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Estimation of Groundwater Recharge Using Water Table Fluctuation Method

Nimmi Kuruppath[1*], A. Raviraj[2], Balaji Kannan[3] and K.M. Sellamuthu[4]

[1]Department of Soil and Water Conservation Engineering, Agricultural Engineering College & Research Institute, Agricultural University, Coimbatore, India
[2]Department of Soil and Water Conservation Engineering, Water Technology Centre, Agricultural University, Coimbatore, India
[3]Department of Remote Sensing and GIS, [4]Department of Soil Science and Agricultural Chemistry, Agricultural University, Coimbatore, India

**Corresponding author*

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A B S T R A C T

The present study attempts to determine groundwater recharge of the two over exploited blocks of Karur district in Amaravathy basin viz., Aravakurichi and K. Paramathi by water table fluctuation method. Rainfall data of eight rain gauge stations for 30 years (1982-2012) and water level data of twenty three stations were collected from the office of State Ground and Surface Water Resources Data Centre, Tharamani, Chennai for analysis. The rainfall occurs in four distinct season's viz., NE monsoon, SW monsoon, summer, winter are 54.1%, 26.58%, 17.57% and 1.73% respectively. The water table fluctuation varied from 0.2 to 3.1 m in SW monsoon, and 0.4 to 6.6 m in NE monsoon in Aravakurichi block, whereas in K. Paramathi block groundwater level fluctuation varied from 0.1 to 3.7 m due to SW monsoon, and 0.4 to 5.4 m in NE monsoon. It was observed that the recharge percentage in Aravakurichi block varied from 5.25% to 16.74% in Aravakurichi block and 5.69% to 16.20% in K. Paramathi block.

Introduction

Quantification of the rate of ground water recharge is a basic prerequisite for efficient ground water resource management (Sophocleous, 1991).

In semiarid areas, where groundwater resources are the key to agricultural development, groundwater quantification is very vital issue. The rate of aquifer recharge in determination in arid and semiarid areas is neither straightforward nor easy.

This is due to the time variability of precipitation in arid and semiarid climates, and spatial variability in soil characteristics, topography, vegetation and land use (Lerner *et al.*, 1990). Accurate quantification of recharge rates is imperative to proper management and protection of valuable groundwater resources. A multitude of methods has been used to

estimate recharge. Techniques based on groundwater levels are among the most widely-applied methods for estimating recharge rates. This is due to the availability of groundwater-level data and the simplicity of estimating recharge rates from temporal fluctuations or spatial patterns of groundwater levels. The present study emphasis on estimating groundwater recharge based on knowledge of groundwater levels. This approach is termed the water table fluctuation (WTF) method, which is the most widely used method for recharge estimation. Due to its accuracy, ease of use and low cost of application in semiarid areas this method is considered to be one of the most promising and attractive (Beekman and Xu, 2003).

The WTF method was first used for ground water recharge estimation and has since been used in numerous studies for the same purpose (Leduc *et al.,* 1997; Moon *et al.,* 2004) or groundwater storage changes estimation (Ruud *et al.,* 2004). In addition to WTF method the study also focuses on various empirical formulas viz., Chaturvedi, UPIRI, Amritsar, Kumar and Seethapathi and Krishna Rao formulas for recharge estimation.

Need for the present study

Rainfall in Tamil Nadu is dependent largely on the north-east monsoons and demand for groundwater is increasing due to frequent failure of monsoons and depleting surface water resources and hence the demand for groundwater is increasing. It is, therefore, necessary to have thorough knowledge about water level fluctuations and groundwater recharge for evolving a system to manage the water resources effectively. As per the recent estimates of groundwater resources by CGWB (Central Ground Water Board, 2011), out of 385 assessed units (blocks) in Tamil Nadu 38% comes under safe category, 15% under semi-critical, 9% under critical, 37% under over-exploited and rest 8 blocks under saline category. The objectives of the study include determining the seasonal groundwater recharge of the two over exploited blocks of Karur district viz., Aravakurichi and K. Paramathi by water table fluctuation method and empirical formulas.

Details of the study area

Karur district lies between 10°63'N and 11°14'N latitude and 77°90'E and 78°61'E longitude. In Karur district, the surface water resources have been utilized fully. The deficient monsoon rainfall has affected the flow of surface water into reservoirs, anaicuts, lakes etc. Hence under these circumstances the farmers has to totally depend on alternate source, viz. groundwater to meet-out their irrigation requirements. Geologically the entire Karur district is underlain by hard rock's except a few patches of alluvial formation along the river Cauvery. Hard rock generally does not contain potential aquifers to store large quantity of water and to transmit to other areas. According to CGWB 2009 out of eight blocks, four blocks (Aravakurichi, K. Paramathi, Thanthoni and Kadavur) are under over exploited category. Krishnarayapuram and Karur blocks are under critical and semi critical category, while only two blocks Kulithallai and Thongamalai are under safe category. The location map of the study area is shown in Figure 1.

The tasks can basically be divided in to the following categories

Collection of secondary data (rainfall and groundwater) for the study area.

Estimation of annual recharge for each of the blocks using water table fluctuation method.

Determination of annual and seasonal recharge using empirical formulas.

Materials and Methods

Analysis of rainfall data

The rainfall data observed on eight raingauge stations in Aravakurichi and K. Paramathi blocks for 30 years (from 1982 to 2012) were collected from the office of State Ground and Surface Water Resources Data Centre, Tharamani, Chennai.

The eight raingauge stations covering the two blocks are listed in Table 1.

Thiessen polygons were imposed on the base map to arrive at weighted mean rainfall for the two blocks separately using the analysis tool in ArcGIS 10.1. The Thiessen polygon method assumes that the rainfall recorded at a station is representative of the area halfway to the stations adjoining it.

Each station is connected to its adjacent stations by straight lines, the perpendicular bisectors of which form a pattern of polygons. The weighted average rainfall was calculated by dividing the sum of the products of station areas and rainfalls by the total area of all the stations. Thiessen polygon with the observations well is shown in the Figure 2.

Analysis of water level data

The water level data of twenty three stations of Aravakurichi and K. Paramathi blocks were collected from the office of State Ground and Surface Water Resources Data Centre, Tharamani, Chennai and the monthly recharge was calculated for all stations.

Recharge due to rainfall

Water level fluctuation method is the most widely used method for recharge estimation. Healy and Cook (2002) gave detailed procedure for estimating the groundwater recharge using the change in groundwater levels. The method takes into account the response of groundwater level fluctuation and specific yield, is more scientific, realistic and is directly measurable, unlike other approaches where assumptions are to be made for most of the components. The recharge volume is given by,

Recharge volume (m^3) = Area (m^2) *Average water level fluctuation (m)* Specific yield

Recharge assessment by various empirical methods

Chaturvedi formula

Based on the water level fluctuations and rainfall amounts in Ganga-Yamuna doab, Chaturvedi in (1936), derived an empirical relationship where recharge is a function of annual precipitation.

$$R = 2.0 (P - 15)^{0.4}$$

Where,

R = net recharge due to precipitation during the year, in inches;

P = annual precipitation, in inches.

The Chaturvedi formula has been widely used for preliminary estimations of groundwater recharge due to rainfall.

U. P. Irrigation Research Institute, Roorkee

Chaturvedi formula was later modified by further work at the U.P. Irrigation Research Institute, Roorkee and the modified form of the formula is

$$R = 1.35 (P - 14)^{0.5}$$

R and P both are measured in inches.

Amritsar formula

Using regression analysis for certain doabs in Punjab, Sehgal developed a formula in 1973 for Irrigation and Power Research Institute, Punjab.

$R = 2.5 (P - 16)^{0.5}$

Where,

R and P both are measured in inches.

Kumar and Seethapathi formula

The following empirical relationship (similar to Chaturvedi formula) was derived by fitting the estimated values of rainfall recharge and the corresponding values of rainfall in the monsoon season through the non-linear regression technique.

$Rr= 0.63 (P - 15.28)^{0.76}$

Where,

Rr= Groundwater recharge from rainfall in monsoon season (inch)

P = Mean rainfall in monsoon season (inch).

Krishna Rao formula

Krishna Rao gave the following empirical relationship in 1970 to determine

The groundwater recharge in limited climatological homogeneous areas:

$R = K (P - X)$

The following relation is stated to hold good for different parts of Karnataka:

R = 0.20 (P - 400) for areas with annual normal rainfall (P) between 400 and 600 mm R = 0.25 (P - 400) for areas with P between 600 and 1000 mm R = 0.35 (P - 600) for areas with P above 2000 mm Where,

R and P are expressed in millimetres.

The groundwater recharge due to rainfall was calculated by using various empirical methods. The relationship between rainfall and recharge was derived and represented graphically.

Water table fluctuation method

Rainfall is the main source of recharge to groundwater regime. Areal extent and specific yield of aquifer formation and controlling factors in determination of monsoonal recharge. The seasonal recharge in both the blocks are computed using water table fluctuation method (Healy and Cook, 2002) for both SW, NE monsoon periods separately. A value of 1.5% was assumed as the specific yield of the Karur district (TWAD, 2014). The area under raingauge stations is 43,689 ha and 53,927 ha for Aravakurichi and K. Paramathi block respectively. As the contribution of North-east and South-west monsoons to the annual rainfall is high compared to other seasons, those two seasons are taken into consideration for recharge calculations. The groundwater level fluctuations in Aravakurichi block varied from 0.2 to 3.1 m due to SW monsoon, while it was from 0.4 to 6.6 m in NE monsoon, whereas in K. Paramathi block groundwater level fluctuation varied from 0.1 to 3.7 m due to SW monsoon and it was from 0.4 to 5.4 m in NE monsoon. The average groundwater fluctuation (2.5 m) was higher during NE monsoon period when compared to that of SW monsoon (1.6 m) in Aravakurichi block, similarly in K. Paramathi block the average groundwater fluctuation was higher during NE (2.4m) compared to SW monsoon (0.9m). The total monsoon recharge percentage during 2002 to 2012 varied from

5.25% to 16.74% with an average of 11.83% in Aravakurichi block. Similarly, in K. Paramathi block, the total monsoon recharge percentage varied from 5.69% to 16.20% with an average recharge percentage of 10.14%. Seasonal recharge was calculated for two seasons, viz. SW monsoon and NE monsoon. Annual recharge percentage calculated for past ten years (2002 – 2012) for Aravakurichi and K. Paramathi block.

Results and Discussion

Recharge assessment by various empirical formulas

The methods for estimation of rainfall recharge involve the empirical relationships established between recharge and rainfall developed for different regions, Groundwater Resource Estimation Committee norms, groundwater balance approach, and soil moisture data based methods. Several empirical formulae have been worked out for various regions in India on the basis of detailed studies. Some of the commonly used formulae are:

Chaturvedi formula

Formula developed by U. P. Irrigation Research Institute

Amritsar formula

Krishna Rao

Kumar and Seethapathi formula

Chaturvedi formula

The recharge was calculated based on the precipitation for both the blocks separately. The maximum recharge of 197.07 mm occurred in the year 2005 in Aravakurichi block and 170.17mm in K. Paramathi block. The recharge would be zero when the rainfall is below 15 inches. The maximum recharge per cent occurred in the year 1987 as 20.08% and the minimum recharge per cent occurred in the year 1985 as 11.53% for Aravakurichi block In K. Paramathi block maximum recharge per cent occurred in the year 2007 and 2011 as 20.09% and minimum recharge per cent occurred in the year 1986 as 8.74%.

Formula developed by U. P. Irrigation Research Institute

According to U.P.I.R.I (modified form of Chaturvedi formula), the recharge is calculated based on annual precipitation. The maximum recharge of 189.82 mm and 159.13 mm occurred in Aravakurichi block and K.Paramathi block respectively during the year 2005.

The recharge would be zero when the rainfall is below 14 inches. The maximum recharge per cent of 18.04% occurred in the years 2009, in Aravakurichi block and minimum recharge occurred in the year 1992 as 8.43%.

Maximum recharge of 18.01% and minimum of 10.28% was observed in K. Paramathi block during the years 1997 and 1986 respectively.

Amritsar formula

The results reveals that the maximum recharge occurred in the year 2005 as 339.85 mm in Aravakurichi block and 280.68mm in K. Paramathi block.

Maximum recharge percentage of 31.25% occurred in the year 2008 and minimum of 9.01% in 2001 in Aravakurichi block.

In K. Paramathi block maximum recharge occurred in 1999 as 31.25% and minimum as 6.23% in 1995.The recharge would be zero when the rainfall is below 406.4 mm.

Fig.1 Location map of the study area

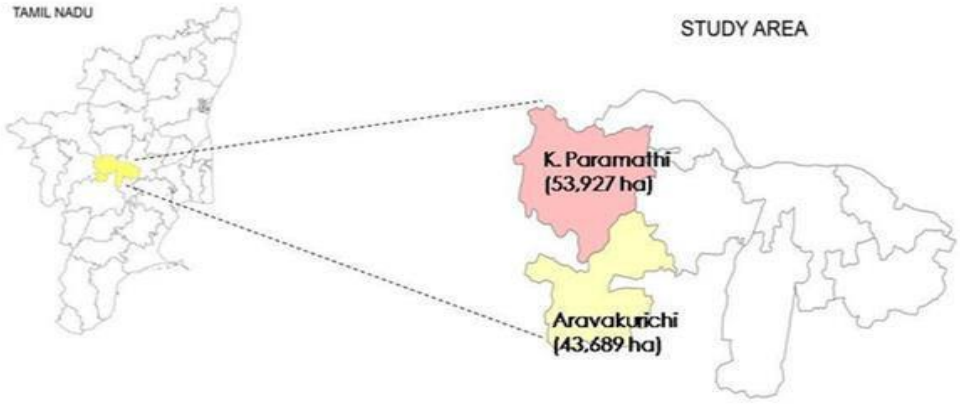

Fig.2 Thiessen polygon map showing the rain gauge stations and observation wells in Aravakurichi and K. Paramathi block

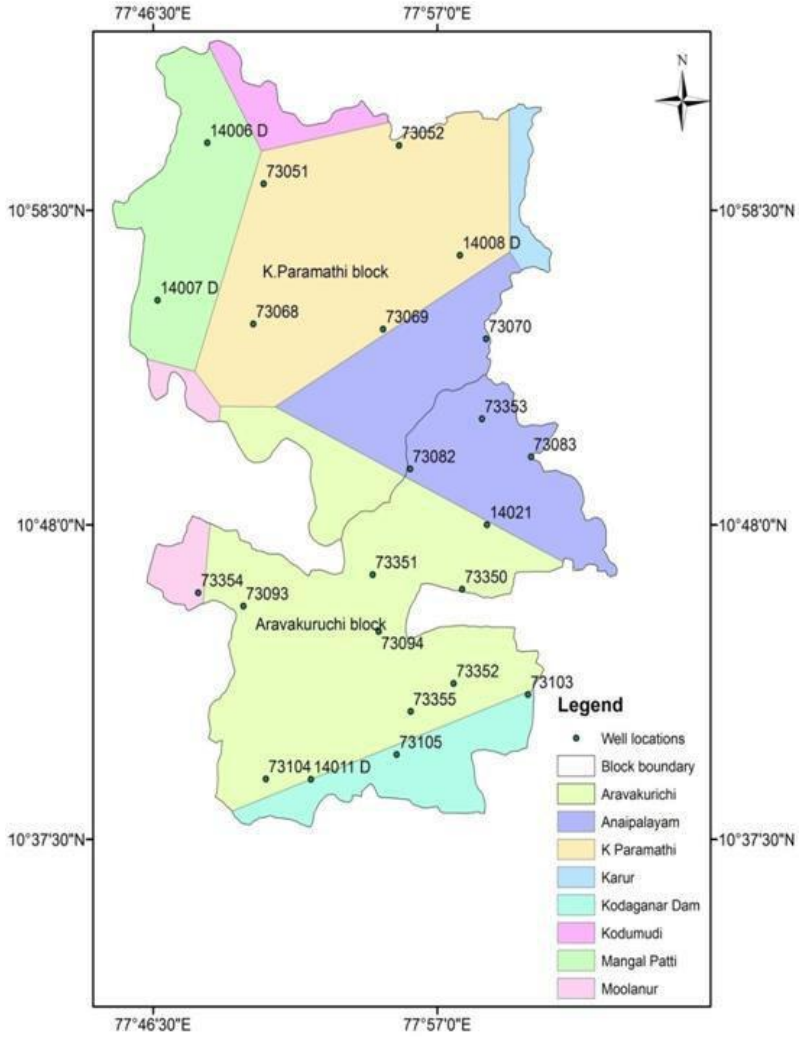

Fig.3 Monsoon rainfall and recharge percentage (Aravakurichi block)

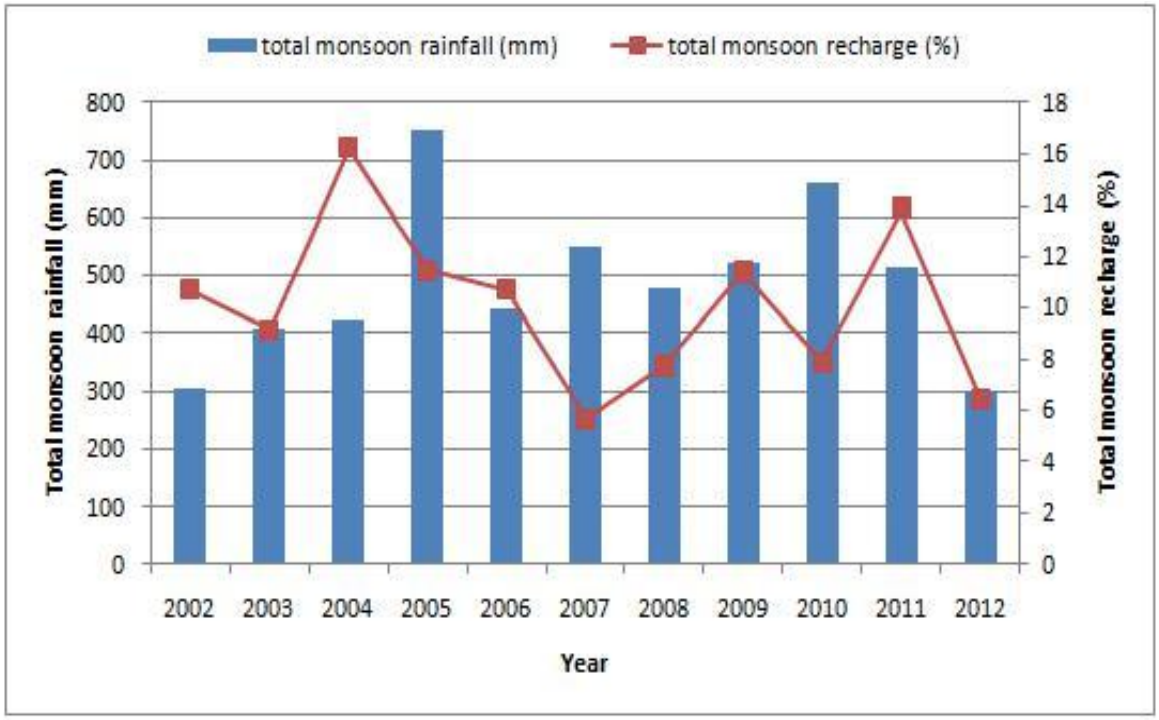

Fig.4 Monsoon rainfall and recharge percentage (K. Paramathi block)

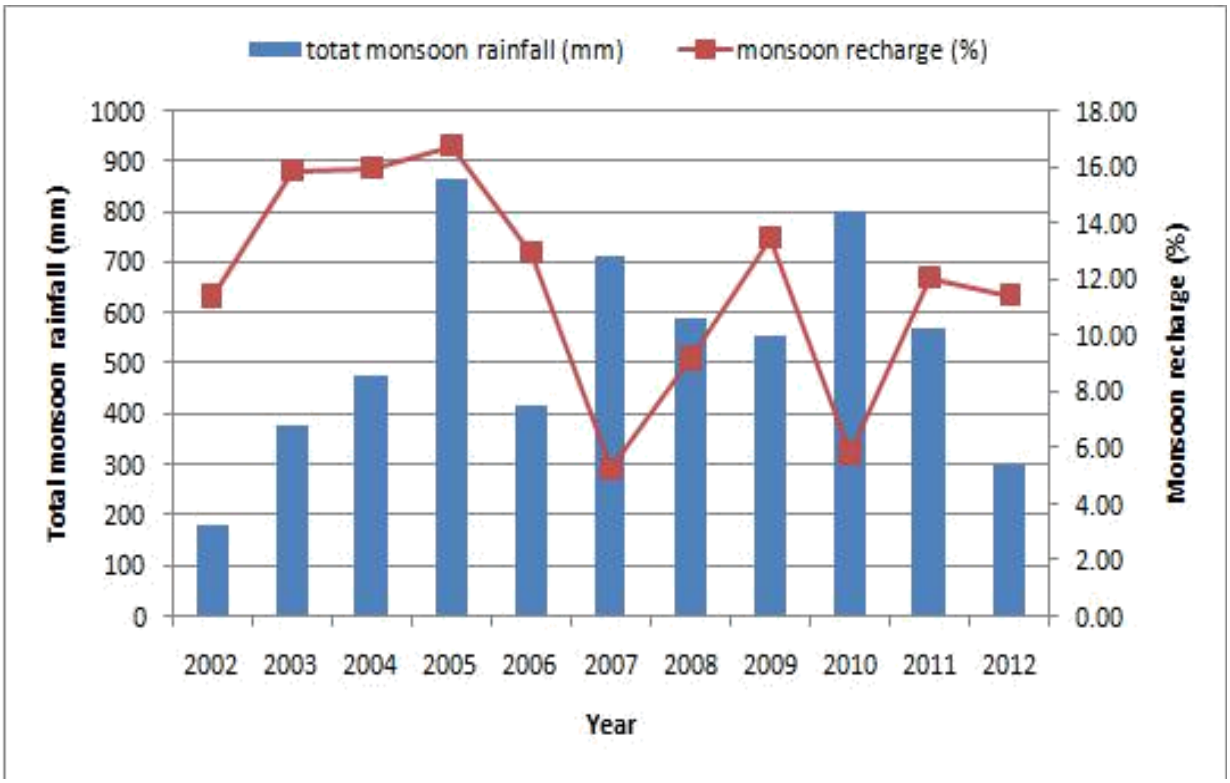

Table.1 Location of Raingauge stations in Amaravathy basin

Sr. No.	Station name	District	Block	Latitude	Longitude
1	Anaipalayam	Karur	Karur	10.87	77.95
2	Aravakurichi	Karur	Aravankurichi	10.77	77.91
3	K. Paramathi (Karur)	Karur	Aravankurichi	10.95	77.91
4	Karur	Karur	Karur	10.95	78.07
5	Kodaganar Dam	Dindigul	Vedasendur	10.59	77.97
6	Kodumudi	Erode	Dharapuram	11.08	77.88
7	Mangal Patti	Erode	Kankeyam	11.00	77.75
8	Moolanur	Erode	Erode	10.79	77.70

Kumar and Seethapathi formula

According to Kumar formula, the recharge is based on the monsoon precipitation. The maximum monsoon recharge occurred in the year of 2005 as 149.21 mm in Aravakurichi block and 121.89 mm in K. Paramathi block. The recharge would be zero when the rainfall is below 400 mm (Fig. 3 and 4).

Krishna Rao formula

The recharge estimated by Krishna Rao formula is based on the rainfall in mm. The maximum recharge percentage occurred in the year 2005 as 12.95% in Aravakurichi block and 11.14% in K. Paramathi block.

A comparative study of the annual recharge percentage by various empirical formulas was also done for both the blocks separately. It was found that maximum recharge percentage was obtained by using Amritsar formula and the least by using Krishna Rao formula. Kumar and seethapathi formula calculates the monsoon recharge. The recharge becomes zero when precipitation is less than 15 inches for Chathurvedi formula, 14 inches for UPIRI formula, 16 inches for Amritsar formula, whereas in Kumar and Seethaathi formula recharge is zero when monsoon recharge is less than 15.28 inches as it calculates the monsoon recharge. For Krishna Rao formula the zero recharge is attained when the precipitation is less than 400mm.

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