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Statistical Analysis of Records at Three Major Meteorological Stations in Jordan

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ملخص

يهتم هذا البحث بتحليل السجلات المطرية لمعدلات الهطول السنوي للأمطار لمحطات الأرصاد الجوية لعمان وإربد والمفرق. استخدمت عدة طرق رياضية إحصـــائية (Normal statistical, Harmonic and Power Spectrum and Time Series) لتحليـــل المعـــدلات السنوية للأمطار. أظهرت النتائج أن أكثر دورية محتملة هـــي ٣-٤ ســـنوات فـــي كافـــة المحطات، أما تحليل السلاسل الزمنية فأظهرت النتائج أنها مقاربة للقياسات الفعلية، وعليـــه يمكن استخدامه من قبل الدارسين أو متخذي القرار للتنبؤ بالقراءات المستقبلية.

Abstract

This article deals with the statistical analysis of the rainfall measurements for three meteorological stations in Jordan, Amman Airport (central Jordan), Irbid (northern Jordan) and Mafraq (eastern Jordan). Normal statistical, harmonic and power spectrum analysis as well as time series analysis were performed on the long-term annual rainfall measurements at the three stations. The result showed that the most expected cyclicity is in the order of ٣-٤ years in all the meteorological stations. A time series model for each station was adjusted, processed, diagnostically checked and lastly an ARIMA model for each station is established with a ٩٥٪ confidence interval. The results indicate a decreasing trend for forecasted rainfall results in all station.

Introduction:

Statistical analysis has been used to verify various hydrological parameters and to get an idea about future forecast of these parameters (Kitanidis and Bras, ١٩٨٠; John, ١٩٩٧;Shumway and Stoffer, ٢٠٠٠;Brockwell et al, ٢٠٠٠). Very little work dealing with rainfall forecasting had been carried out in Jordan. This

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encouraged the authors to carry out this study.

Three main meteorological stations were chosen to apply statistical tests on their data. These stations are Amman Airport, lrbid and Mafraq Meteorological Stations. These stations are located in the central, northern and eastern parts of Jordan respectively (Fig. ١). The rainfall records for these stations are the longest in Jordan where Amman, Irbid and Mafraq records dates back to ١٩٢٢, ١٩٣٧ and ١٩٦٧ respectively (Table ١). In addition, any successful statistical investigation on the records in these stations can be easily extended to other parts of Jordan

STATION SYMBOL	STATION NAME	LATIT. N	LONG. E	ELEVATION (ABOVE SEA LEVAL)(M)	STARTING RFCORDING YEAR
SYNP٠٠١٣	Amman A/P	٣١° ٥٩`	٣٥° ٥٩`	٧٧٩	١٩٢٢
AGRO٠٠٠٨	Irbid	٣٢٥٣٠`	٣٥٥٥١`	٦١٦	١٩٣٧
SYNP٠٠٢٣	Mafraq	٣٢° ٢٢`	٣٦° ١٥`	٦٣٨	١٩٦٧

Table ١: Location, Elevation and starting recording year of Amman A/P,Irbid and Mafraq meteorological stations .

The available annual rainfall records of these stations were subjected to power spectrum and harmonic analyses. In addition, time series tests and models were established. These tests were executed to set a forecasting model for other meteorological stations and to analyze the nature of the data recorded in each station. Furthermore, the cyclicity, if there is any or, periodicity of wet and /or dry years should be detected which helps in future planning.

٢. Nature of the data

As mentioned earlier annual rainfall records of Amman Airport, lrbid and Mafraq stations were used. The length of the record and nature of the data were different in all stations (JMD, ٢٠٠٠).

٢.١. Amman Airport Station

The length of the record used in this article covers the period ١٩٢٢/٢٣ – ٢٠٠٠/٢٠٠١. The plot of annual rainfall measurements against time (Fig. ٢) shows different degrees of fluctuation around the mean value. The maximum-recorded annual amount was ٥٤٧.٧ mm in ١٩٩١/٩٢ while the minimum recorded value was ١١٠.٥ mm recorded in ١٩٩٨/٩٩ (Table ٢).

٢.٢. Irbid Station

The recorded annual rainfall data in this station covers the period ١٩٣٧/٣٨-٢٠٠٠/٢٠٠١ (Fig. ٣). The plot of the annual records against time indicates that the data fluctuates are closer to the mean value relative to the data of Amman Airport Meteorological Station (Fمي ig ٣). The maximum and minimum recorded annual rainfall values are ٩١٢.٩ mm in ١٩٩١/٩٢ and ١٩٢.٥ mm in ١٩٤٦/٤٧ respectively (Table ٢).

٢.٣. Mafraq Station

The length of rainfall record of this station dates back to ١٩٦٧.The plot of the annual records against time shows close fluctuation to the mean value (Fig. ٤). The maximum and minimum recorded annual rainfall were ٢٩٩.٤mm (١٩٧٩/٨٠) and ٦٥.٤mm (١٩٩٨/٩٩) respectively (Table ٢).

STATION	MEAN (MM)	STD.DEV (MM)	MINIMUM (MM)	MAXIMUM (MM)
Amman A/p	٢٧٣.٧٨	٩١.٤١	١١٠ .٥	٥٤٧.٧
Irbid	٤٦٨.٥٤	١٥٢.٧٥	١٩٢ .٥	٩١٢.٩
Mafraq	١٤٧.٧	٥٥	٦٥.٤	٢٩٩.٤

Table ٢ : Mean, STD.DEV., MIN and MAX values Annual rainfall records of Amman A/P,Irbid and Mafraq meteorological stations .

٣. Normality of the Data

Amman Airport annual data showed a mean value of ٢٧٣.٧٨ mm while the calculated standard deviation was ٩١.٤١ mm. The same procedure was applied to Irbid Station with its mean, calculated to be ٤٦٨.٤٥ mm/year while the standard deviation was ١٥٢.٧٥ mm. Finally, Mafraq station annual data showed a mean value of ١٤٧.٧ mm/year and data calculated standard deviation of ٥٥ mm.

٤. Interrelation Between Stations

Correlation measures the strength and direction of the linear relationship between three random variables. The correlation coefficient for the measurements of annual rainfall records for all stations was calculated for the same period of the record. For this reason the three stations share rainfall measurements for the period ١٩٦٧ to ٢٠٠١. The results of the calculation indicate that the correlation coefficient (R) is greater than ٠.٨ (Table ٣), which suggests very good correlation (Chatfield, ١٩٩٢).

MAFRAQ	AMMAN A/P	IRBID	
٠.٨٠٨	٠.٨٢٧	١	Irbid
٠.٨٦٩	١		Amman A/P
١			Mafraq

Table ٣:Inter-Relationship between annual rainfall records forAmman A/P, Irbid and Mafraq meteorological stations.

٥. Time Series Model

A time series is an ordered sequence of observations. Although the ordering is usually through time, particularly in terms of some equally spaced time intervals, the ordering may also be taken through other dimension, such as space.

There are various objectives for studying time series. These include the understanding and description of the generating mechanism, the forecasting of future values, and optimal control of a system. The intrinsic nature of a time series is that its observations are dependent or correlated with the order of observation is therefore important.

Box and Jenkins (١٩٦٥ and ١٩٧٦) have popularized the use of certain models, called autoregressive moving averages (ARMA) and autoregressive integrated moving average (ARIMA) processes for modeling time series. We consider now these models: consider a time series realization of length n, denoted by {X١, X٢…Xn}, and let the back shift operator B be defined by

$$B_j X_t = X_{t-j}$$ j = ٠,١,٢,.... .....(١)

Now we can introduce the general ARIMA by

$$\Psi(B)(1-B)^d X_t = \theta_0 + \Theta(B) a_t$$ … (٢)

where

$$\Psi(B) = 1 - \phi_1 B - \phi_2 B^2 - ...... - \phi_p B^p , \quad ... (٣)$$

$$\Theta(B) = 1 - \theta_1 B - \theta_2 B^2 - ..... - \phi_q B^q \quad ... (٤)$$

θ_0 is a parameter related to the mean ى of the process {Xt}, by

$$\phi = \mu(1 - \phi - \phi - .... - \phi_p) \quad ...(٥)$$

and this process is called a white noise process, that is, a sequence of uncorrelated random variables from a fixed distribution (often Gaussian)

with constant mean E(at)= μa ,usually *assumed to be "zero" , constant variance* $V_m(a_t) = \sigma^2{}_a$ and covariance $Cov\,(a_t + a_t + k) =$ ٠ for all $k \neq$ ٠

The operator $\Psi(B)$ is called autoregressive operator, and the operator $\Theta(B)$ is called the moving average operator. When θ_0 ، $d \geq 1$ is called the deterministic trend term, and, is often omitted from the model unless it is really needed. The resulting model in equation (٢) has been referred to as the Autoregressive Integrated Moving Average model of order*) P, d, q (*and is denoted as the ARIMA *(p, d, q)* model. When $d = 0,$ it is called ARMA*) p, q (*model while when $d = 0$ and $d = 0,$ it is referred to as autoregressive of order *p* model and denoted by AR *(p).* When $p = 0$ and $d = 0,$ it is called Moving Average of order *q* model, and is denoted by MA (q). Examples of such model can be found in most time series analysis books, such as that of Chatfield (١٩٩٢).

The equation of the model cited above is one of the most commonly used models in time series analysis. The most crucial steps, in time series analysis, are to identify and build a model based on the available data. This requires a good understanding of the characteristics of the time series process in terms of their autocorrelation function (ACF) and partial autocorrelation function (PACF). In practice, these ACF and PACF are unknown, and for a given observed time series, they have to be estimated in order to identify the model. After identifying a tentative model. The next step is to estimate the parameters in the model. Once the parameters have been estimated we check on the adequacy of the model for the series. Very often several models can adequately represent a given time series. Thus, after diagnostic checking for the model, we select the best, according to some criteria. Model diagnostic checking is accomplished through careful analysis of the residual series. A useful test is the Portmanteau lack of fit test (Brockwell et al, ٢٠٠٠).

٦. Fitting ARIMA Processes to Data

As we pointed out, the value of ARIMA processes, as models for time-series analysis lies primarily in its ability to approximate a wide range of behavior processes using only a small number of parameters. For this reason, methodology for fitting ARIMA processes to time series data is of interest in its own right.

Fitting an ARIMA process to an observed time series proceeds in the following stages:

١- Identification of the order (p, d, q) of the ARIMA model.
٢- Estimation of the model parameters.
٣- Diagnostic checking of the fitted model.

We consider next each of these stages in turn.

٦.١ Model Identification

We consider the following ARIMA (p, d, q) model to illustrate the model identification

(١-٠١ B- …- ٠ pBp) (١-B)d Zt = ٠ ٠ + (١-٠١ B- …- ٠q Bq)at … (٦)

Model identification refers to the methodology of identifying the required transformation, such as variance stabilizing transformation and difference transformations, the decision to include the deterministic parameter ٠٠ when d ≥ ١, and the proper order of p and q for model.

The first stage in the identification of a time series is to examine a time plot at the data. Through careful examination of the plot, we usually get a good idea about whether the series contains a trend, seasonally outliers, no constant variances, and other non- normal and non- stationary phenomena.

The most commonly used transformations, in time series analysis, are variance-stabilizing transformation and difference. Since difference may create some negative value, we should always apply variance- stabilizing transformations before taking differences. A series with non- constant variance often needs a logarithmic transformation. More generally to stabilize the variance, we apply Box and Cox's (١٩٦٤) power transformation.

If the data appear to be stationary, no difference is needed, and we set d=٠ in the previous model identification equation (٦). If the data appear to be non-stationary, we successively difference the series until its time plot appears to be stationary. In practice, d = ١ or ٢ often suffices.

The next step is to compute and examine the sample autocorrelation function (SACF) and the partial autocorrelation function (PACF) of the properly transformed and difference series {yt } to identify the order of p and q. the kth sample into correlation function for the time series X١, X٢,…Xn, is defined as

$k = $k / $٠ k= ٠, ١, ٢, ٣….. …. (٧) where

$$\gamma_k = \sum_{t=1}^{n-k} (X_t - \overline{X})(X_{t+k} - \overline{X}) \quad ....(٨)$$

and

$$\overline{X} = \frac{1}{n} \sum_{t=1}^{n-k} X_i \quad .... (٩)$$

is the sample mean of the series. That is pk is the correlation between Zt and Zt+k for the same sequence separated only k time lags. A plot of $k is sometimes called a sample correlogram (Shumway and Stoffer, ٢٠٠٠).

Box and Jenkins (١٩٩٤), showed that for a white noise sequence {Xt } and for large n, the approximate sampling distribution of each $k is normal, with mean zero and variance ١/n. This Suggests using the limit ±٢/ n to assess individual pk for significant departure from zero. These limits are useful as a rough guide interpreting a correlogram, but should not be interpreted rigidly. Note in particular that successive $k are themselves correlated. The kth partial autocorrelation between Xt+١, Xt+k after their mutual linear dependency on the intervening variable Xt+١, Xt+k-١, …., has been removed is deported by Pk . The Pk (Box and Jenkins, ١٩٩٤) satisfies the set of equations.

$P_j = P_١ P_{j-١} + \ldots + P_k P_{j-k} j = ١, ٢, \ldots, k$ …. (١٠)

and can be computed through

$$P_k = \frac{\begin{vmatrix} 1 & \rho_1 & \rho_2 & \cdots & \rho_{k-2} & \rho_1 \\ \rho_1 & 1 & \rho_1 & \cdots & \rho_{k-1} & \rho_2 \\ \vdots & \vdots & \vdots & & \vdots & \vdots \\ \rho_{k-1} & \rho_{k-1} & \rho_{k-3} & \cdots & p_1 & \rho_k \end{vmatrix}}{\begin{vmatrix} 1 & \rho_1 & \rho_2 & \cdots & \rho_{k-2} & \rho_1 \\ \rho_1 & 1 & \rho_1 & \cdot\cdot & \rho_{k-3} & \rho_{k-2} \\ \vdots & \vdots & \vdots & & \vdots & \vdots \\ \rho_{k-1} & \rho_{k-2} & \rho_{k-3} & \cdots & p_1 & 1 \end{vmatrix}}$$ …..(١١)

It is useful and interesting to note that a strong duality exists between the AR and the MA models in terms of their.

We identify the orders *p* and *q* by matching the patterns in the sample ACF and PACF with the theoretical patterns of known models. If the ACF tails off as exponential decay or damped sine wave and the PACF cuts of after lag p, the appropriate model is AR (p). If the ACF cuts off after lag q and the PACF tails off as exponential decay or damped sine wave then the appropriate would is MA (q). If the ACF tails off after lag (q-p) and the PACF tails off after lag (p-q) then the appropriate model is ARIMA (q, p). See Box and Jenkins (١٩٩٤) for details.

The final step of model identifications is to test the deterministic trend term θ when $d > 0$. The Parameter θ_0 is usually omitted if difference is made to the time series. Otherwise we can test for its inclusion if there is a reason to believe that the difference series contains a deterministic trend mean.

٦.٢ Estimation of the Model Parameters

For a general ARMA (p, *d, q*) model given by (٦), or its equivalent ARMA (*p,q*) given by

$$(1-\phi_1 B-\ldots-\phi_P B^P)W_t=\theta_0+(1-\theta_1 B-\ldots-\theta_q B^q)a_t \qquad (١٢)$$

where $W_t=(1-B)^d Z_t$.

we are interested in estimating the parameters.

$$\theta_0,\overset{\smile}{\theta}=(\theta_1,\theta_2,\ldots,\theta_q),\overset{\smile}{\phi}=(\phi_1,\phi_2,\phi_3,\ldots,\phi_P),\sigma^2 a=E(a_t^{\,2})$$

in the model (١٢). We assume that we have *n* observed stationary or properly transformed stationery time series $\{W_t\}$ ،and $\{a_t\}$ are independent identically distributed *N*(٠، $\sigma_a^{\,2}$ ،) white noise**.**

There are several estimation procedures that are widely used to estimate the parameters of the ARMA model. See Box and Jenkins (١٩٩٤) chapter ٧, Wei (١٩٩٠), and Thirsted (١٩٨٨) for details of these procedures, with their algorithms.

The estimation process of the parameters of the model (١٢) involves *p+q+* ٢ parameters $\theta_0,\overset{\smile}{\theta},\overset{\smile}{\phi},$ ،and **.** $\sigma_a^{\,2}$ We consider below the maximum likelihood procedure to estimate these parameters.

Set, for simplicity $\sigma=\sigma_a^{\,2},\mu=\theta_0,$ then, (١٢) can be written in the form

$$Z_t=\mu+\sum_{i=1}^{P}\phi_i(Z_{t-i}-\mu)+\sum_{j=1}^{q}\theta_j a_{t-j}+a_t \qquad \ldots.(١٣)$$

Let $\overset{\smile}{Z}=(Z_1,\ldots,Z_n)^t$ and define a matrix $V(\overset{\smile}{\theta},\overset{\smile}{\phi})=$ such that

$$Var(\overset{\smile}{Z})=\sigma^2, \qquad V=\overset{\smile}{\theta},\overset{\smile}{\phi}) \qquad \ldots.(١٤)$$

The elements of $V=(\overset{\smile}{\theta},\overset{\smile}{\phi})$ are proportional to the autocorrelation coefficients of $\{\overset{\smile}{Z}\}$. Using the assumption of the normality of the white noise $\{a_t\}$, $\overset{\smile}{Z}$ has a multivariate normal distribution and the log-likelihood function of $\mu,\sigma^2,\overset{\smile}{\theta},$ and $\overset{\smile}{\phi}$ is

$$L(\mu,\sigma^2,\overset{\vee}{\phi},\overset{\vee}{\theta}=-\frac{n}{2}\left[\log\sigma^2+\log V(\overset{\vee}{\theta},\overset{\vee}{\phi})+\frac{1}{\sigma^2}Z\left[V(\overset{\vee}{\theta},\overset{\vee}{\phi})\right]^{-1}Z\right] \qquad \ldots(١٥)$$

Where $Z=\overset{\vee}{Z}-\mu_1$.

For given values of $\check{\theta}$ and ،ϕ the maximum likelihood estimates of μ and σ^2 are explicitly

$$\check{\mu}(\check{\theta},\check{\phi}) = \check{1}'\left[V(\check{\theta},\check{\phi})\right]^{-1}\check{Z} / \left[\check{1}'\left[V(\check{\theta},\check{\phi})\right]^{-1}\check{1}\right]$$ ….(١٦)

and

$$\sigma^2(\check{\theta},\check{\phi}) = n^{-1}\left[\check{Z} - \check{\mu}(\check{\theta},\check{\phi})\check{1}\right]'\left[Z(\check{\theta},\check{\phi})\right]^{-1}\left[Z - \check{\mu}(\check{\theta},\check{\phi})\check{1}\right]$$ …(١٧)

By substituting expression (١٦) and (١٧) back into (١٥), we obtain a reduced form of the log-likelihood

$$L(\check{\theta},\check{\phi}) = \frac{1}{n}\left[n\log a^2(\check{\theta},\check{\phi}) + \log V(\check{\theta},\check{\phi})\right]$$ ….(١٨)

That involves only θ and ،ϕ from which, maximum likelihood estimates $\check{\theta}$ and $\check{\phi}$ can be obtained by numerical maximization.

Efficient algorithms for computing the log-likelihood function to obtain the maximums likelihood estimates are widely available, such as Jones (١٩٨٠) or Brockwell (٢٠٠٠), as well as through the well – known statistical packages such as Minitab ,SPSS or ITSM and others.

٦.٣ Diagnostic Checking

After fitting a provisional ARIMA model, we can assess its adequacy in various ways. The usual approach is to extract from the data a sequence of residuals to correspond to the underlying, last unobservable, white noise sequence, and to check the statistical properties of these residuals are indeed consistent with white noise. A useful test in these concepts is the portmanteau lack of fit test. This uses the entire residual sample

Joint null hypothesis

Ho: $\rho_1 = \rho_2 = ... = \rho_k = 0$ …(١٩)

with the test statistic

$$Q = n(n+2)\sum_{j=1}^{k}\frac{\mu_j^2}{n-j} \qquad \ldots (٢٠)$$

where k is sufficiently large integer.

This test statistic is the modified Q statistic originally proposed by Box and Pierce (١٩٧٠). Under the null hypothesis of model adequacy, Ljung and Box (١٩٧٨) and Ansley and Newbold (١٩٧٩) show that the Q statistic is approximately follows the $\chi^2(k-m)$ distribution where m is the number of parameters estimated in the model.

٦.٤ Model Selection Criteria

In Time series analysis, there may be several adequate models that can be used to represent a given data set, and hence, numerous criteria for model comparison have been introduced in the literature for model selection.

Akaike (١٩٧٣, ١٩٧٤, ١٩٧٨) introduced a criterion called AIC (criterion) in the literature and is defined as

$$AIC(M) = n\ln a_a^2 + 2M \qquad \ldots (٢١)$$

Where M is the number of parameters in the model and n is the number of observations. The optimal order of the model is chosen by the value of M, which is a function of p and q, so that $AIC(M)$ is minimum. Schwarts (١٩٧٨) suggested a Byesian criterion called SBC (Schwartz's Bayesian Criterion) having the form

$$SBC(M = n\ln a_a^2 + M\ln n \qquad \ldots. (٢٢)$$

These are the same commonly used model selection criteria. Other criteria introduced in the literature can be found in Hannan (١٩٨٠), Brockwell et al (٢٠٠٠) and Shumway and Stoffer (٢٠٠٠).

٧. ARIMA Modeling

As we mention before, that certain steps has to be followed in order to model a time series data an ARIMA model. We are going to consider modeling as ARIMA model for each station measurements separately.

٧.١ Time Series Results:

Figures ٢,٣ and ٤, which reflect the yearly rainfall against time, show a general trend. This trend was removed to arrive to the desired time. Series that is stationary is mean and variance, i.e. no systematic change in mean (no trend) and variance. The results are given in Table ٤.

Therefore, we must remove the trend for the data to arrive to a stationary time series . $\{X^*_t\}$ Now, we compute and examine the sample ACF's and the sample PACF's of the transformed series to further confirm a necessary degree of difference. To do so, we examine the correleogram of the series, in which the sample ACF's and the sample PACF's is plotted against the lag k. Figures (٥,٦ and ٧) show correlogram of the transformed time data $\{X^*_t\}$ for all stations **.**Since the sample ACF tails off as damped sine wave after lag ٦ and the sample PACF out off after lag ٦ for Amman station, it indicates that the series is likely to be generated by an AR (٦) process. We estimate the parameters of the AR (٦) process by using the approximate maximum likelihood method, (see Box and Jenkins ١٩٧٦), to arrive to the model given Table ٤.

For Irbid station the fitted model was found to be of the type AR (٦) while for Mafraq station it was found to be of the type AR (٤). The models for all stations are given in Table ٤. The models given in Table ٤ can be used for forecasting the annual rainfall, which might occur in all the studied station with ٩٥٪ confidence level.

The models were tested for all the stations (Table ٥) for a period of ٥ years (١٩٩٦/٩٧– ٢٠٠٠/٢٠٠١/) and the AIC results (Table ٤) supported the results obtained. The general trend of the three forecasted annual rainfall results is decreasing (Fig.٨, ٩ and ١٠). Table (٦,٧ and ٨) show forecasted results for ٥ years period (٢٠٠١/٢٠٠٢, ٢٠٠٥/٢٠٠٦) for Amman, Irbid and Mafraq meteorological stations respectively. The general trend was negative showing decrease of annual rainfall with time in all stations under consideration. When the results obtained from this model are compared with data obtained in Jordan (e.g. Al-Ansari, et al, ١٩٩٩ and Smadi, ٢٠٠٣) the are more realistic and closer to actual measurements.

STATION	YEARS AND PERIOD OF RECORD	TREND COMPONENT	FITTED MODEL	AIC
Amman A/P	٧٩ ١٩٢٢-٢٠٠١	µt=٢٤٩.٠٣-٠.٥٠٦t	AR(٦) Z t=-٠.٠٨٦Zt-١-٠.١٠٣ Zt-٢+٠.٢٢١ Zt-٣+٠.٠٢٥Zt-٤+٠.٠٥٤Zt-٥-٠.٢٣ Z t-٦+at	٩٤٣.١ ٧
Irbid	٦٤ ١٩٣٧-٢٠٠١	µt=٥٠٧.٣٩-١.١٩٥٤t	AR(٦) Zt=٠.٠٢٦Zt-١-٠.٠٠٢ Zt-٢+٠.١٥١Z t-٣+٠.٠٩٧Zt-٤-٠.١٩٣ Z t-٥-٠.٢٣١Z t-٦+at	٧٣٤
Mafraq	٣٤ ١٩٦٧-٢٠٠١	µt=١٥٢.٨-٠.٢٩t	AR(٤) Zt=-٠.١١٢Zt-١-٠.٣٠٨Zt-٢- ٠.٢٠٢Zt-٣-٠.٣٥١ Zt-٤+at	٣٧٣

Table ٤: Fitted model of annual rainfall records of Amman A/P, Irbid and Mafraq meteorological Stations.

Station	Measured ١٩٩٦/٩٧	Predicted ١٩٩٦/٩٧	Measured ١٩٩٧/٩٨	Predicted ١٩٩٧/٩٨	Measured ١٩٩٨/٩٩	Predicted ١٩٩٨/٩٩	Measured ١٩٩٩/٠٠	Predicted ١٩٩٩/٠٠	Measured ٢٠٠٠/٠١	Predicted ٢٠٠٠/٠١
Amman A/p	١٦٧.٤	٢٦٩.٥	٢٥٨.٨	٢٤٩.٠٩	١١٠.٥	١٩٨.٦	١٧٢.١	٢٥٠.٢	١٧٨.٩	٢٢٧.٧
Irbid	٤٨٤.٣	٤٢٨.٣	٥٢٨.٩	٤٣٠.١	٢١٧.٣	٣٩٩.٢	٣٦٦.٣	٣٩٠.٠٧	٢٧٧.٦	٣٤٠.٨
Mafraq	١٨٥	١٦١.٨	١٨٢.٧	١٥٥.٧٨	٦٥.٤	١٢٣.٤٤	٩١.٦	١٤٩.٢٦	١٤٥.٨	١٥٤.٣

Table (٥) : Actual and predicted annual rainfall values from ١٩٩٦/٩٧to ٢٠٠٠/٢٠٠١ for Amman, Irbid and Mafraq meteorological stations.

YEAR	PREDICTED (MM)	SQRT (MSE)	٩٥٪ PREDICTION BOUNDS
٢٠٠١/٢٠٠٢	٢٠٨.٨	٨٥.٥	[١٩٠.٦٧,٢٢٦.٩٢]
٢٠٠٢/٢٠٠٣	١٩١.٥	٨٥.٨	[١٧٣.٣٤,٢٠٩.٩٢]
٢٠٠٣/٢٠٠٤	١٨٣.٤٤	٨٦.١	[١٦٥.٥٢,٢٠١.٦٣]
٢٠٠٤/٢٠٠٥	٢٣٢.٧٣	٨٨.٥١	[٢١٤.٢٩,٢٥١.١٧]
٢٠٠٥/٢٠٠٦	٢١٧.٤٢	٨٨.٥١	[١٩٨.٩٨,٢٣٥.٨٦]

Table ٦: Annual rainfall forecasting for Amman A/P meteorological station

YEAR	PREDICTED (MM)	SQRT (MSE)	٩٥٪ PREDICTION BOUNDS
٢٠٠١/٢٠٠٢	٤٠٢.٧	١٥٥.٠٣	[٣٧٧.٥٩,٤٢٦.٤]
٢٠٠٢/٢٠٠٣	٤٨٨.٥٢	١٥٥.٨٣	[٤٣٩.٧,٥١٣.٣]
٢٠٠٣/٢٠٠٤	٤٣٧.٣٣	١٥٥.٨٤	[٤١٢.٨٦,٤٦٢.٤٢]
٢٠٠٤/٢٠٠٥	٣٩٥.٣	١٥٦.٢٨	[٣٧٠.٧٩,٤٢٠.٠٠]
٢٠٠٥/٢٠٠٦	٤٥٤.٩	١٥٦.٣٣	[٤٣٠.٣٩,٤٧٩.٤]

Table ٧: Annual rainfall forecasting for Irbid meteorological station

YEAR	PREDICTED (MM)	SQRT (MSE)	٩٥٪ PREDICTION BOUNDS
٢٠٠١/٢٠٠٢	١٥٩.٦	٤٨.٧٢	[١٤٥.٩٢,١٧٣.٢٨]
٢٠٠٢/٢٠٠٣	١٧٦.٣	٤٩.٠٣	[١٦٧.٣,١٨٥.٣]
٢٠٠٣/٢٠٠٤	١٤٧.٠٧	٥١.١	[١٣٨.٠٧,١٥٦.٠٧]
٢٠٠٤/٢٠٠٥	١٢٥.٧٨	٥١.٥٢	[١١٦.٨١,١٣٤.٧٥]
٢٠٠٥/٢٠٠٦	١٢٦.٤٦	٥٢.٦٤	[١١٧.٣٥,١٣٥.٥١]

Table ٨: Annual rainfall forecasting for Mafraq meteorological station

٨. Harmonic and Power Spectrum Analyses (Theoretical Background):

The purpose of the harmonic analysis is to determine the magnitude of those components of the total variance of a record which have a fixed and well defined periodicity given by the length of the time-period analyzed divided by the number of the harmonic. Power spectrum analysis is used for the same purpose as in harmonic analysis but it gives the magnitude of these components, which are spread over a band of periodicities.

To apply the harmonic and power spectrum analysis the mean and standard deviation of the parameter should be calculated. Then linear regression is to be applied to find the time trend and the correlation coefficients. In the case where the trend is significant when evaluated by T-test, it should be removed before carrying out the harmonic and power spectral analysis according to Langguth and Voigt (١٩٨٠). Then the measure of time dependence is to be evaluated by an alternative estimate of the autocorrelation function (r_k), (where k is the lag number ranging from ٠ to N-١) using the following equation:

$$\Gamma_k = \frac{\sum_{t=1}^{N-k}(X_t - \overline{X}_t)(X_{t+k} - \overline{X}_{t+k})}{\left[\sum_{t=1}^{N-k}(X_t - \overline{X}_t)^2 (X_{t+k} - \overline{X}_{t+k})\right]^{1/2}} \quad ...(٢٣)$$

Where:

$\overline{X}_t$: mean of the first N-k values X١, X٢, …,X N-k.

$\overline{X}_{t+k}$: mean of the last N-k values Xk+١, Xk+٢, …,X N.

N : number of values used in statistical procedures.

The probability limits for the correlogram of an independent series was determined as follows:

$$\Gamma_k = \frac{-1 \pm \overline{\alpha}\sqrt{N-k-1}}{N-k} \quad ...(٢٤)$$

Where:

$\overline{\alpha}$ = ١.٩٦ for ٩٥٪ confidence level.

$\overline{\alpha}$ = ٢.٣٢٦ for ٩٩٪ confidence level

Then the correlogram can be drawn using r_k versus k with the probability limits (Chatfield, ١٩٩٢). The periodicity can be determined using harmonic analysis, which implies evaluation of Fourier coefficients A and B as:

$$A_w = \frac{2}{N}\sum_{i=1}^{N} X_i \sin(2\pi wi/N) \quad ...(٢٥)$$

$$B_w = \frac{2}{N}\sum_{i=1}^{N} X_i \cos(2\pi wi/N) \quad ...(٢٦)$$

The amplitude (H_w) of the harmonic w can be determined as follows:

$$H_w = ((A_W)^2 + (B_W)^2)^{1/2} \quad ... (٢٧)$$

The *phase* shift (θ_W) of the harmonic w can then be calculated using the following equation:

$= (\theta_W \ )Arctan\ (A_W / B_W)$ … (٢٨)

The percentage contribution of the harmonic w to the total variance is given by:

$$\%C\ of\ w = \begin{cases} (H_W)^2 / (2S^2) & when\ w < N/2 \\ (H_W)^2 / S^2 & when\ w = N/2 \end{cases} \quad \ldots (٢٩)$$

usually Fishers test is used to detect the significance of the periodicity (including long term components) by employing the following equation:

$$G = ٢S^٢ \left(\sqrt[m-1]{\frac{\alpha}{m}} - 1 \right) \quad \ldots (٣٠)$$

where:

m = N/٢

α = level of significance (٠.٠٥, ٠.٠١)

G = critical significance value.

Further investigations of the periodicity can be approached using power spectral analysis. The fourier transform values (V_k) for each lag is to be determined as:

$$V_k = \frac{z}{m-1}\left(C_0 + C_{m-1}\cos(k\pi) \pm 2\sum_{q=1}^{m-2} C_q \cos\left(\frac{qk\pi}{m-1}\right)\right) \quad \ldots (٣١)$$

where :

k = ٠, ١, ٢, □ m-١

z = ١/٢ for k = ٠ and k = m-١

z = ١ for k = ١, ٢, ٣, , m-٢

m = total number of lags.

and $$Cq = \frac{1}{N-q}\sum_{i=1}^{N-q}(X_i - \overline{X})(X_{i+q} - \overline{X}) \quad \ldots (٣٢)$$

It should be mentioned however that the number of lags should not exceed ٢٠٪ of the number of observations. The percentage contribution of lag k can be determined through:

$$\%C = \frac{V_k}{\sum_{i-0}^{m-1} V_i} \quad \ldots (٣٣)$$

The nominal (main) frequencies (p) for each of the calculated bands can be found by:

$$P_k = \frac{2(m-1)\Delta t}{k} \quad \ldots (٣٤)$$

And the periodicity band (rang) corresponding to the lag number k is considered as:

$$\left[\frac{2(m-1)}{k-1} + \frac{2(m-1)}{k+1}\right] \quad \ldots (٣٥)$$

٨.١ Results of Spectral Analysis:

The harmonic and power spectrum results applied for the studied stations are given in Table ٨ and Figures ٨.٩ and ١٠. For Amman stations the results show two main peaks of frequency ٠.٥٣ π and ٠.٧٩ .π This indicates the periodicity close to ٢.٣ years to ٣.٤٥ years. Irbid and Mafraq stations results were similar to those for Amman (two main peaks) showing periodicity of ٢.٥-٣.٤ years. For Irbid station while it was ٢.٤٤-٤.١ years for Mafraq. All the details are given in Table ٩.

Stations	Frequency(F)	Period of rainfall cycle(year) (٢π/F)
Amman A/P	٠.٥٨π ٠.٨٨π	٣.٤٥ ٢.٣
Irbid	٠.٥٣π ٠.٧٩π	٣.٤ ٢.٥
Mafraq	٠.٤٩π ٠.٨٢π	٤.١ ٢.٤٤

Table (٩): Frequency and period of rainfall cycle for Amman, Irbid and Mafraq meteorological stations.

٩. Conclusions:

Generally, long-term annual rainfall records in Jordan can be used to calculate the periodicity and future forecasting specially in areas where no local convective storms taking place. Three main stations (Amman A/P, Irbid and Mafraq Meteorological stations) were chosen due to their long-term rainfall records and location.

Full agreement of ARIMA model for Amman Irbid and Mafraq Meteorological Stations between the forecasted and actual field measurements of rainfall occurred on both areas. These results were obtained with ٩٥٪ confidence limit. The results showed general annual rainfall decease with time.

Two main peaks of periodicity were noticed in all the individual studied station. They show that a possible periodicity of the order of ٢.٣ - ٣.٤٥, ٢.٥ - ٣.٤ and ٢.٤٤-٤.١ years for Amman, Irbid and Mafraq stations respectively. The correlation between the stations was very good probably due to the nature of the records and very close attitude of the studied stations.

The results are to be used to give an idea about future forecasting and can serve as an excellent base for the researchers, planners and decision makers for better future activities in sustaining the water resources and agricultural productivity. Furthermore, water management schemes can be operated using forecasted data. It should be mentioned, however, that the models could be continuously developed with time on annual basis whereas; more precise results can be obtained when longer data records are to be used.

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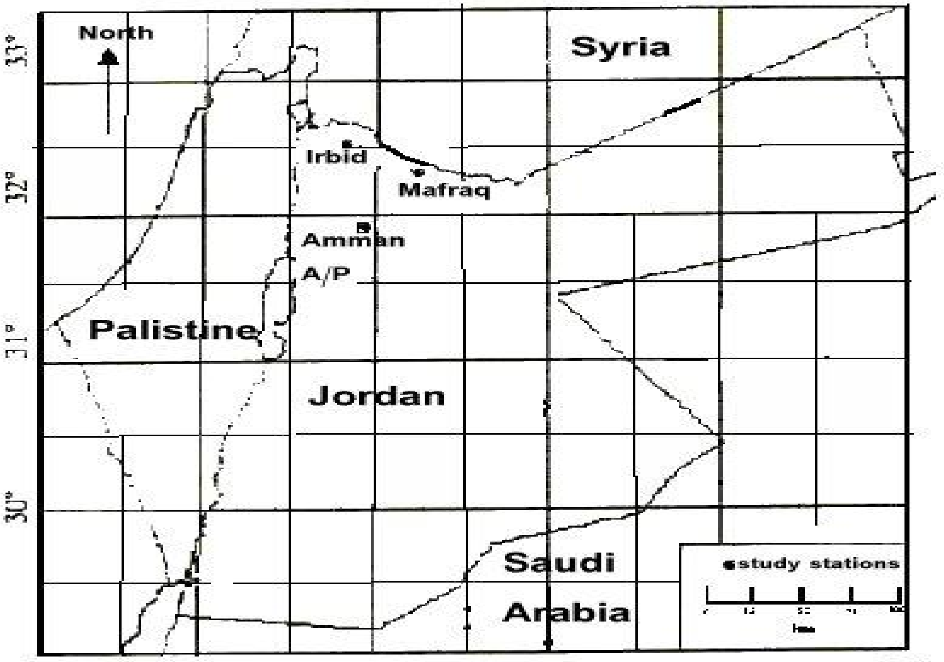

- Fig.(١) :Location map of the studied meteorological staions

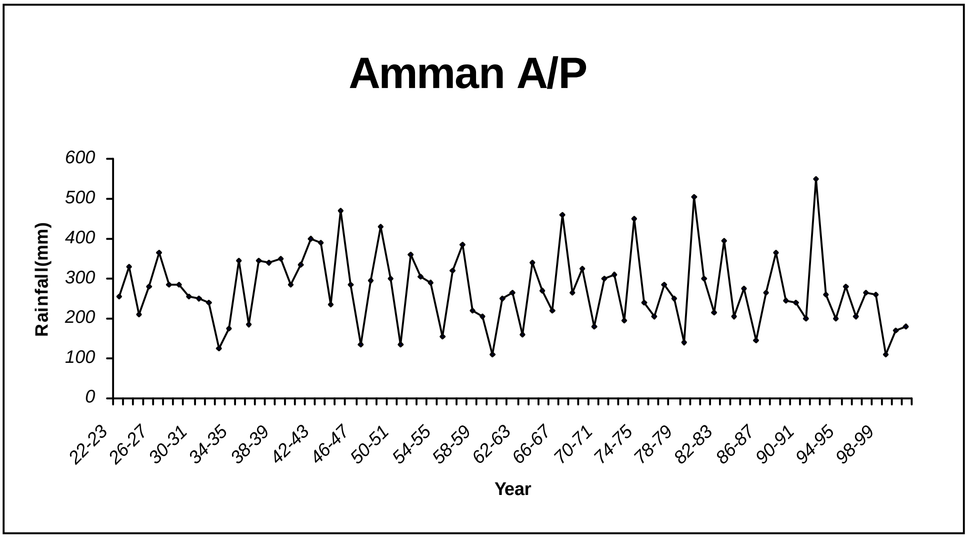

Fig. ٢ : Fluctuations of annual rainfall records of Amman A/P meteorological station.

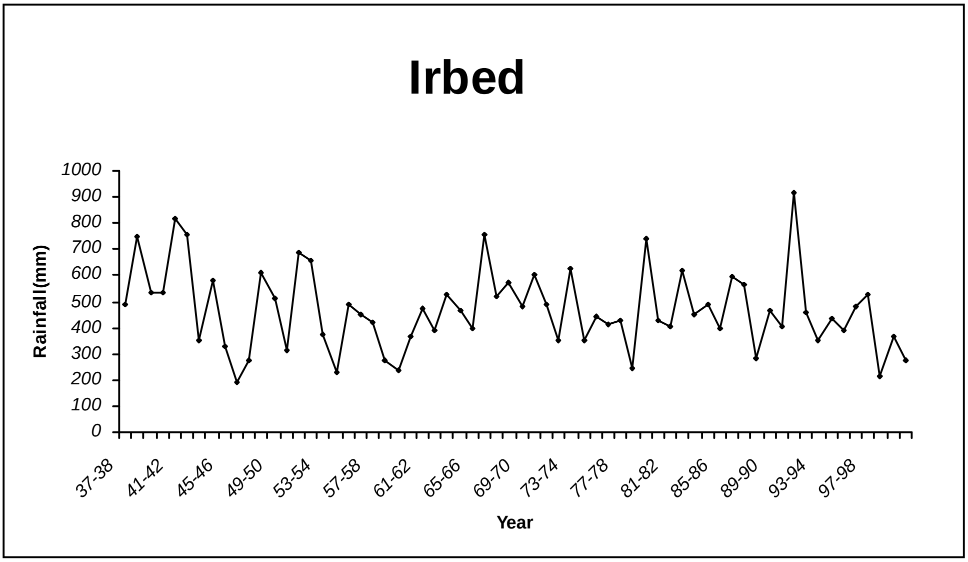

Fig. ٣ : Fluctuations of annual rainfall records of Irbed meteorological station.

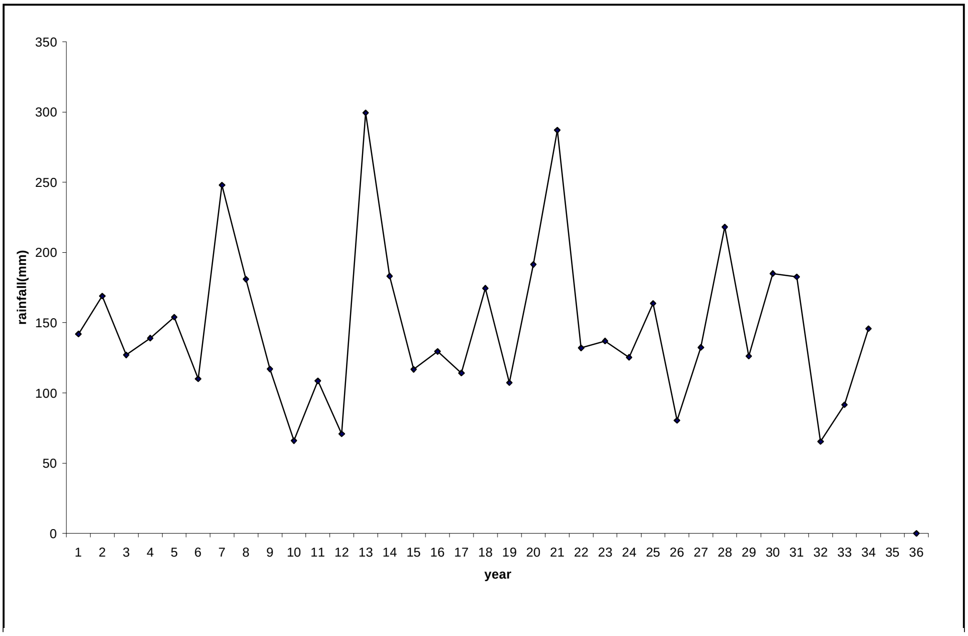

Fig. ٤: Fluctuations of annual rainfall records of Mafraq meteorological station.

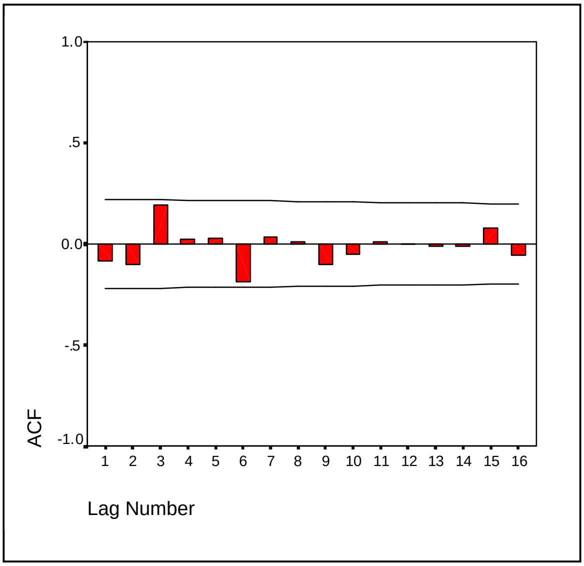

Fig.(٥.a): Autocorrelation diagram of Amman A/P meteorological station

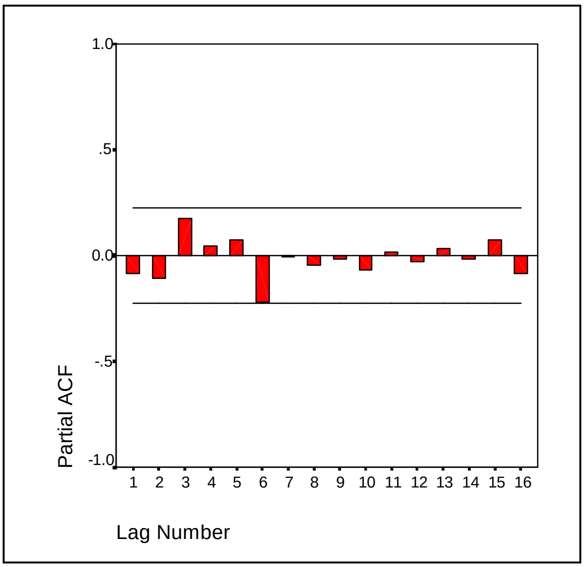

Fig.(٥.b): Partial autocorrelation diagram of Amman A/P meteorolegical station

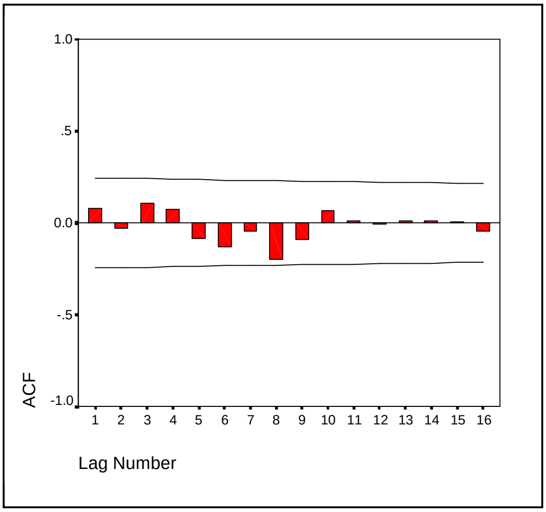

Fig.(٦.a): Autocorrelation diagram of Irbid meteorological station

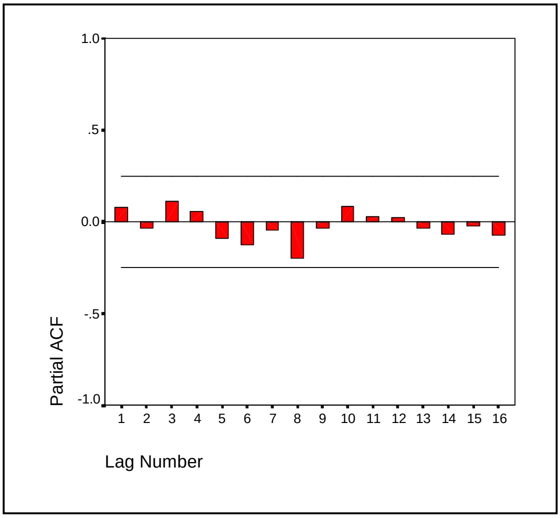

Fig.(٦.b) : Partial autocorrelation diagram of Irbid meteorological station.

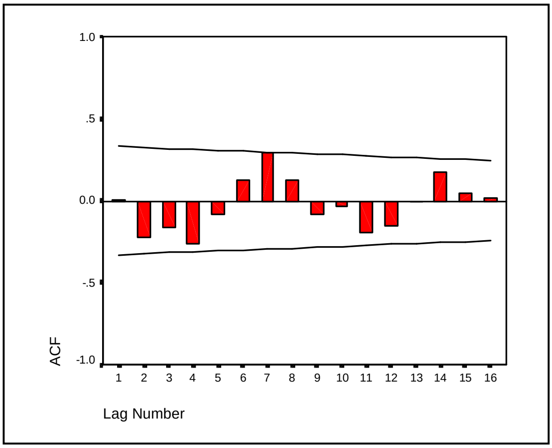

Fig.(٧.a):Autocorrelation of Mafraq meteorological station

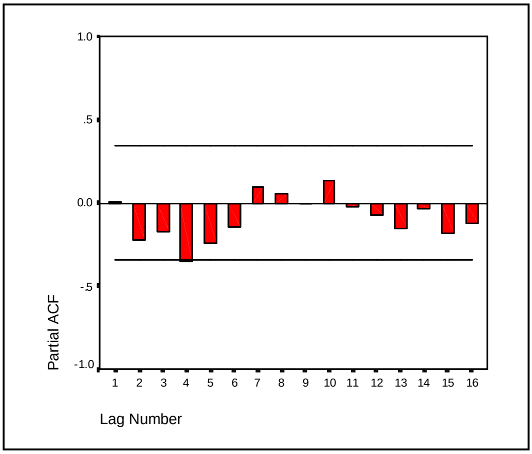

Fig.(٧.b):Partial autocorrelation of Mafraq meteorological station

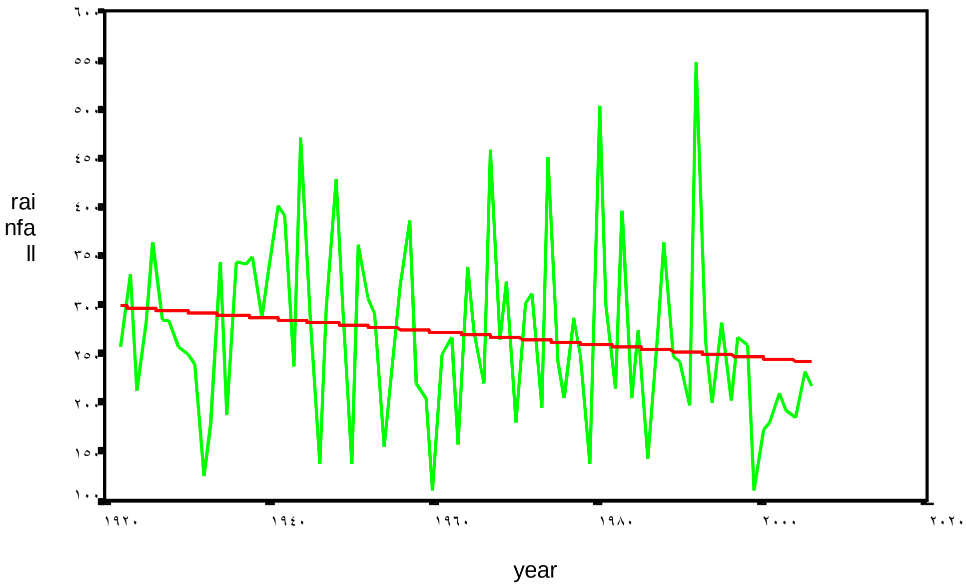

Fig.(٨) :shows the trend of annual rainfall record (١٩٢٢/٢٣-٢٠٠٥/٢٠٠٦) for Amman meteorological station

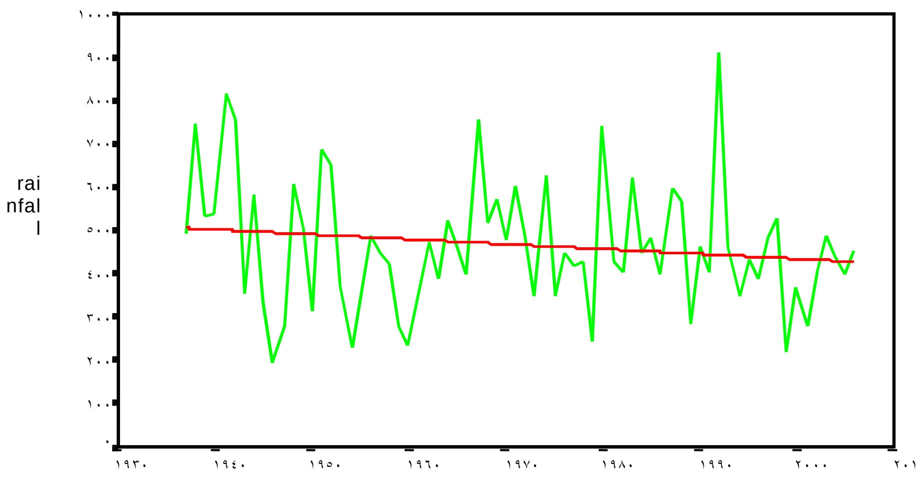

Fig.(٩):shows the trend of annual rainfall record (١٩٣٧/٣٨-٢٠٠٥/٢٠٠٦) for Irbid meteorological station

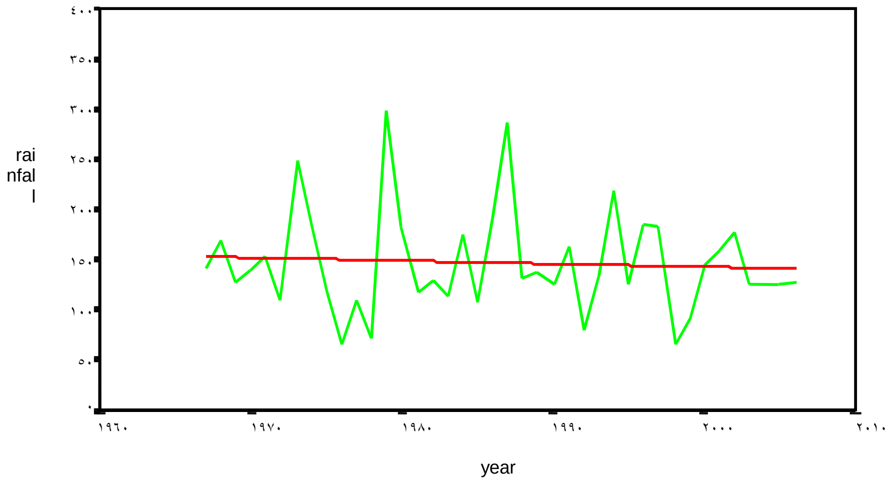

Fig.(١٠) :shows the trend of annual rainfall record (١٩٦٧/٦٨-٢٠٠٥/٢٠٠٦) for Mafraq meteorological station

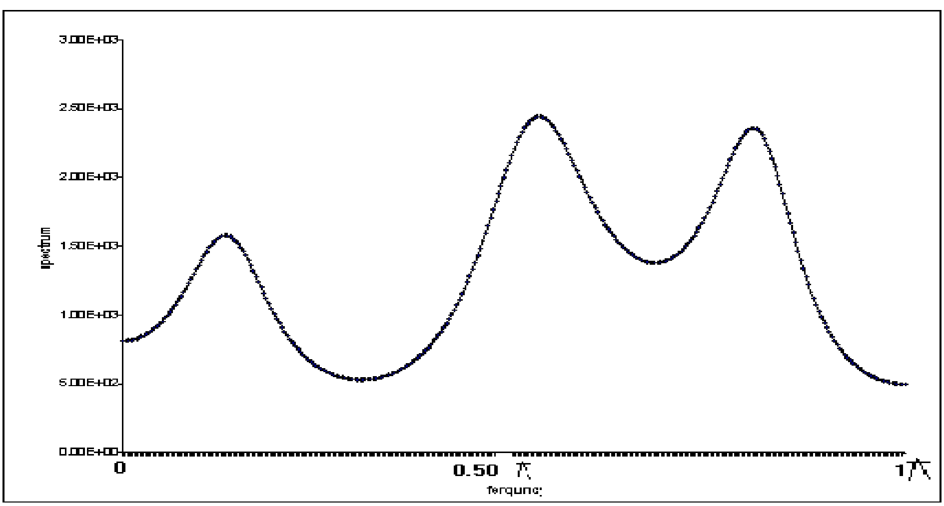

Fig.(١١):The spectral density of Amman A/P Meteorological station

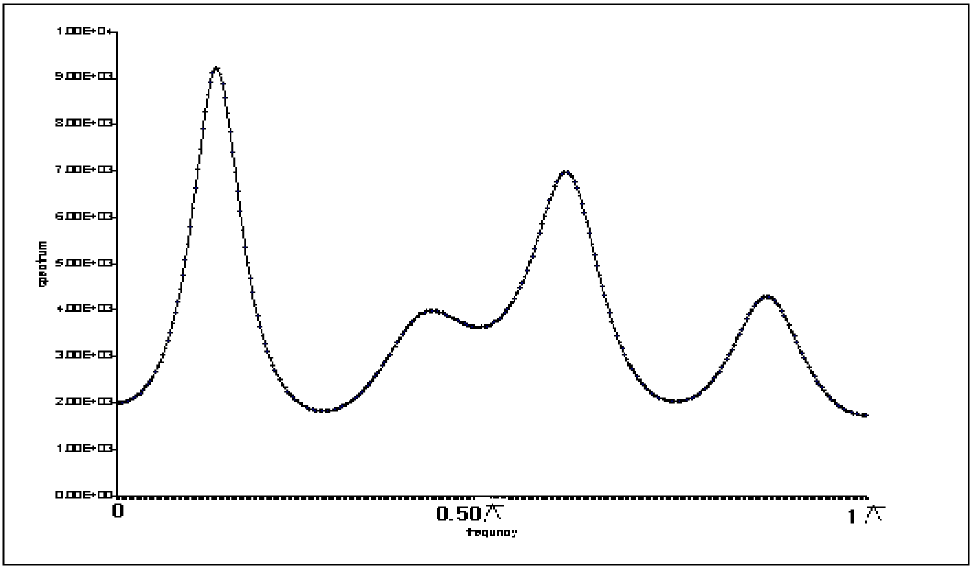

Fig.(١٢):The spectral density of Irbid Meteorological station

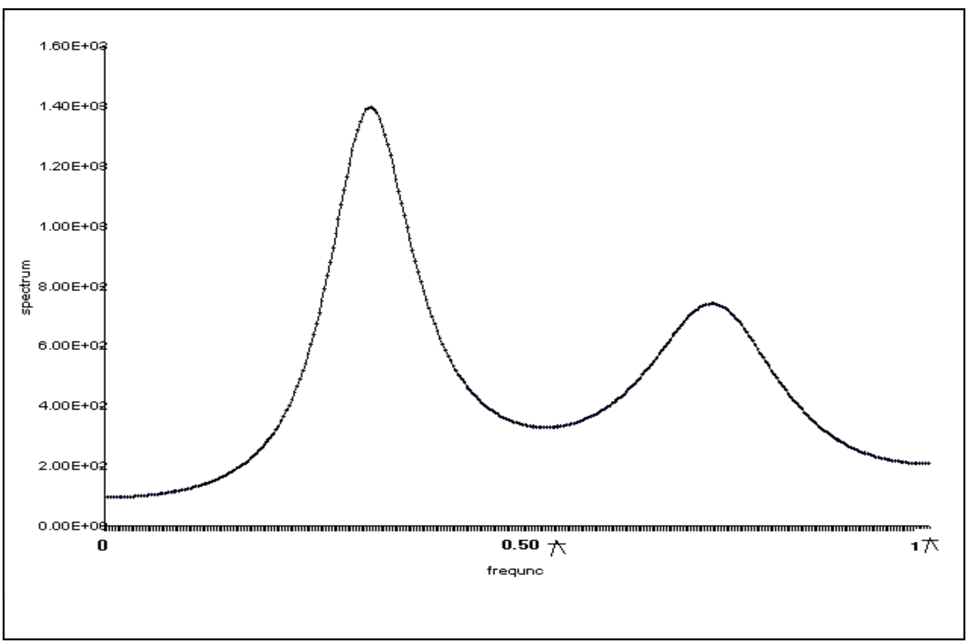

Fig.(١٣):The spectral density of Mafraq Meteorological station