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A SEASONAL ARIMA MODEL FOR FORECASTING MONTHLY RAINFALL IN GEZIRA SCHEME, SUDAN

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ABSTRACT

Monthly rainfall in the Gezira irrigation scheme of Sudan is being modelled by Seasonal Autoregressive Integrated Moving Average (SARIMA) methods. The realization analyzed is from 1971 to 2000. A visual inspection of the time plot gives the expected impression of a generally horizontal trend and 12-month seasonal periodicity. The Augmented Dickey-Fuller (ADF) Test adjudges the series as stationary. However its correlogram gives a contrary impression of non-stationarity. A seasonal (i.e. 12-point) differencing yields a stationary series on ADF test and correlogram grounds. On the basis of its correlogram three models are proposed and fitted: 1) A SARIMA(0, 0, 0)x(0, 1, 1)$_{12}$ model; 2) A SARIMA(0, 0, 1)x(0, 1, 1)$_{12}$ model; 3) A SARIMA(0, 0, 1)x(2, 1, 1)$_{2}$ model. On minimum AIC grounds, the SARIMA(0, 0, 0)x(0, 1, 1)$_{12}$ model is adjudged the most adequate. This model adequacy claim is further corroborated by a residual analysis. This may be used as basis for rainfall forecasting for planning purposes in the region.

KEY WORDS: Gezira Scheme, Sudan, Medina Rainfall Station, Monthly rainfall, SARIMA modelling, Seasonal Time series.

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INTRODUCTION

In the Gezira state in Sudan, which is an arid/semi-arid region, the prediction of rainfall is extremely important for proper management of irrigation, droughts and water demand by different sectors. The physical area considered in this study is located in Central Sudan.

Gezira scheme is the largest irrigation scheme in Sudan. It extends from the Sennar Dam to the Green Belt at Khartoum, a distance of about 300 km with a total area of 2 million feddans. It has good fertile soils and relatively high rainfall intensities. The farming of cotton, sorghum, wheat and groundnuts covers much of the region land. The region is very important for the economy of Sudan. The Gezira scheme is irrigated by gravity or artificial irrigation and partially by rains. The scheme is supplied with water from the Sennar reservoir on the Blue Nile.

Madani is the capital of the Gezira State. It lies on the West Bank of the Blue Nile, nearly 136 km south east of Khartoum, at an elevation of 411 metres. It has good railway and road connections with Khartoum and it is the centre of a cotton-growing region. The city is also the centre of local trade in wheat, barley and livestock. It is also the headquarters of the Irrigation Service.

Madani rainfall station data may be considered to represent a large part of the Gezira scheme.

The Wad Madani station is characterized by annual rainfall of 115-443 mm during the last four decades. The annual number of rainy days (rainfall > 1 mm) is 60 days and the mean annual reference potential evapotranspiration (ET_o) using Penman/Monteith criterion for this station is about 2535mm [1]. Time series analysis conducted using monthly and long-term annual rainfall for the Wad Medani station shows that there has been a gradual decrease in the monthly and annual rainfall during the period of 1940 to 2004 ([2]).

The mean temperature series over the period 1941-1996 for many meteorological stations across Sudan, including Wad Madani, was examined, on seasonal and annual bases to explore any possible trends in recent decades, by Elagib and Mansell [3]. They found that for the hot season the onset of recurrent above-normal temperature anomalies occurred in the late 1960s in the Wad Madani station. The station also shows trends of standardized anomaly indices (SAIs) towards conditions since the mid-1980s.

This write-up is aimed at modelling monthly rainfall records obtained from Medani station by seasonal autoregressive integrated moving average (SARIMA) techniques. Rainfall is a seasonal phenomenon of period 12 months. A seasonal time series like that may be modelled by SARIMA methods. SARIMA modelling has been extensively applied to model seasonal time series. A few researchers that have modelled seasonal time series are Adanacioglu and Yercan [4], Hu et al. [5], Shiri et al. [6], Wongkoon et al. [7], Fannoh et al. [8], Chang et al. [9], Ali et al. [10], Khol et al. [11], Moosazadeh et al. [12], Eni et al. [13], Wongkoon et al. [14], Etuk et al.[15] and Etuk [16]. Etuk and Mohamed [17] fitted a SARIMA(0,0,0)x(0, 1, 1)$_{12}$ model to monthly rainfall data from the Gadaref rainfall station in Sudan.

MATERIALS AND METHODS

Data:

For this study, rainfall data were obtained from the Sudan Meteorological Authority (SMA), for the period 1971 – 2010 from Medani station. The monthly rainfall records for Medani station show most of the rainfalls in the period from June to September, and reach its peak in August.

Sarima Models:

A stationary time series $\{X_t\}$ is said to follow an autoregressive moving average model of orders p and q, denoted by ARMA(p, q), if it satisfies the following difference equation

$$X_t - \alpha_1 X_{t-1} - \alpha_2 X_{t-2} - \dots - \alpha_p X_{t-p} = \varepsilon_t + \beta_1 \varepsilon_{t-1} + \beta_2 \varepsilon_{t-2} + \dots + \beta_q \varepsilon_{t-q} \quad (1)$$

Here the α's and β's are constants such that the model is both stationary and invertible.

Moreover, the sequence of random variables $\{\varepsilon_t\}$ is a white noise process. Equation (1) may be put as

$$A(L)X_t = B(L)\varepsilon_t \quad (2)$$

Here $A(L) = 1 - \alpha_1 L - \alpha_2 L^2 - \dots - \alpha_{pL}{}^p$ and $B(L) = 1 + \beta_1 L + \beta_2 L^2 + \dots + \beta_q L^q$ and L is the backward shift operator defined by $L^k X_t = X_{t-k}$. It is well known that for stationarity and invertibility of model (1) the roots of A(L) = 0 and B(L) = 0 must lie outside the unit circle respectively.

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Most real-life time series are not stationary. Box and Jenkins [18] proposed that a stationary time series may be made stationary after differencing if up to a sufficient order. Suppose this minimum order of differencing necessary for stationarity of the series $\{X_t\}$ is d, the d^{th} difference is denoted by $\{\nabla^d X_t\}$ where ∇ is the difference operator defined by $\nabla = 1 - L$. If $\{\nabla^d X_t\}$ follows an ARMA(p, q) model the original series $\{X_t\}$ is said to follow an *autoregressive integrated moving average model of order p, d and q* and is denoted by ARIMA(p, d, q) model.

If a time series is seasonal of period s, Box and Jenkins [18] made a proposal that such a model may be modelled by

$$A(L)\Phi(L^s)\nabla^d\nabla_s^D X_t = B(L)\Theta(L^s)\varepsilon_t \quad (3)$$

Here $\Phi(L)$ and $\Theta(L)$ are polynomials in L with coefficients such that the model is both stationary and invertible. The operator ∇_s is the seasonal difference operator defined by $\nabla_s = 1 - L^s$. If for $\{X_t\}$ these seasonal autoregressive and moving average operators are of degree P and Q respectively, the time series is said to follow a *seasonal autoregressive integrated moving average model of order p, d, q, P, D, Q and s* denoted by SARIMA(p, d, q)x(P, D, Q)$_s$.

TABLE 1: ESTIMATION OF SARIMA(0, 0, 0)X(0, 1, 1)$_{12}$ MODEL

Dependent Variable: SDMASR
Method: Least Squares
Date: 05/13/14 Time: 19:44
Sample(adjusted): 1972:01 2010:12
Included observations: 468 after adjusting endpoints
Convergence achieved after 12 iterations
Backcast: 1971:01 1971:12

Variable	Coefficient	Std. Error	t-Statistic	Prob.
MA(12)	-0.885833	0.019878	-44.56370	0.0000

R-squared	0.517420	Mean dependent var	-0.223291
Adjusted R-squared	0.517420	S.D. dependent var	40.28285
S.E. of regression	27.98367	Akaike info criterion	9.503254
Sum squared resid	365701.1	Schwarz criterion	9.512118
Log likelihood	-2222.761	Durbin-Watson stat	1.983833

Inverted MA Roots	.99	.86+.49i	.86 -.49i	.49+.86i
	.49 -.86i	.00 -.99i	-.00+.99i	-.49 -.86i
	-.49+.86i	-.86 -.49i	-.86+.49i	-.99

Order Determination:

Estimation of a Box-Jenkins model is preceded by its identification. Firstly the model orders p, d, q, P, D, Q and s are to be determined. The seasonal period s may be obvious from the nature of the time series. This is the case with monthly rainfall data for which the period s is equal to 12 all over the world. Moreover the correlogram of a seasonal series shows a sinusoidal outlook with a positive maximum at lags of integral multiples of s. The non-seasonal difference order d and its seasonal counterpart D are often chosen such that the sum up to at most 2 to ensure stationarity. Stationarity was checked using the Augmented Dickey- Fuller (ADF) Test.

The non-seasonal autoregressive order p and its seasonal counterpart P are chosen by the non-seasonal cut-off lags of the partial autocorrelation function (PACF) respectively. Similarly, the moving average orders q and Q are chosen by the non-seasonal and the seasonal cut-off lags of the autocorrelation function (ACF) respectively.

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TABLE 2: ESTIMATION OF SARIMA(0, 0, 1)X(0, 1, 1)$_{12}$ MODEL

Dependent Variable: SDMASR
Method: Least Squares
Date: 05/13/14 Time: 19:47
Sample(adjusted): 1972:01 2010:12
Included observations: 468 after adjusting endpoints
Convergence achieved after 19 iterations
Backcast: 1970:12 1971:12

Variable	Coefficient	Std. Error	t-Statistic	Prob.
MA(1)	0.043531	0.044675	0.974394	0.3304
MA(12)	-0.872021	0.000201	-4340.186	0.0000
MA(13)	-0.043932	0.045098	-0.974153	0.3305

R-squared	0.514384	Mean dependent var	-0.223291
Adjusted R-squared	0.512296	S.D. dependent var	40.28285
S.E. of regression	28.13186	Akaike info criterion	9.518072
Sum squared resid	368001.8	Schwarz criterion	9.544665
Log likelihood	-2224.229	F-statistic	246.2738
Durbin-Watson stat	2.063784	Prob(F-statistic)	0.000000

Inverted MA Roots	.99	.86+.49i	.86 -.49i	.49 -.86i
	.49+.86i	.00+.99i	.00 -.99i	-.05
	-.49 -.86i	-.49+.86i	-.86+.49i	-.86 -.49i
	-.99			

TABLE 3: ESTIMATION OF SARIMA(0, 0, 1)X(2, 1, 1)$_{12}$ MODEL

Dependent Variable: SDMASR
Method: Least Squares
Date: 05/13/14 Time: 19:39
Sample(adjusted): 1974:01 2010:12
Included observations: 444 after adjusting endpoints
Convergence achieved after 13 iterations
Backcast: 1972:12 1973:12

Variable	Coefficient	Std. Error	t-Statistic	Prob.
AR(12)	-0.187110	0.056191	-3.329869	0.0009
AR(24)	0.052568	0.057150	0.919834	0.3582
MA(1)	0.024098	0.030750	0.783683	0.4336
MA(12)	-0.831504	0.033836	-24.57431	0.0000
MA(13)	-0.065957	0.033865	-1.947649	0.0521

R-squared	0.526831	Mean dependent var	0.061261
Adjusted R-squared	0.522520	S.D. dependent var	40.87075
S.E. of regression	28.24166	Akaike info criterion	9.530671
Sum squared resid	350142.6	Schwarz criterion	9.576795
Log likelihood	-2110.809	F-statistic	122.1969
Durbin-Watson stat	2.037615	Prob(F-statistic)	0.000000

Inverted AR Roots	.88+.24i	.88 -.24i	.86	.74+.43i
	.74 -.43i	.65+.65i	.65 -.65i	.43 -.74i
	.43+.74i	.24 -.88i	.24+.88i	.00 -.86i
	.00+.86i	-.24 -.88i	-.24+.88i	-.43 -.74i
	-.43+.74i	-.65 -.65i	-.65+.65i	-.74+.43i
	-.74 -.43i	-.86	-.88+.24i	-.88 -.24i
Inverted MA Roots	.99	.99	.86+.49i	.86 -.49i
	.50+.85i	.50 -.85i	.00+.98i	.00 -.98i
	-.08	-.49+.85i	-.49 -.85i	-.85+.49i
	-.85 -.49i			

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Parameter Estimation:

Sequel to order determination is the need to estimate the parameters of the model (3). The involvement of members of the white noise process in the model makes it imperative to adopt a non-linear optimization technique for its estimation. A few of such techniques include the least squares techniques, the maximum likelihood technique and the maximum entropy technique.

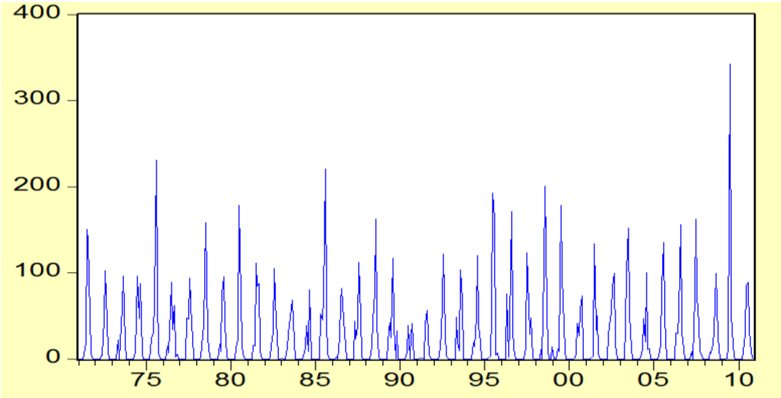
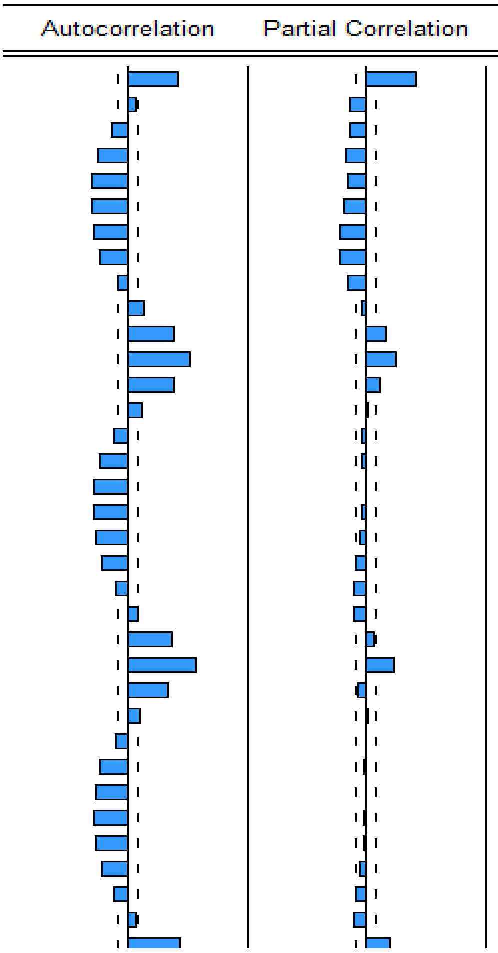


FIGURE 1: MASR



	AC	PAC	Q-Stat	Prob
1	0.428	0.428	88.671	0.000
2	0.071	-0.138	91.115	0.000
3	-0.132	-0.134	99.523	0.000
4	-0.265	-0.179	133.59	0.000
5	-0.304	-0.153	178.47	0.000
6	-0.309	-0.190	224.93	0.000
7	-0.299	-0.229	268.69	0.000
8	-0.243	-0.233	297.57	0.000
9	-0.091	-0.156	301.66	0.000
10	0.132	-0.036	310.19	0.000
11	0.400	0.173	389.16	0.000
12	0.540	0.254	533.18	0.000
13	0.400	0.131	612.55	0.000
14	0.125	0.024	620.37	0.000
15	-0.120	-0.031	627.51	0.000
16	-0.253	-0.026	659.44	0.000
17	-0.289	-0.008	701.08	0.000
18	-0.295	-0.026	744.66	0.000
19	-0.283	-0.048	784.74	0.000
20	-0.237	-0.093	812.90	0.000
21	-0.109	-0.107	818.87	0.000
22	0.089	-0.111	822.87	0.000
23	0.378	0.067	895.16	0.000
24	0.592	0.252	1073.0	0.000
25	0.357	-0.060	1137.8	0.000
26	0.106	0.009	1143.6	0.000
27	-0.101	-0.005	1148.8	0.000
28	-0.242	-0.020	1178.8	0.000
29	-0.280	-0.003	1219.0	0.000
30	-0.289	-0.020	1261.9	0.000
31	-0.280	-0.024	1302.1	0.000
32	-0.230	-0.045	1329.5	0.000
33	-0.116	-0.084	1336.5	0.000
34	0.072	-0.103	1339.1	0.000
35	0.447	0.197	1442.8	0.000

FIGURE 2: CORRELOGRAM OF MASR

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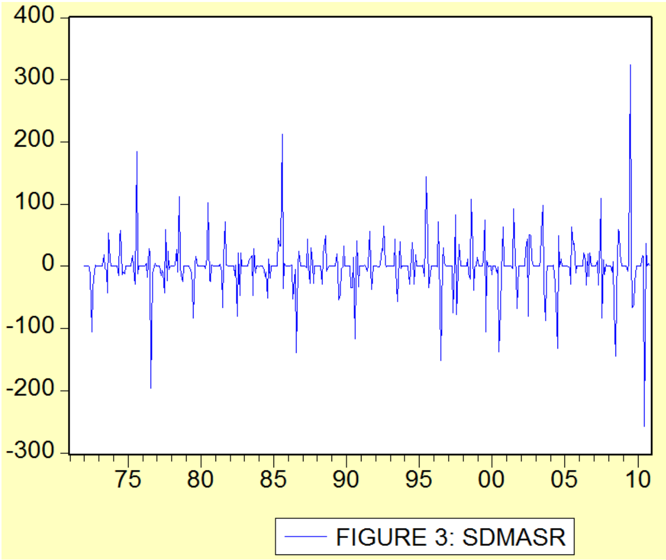
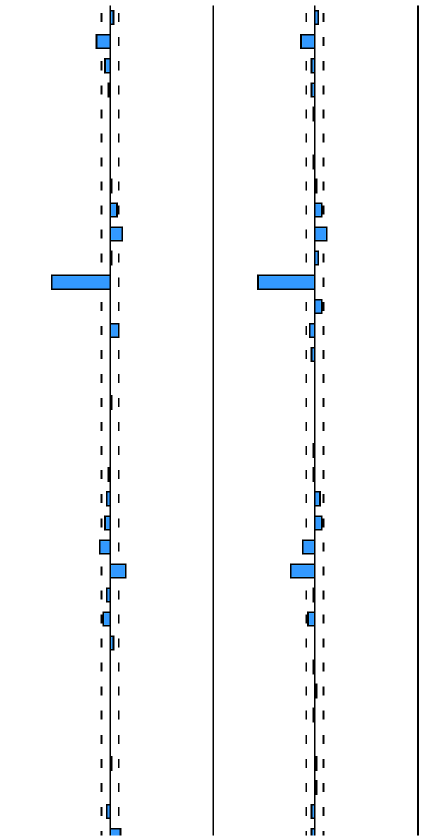
Residual Analysis:

A fitted model should be subjected to diagnostic checking with a view to ascertaining its goodness-of-fit to the data. This is done by analysing its residuals. An adequate model should have uncorrelated residuals. This is the minimal condition. The optimal condition is that the residuals should follow a Gaussian distribution with mean zero.





Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.030	0.030	0.4124	0.521
		2	-0.133	-0.134	8.7751	0.012
		3	-0.042	-0.035	9.6257	0.022
		4	-0.016	-0.032	9.7474	0.045
		5	-0.006	-0.015	9.7628	0.082
		6	0.002	-0.006	9.7639	0.135
		7	-0.008	-0.013	9.7935	0.201
		8	0.017	0.016	9.9260	0.270
		9	0.067	0.064	12.076	0.209
		10	0.123	0.126	19.301	0.037
		11	0.011	0.025	19.362	0.055
		12	-0.585	-0.570	184.35	0.000
		13	0.003	0.071	184.36	0.000
		14	0.082	-0.051	187.61	0.000
		15	-0.004	-0.033	187.62	0.000
		16	0.007	-0.006	187.65	0.000
		17	0.014	0.001	187.74	0.000
		18	-0.003	-0.007	187.75	0.000
		19	0.005	-0.016	187.76	0.000
		20	-0.016	-0.009	187.88	0.000
		21	-0.033	0.042	188.40	0.000
		22	-0.044	0.070	189.34	0.000
		23	-0.102	-0.130	194.45	0.000
		24	0.162	-0.251	207.43	0.000
		25	-0.030	-0.010	207.89	0.000
		26	-0.059	-0.063	209.63	0.000
		27	0.030	0.002	210.08	0.000
		28	-0.007	-0.024	210.10	0.000
		29	-0.007	0.015	210.12	0.000
		30	0.002	-0.012	210.12	0.000
		31	0.004	0.001	210.13	0.000
		32	0.017	0.018	210.28	0.000
		33	-0.005	0.020	210.30	0.000
		34	-0.041	-0.026	211.13	0.000

FIGURE 4: CORRELOGRAM OF SDMASR

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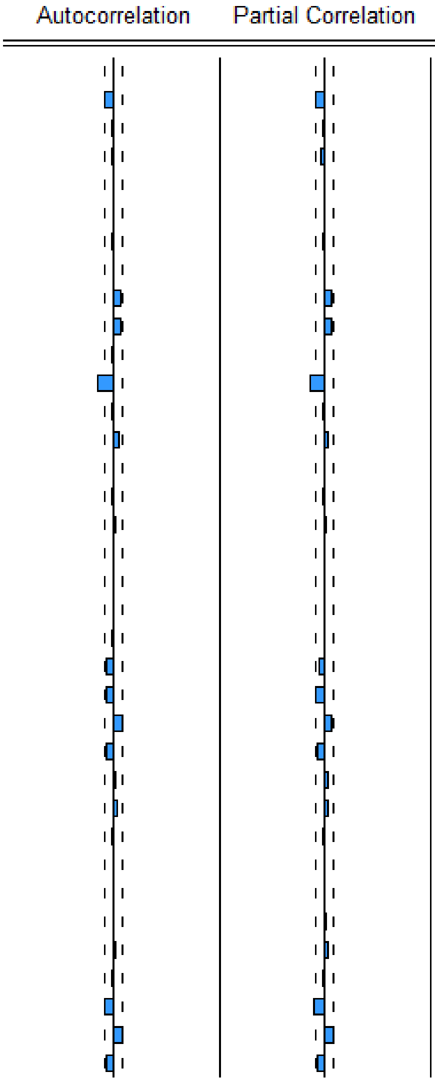

	AC	PAC	Q-Stat	Prob
1	0.008	0.008	0.0305	
2	-0.096	-0.096	4.3984	0.036
3	-0.012	-0.010	4.4633	0.107
4	-0.020	-0.029	4.6533	0.199
5	-0.006	-0.008	4.6704	0.323
6	0.001	-0.004	4.6709	0.457
7	-0.011	-0.013	4.7312	0.579
8	0.006	0.006	4.7509	0.690
9	0.066	0.064	6.8486	0.553
10	0.064	0.064	8.7950	0.456
11	-0.018	-0.006	8.9467	0.537
12	-0.148	-0.137	19.565	0.052
13	-0.022	-0.020	19.802	0.071
14	0.054	0.032	21.215	0.069
15	0.007	0.002	21.238	0.096
16	-0.010	-0.009	21.287	0.128
17	0.012	0.011	21.358	0.165
18	-0.002	-0.007	21.361	0.211
19	0.002	-0.005	21.363	0.261
20	-0.006	-0.007	21.379	0.316
21	-0.013	0.008	21.460	0.370
22	-0.069	-0.054	23.801	0.303
23	-0.072	-0.082	26.344	0.237
24	0.095	0.062	30.846	0.127
25	-0.060	-0.082	32.631	0.112
26	0.010	0.033	32.678	0.139
27	0.041	0.028	33.504	0.148
28	-0.015	-0.013	33.609	0.178
29	-0.002	0.005	33.612	0.214
30	0.002	0.000	33.613	0.254
31	0.003	0.015	33.618	0.296
32	0.020	0.033	33.811	0.333
33	-0.009	-0.013	33.855	0.378
34	-0.092	-0.111	38.172	0.246
35	0.098	0.087	43.017	0.138
36	-0.066	-0.076	45.252	0.115

FIGURE 5: CORRELOGRAM OF SARIMA (0, 0, 0)X(0, 1, 1)$_{12}$ RESIDUALS

Statistical Software:

The econometric and statistical software Eviews was used for all the analytical work. It is based on the least squares optimization criterion.

RESULTS AND DISCUSSION:

The time plot of the 360-point realization of the monthly rainfall data called herein MASR in Figure 1 is typical of monthly rainfall data. Generally the year-to-year trend is horizontal as expected. A yearly seasonal movement is also evident, also as expected. Clearly s = 12. Moreover the correlogram of MASR in Figure 2 shows a sinusoidal pattern with positive spikes at lags 12, 24 and 36 and minimum at lags 6, 18 and 30. This clearly supports the 12-period seasonality hypothesis. ADF Test adjudges MASR as stationary, but the sinusoidal-patterened correlogram does not corroborate a stationarity hypothesis.

Seasonal (i.e. 12-point) differencing of MASR yields the series SDMASR. The time plot of SDMASR in Figure 3 shows a generally zero-level trend. The ADF Test adjudges it as stationary. Its correlogram in Figure 4 supports the stationarity assumption; virtually all the autocorrelations are non-significant. There are negative significant spikes at lag 12 for both the ACF and the PACF. The ACF spike shows seasonality of order 12 and the

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involvement of a seasonal moving average component of order one. This autocorrelation structure leads to a proposal of three models: (i) SARIMA(0, 0, 0)x(0, 1, 1)$_{12}$ (ii) SARIMA(0, 0, 1)x(0, 1, 1)$_{12}$ and (iii) SARIMA(0, 0, 1)x(2, 1, 1)$_{12}$.

The SARIMA(0, 0, 0)x(0, 1, 1)$_{12}$ model as estimated in Table 1 is given by

$SDMASR_t + .8858\varepsilon_{t-12} = \varepsilon_t$ (4)

AIC = 9.50

The SARIMA(0, 0, 1)x(0, 1, 1)$_{12}$ model as estimated in Table 2 is given by

$SDMASR_t - .0435\varepsilon_{t-1} + .8720\varepsilon_{t-12} + .0439\varepsilon_{t-13} = \varepsilon_t$ (5)

AIC = 9.52

The SARIMA(0, 0, 1)x(2, 1, 1)$_{12}$ model as estimated in Table 3 is given by

$SDMASR_t + .1871SDMASR_{t-12} - .0526SDMASR_{t-24} = \varepsilon_t + .0241\varepsilon_{t-1} - .8315\varepsilon_{t-12} - .0660\varepsilon_{t-13}$

AIC = 9.53 (6)

Clearly the model with the least AIC is model (4). The correlogram of its residuals in Figure 5 show that the residuals are mostly uncorrelated since only one of the autocorrelations out of 36 is statistically significant.

CONCLUSION

It has been shown that monthly rainfall in the Gezira irrigation scheme of Sudan follows a SARIMA(0, 0, 0)x(0, 1, 1)^{12} . This means that its seasonal difference depends on the value of its shocks (i.e. residuals) of the past 12 months. This model maybe used to make projections for planning purposes.

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