INTEGRATED ASSESSMENT OF GROUNDWATER RECHARGE IN THE NORTH KELANTAN RIVER BASIN USING ENVIRONMENTAL WATER STABLE ISOTOPES, TRITIUM AND CHLORIDE DATA

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ABSTRACT

Estimation and understanding of groundwater recharge mechanism and capacity of aquifer are essential issues in water resources investigation. An integrated study of environmental chloride content in the unsaturated zone using chloride mass balance method (CMB) and isotopic analyses of deuterium, oxygen-18, and tritium values range in the alluvial channel aquifer profiles (quaternary sediments) of the North Kelantan River basin has been carried out in order to estimate and understand groundwater recharge processes. However, the rate of aquifer recharge is one of the most difficult factors to measure in the evaluation of ground water resources. Estimation of recharge, by whatever method, is normally subject to large uncertainties and errors. In this paper, changes in stable isotopic signatures in different seasons and tritium analysis of the sampled groundwater observed at different depth in the aquifer system were evaluated. Stable isotope data are slightly below the local meteoric water line (LMWL) indicating that there is some isotopic enrichment due to direct evaporation through the soil surface which is exposed prior or during the recharging process. The overall data on water isotopic signatures from boreholes and production wells (shallow and relatively deep aquifer system) are spread over a fairly small range but somewhat distinct compared to river water isotopic compositions. Such a narrow variation in isotopic signatures of the sampled groundwaters may suggest that all groundwater samples originated from the same area of direct recharge predominantly from rainfall and nearby rivers. Environmental tritium data measured in groundwater at different depths and locations together with a medium-term of limited monthly rainfall collections were used to investigate the groundwater age distributions (residence times). The existence of groundwater in the aquifer system (sampled wells) is predominantly designated as modern (young) water that has undergone recharged occurring after1953. Groundwater age data together with other additional information related to the wells bore could then be applied to translate into semi-qualitative estimation of long term average groundwater recharge rate within the aquifer system (mm/y). Environmental isotopic data suggest recharge rate in a range 11 mm/y to 1270 mm/y with an average of ***261.5 mm/y*** *that corresponds to* ***10.5%*** *of the total annual rainfall. Recharge estimation obtained by isotopic approach was found smaller than the amount of recharge rates calculated based on CMB methodology in the unsaturated zone ranged between 155 mm/y to 966 mm/year. These data correspond to the average of* ***484.3 mm/y*** *or* ***19.4 %*** *of the total effective annual rainfall. Spatial variation of the predicted groundwater recharge map from tritium dating method is established in this preliminary study. Accurate estimation of groundwater recharge and further assessment of its source are useful and recommended for proper sustainable management and utilization of groundwater resources in this basin.*

Katakunci/keywords : stable isotope, recharge rate, chloride mass balance (CMB), tritium, isotopic signatures, groundwater, evaporation.

1. INTRODUCTION

Water movement in aquifers is highly dependent of the permeability of the aquifer material. The amount of water that may be extracted from an aquifer without causing depletion is primarily dependent upon the ground water recharge. Recharge is an important process through which groundwater in aquifers is replenished by precipitation (rain water) moving down through the soil and rock layers of the ground and also by infiltration from surface water sources such as rivers and lakes (GWRPH, 1986; Bhattacharya et al., 2003). Without recharge, the groundwater resources would be completely depleted. The rate of recharge is not the same for all aquifers. Thus, a comprehensive understanding of the groundwater recharge process (mechanisms and rates) is therefore crucial for groundwater reserve assessments and its sustainability.

Generally, alluvial river channel aquifers (quaternary sediments) in the temperate climate zone constitute an important source of groundwater not only for the usage of domestic but other activities like agriculture and industry. The quaternary sediments located in the region of Lower Kelantan River Basin were considered the only source of substantial groundwater potential in the area where the amount of water could be safely exploited from the vast reservoir of the lower aquifer system (Noor, 1979). A number of groundwater related studies have been conducted on alluvial aquifers and most studies have focused on assessment of the potential yield and sustainability of the aquifer with no being devoted to enhance the understanding the groundwater recharge processes of the aquifer (Gomo et. al., 2012). Although various techniques exist for groundwater recharge investigation and estimation, it is extremely difficult to assess the accuracy of any method (Healy and Cook, 2002; Scanlon et al, 2006; Crosbie et al, 2010) due to its spatial and temporal variability and hence the application of multiple and complimentary methods cannot be overemphasized. In view of this, therefore, it is recommended that recharge should be estimated using multiple methods to obtain more reliable values (Lerner, 1990; Scanlon et al., 2002) prior to derive a conclusive evidence about the amount of naturally occurring groundwater that can be withdrawn from an aquifer on a sustained basis (safe yield), economically and legally, without impairing the native groundwater quality or creating an undesirable effect such as environmental damage (Fetter, 1994).

This paper aims to investigate and compare recharge processes using environmental isotopes and chloride mass balance (CMB) of the alluvial channel aquifer. The former is commonly used as tracers in recharge studies since they are integrated in the water cycle and reflect changes induced by natural and anthropogenic processes (Diouf et al., 2012). On the other hand, the latter method is based on tracing the geochemical signal (environmental chloride concentration) from rain water and unsaturated zone solutions to ground water. Variations of chloride concentration and environmental isotopes ($^{2}\mathbf{H}$, $^{18}\mathbf{O}$ and $^{3}\mathbf{H}$) between rain water and groundwater have been used in several studies to investigate recharge from infiltration of rainwater and to identify the origin of the water, atmospheric processes (advection of water vapour, condensation and evaporation), and processes during recharge (i.e., mixing and flow paths of groundwater) (Allison et al., 1994; Gaye and Edmunds, 1996; Clark and Fritz 1997; Gupta and Despande, 2005).

In practice, the use of isotopic methods in groundwater investigations is gaining widespread acceptance among hydrogeology professionals. In this respect, isotope data of rain water, groundwater and surface water in parts of the North Kelantan River Basin in the State of Kelantan were used to explain the groundwater recharge regime and identify the source of origin in the area. Information provided by the chloride concentrations in rain water and soil water extracted from the limited unsaturated zone profiles (adjacent to shallow groundwater wells) within the study area were used to estimate aquifer recharge and their results compared with the isotopic method. A rather broad-scale of related study using environmental isotope study has earlier been carried in Kelantan (Daud Mohamad et al., 1985). Groundwater recharge is an important parameter in the development of a decision support system for the management and efficient utilization of groundwater resources in the area. It is hoped that this preliminary study could help the planning of future water resources management in the State of Kelantan by the public water supply that is now handled by Air Kelantan Sdn. Bhd. (AKSB), (Wan Zakaria et al., 2012).

Presently, there are a total of 24 well fields in Kelantan River Basin, 9 old and 15 new well fields which supply fresh groundwater obtaining from a number of tube wells for their limited operation. The old well fields can produce about 72.84 Mld whereas the new well fields can provide more than 115.6 Mld

(Azuhan, 2012). The total groundwater capacity from shallow and deep aquifers over the whole basin has been assessed as approximately 488 Mld (Azuhan, 2012). The total groundwater consumption constitutes about more than 45% (or 83 Mld) of the total water production in AKSB's water treatment plant and the demand of fresh groundwater for potable use will increase at a pace of 2.5% per year (NAHRIM, 2011).

2. DESCRIPTION OF THE STUDY AREA

The North Kelantan River Basin is topographically dominated by the flat coastal plain with elevation less than 75 m above mean sea level and situated on east coast of the Malay Peninsula, as shown in Figure 1 (about 28 sampling sites in red colour). The average total annual rainfall is varied between 2400 - 2700 mm contributed by localized heavy showers of short duration but more extensively during the North-East Monsoon from late October to early February which is often associated with heavy thunderstorm activities. The mean daily temperature and mean humidity are 27^0C and 70%, respectively (Shin, 1977). The study area is principally drained by the meandering Kelantan River (Sg. Kelantan) which has its source is traceable from the higher altitude in the Main Range and Boundary Range of Peninsular Malaysia. Whilst, in the South-East region, the flat coastal alluvial plain is also partly drained by Pengkalan Datu and Kemasin Rivers. The Kelantan river is fed by 4 main tributaries viz. the Galas River, Pergau River, Nenggiri River and Lebir River.

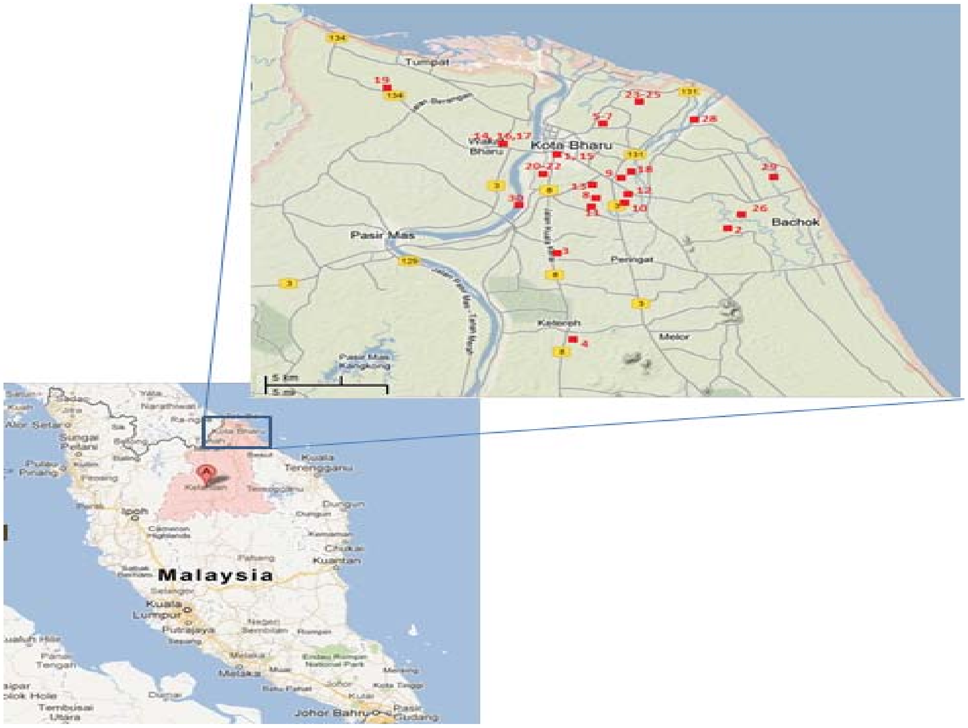


Figure 1: Location of water sampling sites (study area) in the North Kelantan River Basin, Malaysia.

The coastal plain is mainly covered by Quaternary sediments or alluvium (i.e. gravel, sand, silt and clay) formation and constitutes the reservoir in this region. Since the quatenary sediments were considered as the only source of substantial groundwater potential in the area, a drilling programme was carried out in 1974 by the Mineral and GeoScience Department of Malaysia (*formerly* known as Geological Survey of Malaysia) in collaboration with a German Hydrological Team to assess future demand and to make some recommendations for pumping equipment (Shin, 1977). In view of the permeability of the aquifer and relatively thick sequences of course sand and gravel in the surroundings of the major locality, it was concluded that the area could be profitably exploited for groundwater potential. In general, it was found that there are two aquifer zones existing in the area, with the shallow aquifer usually unconfined and its thickness ranging from a few metres to about 30 metres and the lower one is relatively very thick in which it reaches about 80 metres along the coast (Noor,1979). The aquifers are usually separated by an impermeable to semi permeable layer of clay, silty clay and silt. On the other hand, three aquifer zones are also found to exist in some places. The thickness of the aquifer varies from place to place and generally it increases toward the coast. The different in thickness of the overburden unconsolidated sediments between the aquifer zones can have some implications for ground recharge process. The aquifer conceptual model is shown in Figure 2.

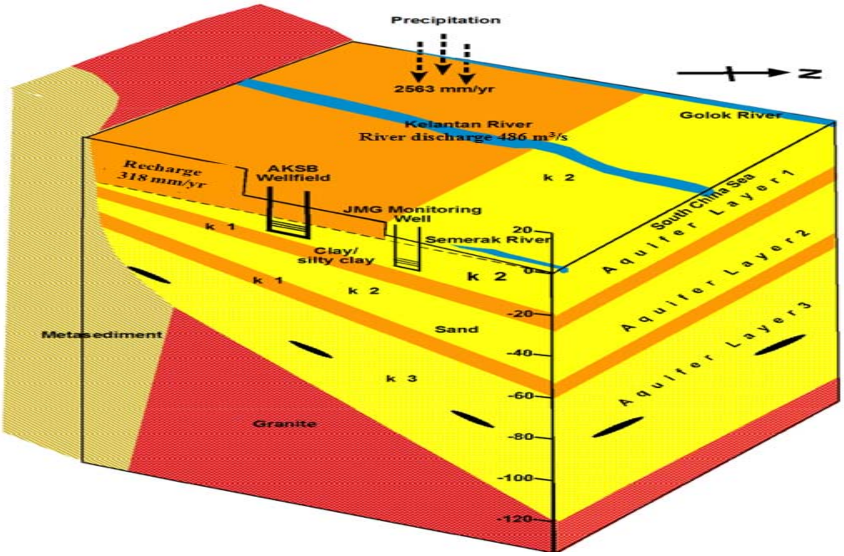


Figure 2: Aquifer conceptual model of the North Kelantan River Basin.

The groundwater fluctuations at shallow unconfined and deep aquifers are typically ranging from 1-2 m and 2-4 m respectively. Current estimation of annual recharge based on water balance budget in the study area is about 12% of the total annual rainfall and grossly confirmed by numerical model (Ismail, 2011).

3. METHODS AND MATERIALS

3.1 Sampling of groundwater and surface water for isotopic analyses.

Four water sampling campaigns were carried out during the dry and wet seasons beginning from January 2012 - November 2013 at several locations distributed within the study area. A third sampling was implemented in the dry season- a couple of weeks after flood event. Water samples from various types of water bodies were collected from selected monitoring boreholes (shallow and deep aquifers), tube wells (production wells), dug wells, rivers, lakes and monthly rain water for environmental isotopes (^{2}**H**, ^{18}**O** and ^{3}**H**) and major ions chemical analyses. Temperature, pH, electrical conductivity, etc of the water samples were also measured in- situ using portable YSI multi-probe conductivity meter. A total number of 36 water samples (28 groundwater, 1 lake water, 5 river water, monthly collection of rain water and 1 sea water) together with 10 soil core-samples in shallow unsaturated zone were collected in the study area as shown in Figure 3.

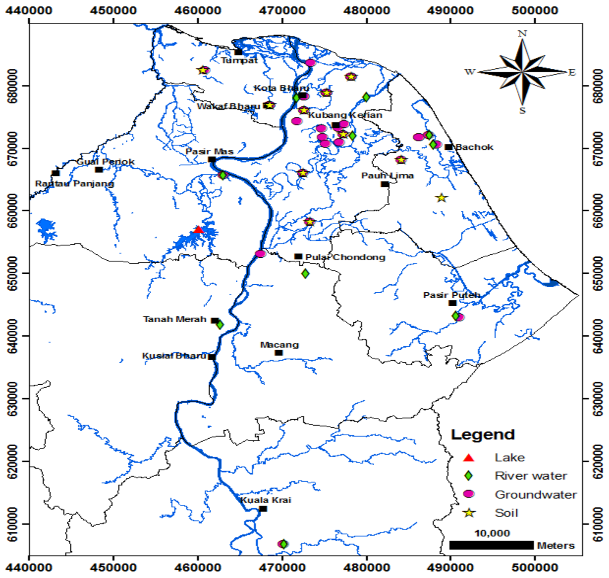


Figure 3: A map of the study area showing location of water and soil samplings

Groundwater samples collected from respective zones are classified into three sub aquifer systems, viz. first layer (0-20m deep), second layer (20-50m deep) and third layer (>50m deep). All the water stable isotope analyses were carried out using SERCON 2020 isotope ratio mass spectrometer (IRMS) at Malaysian Nuclear Agency. These stable isotope data are expressed in delta per mille or per thousand (delta notation, δ ‰) notation relative to international standards, namely standard mean ocean water (SMOW) (precision : ± 1‰ and 0.2 ‰ for δ^{2}H and δ^{18}O, respectively). Tritium concentrations in water samples were analyzed through electrolytic enrichment and the liquid scintillation counting (LSC) methods at PINSTECH laboratory, Pakistan. Whilst, the concentration of major ions in the samples were determined using ion chromatography (anion content) , ICPMS (ion-coupled plasma mass spectrometer) and titration methods in the laboratories at the Malaysian Chemistry Department and Department of Geology, University of Malaya.

Isotopic data of rain water and groundwater were used to infer the sources, origin and the possible relationship between groundwater and surface water. Tritium input data from the rain water and in the groundwater were used to estimate the groundwater residence time (age) in the quaternary sediments aquifer system.

Tritium (^{3}H) is a radioactive isotope of hydrogen with a half-life of 12.32 years. It is naturally produced by cosmic radiation in the atmosphere and incorporated into precipitation (rainfall). This natural production is in the range of 5-20 tritium units (TU) depending on the geographical location (http://pubs.usgs.gov/fs/fs-022-02). In our study area, medium term measurements of naturally tritium contents in the monthly rainfall samples vary between 7.82 to 10.97 TU with the calculated weighted mean about 8.92 TU. 1 TU is equivalent to a concentration of 1 ^{3}H atom per 10^{18} ^{1}H (hydrogen) atoms. However, the thermonuclear tests carried out in the atmosphere starting in 1950's have introduced substantial amount of tritium into the hydrological cycle resulting in about three orders of magnitude higher tritium levels as compared to natural production. Due to international moratorium established in 1963, the thermonuclear tests in the atmosphere were stopped and the tritium content of precipitation has been steadily decreasing since then. It concentration level decreases 50 % every 12.32 years. This relatively rapid natural decay makes tritium a good indicator of recent ground water recharge because water samples containing no detectable concentrations of tritium indicate that post-1953 water is not present in significant amount. Water samples containing tritium at concentrations greater than 0.5 TU indicate some active groundwater recharge since 1953. At present, tritium content of precipitation is almost back to the natural production levels.

3.1.1 Qualitative estimation of groundwater recharge rate based on environmental tritium data

Basically, tritium data were used to examine the occurrence and distribution of post-1950s recharge in selected unconfined aquifer systems. Several assumptions were made to estimate recharge rates in unconfined aquifer systems. Wells or boreholes in the ^{3}H data sets were widely distributed in different layers (aquifers) and not necessarily located along the same or related flow paths. The date of present collection for water samples (i.e., below the water table) with decayed ^{3}H concentrations$\geq$0.5 TU were assessed as having components of post-1950s recharge in the aquifers with a residence time of less than about 50 years. The groundwater recharge rate (RR) estimated using environmental tritium isotopes can be developed and simplified as follow (Toth, 1995; Noble et al., 1996):

$$\text{RR (m/y)} = \frac{depth\ (d)\ \ X\ \ effective\ porosity(\Phi)}{time(t)}, \qquad (1)$$

Time (t) is referred to the age of ground water (residence time) in years based on tritium concentration (TU) in water sample. The "depth (d)" is related to the water column below water table in metre. Whilst, Φ is unitless and referred to the porosity of stratigraphic column (aquifer).

3.2 Sampling of moisture content from soil profiles for chloride analyses.

Initially, soil profile sampling from unsaturated zone profiles were carried out in May 2012 at 10 selected sites nearby the groundwater tube wells or boreholes using a hollow-stem hand auger device. Soil samples were collected at 25cm interval down to the water table. Samples were bulked and homogenized for each depth and immediately sealed in polyethylene bags. Gravimetric moisture contents were determined by oven- drying about 80g of sample at 105^{o}C for 48 hrs. To determine chloride content, double-deionized water was added to the dried sediment sample in a 1:1 ratio by weight. Samples were agitated on a reciprocal shaker for 8 hours. The moist sample (supernatant) was then centrifuged at 10 mins and filtered through 0.45 μm filters. Chloride concentration was analyzed by ion chromatography (detection limit 0.01 mg/L) at the Chemical laboratory, University of Malaya.

3.2.1 Chloride mass balance method (CMB)

Chloride concentrations in pore water in the unsaturated zone or in groundwater have been widely used to estimate recharge (Allison and Hughes, 1978; Scanlon et al, 2002; Phillips, 1994). Precipitation contains low concentrations of chloride. Chloride in precipitation and dry fallout is transported into the unsaturated zone with infiltrating water. Chloride concentrations increase through the root zone as a result of evapotranspiration because chloride is nonvolatile and is not removed by evaporation or by plant transpiration. Below the root zone, chloride concentrations should remain constant if recharge rates have not varied over time. Qualitative estimates of relative recharge rates can be determined using chloride concentrations in the unsaturated zone pore water or groundwater if precipitation and dry fallout are the only sources of chloride to the subsurface. Chloride concentrations are inversely related to recharge rates: low chloride concentrations indicate high recharge rates because chloride is flushed out of the system whereas high chloride concentrations indicate low recharge rates because chloride accumulates in the subsurface as a result of evapotranspiration.

Basically, the chloride mass balance (CMB) technique is based on the assumption that the chloride ion behaves conservatively and is not easily affected by reactions through the unsaturated zone to the saturated zone. If this assumption is valid, then it follows that the chloride ion can adequately trace groundwater recharge processes and can thus provide reasonable estimates of groundwater recharge in the area. Its reliability therefore hinges on the compatibility of the precipitation event that recharged the system under study and recent precipitation. It is also assumed that the main source of chloride in groundwater is precipitation. Therefore, where it can be determined that a substantial proportion of the groundwater chloride is generated from mineral dissolution processes, the method can lead to underestimation of recharge. On the other hand, where the groundwater chloride is negatively affected by a process which reduces its content compared to that of precipitation, groundwater recharge can potentially be underestimated. The CMB methodology has been widely tested and regarded as one of the most reliable direct techniques for estimating groundwater recharge in regional hydrogeological studies and basin wide groundwater resources assessments (for e.g., Dassi,2010; Subyani,2004; Bazuhair and Wood, 1996; Wood and Sanford, 1995). Estimation of aquifer recharge rate (R) by the CMB method is summarised as follow (Marie *et al.*, 2010):

$$R = P * (Cl^{-}_{P}/Cl^{-}_{gw}) \qquad (2)$$

Where, R is recharge (mm/year); P is annual average rainfall (mm/year); Cl^{-}_{P} is the weighted average of chloride concentration (mg/L) in rainfall and Cl^{-}_{gw} is the average chloride concentration in pore water of the unsaturated zone profile (mg/L) and or in groundwater . The weighted average (Cl^{-}_{p}) is calculated according to the following equation:

$$Cl^{-}_{P} = P_1 \text{ x } C_1 + \text{.............} + P_n \text{ x } C_n / (P_1 + \text{........} + P_n) \qquad (3)$$

where P_1 is the first rainfall event (mm) and C_1 is the corresponding chloride concentration in the rainfall (mg/L) in the area for 1 to n events. To determine the weighted chloride average for each hydrological year, the chloride concentration of each rainfall event is first multiplied by the amount of rainfall. The summation of these individual components is then divided by the total annual rainfall.

4. RESULTS AND DISCUSSION

4.1 Assessment of the isotopic signatures in relation to sources,origin and water recharge mechanism.

Water stable isotopes data of 4 different sampling campaigns in the study area are plotted (δD vs $\delta^{18}O$) and shown in Fig. 4 (a,b,c,d) for ground water and surface water to find out the source and origin of the groundwater. Table 1 shows isotopic composition of deuterium, oxygen-18 and tritium data analysed from the water samples in the study area.

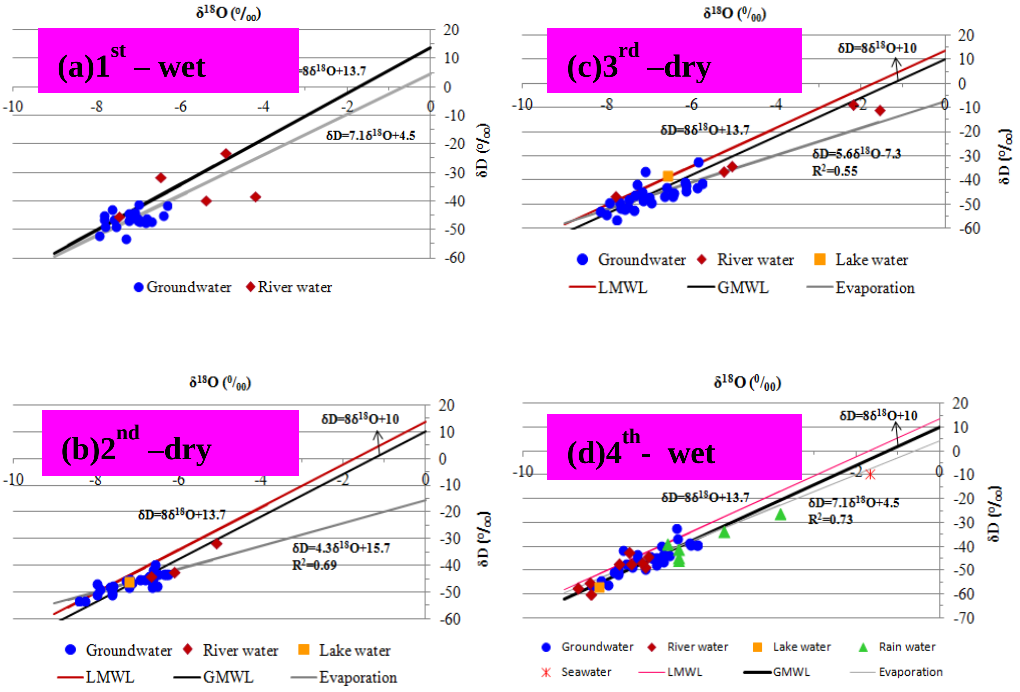


Figure 4: Stable isotope plots of groundwater and surface water collected from the study area in different seasons (Jan 2012 to Nov 2013)

Table 1: δD, δ^{18}O and limited ^{3}H results of water samples (groundwater, surface water)

Sampling	Type of	Depth	1st (wet-Jan 2012)		2nd (dry-Sept 2012)		3rd (dry-May 2013)		4th (wet-Nov 2013)		
location	water	(m)	d^{18}O (‰)	dD (‰)	d^{18}O (‰)	dD (‰)	d^{18}O (‰)	dD (‰)	d^{18}O (‰)	dD (‰)	^{3}H (T.U)
Kg Puteh well#9	groundwater	15.32	-6.76	-46.95	-6.58	-43.11	-5.89	-43.01	-6.33	-32.54	1.26
Kg Puteh well#3	groundwater	91.44	-6.80	-44.39	-7.66	-47.75	-6.96	-49.38	-7.26	-43.41	1.52
Perol	groundwater	62	-6.39	-44.76	-6.72	-44.01	-7.3	-41.44	-6.64	-43.15	0.60
Ketereh	groundwater	11.6	-7.22	-44.26	-6.24	-43.15	-6.6	-42.86	-5.85	-39.44	2.32
Tg Mas well#1	groundwater	79.27	-7.17	-50.22	-7.29	-47.11	-7.03	-46.87	-7.08	-49.38	0.70
Tg Mas well#6	groundwater	42.68	-8.29	-54.50	-7.98	-52.98	-8.19	-52.83	-8.13	-54.50	0.73
Tg Mas well#10	groundwater	35	-7.27	-48.35	-6.96	-48.38	-7.69	-51.47	-8.37	-56.72	1.8
Pdg Penyadap	groundwater	7.8	-7.97	-49.24	-6.51	-47.67	-7.96	-49.23	-7.73	-51.90	2.76
Kubang Kerian well#1	groundwater	15.5	-7.82	-45.96	-6.92	-45.00	-	-	-	-	-
Kubang Kerian KB25	groundwater	59.4	-	-	-7.9	-48.61	-7.17	-47.33	-7.54	-47.14	0.65
Pasir Tumboh well#2	groundwater	36.06	-7.08	-44.67	-7.26	-45.65	-7.17	-48.22	-	-	2.21
Seribong well#4	groundwater	14.5	-6.96	-43.31	-6.65	-47.68	-7.18	-44.5	-7.60	-41.67	2.86
Chica well#3	groundwater	30.49	-7.62	-44.84	-7.08	-43.39	-6.45	-45.34	-6.93	-44.80	0.89
Pasir Hor well#5	groundwater	17.44	-7.05	-46.53	-7.60	-48.13	-5.77	-41.26	-6.81	-44.56	2.36
Kg Chap	groundwater	31.25	-7.52	-47.67	-7.98	-46.49	-7.5	-47.63	-7.38	-48.41	1.74
Wakaf Bharu well#2	groundwater	11.28	-6.98	-42.61	-6.34	-43.21	-7.12	-36.31	-5.83	-39.16	1.14
Wakaf Bharu well#6	groundwater	16.46	-6.97	-46.93	-6.29	-43.21	-7.73	-49.0	-6.02	-38.39	2.26
Wakaf Bharu well#9	groundwater	14.02	-7.09	-43.89	-6.62	-44.46	-6.47	-46.41	-6.68	-39.80	3.37
Kenali well#4	groundwater	33.45	-7.52	-48.66	-7.12	-46.47	-6.16	-44.04	-6.50	-43.58	2.32
Kubang Panjang Dw	gw (dug well)	5	-6.31	-41.28	-6.30	-37.33	-5.87	-32.44	-6.30	-36.82	4.19
Pintu Geng well#3	groundwater	13.72	-7.00	-45.11	-6.49	-43.22	-	-	-5.99	-39.32	
Pintu Geng well#5	groundwater	62.5	-7.57	-44.30	-	-	-	-	-	-	
Pintu Geng well#7	groundwater	13.6	-7.70	-44.94	-6.62	-41.45	-6.47	-45.22	-	-	
Pintu Geng KB49	groundwater	13.7	-	-	-6.71	-39.63	-6.18	-40.78	-	-	2.03
Pengkalan Cepa well#5	groundwater	5.7	-7.00	-44.49	-6.69	-45.25	-6.67	-46.7	-6.96	-44.24	2.55
Pengkalan Cepa well#4	groundwater	64	-8.64	-54.63	-7.15	-50.72	-7.8	-56.14	-7.74	-49.43	0.67
Pengkalan Cepa well#1	groundwater	114	-7.92	-52.96	-7.62	-49.86	-7.53	-50.83	-7.82	-50.81	1.71
Beris Kubur KB31	groundwater	131.4	-	-	-7.98	-50.53	-7.59	-52.05	-7.96	-56.12	4.12
Beris Kubur KB35	groundwater	29.2	-	-	-7.02	-44.45	-8.03	-54.11	-6.64	-46.55	3.7
Jalan Merbau KB15	groundwater	66	-	-	-7.8	-50.25	-7.38	-52.12	-7.74	-50.97	3.63
Jalan Merbau KB16	groundwater		-	-	-	-	-7.36	-46.07	-	-	
Jalan Merbau KB18	groundwater	150	-	-	-7.42	-45.23	-6.15	-41.85	-6.81	-47.71	6.61
Kelar Well#1	groundwater	44	-	-	-	-	-	-	-7.27	-45.14	7.75
Tasek Tok Uban	lake water	0.1	-	-	-7.2	-46.16	-6.59	-38.23	-8.18	-57.07	
Sg. Pengkalan Baru	river	0.3	-5.40	-38.16	-6.11	-42.09	-2.21	-8.27	-8.68	-57.37	
Kuala Sg Semarak	river (near sea)	1.8	-4.21	-23.10	-1.65	2.41	-5.08	-33.91	-	-	
Sg Pengkalan Datu	river	1.5	-5.39	-31.69	-6.63	-40.68	-5.26	-36.1	-8.38	-59.92	
Sg Kemasin	river	0.6	-6.48	-39.80	-5.08	-31.38	-1.57	-10.42	-8.41	-55.06	
Sg Kelantan	river (main)	0.3	-7.46	-45.96	-6.68	-43.95	-7.82	-46.4	-7.14	-46.70	

Note: (i)Weighted mean of rainwater (March 2012-March 2013): δ^{18}O = -6.3 %o ; δ^{2}H = -42.3 %o ; ^{3}H = 8.92 TU (ii) Third sampling was implemented in the dry season a couple of weeks after flood event

Majority of isotopic compositions of the groundwater samples are influenced by evaporation effect where they are found slightly deviated from the LMWL and GMWL with certain best fit of regression lines as shown in Figure 4. The four groundwater data plots on evaporation lines for all sampling occasions with respective gradients range from 4.3 to 7.1, suggesting a high degree of evaporative enrichment of the rainfall in the process of vertical infiltration and percolation through the unsaturated zone into the saturated zone. A local meteoric water line (LMWL) was determined using the isotope data of the rain water from the study area. This LMWL plot would aid in the discussion of the origin of surface water and groundwater.

Insignificant variation in $\delta^{18}0$ and $\delta\,^{2}H$ values of groundwater samples with respect to climate change throughout different sampling occasions (dry- wet period and after flood event) were observed and their somewhat scattered isotopic signatures as compared to stable isotope values of surface waters evaluated. However, it is interesting to note that groundwater particularly in shallow wells is relatively enriched in $\delta^{18}0$ and $\delta^{2}H$ values in the dry season trending toward evaporation line with respect to water in deep wells (>50m) which are slightly and generally depleted in wet season. The respective mean values of $\delta^{18}O$ and $\delta^{2}H$ representing each sampling occasion in sampled wells were -7.30 ‰ , -7.05‰, - 7.01 ‰ , -7.03 ‰ for $\delta^{18}O$ and -46.6‰ , - 45.2‰ , -46.3 ‰ , -45.4 ‰ for $\delta^{2}H$. Obviously, the changes in isotopic signatures and fairly scattered pattern are influenced by the infiltration of rainwater and interconnection or mixing with surface water (nearby river channels especially during flood event) apart from reflecting the evaporation process. Such a narrow isotopic composition variation among the shallow and deep wells may suggest that all groundwater samples originated from the same area of diffused or direct recharge predominantly from rainfall and nearby main river channels. In wet season (especially after or during the flood event), a relatively faster recharge is identified particularly in shallow aquifer system where trending toward depleted values in isotopic signatures from their slightly enriched isotopic compositions were observed during dry season. It is also noticed that the groundwater d-excess values compared to rainwater d-excess values show almost similar range of values which could presuppose that the groundwater is recharged from local rainwater but might have suffered some fractionation due to evapotranspiration, see Figure 5. This analysis suggests that groundwater in the area is mainly of meteoric origin.

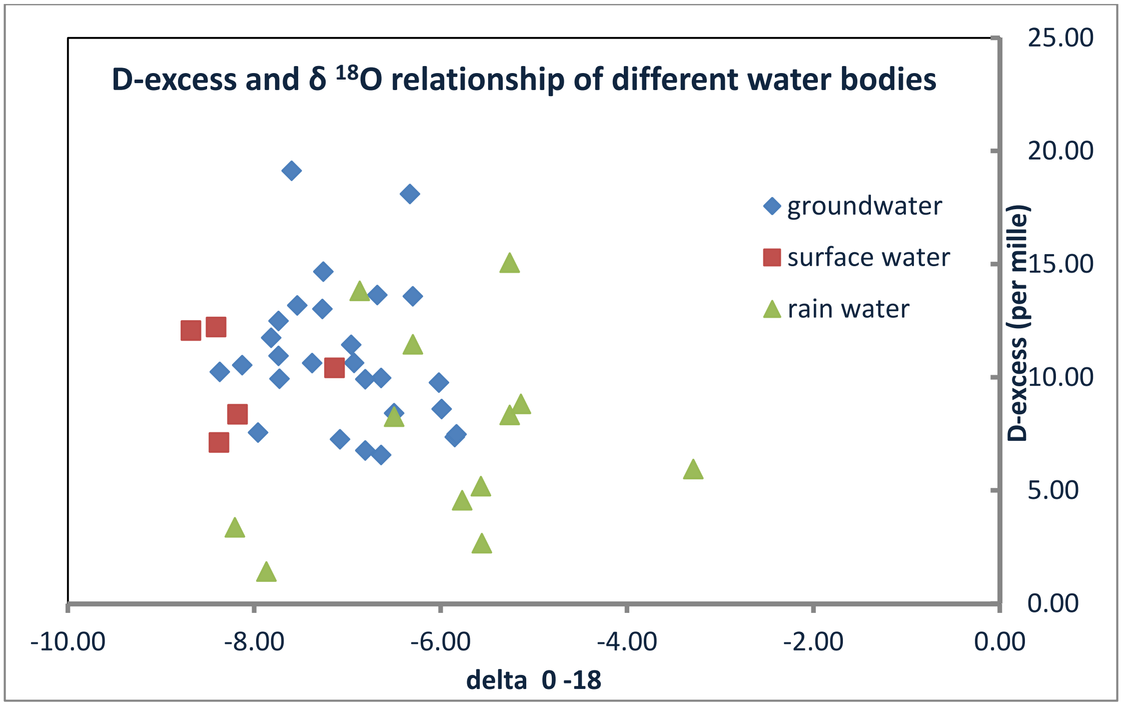


Figure 5: A relation between D-excess and $\delta\,^{18}O$ showing some variations (Groundwater, Surface water and Rainwater).

Recharge rates

Groundwater's tritium content can be qualitatively evaluated to determine the age. Table 2 shows predicted groundwater recharge rates estimated for boreholes or tube wells drilled into the alluvial channel aquifer. The water columns measured by subtracting the well depth and groundwater table of each related tube well or borehole, groundwater tritium-age dating, and effective porosity 0.11 of the aquifer system were used in the calculation of recharge rate. Typically, the rate of recharge is not the same for all aquifers within the basin and may also vary substantially from one sampling location to other locations owing to differences in elevation, geology, texture of aquifer materials, land surface slope, vegetation, and other factors. Based on the tritium data, the recharge rate estimated in the North Kelantan River Basin ranges between 11 mm/y and 1270 mm/y or which is about 0.45% to 49 % of the average annual rainfall in the area. As a whole, the average recharge rate within a basin is estimated about 261.5 mm/y which correspond to 10.5% of the total annual rainfall (2500 mm/y). On the basis of tritium concentrations in groundwater collected for this study, almost all samples were recharged later than 1953 indicating the existence of modern or young water. Typically, only few groundwater sampled locations from deep well fields (Perol wf –well #2, Tanjung Mas wf- well #1, Kubang Kerian wf – KB25, and Pengkalan Chepa wf – well #4) which have fairly low tritium contents about 0.6 - 0.7 TU (slightly above the detection limit) may possibly be considered to have been recharged slightly prior to 1953 (bomb testing period) and regarded as sub-modern water or comprised some extent of older waters (relatively just more than 50 yrs) that have mixed with a smaller fraction of modern groundwater recharge.

Combining together the analyses of stable isotopic signatures and tritium contents (detected above 0.6 – 7.75 TU, where a mixture of sub-modern and recent recharge dominant) from some designated wells in the study area have provided an initial look at identifying source and potential recharge mechanism along with the locations of recharge zones. It is quite obvious that active groundwater recharge is sustained within a basin. Figure 6 shows the spatial variation of general estimated groundwater recharge in the study area using environmental tritium data.

Table 2: Environmental tritium concentrations in groundwater samples, North Kelantan River Basin (November 2013)

Sampling location	Water column (m) (depth below WT)	sub "aquifer" system	Env.tritium conc. in g/water (TU)	"age" of g/water @ residence time (year)	Recharge rate (mm/y)	% rainfall
Kg. Puteh wf (Well # 9)	6.32	Layer 1	1.26	34.8	19.98	0.80
Pintu Geng (KB49)	5.12	Layer 1	2.03	26.3	21.41	0.86
Ketereh well#1	5.25	Layer 1	2.32	23.9	24.13	0.97
Wakaf Bharu (PW#2)	7.62	Layer 1	1.14	36.6	22.92	0.92
Wakaf Bharu (PW#6)	11.36	Layer 1	2.26	24.4	51.21	2.05
Wakaf Bharu (PW#9)	8.69	Layer 1	3.37	17.3	55.25	2.21
Pasir Hor (Well#5)	15.73	Layer 1	2.36	23.6	73.22	2.93
Pdg Penyadap (Well#5)	2.13	Layer 1	2.76	20.9	11.24	0.45
Serinbong (Well#4)	5.81	Layer 1	2.86	20.2	31.61	1.26
Kubang Panjang (Dug Well)	2.25	Layer 1	4.19	13.4	18.43	0.74
Tanjung Mas wf (KB10)	27.77	Layer 2	1.8	28.4	107.38	4.30
Pengekalan Chepa wf (KB5)	25.44	Layer 2	2.55	22.3	125.73	5.03
Kenali (Well#2)	29.89	Layer 2	2.32	23.9	137.36	5.49
Pasir Tumboh (Well#2)	36.91	Layer 2	2.21	24.8	163.71	6.55
Beris Kubur (KB35)	25.99	Layer 2	3.7	15.6	182.79	7.31
Kelar (Well#1)	28.86	Layer 2	7.75	2.5	1270.31	50.81
Kg. Chap, Bachok (rw)	27.18	Layer 2	1.74	29.1	102.92	4.12
Chicha tm (PW#3)	20.84	Layer 2	0.89	41.0	55.96	2.24
Tanjung Mas wf (KB6)	131.68	Layer 3	0.73	44.5	325.59	13.02
Kubang Kerian (KB25)	52.89	Layer 3	0.65	46.6	124.98	5.00
Kg. Puteh wf (Well # 3)	82.91	Layer 3	1.52	31.5	289.96	11.60
Tanjung Mas wf (PW#1)	67.08	Layer 3	**0.70**	45.2	163.12	6.52
Perol wf (well#2)	60.45	Layer 3	**0.60**	48.0	138.61	5.54
Pengekalan Chepa wf (KB1)	108.74	Layer 3	1.71	29.4	407.42	16.30
Pengekalan Chepa wf (KB4)	58.8	Layer 3	0.67	46.0	140.57	5.62
Beris Kubur (KB31)	128.4	Layer 3	4.12	13.7	1028.74	41.15
Jalan Merbau (KB 15)	143.9	Layer 3	3.63	16.0	990.55	39.62
Jalan Merbau (KB 18)	59.88	Layer 3	6.61	5.3	1236.47	49.46

Note: Layer 1(0-20m); Layer 2 (20-50m); Layer 3 (>50m).

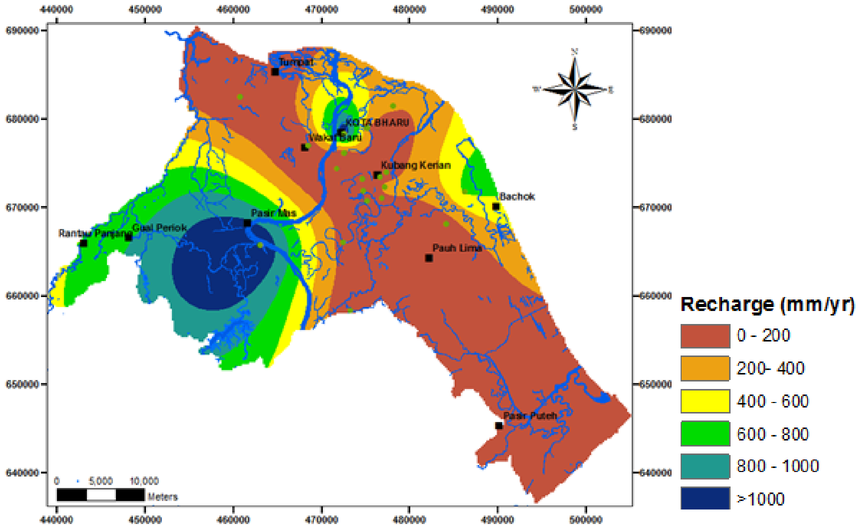


Fig. 6: Predicted contour map showing the spatial variation of general - estimated groundwater recharge from tritium dating method in the study area

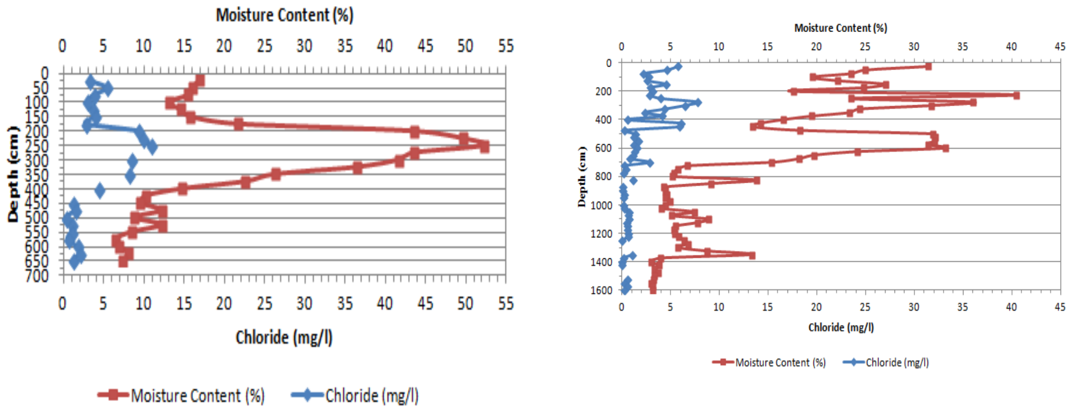
4.2 Recharge estimates from the CMB method

Table 3 summarises the recharge rate estimation results at 10 soil sampling sites in the studied basin by using the chloride mass balance method. An average chloride concentration in rainfall of 1.17 mg/L was applied for the calculation. The chloride mass - balance method shows that the annual recharge rate is between 155 mm/y - 966 mm/y. The average annual recharge rate in this basin is 484.3 mm/y or 19.4 % of the effective annual rainfall (i.e. 2500 mm/y).

Table 3: Unsaturated zone profile locations and recharge rate estimated using CMB method

No	Core	Depth (m)	Chloride (mg/l)	Recharge (mm/yr)	(%) of the annual rainfall
1	Alor Pulai, Jelawat	6.65	0.81 - 6.87	654.34	26.17
2	Perol	9.75	0.91 - 15.79	284.61	11.38
3	Tanjung Mas	6.5	1.01 - 16.28	517.49	20.7
4	Wakaf Bharu	17.75	0.021 - 8.90	321.17	12.85
5	Pengkalan Chepa	16	0.20 - 15.89	585.84	23.43
6	Kubang Panjang	9	0.76 - 15.63	578.82	23.15
7	Ketereh	12.5	1.00 - 177.00	154.89	6.2
8	Kg. Puteh	12.75	0.34 - 7.56	965.96	38.64
9	Chicha	14.25	0.22 - 34.74	287.67	11.51
10	Kg. Chap	6.5	0.29 - 10.82	492.52	19.7

Owing to the nature of recharge estimation by this method, a relatively discernible correlation of typical chloride variation in soil profile and the changes of soil moisture contents trend is probably inter-related (see Fig. 7 as example). In general, high soil moisture content (%) reflects high amount of bulk deposition of chloride content in the unsaturated zone that can be translated into lower value of recharge rate by itself.



(a) Kg. Chap (b) Wakaf Bharu

Fig. 7: Typical variation of vertical chloride profile and soil moisture change at Kg. Chap and Wakaf Bharu (both parameters are associated with the recharge rate estimation)

Comparatively, the result generated using CMB approach does not show excellent match with the recharge rate obtained by isotope method (environmental tritium data). A question can therefore be raised as to which is the reasonably accurate recharge mechanism for this alluvial channel aquifer. The discrepancy of results may be discussed in the following manner without discredit the usefulness of both techniques in understanding the water budget of the basin.

Bearing in mind that, recharge rate estimated from CMB method is provided for a very local recharge value in the unsaturated zone and just to the top layer of saturated zone. The input function as a local time series of reasonable and accurate chloride concentrations in rainfall is difficult to obtain as well as the output function of dry deposition in soil profile. Such quality of data are rarely available with confident and normally should be established from the long time series of data probably at least for three year observations under variability in rainfall pattern over the basin, before reaching a conclusive justification. In addition, if there are possibilities like having other sources of chloride in the soil (for e.g. halites) other than the chloride contained in the rainwater, recycling of dried salt by wind, unaccounted runoff and uptake by harvested plants may also distort the recharge rate results based on this method (UNEP/DEWA/RS.02-2., 2002). Similarly, in the case of recharge rate evaluated by tritium data a good estimate of the aquifer porosity is probably easy in unconsolidated media but rather difficult in fractured media. The reasonable porosity value is usually assumed for all recharge calculations and sometimes the chosen value may be inaccurate. Other major of error is when interpreting samples from wells which mix waters of different age (residence time) and variability in age as indicated by tritium concentration of rainfall will indirectly end up with underestimate of recharge rates calculation. Normally, a lumped parameter model (LPM) is chosen for interpreting the measured values of groundwater age distribution from environmental tritium data. LPMs are mathematical models of transport based on simplified aquifer geometry and flow configurations that account for effects of hydrodynamic dispersion or mixing within aquifer, well bore, or discharge data (Jurgens et al., 2012).

5. CONCLUSION AND RECOMMENDATIONS

Two approaches involving the use of environmental isotopes (**^{2}H**, **^{18}O** and **^{3}H**) and chloride mass balance techniques have been shown to give reasonable understanding and information on the origin (source of recharge) and determination of groundwater recharge rates in the North Kelantan River Basin. Based on the limited results available and discussion presented, the following conclusions can be drawn:

(a) Most of the groundwater in the basin is originated from the same area of recharge or same water regime. The source of recharge is predominantly by local rainfall and some proportions from nearby main river channels (Sg. Kelantan and Sg. Kemasin). It is quite obvious that active groundwater recharge is sustained within this basin and subjected for long term exploitation of groundwater source with proper strategy and careful planning.

(b) The isotopic data also reveals the effect of evaporation on surface water (river and lake) and some groundwater components. Deep groundwater shows a little enrichment trend due to delayed contribution from precipitation (rainfall) and river infiltration.

(c) Overall, groundwater in the study area mostly comprises young (recent) water components. It is a renewable resource and water exploitation is potentially sustainable. Though, at certain well fields of the alluvial aquifer, groundwater has possibly mixed with insignificant fraction of old-age water component having recharge that took place somewhat prior to 1953. A more thorough work on stable isotopic composition and tritium or with other tracer combined study is needed to improve our understanding about aquifers that are being" mined" by AKSB in the recharge zones where their resource is inherently finite or limited.

(d) The CMB method suggests recharge rate in a range of 155 mm/y to 966 mm/year with an average of **484.3 mm/y** which translates into about **19.4%** of the total effective annual rainfall. Whilst, the recharge rate in a range of 11 mm/y to 1270 mm/y with an average of **261.5 mm/y** that corresponds to **10.5%** of the total annual rainfall was estimated using environmental isotope (tritium) data. Recharge estimation obtained by this approach was found smaller than the amount of recharge rates calculated based on CMB methodology in the unsaturated zone.

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