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Estimating Groundwater Recharge Using Empirical Method: A Case Study in the Tropical Zone

(Menganggarkan Aliran Masuk Air Bawah Tanah Menggunakan Kaedah Empirik: Kajian Kes di Zon Tropika)

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ABSTRACT

Estimation and forecast of groundwater recharge and capacity of aquifer are essential issues in water resources investigation. In the current research, groundwater recharge, recharge coefficient and effective rainfall were determined through a case study using empirical methods applicable to the tropical zones. The related climatological data between January 2000 and December 2010 were collected in Selangor, Malaysia. The results showed that groundwater recharge was 326.39 mm per year, effective precipitation was 1807.97 mm per year and recharge coefficient was 18% for the study area. In summary, the precipitation converted to recharge, surface runoff and evapotranspiration are 12, 32 and 56% of rainfall, respectively. Correlation between climatic parameters and groundwater recharge showed positive and negative relationships. The highest correlation was found between precipitation and recharge. Linear multiple regressions between recharge and measured climatologic data proved significant relationship between recharge and rainfall and wind speed. It was also proven that the proposed model provided an accurate estimation for similar projects.

Keywords: Effective rainfall; groundwater recharge; recharge coefficient; tropical zone

ABSTRAK

Anggaran dan unjuran aliran masuk air bawah tanah dan keupayaan akuifer adalah isu-isu penting dalam penyiasatan sumber air. Dalam penyelidikan ini, aliran masuk air bawah tanah, pekali aliran masuk dan keberkesanan hujan telah ditentukan melalui kajian kes yang menggunakan kaedah empirikal berkenaan zon tropika. Data yang berkaitan dengan klimatologi antara Januari 2000 dan Disember 2010 telah dikumpulkan di Selangor. Keputusan menunjukkan bahawa aliran masuk air bawah tanah adalah 326.39 mm setahun, pemendakan berkesan adalah 1807.97 mm per tahun dan pekali aliran masuk adalah 18% bagi kawasan kajian. Secara ringkasnya, pemendakan ditukar kepada tenaga, air larian permukaan dan penyejatpeluhan masing-masing 12, 32 dan 56% daripada hujan. Korelasi antara parameter iklim dan aliran masuk air bawah tanah menunjukkan hubungan positif dan negatif. Korelasi yang tertinggi didapati antara pemendakan dan aliran masuk. Regresi linear berganda antara aliran masuk dan diukur daripada data iklim membuktikan hubungan yang signifikan antara aliran masuk dan hujan serta kelajuan angin. Ia juga membuktikan bahawa model yang dicadangkan memberi anggaran yang tepat bagi projek-projek yang sama.

Keywords: Aliran masuk air bawah tanah; hujan berkesan; pekali aliran masuk; zon tropika

INTRODUCTION

Groundwater, as a dynamic system, is located in the subsurface of the earth. It occurs and moves under the control of some different factors, which are studied in various fields of sciences such as hydrogeology, hydrology and climatology (Kumar 1977). Among the factors controlling situation and fluctuation of groundwater, recharge is an important parameter need to be assessed more fully.

Recharge occurring in small- and large-scale and spatially and temporally is influenced by factors such as meteorology, soil characteristics, surface cover, slope and depth of groundwater level (Bouwer 1978; Shukla & Jaber 2006; Sumioka & Bauer 2003). The estimation of groundwater recharge from precipitation is a principal part of hydrology and hydrogeology (Xi et al. 2008). Although precipitation is the most important source of groundwater recharge (Kumar & Seethapathi 2002) the accuracy of currently attainable techniques for measuring recharge are not completely acceptable (Sumioka & Bauer 2003). Furthermore, there is no technique for direct measurement of recharge due to the lack of universal standard methods (Anderson & Woessner 1992). Nevertheless, a number of methods were suggested to estimate the groundwater for various climates such as arid, semiarid and tropical, each with its own advantages and disadvantages.

The models and equations for determining the groundwater recharges can be classified into three groups: physical model: calculated from base flow; chemical model: measurement of water-soluble substances and numerical model: using numeric method, like HELP, RORA, PULSE, PART, HYSEP and WTF (Risser et al. 2008).

Chandra (1979) stated that the following methods can be prevalently applied to estimate the natural groundwater recharge: soil water balance method; zero flux plane method; one-dimensional soil-water flow model; inverse modeling technique; ground water level fluctuation method; hybrid water fluctuation method; ground water balance method; isotope and solute profile techniques. Another classification for estimation of groundwater recharge offered by Kumar (2000) classified the methods of estimation of groundwater recharge into four groups: empirical methods; groundwater resource estimation; groundwater balance approach and soil moisture data based methods.

Since the study area is located in a tropical area with average 3000 mm rainfall per year, it is classified as rich zone in terms of groundwater resources. This amount is translated to nearly 323.2 mm of water per person per year which shows that a large amount of water resource is available in Malaysia. According to Hj. Keizrul (1998), the total annual rainfall is 990 billion cubic meters, while effective rainfall and groundwater recharge per annum are 660 and 64 billion cubic meters, respectively (Figure 1).

Although different prediction models were resulted from the study of groundwater recharge in the United States and Europe, but these models are not proven to be determine groundwater recharge in equatorial climates, (e.g. Malaysia) precisely. Therefore, determining groundwater recharge needs to consider different parameters for obtaining accurate results. In such circumstances, the objectives of this paper were to define effective rainfall, groundwater recharge and recharge coefficient and to assess a relation between parameters using statistical tools.

Materials and Methods

STUDY AREA DESCRIPTION

The selected study area lies within N3°30´ - 3°35´, E101°38´ - 101°41´, Selangor, Malaysia (Figure 2). The area is characterized by hot summers and pleasant winters. Vegetation cover consists of trees, shrubs, grass and low bush.

The annual rainfall is 2996.3 mm. However, half of the precipitation is lost due to evapotranspiration (Saghravani et al. 2009b). The remaining percolates in soil or streams as surface water. Groundwater level fluctuates between 0.8 m and 1.4 m in the study area (Saghravani et al. 2009b). Figure 3 illustrates an annual rainfall in the region between years 2000 and 2010.

Based on the meteorological data, the maximum and minimum daily air temperatures are 34.12 and 22.65ºC, respectively (Saghravani et al. 2009a). Table 1 describes the general meteorological characteristics of study area, which include precipitation, humidity, temperature, wind speed and sunshine hours.

From the geological point of view, the study area mainly consists of clay loam, sandy clay and sandy silt soils (Saghravani et al. 2009a) belong to recent Pleistocene period (Gobbett & Hutchiston 1973). Figure 4 illustrates the profile of soil and rock in two separate locations in the study area. The upper part of profile consist of unsaturated zone while the groundwater table is located in silty clay and silty sandy clay layers. Figure 4 shows stratigraphy of formation in vicinity of University Putra Malaysia, Serdang (Borehole 1: 3°00´ 27˝N 101°43´ 20.5˝E and Borehole 2: 3°00´ 27˝N 101°43´ 20.5˝E). The distance between these two boreholes is 390 m from each other.

Model Description

ESTIMATION OF EFFECTIVE RAINFALL

Equation (1) was used to calculate the effective rainfall in the study area. The following equation was applied since the land slope in the study area is less than 4-5%:

$$Pe = P - ET, \quad (1)$$

where P is rainfall or precipitation (mm/month), Pe, always larger than or equal to zero, is the effective rainfall or effective precipitation (mm/month) and ET is evapotranspiration.

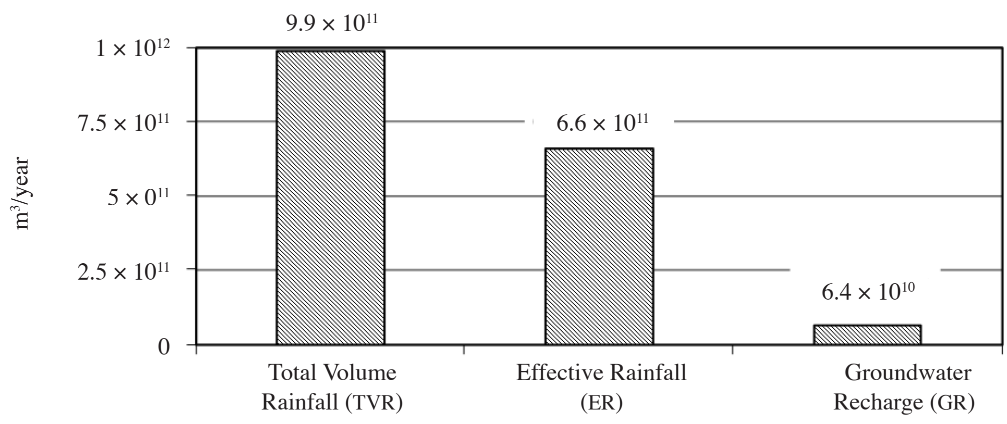

FIGURE 1. Values of TVR, ER and GR in Malaysia

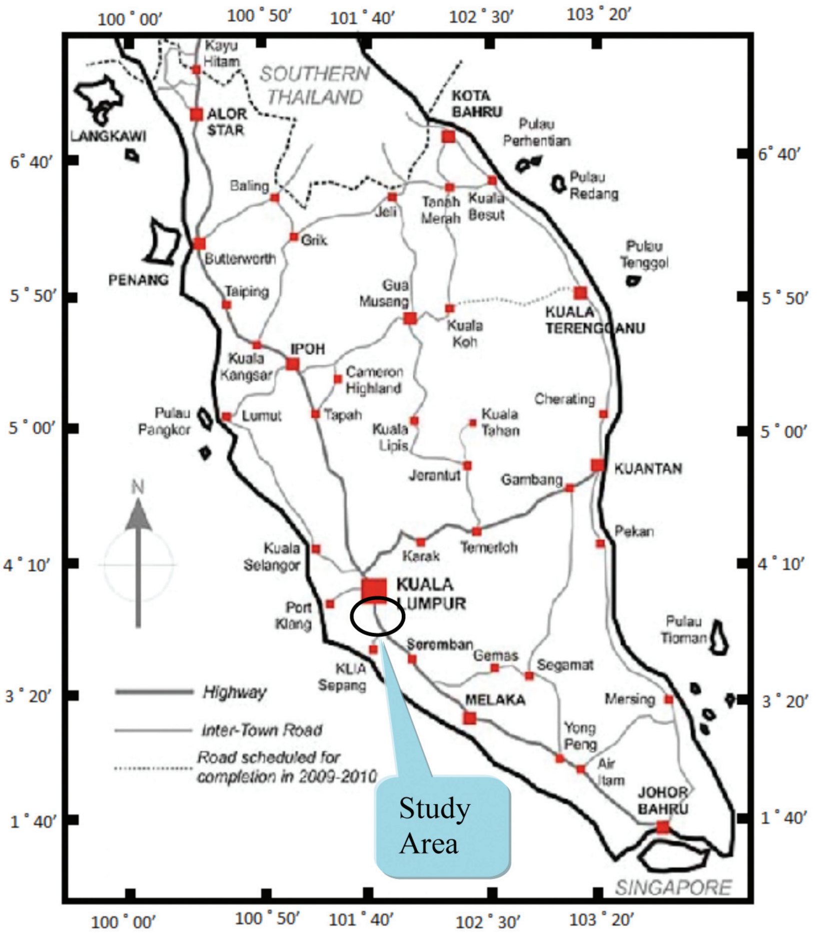

FIGURE 2. Location of study area

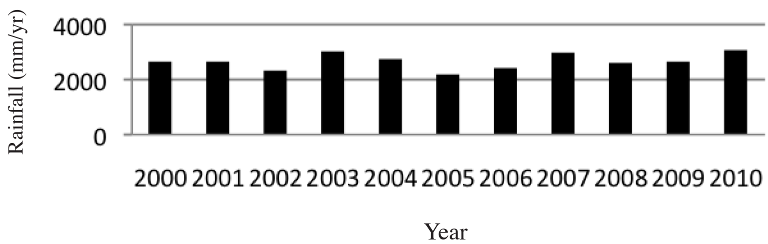

FIGURE 3. Annual rainfall between 2000 and 2010 (mm per year)

TABLE 1. Climatic characteristics of the study area

Year	Precipitation (mm/yr)	Humidity (%)	Maximum temperature (°C)	Minimum temperature (°C)	Wind speed (cm/s)	Sunshine hours (h)
2000	2634.996	95.60	32.70	22.65	0.97	6.01
2001	2633.472	95.68	33.19	22.86	0.97	6.49
2002	2315.210	95.23	33.90	22.91	0.91	6.39
2003	3040.126	94.16	33.29	23.11	0.84	5.97
2004	2750.566	92.59	33.28	23.30	1.04	6.61
2005	2175.764	95.17	33.27	22.88	0.91	6.21
2006	2427.986	94.65	33.27	22.97	0.94	6.29
2007	2996.438	94.74	33.27	22.95	0.94	6.28
2008	2590.038	94.73	33.27	22.96	0.94	6.28
2009	2666.492	93.40	33.45	23.44	1.04	6.24
2010	3076.194	93.30	34.12	23.91	0.76	6.48
Mean	2664.206	94.48	33.36	23.09	0.91	6.30

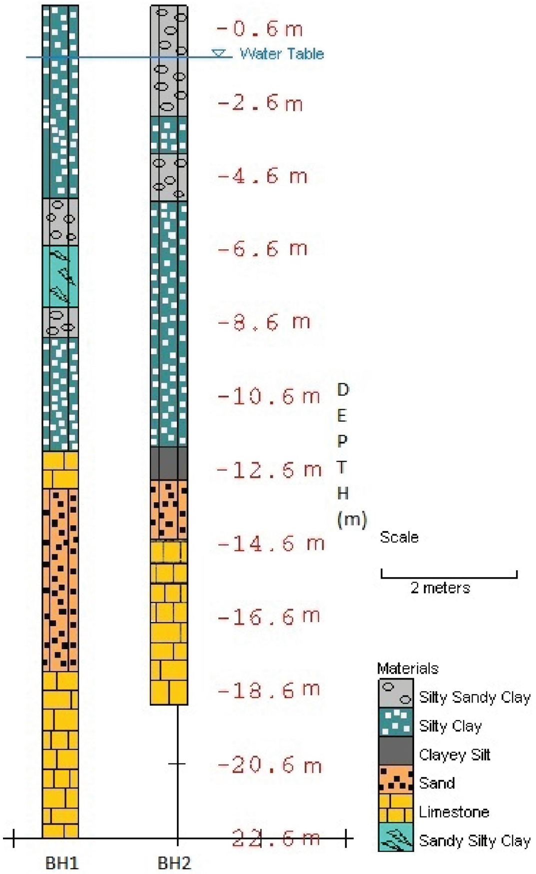

FIGURE 4. Stratigraphy of soil and rock in the study area

ESTIMATION OF GROUNDWATER RECHARGE

Calculation of recharge (R) in the study area was conducted by a modified version of Chaturvedi (1973) for tropical regions based on water level fluctuation and rainfall depths as given by:

$$R = 1.35\ (P\text{-}14)^{0.5} \quad (2)$$

where, *R* is the net recharge due to precipitation during the year and P is the annual precipitation, both in inches.

ESTIMATION OF RECHARGE COEFFICIENT

The amount of recharge coefficient is defined as the ratio of recharge to effective rainfall and expressed in percentage (Misstear et al. 2009). The amount of vertical hydraulic gradient is equal to unity as assumed by Misstear et al. (2009) for similar study area with almost identical annual rainfall (2500 mm).

ESTIMATING DIRECT RUNOFF

Schicht and Walton (1961) developed a water budgets approach for estimating runoff (3). In this equation P is precipitation, ET is evapotranspiration (ET) and R denoted recharge:

$$R_{off} = P\text{-}ET\text{-}R \quad (3)$$

CORRELATION AND REGRESSION ANALYSIS

To evaluate the strength of the relationship between meteorological factors, Pearson correlation coefficient was used. In this case, multiple regressions were implemented to evaluate the impact of independent variables (i.e. humidity, temperature, rainfall, wind speed and duration of daily solar radiation) on estimated recharge.

ANALYSIS APPROACH AND RESULTS

RECHARGE ESTIMATION

The proposed methods are used to estimate all parameters for 11 years (from January 2000 to December 2010). Table 2 shows the amount of calculated groundwater recharge, the ratio of precipitation to evapotranspiration, the effective rainfall, the recharge coefficient and the surface runoff.

The ratio of recharge to total precipitation is 12.25% which according to Misstear et al. 2009, is classified as a low rate of recharge. It is proven that beside precipitation (with the high rate), other parameters (such as surface cover) also have a key role (Shukla & Jaber 2006; Sumioka & Bauer 2003) in the recharge, as will be assessed in the next step in this paper.

TABLE 2. Hydrological data of the study area (calculated)

Year	Precipitation (mm/yr)	ET (mm/yr)	P/ET (mm/yr)	Groundwater recharge (mm/yr)	Effective rainfall (mm/yr)	Recharge coefficient (%)	Surface runoff (mm/yr)
2000	2635.00	1370.08	48.77	324.87	1807.97	18	940.05
2001	2633.47	1433.32	46.74	324.61	1806.96	18	875.54
2002	2315.21	1446.78	40.64	301.24	1561.08	19	567.18
2003	3040.13	1402.84	55.12	352.55	2132.08	17	1284.73
2004	2750.57	1462.02	47.75	332.99	1912.87	17	955.55
2005	2175.76	1459.99	37.85	290.32	1458.72	20	425.45
2006	2427.99	1434.08	42.93	309.63	1642.36	19	684.02
2007	2996.44	1424.69	53.34	349.76	2097.02	17	1221.99
2008	2590.04	1433.32	45.97	321.56	1781.30	18	835.15
2009	2666.49	1432.81	47.24	327.15	1833.12	18	906.53
2010	3076.19	1466.60	53.34	354.84	2160.78	16	1254.51
Mean	2664.21	1433.32	47.24	326.39	1807.97	18	904.75

Figure 5 illustrates the mean of annual rainfall, runoff, evapotranspiration and recharge during 2000 to 2010. Groundwater recharge and surface runoff increases and decreases with precipitation and they show the same trends throughout the years. However, evapotranspiration shows a constant trend throughout the years. This is not unexpected since ET is a function of solar radiation, wind speed and daily dew point (Linsley et al. 1982) and these parameters did not show a remarkable change during the research period.

In another study (Hj. Keizrul 1998), the recharge was estimated to be 6.5% of precipitation for the study area, almost half of the value found in the present study, 12.25%. The difference is due to the scale of the study area, the former research was conducted over the whole country while the current study evaluated the rate of recharge in very smaller portion of the same territory. There are bona fide objections to the use of either of these data since the data from the greater area is more useful for nation decision makers, the present method would be a great help to the local authority for future sustainable development of the region. The percentage of evapotranspiration, run-off and recharge in the study area are 54, 34 and 12%, respectively. Typically low recharge causes high runoff over the surface. Misstear et al. (2009) proved that effective rainfall would correspond to more than 70% of precipitation in an area with low recharge and high runoff. Referring to Table 2, mean value for effective rainfall (between 2000 and 2010) is almost 67.8% of precipitation, a very good agreement with the above rate.

CORRELATION AND REGRESSION ANALYSIS

The second goal in this study was to assess the correlation between the groundwater recharge and precipitation. Table 3 lists the Pearson correlation coefficients for meteorological parameters between January 2000 and December 2010. Correlation significant at the 0.01 level (two tailed) is shown with a double asterisk. Correlation significant at the 0.05 level (two tailed) is shown with an asterisk.

It is interesting to note from Table 3 that the minimum temperature was negatively correlated with real humidity while sunshine hour was correlated with ET at 0.01 level. The maximum temperature was also correlated with minimum temperature and ET at 0.05 level. Among the parameters in Table 3, there is no more significance relationship at either the 0.01 or 0.05 levels (two tailed).

The second goal also involved performing multiple linear regression analysis on the dependent database. SPSS for windows version 18 was employed to carry out the regression analysis by the mean of stepwise predictor selection method.

Multiple linear regressions were conducted to evaluate the effect of different climatologic parameters (including annual precipitation, humidity, temperature, wind speed and sunshine hours) and estimation of annual recharge. The results may be explained by variations in precipitation (R^2 = 0.999; Figure 7) and precipitation and wind speed (R^2 = 1). In (4) recharge was expressed only by the mean of precipitation while in (5) precipitation and wind speed were considered to estimate the recharge.

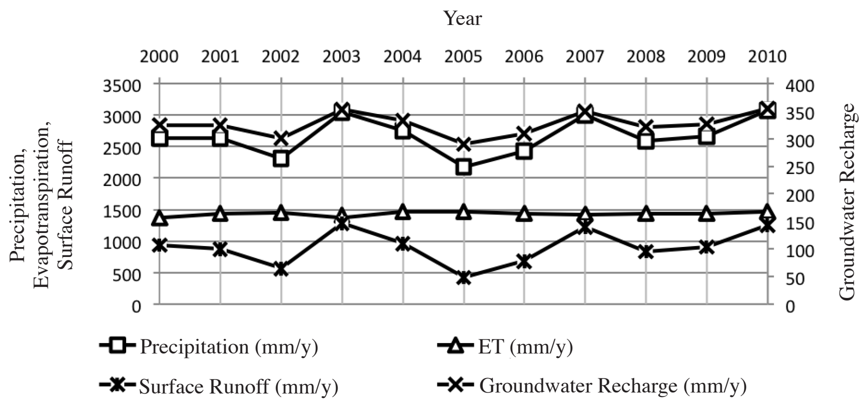

FIGURE 5. Total annual precipitation, recharge, runoff and evapotranspiration

TABLE 3. Pearson correlation coefficients for meteorological parameters

Parameters	P	ET	Real humidity	Max. Temp.	Min. Temp.	Wind speed	Sunshine hour
P	1	-.174	-.481	.146	.532	-.358	-.019
ET	-.174	1	-.453	.695*	.548	-.110	.777**
Real humidity	-.481	-.453	1	-.396	-.824**	-.046	-.374
Max. Temp.	.146	.695*	-.396	1	.712*	-.528	.484
Min. Temp.	.532	.548	-.824**	.712*	1	-.347	.411
Wind Speed	-.358	-.110	-.046	-.528	-.347	1	.127
Sun Shine Hour	-.019	.777**	-.374	.484	.411	.127	1

Note: ** means Correlation is significant at the 0.01 level. * means correlation is significant at the 0.05 level

$$R = 5.377 + 0.071(\mathrm{P}) \quad (4)$$

$$R = 5.170 + 0.072(\mathrm{P}) + 0.014(\mathrm{WS}) \quad (5)$$

where R is recharge; P is precipitation; WS is wind speed in one-meter height and 5.377 to 5.170 are constant for the study area.

Figures 6 to 10 illustrate the rate of groundwater recharge versus precipitation, humidity, wind speed, maximum and minimum temperature and sunshine hours. R^2 for all climatic parameters versus groundwater recharge calculated. All parameters, except precipitation, showed very low percentage which is shown dominant role of rainfall on percolation of water into groundwater in the study area.

Groundwater recharge always increased with precipitation which means these two variables have reciprocal effect on each other. Except precipitation, other climatic parameters show very low correlation with groundwater recharge and they can be assumed negligible. However, these parameters have significant effect on rate of evapotranspiration and other parameters that estimating and calculating in terms of humidity, wind speed, maximum and minimum temperature and sunshine hours.

CONCLUSION

The application of current method for calculating groundwater recharge at the study area helped to reach to plausible recharge estimation. An estimation of mean annual recharge for 2000-2010 is 326.39 mm per annum. The mean of the recharge coefficient is 18%, rate of evapotranspiration is about 56% and groundwater recharge is about 12%. Therefore, 33% of rainfall water makes some allowance for runoff (and/or interflow) in the study area.

The correlation between parameters showed the highest positive correlation between recharge and rainfall.

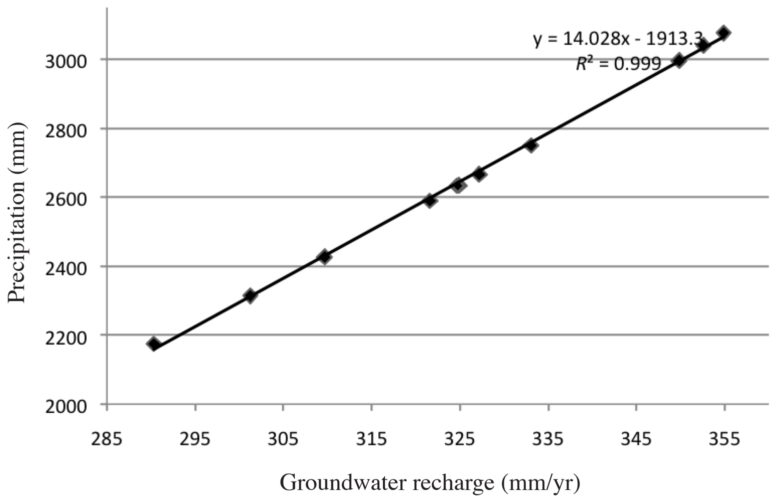

FIGURE 6. Groundwater recharge vs. precipitation

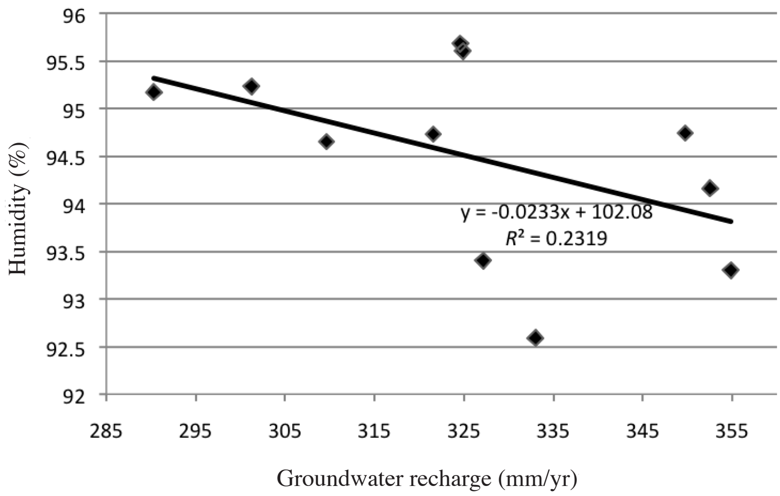

FIGURE 7. Groundwater recharge vs. humidity

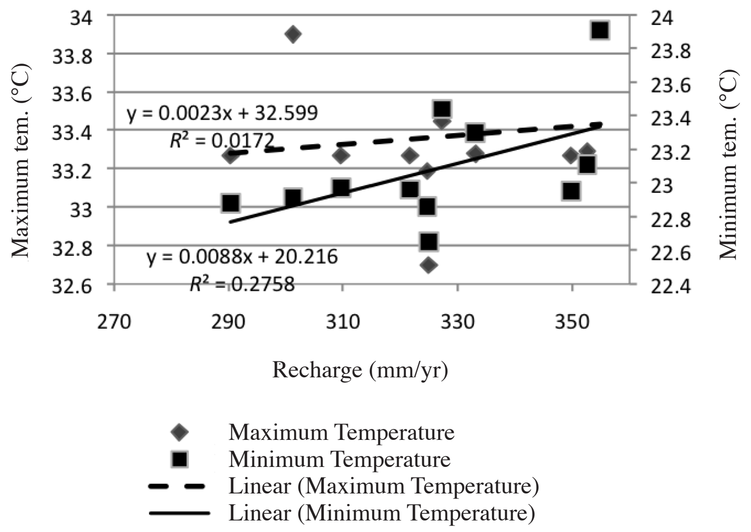

FIGURE 8. Groundwater recharge vs. maximum and minimum temperature

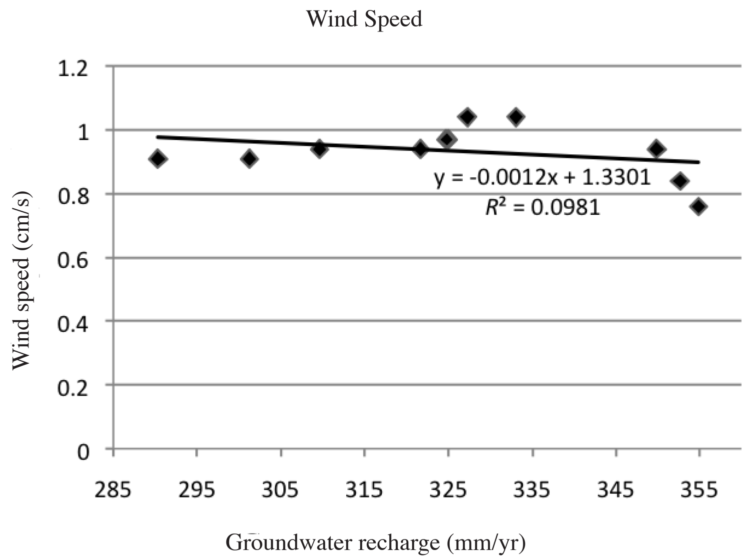

FIGURE 9. Groundwater recharge vs. wind speed

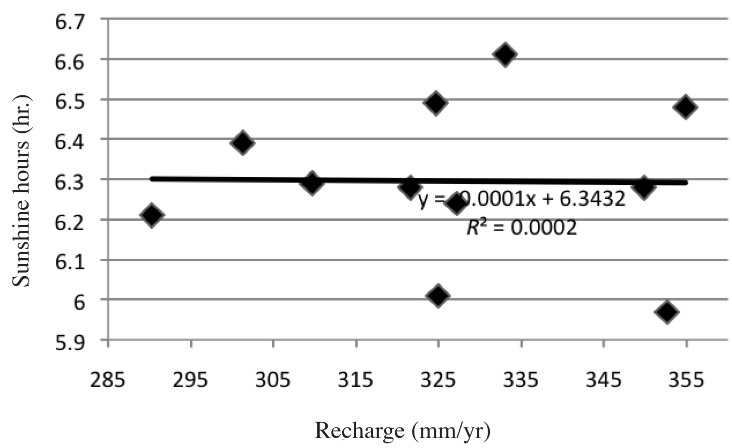

FIGURE 10. Groundwater recharge vs. sunshine hours

In addition, correlation between temperature and humidity, sunshine hours and ET were at 0.01 level. Correlation between maximum temperature, minimum temperature and ET were at 0.05 level. The results of linear regressions approved precipitation and wind speed have significant effect (with $r^2 = 0.99$) on estimating of recharge. Therefore, models may be applied to other tropical climate zones with precipitation less than 300 mm per month.

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