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**Research Article**

# ARIMA MODELLING OF WATER TABLE FLUCTUATIONS DUE TO RAINFALL VARIATIONS IN SHANMUGA NADHI SUB-BASIN OF UPPER AMARAVATHI BASIN, TAMILNADU, INDIA

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**ABSTRACT**

The study is aimed in the understanding of groundwater level fluctuations in the Shanmuga Nadhi sub basin due to variations in monthly rainfall. Auto Regressive Integrated Moving Average (ARIMA) model of Box and Jenkins method is used as a stochastic processing time series study. Thirty three years of monthly rainfall and monthly water level records as a time series are statistically analysed for understanding the relationship and influence of rainfall over the natural recharge systems of the Shanmuga Nadhi sub basin in order to evaluate the aquifer behaviour of the study area. 6 rainfall stations and 12 dugwells are selected for the study. The long term data analysis automatically removes any existing bias and the normalisation generalises the relationship in a given point of time. The ARIMA model validated using normalised BIC with minimal standard error on the statistical manipulations are further analysed using regression analysis for goodness of fit on a linear scale. The goodness of fit and higher confidence level of water table fluctuations along with the linear relationship on the algebraic equation provides a stochastic forecast model for groundwater management of the basin.



## INTRODUCTION

Ground water is a dynamic resource with an integral link in the hydrological cycle. Any imbalance in management of ground water resource is reflected in the form of waterlogged areas at one extreme and an acute shortage of water at the other end. The need for enhanced recharge of ground water is increasing worldwide as populations and water demand increase. The magnitude of replenishment or recharging of ground water storage is explicitly controlled by the topographical, geological and hydrological situation of an area.

Study of ground water resources in relation to effect of rainfall on water table fluctuations is an important factor which plays a major role in sustainable groundwater development. A time series analysis is a valuable tool to get information about analysed data structures and their components, which provides a good basis for successful future predictions. The formation of predictive linear models for time series data on a stochastic platform is attempted in this study for a small catchment of Shanmugha nadhi, a tributary of upper Amaravathi basin.

The long term meteorological data of rainfall and relative water level fluctuations can be used to assess the ground water table and storage variations in order to have a better insight into the problem posed in the future [Aflatooni M (2011)]. In general, if the statistical parameters such as mean and variance of a long term meteorological time series changes steadily, it can be said that the climate change is inevitable, so using these historical times series and their effects on water resources, mainly ground water, may have a similar future impact. Analysis of time series as related to ground water table seeks two objectives; modelling of random variables to have an understanding of historical data and forecasting future data behaviour based on the past data (Ahn, 2000). In this study, Box-Jenkings time series method (Pankratz, 1983) was used to predict the possible future ground water table fluctuations. Box- Jenkings method was used because it takes into account all behaviours of the water table time series including randomness, seasonality, periodicity and stationarity.

## MATERIALS AND METHODS

Box-Jenkings is a type of stationary time series model in the form of *ARIMA* $(p,q)(P,Q)$ where $p,q$ are non-seasonal and $P,Q$ are seasonal order of auto-regressive and moving average processes, respectively. Introducing two differential coefficients $d,D$ to this form to overcome the problem of trend, seasonality and non-stationarity, the model is corrected and written in the form of *ARIMA*$(p, d, q)(P,D,Q)$ where $d,D$ are respectively the degree of simple and seasonal differentiation which comes up to less than or equal to unity. In general, to show the capability of a mathematical or statistical model, we have to perform three basic procedures, namely; identification

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of parameters, fitting the model in observed data and validation of the model in order to be able to use it for predictive or forecasting purposes. The general Box-Jenkings model is written as follows (Pankratz, 1983):

$$\phi_p(B)\phi_p(B^s)\nabla_s^D \nabla^d X_t = \theta_\circ + \theta_q(B)\theta_Q(B^s)Z_t$$

Given the observed piezometer (water well) data, the initial statistical analysis consisted of removing the outliers, test of normal distribution, using ACF and PACF to determine the correlation of model components and computation of coefficients, removing trend and seasonality from time series, determination of seasonal index, statistical test of time length of data and converting non-stationarity to stationary state. Calculation of seasonal index for each month was done by normalized multiplicative method.

***Parameter estimation***: There are many methods and criteria for selecting the order of an AR or ARIMA model available. One of them is based on the so-called information criteria. The idea is to balance the risks of underfitting (selecting an order smaller than the true order) and overfitting (selecting an order larger than the true order). The order is chosen by minimizing a penalty function. The most commonly used function is the Bayesian information criterion (BIC):

BIC (p, q) = ln $\sigma^{\wedge 2}$ $\frac{(p+q)\ln(n)}{n}$, where ($\sigma^{\wedge 2}$ is a sample covariance function ).

***Regression Analysis***: The degrees of linear relationship or correlation between variables are studied through correlation analysis. The scatter of the trend of the data and the deterministic reliability over variables are not better understood with correlation analysis.

Regression analysis is the solution upon such situation where a formulation and determination of the relationship between the variables analyzed are concerned. Regression methods are used in the analysis of bivariate data set where one variable can be the function of the other. The nature of the trends and their changes are clearly interpolated.

Rainfall is the independent variable and fluctuation is the dependent or explained variable. Their deviation and the functional relationship between the variables when plotted on a scatter diagram, cluster around a straight line called the line of regression as

1. Regression of Y on X
2. Regression of X on Y

The line of regression of Y on X or X on Y are in the algebraic from Y=a+bX or X=a+bY respectively where Y is the dependent variable on the independent variable X. a and b in the algebraic regression equation are obtained by using methods of normal equation by the principles of least squares.

Normal equation $\sum y = na + b\sum x$
$\sum xy = a\sum x + b\sum x2$

Least square equation by $x = \frac{n\sum dxdy - (\sum dx)(\sum dy)}{n\sum dx^2 - (\sum dx)^2}$

$$b\,x\,y = \frac{n\sum dxdy \quad (\sum dx)(\sum dy)}{n\sum dy^2 \quad (\sum dy)^2}$$

The regression line of Y on X is used to estimate and predict the best value in the least square sense of Y for X given value of X, where Y is dependent of X. The fitting on straight line is to illustrate the linear regression line by method of least squares. The line of regression of obtained by calculating the regression value to the observed values upon the method of least squares. Where the difference between two values calculated has deviation, error or residual. As the next step in the procedure the total error on residual sum of squares is used to find the values of a and b by keeping the error or residual sum of square minimum. The values of a and b are substituted in the normal equation Y=a+bX or X=a+bY to get the line of best fit in the least square sense.

The standard error of estimate measures the accuracy of the estimated or predicted value obtained by regression lines. A smaller value of the standard error indicates that these scatter of points around the regression line is small and the prediction of estimation is precise and accurate. The standard error of estimate is a concept analogous to standard deviation. While standard deviation measures the scattered nests of observation around its mean, the standard error of estimate measures the scatter of points around the corresponding regression line. If correlation between the variables is perfect, the standard error of estimate will be zero, i.e., the scatter of points around the regression line will be zero and point will lie evenly scattered closely along the regression line. The standard deviation of the sampling distribution of a statistic is called as standard error of the statistic.

The present study is on the effects of natural Geological dynamics of rainfall ground water inter action with ARIMA model is attempted to

1. To identify the interactive dependency of water level fluctuation upon rainfall observed on a chronological set of the thirty three years.
2. To study, analyze and develop the relationship of these natural forces in order to understand the recharge-discharge probabilities of Shanmuga Nadi sub basin.

***Study Area***

Shanmuga Nadi River is one of the major tributary of Amaravathy River. The study area Shanmuga Nadi sub basin lies between 10.05' and 10.9' North latitude and 77.30' and 78.20' East longitude covering Dindugal and Tirupur districts of Tamil Nadu and covered by the topographic sheet no:58 F6,F7,F10,F11 in the scale 1: 50,000 of Survey of India. The study area extends to about 808.023sq.km. The sub basin consists of three taluks namely Kodaikanal, Palani, and Dharapuram. Shanmuga Nadi River has three major tributaries such as Palar, Porundhalar, and Vettar. Physiographic divisions of the water shed are as follows

1. Elevated and forested terrain in south.
2. River plains and valley plains in north.

Shanmuga Nadi is an ephemeral river supporting surface flow only during monsoonal precipitation. Hence groundwater is the main source for irrigation and nearly 90% of the agricultural lands are fed by groundwater. The geology of the area is of hard rock represented by Migmatite gneisses and Charnockites.

### Geology of the Study Area

Most of the gneisses in the southern part of Tamil Nadu are made up of garnet-biotite gneiss and garnetiferous quartzofeldspathic gneisses that represent the migmatised and retrograded equivalents of Charnockite and Khondalite groups (Narayanaswamy and Purnalakshmi, 1967, Narayanaswamy 1971). The complex gneisses made up of hornblende-biotite gneiss, biotite gneiss and granitoid gneiss etc. with remnant patches of Charnockite Group occurring in the study area and the adjoining areas of watershed are considered as regional migmatites, where different stages of their formation from meta-texites to diatexites (homophanous pink granite gneiss) could be distinguished (Gopalakrishnan *et.al*., 1976). Laterite (Czl) associated with reddish brown ferruginous clayey soil caps the crystalline rocks at high altitudes in Palani and Kodaikkanal Hills.

### Climate and Rainfall

#### Climate

Semi and tropical monsoon type of climate is prevailing in the plains area. However upper Palani has recorded low temperature and fairly heavy rainfall. The normal annual rainfall over the district varies from about 700 mm. to about 1600 mm. It is a minimum around Palani (709 mm) in the northwestern part. It gradually increases towards south and southwest and reaches a maximum around Kodaikanal (1606.8 mm). The period from April to June is generally hot and dry.

#### Rainfall

| (1) Winter period (January – February) | **44.7 mm** |
|---|---|
| (2) Summer period (March – May ) | **155.1 mm** |
| (3) South West Monsoon (June – Sept.) | **218.3 mm** |
| (4) North East Monsoon (Oct. – Dec.) | **417.9 mm** |
| **Total** | **836.0 mm** |

**(Source: CGWB)**

#### Humidity

The period from April to June is generally hot and dry. The weather is pleasant during the period from November to January. Usually mornings are more humid than afternoons. The relative humidity varies between 65 and 85% in the mornings while in the afternoon it varies between 40 and 70%.

#### Soil Types

The soil can be categorized according to the development of soil or the amount of substances present in the soil. As there are various systems to classify soils, it means soil classification is not static. This makes soil classification vast and sometimes confusing. However, mostly classification of soil is based on the size of the particles it contains.

Depending on the size of the particles in the soil, it can be classified into these following types:

- Sandy soil
- Silty soil
- Clay soil
- Loamy soil
- Peaty soil
- Chalky soil

The major soil types in the study area are 1. Red soil 2. Red sandy soil and 3. Black Cotton soil. Red soils and loamy soils are prevalent in Palani, Dharapuram and Thoppampatti. Black soils are found in all areas except Kodiakkanal.

### Landuse and Land Cover

Land use and land cover of the study area is characterized by mixture of forest cover and full of agricultural activities. The southern part of the watershed has full of forest cover and other side of the river has agricultural land.

### Cropping Pattern

#### Wet lands

| | | | | |
|---|---|---|---|---|
| I | Crop | : | Paddy | (Oct–Feb) |
| II | Crop | : | Paddy | (Feb–March) |
| I | Crop | : | Paddy | (Oct–Feb) |
| II | Crop | : | Paddy | (March–May) |

Single Crop: Sugarcane / Banana (Dec – Jan) (June – July

#### Garden lands

I Crop: Paddy (Aug – Dec)
II Crop : Millets / Pulses / Groundnut/ Vegetables( Dec, Jan – March)

I Crop: Cotton (Sept – Feb)
II Crop: Millets / Pulses / Vegetables (Feb – March)

Single Crop : Sugarcane / Banana (Dec – Jan) (June – July)

#### Dry lands

*(i) Red soils*
Corn (June – Aug)
Cumbu (Aug – Sept)
Groundnut (June – July)
Minor Millets; Horse gram (Sept – Oct)
*(ii) Black soils*
Corn (Sept – Oct)
Cotton (Sept – Oct)
Sunflower (Sept – Oct)

### Irrigation Practice

| S.No. | Block | Net area irrigated by | | | | | Total |
|---|---|---|---|---|---|---|---|
| | | Canals | Tanks | Tube wells | Ordinary wells | Other Sources | Net Area Irrigated |
| 1 | Dharapuram | 9285 | 46 | 22 | 5930 | 0 | 15283 |
| 2 | Palani | 6349 | 641 | 438 | 6635 | 0 | 14063 |
| 3 | Thoppampatti | 522 | 346 | 517 | 12940 | 0 | 14325 |
| 4 | Kodaikanal | 0 | 0 | 0 | 0 | 953 | 953 |

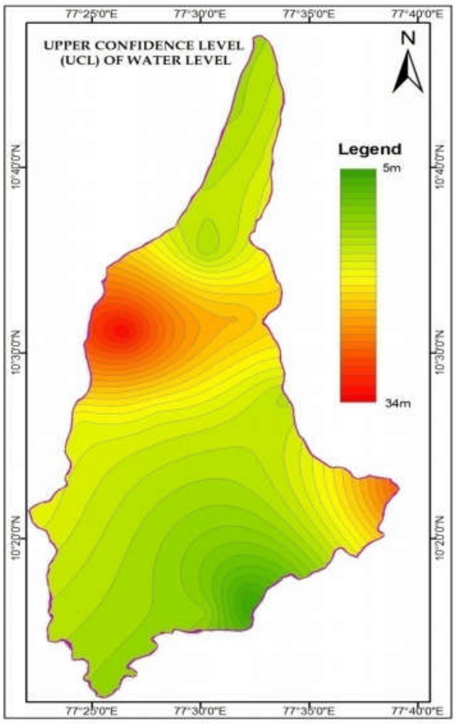
### Hydrogeology of the Study Area

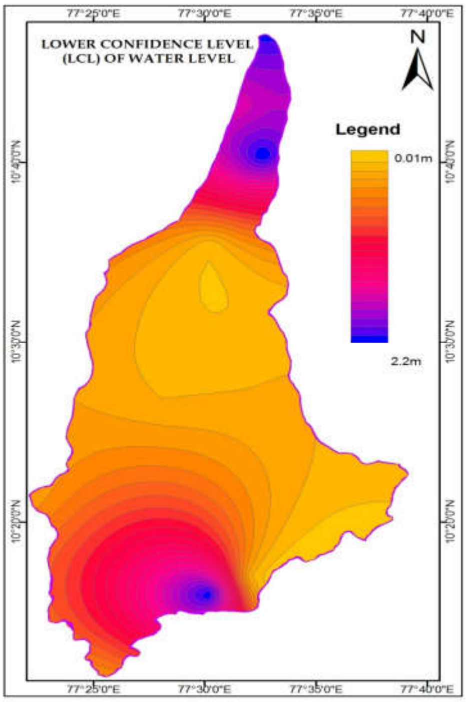
The major part of the study area is underlain by Archaean crystalline metamorphic complex. The important aquifer systems encountered in the study area are classified into

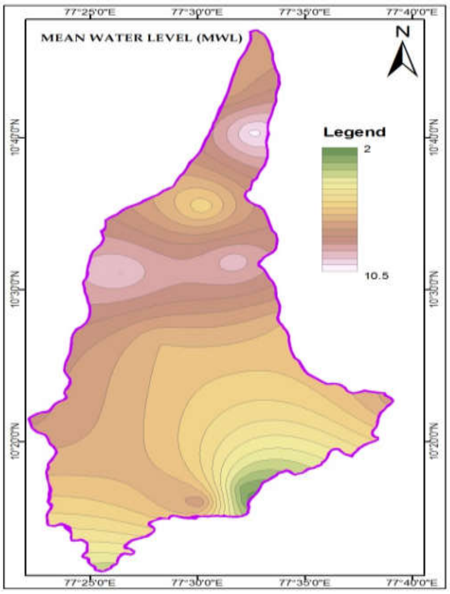
1. Fissured, fractured and weathered crystalline formations consisting of charnockites, Granite Gneisses and
2. Valley fill sediments (Unconsolidated Sediments) comprising clay, sand, silt and kankar.

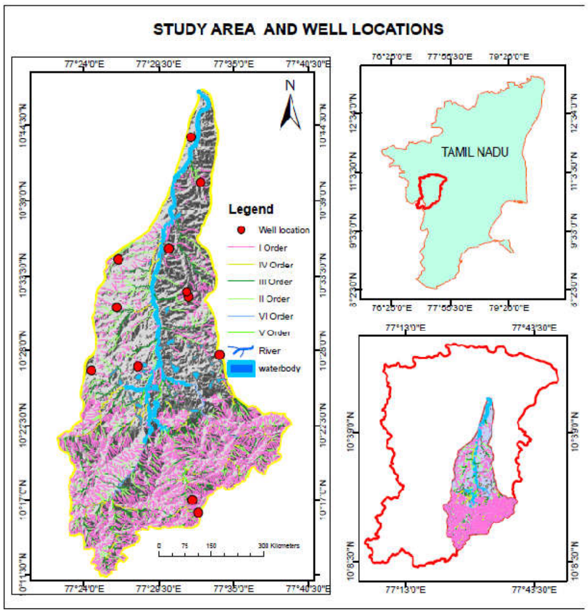
**Table 1** ARIMA and Regression (Goodness of Fit) parameters of the Shanmuga nadhi sub - basin area.

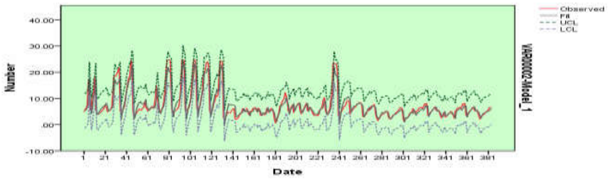
| Sl. NO. | Name of the Water Well Location | Lat | Long | UCL (mbgl) | LCL (mbgl) | MWL (mbgl) | Goodness of Fit |
|---|---|---|---|---|---|---|---|
| 1 | Villupathi | 10.267 | 77.504 | 12.26 | 2.24 | 7.34 | Moderate to good fit |
| 2 | Pettuparai | 10.283 | 77.533 | 5.76 | 0.14 | 2.44 | Moderate to good fit |
| 3 | Perumalmalai | 10.268 | 77.54 | 4.79 | 0.1 | 1.76 | Moderate to good fit |
| 4 | Nandavanapatti | 10.461 | 77.566 | 14.58 | 0.12 | 6.46 | Good Fit |
| 5 | Neikkarapatti | 10.447 | 77.468 | 17.84 | 0.1 | 6.54 | Good Fit |
| 6 | Pappampatti | 10.442 | 77.409 | 18.09 | 0.2 | 7.67 | Good Fit |
| 7 | Dharapuram | 10.719 | 77.525 | 13.64 | 1.59 | 7.08 | Poor fit |
| 8 | Perumalkovilvalasu | 10.638 | 77.647 | 29.22 | 0.05 | 7.43 | Moderate fit |
| 9 | Manakkadavu | 10.672 | 77.543 | 15.74 | 2.22 | 10.24 | Moderate to poor fit |
| 10 | Keeranur | 10.591 | 77.504 | 14.25 | 0.01 | 5.541 | Moderate to good fit |
| 11 | Thumbalapatti | 10.532 | 77.528 | 23.14 | 0.01 | 9.39 | Moderate to good fit |
| 12 | Thalaiyuthu | 10.519 | 77.44 | 33.39 | 0.13 | 9.57 | Moderate to good fit |



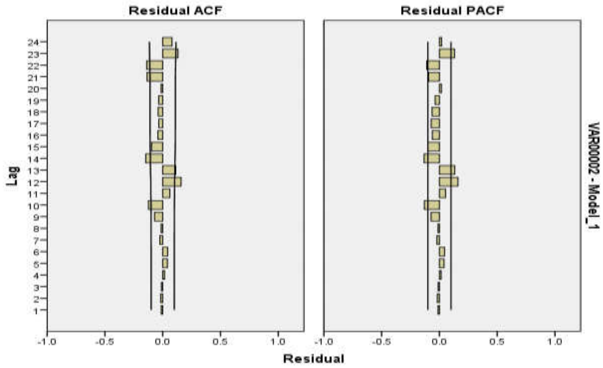



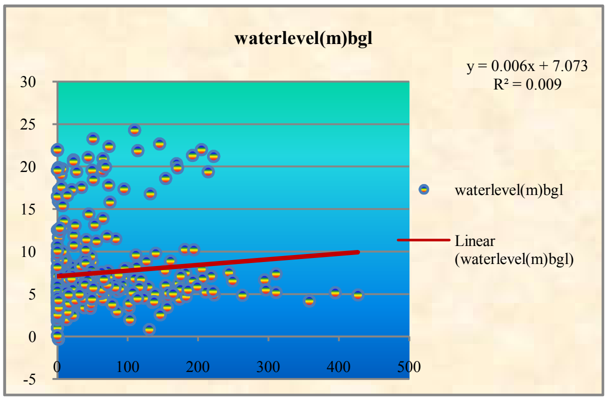


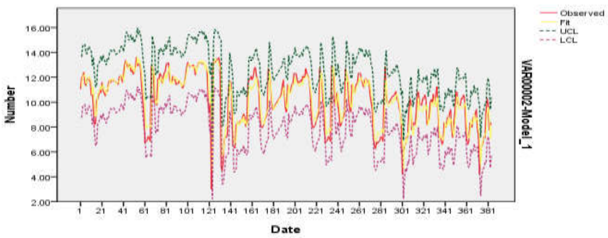

ARIMA Perumalkovilvalasu



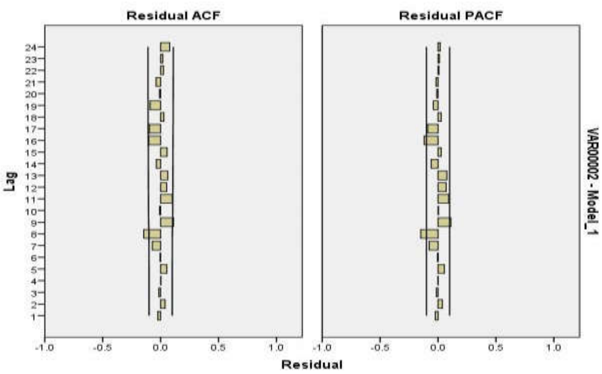

ACF and PACF plots Perumalkovilvalasu

Linear Regression Plot Perumalkovilvalasu

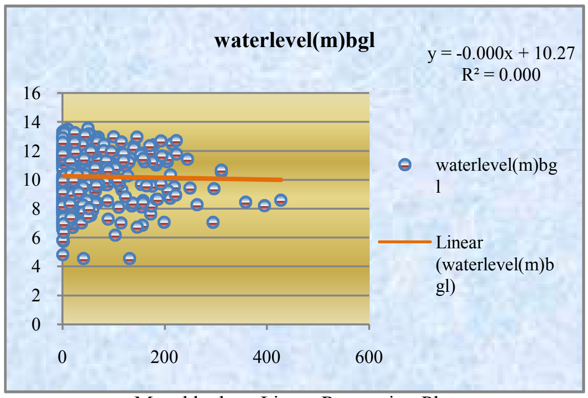


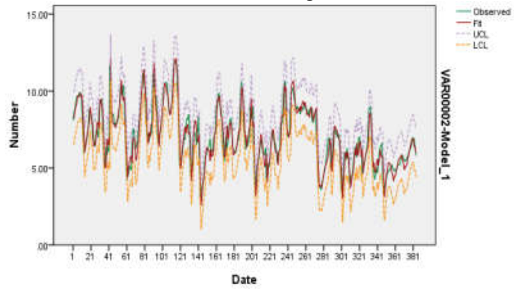

ARIMA Manakkadavu



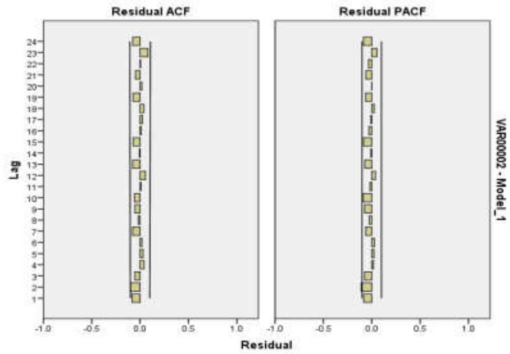

Manakkadavu ACF and PACF plots



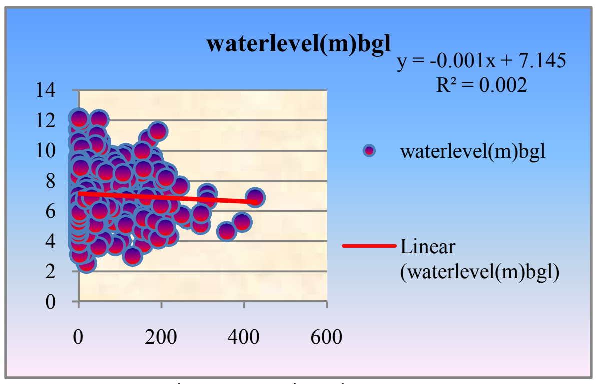

Manakkadavu Linear Regression Plot



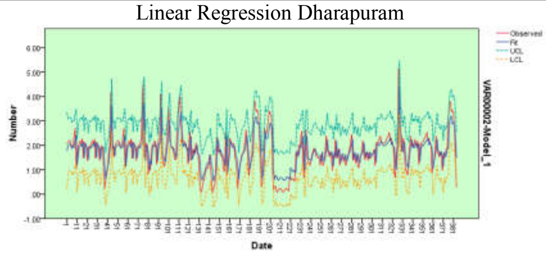

ARIMA Dharapuram



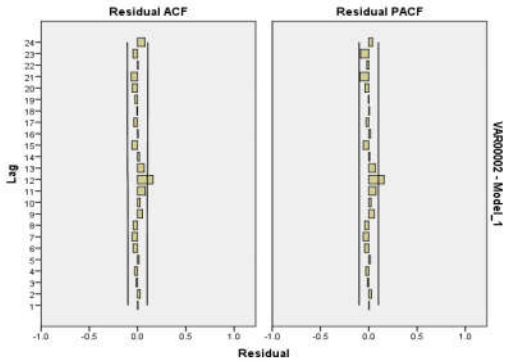

ACF and PACF plots Dharapuram



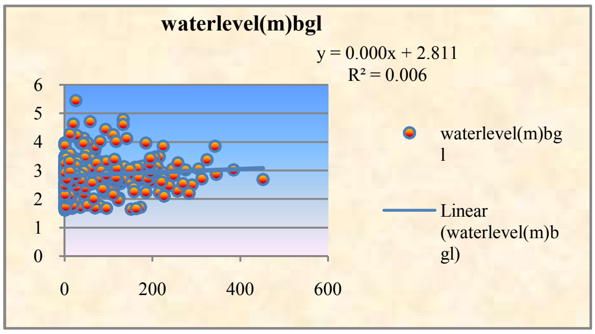

Linear Regression Dharapuram



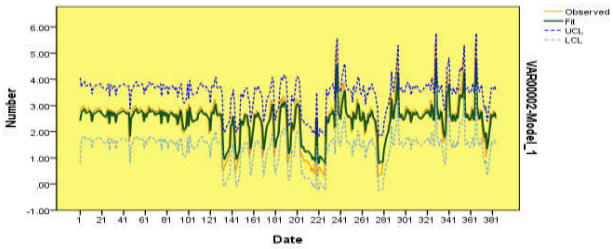

ARIMA Perumalmalai



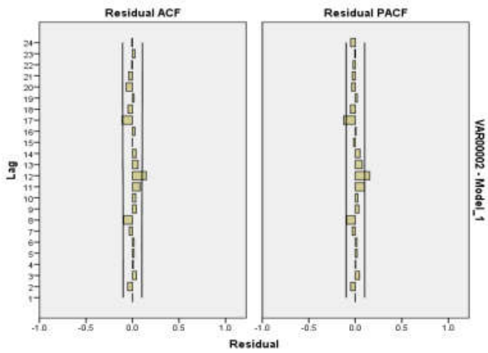

PACF and ACF plots Perumalmalai



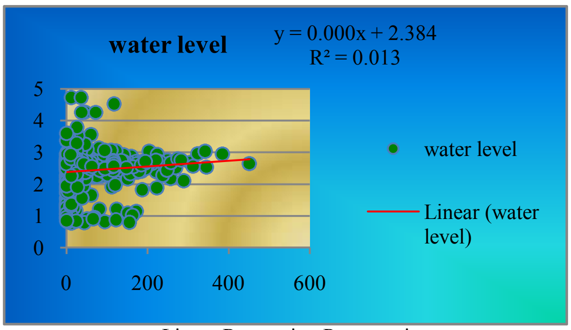

Linear Regression Perumalmalai



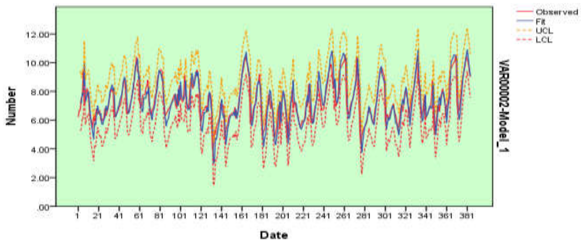

ARIMA Pettuparai



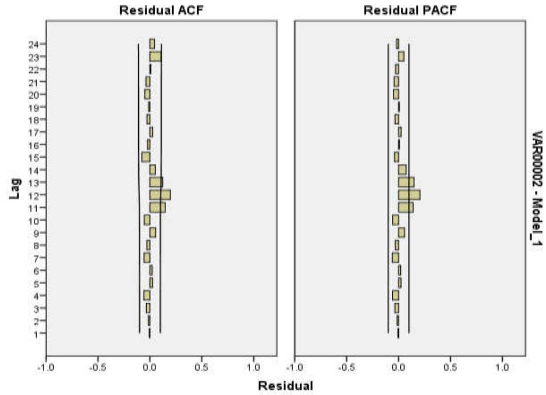

ACF and PACF plots Pettuparai



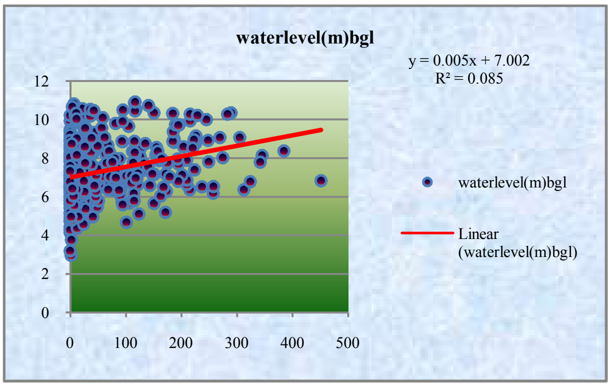

Linear Regression Pettuparai



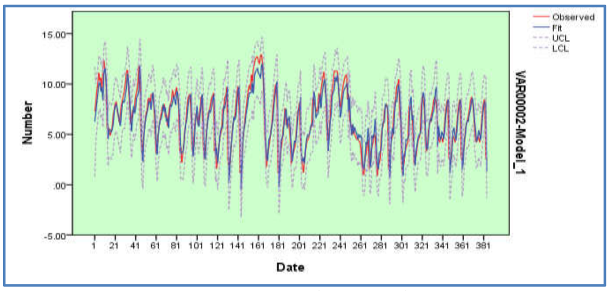

ARIMA Villupathi



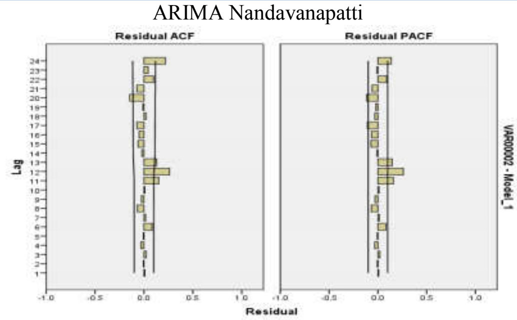

ACF and PACF plots Villupathi



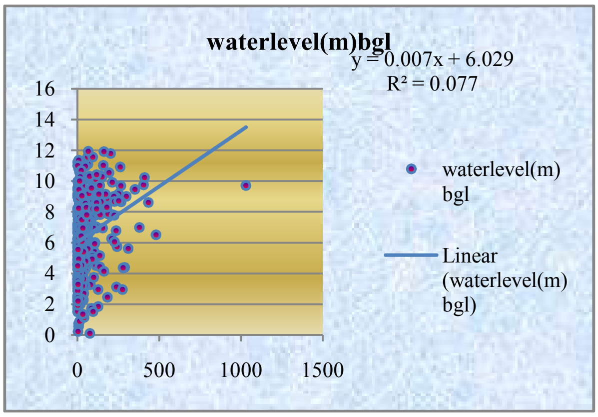

Linear Regression Plot Villupathi



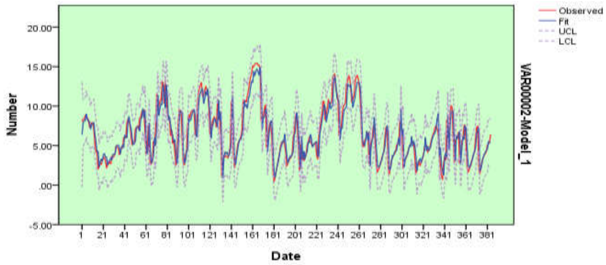

ARIMA Nandavanapatti



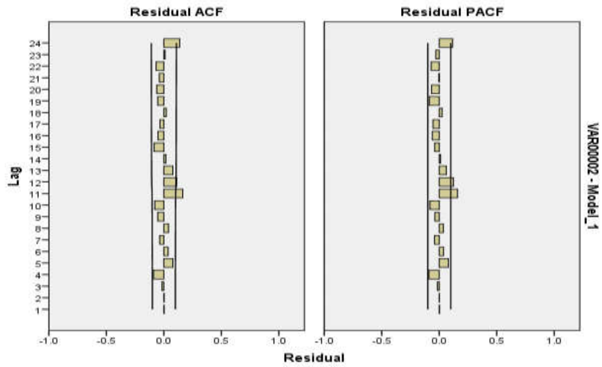

ACF and PACF plots Nandavanapatti




Linear Regression Plot Nandavanapatti




ARIMA Neikkarapatti

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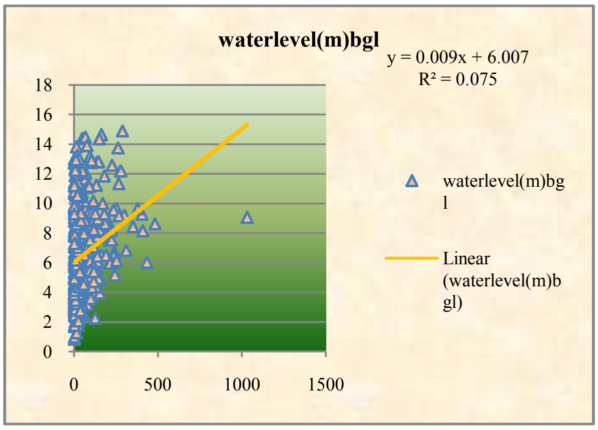
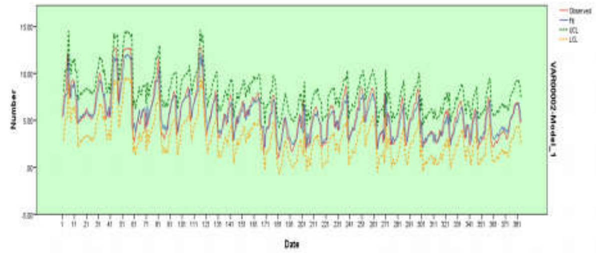
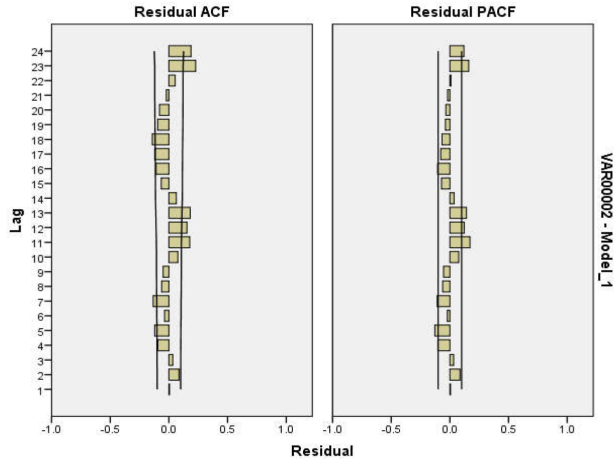



Linear Regression Plot Neikkarapatti

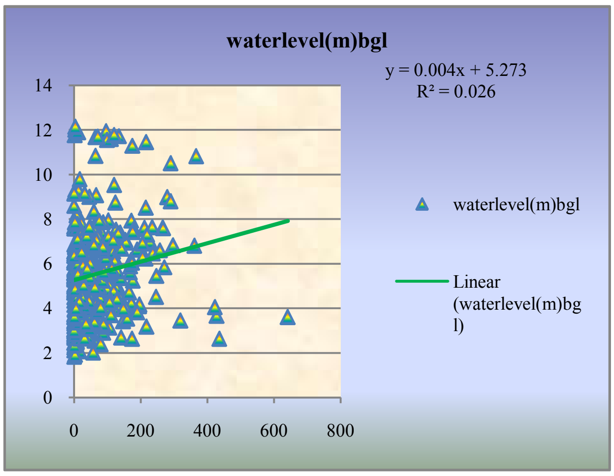
Valley fill sediments have been observed along valley portions in the depth range of 35 to 40 m in the study area. They are characterized by deeper water levels showing high fluctuations. Groundwater occurs under water table condition. In general, dug wells are used to extract groundwater from these zones and the wells can yield about 200 Cu.m per day and can sustain pumping of 3 – 4 hrs in a day. In case of crystalline formations, groundwater occurs under water table condition in weathered and shallow fractures and under semi-confined to confined conditions in deeper fractures. The depth of weathering varies from place to place from less than a meter to a maximum of 40 m. The number of saturated fracture zones varied from 1 to 6 occurring at depths between 10 and 164 m.



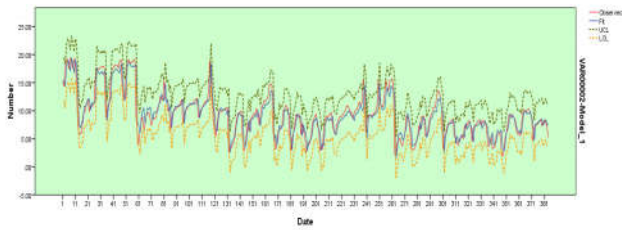

ARIMA Keeranur



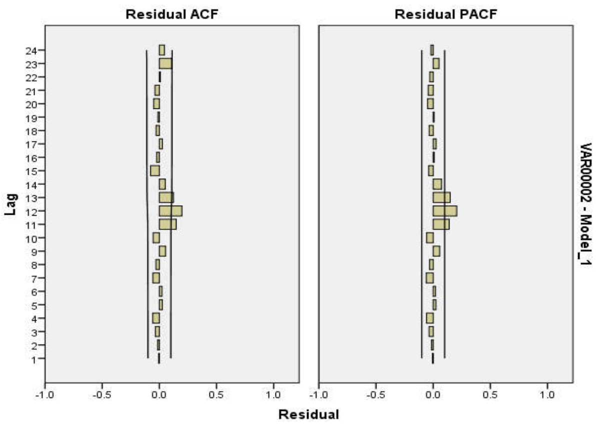

ACF and PACF Plots Keeranur



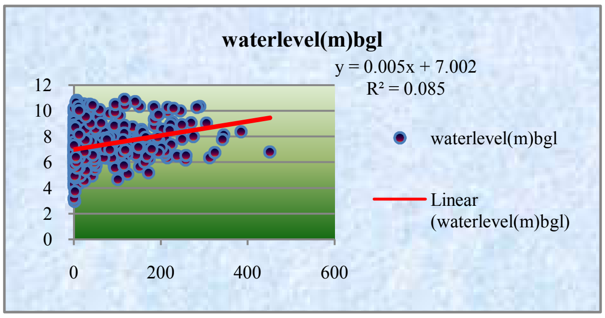

Linear Regression Plot Keeranur



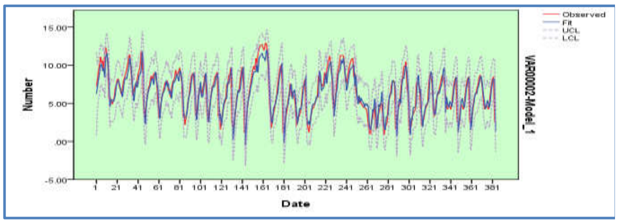

ARIMA Thumbalapatti



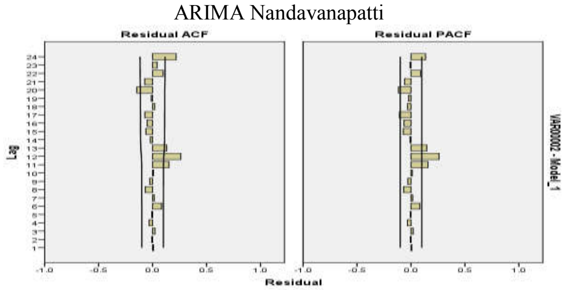

ACF and PACF plots Villupathi



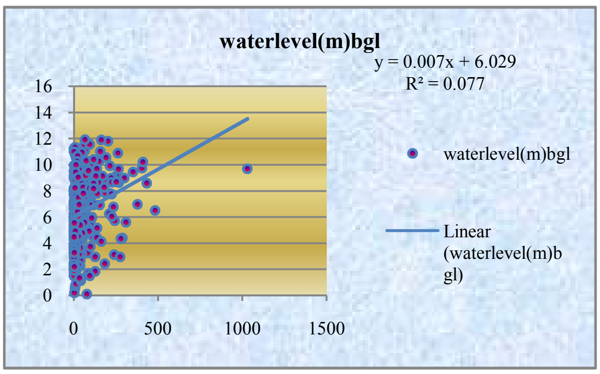

Linear Regression Plot Villupathi



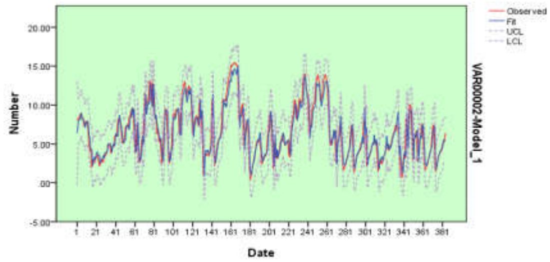

ARIMA Nandavanapatti



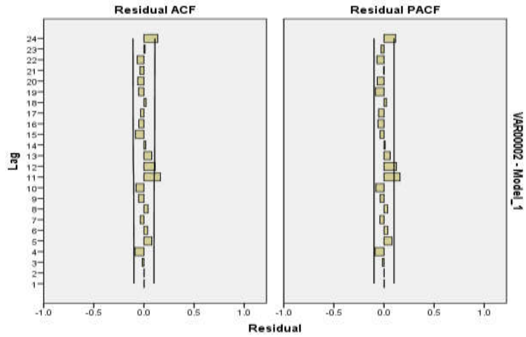

ACF and PACF plots Nandavanapatti



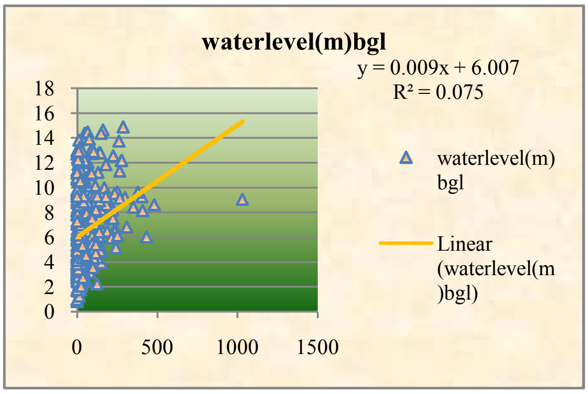

Linear Regression Plot Nandavanapatti



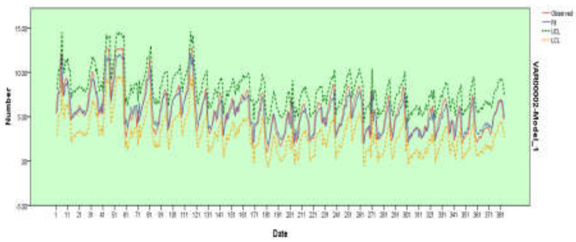

ARIMA Neikkarapatti



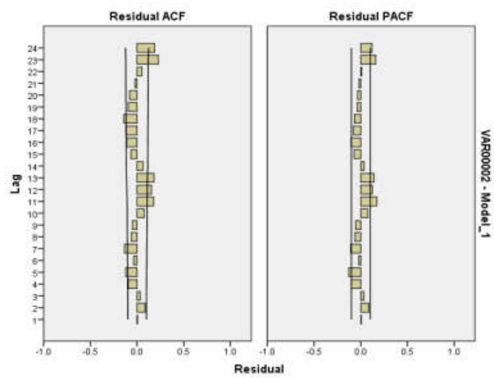

ACF and PACF plots Neikkarapatti



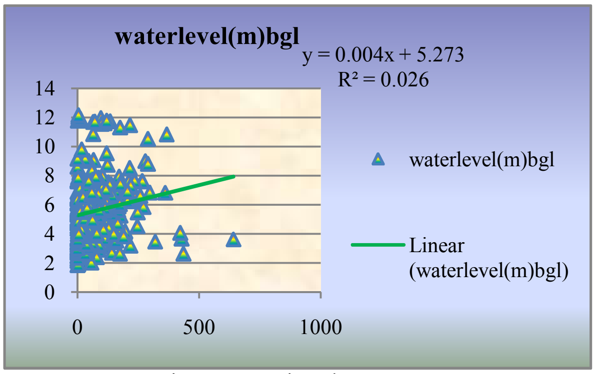

Linear Regression Plot Neikkarapatti



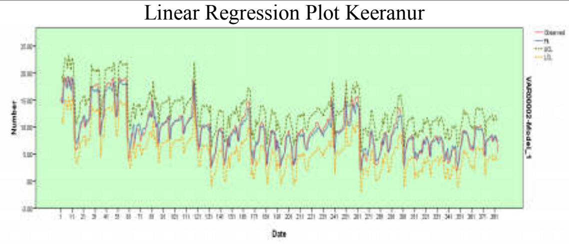
ARIMA Keeranur



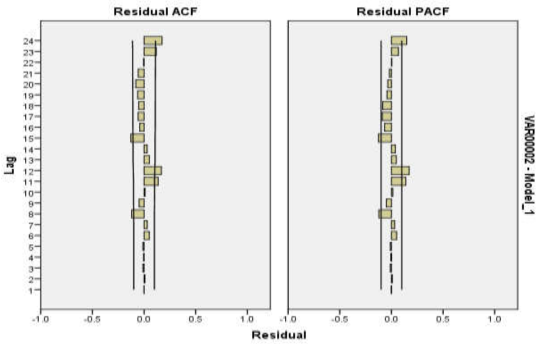

ACF and PACF Plots Keeranur



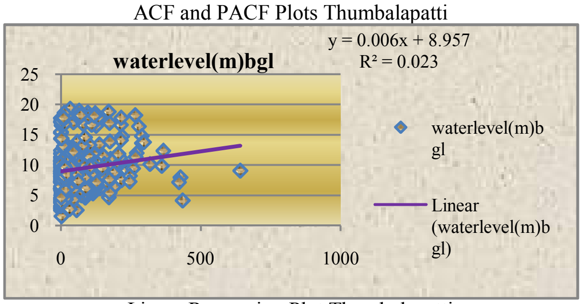

Linear Regression Plot Keeranur



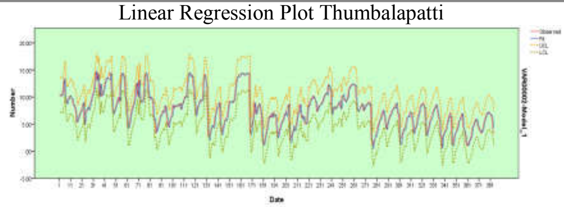
ARIMA Thumbalapatti



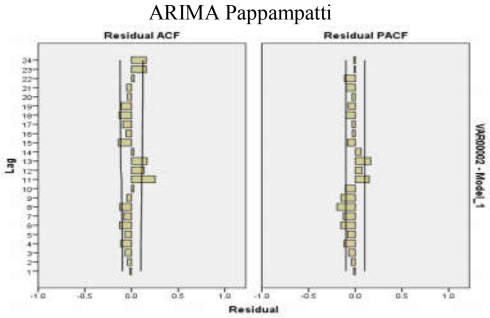

ACF and PACF Plots Thumbalapatti



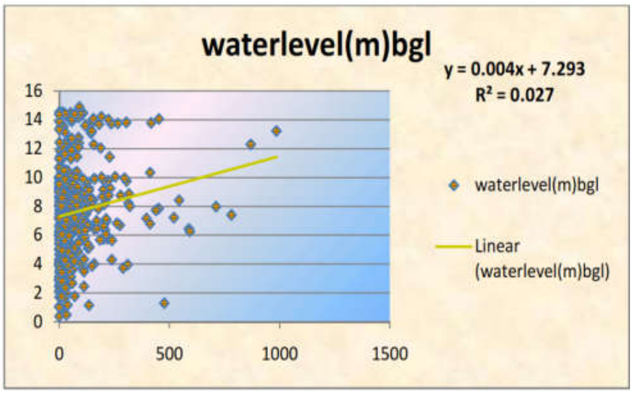

Linear Regression Plot Thumbalapatti



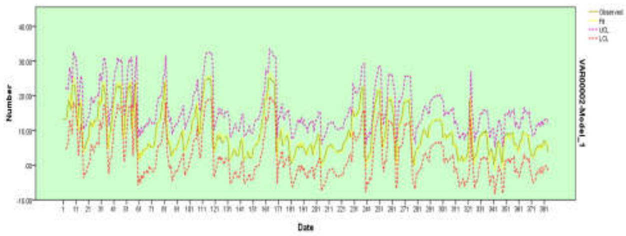
ARIMA Pappampatti



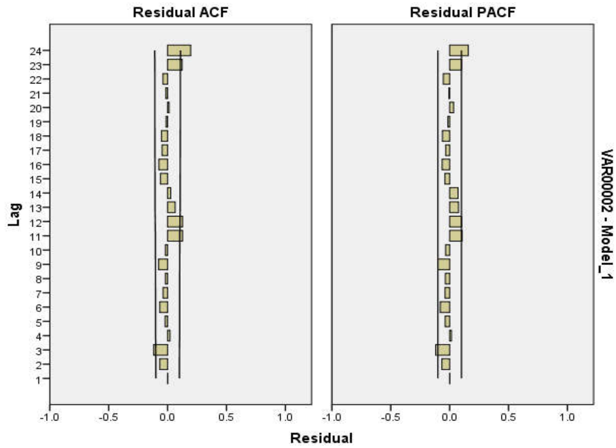

ACF and PACF Plots Pappampatti



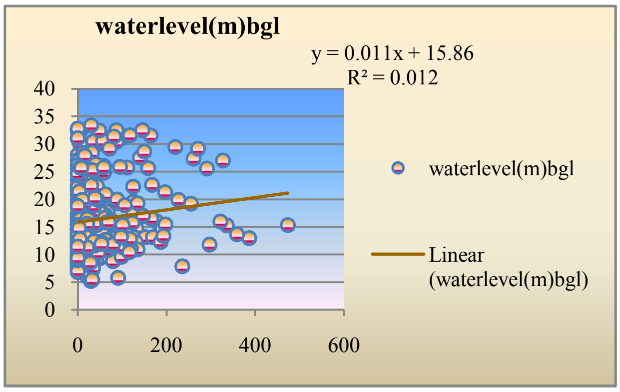

Linear Regression Plot Pappampatti



ARIMA Thalaiyuthu




ACF and PACF Plots Thalaiyuthu




Linear Regression Plot Thalaiyuthu

The ground water exploration in deeper aquifer reveals that in about 11 percent of the wells drilled, the yield was more than 3 lps (litres per second), whereas in about 15 percent of the wells, the yield ranges from 1 to 3 lps. A few of the wells have been abandoned due to poor yield.

**Rainfall, Waterlevel and ARIMA parameters of Thalaiyuthu**

| | Month | Rainfall(mm) | Waterlevel(m)bgl Observed | ARIMA MWL Waterlevel(m)bgl | ARIMA LCL Waterlevel(m)bgl | ARIMA MWL Waterlevel(m)bg |
|---|---|---|---|---|---|---|
| 1983 | January | 0 | 13.10 | 13.1 | 4.5 | 22.48 |
| | February | 0 | 13.30 | 13.3 | 4.63 | 22.54 |
| | March | 0 | 13.33 | 13.58 | 4.63 | 22.54 |
| | April | 0 | 14.20 | 13.55 | 5.44 | 21.66 |
| | May | 124.4 | 18.70 | 14.6 | 6.89 | 22.3 |
| | June | 22.4 | 18.10 | 20.62 | 13.11 | 28.14 |
| | July | 0 | 16.00 | 18.85 | 11.48 | 26.22 |
| | August | 0 | 23.00 | 16.25 | 8.97 | 23.54 |
| | September | 0 | 23.00 | 25.48 | 18.27 | 32.69 |
| | October | 76.8 | 23.00 | 24.08 | 16.92 | 31.25 |
| | November | 100.2 | 18.90 | 24 | 16.89 | 31.12 |
| | December | 158.6 | 11.20 | 18.52 | 11.43 | 25.61 |
| 1984 | January | 0 | 14.85 | 9.93 | 2.88 | 16.99 |
| | February | 37 | 18.10 | 15.5 | 8.46 | 22.53 |
| | March | 112 | 16.00 | 18.75 | 11.74 | 25.76 |
| | April | 4 | 5.40 | 15.81 | 8.81 | 22.8 |
| | May | 46.1 | 4.85 | 3.33 | -3.64 | 10.31 |
| | June | 0 | 4.88 | 4.47 | -2.49 | 11.44 |
| | July | 8.4 | 6.30 | 4.48 | -2.48 | 11.43 |
| | August | 0 | 7.25 | 6.45 | -0.49 | 13.4 |
| | September | 124.4 | 8.35 | 7.03 | 0.1 | 13.97 |
| | October | 122 | 12.30 | 8.31 | 1.38 | 15.24 |
| | November | 29 | 12.20 | 12.71 | 5.8 | 19.63 |
| | December | 48.6 | 11.20 | 12.15 | 5.24 | 19.07 |
| 1985 | January | 67 | 12.10 | 10.85 | 3.95 | 17.75 |
| | February | 0 | 12.90 | 12.27 | 5.38 | 19.17 |
| | March | 0 | 13.20 | 13.02 | 6.13 | 19.91 |
| | April | 35 | 13.00 | 13.4 | 6.51 | 20.29 |
| | May | 6 | 18.50 | 13.06 | 6.18 | 19.94 |
| | June | 3 | 17.50 | 19.77 | 12.9 | 26.65 |
| | July | 0 | 18.00 | 17.62 | 10.75 | 24.5 |
| | August | 0 | 23.00 | 18.71 | 11.84 | 25.58 |
| | September | 60 | 23.00 | 24.17 | 17.3 | 31.03 |
| | October | 62 | 20.80 | 23.62 | 16.76 | 30.49 |
| | November | 140 | 11.10 | 20.7 | 13.84 | 27.56 |
| | December | 18 | 5.25 | 9.89 | 3.04 | 16.75 |
| 1986 | January | 11 | 8.30 | 4.44 | -2.41 | 11.3 |
| | February | 8 | 9.00 | 8.98 | 2.13 | 15.83 |
| | March | 43 | 12.15 | 9.19 | 2.34 | 16.04 |
| | April | 0 | 16.70 | 13.04 | 6.19 | 19.88 |
| | May | 34 | 19.30 | 17.68 | 10.84 | 24.52 |
| | June | 0 | 20.50 | 20.31 | 13.47 | 27.15 |
| | July | 0 | 23.00 | 21.22 | 14.38 | 28.06 |
| | August | 0 | 22.50 | 24.2 | 17.36 | 31.04 |
| | September | 67 | 22.37 | 22.99 | 16.15 | 29.82 |
| | October | 46 | 23.00 | 23.14 | 16.3 | 29.97 |
| | November | 35 | 16.85 | 23.66 | 16.83 | 30.5 |
| | December | 8 | 8.45 | 16.67 | 9.83 | 23.5 |
| 1987 | January | 0 | 9.60 | 7.72 | 0.89 | 14.55 |
| | February | 0 | 14.70 | 10.52 | 3.69 | 17.35 |
| | March | 16 | 19.10 | 16.04 | 9.22 | 22.87 |
| | April | 16 | 22.50 | 20.67 | 13.84 | 27.49 |
| | May | 57 | 22.25 | 23.73 | 16.91 | 30.55 |
| | June | 5 | 23.25 | 23.21 | 16.39 | 30.04 |
| | July | 0 | 10.55 | 24.31 | 17.49 | 31.13 |
| | August | 0 | 13.80 | 9.57 | 2.75 | 16.39 |
| | September | 8 | 19.30 | 15.33 | 8.52 | 22.15 |
| | October | 261 | 23.50 | 20.57 | 13.75 | 27.39 |
| | November | 164 | 4.15 | 24.73 | 17.91 | 31.54 |
| | December | 235.5 | 3.40 | 1.07 | -5.75 | 7.89 |
| 1988 | January | 0 | 2.15 | 3.76 | -3.06 | 10.57 |
| | February | 0 | 3.30 | 1.66 | -5.15 | 8.48 |
| | March | 37 | 3.29 | 4.01 | -2.81 | 10.82 |
| | April | 99 | 4.20 | 2.9 | -3.92 | 9.71 |
| | May | 92 | 4.70 | 4.73 | -2.08 | 11.54 |
| | June | 12 | 4.75 | 4.41 | -2.4 | 11.22 |
| | July | 54 | 5.00 | 5.2 | -1.61 | 12.01 |
| | August | 54 | 6.00 | 4.67 | -2.14 | 11.48 |
| | September | 91 | 6.22 | 6.5 | -0.3 | 13.31 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | October | 57 | 5.20 | 5.82 | -0.98 | 12.63 |
| | November | 53 | 5.25 | 5.38 | -1.42 | 12.19 |
| | December | 3.1 | 5.00 | 4.92 | -1.88 | 11.73 |
| 1989 | January | 0 | 6.35 | 5.42 | -1.39 | 12.22 |
| | February | 0 | 9.35 | 6.39 | -0.42 | 13.19 |
| | March | 40 | 12.20 | 10.33 | 3.53 | 17.14 |
| | April | 47 | 12.30 | 12.51 | 5.71 | 19.32 |
| | May | 125 | 12.90 | 12.74 | 5.93 | 19.54 |
| | June | 25 | 13.65 | 12.86 | 6.06 | 19.66 |
| | July | 21.2 | 18.00 | 14.27 | 7.47 | 21.08 |
| | August | 21.2 | 18.65 | 18.65 | 11.85 | 25.45 |
| | September | 59.4 | 23.95 | 19.26 | 12.46 | 26.06 |
| | October | 97 | 12.40 | 24.76 | 17.96 | 31.55 |
| | November | 125.2 | 8.40 | 10.85 | 4.06 | 17.65 |
| | December | 10.4 | 6.15 | 7.88 | 1.08 | 14.68 |
| 1990 | January | 0 | 6.50 | 5.96 | -0.84 | 12.75 |
| | February | 0 | 2.77 | 6.72 | -0.08 | 13.52 |
| | March | 0 | 2.85 | 2.43 | -4.37 | 9.22 |
| | April | 0 | 4.05 | 3.19 | -3.61 | 9.99 |
| | May | 9 | 4.60 | 4.51 | -2.28 | 11.31 |
| | June | 0 | 4.50 | 5.13 | -1.66 | 11.93 |
| | July | 0 | 5.20 | 4.92 | -1.87 | 11.72 |
| | August | 0 | 6.95 | 5.9 | -0.89 | 12.7 |
| | September | 0 | 7.40 | 7.79 | 1 | 14.59 |
| | October | 132 | 8.75 | 7.97 | 1.18 | 14.76 |
| | November | 178 | 9.90 | 9.2 | 2.4 | 15.99 |
| | December | 61 | 4.40 | 10.38 | 3.58 | 17.17 |
| 1991 | January | 0 | 4.30 | 3.89 | -2.9 | 10.68 |
| | February | 0 | 5.15 | 4.79 | -2 | 11.58 |
| | March | 0 | 5.80 | 5.64 | -1.15 | 12.43 |
| | April | 87 | 7.80 | 6.38 | -0.41 | 13.17 |
| | May | 22 | 8.60 | 8.46 | 1.67 | 15.25 |
| | June | 47.4 | 10.00 | 9.24 | 2.45 | 16.03 |
| | July | 32 | 12.90 | 10.62 | 3.83 | 17.41 |
| | August | 7 | 13.60 | 13.96 | 7.17 | 20.75 |
| | September | 4 | 14.00 | 14.25 | 7.46 | 21.04 |
| | October | 196.8 | 17.25 | 14.52 | 7.73 | 21.31 |
| | November | 59 | 12.80 | 18.05 | 11.26 | 24.84 |
| | December | 33 | 8.90 | 12.58 | 5.8 | 19.37 |
| 1992 | January | 0 | 9.85 | 8.8 | 2.01 | 15.59 |
| | February | 0 | 16.35 | 10.54 | 3.75 | 17.33 |
| | March | 0 | 19.20 | 17.9 | 11.12 | 24.69 |
| | April | 0 | 22.45 | 20.29 | 13.51 | 27.08 |
| | May | 87 | 24.45 | 23.61 | 16.82 | 30.39 |
| | June | 5 | 24.65 | 25.45 | 18.66 | 32.24 |
| | July | 0 | 24.80 | 25.53 | 18.75 | 32.32 |
| | August | 0 | 24.90 | 25.69 | 18.9 | 32.47 |
| | September | 87 | 24.90 | 25.75 | 18.96 | 32.53 |
| | October | 48 | 22.50 | 25.68 | 18.9 | 32.47 |
| | November | 220 | 5.50 | 22.66 | 15.87 | 29.44 |
| | December | 38 | 4.20 | 3.43 | -3.36 | 10.21 |
| 1993 | January | 0 | 5.55 | 4.73 | -2.06 | 11.51 |
| | February | 0 | 6.60 | 6.1 | -0.69 | 12.88 |
| | March | 15 | 8.65 | 7.55 | 0.77 | 14.34 |
| | April | 15 | 7.55 | 9.42 | 2.63 | 16.2 |
| | May | 60 | 8.50 | 8.18 | 1.4 | 14.97 |
| | June | 0 | 7.00 | 9.2 | 2.42 | 15.99 |
| | July | 0 | 6.40 | 7.68 | 0.9 | 14.47 |
| | August | 0 | 7.40 | 7.03 | 0.25 | 13.82 |
| | September | 0 | 8.10 | 8.57 | 1.78 | 15.35 |
| | October | 107 | 8.09 | 8.86 | 2.08 | 15.64 |
| | November | 335.4 | 7.00 | 8.5 | 1.72 | 15.28 |
| | December | 48 | 1.70 | 7.08 | 0.3 | 13.87 |
| 1994 | January | 0 | 1.77 | 1.44 | -5.34 | 8.23 |
| | February | 0 | 2.15 | 2.2 | -4.58 | 8.99 |
| | March | 0 | 3.65 | 2.79 | -3.99 | 9.57 |
| | April | 108 | 4.55 | 4.25 | -2.53 | 11.03 |
| | May | 74 | 3.42 | 5.11 | -1.67 | 11.89 |
| | June | 0 | 3.00 | 3.69 | -3.09 | 10.48 |
| | July | 0 | 2.60 | 3.54 | -3.24 | 10.32 |
| | August | 0 | 4.36 | 3.1 | -3.68 | 9.89 |
| | September | 32 | 6.90 | 5.3 | -1.48 | 12.09 |
| | October | 187 | 7.56 | 7.59 | 0.81 | 14.38 |
| | November | 190 | 2.20 | 7.88 | 1.1 | 14.66 |
| | December | 0 | 1.45 | 1.63 | -5.15 | 8.41 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1995 | January | 0 | 2.15 | 1.8 | -4.98 | 8.58 |
| | February | 0 | 2.33 | 2.55 | -4.23 | 9.33 |
| | March | 3 | 3.80 | 2.93 | -3.85 | 9.71 |
| | April | 45 | 2.23 | 4.39 | -2.39 | 11.17 |
| | May | 50 | 2.00 | 2.53 | -4.25 | 9.31 |
| | June | 0 | 2.17 | 2.45 | -4.33 | 9.23 |
| | July | 0 | 4.50 | 2.85 | -3.92 | 9.63 |
| | August | 20 | 5.48 | 5.44 | -1.34 | 12.22 |
| | September | 50.2 | 5.90 | 6.29 | -0.49 | 13.07 |
| | October | 125 | 6.00 | 6.43 | -0.35 | 13.21 |
| | November | 152 | 6.58 | 6.38 | -0.39 | 13.16 |
| | December | 36.8 | 8.65 | 7.02 | 0.24 | 13.8 |
| 1996 | January | 15 | 9.50 | 9.42 | 2.65 | 16.2 |
| | February | 0 | 12.90 | 10.1 | 3.32 | 16.88 |
| | March | 0 | 13.60 | 14.05 | 7.27 | 20.83 |
| | April | 30 | 18.90 | 14.25 | 7.47 | 21.03 |
| | May | 10 | 19.10 | 20.47 | 13.7 | 27.25 |
| | June | 5 | 19.15 | 19.76 | 12.98 | 26.54 |
| | July | 0 | 25.00 | 20.15 | 13.38 | 26.93 |
| | August | 30 | 25.00 | 26.61 | 19.83 | 33.39 |
| | September | 0 | 25.00 | 26.03 | 19.25 | 32.8 |
| | October | 145.3 | 24.20 | 25.73 | 18.95 | 32.51 |
| | November | 117.5 | 24.00 | 24.81 | 18.04 | 31.59 |
| | December | 81.4 | 23.60 | 24.56 | 17.78 | 31.34 |
| 1997 | January | 0 | 3.70 | 24.3 | 17.52 | 31.08 |
| | February | 0 | 5.90 | 1.42 | -5.36 | 8.2 |
| | March | 0 | 6.60 | 7.31 | 0.53 | 14.09 |
| | April | 11.4 | 8.30 | 7.16 | 0.38 | 13.93 |
| | May | 37.9 | 10.20 | 9.71 | 2.93 | 16.49 |
| | June | 48.1 | 5.75 | 10.95 | 4.17 | 17.72 |
| | July | 2.5 | 6.10 | 6.3 | -0.48 | 13.07 |
| | August | 0 | 7.30 | 6.84 | 0.07 | 13.62 |
| | September | 116.8 | 8.00 | 8.53 | 1.76 | 15.31 |
| | October | 96.3 | 8.60 | 8.59 | 1.82 | 15.37 |
| | November | 321.6 | 6.30 | 9.21 | 2.43 | 15.98 |
| | December | 36.6 | 2.10 | 6.07 | -0.7 | 12.85 |
| 1998 | January | 0 | 0.60 | 2.17 | -4.61 | 8.94 |
| | February | 0 | 1.00 | 0.65 | -6.13 | 7.42 |
| | March | 0 | 2.20 | 1.83 | -4.95 | 8.6 |
| | April | 34 | 3.10 | 2.71 | -4.07 | 9.48 |
| | May | 84 | 5.00 | 3.93 | -2.84 | 10.71 |
| | June | 11 | 5.60 | 5.64 | -1.14 | 12.41 |
| | July | 45 | 4.95 | 6.44 | -0.34 | 13.21 |
| | August | 27 | 5.90 | 5.26 | -1.51 | 12.04 |
| | September | 10.4 | 5.10 | 6.89 | 0.12 | 13.67 |
| | October | 120 | 5.90 | 5.3 | -1.48 | 12.07 |
| | November | 386 | 4.70 | 6.18 | -0.6 | 12.95 |
| | December | 122 | 4.00 | 4.2 | -2.57 | 10.97 |
| 1999 | January | 0 | 3.10 | 4.12 | -2.65 | 10.9 |
| | February | 0 | 4.60 | 2.81 | -3.96 | 9.58 |
| | March | 0 | 5.05 | 5.19 | -1.59 | 11.96 |
| | April | 86.4 | 5.55 | 4.93 | -1.84 | 11.71 |
| | May | 31.4 | 6.10 | 5.96 | -0.81 | 12.73 |
| | June | 0 | 2.85 | 6.12 | -0.65 | 12.9 |
| | July | 4.6 | 5.10 | 2.83 | -3.94 | 9.6 |
| | August | 10 | 5.90 | 5.55 | -1.22 | 12.32 |
| | September | 39.6 | 7.10 | 6.46 | -0.32 | 13.23 |
| | October | 358.7 | 8.70 | 6.89 | 0.12 | 13.66 |
| | November | 197.4 | 8.95 | 8.65 | 1.88 | 15.43 |
| | December | 24.8 | 0.70 | 8.5 | 1.73 | 15.27 |
| 2000 | January | 20.6 | 0.90 | -0.69 | -7.47 | 6.08 |
| | February | 34.2 | 1.05 | 0.6 | -6.17 | 7.37 |
| | March | 0 | 2.15 | 0.86 | -5.91 | 7.64 |
| | April | 79.3 | 3.00 | 2.01 | -4.77 | 8.78 |
| | May | 10 | 4.70 | 2.92 | -3.85 | 9.69 |
| | June | 0 | 5.30 | 4.81 | -1.97 | 11.58 |
| | July | 0 | 5.55 | 5.33 | -1.44 | 12.1 |
| | August | 64.5 | 5.70 | 5.5 | -1.28 | 12.27 |
| | September | 130.6 | 6.00 | 5.49 | -1.28 | 12.26 |
| | October | 67 | 5.10 | 5.81 | -0.97 | 12.58 |
| | November | 122 | 4.70 | 4.6 | -2.18 | 11.37 |
| | December | 135 | 4.10 | 4.16 | -2.61 | 10.93 |
| 2001 | January | 14.5 | 3.85 | 3.58 | -3.19 | 10.35 |
| | February | 4.6 | 3.95 | 3.48 | -3.29 | 10.25 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | March | 28 | 4.20 | 3.62 | -3.15 | 10.39 |
| | April | 36 | 4.35 | 3.94 | -2.83 | 10.72 |
| | May | 66 | 4.15 | 4.01 | -2.76 | 10.79 |
| | June | 28.4 | 6.10 | 3.84 | -2.94 | 10.61 |
| | July | 10 | 6.65 | 6.14 | -0.63 | 12.91 |
| | August | 3.5 | 7.15 | 6.56 | -0.22 | 13.33 |
| | September | 32 | 8.05 | 7.09 | 0.32 | 13.86 |
| | October | 109 | 9.55 | 7.92 | 1.15 | 14.69 |
| | November | 17 | 10.05 | 9.6 | 2.83 | 16.37 |
| | December | 61 | 8.05 | 9.9 | 3.13 | 16.67 |
| 2002 | January | 0 | 15.47 | 7.66 | 0.88 | 14.43 |
| | February | 28.6 | 15.75 | 16.5 | 9.73 | 23.28 |
| | March | 43 | 14.10 | 15.61 | 8.84 | 22.38 |
| | April | 63 | 14.20 | 13.88 | 7.11 | 20.65 |
| | May | 13 | 14.75 | 14.1 | 7.32 | 20.87 |
| | June | 0 | 15.35 | 14.96 | 8.19 | 21.73 |
| | July | 0 | 16.90 | 15.47 | 8.7 | 22.24 |
| | August | 5 | 20.90 | 17.4 | 10.63 | 24.17 |
| | September | 13 | 22.30 | 21.64 | 14.87 | 28.41 |
| | October | 271 | 22.55 | 22.41 | 15.64 | 29.18 |
| | November | 71 | 2.20 | 22.4 | 15.63 | 29.17 |
| | December | 91 | 1.65 | -1 | -7.77 | 5.77 |
| 2003 | January | 0 | 1.75 | 1.64 | -5.13 | 8.41 |
| | February | 18 | 2.65 | 1.4 | -5.37 | 8.17 |
| | March | 21 | 2.70 | 2.92 | -3.85 | 9.69 |
| | April | 41.5 | 4.80 | 2.39 | -4.39 | 9.16 |
| | May | 34.4 | 11.50 | 5.29 | -1.49 | 12.06 |
| | June | 10.2 | 14.02 | 12.26 | 5.48 | 19.03 |
| | July | 3 | 17.40 | 14.66 | 7.88 | 21.43 |
| | August | 0 | 18.70 | 17.9 | 11.13 | 24.67 |
| | September | 2 | 21.20 | 19.29 | 12.52 | 26.07 |
| | October | 31.5 | 21.60 | 21.7 | 14.93 | 28.47 |
| | November | 150 | 21.10 | 21.88 | 15.11 | 28.65 |
| | December | 16 | 10.20 | 21.1 | 14.33 | 27.87 |
| 2004 | January | 0 | 5.25 | 8.95 | 2.18 | 15.72 |
| | February | 0 | 7.10 | 4.84 | -1.93 | 11.61 |
| | March | 0 | 7.40 | 7.76 | 0.99 | 14.53 |
| | April | 52 | 11.60 | 7.72 | 0.95 | 14.49 |
| | May | 87 | 18.40 | 12.55 | 5.78 | 19.32 |
| | June | 41 | 18.95 | 19.61 | 12.84 | 26.38 |
| | July | 0 | 18.60 | 19.45 | 12.68 | 26.22 |
| | August | 5 | 18.70 | 19 | 12.23 | 25.77 |
| | September | 95 | 16.10 | 19.12 | 12.35 | 25.89 |
| | October | 167 | 14.20 | 15.86 | 9.09 | 22.63 |
| | November | 63 | 1.70 | 14.15 | 7.38 | 20.92 |
| | December | 0 | 1.40 | 0.04 | -6.73 | 6.81 |
| 2005 | January | 0 | 10.40 | 1.85 | -4.92 | 8.62 |
| | February | 0 | 10.90 | 11.89 | 5.12 | 18.66 |
| | March | 5 | 12.10 | 11.49 | 4.72 | 18.26 |
| | April | 135 | 12.80 | 12.48 | 5.71 | 19.25 |
| | May | 88.4 | 15.20 | 13.2 | 6.43 | 19.97 |
| | June | 30 | 18.10 | 15.76 | 8.99 | 22.53 |
| | July | 19 | 18.20 | 18.9 | 12.13 | 25.67 |
| | August | 33 | 18.40 | 18.49 | 11.72 | 25.26 |
| | September | 8 | 18.65 | 18.92 | 12.15 | 25.69 |
| | October | 58 | 18.76 | 19 | 12.23 | 25.77 |
| | November | 291 | 13.13 | 18.82 | 12.05 | 25.59 |
| | December | 106 | 3.83 | 12.14 | 5.37 | 18.91 |
| 2006 | January | 17 | 1.43 | 2.56 | -4.2 | 9.33 |
| | February | 0 | 0.03 | 1.08 | -5.69 | 7.85 |
| | March | 26 | 3.83 | -0.09 | -6.86 | 6.68 |
| | April | 86 | 4.20 | 4.34 | -2.43 | 11.11 |
| | May | 26 | 5.03 | 4.25 | -2.52 | 11.02 |
| | June | 0 | 5.43 | 5.28 | -1.49 | 12.05 |
| | July | 0 | 5.73 | 5.63 | -1.14 | 12.4 |
| | August | 11 | 7.90 | 6.04 | -0.73 | 12.8 |
| | September | 61 | 9.50 | 8.39 | 1.62 | 15.16 |
| | October | 166 | 10.30 | 9.74 | 2.97 | 16.51 |
| | November | 147 | 9.60 | 10.26 | 3.49 | 17.03 |
| | December | 0 | 8.70 | 9.48 | 2.71 | 16.25 |
| 2007 | January | 0 | 7.90 | 8.61 | 1.84 | 15.38 |
| | February | 0 | 11.20 | 7.91 | 1.14 | 14.68 |
| | March | 11.1 | 11.80 | 11.85 | 5.08 | 18.62 |
| | April | 36.5 | 12.20 | 12.03 | 5.26 | 18.8 |
| | May | 14.7 | 12.60 | 12.54 | 5.77 | 19.3 |
| | June | 6.1 | 12.80 | 12.92 | 6.15 | 19.69 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | July | 45 | 12.80 | 13.16 | 6.4 | 19.93 |
| | August | 10 | 12.95 | 13.13 | 6.36 | 19.9 |
| | September | 40 | 13.10 | 13.38 | 6.61 | 20.14 |
| | October | 227 | 13.30 | 13.14 | 6.37 | 19.91 |
| | November | 39 | 12.80 | 13.48 | 6.71 | 20.25 |
| | December | 255 | 12.20 | 12.44 | 5.67 | 19.2 |
| 2008 | January | 0 | 8.10 | 12.04 | 5.27 | 18.81 |
| | February | 54 | 8.60 | 7.31 | 0.54 | 14.07 |
| | March | 84 | 8.85 | 8.56 | 1.79 | 15.33 |
| | April | 0 | 7.90 | 8.66 | 1.89 | 15.43 |
| | May | 0 | 8.35 | 7.81 | 1.04 | 14.58 |
| | June | 0 | 8.90 | 8.36 | 1.59 | 15.12 |
| | July | 64 | 9.20 | 9.04 | 2.27 | 15.81 |
| | August | 26 | 9.45 | 9.19 | 2.42 | 15.96 |
| | September | 6 | 6.00 | 9.66 | 2.89 | 16.43 |
| | October | 297 | 6.10 | 5.06 | -1.71 | 11.83 |
| | November | 62 | 5.90 | 5.92 | -0.84 | 12.69 |
| | December | 54 | 3.25 | 5.41 | -1.35 | 12.18 |
| 2009 | January | 3 | 1.30 | 2.74 | -4.03 | 9.5 |
| | February | 0 | 1.60 | 0.74 | -6.03 | 7.51 |
| | March | 12 | 1.95 | 1.63 | -5.14 | 8.39 |
| | April | 34 | 2.65 | 1.77 | -5 | 8.53 |
| | May | 28 | 1.20 | 2.78 | -3.99 | 9.55 |
| | June | 34 | 1.75 | 0.8 | -5.97 | 7.57 |
| | July | 9 | 2.00 | 1.97 | -4.8 | 8.73 |
| | August | 6 | 2.65 | 1.95 | -4.81 | 8.72 |
| | September | 99 | 5.75 | 2.85 | -3.92 | 9.62 |
| | October | 96 | 18.80 | 5.96 | -0.81 | 12.73 |
| | November | 327 | 11.40 | 20.27 | 13.51 | 27.04 |
| | December | 75 | 5.80 | 9.5 | 2.73 | 16.27 |
| 2010 | January | 75 | 1.50 | 4.78 | -1.99 | 11.54 |
| | February | 0 | 2.35 | 0.06 | -6.7 | 6.83 |
| | March | 0 | 2.90 | 2.4 | -4.37 | 9.16 |
| | April | 15 | 4.35 | 2.23 | -4.53 | 9 |
| | May | 0 | 7.10 | 4.61 | -2.16 | 11.37 |
| | June | 10 | 8.25 | 6.9 | 0.13 | 13.67 |
| | July | 42 | 8.70 | 8.5 | 1.73 | 15.27 |
| | August | 31 | 9.10 | 8.23 | 1.47 | 15 |
| | September | 73 | 9.60 | 9.22 | 2.45 | 15.99 |
| | October | 123 | 9.40 | 8.98 | 2.22 | 15.75 |
| | November | 473 | 10.10 | 8.58 | 1.81 | 15.34 |
| | December | 81 | 6.50 | 8.87 | 2.1 | 15.63 |
| 2011 | January | 13.2 | 2.70 | 5.26 | -1.51 | 12.03 |
| | February | 0 | 3.40 | 1.01 | -5.76 | 7.78 |
| | March | 0 | 4.70 | 2.93 | -3.84 | 9.7 |
| | April | 30.7 | 4.20 | 3.8 | -2.97 | 10.57 |
| | May | 46.1 | 0.10 | 3.56 | -3.21 | 10.33 |
| | June | 29.3 | 1.60 | -1.53 | -8.3 | 5.24 |
| | July | 0 | 3.98 | 1.41 | -5.36 | 8.17 |
| | August | 0 | 6.58 | 3.39 | -3.38 | 10.16 |
| | September | 169.4 | 6.83 | 6.39 | -0.38 | 13.16 |
| | October | 186.3 | 5.33 | 5.51 | -1.25 | 12.28 |
| | November | 119.5 | 0.71 | 4.26 | -2.5 | 11.03 |
| | December | 32.7 | 0.89 | -1.34 | -8.11 | 5.43 |
| 2012 | January | 0 | 8.10 | 0.22 | -6.54 | 6.99 |
| | February | 0 | 8.60 | 7.9 | 1.13 | 14.67 |
| | March | 0 | 8.85 | 8.04 | 1.27 | 14.8 |
| | April | 0 | 9.30 | 7.89 | 1.12 | 14.65 |
| | May | 36.8 | 8.35 | 8.81 | 2.04 | 15.58 |
| | June | 14.5 | 8.90 | 7.28 | 0.52 | 14.05 |
| | July | 0 | 9.20 | 8.57 | 1.81 | 15.34 |
| | August | 0 | 9.45 | 8.46 | 1.69 | 15.22 |
| | September | 69.1 | 6.00 | 9.1 | 2.34 | 15.87 |
| | October | 100.7 | 6.10 | 4.58 | -2.19 | 11.34 |
| | November | 116.3 | 5.90 | 5.58 | -1.19 | 12.35 |
| | December | 38.4 | 4.25 | 4.84 | -1.93 | 11.61 |
| 2013 | January | 0 | 5.25 | 3.58 | -3.19 | 10.35 |
| | February | 0 | 7.10 | 4.55 | -2.22 | 11.32 |
| | March | 0 | 7.40 | 7.05 | 0.28 | 13.82 |
| | April | 15.8 | 9.60 | 6.72 | -0.05 | 13.49 |
| | May | 21.4 | 9.40 | 9.71 | 2.94 | 16.48 |
| | June | 19.5 | 8.95 | 8.72 | 1.95 | 15.48 |
| | July | 20.7 | 8.60 | 8.78 | 2.02 | 15.55 |
| | August | 3 | 8.70 | 8.02 | 1.25 | 14.78 |
| | September | 100.5 | 6.10 | 8.57 | 1.81 | 15.34 |
| | October | 79.4 | 4.20 | 5.04 | -1.72 | 11.81 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | November | 116 | 2.70 | 3.65 | -3.12 | 10.42 |
| | December | 28.3 | 2.40 | 1.74 | -5.03 | 8.5 |
| 2014 | January | 0 | 3.10 | 2.19 | -4.57 | 8.96 |
| | February | 0 | 4.60 | 2.6 | -4.16 | 9.37 |
| | March | 11.6 | 5.05 | 4.77 | -2 | 11.53 |
| | April | 13.8 | 5.55 | 4.62 | -2.14 | 11.39 |
| | May | 36.2 | 5.10 | 5.64 | -1.12 | 12.41 |
| | June | 20.8 | 5.85 | 4.61 | -2.16 | 11.37 |
| | July | 4.1 | 5.10 | 6.1 | -0.67 | 12.87 |
| | August | 0 | 5.90 | 4.7 | -2.07 | 11.46 |
| | September | 117.6 | 7.10 | 6.11 | -0.65 | 12.88 |
| | October | 193.1 | 6.70 | 6.61 | -0.16 | 13.37 |
| | November | 97.4 | 5.95 | 6.44 | -0.33 | 13.2 |
| | December | 53.1 | 3.70 | 5.15 | -1.61 | 11.92 |

Dug wells are used to extract groundwater from weathered formation while deeper fractures are tapped through bore wells and dug wells. The yield of open wells in the district tapping the weathered mantle of crystalline rocks generally ranges from 100 to 400 lpm (litres per minute) for drawdown ranging from 2 to 4.5 m. The dug wells can sustain a pumping of 3-4 hrs in a day. The wells tapping the deep seated fracture system can yield about 1 – 5 lps and can sustain a pumping of 6-8 hrs a day.

## RESULTS AND DISCUSSION

The ARIMA modelling of the water table fluctuations to rainfall of the study area with the arima parameters of (1,1,1) revealed a precarious situation of the aquifer behaviour of the study area.

The withdrawal of ground water has reached alarming conditions at most of the locations exceeding the natural recharge to the groundwater systems. Dharapuram, a major human settlement of the study area show poor fit of the regression with Mean water level (MWL). The withdrawal for various usages has many years exceeded the natural recharge into the system with a steady decrease of the water table (bgl). The ARIMA parameters (Table 1) also return a very poor regression informing no direct relation between recharge and discharge from the well resulting in the depletion of the bank storage from the groundwater aquifers. The fluctuations of water level during poor monsoon seasons exceed 100% of the mean water level averaged over the study window period. The steady decrease of the water level over successive years also informs a regular excess withdrawal from the bank storage exceeding the natural quantum of recharge.

Wells from Perumalkovilvalasu and Manakkadavu located near Dharapuram also inform similar conditions of non to poor relationship between fluctuations and rainfall. The moderate to poor fit and an ever decreasing groundwater level return a situation no less than that of Dharapuram.

Study locations Keeranur, Thumbalapatti, Thalaiyuthu, are slightly better with the fluctuation patterns and their goodness of fit returning a moderate fit informing the behaviour of aquifers to rainfall recharge. The larger differences between the lower confidence levels and upper confidence water levels show the aquifer having a good recharge potential and the steady decrease of the water levels over years has decreased the quantum of bank storage and if proper recharge systems are practised, the locations will return to have lesser fluctuation of the water levels from withdrawal.

Locations Villupathi, Pettuparai and Perumalmalai are located in regions of higher elevations than other well locations and have different geomorphic conditions to other wells of the study area. The drainage pattern of these locations is of lower orders informing surface flow and thus well connected aquifer systems. The relatively lesser tapping of groundwater for agricultural uses are reflected in the arima parameters and the fluctuations. The good to moderate fit for regression show a normal relationship existing between rainfall and recharge. Pettuparai and Perumalmalai locations show a lean difference between upper, mean and lower confidence levels of water informing better aquifer behaviour to rainfall recharge.

Well locations Nandhavanapatti, Neikkarapatti and Pappampatti located near the river Shanmugha Nadhi show a good connectivity with rainfall and recharge with a good fit of regression. The water levels over the study period also are fluctuating with the pattern of monsoon.

The arima parameters of the study area inform the control of geology and geomorphology with the fractured crystalline aquifers dominating the region and the geomorphology, geology and the structural characters of the locations help a good recharge to the groundwater systems and their presence near the river Shanmugha Nadhi also make them recharge from the surface flow during monsoonal periods. The differences between the lower and upper confidence levels reflected over years inform a good recharge potential of the aquifers and the steady decrease in the water levels also inform the gradual increase of the quantum of withdrawal of groundwater from the wells and augmentation of the natural recharge to the crystalline aquifers of the region will yield good results. The near goodness of fit also justifies this character of the aquifers of this part of the study area.

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