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Isotope hydrological study of Pulau Langkawi, Malaysia

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Abstract: A survey on the stable isotopes and radioisotopes of Pulau Langkawi have been carried out between 1985 and 1989. Groundwater, river water, spring water and sea water were sampled every year whereas rain water was sampled on a monthly basis. The monthly rainwater showed variation in stable isotopes content. But the groundwater response to this variation is very slow with an average ^{18}O value of -6.5‰. From the prepared models and based on the ^{18}O value, the global minimum turnover time for Pulau Langkawi is between eight to ten months. The Meteoric Water Line for Langkawi was established as $\delta D = 8.\delta\ ^{18}O + 13.7$. Based on the stable isotopes and physico-chemical data, the wells are locally recharged by rainwater. Some of the wells are also recharged by nearby rivers. At the present rate of pumping there would be no intrusion of sea water into the studied aquifers. The high chloride content in some wells are of local feature, due to evaporation. The chloride content at hot springs may originate from mixing with sea water.

INTRODUCTION

This study was undertaken between 1985 and 1989. During the same period, Authority of the Kedah State Government was in the process of harnessing the surface water by constructing the Malut and Langkanah Dams upon completion of which (phase 1 and phase 2) would increase the water supply by 7.5 mgd. The water authority concerned was contemplating the exploitation of groundwater potential which at that time was extracted on a relatively small scale. Extensive boreholes construction was launch earlier (Gov. of Malaysia, 1983).

It was projected that the domestic water demand for Langkawi would increase from 1.2 ML/d in 1980 to 33.08 ML/d by 2015. The awareness on the exploitation of groundwater, brought Malaysian Institute for Nuclear Technology Research (MINT) to do undertake this collaborative study with the Public Works Department (PWD) Langkawi. The information on the appraisal of groundwater of the area might assist the long term planning for future water requirements.

OBJECTIVES

The isotope hydrological study of Langkawi Island aims to determine the following:

i) Surface water-groundwater interrelationships
ii) Source of recharge to the groundwater
iii) Source of salinity in groundwater
iv) Mobility and dynamic storage of groundwater
v) Mixing in the aquifer system

PRINCIPLES

The utilisation of environmental isotopes in groundwater evaluation in Malaysia has been made available by MINT since the early 1980's (Ayub and Mohamad, 1990). The term 'environmental isotopes' in hydrogeology is normally used to describe isotopes which exist in water that occur naturally in the hydrological cycle and do not include isotopes introduced into the systems artificially for tracer purposes.

The environmental isotopes commonly used in groundwater studies are tritium (T or ^{3}H) and carbon-14 (^{14}C) which are radioactive and oxygen-18 (^{18}O), deuterium (D or ^{2}H) and carbon-13 (^{13}C) which are non radioactive or stable isotopes. Radioisotopes tritium and carbon-14 are principally used as guides to the age of groundwater (Fontes, 1983). Tritium is also useful in obtaining information on recharge conditions.

Tritium is produced in the atmosphere from two sources namely naturally and man-made. Naturally produced tritium is due to interaction of high energy cosmic radiation with atmosphere gases such as nitrogen, oxygen and argon. Man-made tritium was added to the atmosphere due to thermonuclear tests carried out in the years 1953–

1963, and then smaller amounts continue to be released to the atmosphere from nuclear reactors around the world. Carbon-14 is present in the groundwater principally as bicarbonate ions and to a small extent as dissolved CO_2. It is important in dating the groundwater for up to 50,000 years old.

Stable isotopes undergo no radioactive decay. However, those which are studied exclusively on their own merits (i.e. ^{18}O, ^{2}H) form part of the water molecule and are influenced by changes of H_2O state.

The variations in isotopes abundance in waters may come about through various processes and reasons such as isotopes fractionation of water, evaporation, transpiration, age effect, high temperatures or altitude effects, seasonal variation and contamination or assimilation. As an example, a depletion of stable isotope composition in precipitation is observed with decreasing temperature and hence with increasing latitude, altitude and distance from the sea.

STUDY AREA

Langkawi Island lies about 25 km off the Perlis Coast of Peninsular Malaysia at latitudes between 6°15'N and 6°30'N and longitudes 99°38'E to 99°55'E. The island experiences an equatorial maritime climate. Rainfall is controlled by the movements of the Inter Tropical Convergence Zone and the consequence effect of the south-west and the north-east monsoon. The rainfall pattern exhibits seasonal variation. It occurs mostly in April and November with peak periods in April–May, and December to March is often effectively dry. Langkawi Island rainfall averages about 2,500 mm. Mean daily temperatures vary little from 27°C throughout the year. Relative humidity is high and reflects the seasonal rainfall pattern.

The topography of Langkawi is dominated by the central granite hills and the western block of the Machincang Formation (Jones, 1978). The granite is fringed by undulating low hills of the Singa Formation to the east and south. Limestone hills occur along the eastern coast, the northern part of which consists of small isolated blocks with swampy forest land in between. The Melaka basin in the west of the island is the only significant alluvial plain area.

SAMPLING, FIELD PROCEDURES AND LABORATORY ANALYSIS

Groundwater, river water, sea water and spring water samples were collected from the study sites in five sampling occasions between 1985 and 1989 which cover the dry and wet seasons. Forty four sampling sites were established throughout the island (Fig. 1). Other studies elsewhere in Malaysia indicate that there is no significant effect of seasons on the isotopic composition of the groundwater (Mohamad *et al.*, 1985, and Ayub *et al.*, 1989). These samples were analysed for their tritium, deuterium and ^{18}O. In addition, ^{14}C investigations from seven selected wells were also carried out in the September 1987 sampling campaign.

A rain gauge station was set up at Kuah Hospital. Monthly sampling of rainwater started from November 1985 onwards. About 3 litres of samples were collected each month, and the monthly amount of rainfalls were recorded. These samples were analysed for deuterium, ^{18}O and tritium.

Prior to sampling of well water, a volume of three times the water column was removed (pumped out continuously). Three samples were collected in polyethylene bottles (1 litre) from each site for tritium and chemical analysis. Another two samples were collected in 30 ml glass bottles for deuterium and ^{18}O determinations. Physico-chemical data such as temperature, conductivity, salinity, pH etc. were measured *in situ*.

For ^{14}C analysis, pre-concentration of bicarbonate content was done in the field. The samples collected should be enough for the preparation of 8 g of carbon (extracted quantitatively from the water sample) to get about 5 g of benzene.

Once collected the samples were sent to MINT laboratory for analysis. Tritium was analysed using liquid scintillation counter. Due to the small amount of tritium present naturally, the sample would be enriched by electrolysis before analysis could be performed. ^{18}O and deuterium were analysed by mass-spectrometer. Chemical analysis was performed only on major anions and cations.

RESULT AND DISCUSSION

Precipitation

A depletion of stable isotopes composition in precipitation is observed with increasing amount of monthly precipitation (see Fig. 2). There seams to be a negative correlation between the values of stable isotopes and the amount of precipitation. Their relationships are represented by the respective equations below:

$\delta^{18}O = -0.085$ Amount (mm) $- 4.2288$ and

$\delta^{2}H = -0.0616$ Amount (mm) $- 22.47$

These relationships indicated a depletion of 0.85‰ of ^{18}O and 6.16‰ of ^{2}H per 100 mm rainfall respectively. The two lines are actually made up of two broad zones, both with r^2 0.3. The deviation from the lines are more significant for very high and low amounts of monthly rainfalls. The high

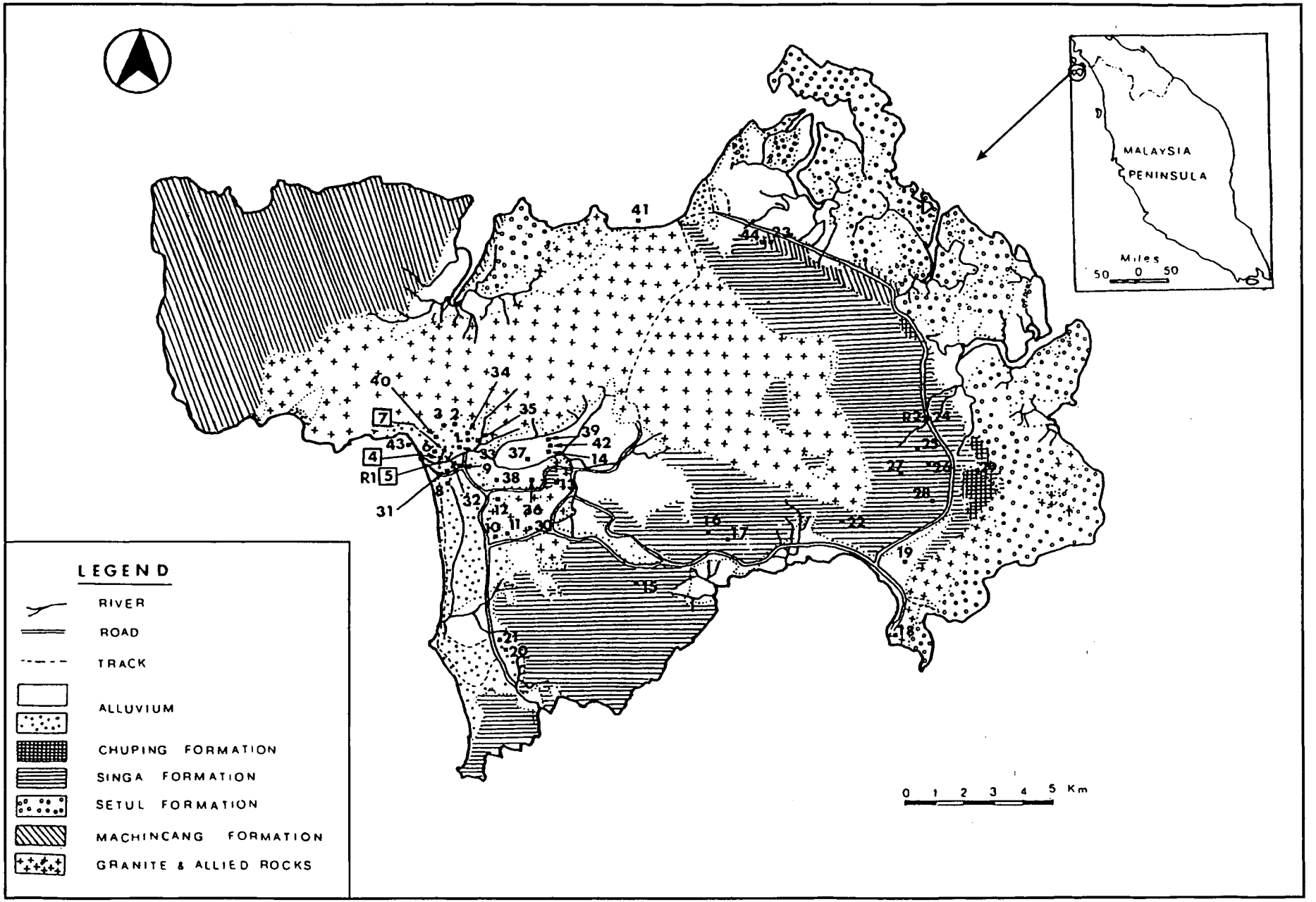

Figure 1. Study area and sampling locations in Langkawi.

amount rainfalls are mostly from the monsoon rains; the north-east monsoon originates from the Artic region and the south-west monsoon which is less significant originates from the Antartic region. These monsoons might give latitude effect into the rainfall regimes of Langkawi which reflects the enrichment of stable isotopes as compared to the amount of precipitation. But we cannot expect these to be due to latitude effect solely because the monsoons while moving towards this region might picked up water vapour above the oceans. The low amount of precipitation comes from the dry months. The source of precipitation during these months are mostly from convection rains. Hence the evaporation effect is greater which is reflected by the depletion of stable isotopes as compared to the precipitation amount.

This strong negative correlation between stable isotopes and monthly rainfall, with heavy rainfall resulting in more negative stable isotopes is termed as the amount effect (Dansgaard, 1964). The amount effect can be explained as due to different amount of removal of water from the atmosphere which cooled during its passage.

Due to various circumstances, the near complete available stable isotope data are restricted to less than three years. The ^{2}H-^{18}O relationship derived on an assumed slope of eight for the entire

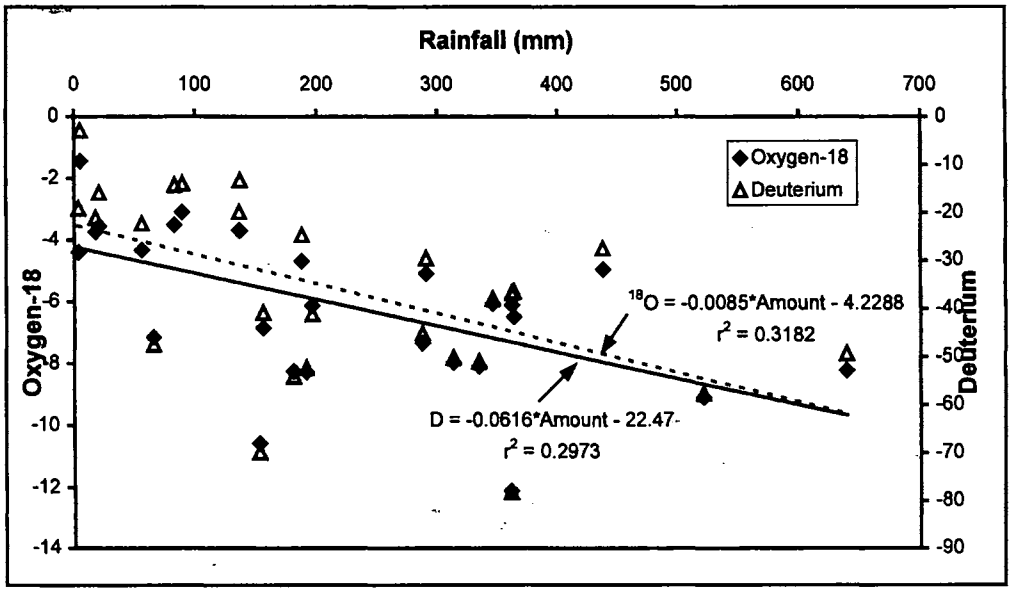

Figure 2. Amount effect on Langkawi precipitation.

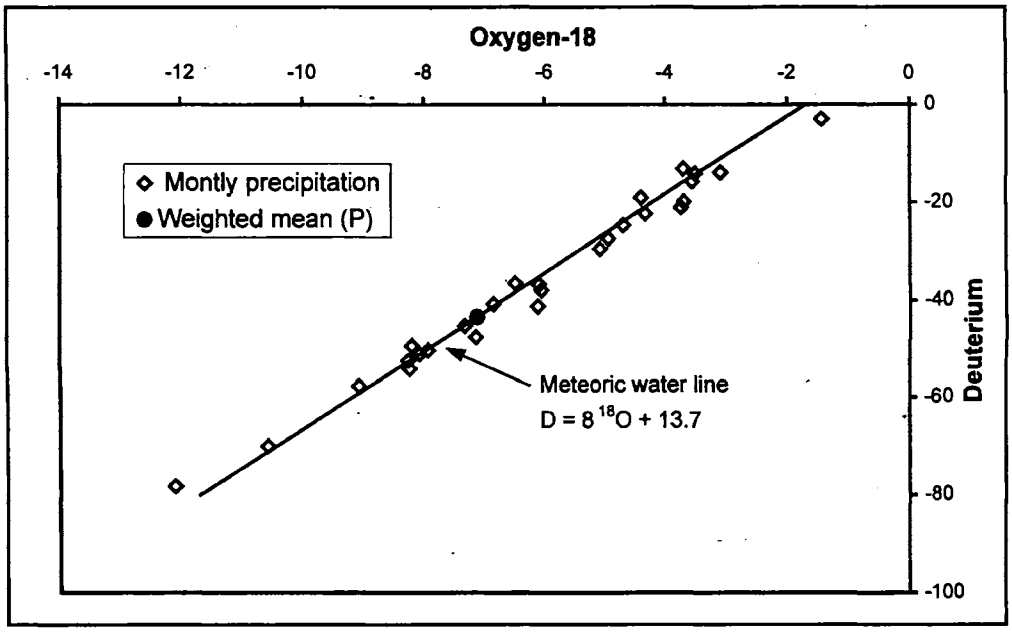

Figure 3. Stable isotopes relationship in Langkawi precipitation.

observation period is:

$$\delta D = 8.\delta^{18}O + 13.7 \text{ (see Fig. 3)}$$

This relationship differs slightly from the Peninsular Malaysian meteoric water line of

$$\delta D = 8.\delta^{18}O + 13.0$$

The difference may be due the insular effect of Langkawi where by evaporation is significantly more compared to the mainland.

The weighted mean values for the entire period are $^{18}O = -7.12$ and $D = -43.4$. This relationship is adopted for the local meteoric water line to which the data from the study area will be referred to. All the observed values for monthly precipitation scattered along this line (see Fig. 3).

For tritium, only 20 samples were analysed, with a mean value of 5.46 TU. The weighted mean values for 1987 and 1988 were 7.13 TU and 3.81 TU respectively. Tritium varies within 3.3 to 12.3 TU, with maximum concentration in July 1987 (12.3 TU) and minimum concentration in December 1987 (3.3 TU). 1988 exhibited monotonous tritium content ranging from 3.5 to 4.8 TU. It is unfortunate that no data for tritium was available for the very dry months (January to February except for February 1988) period. The concentration of tritium was generally low because of the strong dilution by the oceanic water vapour. The tritium seems to be reaching the pre-bomb test period (5–10 TU) and of non significant for valuable interpretation.

Groundwater, River, Hot Spring and Sea Water

The stable isotope plot of Langkawi waters is shown in Figure 4. As discussed earlier, the rain water has a weighted mean of –7.12 for ^{18}O and –43.4 for ^{2}H. All the ground water as well as the river water display slight enrichment of ^{18}O and ^{2}H with reference to the rain water but not very significant. Considering the groundwater is recharged by the local precipitation, the trend could be explained that while infiltrating the soil and the aerated zones the water experience slight evaporation and as a result the descending water got slightly enriched in the heavy isotopes.

Tritium in the wells vary between very low (< 1 TU) and to about 6–7 TU with not much time variations. The tritium has no distinct pattern of variations with depth. Any value can be found at all depths, mostly due to mixing in the wells, since most of the wells have perforations at both upper alluvium and lower Singa limestone.

From few wells available that tap only either from the upper alluvium or lower limestone, the low tritium values are found in the alluvium and high values (4–6 TU) found in the limestone. Typical example is well 29 tapping only from the limestone and having tritium value comparable to very recent values. This indicated that the circulation and groundwater movement in the lower limestone aquifers are relatively faster, and being replenished at higher rate than the shallow alluvium aquifer. Since majority of the wells have perforations at both levels of upper alluvium and lower limestone, the tritium and the chemical characteristics of the wells are a rather result of mixing in the wells, and do not allow detailed evaluations for each aquifer system separately.

The monthly rainwater determination as discussed earlier indicated variation in the isotopes content. But the response from the groundwater to

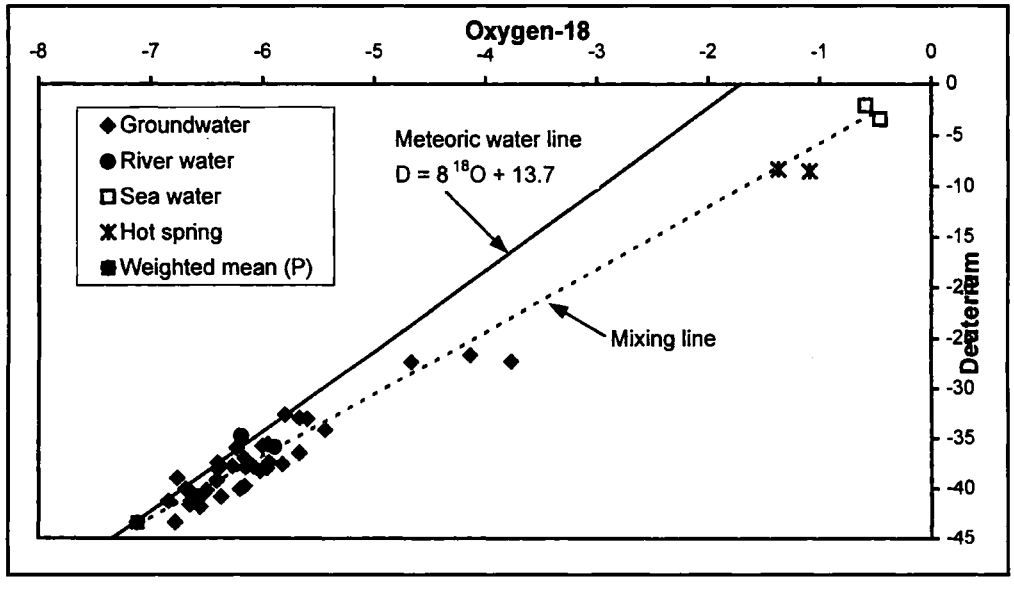

Figure 4. Plot of deuterium vs ^{18}O for Langkawi water (average).

this variation is negligible, i.e. the stable isotopes values in the groundwater do not change significantly throughout the entire period of investigation. The mean value of ^{18}O in the groundwater was about 6.5‰. Modelling (Yurtsever, 1983) with stable isotopes and tritium have given two turn over times of the area. Figure 5 revealed that the global minimum turnover time for groundwater in Langkawi is eight to ten months. This is related to the minimum reserve of the groundwater at the then rate of pumping. The reserve can be estimated if water balance study was undertaken.

A similar model on tritium (not shown), indicated a turnover time of between 50 to 200 years. This reflects that the groundwater reserve was extremely large. But this should be treated cautiously, because of lately, there is big disparity of tritium in the environment. The tritium content in the present rain is almost back to the pre-bomb

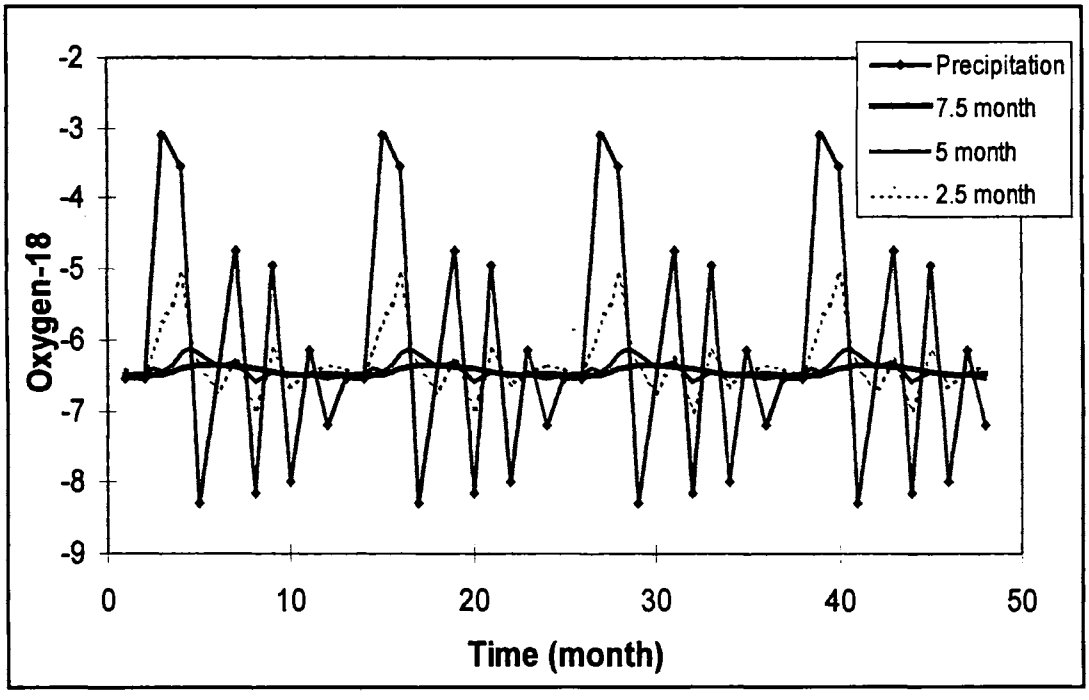

Figure 5. Turn over time of Pulau Langkawi based oxygen-18.

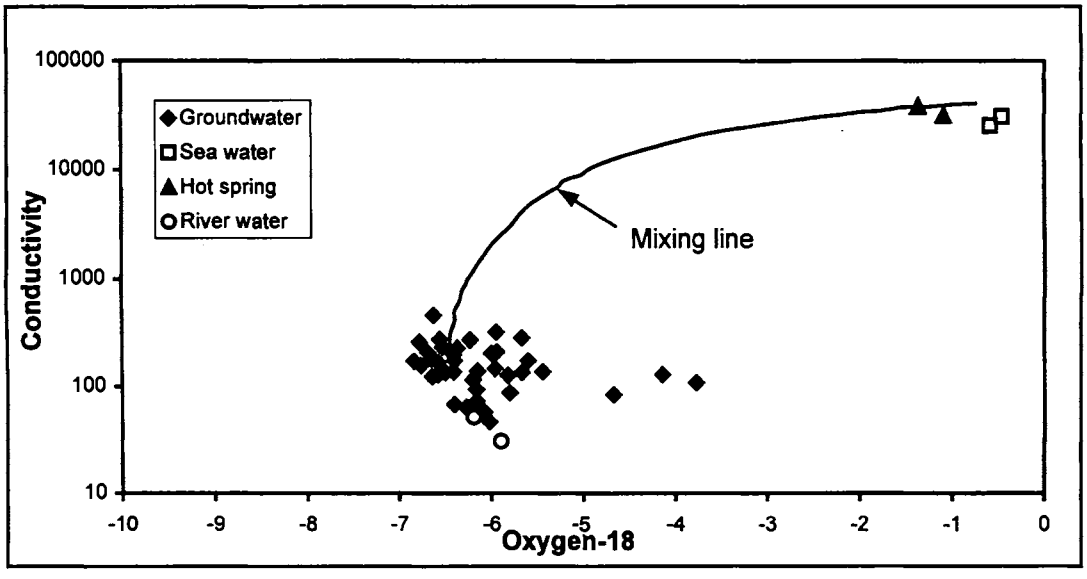

Figure 6. Plot of conductivity vs oxygen-18.

test, thus the interpretation is no longer accurate.

Based on the combination of stable isotope and physico-chemical data, the recharge of the wells in the area is of local rainfall (see Fig. 6). But those wells close to the rivers do indicated mixing with the river water to a some extent. Some of the water have undergone evaporation. The hot springs at Air Hangat indicated the result of mixing between sea water and the upcoming fresh water before being emplaced at the site (see Fig. 6). It can be concluded that there was no intrusion of sea water into the fresh water aquifer then. The slightly higher conductivity/chloride content at certain sites was due to local effect for example evaporation.

CONCLUSION

This study indicated that the groundwater of Langkawi Island is recharged by local rainfall and the minimum turnover time is between eight to ten months. There is no sea water intrusion into the freshwater aquifers but the hot springs had shown the mixing effect where as some of the wells in proximity to the rivers had indicated mixing with the river water.

In some areas the groundwater cycle in the Singa Formation is faster than the upper alluvium. It (Singa Formation) is also replenished at a faster rate than the alluvium. For the production of more and continuous supply of water, the aquifer in the Singa Formation is more important and should be emphasised.

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