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Comparative Analysis of Empirical Formulae Used in Groundwater Recharge in Parambikulam Aliyar Basin, Tamil Nadu

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Abstract Precipitation is the main component associated with the aquifer recharge process. Accurate estimation of natural recharge is essential for better development and management of groundwater. In this paper, an attempt has been made to derive groundwater recharge from rainfall in Parambikulam Aliyar Basin using four empirical formulae Chaturvedi formula, Amritsar formula, Krishna Rao. Results from these four empirical formulae were compared using inter-item correlation and one way analysis of variance (ANOVA). A correlation coefficient of the range of 0.99–1.0 exist between each formula and the rejection the null hypothesis that the means of the four formulae are not different from each other leading to the conclusion that although any of the recharge formula can be used for estimations, the Kumar and Seethapathi formula is preferred for preliminary recharge estimation in the basins.

Keywords Empirical formulae, Groundwater recharge, Parambikulam Aliyar Basin, Inter item correlation, ANOVA.

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Introduction

Precipitation is the main component associated with the aquifer recharge process. In order to understand the behavior of ecosystems in semi-arid areas, rainfall must be analyzed over time. The quantification of the rate of natural groundwater recharge is a pre-requisite for efficient groundwater resource management (Kumar 1977, Kumar 2004, Manikandan and Tamilmani 2013). Hence recharge estimate is peculiarly important in regions with large demands for groundwater supplies, where such resources are the key to economic development. While the estimation of recharge, by whatever method, is normally subject to large uncertainties and errors ; the use of empirical formulae shows great potential as an easy means of estimating recharge, which is often difficult if not impossible to obtain reliably by other methods (Adelana et al. 2006). This paper employed the use of empirical formulae to assess the groundwater recharges from rainfall obtained from raingauges stations in Parambikulam Aliyar Basin.

Study area

Parambikulam Aliyar Basin is located in the South Western part of the Peninsular India covering areas in Kerala and Tamil Nadu States. The PAP basin spreads in 2388.72 sq km spread over in Coimbatore

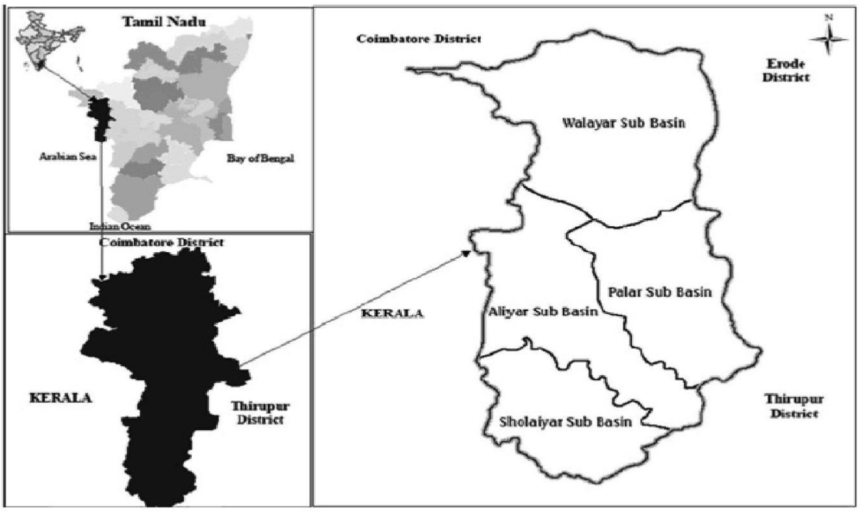

Fig. 1. Location of study area.

District of which, one third of the area 822.73 sq km is covered with hills and dense forest cover. The basin is surrounded by Cauvery basin on the North and East, Kerala State on the South and West. PAP has an undulating topography with maximum contour elevation in the plain is 300 m and the maximum spot height in the plain is 385 m above MSL. This basin area lies (except the Ayacut area) within the coordinates of North latitude between 10°10′00′′ to 10°57′20′′ and East longitudes 76°43′00′ ′to 77°12′30′′.

The project area is situated in tropical monsoon zone having two distinct periods i.e., (1) Monsoon period spanning from June to December and (2) Non-monsoon period spanning from January to May. The maximum monthly rainfall observed during the months of July and October was 148.2 and 153.0 mm, respectively. The mean monthly evaporation rate is highest in the month of May i.e. 5.8 mm/day and lowest in the month of November i.e., 3.2 mm/day. The mean maximum temperature of 38.40 C during the month of May was recorded. The mean minimum temperatures varied from 5.40 C to 25.70 C. The wind velocities were highest during the month of June (8.7 kmph) and lowest in the month of November (2.5 kmph). The maximum sunshine hours were recorded during the month of May (10.6 h) and minimum during the month of August (Fig. 1).

Materials and Methods

Modified Chaturvedi formula (1936)

Based on the water level fluctuations and rainfall amounts in Ganga-Yamuna doab, Chaturvedi, derived an empirical relationship to arrive at the recharge as a function of annual precipitation.

$$Rr = 2.0\,(P-15)^{0.4} \qquad \text{... (1)}$$

Where, Rr = net recharge due to precipitation during the year, in inches ; and P = annual precipitation, in inches. This formula was later modified by further work at the UP Irrigation Research Institute, Roorkee and the modified form of the formula is :

$$Rr = 1.35\,(P-14)^{0.5} \qquad \text{... (2)}$$

Amritsar formula (1973)

Using regression analysis for certain doabs in Punjab, the Irrigation and Power Research Institute, Amritsar, developed the following formula.

$$Rr = 2.5\,(P-16)^{0.5} \qquad \text{... (3)}$$

Where, Rr and P are measured in inches.

Kumar and Seethapathi formula (2002)

A detailed seasonal groundwater balance study in Upper Ganga Canal command area for the period 1972-73 to 1983-84 by 40 to determine groundwater recharge from rainfall. It was observed that as the rainfall increases, the quantity of recharge also increases but the increase is not linearly proportional. The recharge coefficient (based upon the rainfall in monsoon season) was found to vary between 0.05 and 0.19 for the study area. The following empirical relationship (2002) was derived (similar to Chaturvedi formula) by fitting the estimated values of rainfall recharge and the corresponding values of rainfall in the monsoon season through the non-linear regression technique.

$$Rr = 0.63\ (P–15.28)^{0.76} \qquad \text{... (4)}$$

Where, Rr = Groundwater recharge from rainfall in monsoon season (inch), P = Mean rainfall in monsoon season (inch).

Krishna Rao (1970)

Krishna Rao gave the following empirical relationship in 1970 to determine the groundwater recharge in limited climatological homogeneous areas :

$$Rr = K\ (P–X)$$

Where, Rr = Recharge, K = Constant, P = Precipitation, X = No of point rainfall.

The following specific empirical equations were applied to different parts of Karnataka :

Rr = 0.20 (P–400) ; for areas with annual normal rainfall (P) between 400 and 600 mm.

Rr = 0.25 (P–400) ; for areas with P between 600 and 1000mm.

Rr = 0.35 (P–600) ; for areas with P above 2000 mm, (this equation was used in this study).

Where, Rr and P are expressed in millimeters.

The areal rainfall for the two river basins under investigation was computed using Arithmetic mean before recharge using the formulae.

$$Ra = \sum_{i=1}^{n} \frac{Pa}{N} \qquad \text{... (5)}$$

Where, Ra=Areal rainfall, Pa = Point rainfall, N= Number of total point rainfall.

Datta analysis was undertaken using descriptive statistics with graphical re-presentation and inferential statistics, which include inter-item correlation and ANOVA. Statistical analysis was generally carried out on rainfall and recharge of the PAP river basin using Microsoft excel.

Results and Discussion

This paper examines the results obtain from the data analysis and discusses salient issues emanating from recharge calculations using the four empirical formulae under the following sub headings.

Descriptive statistics of rainfall

Table 1 shows the annual rainfall data obtained from PWD, Tharamani, Chennai for the period of 1972 to 2008.

Table 1. Rainfall station with coordinates selected for PAP studies.

Sl. No.	Station	Taluk	Latitude	Longitude
1	Aliyar Nagar	Pollachi	10°29′10′′	76°58′00′′
2	Weaverly	Pollachi	10°24′30′′	76°59′43′′
3	Vettaikaranputhur	Pollachi	10°33′05′′	76°55′05′′
4	Varattuparai	Pollachi	10°22′10′′	76°54′50′′
5	Valparai	Valparai	10°19′35′′	76°57′07′′
6	Upper Nirar	Pollachi	10°18′04′′	77°01′22′′

Table 1. Continued.

Sl. No.	Station	Taluk	Latitude	Longitude
7	Udumalpet	Udumalpet	10°35′00′′	77°15′00′′
8	Topslip	Valparai	10°28′10′′	76°51′00′′
9	Thunakadavu	Pollachi	10°26′10′′	76°46′40′′
10	Thirumoorthy Nagar	Udumalpet	10°29′10′′	77°09′20′′
11	Sulthanpet	Coimbatore	10°52′15′′	77°12′00′′
12	Sholaiyar	Valparai	10°18′10′′	76°52′50′′
13	Poolankinar	Udumalpet	10°35′25′′	77°11′50′′
14	Pollachi	Pollachi	10°39′40′′	77°00′30′′
15	Podanur	Coimbatore	10°58′00′′	76°59′40′′
16	Pedappampatti	Udumalpet	10°40′40′′	77°13′15′′
17	Parambikulam	Pollachi	10°23′30′′	76°46′30′′
18	Negamam	Pollachi	10°44′56′′	77°06′10′′
19	Nattakalapalayam	Pollachi	10°37′45′′	77°03′00′′
20	Nallar	Udumalpet	10°33′50′′	77°04′50′′
21	Lower Nirar	Pollachi	10°18′40′′	76°57′07′′
22	Krishnapuram	Udumalpet	10°55′10′′	77°13′10′′
23	Amaravathy Nagar	Udumalpet	10°25′51′′	77°15′30′′
24	Iyerpadi	Pollachi	10°22′15′′	76°58′30′′
25	Gomangalam	Udumalpet	10°37′14′′	77°09′00′′
26	Chinna Kallar	Pollachi	10°18′00′′	77°02′00′′
27	Attakatti	Pollachi	10°26′40′′	76°59′10′′
28	Anamalai	Pollachi	10°34′50′′	76°56′05′′

Annual areal rainfall PAP basin

Annual areal rainfall in PAP basin annual areal rainfall was calculated using the Arithmetic mean method.

Table 2. Table of annual areal rainfall.

Sl. No.	Year	Rainfall	Year	Rainfall
1	1972	1736.7	1991	1450
2	1973	1381.3	1992	1851.5
3	1974	1485.7	1993	1566.5
4	1975	1703.2	1994	2064.4
5	1976	1321.9	1995	1427.2
6	1977	1921.3	1996	1762
7	1978	1706.8	1997	1849
8	1979	1931.8	1998	2069.8
9	1980	1719.5	1999	1882.2
10	1981	1661	2000	1827.9
11	1982	1076.7	2001	1621.9
12	1983	1339.2	2002	1334.8
13	1984	1434.2	2003	1414.4
14	1985	1471.6	2004	1983.4
15	1986	1425	2005	2452.5
16	1987	1407.5	2006	1893.9
17	1988	1530.4	2007	2567.4
18	1989	1497.8	2008	1703.5
19	1990	1335.2		

The technique calculates areal pre-cipitation using the Arithmetic mean of all the point considered in the study which includes 28 stations data (Table 2).

The annual areal rainfall statistically described in Table 3 shows that for the 37 years of study, the mean annual areal rainfall of the river basin was 1670.50 mm. The standard deviation of 314.30 mm shows that the areal rainfall deviated largely within the 37 years ; with the highest areal rainfall of 2567.40 mm in 2007, and lowest mean annual rainfall of 1076.70 mm in 1982. Also rainfall along the trend in rainfall is shown in Fig. 2 the rising trend is observed in the rainfall (Antonio et al. 2004).

Groundwater recharge estimation

The annual areal recharge of the river basin within 1972 and 2008 was calculated using the formulae: Modified Chaturvedi formula (MCF), (Kumar and Seethapathi 2002, Chaturvedi 1973, Oke et al. 2013). Amritsar formula (AF) and Kumar and Seethapathi (2002) formula (KSF). The calculations were made in inches, the final recharge estimated was converted to

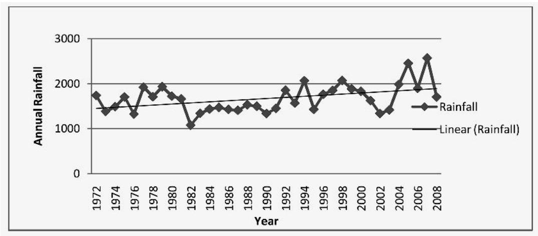

Fig. 2. Showing trend in annual rainfall (1972–2008).

millimeters (mm) to ensure consistency in unit of measurement. Table 4 shows that the computed values of groundwater recharge using Modified Chaturvedi formula (MCF) ranged from 182.70 mm/year to 319.98 mm/year, with an average of 245.08 mm/year. The percentage recharge of rainfall ranged from 12.46% to 16.97% with an average of 14.85%. Result from AF revealed that the values of groundwater recharge ranged from 326.21 mm/year to 585.71 mm/year, with an average of 444.76 mm/year. The recharge percentage of rainfall ranged from 22.81% to 30.30%, with 26.92% as average. Using KSF the computed values for groundwater recharge for the PAP river basin ranged from 196.49 mm/year to 471.65 mm/year, with an average of 313.60 mm/year, while the percentage groundwater recharge of rainfall ranged from 18.25% to 18.87%, with an average of 18.78%. Based on the three methods, the ground water recharge on the average ranged from 245.08 mm/year to 444.76 mm/year. This is 14.85% to 26.92% of rainfall.

Table 5 shows that the standard deviation of 28.35 mm signifies that the recharge slightly deviate from the mean of 245.08 mm. However, when the mean of the annual areal recharge is divided by the mean of the annual areal rainfall and multiplied by 100 ; it was discovered that 14.85% of the rainfall became groundwater recharge.

The recharge estimated from the Kumar and

Table 3. Descriptive statistics of annual areal rainfall.

N	Mean	Standard error	Median	Standard deviation	Minimum	Maximum
37	1670.516	51.62626	1661	314.0303	1076.7	2567.4

Table 4. Groundwater recharge computed using different empirical formulae.

Year	Rainfall	MCF	%	AF	%	KSF	%	KRF	%
1972	1736.7	252.85	14.56	459.55	26.46	327.50	18.86	397.85	22.91
1973	1381.3	217.90	15.78	393.40	28.48	259.56	18.79	273.46	19.80
1974	1485.7	228.72	15.39	413.93	27.86	280.05	18.85	310.00	20.87
1975	1703.2	249.76	14.66	453.73	26.64	321.30	18.86	386.12	22.67
1976	1321.9	211.50	16.00	381.23	28.84	247.68	18.74	252.67	19.11
1977	1921.3	269.22	14.01	490.40	25.52	361.04	18.79	462.46	24.07
1978	1706.8	250.10	14.65	454.36	26.62	321.96	18.86	387.38	22.70
1979	1931.8	270.12	13.98	492.09	25.47	362.92	18.79	466.13	24.13
1980	1719.5	251.27	14.61	456.57	26.55	324.32	18.86	391.83	22.79
1981	1661	245.82	14.80	446.28	26.87	313.43	18.87	371.35	22.36
1982	1076.7	182.70	16.97	326.21	30.30	196.49	18.25	166.85	15.50
1983	1339.2	213.38	15.93	384.81	28.73	251.16	18.75	258.72	19.32
1984	1434.2	223.45	15.58	403.93	28.16	270.01	18.83	291.97	20.36
1985	1471.6	227.29	15.45	411.22	27.94	277.31	18.84	305.06	20.73
1986	1425	222.50	15.61	402.12	28.22	268.20	18.82	288.75	20.26
1987	1407.5	220.67	15.68	398.65	28.32	264.75	18.81	282.63	20.08
1988	1530.4	233.20	15.24	422.42	27.60	288.68	18.86	325.64	21.28
1989	1497.8	229.94	15.35	416.24	27.79	282.39	18.85	314.23	20.98

Table 4. Continued.

Year	Rainfall	MCF	%	AF	%	KSF	%	KRF	%
1990	1335.2	212.95	15.95	383.99	28.76	250.36	18.75	257.32	19.27
1991	1450	225.08	15.52	407.03	28.07	273.10	18.83	297.50	20.52
1992	1851.5	263.15	14.21	478.97	25.87	348.48	18.82	438.03	23.66
1993	1566.5	236.76	15.11	429.15	27.40	295.58	18.87	338.28	21.59
1994	2064.4	281.25	13.62	513.04	24.85	386.37	18.72	512.54	24.83
1995	1427.2	222.72	15.61	402.56	28.21	268.63	18.82	289.52	20.29
1996	1762	255.16	14.48	463.90	26.33	332.16	18.85	406.70	23.08
1997	1849	262.93	14.22	478.55	25.88	348.02	18.82	437.15	23.64
1998	2069.8	281.70	13.61	513.87	24.83	387.32	18.71	514.43	24.85
1999	1882.2	265.84	14.12	484.03	25.72	354.02	18.81	448.77	23.84
2000	1827.9	261.07	14.28	475.04	25.99	344.20	18.83	429.77	23.51
2001	1621.9	242.11	14.93	439.27	27.08	306.09	18.87	357.67	22.05
2002	1334.8	212.91	15.95	383.91	28.76	250.28	18.75	257.18	19.27
2003	1414.4	221.39	15.65	400.02	28.28	266.11	18.81	285.04	20.15
2004	1983.4	274.51	13.84	500.35	25.23	372.10	18.76	484.19	24.41
2005	2452.5	311.56	12.70	569.93	23.24	452.63	18.46	648.38	26.44
2006	1893.9	266.85	14.09	485.94	25.66	356.12	18.80	452.87	23.91
2007	2567.4	319.98	12.46	585.71	22.81	471.65	18.37	688.59	26.82
2008	1703.5	249.79	14.66	453.78	26.64	321.35	18.86	386.23	22.67
Mean	1670.52	245.08	14.85	444.76	26.92	313.60	18.78	374.68	22.02

Seethapathi's formula within the 20 years of study has a mean of 313.60 mm and standard variations of 57.81 mm showing that the recharge values deviate largely from their mean. When the mean of the annual areal recharge is divided by the mean of the annual areal rainfall and multiplied by 100, it was deduced that about 18.78% of the rain that fell in the 37 years of study went into the ground. Recharge from Kumar and Seethapathi's formulae has the highest mean. Recharge values from the Amritsar formula is quite similar to Kumar and Seethapathi's, because it also deviate largely from its mean of 444.76 with a standard deviation of 57.81. When considering the amount annual areal rainfall within the years of study with the estimated recharge like the Kumar and Seethapathi's formula about 18.78% of the rainfall became groundwater recharge. From descriptive statistics it can be concluded that Kumar and Seethapathi and the Amritsar formulae are similar, while the modified Chaturvedi formula and Krishna Rao formula is slightly different from both.

Table 5. Descriptive statistics of annual areal groundwater recharge.

	N	Mean	Standard deviation
Modified Chaturvedi formula	37	245.08	28.35
Amritsar formula	37	444.76	54.27
Kumar and Seethapathi	37	313.60	57.81
Krishna Rao formula	37	374.68	109.91

Comparative analysis of recharge formulae using inter-item correlation matrix and ANOVA

In other to find out if any differences actually exist between these formulae, inter item correlation matrix was used. Table 6 shows that the correlation between Modified Chaturvedi formula and Amritsar formula is positive (+0.9999) and Kumar and Seethapathi is (+0.9991), which means they are highly positively correlated ; while its correlation with Krishna Rao formula is (+0.9967), which means they are highly posi-

Table 6. Inter-item correlation matrix of annual areal recharge.

	MCF	AF	KSF	KRF
MCF	1	0.999994	0.999163	0.996787
AF	0.999994	1	0.999022	0.996519
KSF	0.999163	0.999022	1	0.999228
KRF	0.996787	0.996519	0.999228	1

Table 7. Summary item statistics of the recharge formulae.

Mean	Minimum	Maximum	Standard deviation	Max/ Min
0.998839	0.996519	1	0.001362159	1.002328

tively correlated. The correlation between Amritsar formula and Kumar and Seethapathi is positive (+0.9990) and Krishna Rao is (+0.9965), which means they are positively correlated. The Kumar and Seethapathi formula and Krishna Rao formula have a correlation of (+0.9992) which make them correlated to each other.

Being perfectly and positively correlated needed to be examined further to confirm if there exist any variations. Thus, the item statistics showing the mean, minimum and maximum, variation of the three formulae was analyzed (Table 7). Table 8 reveals that the three formulae do not vary in correlations which make them highly similar to each other. Tests for hypothesis using one way- ANOVA.

The hypothesis of the paper was tested using one-way ANOVA in other to determine if there are significant differences between the means of the three recharge formulae. The hypothesis is stated thus ; H_0 = there is no significant difference between the means of the three recharge formulae, H_1 = there is significant difference between the means of the three recharge formulae.

The Table 8 below show that with a degree of freedom of dl=3, and d2 = 144 ; ft=56.03 at 0.05 significant level. The significant value of 0.00 is less than 0.05 ; we reject the null hypothesis that there is no significant difference between the means of formulas and accept the alternate hypothesis that there is significant difference in the means of the three formulae. It is argued that, taking a clue from the Table 6 that although Modified Chaturvedi formula, Kumar and Seethapathi's formula and Krishna Rao formula are highly correlated ; Table 8 shows that there exists a significant difference in the means. Thus, the correlation between Krishna Rao and Modified Chaturvedi formula at 0.996 is suspected. It is therefore concluded that although any of the recharge formula can be used for estimations, it is safer to use modified Kumar and Seethapathi than any of the other four.

Conclusion

This paper compares four empirical methods used to estimate recharge in the Parambikulam Aliyar Basin, Tamil Nadu. The high amount of rainfall both in temporal and spatial strongly affects recharge in this area and as a result high recharge coincided with periods of high rainfall and low recharge with low rainfall. It was observed that about 16% to 18% of the areal rainfall of the study area became groundwater recharge which fell within the result (2 – 20%) of a study carried out by Thenmozhi and Mayilswami (2015) on the groundwater recharge estimation using water level fluctuation method in the vadachitur watershed which is one of sub-water shed of the PAP basin.

The empirical formula correlated positively with each other when subjected to inter-item correlation analysis, and with results from the analysis of variance (ANOVA). It can be concluded that although Modified Chaturvedi formula, Amritsar formula, Kumar and Seethapathi formula and Krishna Rao formula are perfectly correlated, there exists a significant difference in the means. Thus, the correlation between Krishna Rao formula and Modified Chaturvedi formula at 0.996 could be suspected. It is therefore concluded that although any of the recharge formula can be used for estimations, the Kumar and Seethapathi

Table 8. Showing the result of one way ANOVA.

Source of variation	SS	df	MS	F	p-value	F crit
Between groups	806654	3	268884.7	56.03494	4.61E24	2.667443
Within groups	690986.6	144	4798.518			
Total	1497641	147				

formula is preferred for preliminary recharge estimation in the basins.

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