climate variables estimated for mean annual rainfall, temperature, humidity, evaporation and moisture availability index maps were created using Ordinary Kriging. Accuracy of the estimates for each 1000 m x 1000 m pixel. The methods used estimated were determined to be reasonably accurate.

The applied GIS methodology for the spatial analysis of the rainfall levels is as illustrated in the following steps:

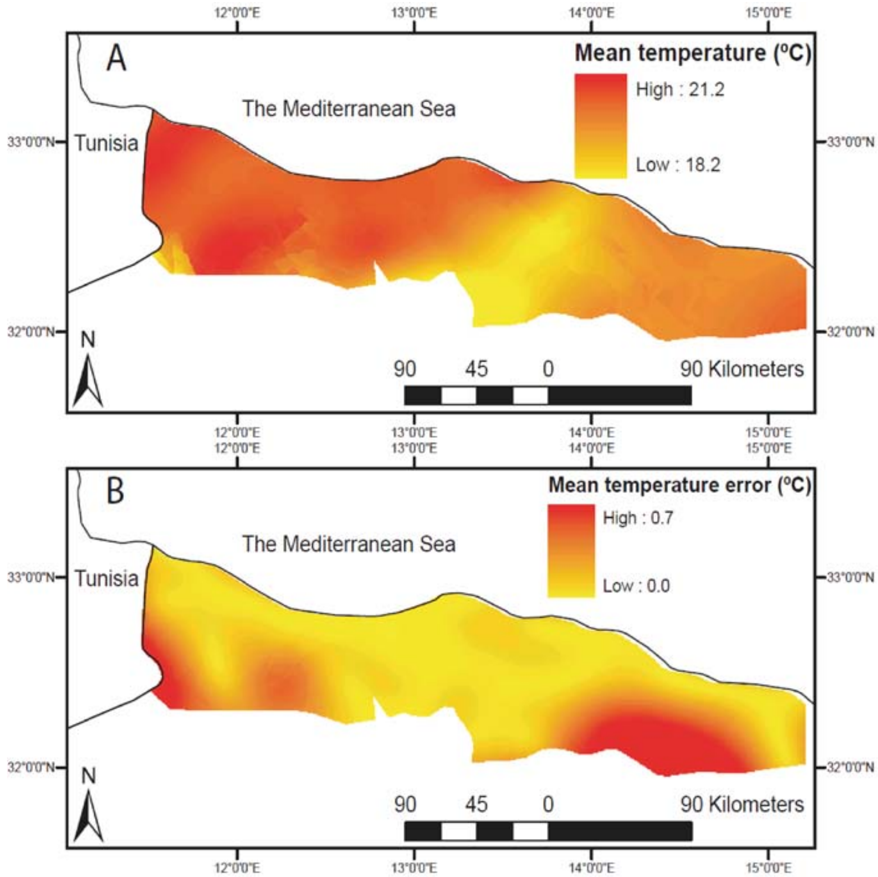


Fig. 5: Spatial distribution of mean annual Temperature (A) and its prediction of standard error using Ordinary Kriging (B)

**Prediction and Modelling of Mean Annual Temperature:** Figure 5 (A) provides the estimates of mean annual temperatures for each square kilometre in the area. Mean annual temperature was estimated for each pixel in the region North West of Libya.

A progressive cooler gradient can be observed when moving from the coastline to the South (to the mountains) and some exceptional cooler areas can be found near the coast due to the high altitudes of some sierras which are very close to the coast in east parts (Tarhuna mountains). Warm areas occurred in middle-west parts of the main basin.

In general the estimates of mean annual temperatures of north west Libya is ranging between 18 to 21°C, it dose not show a big difference but in the spatial distribution, it can be note that the patterns of temperature observed across the region showed a general trend of decreasing temperature from the west to east and most of northern and western parts in the region experienced the warmer while the eastern and south eastern parts shown to be lowest warmer especially in the mountains parts between Tarhuna and Komas. The estimates of mean annual temperatures pattern of the region suggests that older temperature maps with broad temperature regions did not adequately represent temperature at the local scale.

The accuracy of temperature estimates is shown in Figure 5 B the mean standard error of temperature estimates recorded from 0 to 0.7°C. The largest error was noted in the end of southern parts where there are not many stations.

It can be conclude that most of temperature estimates are very close to actual. The figure shows a close match between estimated and actual temperature. This method could be used to correct the temperature estimates for each station. In addition, Temperature controls evaporation of rainfall, which is inversely related to vegetation.

**Prediction and Modelling of Mean Annual Rainfall:** Mean annual rainfall was estimated for each pixel in the region of northern west of Libya. Figure 6 (A) provides

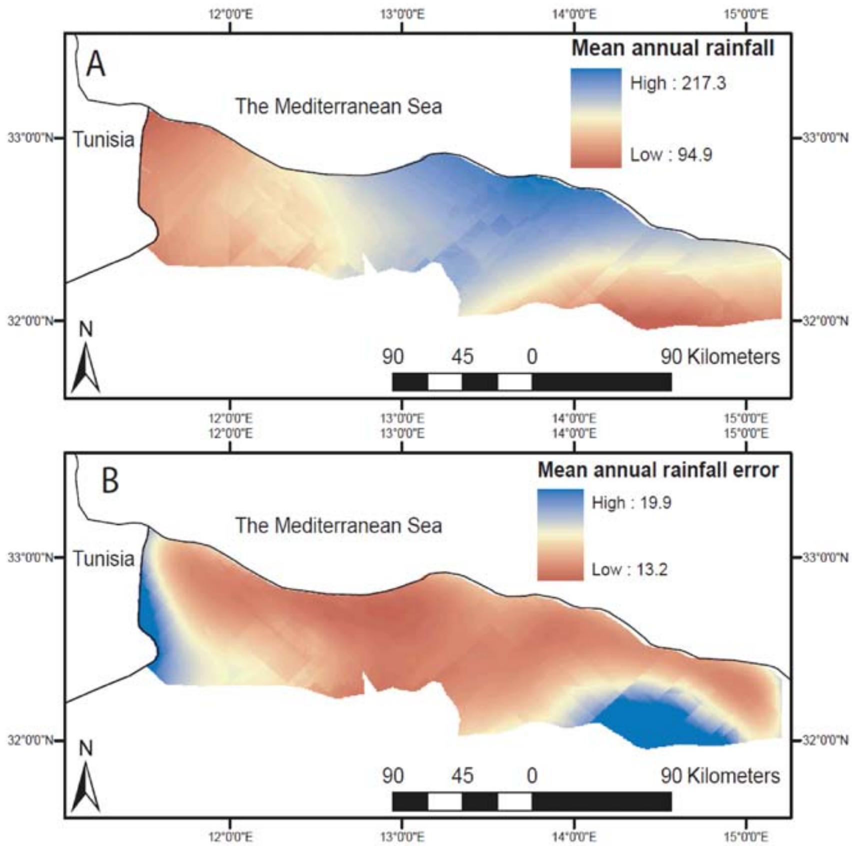


Fig. 6: Spatial distribution of mean annual rainfall (A) and its prediction of standard error using Ordinary Kriging (B)

the mean annual rainfall for each square kilometre in the area. Rainfall patterns were very different than those observed for temperature because rainfall increased markedly from south to north: from about 95 mm in to over 200 mm in the north of the study area Figure 6 (A). There are also rainfall "wet spots" are prevalent throughout the interpret these locations as areas near changes in elevation. These locations are found at the foot of Tarhuna Mountains in the southern middle part of the region.

In general the estimates of mean annual rainfall of north west Libya show a clear difference in the spatial distribution, it can be note that the patterns of rainfall observed across the region showed a general trend of decreasing rainfall from the north to south but there is a pocket of highest rainfall in the area is found on the area between Al Zawiyah in the west to Misratah in the east and it includes most of the mountains parts.

Accuracy of precipitation estimates is shown in Figure 6 (B) the standard errors of mean annual rainfall estimates were from 13 to 19 (mm) . It can be conclude that the estimate of mean annual rainfall is close to the actual values.

The estimates of mean annual rainfall patterns of the region suggest that older rainfall maps with broad rainfall regions did not adequately represent rainfall at the local scale.

**Prediction and Modelling of Mean Annual Evaporation:** Estimate map of evaporation Figure 7 (A) shows that the highest daily rates of evaporation are in the southern parts of the region especially in the south western part and they are decreasing toward to north.

There is a similar distribution of the spatial evaporation rates presented by evaporation map to a spatial distribution of temperature and rainfall rates in most of the parts which presented in Figures 5 and 6.

The accuracy of evaporation estimates is shown in Figure 7 (B) the mean standard error of temperature estimates recorded from 0.05 to 0.06 mm. The largest error was noted in the parts where there are not many stations.

**Prediction and Modelling of Mean Annual Humidity:** Figure 8 (A) shows the spatial distributions of mean annual humidity in North West of Libya. The highest humid values are found in the coast line about 65 % and

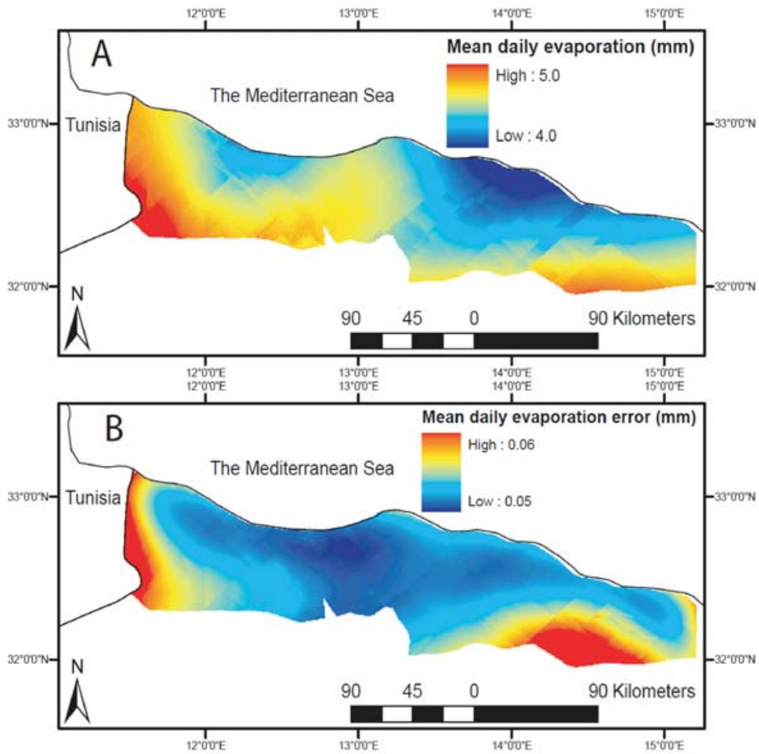


Fig. 7: Spatial distribution of mean annual evaporation (A) and its prediction of standard error using Ordinary Kriging (B)

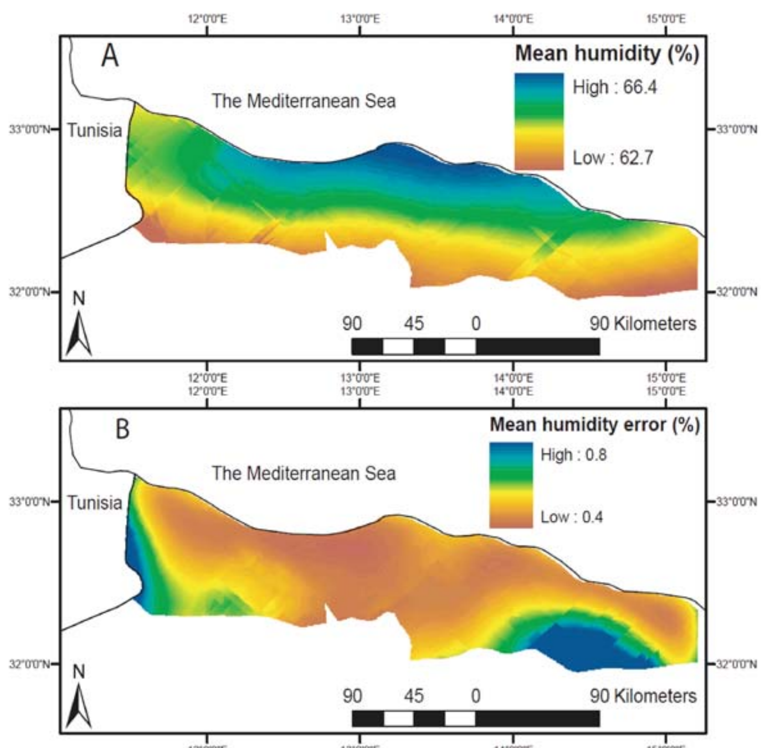


Fig. 8: Spatial distribution of mean annual humidity (A) and its prediction of standard error using Ordinary Kriging (B)

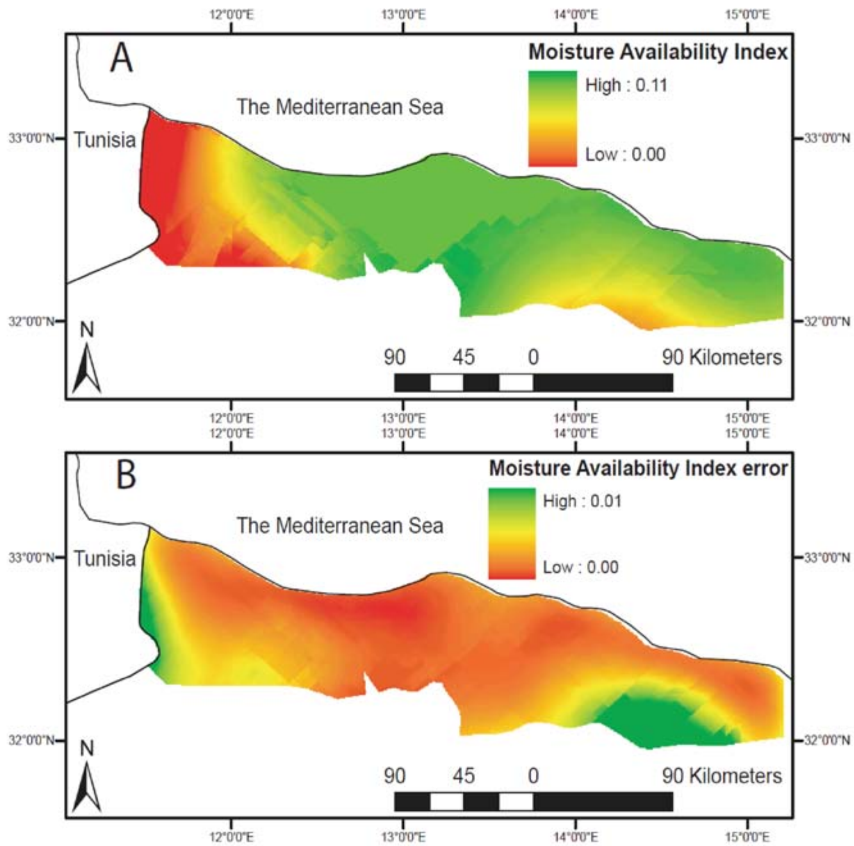


Fig. 9: Spatial distribution of mean annual moisture index (A) and its prediction of standard error using Ordinary Kriging (B)

it decreasing to warding to south. The higher values of humid found in the Northern parts and it decreases regularly to warding south to the south due to effecting of the Mediterranean Sea. Low humidity is the main cause of the high evaporation.

The accuracy of relative humid estimates is shown in Figure 8 (B) the mean standard error of the relative humid estimates recorded from 0.4 to 0.8%. The largest error was noted in the parts where there are not many stations.

**Prediction and Modelling of Mean Annual Moisture Availability Index:** Prediction and modelling of mean annual moisture availability index Moisture availability index map is created to provide an image that combined rainfall and evaporation rates. The moisture index values for the northern west area in Libya presents in Figure 9 (A), it shows that the spatial distribution of moisture availability index in agreement with the spatial distribution of rainfall, temperature and evaporation.

The estimate map of moisture availability index values are strongly related to UNEP, [18] climatic types and range from "semi arid" to "arid" and small area around Tripoli is moist sub humid.

Moisture index values indicate that there are pixels in the area with an annual water deficit. Although moisture index values are individually important, but even more informative could be provided when it provided an important union combined of rainfall and ETO.

Accuracy of moisture index values estimates is shown in Figure 9 (B) the standard errors of mean moisture index values estimates were from 0.0 to 0.1. It can be conclude that the estimate of mean annual moisture index values is close to the actual values.

## DISCUSSION

Brown and Comrie, [19] found that Kriging gave unbiased, optimal estimates based on the spatial correlation between values, but may produce too smooth a surface for this reason Kriging was chosen to create kriging maps for spatial distribution pattern of rainfall, temperature, humidity, evaporation and moisture availability index levels in the North West area of Libya from 1970 to 2000 depended on 100 standard meteorological stations were used in the investigation. This works due to the fact and it can capture local variations well and draws exactly to values at co-located grid points.

Kriging has been used for the interpolation of temperature and precipitation regression residuals across a wide region (the Mediterranean) by Agnew and Palutikof [20], while Holdaway [21] used residual kriging for the interpolation of temperature in a forest area and Goovaerts [13] used co-kriging to incorporate elevation into the mapping of rainfall.

**Conclusion and Suggestions:** The following conclusions and suggestions may be drawn from the study.

- A spatial distribution pattern of mean annual rainfall, temperature, humidity, evaporation and moisture availability index levels have similar regional distribution patterns in the North West of Libya. This distribution pattern provides valuable information for regional; this distribution pattern provides valuable information for regional planning on the environment, the agriculture and hydrological studies.
- There are similar patterns with reasonable estimation errors, as well as error estimations, which indicates the adequacy of the spatial models developed. Furthermore, a new approach based on XYZ kriging with zonal anisotropy in the Z direction has been applied with promising results.
- Climatic maps and their standard errors have generated in this study used each square kilometre for information for rainfall, temperature, humidity, evaporation and moisture availability index which can be helpful to use in solving problems pertaining to the management and regional planning on the environment, the agriculture and hydrological in the region.
- Climatic maps have generated in this study was an improvement over past methods. This study utilized the simple spatial properties of a location to estimate there climatic parameters. Climate estimates can be generated with ease. The programs used in this study can be either translated into other software packages, or they can be re-written to be used in most GISs currently on the market.
- Future the use of geostatistical techniques to generate a spatial distribution of climatic factors variability is a key aspect for every natural resources management in future directions of this research it can include the use of other variables in the multivariate kriging methods.
- Finally, it clear to conclude that using these techniques was satisfactory, since other predictive models had lower predictive power than (OK).

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