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Fracture pattern and its relationship to groundwater in hardrocks of Negeri Sembilan

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Abstract: Granite and metamorphic rocks in Negeri Sembilan and in other parts of Peninsular Malaysia have been considered to be of poor aquifer. The hydrogeologic map of the Malay Peninsula, 1975, shows the area underlain by the hard rocks as having poor to moderate potential for groundwater production (< 230 m^3/well/day).

This paper presents a new finding about productive hard rock aquifers in Negeri Sembilan. Data from tubewell drillings in the past four years were analyzed. The drillings for groundwater were carried out mostly to meet the growing industrial water demand in the state. It was found that the hard rocks could yield fresh water more than 300 m^3/well/day. Discharge rates up to 890 m^3/well/day, 408 m^3/well/day, 590 m^3/well/day, 545 m^3/well/day and 960 m^3/well/day were found in Seremban, Kuala Pilah, Lenggeng, Tampin and Rembau respectively. The wells were between 50 m and 200 m deep.

High discharge rates of groundwater above 300 m^3/well/day were encountered from wells that penetrate major fracture zones. Both the granite and metamorphic rocks are generally fractured at various depths. Groundwater in interconnected fractures has a steady flow that sustained production during pumping tests and actual usage of the wells. This phenomenon indicates that the groundwater is being recharged by infiltration of rainwater through the overlying weathered rocks and soils. Tubewells in hardrocks of Sungai Gadut, Kuala Pilah and Tampin areas were found to have average discharge rates of 650 m^3/well/day, 408 m^3/well/day and 500 m^3/well/day respectively. Shallow tubewells in Tampin, of less than 50 m deep, penetrated only weathered granite, are generally non-productive (< 70 m^3/well/day). Limited fracture openings at shallow depth and restricted recharge areas are likely to be the reason for the low discharge.

The fracture patterns inside the wells could not be ascertained although it was assumed that the patterns follow the major regional N-S and NW-SE structural trend of the Main Range Granite. Topographic features and lineaments of the valleys and ridges were used for locating productive sites. About 90% deep tubewell drilling (100 to 200 m) in granitic areas of Sungai Gadut, Tampin and Kuala Pilah was successful in obtaining discharge rates of more than 100 m^3/well/day. In contrast, only 30% success rate was obtained from drilling in metamorphic rocks of Linggi area. Clay particles in fractures was observed to be the factor for the low success rate and poor quality of the water.

INTRODUCTION

Negeri Sembilan is one of the states in Malaysia that practically has no alluvial sand or gravel aquifers on its coastal areas. Most of the land is undulating to hilly ground underlain by metasedimentary rocks or granite (Wodeyar and Marihal, 1990). Groundwater potential from the hardrocks has been considered as poor to moderate with yield generally less than 200 m^3/well/day (Geological Survey Malaysia, 1975). Only very limited area, about 20% of the total area, was classified as capable of producing water between 200 m^3/well/day and 400 m^3/well/day. As water demand in the state increases due to population growth and opening up of new industrial areas, groundwater has become more and more an attractive alternative water source especially for industrial uses.

This paper presents the findings of tubewell drillings in hardrocks in the state of Negeri Sembilan. It discusses the availability of groundwater and the importance of fracture zones as water sources in the tubewells.

MATERIALS AND METHODS

A total of 61 tubewells in Negeri Sembilan was analyzed in terms of their location, well logs, yield, depth, water quality and sources of water through fracture zones. The locations of the wells, as shown in Figure 1, are situated on hardrocks consisting of granite, schist, gneiss, volcanic tuff and sedimentary rocks (Fig. 2).

Drilling and tubewell construction

The drilling for the tubewell started with 355 mm diameter borehole, by rotary direct circulation

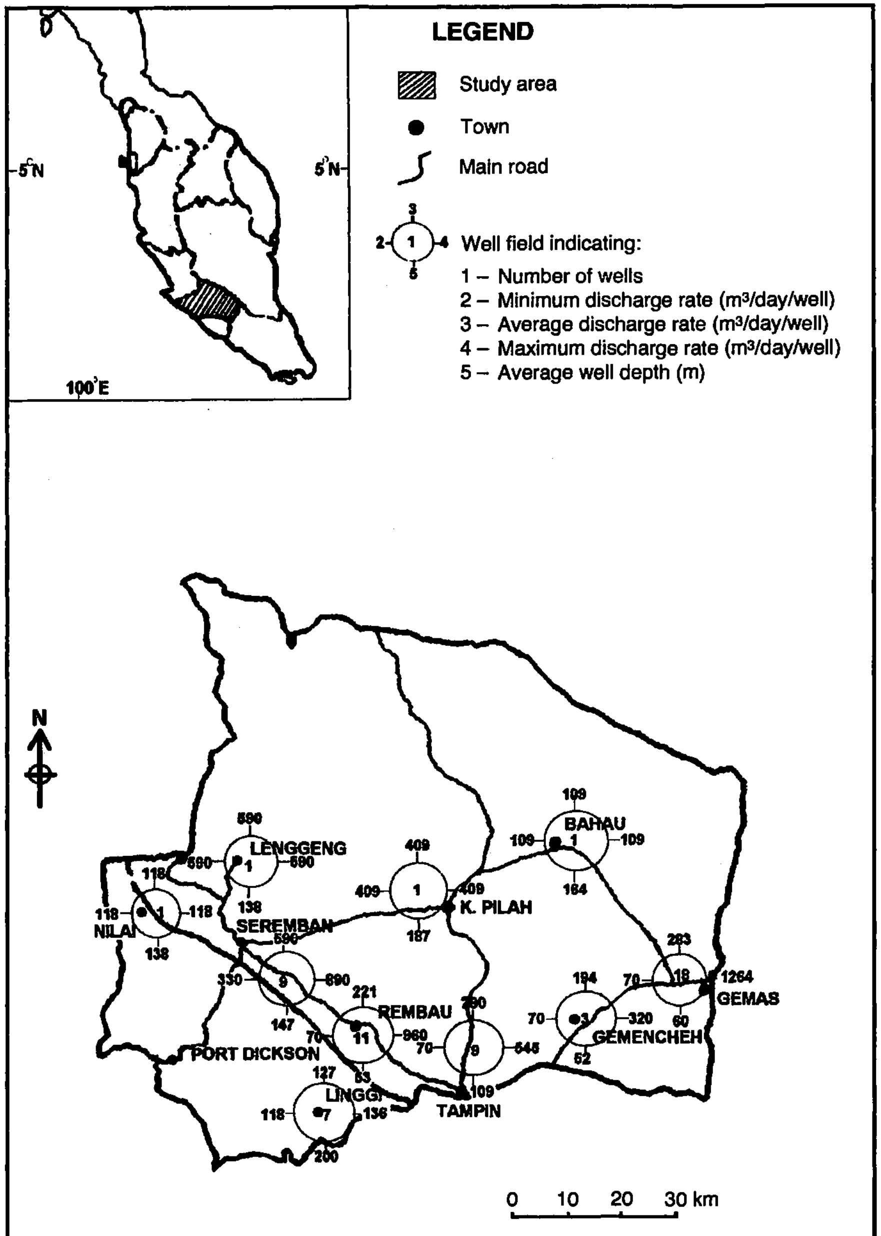

Figure 1. Location of the study area.

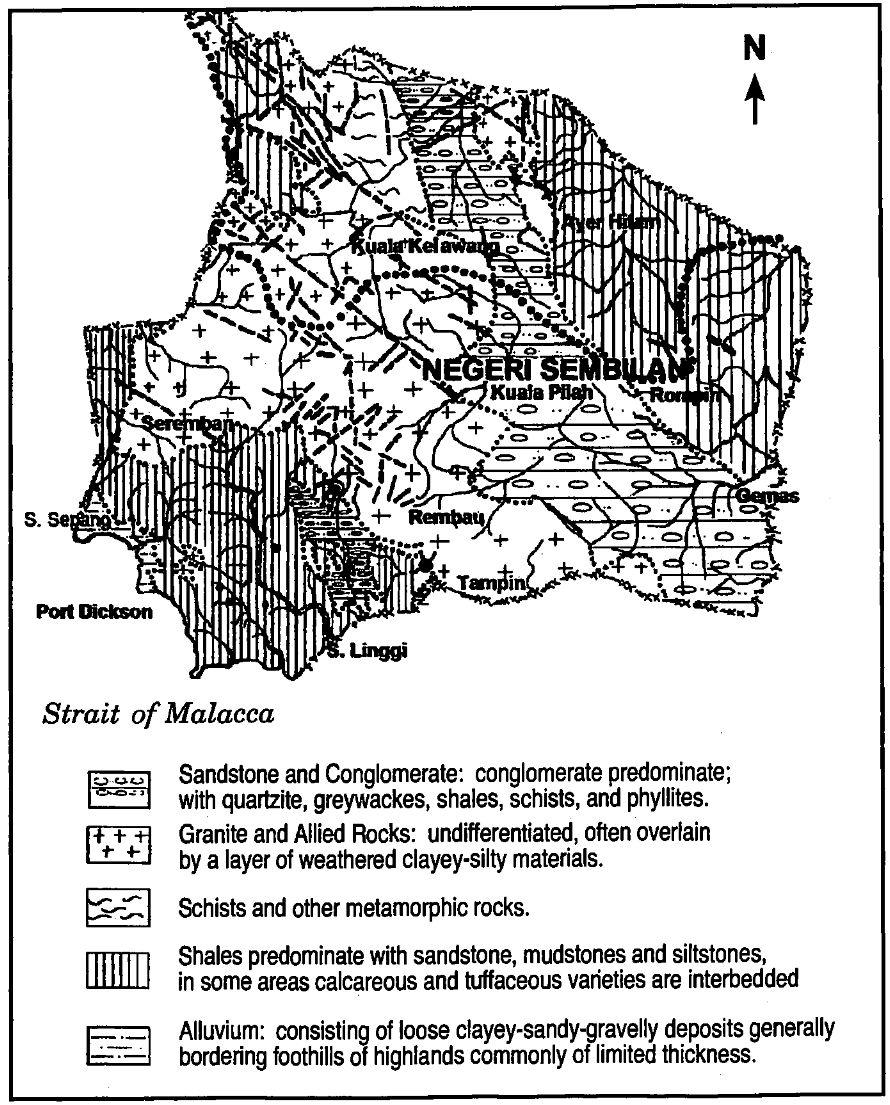

Figure 2. Geology of the study area.

using bentonite mud or polymer through residual soil until it reached a medium hard rock. The thickness of the residual soil and weathered layer varies from about 20 m to 40 m. Galvanized iron (GI) casings of 203 mm diameter were installed immediately after the borehole was constructed to prevent soil collapse. Further drillings in the medium hard rocks were done by using an air-percussion rotary method. The size of the borehole in this section of the well was 200 mm and it reached about 100 m depth. Below this depth, in fresh and hardrocks, air foam rotary drilling method was employed to a maximum of about 200 m. The foam facilitated the removal of rock chips from the bottom of the borehole. The size of the borehole in the hard rock was 150 mm. All tubewells were provided with internal casing of 150 mm PVC pipes and screen at the entire section in the residual soil and medium hard rock. The outside of the screen was packed with coarse river sand and granule.

Analysis on the texture of the packing material indicated a mixture of grain sizes containing 15% of 1.00 mm to 2.00 mm coarse sand, 60% of 2.00 mm to 4.76 mm granules and 25% of 4.76 to 6.35 mm coarse granules/gravel. After placement of the packing material, the annular space above the gravel was grouted with concrete made up of a mixture of cement and sand at 1:3 ratio. This method of well construction ensures abstraction of groundwater directly from medium hard and hard rock without contamination of surface water.

Estimation of Optimum Discharge

Optimum discharge of the tubewells was determined from pumping tests. Two methods of pumping test were used, one by pumping at constant discharge rate over 10 hour period, and the other by pumping at 4 steps drawdown over 90 minutes for each step. The pumping rates were progressively increased from one step to the subsequent step at approximately equal increments. Should there be no limitation of pump capacity, the rate for the final step could be considered to be nearly equal to the highest discharge rate of the tubewell. Data from the pumping tests were used to evaluate the properties of aquifers.

Water Quality Determination

Water samples were collected at the end of the pumping tests i.e. after more than 12 hours of pumping. This was to ensure that the samples represent fresh groundwater from the rock aquifer. The parameters to indicate the groundwater quality include pH, electrical conductivity, total dissolved solids, color, turbidity, major cations and anions and metal contents. Color, pH, conductivity and turbidity were measured *in-situ*. While the other parameters were determined in laboratory after sample collection and preservation according to USEPA, 1979. Analyses on the characteristics of groundwater were made based on 14 selected tubewells: 7 from granitic aquifers and another 7 from metasedimentary aquifers. The water samples taken from the granitic aquifers include samples from two tubewells in Kota (KTC-1 and KTC-2), four tubewells in Rembau-Tampin-Gemas Area (RTG-40, RTG-41, RTG-42 and RTG-58) and one tubewell in Kuala Pilah (SFI-1). The water samples from metasedimentary aquifers were from seven tubewells located in Sungai Gadut, Seremban (SC-2, SC-3, SC-4, SED-1, SED-2, SED-3, SED-4).

Source of Water

The sources of water in the tubewells were identified by a sudden increase in discharge rate of water during drilling operation. The increase in discharge was commonly associated with penetration of the tubewells through fracture zones. The depths of the fracture zones below ground level were recorded. Fracture orientations found in rock outcrops in the surrounding area were measured in the field. The fracture patterns were analyzed by plotting the poles of the fracture planes on the stereographic net.

RESULTS AND DISCUSSION

Groundwater was found in different types of hard rocks all over the state of Negeri Sembilan (Table 1 and Table 2). The highest discharge rate from the metasedimentary rock aquifer was 960 m^3/well/day. This was found from a fractured schist in Rembau although in Linggi the old schist is relatively very poor aquifer. The highest production from Linggi was only 136 m^3/well/day. The sedimentary aquifer in Tampin-Gemas area which has volcanic tuff intercalation was found to be capable of producing water to a maximum of 1,264 m^3/well/day (Geological Survey Malaysia, 1987). This was the highest discharge rate recorded by the Department from a tubewell in the state so far. The volcanic rock is likely to be more fractured than the other rock types. Recharge rate into the aquifer is also likely to be significantly high.

Information obtained during the drilling and pumping tests is summarized in Table 1.

The lithology that was penetrated by the wells can be classified into three types as shown in Table 2.

The discharge rate of the tubewells in Negeri Sembilan was generally higher than the rate of hardrocks aquifer in India by Limaye, 1987 and in Ghana by Quist, 1987 (Table 3). High rainfall intensity and thick weathered zone in Malaysia were likely to be the reasons for the high discharge rate.

Table 1. Location of the well fields, well depth and discharge rate.

Location (No. of wells)	Average Depth (m)	Average Discharge Rate/well (m^3/day)	Maximum Discharge Rate/well (m^3/day)	Minimum Discharge Rate/well (m^3/day)	Number of Dry Wells (< 70 m^3/day)
Seremban (9)	147	590	890	330	0
Kuala Pilah (1)	186	408	408	408	0
Nilai (1)	138	118	118	118	0
Lenggeng (1)	138	590	590	590	0
Tampin (9)	109	290	545	70	3
Linggi (7)	200	127	136	4.5	5
Bahau (1)	164	109	109	109	0
Gemas (18)	60	283	1264	70	6
Rembau (11)	52	221	960	70	2
Gemencheh (3)	52	194	320	70	0

Table 2. Discharge rate (m^3/well/day) from different hard rock aquifers.

Lithology	No. of wells	Discharge rate (m^3/day)	
		Max.	Min.
Metasedimentary rocks (phyllite, schist, marble, gneiss)	32	960	4.5
Sedimentary rock with volcanic intercalation (shale and tuff)	16	1,264	48
Granite	13	650	25

Table 3. Rate of groundwater yield from tubewell in hard rocks.

Researcher (year)	Source of Groundwater	Average Rainfall mm/year	Discharge Rate m^3/well/day
Limaye (1987)	max 100 m depth tubewells in hard rock terrain in India	750	max = 360 min = 24
Quist (1987)	max 90 m depth tubewells in fractured Precambrian basement complex in Ghana	900	max = 648 min = 96
This study*	max 200 m depth tubewells in fractured metasedimentary rocks and granite	2,000	max = 1264 mean = 297

* Tubewell with yield < 70 m^3/day was not counted.

The water facies from the metasedimentary aquifers were found to be of calcium-magnesium-sodium-bicarbonate type. The water is fresh with an average TDS of 111 mg/l and soft to slightly moderate hard with total hardness ranging from 52 mg/l to 97 mg/l. The average iron content of the water from metasedimentary aquifers was 5.09 mg/l. This is relatively a high value considering the WHO drinking water quality standard of 0.3 mg/l.

Granite in Negeri Sembilan was also found to be capable of producing groundwater with discharge up to 650 m^3/well/day. This rate of production was found in Kota area. Boreholes that do not penetrate fracture zone, practically were dry holes. However deep boreholes were found to be having more chances of hitting fracture zones. An example of such deep well was the well in Kuala Pilah where the borehole was practically dry until when it penetrated a fracture zone at 135 to 172 m below ground level. The fracture zone provided water to the tubewell with an average discharge of about 400 m^3/day.

The water from granitic aquifers can be classified as fresh with an average TDS around 170 mg/l and neutral pH of about 7.2. The hardness of the water ranged from 43 mg/l to 152 mg/l indicating soft to hard quality. The average iron content of the water was 0.98 mg/l. This is lower than the iron content in groundwater of the metasedimentary aquifers, although it was still higher than the WHN Ñrinking water quality standard of 0.3 mg/l. From the Piper Diagram, the water can be classified as calcium-sodium-bicarbonate water (Fig. 4).

Fracture patterns and lineaments

The hardrocks in Negeri Sembilan have undergone brittle deformation phases which resulted in jointing and faulting of the rocks. The pattern of the fracture planes in three locations namely Mantin, Kuala Pilah and Tampin areas are indicated in Figure 3. There is a close relationship between the fracture pattern of the rocks and the lineaments of the stream. There are four major rivers in the state of Negeri Sembilan namely Sg. Linggi, Sg. Gemencheh, Sg. Serting and Sg. Pertang. The flow directions of the rivers are strongly influenced by the structure of the underlying rocks. Sg. Linggi, the biggest river in the state, is flowing in N-S direction with tributaries in NW-SE and NE-SW directions. Sg. Gemencheh which is located in the eastern part of the state is flowing from West to East with tributaries flowing from NW to SE, SW to NE and South to North. One important point to note is that the tributaries that are flowing from south to north join the main river at almost 90° angle thus making an angular river system. In the northern part of the state, Sg. Serting and Sg.

Pertang are strongly influenced by NW-SE and NE-SW fracture patterns although both of the rivers have general flow direction from south to north.

The analyses on fracture patterns of the hardrocks indicate that there is a strong relationship between the fracture lines and the flow direction of the rivers. Groundwater in hardrocks is mostly present in fracture openings and in the weathered part of the rocks (Quist, 1987). In the state of Negeri Sembilan, the water bearing fractures is likely to be the N-S, NE-SW and NE-SW fractured zones. Weathering profile of the hardrocks was found to vary between a few meters in ridge areas to about 25 meters in sloping ground. However, the profile is very thin or totally absent in river beds to hilly areas. This was observed in the river of Hulu Bendul area, which is located near the water divide between Seremban and Kuala Pilah. This phenomenon indicates that there is a direct connection between the water in the river and the groundwater in the hardrocks. Groundwater recharge through river beds was found to be an important phenomenon during high flow. During low flow, discharge of groundwater from the hardrocks into the river takes place through the fracture openings. The river could therefore sustain its flow even during dry periods.

CONCLUSION

Groundwater in Negeri Sembilan are mostly present in hardrocks aquifers. The availability of the water is influenced by fracture openings, fault zones and in the weathering profile of the rocks. Drilling of tubewells up to 200 m below ground in Gemas, Rembau and Seremban was capable of penetrating water bearing fractures that can sustain yield up to 1264 m^3/well/day, 960 m^3/well/day and 650 m^3/well/day respectively. Shallow wells of less than 50 m that do not penetrate fractures in the hardrocks were mostly non productive with yield mainly less than 70 m^3/well/day. Groundwater recharge into the hardrocks varies considerably from place to place depending on the type and

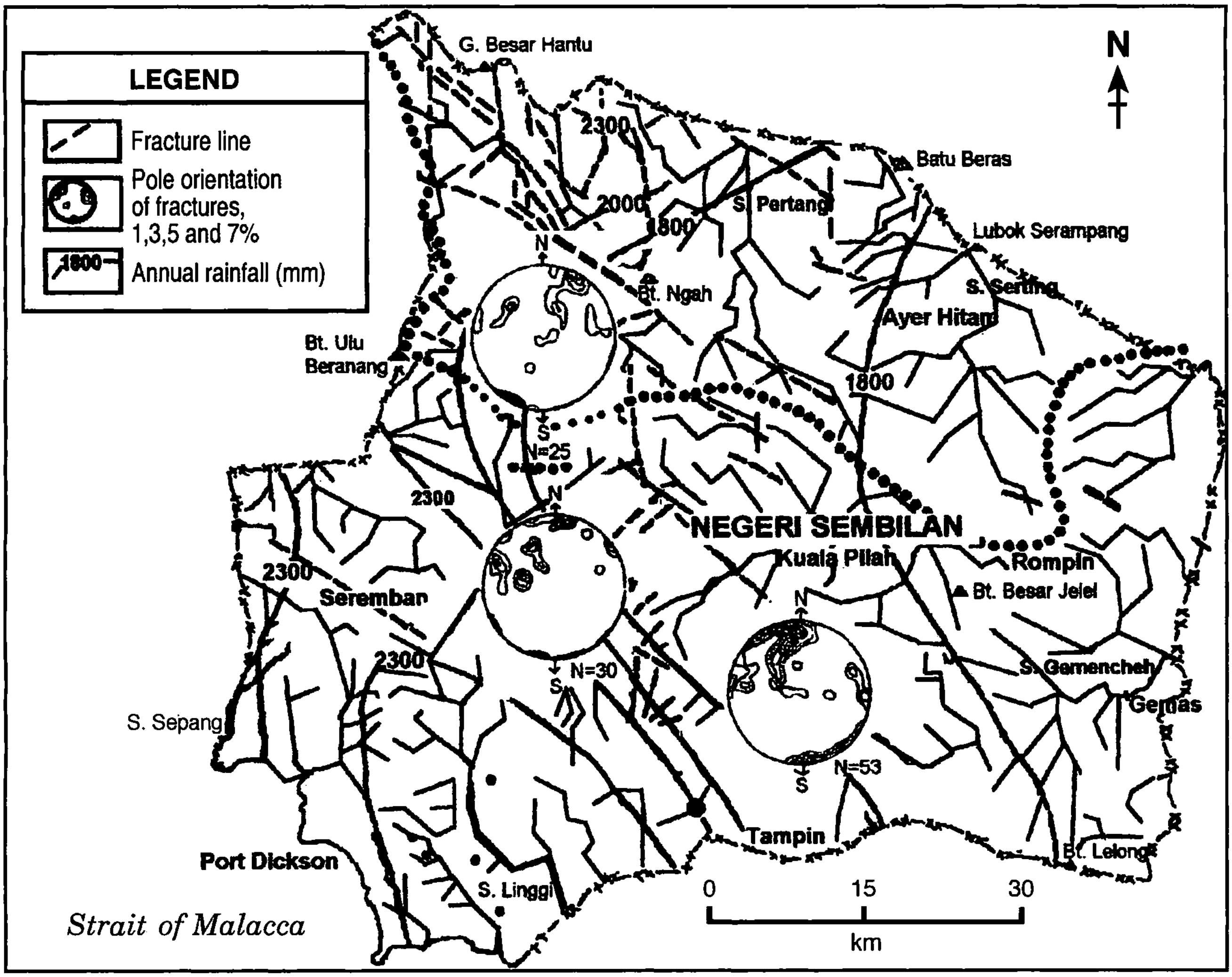

Figure 3. Fracture pattern, lineaments and annual rainfall intensity of the study area.

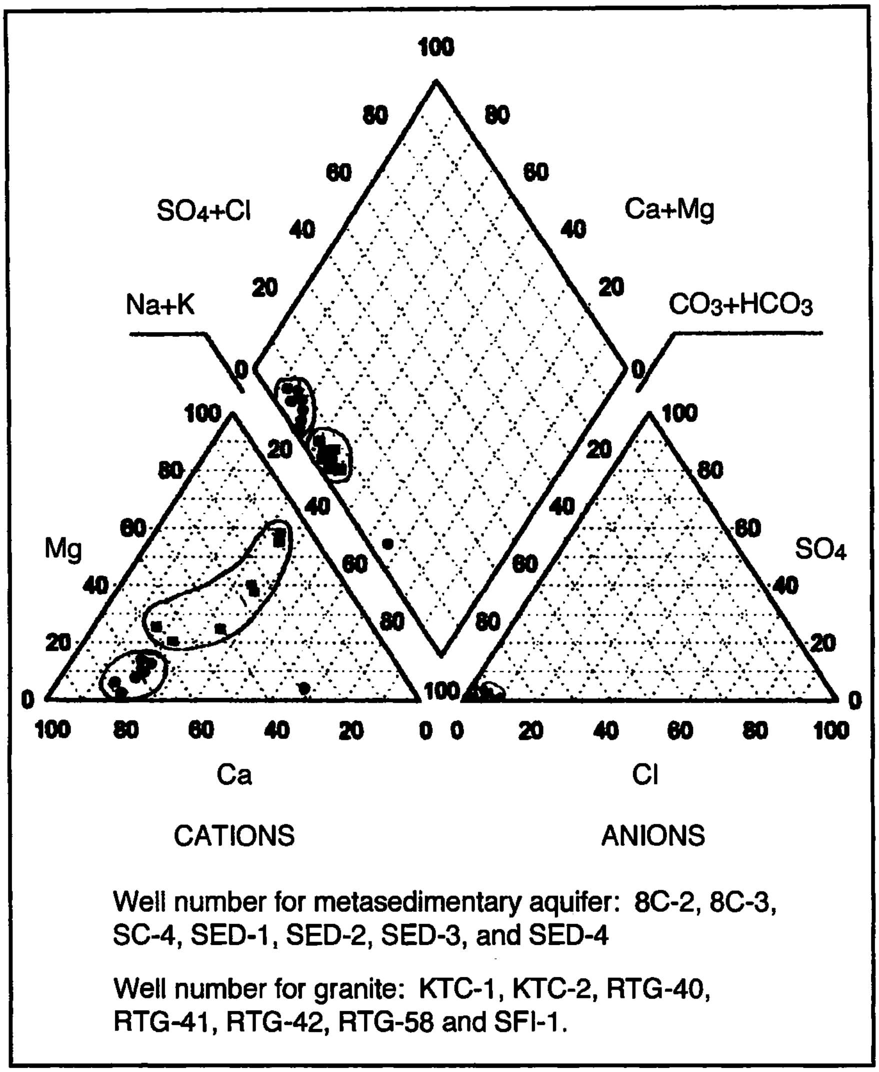

Figure 4. Piper diagram indicating major ions in water from the metasedimentary aquifer (n) and fractured granite (•) of Negeri Sembilan.

thickness of the soil. Significant amount of the recharge takes place through river bed infiltration via fracture openings exposed at the river.

Three major fracture orientations are related to the main rivers in Negeri Sembilan. Fracture zones in N-S, NW-SE and NE-SW directions are the most potential areas for groundwater production. The fracture pattern is following the regional structural trend of the Main Range Granite.

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