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Building a Hybrid Model to Forecast the Numbers of Children with Respiratory Diseases in Kirkuk Governorate

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Abstract
Hybrid models that combine linear and nonlinear models are among the most important tools for analyzing time series, This article discussed a methodology for building hybrid time series models and its application in identifying the behavior of the monthly series of the number of children admitted to the Children's Hospital in Kirkuk Governorate related to respiratory diseases.. By applying the linear models to the studied series then using the residuals of the linear model as inputs for the later stages, we were able to find the best and optimal hybrid model from all the models that were evaluated in this study according to the criteria that were used to determine the best model, the study concluded that the hybrid model (ARIMA-EGARCH) was the optimal model that can be relied upon in making forecasting for the series studied in the application.

Key words: Box-Jenkins methodology, Hybrid models, linear models, nonlinear models, Respiratory Diseases.

1. Introduction

Forecasting the future is one of the basic issues that enable administrations and decision makers to take correct and sound decisions in various health, service, social and other fields. Time series is one of the most important methods of future prediction about the values of the phenomenon as what happened to it in the past, that the forecasting process in the time series is directly affected by the selection of the appropriate model for the time series data, as this step directly affects the accuracy of the forecasts expected to be obtained in the future.
Because of the importance of the topic of forecasting, there is an urgent need to develop statistical methods to increase accuracy and knowledge of forecasting. These methods include: linear time series models and non-linear time series models and the use of these two models together in their modern and advanced form known as the hybrid model, in line with the nature of the data available to us in order to reach the best and most efficient model that will be used for forecasting.

There are several articles dealing with hybrid models and their applications in many fields, including (Aladag et al.,2012), (Pahlavani& Roshan,2015), (Abdel Aziz,2016), (Al Telbani& Al Hajj, 2018), (Al-Farhoud , et al., 2019) ,(Sukano etal.,2020).

The health aspect is one of the basic aspects of life development because it is concerned with human health and getting rid of the diseases they suffers from, especially the health aspect related to children and what they suffer from health problems and various diseases such as respiratory diseases, Therefore, the article focused on the use of the hybrid model in studying the series of number of children with respiratory diseases for the purpose of developing a future prediction model for the number of children expected to be admitted to hospital for the coming years, and provide forecasts to health authorities and decision makers in order to take the necessary measures to confront this health crisis.

2. Hybrid time series model

Time series models are divided into (linear models, nonlinear models, hybrid models) as follows :

2.1. Linear models:

Linear models can be defined by a general mathematical model as follows (Palitand Popovic ,2005):

$$y_t = \sum_{i=-\infty}^{\infty} \psi_i Z_{t-i}$$

whereas:

ψ_i = a group of Constants that fulfill the condition:$\sum_{i=-\infty}^{\infty} |\psi_i| < \infty$

$|Z_t|$ = is the white noise series with mean equal to zero and variance equal to σ^2.

Common linear models are:

- Autoregressive model of order (p), AR(p)
- Moving Average model of order (q), MA(q)
- Autoregressive and Moving Average model (mixed model) ARMA (p,q)
- Autoregressive Integrated Moving Average model ARIMA (p,d,q), this model is the general case of the three models mentioned above.

The time series (y_t) is said to follow an ARIMA(p,d,q) model in the case of taking the differences of the series, which is defined as follows: $W_t = \nabla^d y_t$. This difference factor is a process by which a new time series is built by taking the successive differences of the successive values along the pattern of the non-stationary series and write an abbreviation ARIMA (p, d, q), The model can be rewritten using the back shift operator as follows (Cryer and Chan, 2008):

$$(1-B)^d y_t = \left(1-\theta_1 B - \cdots - \theta_q B^q\right) a_t \quad (1\text{-}\emptyset_1 B - \cdots - \emptyset_p B^p)$$

$$\emptyset(B)(1-B)^d y_t = \theta(B) a_t$$

2.2. Nonlinear Models:

There are several types of nonlinear models, including the following:

1- ARCH(p) Model: The ARCH model describes the conditional variance of the current model as a function of the real sizes of random errors in the previous time. The formula of the ARCH of order (p) model is as follows (Raheemaet al.,2020):

$$\sigma_t^2 = \alpha_0 + \alpha_1 a_{t-1}^2 + \cdots + \alpha_m a_{t-m}^2$$

2- GARCH Models (p,q): The conditional variance of the model GARCH contains the squared errors of the past in addition to the shifted conditional variances. The (GARCH) model is preferred over the (ARCH) model because it contains fewer parameters.
The mathematical form of the GARCH model can be written as follows (LAM ,2013):

$$\sigma_t^2 = \alpha_0 + \alpha_1 a_{t-1}^2 + \cdots + \alpha_p a_{t-p}^2 + \beta_1 \sigma_{t-1}^2 + \cdots + \beta_q \sigma_{t-q}^2$$

3- EGARCH Models (p,q): It's the model that use to avoid the weakness in the GARCH model and to allow positive and negative asymmetric effects, this model is known as EGARCH. The model is characterized by taking the natural logarithm of the conditional variance (AlTelbani and AlDoub, 2020):

$$ln\, ln(\sigma_t^2) = \alpha_0 + \sum_{i=1}^{q} \alpha_i \left|\frac{\varepsilon_{t-i}}{\sigma_{t-i}}\right| - \gamma_i \left(\frac{\varepsilon_{t-i}}{\sigma_{t-i}}\right) + \sum_{j=1}^{p} \beta_j\, ln\left(\sigma_{t-j}^2\right).$$

2.3. Hybrid Models:

Hybridization is the merging or mixing of two time series models (linear and non-linear) and exploiting the characteristics of each model to obtain a new model that combines them and addresses the weakness and gap in each model separately, thus generating a more accurate and reliable model in prediction(AlTelbaniand AlHajj,2018). The idea of merging linear models and Non-linearity models is based that the single model may not be sufficient to diagnose all the properties and characteristics of the time series and the reason is due to the presence of the linear and nonlinear components in the series over time, which prevents the linear or nonlinear model from being able to treat these two components together, As in the model under study (ARIMA-EGARCH).
The process of building hybrid models depends on the time series being composed of two components, the first is linear L_t and the second is not linearN_t in time (t) As shown by the following equation (AlFarhoud et al., 2019):

$$y_t = L_t + N_t \qquad\qquad t = 1,2, \ldots ....$$

Thus, the building stages (ARIMA - EGARCH) is based on the following steps:
1- Determining the best model from ARIMA models and obtaining the estimated values and residuals where the residuals contain the non-linear relationships that the proposed ARIMA could not modeling the series, and the residuals (e_t) are obtained at time t according to the following relationship:

$$e_t = y_t - \hat{L}_t$$

Where $\hat{L}_t$= the estimated values obtained from the best model of (ARIMA).
2- Knowing and determining the type of residuals obtained from the studied linear model. If the residuals have a linear relationship, we cannot use them to build a model (ARIMA-EGARCH) and therefore we rely on a model ARIMA conducting the forecasting process, the predictions that will be obtained will be of high efficiency and good accuracy, meaning that

the linear model is the most efficient and best model and there is no need for the hybridization process. But if the residuals have a non-linear relationship, that is, they contain non-linear relationships, that ARIMA can't Model it, we use these non-linear residuals as inputs to build a model GARCH. The linearity of the residuals is checked using statistical graphics and graphs of the autocorrelation function and partial autocorrelation of the residuals, or by using statistical tests such as the (Jarque-Bera) test , (Ljung-Box) test and (ARCH -test) which decides the issue of the existence of the relationship or not, that is, it is considered an indicator of the validity of the graphs.

3. Application to the Respiratory Diseases

The methodology of practical application was to use two models which are linear model (ARIMA) and hybrid model (ARIMA-EGARCH) in addition to statistical tests and diagnostic tests were applied and conducted for both models on a series represented by the real data of the monthly entry of children with respiratory diseases. Data taken on the number of children admitted to the Children's General Hospital in Kirkuk government for the period from 2010 to 2020.

The ARIMA model will be built first passing through the collection of the stages of its construction, then we build the hybrid model based on the residual of best models that have been adapted from the (ARIMA) models, Finally, finding a hybrid model that can be relied upon in building forecasts for the coming years for the studied series.

3.1. Application ARIMA Models

Application of (ARIMA) models requires going through four basic stages, which are, identification, estimation of parameters , Verification of the Model and finally the evaluation of the quality of the model in preparation for its use in forecasting. These stages will be applied in the following paragraphs, as follows:

The series will first be examined whether it is stationaryor not by the variance and the mean. Through the diagram, it is possible to see the nature of the fluctuation in it, and to note whether it includes a general trend. Figure (1) shows the graph of the original series, the monthly entry of the number of children with all respiratory diseases.

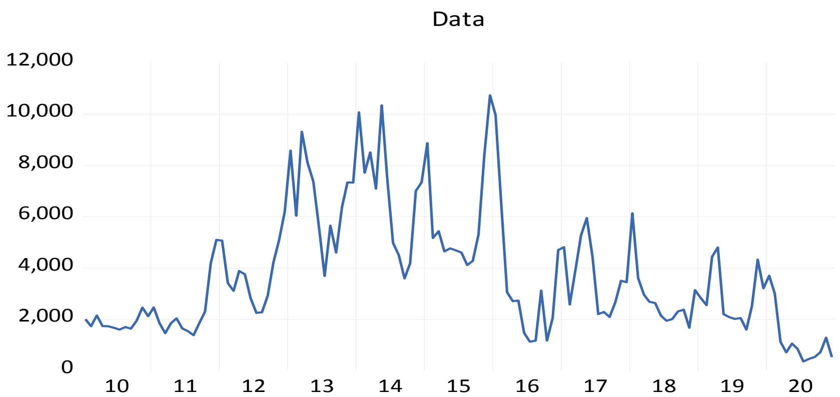


Figure (1): Graph of the original time series

We notice that the series fluctuates irregularly, which indicates that the series is not characterized by a fixed level, that is, it is non-stationary in the mean, this means that the mean is not stable over time, which leads to the need to take the differences to make it stationary, since the stationary series is one of the important conditions for modeling the time series in a manner Box and Jenkins methodology .Figure (2) shows the time series drawing after taking the first difference where it is noticed from the figure that the series has become stationary:

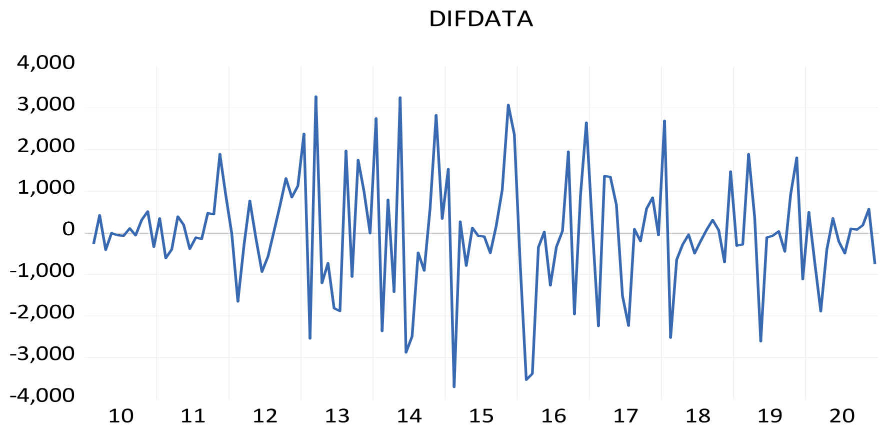


Figure (2): Graph of the time series after taking the first difference

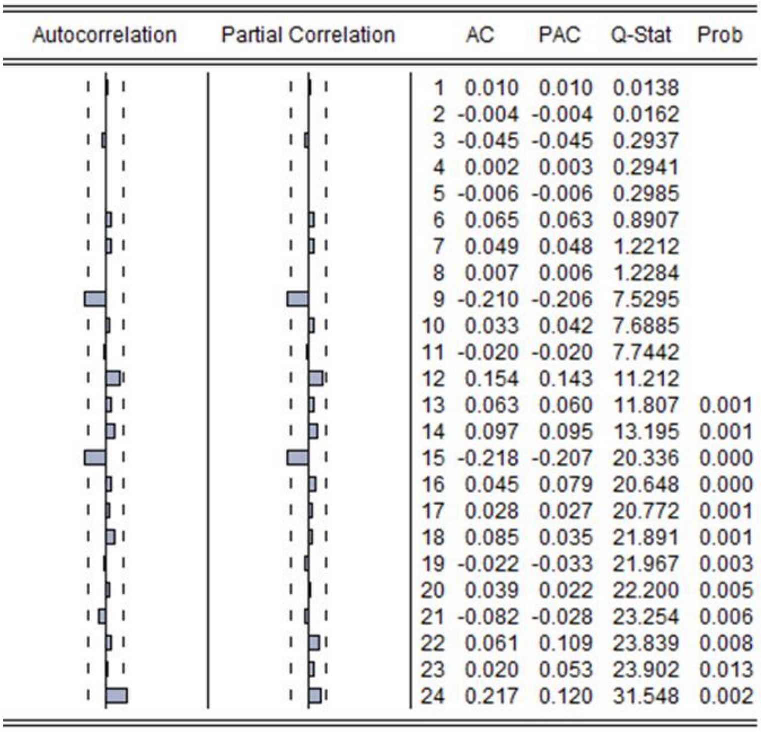
Also the augmented Dickey-Fuller test of the unit root of the first differences of series was used to make more sure of the stationary of the time series, where the probabilistic values of test less than (0.05), which indicates the stationary of the time series.as shown in the table (2):

Table (1): Augmented Dickey-Fuller test of the first differences

Models	ADF-test	P- value
The first model (intercept)	- 11.88627	0.0000
The second model (trend and intercept)	-11.87272	0.0000
The third model (none)	-11.93209	0.0000

After the time series has settled, the stage of identifying the initial model comes by determining the degree of autoregressive AR (p) and the degree of the moving average MA (q). an initial model is determined based on the autocorrelation and partial autocorrelation functions of the first differences of series. , the initial model is ARIMA (6,1,6) . In order to more accurately determine the order of the model, we do the following:

Examine the graph of the autocorrelation function for the residuals of the initial model in order to make sure that the correlation coefficients fall within the confidence interval limits, as in figure (3):



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob
		1	0.010	0.010	0.0138	
		2	-0.004	-0.004	0.0162	
		3	-0.045	-0.045	0.2937	
		4	0.002	0.003	0.2941	
		5	-0.006	-0.006	0.2985	
		6	0.065	0.063	0.8907	
		7	0.049	0.048	1.2212	
		8	0.007	0.006	1.2284	
		9	-0.210	-0.206	7.5295	
		10	0.033	0.042	7.6885	
		11	-0.020	-0.020	7.7442	
		12	0.154	0.143	11.212	
		13	0.063	0.060	11.807	0.001
		14	0.097	0.095	13.195	0.001
		15	-0.218	-0.207	20.336	0.000
		16	0.045	0.079	20.648	0.000
		17	0.028	0.027	20.772	0.001
		18	0.085	0.035	21.891	0.001
		19	-0.022	-0.033	21.967	0.003
		20	0.039	0.022	22.200	0.005
		21	-0.082	-0.028	23.254	0.006
		22	0.061	0.109	23.839	0.008
		23	0.020	0.053	23.902	0.013
		24	0.217	0.120	31.548	0.002

Figure (3): Autocorrelations of Residual Series ARIMA (6,1,6)

Notes from the figure (3) which shows that the autocorrelations of the residual of the model do not all fall within the confidence interval limits, which indicates that the chosen model is not an appropriate model.

After that, we compare the selected model ARIMA (6,1,6) with a number of proposed models for the purpose of improving the efficiency of the model and choosing the model with good specifications with the lowest value for the model selection criteria, among these criteria are (AIC, SIC, HQ), in addition to the adjusted coefficient of determination (adj-R^2) for each model and compare these models for accuracy in obtaining the appropriate model for data representation. And shown in the table(2):

Table (2): ARIMA Models and Comparison Criteria Values

Models	AIC	SIC	HQ	adj-R^2
ARIMA(3,1,6)	17.2424	17.4839	17.3406	0.10
ARIMA(4,1,6)	17.2311	17.4945	17.33815	0.12
ARIMA(5,1,4)	**17.1867**	**17.4281**	**17.2848**	**0.20**
ARIMA(5,1,6)	17.1973	17.4826	17.3132	0.20
ARIMA(3,1,5)	17.2346	17.4541	17.3238	0.12
ARIMA(6,1,6)	17.2436	17.5509	17.3685	0.11

We note from table (2) the ARIMA (5,1,4) model recorded the lowest value for all criteria compared to the proposed models and the initial model ARIMA (6,1,6),

The following stage is one of the most important stages in the analysis, during which the adequacy of the model is verified in order to keep it as it is or improve and develop it into a hybrid model that accommodates the deficiency in the current model, as we are subjecting the model that has been reached, which is a model ARIMA(5,1,4) for a number of statistical tests and graphical checks, if the model passes these tests, it is valid for use and forecasting , these tests lie in the analysis of Stability and Invertible, the analysis of residuals as shown in the next paragraphs:

Stability and Invertible Analysis: The achievement of the two conditions of stability and invertible in the model parameters is evidence of the adequacy of the model for the data under study, all the series of moving averages and Autoregressive they are all unconditionally Stability, as noted in the table (3) as the absolute value of all estimators was less than one, this is confirmed by the unit roots test of the model by examining the structure of the proposed model

Table (3): Stability and invertible Test for ARIMA (5,1,4)

AR Root(s)	Modulus	Cycle
-0.533394 ± 0.726548i	0.901322	2.850713
0.832356 ± 0.217306i	0.860255	24.60388
0.079685	0.079685	
No root lies outside the unit circle. ARMA model is stationary.		
MA Root(s)	**Modulus**	**Cycle**
-0.558111 ± 0.829766i	1.000000	2.904976
0.982989 ± 0.183631i	0.999994	34.02190
No root lies outside the unit circle. ARMA model is invertible.		

From the above table, we see that a model ARIMA (5,1,4) is a stable and invertible model since all its roots lie outside the unit circle.

Residual Analysis: This process is done using some statistical tests as follow:
By using Jarque - Bera test to check the normality of residuals, we note that the p-value was equal to (0.0187) which is less than 0.05, which indicates the need to reject the null hypothesis that the residuals follow a normal distribution and accept the alternative hypothesis that the residuals do not follow a normal distribution. We also note that the kurtosis coefficient was equal to (4.006) so it is greater than 3, which confirms the non-normality of the distribution of the residuals with the presence of skewness to the right according to the value of the positive skewness equal to (0.332). Thus, the residuals have lost

the condition of the normality of the distribution, which confirms the existence of non-linear patterns in the residuals of the series that call for the use of non-linear models.

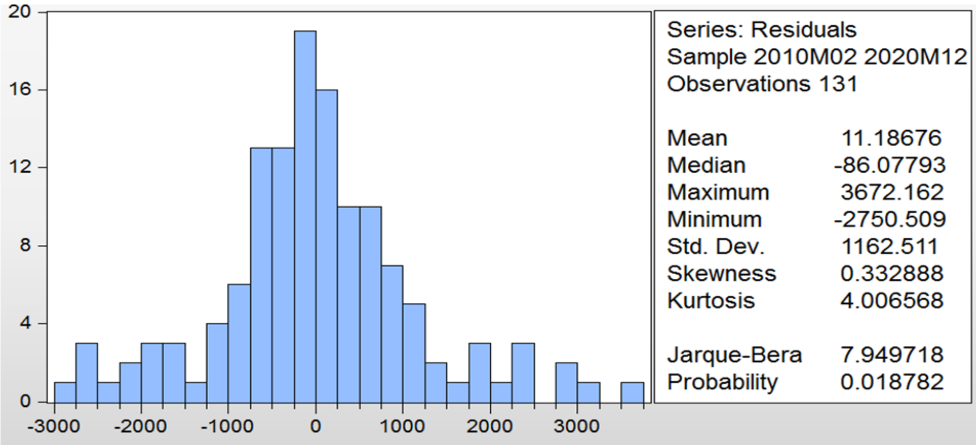


Figure (4): The Jarque-Bera test for normal residual distribution

Another test can be applied which is Ljung-Box test to check the residual correlation, where the value of the correlation coefficients for the residual squares was significantly different from zero, meaning that their values were less than 0.05, this is a sufficient reason to reject the hypothesis $H_0: \rho(k) = 0$ and accept$H_0: \rho(k) \neq 0$ that is, there is an autocorrelation in the residual square

Also ARCH LM-test can be used to check the stability of variance, we notice in this test the presence of an ARCH effect, that is, there is an effect of heterogeneity of variance for the residuals, since the p-value of the test is equal to (0.0374), which is less than 0.05, that is, rejecting the null hypothesis ($H_0: \alpha_i = 0$) and accepting the alternative hypothesis ($H_0: \alpha_i \neq 0$) . Also Fisher's statistic supports this hypothesis because its value was equal to (0.0376) which is less than 0.05.

Table (4): Heteroscedasticity ARCH Test

Heteroskedasticity Test: ARCH

F-statistic	4.413467	Prob. F(1,128)	0.0376
Obs*R-squared	4.333024	Prob. Chi-Square(1)	0.0374

Test Equation:
Dependent Variable: RESID^2
Method: Least Squares
Date: 05/16/21 Time: 23:30
Sample (adjusted): 2010M03 2020M12
Included observations: 130 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1105847.	234254.9	4.720698	0.0000
RESID^2(-1)	0.182386	0.086816	2.100825	0.0376

R-squared	0.033331	Mean dependent var	1351198.
Adjusted R-squared	0.025779	S.D. dependent var	2345744.
S.E. of regression	2315311.	Akaike info criterion	32.16325
Sum squared resid	6.86E+14	Schwarz criterion	32.20737
Log likelihood	-2088.611	Hannan-Quinn criter.	32.18118
F-statistic	4.413467	Durbin-Watson stat	2.065203
Prob(F-statistic)	0.037618		

We conclude from the above that we can use the ARIMA (5,1,4) model in the last stage, which is the forecasting stage, but it is not preferred to adopt it to represent the series data because it does not represent the optimal model and the resulting predictions may be characterized by insufficient accuracy. The above model is what contributed to reducing its efficiency, so a model will be entered ARCH-GARCH specialist in dealing with this type of problem on a model ARIMA (5,1,4) to reach the optimal hybrid model

3.2. Application Hybrid Models

Identification is the first stage in which the residual series of the model under study is presented and based on the drawing of the residual series, it is clear from the figure that the residuals are fixed on the mean but not fixed in the variance, meaning that the series contains fluctuations in the residuals

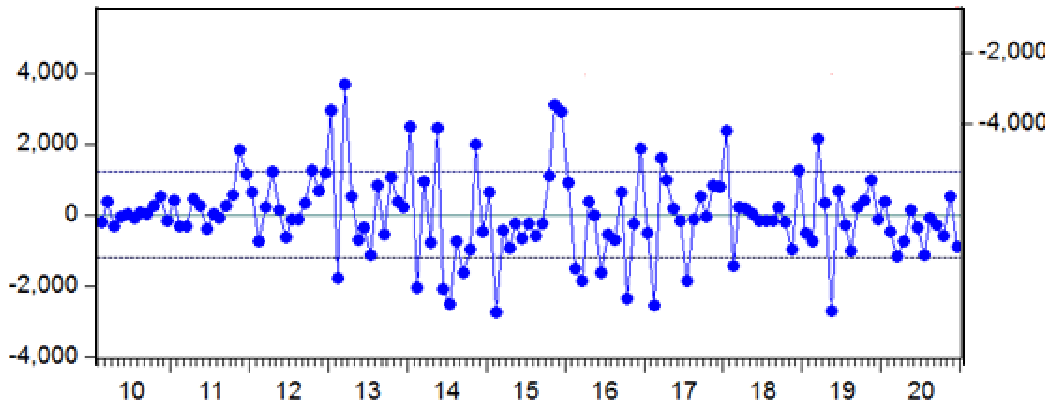


Figure (5) : Residual series for ARIMA model (5,1,4)

In Hybrid Model Selection stage, a set of models were proposed (ARCH & GARCH) depending on the residual of ARIMA (5,1,4) model,to reach the first model suitable for building a hybrid model that has the ability and efficiency to overcome the non-linear problem, and the probability value (P-Value) should be greater than 0.05 for the ARCH LM-test. To choose the best model among the proposed models, the values of the selection criteria used (AIC-SIC-HQ) should be as small as possible as shown in table (5):

Table (5): Comparison between proposed models

Models	Ljung-box Q-stat (R^2)				LM ARCH Test	AIC	SIC	HQ
	Q(5)	Q(10)	Q(15)	Q(20)				
ARCH 1	0.947	0.978	0.974	0.925	0.4278	17,226	17,496	17,336
ARCH2	0.588	0.684	0.892	0.800	0.8118	17,198	17,490	17.316
GARCH(0,1)	0.080	0.144	0.131	0.012	0.028	17.101	17.371	17.210

GARCH(0.2)	0.600	0.257	0.204	0.039	0.5020	16,969	17,262	17.088
GARCH(1,1)	0.197	0.072	0.063	0.010	0.1196	17.060	17,353	17,179
GARCH(1,2)	0.295	0.122	0.112	0.015	0.2465	17.071	17.386	17.199
GARCH(2,1)	0.854	0.770	0.839	0.555	0.3568	17,085	17.400	17,213
GARCH(2,2)	0.696	0.180	0.303	0.019	0.9357	16,987	17,325	17,124
EGARCH (0,1)	0.568	0.654	0.877	0.669	0.3955	16.925	17.2176	17.0439
EGARCH (1,1)	**0.677**	**0.901**	**0.953**	**0.159**	**0.7430**	**16,866**	**17.1815**	**16.9944**
EGARCH (1,0)	0.623	0.798	0.509	0.331	0.8538	17.213	17.5058	17.3321

It is clear from the above table that the best model that achieved the least value for the criteria (AIC, SIC, HQ) is a model (E GARCH (1,1)) with few number of parameters as possible. Therefore, the hybrid model is: ARIMA (5,1,4) - E GARCH (1,1).
After determining the optimal hybrid model, its validity and efficiency must be tested, this is done through the test (ARCH-Test) and (Ljung-Box test) for squares of residual:

First : ARCH-Test: In which the test value appears equal to (0.7430), which is greater than 0.05, that is accepting the null hypothesis, in this case the problem of Heteroscwdasticity was eliminated , as shown as in table (6):

Table (6): Heteroscwdasticity ARCH Test

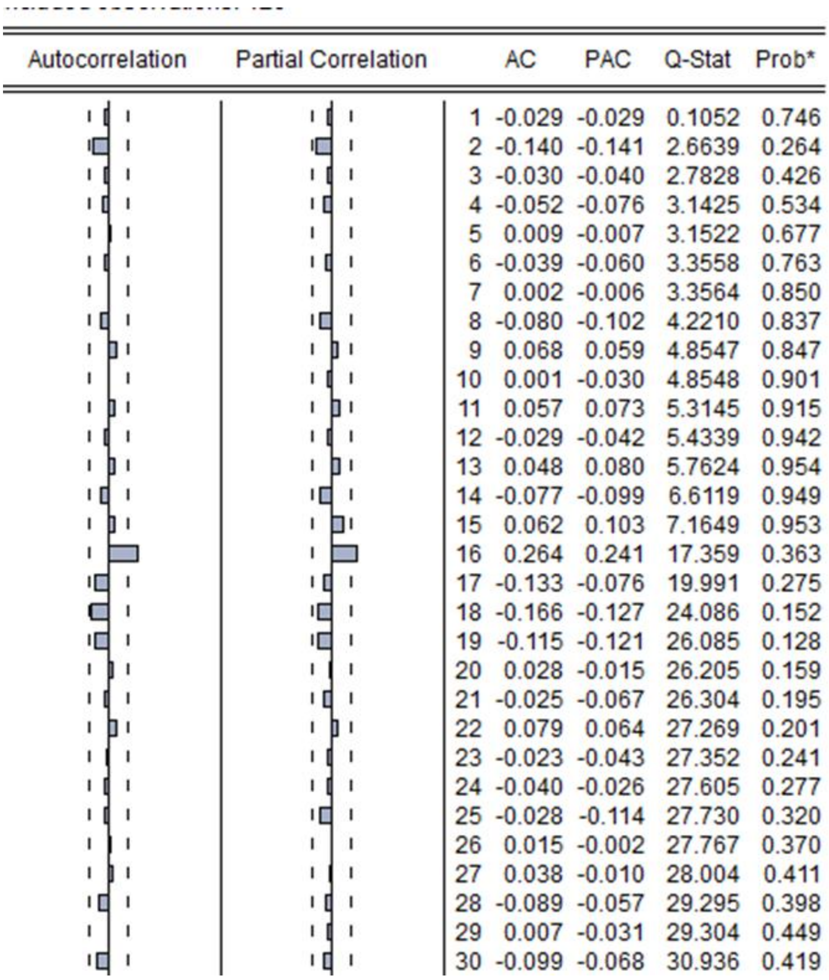
Heteroskedasticity Test: ARCH

F-statistic	0.105875	Prob. F(1,123)	0.7454
Obs*R-squared	0.107504	Prob. Chi-Square(1)	0.7430

Test Equation:
Dependent Variable: WGT_RESID^2
Method: Least Squares
Date: 07/22/21 Time: 21:15
Sample (adjusted): 2010M08 2020M12
Included observations: 125 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	1.032769	0.144197	7.162220	0.0000
WGT_RESID^2(-1)	-0.030145	0.092645	-0.325385	0.7454

Second: Ljung-Box Test: As it is clear, the p-values were greater than 0.05, which means accepting the null hypothesis that there is no serial correlation between the values of the residual squares series.
Thus, the hybrid model has got rid of the problem of the heteroscedasticity, as well as the problem of autocorrelation. It is an ideal model for forecasting



Autocorrelation	Partial Correlation		AC	PAC	Q-Stat	Prob*
		1	-0.029	-0.029	0.1052	0.746
		2	-0.140	-0.141	2.6639	0.264
		3	-0.030	-0.040	2.7828	0.426
		4	-0.052	-0.076	3.1425	0.534
		5	0.009	-0.007	3.1522	0.677
		6	-0.039	-0.060	3.3558	0.763
		7	0.002	-0.006	3.3564	0.850
		8	-0.080	-0.102	4.2210	0.837
		9	0.068	0.059	4.8547	0.847
		10	0.001	-0.030	4.8548	0.901
		11	0.057	0.073	5.3145	0.915
		12	-0.029	-0.042	5.4339	0.942
		13	0.048	0.080	5.7624	0.954
		14	-0.077	-0.099	6.6119	0.949
		15	0.062	0.103	7.1649	0.953
		16	0.264	0.241	17.359	0.363
		17	-0.133	-0.076	19.991	0.275
		18	-0.166	-0.127	24.086	0.152
		19	-0.115	-0.121	26.085	0.128
		20	0.028	-0.015	26.205	0.159
		21	-0.025	-0.067	26.304	0.195
		22	0.079	0.064	27.269	0.201
		23	-0.023	-0.043	27.352	0.241
		24	-0.040	-0.026	27.605	0.277
		25	-0.028	-0.114	27.730	0.320
		26	0.015	-0.002	27.767	0.370
		27	0.038	-0.010	28.004	0.411
		28	-0.089	-0.057	29.295	0.398
		29	0.007	-0.031	29.304	0.449
		30	-0.099	-0.068	30.936	0.419

Figure (6) : Autocorrelations of a series of residual squares of the hybrid model

Forecasting is the last step in analyzing and diagnosing the appropriate model in the time series, it is one of the most important goals of building the statistical model. On this basis, the numbers of children admitted to Kirkuk Children's Hospital (the sentinel and the consultant) were predicted on a monthly basis and for the next two years, the results were as follows in table (7). It is evident in the graph of the real series and the series of the forecasting values for the next two years:

Table (7): Forecasting values for the next two years (2021-2022)

Months	2021	2022
January	782	3348
February	1031	3475
March	1343	3474
April	1685	3569

May	1913	3634
June	2247	3668
July	2466	3822
August	2675	3885
September	2918	4051
October	3015	4241
November	3198	4393
December	3291	4684

Conclusions

In this article, the stationary of the original series for the number of children admitted to Kirkuk Children's Hospital was is examined and found to be non-stationary series, the stationary state was reached in the series after taking the first difference. A number of tests were conducted on the residuals of the proposed linear model ARIMA (5,1,4) for the purpose of verifying its validity. It was concluded that the residuals had a non-linear effect, and the residuals were non-normally distributed, which calls for improving and developing the linear model for the purpose of getting rid of these problems to reach a model that gives real estimates and forecasting. Depending on the residuals of the linear model, a hybrid model was built from among the linear (ARIMA) and nonlinear (ARCH & GARCH) family models for the purpose of obtaining a model that allows to get rid of the problems that faced the linear model. A number of proposed hybrid models were reached, and the best hybrid model that has the lowest statistical comparison criteria is the ARIMA (5,1,4)-EGARCH (1,1) hybrid model. Tests were carried out on the residuals hybrid model, the results showed that it was free of non-linear effects, meaning that the hybridization process formed a valid model for carrying out the prediction process without any problems, therefore future predictions will be of high accuracy.

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