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ORIGINAL ARTICLE

Comparison of water table fluctuation and chloride mass balance methods for recharge estimation in a tropical rainforest climate: a case study from Kelantan River catchment, Malaysia

Seyed Reza Saghravani · Ismail Yusoff · Wan Zakaria Wan Md Tahir · Zainudin Othman

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Abstract Estimated groundwater recharge for selected locations in northeast Peninsular Malaysia (North Kelantan River catchment) was determined using the water table fluctuation (WTF) and chloride mass balance (CMB) methods. The WTF method recharge estimates were compared to the CMB method estimates to see if results are similar and the methods can be applied in a humid, tropical region, such as Malaysia. Effective specific yields of 0.18 and 0.16 were obtained for sites which are much lower than values in the literature for use with the WTF method. The WTF gives mean recharge values of 447 and 319 mm/year at PC61 and Wakaf Bharu (WB), respectively. The difference between sites may be attributed to the difference in lithology, whereby less water table fluctuation is observed for finer-grained lower permeability soil or sediment and higher water table fluctuation observed for more granular larger grain soil or sediment. For the site with lower permeability, the time lag between the storm events and water level rise in a well is longer and water does not reach the water table for small storms. Recharge from chloride profile study was estimated through measurement of enrichment of chloride concentration in soil. Rain-fed groundwater direct recharge ranged from 263.3 to 627.7 mm/year in WB and averaged 691.8 mm/year for Pengkalan Chepa. Recharge estimates from unsaturated zone chloride strongly correlate with soil texture, generally and is greater in the coastal area due to a higher percentage of sand content. Parts of the study area located toward the interior of the peninsula showed lower recharge due to the presence of fine-grained sediment. Comparison of methods from different sites indicates that lithologic setting has a significant role in controlling natural recharge rate. The inconsistency observed between recharge value estimated by the WTF and CMB method may in part be due to adsorption/desorption process and ion exchange in the unsaturated soil, which affects the initial assumption that chloride is a conservative tracer.

Keywords Recharge · Water level · Chloride · Unsaturated zone · Malaysia

Introduction

Groundwater recharge is the important issue of the modern environment and human health that should be thoroughly considered relative to protection of aquifers as sources of drinking and potable water. Recharge can be defined as water that reaches into groundwater table through the unsaturated zone which is able to raise water table by a measurable amount (Sophocleous 1991). There are several chemical and physical methods to measure diffuse (direct) recharge into groundwater. Each of the methods has limitations in terms of applicability and validity of results (Simmers 1988). A comprehensive summary of these methods can be found in Healy and Cook (2002), Healy and Scanlon (2010), Nimmo and Perkins (2008), and Scanlon et al. (2002).

S. R. Saghravani (✉) · I. Yusoff
University of Malaya, 50603 Kuala Lumpur, Selangor, Malaysia
e-mail: saghravani@siswa.um.edu.my

W. Z. Wan Md Tahir
Malaysian Nuclear Agency, Bangi, 43000 Kajang, Selangor, Malaysia

Z. Othman
University Pendidikan Sultan Idris, 35900 Tanjung Malim, Perak, Malaysia

Among the available methods for estimating recharge, the water table fluctuation (WTF) method provides an accurate recharge rate based on multiplying the water level rise by the storage parameter. Healy and Cook (2002) presented the theory and application of the method and identified pertinent factors that may result in overestimated or underestimated recharge calculations. These include the Lisse effect as explained by Weeks (2002), difficulty in determining specific yield, diurnal fluctuation due to evapotranspiration, and rainfall with low intensity and long duration. The method has been widely used to predict the water level in wells (Graham and Tankersley 1993; Bierkens et al. 2001) and estimate recharge (Viswanathan 1984; Crosbie et al. 2005) at the field sites. The current study attempts to evaluate specific yield to determine water level rise to improve calculation of recharge through 2-year records of precipitation and water level. Determination of specific yield using representative values or constant values at the basin scale results in overestimation of recharge rate (Sophocleous 1985). The specific yield was obtained in this paper using the difference between residual and saturated water content (see Flint 1998).

In some techniques, natural tracers are used for solute profiling in the unsaturated zone between root zone and groundwater table. Isotopes such as tritium (H-3), oxygen-18 (O-18), and deuterium (H-2) and chloride are natural tracers used to measure groundwater recharge in different types of areas with various characteristics (Bromley et al. 1997). However, the disadvantage of using the techniques based on natural isotopes (H-3, H-2, O-18), relative to mass balance evaluation, is impossibility of conserving concentrations of natural isotopes during infiltration and percolation of rainwater into groundwater. However, chloride is conserved and, consequently, able to provide more precise results (Gaye and Edmunds 1996).

The chloride mass balance (CMB) method (also known as chloride budget technique) is a simple inexpensive method for estimating groundwater recharge. The basic concept of this method is that the atmospheric input of chloride precipitation remains in and enriches soil water during evapotranspiration. The CMB method can estimate groundwater recharge representing mean values of hundreds of years and can be applied to both saturated and unsaturated zones (Edmunds et al. 2002). The method was applied successfully in Asia (Ting et al. 1996; Liu et al. 2009), America (Nolan et al. 2007; Scanlon 1991; Sophocleous 1991), Africa (Edmunds and Darling 1988; Takounjou et al. 2011), Europe (Russo et al. 2001), and Australia (Allison and Hughes 1978, 1985; Guan et al. 2009) to measure groundwater recharge in arid, semiarid, and humid regions. In Malaysia, this method has never been reported before and was applied for first time in the region.

Assessment of recharge using the CMB method requires the measurement of chloride concentration in rainfall. In particular, the accuracy of the method depends on measurement of the rate of long-term chloride accumulation in precipitation. Factors that control the distribution and concentration of chloride in rainfall have not been investigated in this study. However, previous studies in humid climate recognized and categorized several factors that are important in concentration of chloride in rainwater, including volume of rainfall, distance from the coast (as ocean water is the major source of chloride ions in rainwater), wind direction and speed, and seasonality (i.e., wet and dry seasons) that are important in concentration of chloride in rainwater (Andre et al. 2007; Keywood et al. 1997). According to Edmunds and Gaye (1994) lack of information on the chemistry of rainfall is a source of uncertainty in results. However, several studies have used current chloride concentration in precipitation to determine the accumulation rate (Eriksson and Khunakasem 1969; Guan et al. 2009; Russo et al. 2003; Sharma and Hughes 1985; Ting et al. 1998).

The objective of this study was to investigate annual groundwater recharge in the humid and tropical forest area of Malaysia which is characterized with high rates of rainfall and humidity. Evaluation of recharge rate was implemented using WTF and CMB methods which are employed as local and point scales of estimation, respectively. The case of the north Kelantan River catchment was used to illustrate the application of this methodology. Monthly groundwater level, rainfall, and concentration of chloride in rainwater have been measured in the study area prior to the start of this project (Chong et al. 1977; Ismail 1993).

Site description

The study area is bound by longitudes 102°–102.30°E and latitudes 5.50°N–6.2°N (Fig. 1). The area is in northeastern Malaysia which is adjacent to the South China Sea (to the north and east) and the Thailand border to the west.

Regional climate and hydrogeology

The region has a tropical rainforest climate and rainfall distribution throughout the year is uneven. More than half of the annual precipitation results from storms in the rainy season that occurs from October to December. The highest and lowest monthly mean temperatures in the study area are 23 and 32 °C. According to climatic data acquired by the Malaysian Meteorological Department in Kuala Lumpur, average of monthly precipitation is 2,563 mm, based on four stations (Tumpat Railway Station, Pasir Mas Pump House, Teratak Pulai, and Pengkalan Chepa) between 1979

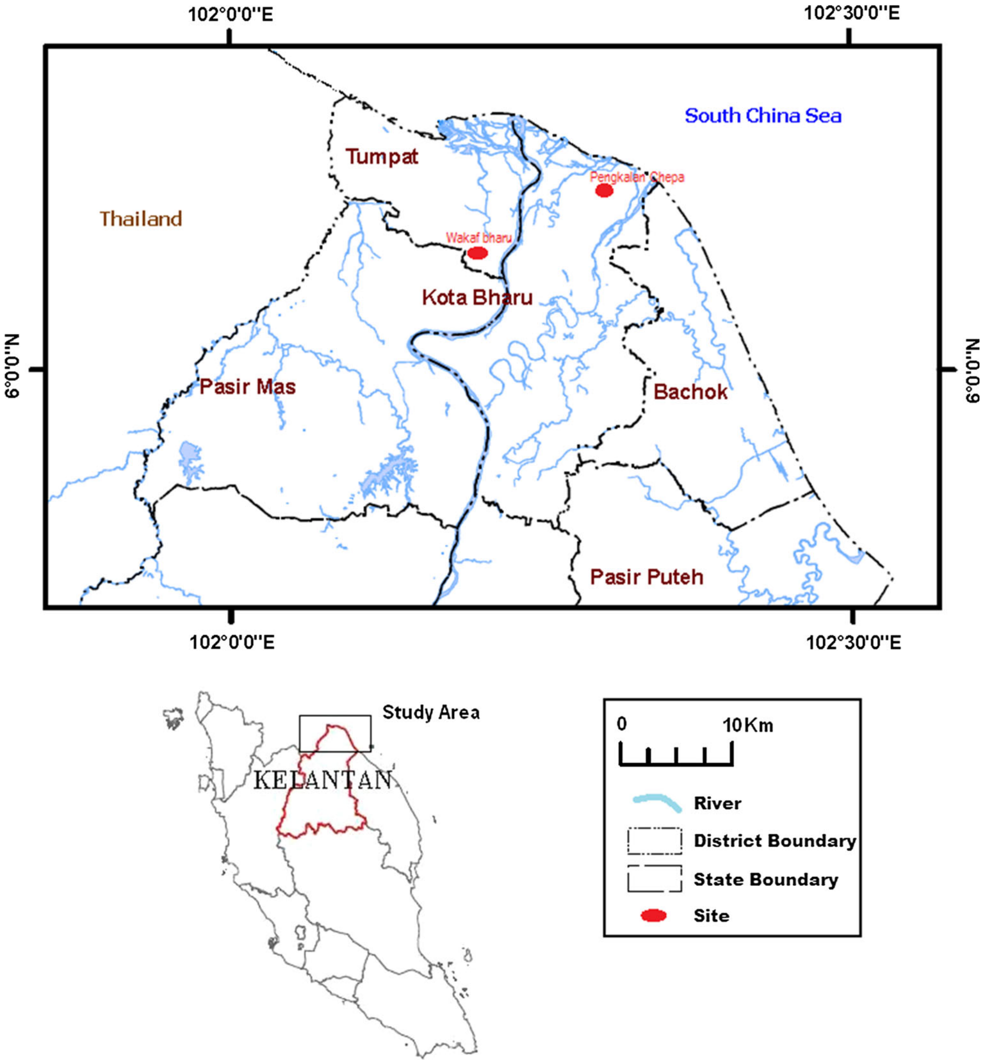

Fig. 1 General view of north Kelantan catchment

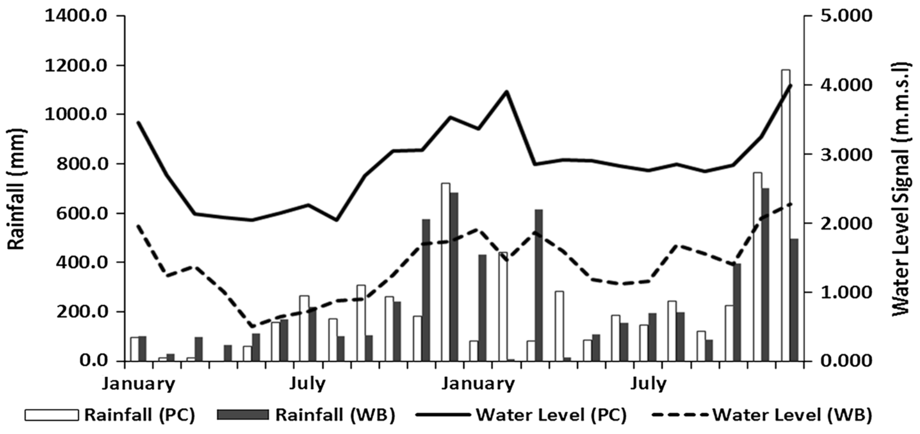

Fig. 2 Monthly rainfall and water level fluctuation at PC and WB sites

and 2011. The highest and the lowest rainfalls were recorded in 1999 and 1989 at 3,734.50 and 1,540.50 mm/year, respectively. Two years of monthly water level fluctuation and rainfall in PC61 (between January 1998 and December 1999) and WB (between January 2010 and December 2011) are shown in Fig. 2. These data were obtained from the Minerals and Geoscience Department Malaysia and Malaysian Meteorological Department.

Table 1 Thornthwaite monthly water balance in north Kelantan catchment

Month	J	F	M	A	M	J	J	A	S	O	N	D	Mean	Total
P	177.2	91.5	197.2	86.2	154.7	138.2	170.4	158.0	195.1	284.6	611.9	570.7	236.3	3,071.9
PET	107.7	99.3	117.0	121.3	126.2	120.9	123.3	120.2	113.4	113.8	104.8	107.1	114.6	1,489.6
P-PET	60.7	−12.4	70.3	−39.5	20.7	10.3	38.6	29.9	72.1	156.5	476.5	435.1	109.9	1,428.7
SMS	236.4	201.3	204.7	170.9	182.8	191.4	214.1	227.5	248.4	251.6	252.0	252.0	219.4	2,852.5
AET	107.7	96.7	113.5	111.5	122.2	118.6	123.2	119.6	113.3	113.8	104.8	107.1	112.7	1,464.7
PET-AET	0.0	2.6	3.5	9.9	4.1	2.3	0.1	0.5	0.0	0.0	0.0	0.0	1.9	24.9
SW	69.0	25.3	70.4	4.1	12.9	4.1	16.0	17.0	51.2	153.3	476.1	435.1	111.2	1,445.7

P precipitation (mm), *PET* potential evapotranspiration (mm), *P-PET* monthly effective rainfall (mm), *SMS* soil moisture storage (mm), *AET* actual evapotranspiration (mm), *SW* surplus water

In the study area, the aquifer consists of a large volume of unconsolidated sediment, with high storage capacity. The thickness of the aquifer varies from 40 to 100 m. The maximum aquifer thickness is located in the coastal area whereas toward the inner parts of peninsula thickness is reduced. The aquifer has been studied thoroughly by previous investigators (e.g., Chong and Tan 1986; Pfeiffer and Tieddemann 1986). Overall, the aquifer consists of three zones which are separated by semipermeable silty and clayey layers.

The shallow aquifer receives direct recharge. This occurs at depths between 0 and 20 m and extends over the entire basin. The intermediate aquifer is located between 21 and 50 m, and the deep aquifer occurs at depths of more than 50 m. Groundwater levels were measured prior to collection of soil profiles at 430 and 420 cm below ground surface in Pengkalan Chepa (PC) and Wakaf Bharu (WB), respectively. Groundwater tables of both sites have been monitored by the Geoscience Department Malaysia for several years and their past positions are quite similar to the current positions (Amir Mizwan and Ab Rashid 2011).

Climatic water budget

The Thornthwaite monthly water balance program version 1.1.0 (McCabe and Markstrom 2010) was used to examine component of the hydrologic system through continuous monthly rainfall and temperature data in the catchment between January 1999 and December 2012. Table 1 shows the climatic water budget for the study area based on an available soil moisture storage capacity of 260 mm. The results emphasize the seasonality of the water budget components. Potential evapotranspiration during the dry season (between February and August) was higher than average value and during November and December lower than average. In addition, production of surplus water and soil moisture recharge during the last 2 months of year (wet season) have high values in comparison to the average monthly value. Consequently, these two months are the time of the highest natural groundwater recharge in the catchment.

Geological setting

Geology of the north Kelantan basin mainly consists of Quaternary unconsolidated alluvium, and marine sediments with variable thickness (MacDonald 1967). The alluvial plain is mostly underlain by Mesozoic granites. However, the bedrock also locally contains metamorphic rocks. Quaternary deposits consist of Gula formation and Beruas/Simpang formations.

1. The Holocene Gula formation consists of marine sediments. The formation has two members which are made up of clay and silt (Port Weld Member) and sand with some gravel (Matang Gelugor Member). However, shell and coral deposits also occur in both members (Hutchison and Tan 2009).
2. The Holocene Simpang/Beruas formation (Pengkalan member) consists of terrestrial deposits containing clay and silt with peat. However, Simpang formation consists of in situ vegetation with minor intercalation of paludal sediment. The Beruas formation represents a major low-level sea stand (Hutchison and Tan 2009).
3. The unsaturated zones in the two sites examined are located in different quaternary formations. WB is covered by Simpang formation and PC is in Gula formation (Matang Gelugor member). In WB site, the upper 175 cm consists of clay (silty and laterilic, reddish brown) with underlying sand (coarse to very coarse with some gravel) down to 11 m depth.

Quaternary sediments in the study area contain silty and clayey lenses which are interbedded with sand and gravel. Near the coastline, the lithology of the upper layer consists of medium- to coarse-grained sand (Ismail 1993) with silty and/or peat lenses (Chong et al. 1977).

Methodology

Water table fluctuation

This method is based on the theory of rising water level due to rainfall recharging into the aquifer. There are two key steps implemented to determine natural recharge (q): determining groundwater rise and calculating specific yield. If specific yield (S_y) and water level change at time t and $t-1$ ($\Delta h/\Delta t$) are known then recharge is given by:

$$q = (\Delta h/\Delta t) \times S_y. \tag{1}$$

However, some consideration should be taken into account that affects the results, including evaporation, transpiration, and lateral flow to the boundaries of the aquifer that can be grouped as the drainage (D) amount. The drainage value of rainy days must be added to the water table rise to compensate for the falling water level due to the above factors. However, monthly recharge would be overestimated if one complete month of drainage is applied. According to Crosbie et al. (2005), after 15 h impact of the rainfall event is not significant anymore. Due to similarities, 15 h of daily value is used to calculate the drainage rate for this study area. Thus, recharge is calculated based upon following equation:

$$q_t = [(\Delta h/\Delta t) + D] \times S_y \quad \text{if} \quad \Delta h > 0 \tag{2}$$

where q_t is recharge [LT^{-1}]; $\Delta h/\Delta t$ is differenced water level (h_t–h_{t-1}) at differenced time ($t-(t-1)$) [LT^{-1}]; S_y is specific yield [−]; and D is net groundwater drainage [LT^{-1}]. In the period of no rainfall, the drainage rate was estimated from the decreasing water level. Daily water level fluctuation, which was recorded between January and February 1975 (Chong et al. 1977) in the study area, has been reanalyzed to calculate drainage.

The specific yield was estimated from saturated water content (effective porosity) and residual water content in samples from the interval of water level fluctuation. Undisturbed samples were collected during January 2012 in PC and WB field sites a few meters from observation wells from which water levels fluctuation data were obtained. In an unconfined aquifer, the volume of water released from groundwater storage per unit surface area of aquifer per unit decline in the water table is known as the drainable porosity or the specific yield (S_y), which can be defined based on following equation:

$$S_y = V_d/V_t,$$

where V_d is the volume of water drainable by gravity and V_t is the total volume. Some moisture will be retained in the soil or sediment and cannot be drained by gravity. Therefore, specific yield can be expressed as:

$$S_y = \theta s - \theta r \tag{3}$$

where θs is saturated moisture content and θr is residual moisture content. Complete procedures of concluding saturated and residual moisture content from soil samples were explained thoroughly by Flint (1998).

Chloride profile method

The CMB method is explained in several papers (Allison and Hughes 1978; Edmunds and Darling 1988; Eriksson and Khunakasem 1969; Scanlon 1991, 2009). The method assumes that the chloride in the water of unsaturated zone is from precipitation. Most plants cannot take up chloride, therefore, its concentration increases in the soil until it reaches a steady-state condition. Lower concentrations of chloride in soil indicates higher rate of groundwater recharge, if the following assumptions are considered: (1) precipitation contains sufficient chloride; (2) no external source of chloride in the soil or aquifer is present (e.g., fertilizers, irrigation water, pesticides, animal and/or human urine, and feces); (3) concentration of chloride in the rainfall is constant.

Recharge is calculated by the following Equation:

$$R = \left(C_p * P\right)/C_r \tag{4}$$

where R is recharge; P is precipitation; C_p and C_r are mean chloride concentration in precipitation and in the profile, respectively. Concentration of Cl^- in rainwater was measured at the Puteh Village Water Plant in south of Kota Bharu, Kelantan during 1st March 2012–28th February 2013. The weekly samples were collected and average value of chloride concentration in rainfall was measured. Because of possible water loss during sample collection and processing, concentrations are considered to be on mass basis (mg ion/kg dry soil)—supernatant concentration multiplied by extraction ratio (g water/g soil) and divided by water density.

Soil samples were collected from boreholes at each study location (see Fig. 1). Samples were collected in January 2012 by core boring (pushed) with a 50-mm-diameter thin-wall sampler without any addition of fluid. Cores were acquired to the top of water table. Both ends of the samples were sealed by wax to reduce evaporation of water content. Samples were collected from the cores at 10 cm intervals. All soil samples were analyzed for chloride, ambient moisture, pH using procedures proposed by Scanlon (2009), and Jackson (2000).

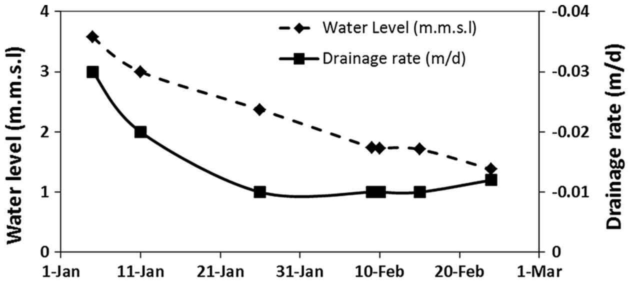

Fig. 3 Drainage rate and water level

Results

Water level fluctuation

Water level changes

Water level increase occurs also as a result of rainfall infiltration and percolation. Different factors may result in overestimation or underestimation of recharge rate, including pumping, barometric pressure, ocean tides, and lateral flow. The influence of pumping, ocean tides, and lateral flow must be eliminated from the water level signal by careful site selection. In this study, both observation wells are far from the ocean and from pumping infrastructure to minimize adverse effects. Shallow unconfined aquifers tend not to respond to changes in barometric pressure (Weeks 1979).

In the periods of no rainfall, drainage rate was estimated from the decreasing water level. According to Fig. 3, as expected from Darcy's law, it can be seen that the higher the groundwater table is, the greater the drainage rate. The rate of drainage for the study sites is in the order of 3 cm/day.

Rainfall infiltration through the profile is able to trap air in the unsaturated zone and causes Lisse effect. According to Meyboom (1967) and Heliotus and DeWitt (1987), the Lisse effect occurs at <1–1.3 m depth. At the sites, water level fluctuates 4 m below the surface, thus, the Lisse effect was assumed to be negligible for these sites.

Determination of specific yield

Specific yield was inferred at the PC and WB field sites using the difference between residual and saturated moisture content. Mean values of soil properties are shown in Table 2. In application of the WTF method using representative values of specific yield (i.e., Johnson 1967), gives recharge estimates of 648 and 719 mm/year for year one and two of the study period, respectively. The results were obtained from positive water level signal at the PC site multiplied by 0.29 (as a representative specific yield for fine to coarse sand). For calculated S_y here, recharge is much lower and was determined to be 402 and 491 mm/year for year one and two of the study period, respectively. Values of specific yield depend on grain size, form and distribution of pores, compaction of soil materials. In unconsolidated formations, S_y is expected to fall between 7 and 15 % (Todd and May 2005) which agrees with current findings.

Table 2 Mean values of soil properties at each field site

Site	W_T	$\theta w1$	$\theta w2$	α	θr	θs	S_y
PC	210.66	203.77	187.63	0.41	0.19	0.37	0.18
WB	111.82	109.06	104.97	0.31	0.12	0.28	0.16

W_T total weight (g), $\theta w1$ weight after RH-oven dried (g), $\theta w2$ weight after standard oven dried (g), α porosity (%), θr residual moisture content (%), θs saturated moisture content (%), S_y specific yield

Recharge estimation

Table 3 shows the annual recharge at PC and WB. Recharge is calculated using Eq. 3 between January 1998 and December 1999 for PC and between January 2010 and December 2011 for WB which is the latest data recorded in the database of Minerals and Geoscience Department Malaysia. An average value of 319 and 447 mm/year is obtained for WB and PC, respectively. At PC, annual recharge for 1998 is less than 1999 but the recharge coefficient (*R*/*P* %) for 1998 is higher. The same trend occurs at WB. The value of R1 is lower than R2 but the recharge coefficient for 2011 is higher. It is due to difference in rainfall values for 1999 and 2011 (see Fig. 2) which are recorded 1,886 and 910 mm more than the prior year. It is inferred that first-year estimation represents groundwater recharge through a year with the average annual precipitation and second year represents high annual rainfall.

At PC, water table depth is about 4 m. As the observation well is located in sandy texture sediment, the groundwater can rise with a short time lag. At WB, with almost same groundwater level as PC, the overlying silty clay layer has lower permeability and high capacity in holding water. The rainfall takes a longer time delay to infiltrate and percolate to groundwater table. Thus, it can be

Table 3 Recharge calculation at field sites

Site	Δh_1	Δh_2	R_1 (R/P %)	R_2 (R/P %)
PC	1.77	2.37	402 (17 %)	491 (13 %)
WB	2.68	2.11	297 (12 %)	341 (10 %)

Δh_1, Δh_2 annual water level rises contributing to recharge in first and second year(m), R_1, R_2 recharge in first and second year (mm per year), P precipitation

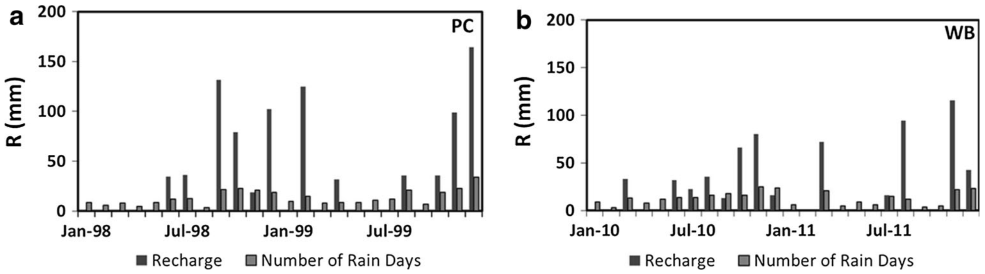

Fig. 4 Monthly recharge and number of rain days at field sites

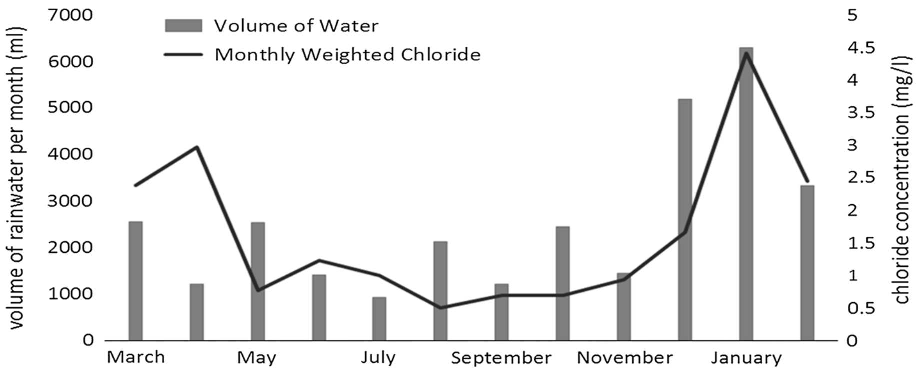

Fig. 5 Volume of water and monthly weighted chloride at field site

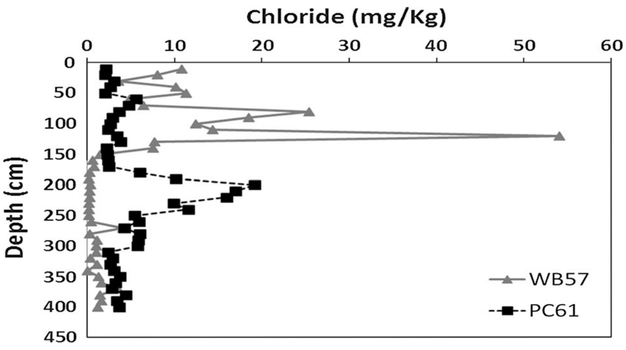

Fig. 6 Chloride concentration at the WB and PC sites

anticipated to detect the recharge in the longer events of rainfall. One of characteristic of humid environment in Southeast Asia is precipitation with high intensity and short duration. Therefore, there is lower probability of underestimation of calculated recharge due to low intensity and long duration of rainfall in the area. To better understand the mechanism of recharge, correlation between the number of rain days of each month and monthly recharge was examined. Figure 4a, b shows number of rain days and recharge values at the field sites.

At WB, 64 % correlation between number of rain days and recharge rate was obtained. This value was 82 % for PC. In coastal area, correlation is higher, which is related to the higher permeability of sediment compared to the inland area, which consists of finer-grain size of soils in upper layer.

Chloride mass balance

Volume-weighted mean annual chloride concentration in rainwater is measured to be 1.43 mg/l. Chloride must be measured on chloride input from either wet or dry deposition. However, there are no available data for dry deposition. Figure 5 shows monthly volume of rainwater and chloride concentration between March 2012 and February 2013 (Fig. 5). For the recharge calculation, chloride concentrations in sediment (Fig. 6) and related gravimetric moisture contents (Fig. 7) were determined in 40 samples at PC and 37 samples at WB.

The sites were chosen based on lithology with different textures that are in non-polluted areas, unaffected by brackish water influence and other sources of chloride, except precipitation. Anthropogenic deposition of chloride was not observed. The average profile values represent a long-term record of groundwater recharge into saturated soil. Long-term recorded chloride values in shallow groundwater samples were constant or had only minor variation through the wet and dry seasons (Ismail 1993) which describes conservative behavior of chloride in the study area. Major roots were determined to be confined in the top 20 cm at WB and PC. Therefore, below this boundary, percolation can be taken as the natural recharge. The relation between chloride concentration and depth is different for each site. In the WB profile, chloride concentration is high (up to 175 cm) due to clay texture. High chloride concentration results in low recharge rates at this depth (263.3 mm/year). Below 175 cm chloride concentration dramatically

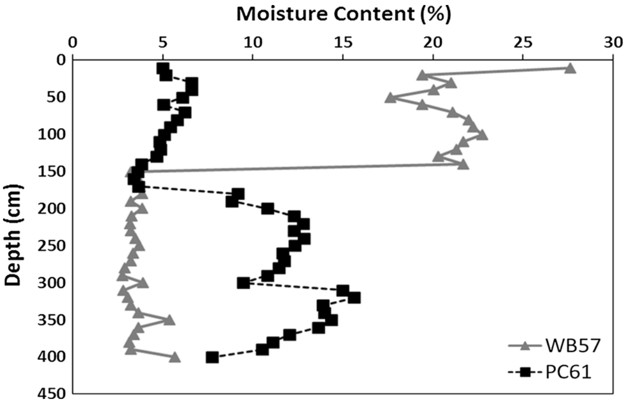

Fig. 7 Moisture contents at the WB and PC sites

decreases and recharge rates are significantly higher due to soil texture (sand; course to very coarse with some gravel). Therefore, the average groundwater recharge for whole the profile is 627.7 mm/year of local rainfall. The recharge maybe controlled by the first layer, therefore, the process of recharge in sandy layer depends on the volume of water passed through upper clay layer.

In PC site, profile is sandy, which results in low chloride concentration, and high rate of recharge. The average groundwater recharge for this site is 691.8 mm/year of local rainfall. The chloride concentration in soil profile is generally low except at the depth of 200 cm where the value increases markedly to 19.1 mg/kg which is high for medium to course sand. This is due to a silty lens within the interval.

Distribution of soil moisture depends mainly on soil texture. For two profiles, moisture ranges between 3 and 16 % for PC and between 3 and 28 % for WB sites (see Fig. 7). There is a clear contrast between clay and sandy texture sediment in the moisture distribution in WB due to change in type of soil through lithology of profile in unsaturated zone. The water content between the ground surface and the bottom of clay layer is 17–28 %. The soil is fine grained to 175 cm depth below which it is coarse grained. Thus, in the lower interval, soil moisture decreases to 3–6 %. In PC, the range of moisture content in unsaturated zone (alluvial deposits, Quaternary age) ranges from 3 to 15 %.

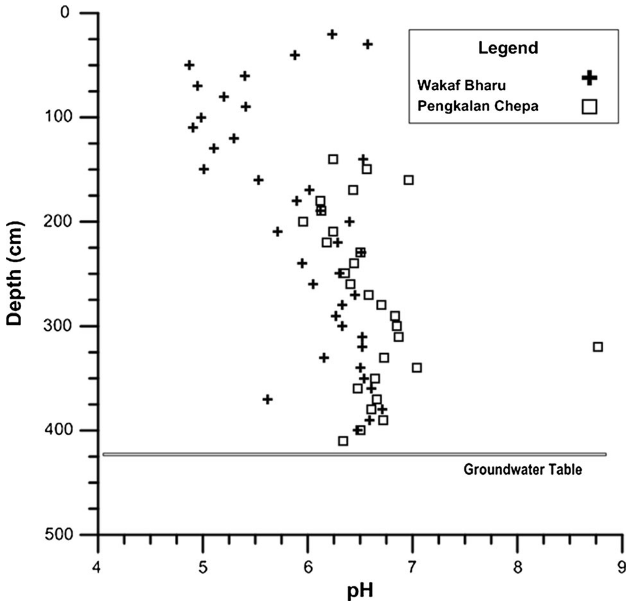

Fig. 8 pH versus depth

Table 4 Summary of chloride concentration and computed recharge

Site	Number of samples	Depth (cm)	Interval (cm)	C_p (mg/kg)	C_r (mg/kg)	*R* (mm/year)	*R* (%)
WB	17	25–175	10	1.43	13.9	263.3	10.2
	37	25–410	10	1.43	5.83	627.7	24.5
PC	40	25–420	10	1.43	5.29	691.8	27

C_p and C_r represent average chloride concentration in precipitation and the profiles

Figure 8 shows pH variation in the soil profiles above groundwater table. pH in the WB profile was measured between 20 and 370 cm depth. In upper part (clay texture), the average pH is 5.5. In the lower section (sand deposit), the average pH is 6.25. In PC, pH was measured between 140 and 400 cm below ground surface. The pH ranges from 5.96 to 7.04 with an average of 6.6, with one outlier at 8.77. As shown in Fig. 6, the concentration of pH in soil displays coherent behaviors with more Cl-rich soil having the lower pH values, and more Cl-poor soil having the highest pH values. This relationship throughly suggests that the pH and Chloride are directly related. This is due to adsorption/desorption processes which are controlled by pH and pH is directly related to the amount of organic matter (Thurman 1985). Peat (as an organic matter) was reported in the Simpang and Beruas Formation (Hutchison and Tan 2009) and enhances the buffer capacity of the soil. Unfortunately, the discussion of this hypothesis is restricted because of objective of manuscript.

Table 4 summarizes results of the estimated groundwater recharge at the field sites. Recharge is between 263.3 and 691.8 mm/year. These values represent 10.2 and 27 % of the mean annual precipitation. It is apparent that recharge is not consistent between methods. However, at WB, the recharge rate is not very different. Similar result was found by Takounjou et al. (2011) in a tropical zone (of Cameroon) in shallow aquifers. They concluded that concentrations of chloride show non-conservative behavior in humid climates and is governed also by hydrological processes. O'Brien et al. (1996a, b), by studying recharge in loess, stated that piston flow was not the sole process in their systems, and that preferential vertical or lateral flow must be occurring.

It should be noted that the estimated recharge values, based on Eq. 4, assumed that soil texture throughout the sediment in unsaturated zone is in uniform conditions. If texture varies excessively which is possible in alluvial horizons, in the area or any source with the presence of salts/chloride, the values discussed above may not be acceptable. Therefore, this may be a significant error in calculation. Another source of error is the average concentration of chloride in rainfall. Groundwater recharge is estimated using CMB method, as point scale method, based on chloride concentration from rainfall samples collected in a larger area including the northern part of the Kelantan River basin. The average of geochemical content may not be representative of the field sites.

Conclusion

The average rate of direct recharge within two different types of formations, Pleistocene and Holocene, was estimated using WTF and CMB methods. Specific yield values of 0.18 and 0.16, corresponding to mean recharge values of 447 and 319 mm/year, representing 15 and 11 % of annual precipitation, were obtained from water level at the field sites. The average groundwater recharge based on CMB method was estimated to be 691.8 and 263.3 mm/year at PC and WB, respectively, representing 27 and 10.2 % of the annual precipitation. However, there were differences in amounts of recharge principally due to different scale of measurements. CMB method is a point scale and WTF is a local scale. The WTF method covers an area instead of point. However, results of the current study show agreement between methods and indicate the possibility of using chloride method in tropical area. In addition, results of the two methods indicate that mean recharge in coastal area is greater than recharge in inland areas.

The results can be extrapolated to the entire coastal aquifer with similar characteristics as the sampled sites. Clearly, the coastal area provided significantly high recharge due to the presence of sandy soils. Lower groundwater recharge is related to continental deposits that extend to the south and east of area, where the sediments are finer grained. The recharge values reflect the significance of lithology in shallow aquifer systems. It is recommended that a future study of soil chemistry might be implemented to reveal conservative/non-conservative behavior of chloride and effect of adsorption/desorption process and ion exchange in unsaturated soil.

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