

# Statistical Analysis of Groundwater Table Depths in Upper Swarnamukhi River Basin

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## Abstract

Development and effective utilization of groundwater resources is essential in semi-arid regions for activities such as water supply and irrigation. The present study aims to analyze statistically the groundwater data at the Chinnagottigallu, Yerravaripalem, Chandragiri, Srirampuram, Tirupati, Renigunta, Karvetinagam and Yerpedu piezometric stations of upper Swarnamukhi river basin in the drought prone Rayalaseema region of Andhra Pradesh, India and to develop models through multiple linear correlation and regression analysis. The monthly rainfall and groundwater data at the raingauge and piezometric stations of the basin for the period 2001-2006 were collected from the Groundwater and Irrigation Departments of the region. It is observed from the analysis that the groundwater table depth in any period is influenced by the rainfall in the period and, the rainfall and groundwater table depth in the previous period. The study also reveals that the effect of antecedent groundwater table depth is more pronounced than that of rainfall and antecedent rainfall. The models proposed may be adopted for the estimation of groundwater table depths to effectively plan and efficiently manage groundwater resources of the basin.

**Keywords:** Multiple Linear Correlation, Partial Correlation Coefficient, Root Mean Square Error, Efficiency Coefficient

## 1. Introduction

Groundwater constitutes the largest available source of water for water supply and irrigation in semi-arid regions and therefore the development and utilization of groundwater resources is of great interest to meet these requirements. As rainfall is the primary source of recharge for many aquifers, variations of rainfall and groundwater table depth are closely related. However, the correlation may sometimes be imperfect because differences in rainfall intensity and distribution produce different amounts of recharge for the same amount of rainfall. Therefore proper understanding of the groundwater status is important in order to meet the increasing demand due to growing population and urbanization, and to formulate future development and management strategies.

Statistical analysis of water table data carried out at Powarkheda in Hoshangabad District of Madhya Pradesh, India [1] suggested the optimum utilization of open wells, putting the area to high water requiring crops and minimizing canal seepage and other losses to prevent water logging. A water balance and groundwater flow model [2] was proposed to develop groundwater draft/recharge

maps for planning groundwater development of Ponnaiyar river basin of Karnataka state, India. The studies [3,4] carried out on the rejuvenation of Swarnamukhi basin suggested the construction of rainwater harvesting structures for improving the groundwater potential of the basin. The groundwater development studies in the Koyna river basin in Maharashtra, India [5] suggested artificial recharge measures for water scarce areas. The pattern of water level fluctuations in different physiographic regions of Nileshwar river basin in Kasargod District of Kerala state, India was studied [6] and concluded that the Nileshwar basin is 'SAFE' for future groundwater development. The study conducted on the groundwater status in Dhund river basin in Jaipur District of Rajasthan, India [7] recommended proper groundwater management strategies to stabilize the declining trend of water levels.

## 2. Study Area and Data

The Swarnamukhi, an ephemeral river, spreading over a catchment area of 3092 km<sup>2</sup> is bounded by latitudes 13°25'30" N and 14°08'30" N and longitudes 79°07'39"E and 80°11'E in Chittoor and Nellore Districts of Andhra

Pradesh, India as shown in **Figure 1**. It originates at the Pakala Mandal of Chittoor District, flows in a northeasterly direction and finally joins the Bay of Bengal. The upper Swarnamukhi basin covering an area of 2217 km<sup>2</sup> lying in Chittoor District has been selected for the present groundwater study. The area falls under semi-arid climate. The maximum, minimum and mean temperatures are 44<sup>o</sup>.18C, 12<sup>o</sup>.48C and 27<sup>o</sup>.49C respectively. The maximum, minimum and mean wind speeds at 3 m height are 18.15 kmph, 5.14 kmph and 9.72 kmph respectively. The average annual rainfall is about 920 mm. The drainage pattern is dendritic to subdendritic.

The area under irrigation in Chittoor District, drought prone area of Rayalaseema region of Andhra Pradesh, is about 2.02 lakh hectares which mainly depends on groundwater as there are no major irrigation projects. The groundwater in the basin over a period of time has been overexploited leading to water scarcity and deterioration of its quality. Degradation of catchment area, indiscriminate groundwater use, erratic rainfall and sand quarrying are some of the causes for the present status. The present study aims to analyze the groundwater table depths statistically and develop models through multiple linear correlation and regression analysis to estimate the groundwater table depths for better planning and management of groundwater resources.

The monthly groundwater table depth and rainfall data at Chinnagottigallu (Cgg), Yerravaripalem (Yvp), Chandragiri (Cgr), Srirampuram (Srp), Tirupati (Tpt), Renigunta (Rng), Karvetinagaram (Kvt) and Yerpudu (Ypd) piezometric and rainguage stations located in the basin as shown in **Figure 1** for the period 2001-2006 were collected from the Groundwater and Irrigation Departments respectively, and used for the model development. **Tables 1** and **2** present the rainfall and groundwater table depths at the rainguage and piezometric stations respectively. The groundwater table depth data showed that there is no systematic trend with rainfall as the processes

are complex exhibiting high degree of both spatial and temporal variability. The model coefficients, however, may be updated to obtain the refined models for better forecasting accuracy.

### 3. Model Development

An association of three or more variables is best investigated by multiple regression and correlation analysis. Since linear equations are easier to treat than nonlinear equations, variables of nonlinear relations in hydrology are often transformed to linear relations for the purpose of development of a multiple regression model. If there are m variables to correlate, including one dependent and (m-1) independent variables, the multiple linear regression model is generally expressed as (1).

$$X_1 = b_1 + b_2 X_2 + b_3 X_3 + \dots + b_i X_i + \dots + b_m X_m \quad (1)$$

in which  $b_1$  is the intercept and  $b_i$  ( $i = 2, 3, \dots, m$ ) are the multiple regression coefficients of the dependent variable  $X_1$  on the independent variable  $X_i$  ( $i = 2, 3, \dots, m$ ) with all other variables kept constant.

Applying the least squares method of the sum of residuals, the m partial differential equations in  $b_1, b_2, \dots, b_m$  yield m linear equations. The solution of these equations facilitates determination of m parameters.

#### 3.1. Linear Regression Model

In the present study, the monthly groundwater table depth model at a piezometric station is developed using the rainfall, antecedent rainfall and antecedent ground water table depth data of the piezometric station under consideration and also the piezometric stations upstream. The steps in the modeling include 1) identification of influencing parameters 2) development of a model and 3) performance evaluation of the model developed.

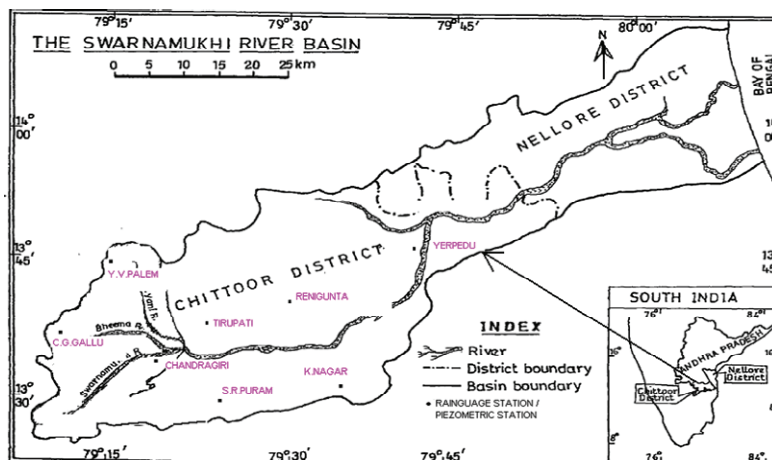


Figure 1. Location map of Swarnamukhi river basin.

Table 1. Monthly rainfall in mm at piezometric stations.

Raingauge Station	Month Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Yvp	2001	1.8	0.0	0.0	52.6	19.8	12.0	84.4	66.8	166.8	455.2	21.6	42.4
	2002	0.0	0.0	0.0	0.8	7.4	162.4	8.0	54.0	77.4	183.6	9.8	5.2
	2003	0.0	0.0	2.2	10.0	0.0	48.0	258.2	230.4	111.2	171.6	0.0	0.0
	2004	0.0	30.0	28.0	30.2	169.4	48.8	139.1	19.8	169.6	36.4	40.0	0.0
	2005	0.0	0.0	0.0	63.0	46.2	93.8	93.2	130.4	73.0	232.6	192.2	244.8
	2006	0.0	0.0	80.4	4.4	10.8	93.2	2.2	142.0	77.8	82.6	60.4	10.2
Cgg	2001	0.0	0.0	0.0	88.9	43.8	7.2	70.4	51.6	153.7	366.5	29.3	53.1
	2002	1.8	0.0	0.0	0.0	29.1	55.0	0.0	64.9	49.3	169.2	16.4	10.4
	2003	0.0	0.0	0.0	0.0	0.0	61.2	202.4	178.8	139.8	171.4	0.0	0.0
	2004	0.0	0.0	20.0	14.6	177.4	39.4	108.2	21.2	118.4	80.7	50.8	0.0
	2005	0.0	15.2	0.0	67.2	56.2	109.6	117.0	207.8	111.2	209.8	208.6	133.4
	2006	0.0	0.0	58.8	65.9	94.6	53.0	18.0	127.2	82.6	95.2	82.8	11.2
Kvt	2001	3.2	0.0	0.0	131.2	40.6	9.2	76.6	60.8	207.4	180.8	58.2	43.2
	2002	0.0	0.0	0.0	0.0	25.6	160.1	8.6	50.2	89.8	156.3	54.5	14.6
	2003	0.0	0.0	26.6	0.0	0.0	108.1	381.1	149.2	107.0	116.2	19.6	5.4
	2004	0.0	0.0	0.0	61.4	207.5	45.3	63.1	5.2	300.8	93.0	88.6	0.0
	2005	0.0	0.0	0.0	64.6	54.3	83.4	129.8	114.2	144.9	458.7	240.3	228.1
	2006	0.0	0.0	0.0	0.0	71.1	117.7	9.8	152.2	220.7	177.6	21.0	61.4
Srp	2001	0.0	0.0	5.2	138.0	19.1	52.6	87.4	173.6	156.0	343.3	53.0	52.4
	2002	0.0	0.0	0.0	0.0	8.6	140.2	65.0	54.6	71.0	129.1	59.0	13.6
	2003	0.0	0.0	50.0	0.0	0.0	50.0	325.9	125.8	126.6	135.2	31.0	0.0
	2004	0.8	0.0	0.0	20.0	258.2	15.0	95.4	0.0	173.0	156.7	85.8	0.0
	2005	0.0	0.0	0.0	50.4	4.2	55.5	114.5	116.3	162.5	314.1	158.0	167.4
	2006	0.0	0.0	0.0	2.0	68.2	48.0	28.0	58.2	175.2	108.2	41.5	25.8
Cgr	2001	0.0	0.0	0.0	97.8	45.4	24.8	116.6	46.0	144.7	304.8	59.8	66.1
	2002	37.4	0.0	0.0	0.0	29.4	89.7	13.6	68.5	111.1	222.4	53.6	19.4
	2003	0.0	0.0	16.3	15.3	9.6	140.1	190.9	149.0	125.7	157.8	17.6	9.7
	2004	0.0	0.0	0.0	53.3	146.6	87.8	107.0	34.6	239.7	68.4	74.2	0.0
	2005	0.0	0.0	0.0	69.1	36.5	18.3	152.3	132.5	180.4	282.9	324.4	241.9
	2006	0.0	0.0	16.4	1.7	114.2	31.0	7.2	132.5	117.0	243.6	110.6	21.8
Tpt	2001	0.0	0.0	0.0	69.6	17.2	45.3	137.4	22.8	168.3	297.0	84.8	130.7
	2002	25.8	0.0	0.0	1.0	77.2	196.7	8.2	106.6	188.5	267.7	89.0	27.8
	2003	0.0	0.0	22.2	11.8	23.0	222.0	289.0	98.7	145.4	146.7	19.7	13.4
	2004	0.0	3.2	0.0	81.4	207.9	60.5	100.2	35.4	279.5	163.4	132.4	0.0
	2005	0.0	9.8	0.0	27.0	22.7	66.4	153.5	73.4	134.2	332.8	517.9	164.0
	2006	0.0	0.0	38.6	19.4	142.2	126.2	4.8	75.6	108.0	165.2	150.2	14.2
Rng	2001	3.1	0.0	0.0	75.7	46.0	37.5	88.7	62.4	185.6	318.8	147.1	149.7
	2002	17.3	0.0	0.0	0.0	83.9	121.2	33.9	91.8	267.5	313.6	196.9	74.7
	2003	0.0	0.0	35.3	0.0	0.0	94.5	373.1	131.2	177.1	174.3	35.7	14.4
	2004	0.0	0.0	0.0	39.6	195.2	66.2	103.6	65.6	425.2	198.6	232.0	0.0
	2005	0.0	8.2	0.0	38.0	21.6	50.0	171.4	157.8	116.0	454.3	592.6	202.0
	2006	0.0	0.0	54.3	0.0	13.9	27.8	4.2	17.8	20.8	162.5	204.2	26.2
Ypd	2001	22.3	0.0	0.0	61.3	83.2	20.0	69.9	42.3	110.4	400.1	187.2	136.3
	2002	62.2	0.0	0.0	4.2	13.8	125.7	54.3	64.9	138.2	292.6	216.4	80.5
	2003	0.0	0.0	13.4	0.0	3.6	89.6	288.5	163.3	154.8	155.8	26.0	29.6
	2004	0.0	2.6	0.0	75.8	198.3	45.0	70.4	25.4	219.4	213.3	162.8	0.0
	2005	0.0	35.8	10.6	23.8	34.8	77.2	142.0	64.8	115.0	474.6	550.1	341.8
	2006	5.6	0.0	0.0	0.0	38.0	41.4	75.8	304.1	262.2	74.2	5.2	0.0

3.1.1. Identification of Influencing Parameters

The identification of influencing parameters is based on multiple correlation analysis. The values of multiple and partial correlation coefficients indicate the degree of influence of independent variables on the dependent one.

3.1.2. Development of Model

The linear regression model in terms of influencing parameters is expressed as a simple linear model as (2).

$$G_t = b_1 + b_2R_t + b_3R_{t-1} + b_4G_{t-1} + b_5G_{t-1(us1)} + b_6G_{t-1(us2)} + \dots \tag{2}$$

where  $G_t$  is the groundwater depth in m in the  $t^{th}$  month,  $b_1, b_2, \dots$  are empirical constants,  $R_t$  is the rainfall in mm in the  $t^{th}$  month,  $R_{t-1}$  is the antecedent rainfall in mm and  $G_{t-1}$  is the antecedent groundwater depth in m at the stations.  $G_{t-1(us1)}, G_{t-1(us2)}, \dots$  are the groundwater table depths at the piezometric stations on the upstream of the

**Table 2. Monthly groundwater table depth in m at piezometric stations.**

Piezometric Station	Month Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Yvp	2001	30.0	-	-	-	29.50	30.00	30.00	30.0	30.0	15.80	11.05
2002		11.0	13.27	15.15	16.75	19.25	20.19	21.02	18.01	20.15	20.62	18.26	18.70
2003		20.13	20.57	21.09	21.95	23.61	21.95	23.32	20.09	16.93	13.93	10.77	7.55
2004		11.55	12.58	14.20	15.40	15.45	16.06	16.71	17.76	17.50	16.80	15.27	15.55
2005		16.32	20.58	21.45	21.85	21.89	22.41	22.52	22.36	20.48	18.85	13.31	6.12
2006		6.0	17.40	17.77	10.55	10.72	11.79	13.53	14.52	14.65	12.79	11.26	10.96
Cgg	2001	40.0	-	-	-	13.05	13.93	14.25	14.56	15.0	14.01	11.94	12.17
	2002	11.74	12.28	13.06	13.77	14.20	14.68	14.95	15.37	15.75	15.53	14.52	14.45
	2003	14.70	15.04	15.79	16.12	16.47	16.48	16.78	16.46	16.0	15.54	14.86	15.18
	2004	15.63	16.08	16.61	17.31	17.90	17.33	17.91	18.64	19.06	18.01	17.55	18.15
	2005	18.96	18.96	18.93	19.77	21.01	22.23	21.62	21.33	18.64	17.96	15.12	5.88
	2006	4.58	4.77	5.07	5.22	5.70	6.07	6.57	9.98	9.93	9.95	9.62	9.16
Kvt	2001	9.0	-	-	-	-	9.95	9.95	10.01	10.44	8.9	7.14	7.07
	2002	6.57	6.8	7.39	8.10	8.63	9.26	9.44	9.74	10.13	10.5	9.58	9.67
	2003	10.76	11.25	12.34	14.78	16.41	17.16	15.42	10.17	9.79	10.44	10.21	11.04
	2004	11.77	12.45	14.15	15.61	15.72	14.92	16.0	16.58	16.67	12.7	11.74	12.04
	2005	13.07	13.27	14.30	15.85	16.73	17.17	18.75	20.18	7.99	12.98	6.86	1.20
	2006	1.99	2.89	3.33	4.09	4.95	4.09	4.91	5.54	4.56	9.99	4.02	4.25
Srp	2001	10.1	-	-	-	21.66	23.32	24.86	26.65	27.57	27.32	21.99	19.21
	2002	16.62	16.35	16.87	17.84	18.92	21.01	21.88	21.64	22.95	23.94	23.78	23.83
	2003	24.69	25.25	26.06	27.81	29.28	30.45	31.18	30.49	30.07	29.99	29.34	29.17
	2004	29.53	29.93	30.85	31.78	32.15	31.96	32.49	33.13	33.69	34.21	33.79	32.88
	2005	33.0	33.56	34.50	36.12	36.19	36.19	36.19	36.19	36.19	36.19	36.19	30.11
	2006	22.46	19.1	18.35	18.69	19.77	20.43	21.70	23.07	24.08	24.66	24.89	24.74
Cgr	2001	14.3	-	-	-	-	17.76	17.76	17.28	18.20	14.08	13.35	13.2
	2002	12.45	12.80	13.74	14.37	14.89	15.31	15.59	15.86	16.39	16.18	14.24	14.42
	2003	16.0	16.71	17.34	18.02	18.32	18.6	17.21	16.46	16.25	15.68	14.96	16.22
	2004	16.23	16.45	17.16	18.13	17.08	16.74	16.77	16.03	14.67	14.94	14.48	14.55
	2005	15.10	15.80	16.57	17.05	17.32	17.69	17.73	16.46	14.58	13.92	9.99	6.83
	2006	7.86	8.0	8.06	8.43	9.03	9.97	9.48	8.75	8.13	8.20	5.86	5.70
Tpt	2001	6.5	-	-	-	17.81	18.38	19.34	19.8	20.13	20.13	19.65	19.66
	2002	19.12	19.44	19.78	19.94	20.18	20.53	20.56	20.77	21.08	21.09	20.77	20.72
	2003	20.86	21.21	21.33	21.64	21.92	22.32	22.52	22.59	22.48	22.33	22.21	22.36
	2004	22.42	22.54	22.66	22.73	22.67	22.95	23.13	23.35	23.66	23.92	24.02	24.10
	2005	24.31	24.43	24.31	25.30	25.59	25.93	26.25	26.55	26.79	26.86	24.10	22.74
	2006	21.9	21.2	20.66	20.16	16.84	19.65	19.53	19.57	19.58	19.45	19.22	19.05
Rng	2001	2.5	-	-	-	-	8.4	8.4	8.67	11.92	4.71	2.94	3.21
	2002	2.15	3.49	3.76	4.50	5.31	5.81	6.44	6.85	7.25	6.76	4.99	2.94
	2003	3.92	5.26	6.11	7.02	9.80	8.63	4.18	3.55	4.34	3.95	4.95	5.51
	2004	4.9	6.55	7.43	7.35	6.26	5.62	6.19	7.29	6.58	6.76	3.67	4.45
	2005	6.93	5.59	6.77	7.56	9.54	9.30	9.79	9.71	11.65	4.03	0.56	0.64
	2006	1.69	3.01	3.66	5.27	7.11	7.38	7.88	8.45	8.88	7.15	2.82	2.88
Ypd	2001	3.4	-	-	-	13.36	18.80	19.09	18.76	18.65	13.96	9.59	8.61
	2002	7.15	8.41	8.87	9.98	11.19	14.25	15.20	16.11	16.41	16.66	11.86	11.89
	2003	12.89	14.41	16.59	16.78	17.78	17.78	17.78	13.98	13.65	13.84	13.18	15.75
	2004	16.05	16.95	16.95	16.95	16.95	16.95	16.95	15.98	15.98	15.95	11.85	10.67
	2005	12.11	13.35	15.25	15.95	16.24	15.95	15.95	15.95	15.85	15.85	6.73	3.42
	2006	4.82	6.87	7.05	8.1	9.17	10.62	14.26	15.76	15.76	15.76	15.62	14.25

piezometric station under consideration.

**3.1.3 Performance Evaluation Criteria**

The performance of the model is verified through selected performance evaluation criteria as explained below. Out of the several numerical model performance indicators, the coefficient of determination ( $R^2$ ), root

mean square error (RMSE) and efficiency coefficient (EC) are chosen for the present study. The scatter plot of the observed versus estimated groundwater table depths is selected as a graphical indicator.

**Coefficient of Determination ( $R^2$ ):** It is the square of the correlation coefficient (R) and the correlation coefficient is expressed as (3).

$$R = \frac{\sum_{i=1}^n (y_i - \bar{y})(\hat{y}_i - \bar{\hat{y}})}{\left[ \sum_{i=1}^n (y_i - \bar{y})^2 \sum_{i=1}^n (\hat{y}_i - \bar{\hat{y}})^2 \right]^{1/2}} \times 100 \quad (3)$$

where  $y_i$  and  $\hat{y}_i$  are the observed and estimated values respectively and,  $\bar{y}$  and  $\bar{\hat{y}}$  are the means of observed and estimated values.

**Root Mean Square Error (RMSE):** It yields the residual error in terms of the mean square error and is expressed as (4).

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (y_i - \hat{y}_i)^2}{n}} \quad (4)$$

where n = number of observations.

**Efficiency Coefficient (EC):** It is used to assess the performance of the models and is given by (5).

$$EC = 1 - \left( \frac{F}{F_0} \right) \times 100 \quad (5)$$

where

$$F_0 = \sum_{i=1}^n (y_i - \bar{y})^2 \quad \text{and} \quad F = \sum_{i=1}^n (y_i - \hat{y}_i)^2$$

A value of EC of 90% generally indicates a very satisfactory model performance while a value in the range 80-90%, a fairly good model. Values in the range 60-80% would indicate an unsatisfactory model fit.

### 4. Results and Discussion

The groundwater table depth in any month at a piezometric station of upper Swarnamukhi basin is correlated with the rainfall of the month, antecedent rainfall and an-

tecedent groundwater table depth at the station and also at the stations upstream. The measures of correlation such as multiple correlation coefficients and partial correlation coefficients have been computed and presented in **Table 3**. The high multiple correlation coefficients (**Tables 3 and 4**) indicate that the monthly groundwater table depth at any station can better be correlated with rainfall, antecedent rainfall and groundwater table depths of the station and the upstream stations. The partial correlation coefficients, which measure the extent of association of independent variable with the dependent one indicate that the effect of antecedent groundwater table depth at the station is more pronounced than that of rainfall and antecedent rainfall. This may be due to the fact that the groundwater in the basin may be overexploited at the rates of withdrawal more than critical, because of scanty rainfall and degradation of catchment during the period. It may also be observed from **Table 4** that there is only marginal improvement in the correlation when the effect of groundwater table depths at the piezometric stations upstream of the station under investigation is also included in the analysis due to local dyke formations.

The linear regression models in terms of influencing parameters are presented in **Table 5**. The scatter plots of observed versus estimated groundwater table depths are shown in **Figure 2**.

The results of the study have been evaluated through  $R^2$ , RMSE and EC as presented in **Table 6**. The higher values of  $R^2$  and EC and, low values of RMSE indicate that the regression models developed are fairly good and yield satisfactory results. Therefore the regression models developed may be adopted for the reasonable estimation of groundwater table depths at the piezometric station based on rainfall, antecedent rainfall and antecedent groundwater table depth for effective planning and management of groundwater resources of the basin.

**Table 3. Measures of multiple linear correlation.**

Piezometric Station	Multiple Correlation Coefficient				Partial Correlation Coefficient		
	Independent Variable Omitted				Independent Variable Omitted		
	-	$R_t$	$R_{t-1}$	$G_{t-1}$	$R_t$	$R_{t-1}$	$G_{t-1}$
Yerravaripalem (Yvp)	0.902	0.884	0.872	0.291	0.199	0.256	0.947
Chinnagottigallu (Cgg)	0.964	0.964	0.947	0.194	0.000	0.187	0.980
Karvetinagaram (Kvt)	0.914	0.914	0.877	0.272	0.000	0.282	0.955
Srirampuram (Srp)	0.967	0.965	0.959	0.324	0.064	0.128	0.942
Chandragiri (Cgg)	0.980	0.972	0.974	0.337	0.128	0.110	0.939
Tirupati (Tpt)	0.980	0.980	0.976	0.155	0.000	0.090	0.987
Renigunta (Rng)	0.820	0.759	0.817	0.477	0.379	0.086	0.813
Yerpedu (Ypd)	0.922	0.918	0.888	0.464	0.093	0.269	0.864

**Table 4. Measures of multiple linear correlation (Effect of groundwater table depths of upstream piezometric stations also considered).**

Piezometric Station	Multiple Correlation Coefficient													
	Independent Variable Omitted													
	-	R <sub>t</sub>	R <sub>t-1</sub>	G <sub>t-1</sub>										
Yerravaripalem	0.902	0.884	0.872	0.291										
Chinnagottigallu					R <sub>t(Yvp)</sub>	R <sub>t-1(Yvp)</sub>	G <sub>t-1(Yvp)</sub>							
	0.969	0.966	0.966	0.190	0.965	0.969	0.967							
Karvetinagaram					R <sub>t(Cgg)</sub>	R <sub>t-1(Cgg)</sub>	G <sub>t-1(Cgg)</sub>							
	0.923	0.923	0.919	0.270	0.923	0.920	0.918							
Sriramapuram					R <sub>t(Kvt)</sub>	R <sub>t-1(Kvt)</sub>	G <sub>t-1(Kvt)</sub>	R <sub>t(Cgg)</sub>	R <sub>t-1(Cgg)</sub>	G <sub>t-1(Cgg)</sub>	R <sub>t(Yvp)</sub>	R <sub>t-1(Yvp)</sub>	G <sub>t-1(Yvp)</sub>	
	0.983	0.983	0.983	0.321	0.983	0.983	0.982	0.983	0.983	0.983	0.983	0.981	0.981	
Chandragiri														
	0.980	0.972	0.974	0.337										
Tirupati					R <sub>t(Cgr)</sub>	R <sub>t-1(Cgr)</sub>	G <sub>t-1(Cgr)</sub>	R <sub>t(Srp)</sub>	R <sub>t-1(Srp)</sub>	G <sub>t-1(Srp)</sub>				
	0.991	0.990	0.991	0.154	0.991	0.991	0.991	0.991	0.990	0.987				
Renigunta					R <sub>t(Tpt)</sub>	R <sub>t-1(Tpt)</sub>	G <sub>t-1(Tpt)</sub>							
	0.839	0.802	0.838	0.475	0.831	0.835	0.833							
Yerpedu					R <sub>t(Rng)</sub>	R <sub>t-1(Rng)</sub>	G <sub>t-1(Rng)</sub>	R <sub>t(Tpt)</sub>	R <sub>t-1(Tpt)</sub>	G <sub>t-1(Tpt)</sub>	R <sub>t(Cgr)</sub>	R <sub>t-1(Cgr)</sub>	G <sub>t-1(Cgr)</sub>	
	0.951	0.950	0.949	0.460	0.950	0.948	0.951	0.951	0.950	0.951	0.950	0.950	0.951	

Piezometric Station	Partial Correlation Coefficient												
	Independent Variable Omitted												
	R <sub>t</sub>	R <sub>t-1</sub>	G <sub>t-1</sub>										
Yerravaripalem	0.199	0.256	0.947										
Chinnagottigallu				R <sub>t(Yvp)</sub>	R <sub>t-1(Yvp)</sub>	G <sub>t-1(Yvp)</sub>							
	0.079	0.079	0.981	0.091	0	0.064							
Karvetinagaram				R <sub>t(Cgg)</sub>	R <sub>t-1(Cgg)</sub>	G <sub>t-1(Cgg)</sub>							
	0	0.093	0.956	0	0.081	0.104							
Sriramapuram				R <sub>t(Kvt)</sub>	R <sub>t-1(Kvt)</sub>	G <sub>t-1(Kvt)</sub>	R <sub>t(Cgg)</sub>	R <sub>t-1(Cgg)</sub>	G <sub>t-1(Cgg)</sub>	R <sub>t(Yvp)</sub>	R <sub>t-1(Yvp)</sub>	G <sub>t-1(Yvp)</sub>	
	0	0	0.945	0	0	0.045	0	0	0	0	0.064	0.064	
Chandragiri													
	0.128	0.110	0.939										
Tirupati				R <sub>t(Cgr)</sub>	R <sub>t-1(Cgr)</sub>	G <sub>t-1(Cgr)</sub>	R <sub>t(Srp)</sub>	R <sub>t-1(Srp)</sub>	G <sub>t-1(Srp)</sub>				
	0.045	0	0.988	0	0	0	0	0.045	0.090				
Renigunta				R <sub>t(Tpt)</sub>	R <sub>t-1(Tpt)</sub>	G <sub>t-1(Tpt)</sub>							
	0.294	0.049	0.824	0.138	0.098	0.119							
Yerpedu				R <sub>t(Rng)</sub>	R <sub>t-1(Rng)</sub>	G <sub>t-1(Rng)</sub>	R <sub>t(Tpt)</sub>	R <sub>t-1(Tpt)</sub>	G <sub>t-1(Tpt)</sub>	R <sub>t(Cgr)</sub>	R <sub>t-1(Cgr)</sub>	G <sub>t-1(Cgr)</sub>	
	0.046	0.065	0.875	0.046	0.079	0	0	0.079	0	0.079	0.079	0	

**Table 5. Regression equations.**

Piezometric Station	Regression equation
Yerravaripalem	$G_t = 3.303 - 0.013R_t - 0.015R_{t-1} + 0.906 G_{t-1}$
Chinnagottigallu	$G_t = 0.887 - 0.011 R_{t-1} + 0.987 G_{t-1}$
Karvetinagaram	$G_t = 1.920 - 0.012 R_{t-1} + 0.901 G_{t-1}$
Sriramapuram	$G_t = 1.049 + 0.005 R_t - 0.01 R_{t-1} + 0.975 G_{t-1}$
Chandragiri	$G_t = 0.866 + 0.006 R_t - 0.006 R_{t-1} + 0.992 G_{t-1}$
Tirupati	$G_t = 0.680 - 0.002 R_{t-1} + 0.981 G_{t-1}$
Renigunta	$G_t = 2.100 + 0.008 R_t - 0.002 R_{t-1} + 0.809 G_{t-1}$
Yerpedu	$G_t = 3.246 + 0.004 R_t - 0.01 R_{t-1} + 0.860 G_{t-1}$

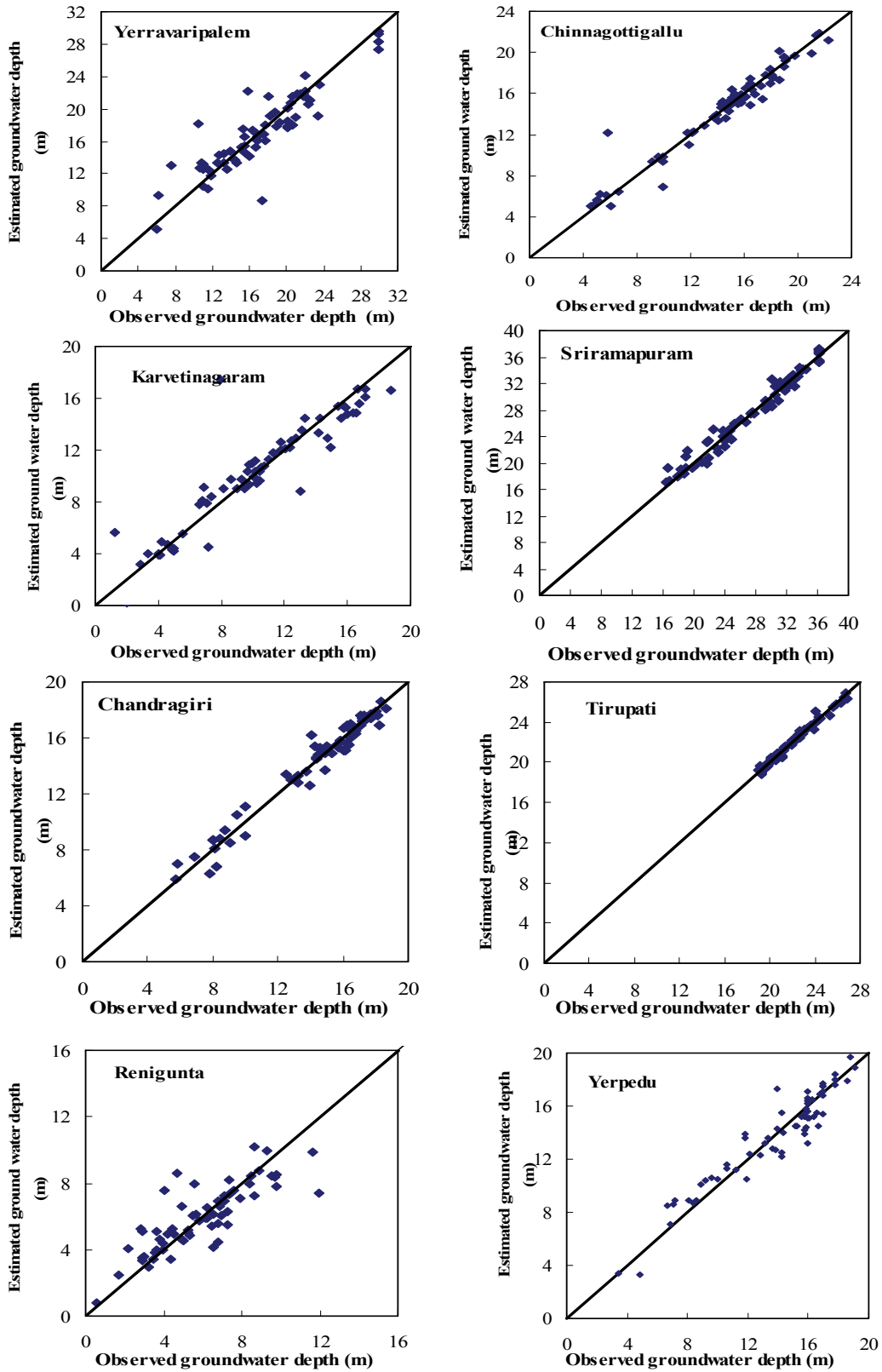


Figure 2. Comparison of observed and estimated groundwater table depths.

**Table 6. Performance evaluation indicators.**

Piezometric station	R <sup>2</sup>	RMSE (m)	EC (%)
Yerravaripalem	0.83	2.29	82.78
Chinnagottigallu	0.93	1.16	93.01
Karvetinagaram	0.84	1.81	83.60
Sriramapuram	0.94	1.51	93.60
Chandragiri	0.96	0.69	95.70
Tirupati	0.96	0.42	96.29
Renigunta	0.68	1.40	67.68
Yerpedu	0.85	1.43	84.95

## 5. Conclusions

The multiple linear correlation analysis has been carried out to study the influence of rainfall, antecedent rainfall and antecedent groundwater table depth on groundwater depth in the upper Swarnamukhi river basin. The influencing variables have been selected based on the measures of multiple linear correlations. It is observed that the rainfall, antecedent rainfall and antecedent groundwater table depth influence the groundwater table depth significantly. Further, the effect of antecedent groundwater table depth is more pronounced than that of rainfall and antecedent rainfall. The relationships proposed may be adopted to predict the groundwater table depths to a reasonable degree of accuracy for better planning and management of groundwater resources of the basin.

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