General geology and groundwater quality analysis of domestic wells around Kampung Panglima Bayu, Tanah Merah District, Kelantan, Malaysia.

Heeralena A/P Arul Patrick[1], *Hafzan Eva* Mansor[1], *Mohammad Muqtada Ali* Khan[1*] *and Zameer Ahmad* Shah[2]

[1]Water Resources and Groundwater Management (WRGM) Research Group, Faculty of Earth Science, Universiti Malaysia Kelantan, 17600 Jeli, Kelantan, Malaysia
[2]Department of Geology, Aligarh Muslim University, 202002, India

Abstract. The current research project focuses on geological mapping and groundwater quality analysis of domestic wells in and around Kampung Panglima Bayu, in Tanah Merah district, Kelantan. The objective of this research is to produce an updated geological map of the study area at a scale of 1:25000 and to conduct groundwater quality analysis in the research region. Groundwater samples were obtained from 12 domestic wells for the analysis of physicochemical parameters. Temperature, pH, electrical conductivity, turbidity, and total dissolved solids were measured using a multiparameter and turbidity meter on site. Atomic Absorption Spectroscopy (AAS) was used to analyse major trace elements such as potassium, sodium, calcium, magnesium, iron, and manganese, while the titration method was used to analyse bicarbonate and chloride. While spectrophotometer methods were used to analyse fluoride, sulphate, and nitrate. Based on the data analysis of the geology of Kampung Panglima Bayu, three rock units can be found: granite is the most common kind of rock detected in the research region, followed by schist and alluvium. Furthermore, the geomorphology of the study area revealed elevation differences consisting of low land to high hills. The petrographic analysis revealed principle minerals like quartz, alkali feldspar, plagioclase and biotite with the granitic rocks identified as 'biotite granite porphyry' due to the high amount of biotite mineral present in the thin section. In addition, the results of our analysis for groundwater quality were compared to World Health Organization (WHO) and Ministry of Health Malaysia (MoHM) standards values. It was observed that 7 of the 12 wells were contaminated because the pH values were below the normal level. Turbidity was high in wells 4, 5, and 11, and sodium ion levels surpassed the standard allowable limit in well 11.

---

[*] Corresponding author: muqtada@umk.edu.my

1 Introduction

Geological mapping is a scientific method used to produce maps depicting various aspects of geology, including groundwater quality and pollution hazards [1]. Understanding the geology of Tanah Merah is crucial due to the constant changes caused by development activities and geological processes such as folding, fracturing, and faulting. Groundwater is a vital natural resource globally, and in Malaysia, less than 10% of groundwater was used for drinking purposes, with Kelantan being one of the states relying heavily on groundwater [2]. In Kelantan, approximately 70% of the water supply in Kota Bharu and neighboring areas comes from groundwater sources [3]. In northern Kelantan, village residents predominantly rely on groundwater extracted from shallow aquifers, such as hand-dug home wells and conventional wells less than 10 meters deep, for essential domestic, industrial, and agricultural needs [3]. Thus, protecting this essential resource from pollution is crucial since it serves as the community's main water source.

Development activities in the area, such as road connections, industrial activities, and plantations (rubber and oil palm), have caused changes in the Earth's surface that have not been adequately mapped on a small scale, incorporating all aspects of geological knowledge [4]. On the other hand, groundwater contamination is a potential concern resulting from both human activities, such as sewage system usage, and geogenic factors, alongside the significant role of rainfall in groundwater quality, as it dissolves atmospheric pollutants, ultimately causing acidic rain that contributes to contamination and increased acidity [5]. This is highlighted by the analysis of rainfall data from January to December 2020, indicating the pronounced influence of the monsoon season, spanning from October to March, which significantly impacts the region with intense precipitation and frequent flood monitoring [6]. Lack of attention to groundwater management and quality can lead to health problems for those using contaminated groundwater [7]. Therefore, the research aims to address several objectives, including producing an updated geological map of the study area at a scale of 1:25000, and conducting groundwater quality analysis of domestic wells.

2 Materials and Methods

2.1 Study Area

The study area at a scale of 1:25000 is surrounded by 9 other villages. As seen in Figure 1, Kampung Panglima Bayu is a 25km2 sub-district in Tanah Merah, Kelantan, with latitudes ranging from 05° 47’ 30.00”N to 05° 50’ 20.00”N and longitudes ranging from 101° 56’ 20.00”N to 101° 59’00.00”N. The land is primarily used for plantations, with rubber and oil palm being the most prevalent crops [4]. The area is also well connected by road networks, with the East-West Federal Highway and the Pasir Mas-Tanah Merah Street providing access to the research location [4].

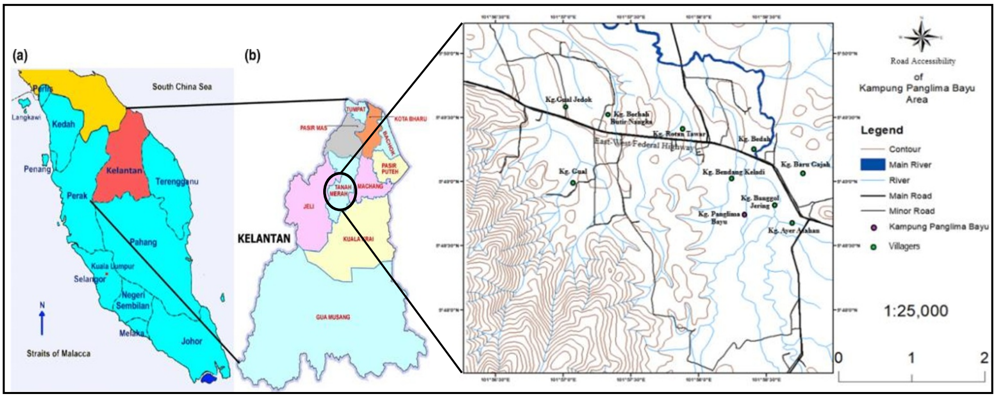

Fig. 1. a) Map of Kelantan, b) Map of Tanah Merah District and c) Base Map near Kampung Panglima Bayu Area

2.2 Methodology

The research began with preliminary studies that involved reviewing previous studies on groundwater quality and understanding the geological characteristics of the study area. Field studies were then conducted, including geological mapping and groundwater analysis, with the support of secondary data. The geological mapping involved observing and documenting various features and measurements in the field using equipment like GPS, hammer, hydrochloric acid, etc. Groundwater sampling was performed using in situ analysis techniques, and the collected samples were preserved with aluminum foil, icebox, and polyethylene bottles for laboratory analysis.

The Water Quality Index (WQI) was calculated to evaluate the overall water quality and assess groundwater sensitivity to contamination. Microsoft Excel was utilized to create graphs and charts for data interpretation. The Piper Trilinear Diagram was plotted to determine the water facies type based on the composition of cations and anions. Lastly, Surfer 16 software was employed to create 2D and 3D graphics that depicted the factors used to assess groundwater vulnerability to pollution.

Overall, the research involved a comprehensive approach, combining field studies, laboratory work, data analysis, and the use of various software tools to gain insights into groundwater quality and geological characteristics of the study area.

3 Results and Discussion

3.1 General Geology

The study area's general geology is diverse, with a range of geomorphological features, from low-lying areas to elevated hills (60-780 meters), displaying three weathering processes (physical, biological, and chemical) indicating a dynamic geological environment impacting landscape and soil profiles over time. The drainage patterns (dendritic, parallel, and rectangular) suggest a complex history involving erosion, tectonic forces, and landform development, with three significant fault lines shaping the geological history. Moreover, a predominant trend lineament from Northeast to Southwest indicates essential tectonic influences on the current geological configuration.

The study area's geological map in Figure 2, reveals three rock units—schist, granite, and alluvium—each associated with a distinct age. Schist, known as Taku Schist, stretches north-south in the northwest, injecting into the granite and forming extensive schist enclaves. It's suggested to be of Permo-Triassic period, characterized by a light grey, foliated texture with coarse grains, influenced by the Taku River [8]. Among these rock types, granite predominates, covering most of the region; it's Cretaceous age, forming the Kemahang granite [9]. This significant granitic batholith near the Thai border reflects an intrusive magmatic formation shaped by solidification, tectonic forces, and contact metamorphism. Extending into southern Thailand as the Buke pluton within the Taku Schist body, the Kemahang Granite encompasses diverse granitic rocks, including the notable Cataclastic porphyritic biotite granite with medium-to-coarse-grained, grey composition rich in biotite, silica, and prominent feldspar phenocrysts/megacrysts, showing distinctive lineation in specific areas [10]. Lastly, alluvium, deposited in the Quaternary period, is present in flat areas near stream channels, comprising poorly sorted sands, gravels, and boulders, with finer particles settling on larger ones, creating well-sorted deposits resulting from earlier weathering and erosion, transported downstream by river flows [9].

Furthermore, a comprehensive petrographic analysis was conducted on six samples, indicating essential details about their composition, with a particular emphasis on major minerals such as quartz, K-feldspar, plagioclase, biotite, and additional minerals, collectively signifying an acidic composition, and leading to their classification as acid intrusive igneous rock due to consistent physical properties and distinctive petrographic characteristics. The collected igneous samples from outcrops 1, 2, 3, 4, and 6 are grouped together as they fall within the main group of the granite column, as indicated by the plotted points in Figure 3. This classification is based on the mineral constituents of feldspar, quartz, and biotite. Quartz is the most abundant mineral found in the granite samples, followed by alkali feldspar, which is present in all samples. During the examination of outcrop 6, the Kemahang granite body was identified as a batholitic feature that comes into contact with the Taku Schists. From these investigations, the granite rocks of Kampung Panglima Bayu, primarily composed of the Kemahang Granite, can be classified as "biotite granite porphyry," reflecting the significant presence of biotite minerals observed in the hand specimens, aligning with the earlier study [10].

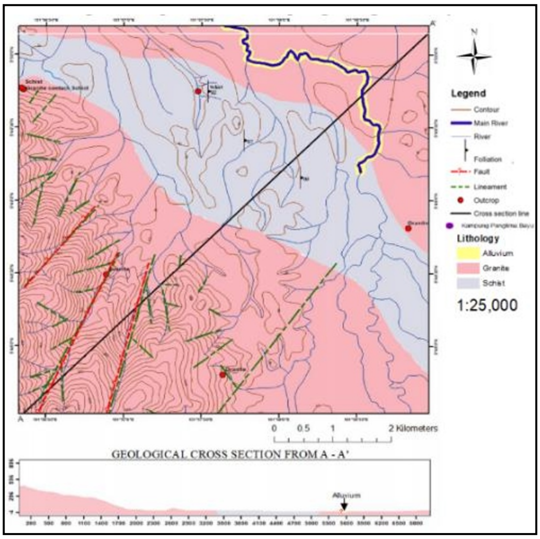

Fig. 2. Geological map around Kampung Panglima Bayu (Source: Generated from ArcGIS 2022)

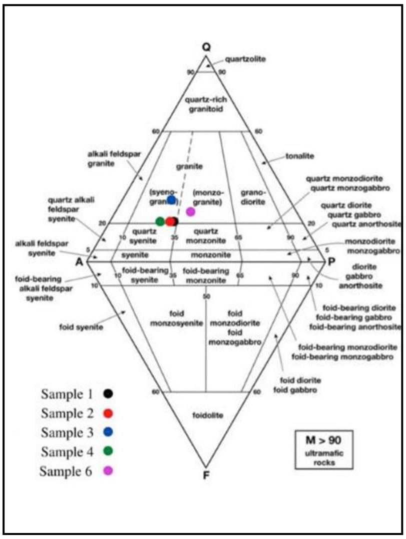

Fig. 3. QAP Diagram for Igneous Rock Classification

3.2 Water Quality Analysis

In this study, the data of 16 physiochemical parameters from 12 groundwater sampling location (Figure 4) is compared to the MoHM and WHO values to determine whether the element's value in the water samples is within a safe limit for domestic use [11]. Furthermore, the data will be converted into percentage form and plotted using a Piper trilinear diagram for a graphical representation of the type of water facies. Lastly, the WQI calculationis was used to determine the groundwater quality status.

3.2.1 In-situ Analysis

In-situ analysis was conducted using multiparameter probes and portable turbidimeters to measure key parameters, including electrical conductivity (EC), turbidity, total dissolved solids (TDS), temperature, and pH (Table 1). Given the dynamic nature of these physical criteria in response to environmental changes, on-site measurements were essential. Groundwater samples were collected in polyethylene bottles, immediately covered with aluminum foil, and stored in a cool box to ensure sample preservation and prevent contamination prior to laboratory analysis. This preservation process played a pivotal role in maintaining sample integrity, shielding the water samples from unnecessary contaminants and safeguarding the accuracy of subsequent analyses.

The groundwater pH ranges from 4.65 to 7.71 in the research area. WHO and MoHM consider the safe pH range for drinking water to be 6.0 to 9.0. Except for wells 4, 7, 8, 9, 11, and 12, which exhibit low pH levels, most domestic wells are within the safe range. Acidic groundwater results from acidic rainwater accumulation and the presence of strong/weak acids, salts, and weak bases in clay minerals. Such acidity can corrode pipes, releasing elements like zinc, iron, copper, and lead into the water, requiring pH stabilization to minimize risks. Turbidity in the research area ranges from 0.37 to 42.6 mg/L, indicating potential contamination. The highest turbidity (well 5) surpasses WHO drinking water guidelines (should be <1 NTU, max 5 NTU), and this well is abandoned, only used during droughts. Turbidity results from suspended particles (clay, silt, organisms), reducing oxygen and warmth absorption from sunlight. Solutions involve filtration, coagulation, and sedimentation, crucial for safe drinking water production.

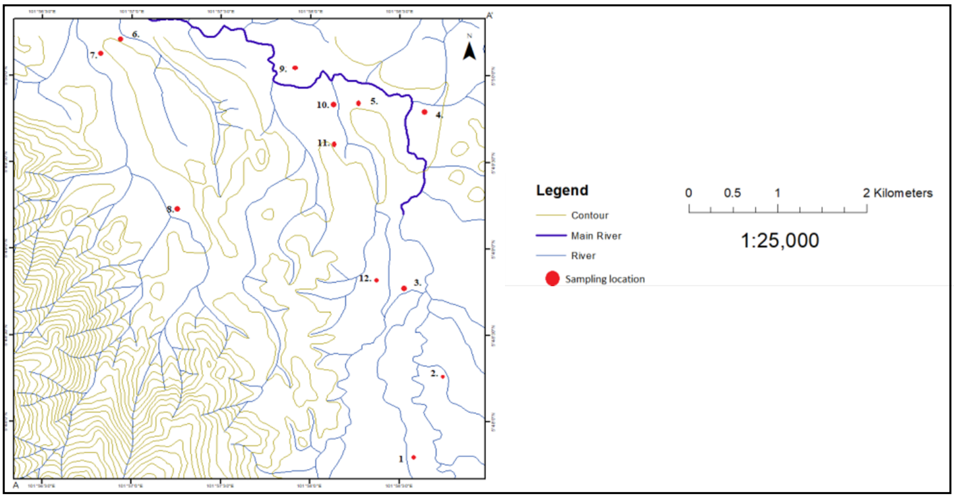

Fig. 4. Sampling well map around Kampung Panglima Bayu area. (Source: Generated from ArcGIS 2022)

Table 1. Locations of Sample well and Result of In-Situ parameters in the research area.

Well No.	Location	Elevation (m)	Temperature (°C)	pH	Turbidity (NTU)	TDS (mg/L)	EC (µS/cm)
W 1.	5°47'35.70"N, 101°58'37.10"E	52	27.9	6.55	0.65	94.85	135.57
W 2.	5°48'8.20"N, 101°58'44.10"E	54	27.0	6.60	1.50	119.25	170.52
W 3.	5°48'33.70"N, 101°58'38.10"E	58	28.0	7.50	2.19	91.6	131.52
W 4.	5°49'10.80"N, 101°58'49.90"E	46	27.6	🟥 5.22	🟥 7.54	221.6	316.76
W 5.	5°49'28.91"N, 101°58'25.90"E	45	27.0	6.72	🟥 42.6	179.35	258.38
W 6.	5°50'05.70"N, 101°57'02.30"E	21	28.0	7.71	0.71	98.10	142.19
W 7.	5°50'03.50"N, 101°56'48.70"E	27	27.0	🟥 5.25	3.02	95.50	136.57
W 8.	5°49'14.80"N, 101°57'12.90"E	42	27.9	🟥 4.73	1.27	116.75	168.43
W 9.	5°49'50.71"N, 101°57'51.30"E	45	27.5	🟥 5.74	1.55	160.3	225.79
W 10.	5°49'28.40"N, 101°58'6.40"E	42	28.0	🟥 6.15	0.37	86.4	121.84
W 11.	5°49'12.87"N, 101°58'1.05"E	48	26.7	🟥 4.65	🟥 25.2	94.20	132.87
W 12.	5°48'36.49"N, 101°58'13.11"E	40	28.4	🟥 5.05	0.53	106.55	151.79

🟥 Values exceed WHO and MOHM limit

3.2.2 *Major Cations & Anions Analysis*

Major cation concentrations in Table 2 (Ca2+, Mg2+, Na+, Fe+, Mn2+, and K+) were assessed using an atomic absorption spectrophotometer (AAS) in the lab, necessitating sample filtration to prevent blockages. Dilution with distilled water accommodated the AAS measurement range, and the element concentrations were determined based on light absorption, ensuring reliable results.

To determine major anion concentrations (Table 2), different methods were utilized based on their chemical properties. Spectrophotometry measured sulfate, nitrate, and fluoride ions by assessing their light absorption characteristics. Titration accurately determined bicarbonate concentrations through neutralization with strong acid using indicators. For chloride, a titration method with silver nitrate was employed, forming a precipitate (AgCl) and further reacting with chromate. These distinct techniques were chosen to ensure precise measurements, considering the unique behaviors and reactions of each element, resulting in comprehensive chemical analysis.

The sodium levels in well water range from 0.856 mg/L to 463.1 mg/L, with well 11 having the highest concentration due to nearby domestic waste disposal in a river. Inflow from the river into the aquifer likely contributes to this high sodium content, though it remains within WHO and MoHM limits (200 mg/L). Other sampling points do not pose pollution risks, preventing potential health issues and taste changes in the water. As per the facies analysis, the water in the area is dominated by sodium bicarbonate facies (Figure-5).

Table 2. Result of Major Cations and Anions in the research area.

Well No.	Na^+	K^+	Ca^{2+}	Mn^{2+}	Fe^+	Mg^{2+}	F^-	NO_3^-	SO_4^{2-}	HCO_3^-	Cl^-
W 1.	3.5	2.985	2.512	0.059	0.037	0.617	0.05	2.8	0	130	10.4
W 2.	9.967	2.307	12.83	0.001	0.005	0.364	0.02	2.4	2	250.33	21.7
W 3.	2.668	2.67	1.549	0.021	0.096	0.432	0.04	0.9	2	300	32.5
W 4.	5.805	1.499	6.757	0.045	0.178	0.344	0.02	0.7	0	383.67	22.3
W 5.	0.856	0.726	6.942	0.025	0.22	0.322	0.05	1	0	120	28.5
W 6.	2.496	1.449	1.036	0.024	0.182	0.376	0	2.8	1	230.33	18.8
W 7.	2.103	3.988	3.181	0.099	0.009	0.669	0	2.6	3	346	38.9
W 8.	12.34	0.763	1.223	0.027	0.009	0.31	0.16	1.5	0	180.33	27.2
W 9.	2.474	2.897	17.7	0.283	0.076	0.828	0	3.9	0	306.67	46.9
W 10.	50.39	0.791	0.345	0.025	0.026	0.412	0.09	2.8	0	175	20.9
W 11.	463.1	4.005	0.028	0.001	0.009	0.463	0.03	2.3	6	325	55.7
W 12.	4.264	2.47	4.622	0.024	0.009	0.458	0	2.5	5	296.67	15.9

🟥 Values exceed WHO and MOHM limit

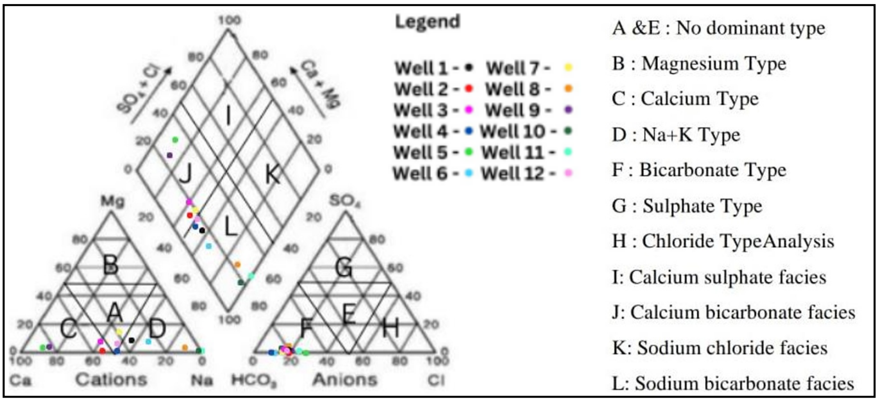

Fig. 5. The concentration of Anions and Cations in all wells plotted in Piper Trilinear Diagram

3.2.3 *Water Quality Index Analysis*

The Water Quality Index (WQI) was used to determine the overall water quality of the study area and the groundwater's sensitivity to any potential sources of contamination. Water quality analysis includes assessing various physico-chemical parameters that have standardized limits set by the World Health Organization (WHO) [11].

The Water Quality Index (WQI) is calculated using the following formula:

$$WQI=\sum_{(i=1)}^{n} qiWi \,/\, \sum_{(i=1)}^{n} wi \tag{1}$$

$$WQI=41.013 \tag{2}$$

The groundwater status was determined through the analysis of the Water Quality Index (WQI), which categorizes groundwater quality into different levels. A WQI value between 0 and 25 indicates a very good groundwater quality, while a value between 26 and 50 represents good quality. A WQI value ranging from 51 to 75 suggests poor groundwater quality, and values above 75 indicate very poor quality. Thus, the value of WQI at the study area is qualified good quality.

4 Conclusion

In summary, the geological mapping identified three lithologies: schist, granite, and alluvium, with different ages. Petrographic analysis and QAP diagram of the igneous category revealed the presence of minerals such as quartz, alkali feldspar, plagioclase, and biotite, with quartz being the most abundant in the granite rocks. The granite rocks in Kampung Panglima Bayu were categorized as "biotite granite porphyry" based on the significant presence of biotite.

The analysis of groundwater quality in a study area indicated that the water is generally safe for drinking and domestic use, with most main ion concentrations within permissible limits. However, some parameters exceeded thresholds, particularly in relation to agriculture, posing concerns for irrigation. Seven of the twelve well water samples had low pH levels, making them unsuitable for drinking and irrigation. Moreover, turbidity was high in wells 4, 5, and 11, and sodium ion levels surpassed the standard allowable limit in well 11. The factors influencing ion concentrations included agricultural activities, geological features, concentration duration, recharge attenuation, and the presence of streams and tributaries. The dominant facies in domestic well water was identified as sodium bicarbonate. Overall, the research findings supported the notion of good groundwater quality, making it a viable alternative source, considering underutilization of public water supply. The Water Quality Index (WQI) assessment also supported the notion of good water quality in the study area.

Acknowledgement

The financial assistance received from Fundamental research Grant (FRGS/1/2018/WAB08/UMK/02/2) is highly acknowledged. The authors are also grateful to the Faculty of Earth Science, Universiti Malaysia Kelantan, Campus Jeli, for endowing with basic facilities to carry out the present investigation.

References

1. Soller, D. R. *Introduction to Geologic Mapping.* (2004)
2. Ong, C., Ibrahim, S., & Gupta, B. S. Urban Water J **29**–41 (2007)
3. Islami, N., Nor, M., & Muhammad, R. *Physical and Chemical Characteristics Interpretation for Groundwater Quality Assessment in the Coastal Area, North Kelantan, Malaysia*, **22**(3), 281–288 (2015).
4. Rajaveni, S. P., Brindha, K., & Elango, L. *Geological and Geomorphological Controls on Groundwater Occurrence in a Hard Rock Region*. Applied Water Science, **7**(3), 1377–1389. (2015)
5. Khan, M. M. A., Mardhiya, A., Kamal, Z. A., Mansor, H. E., & Mathialagan, K. R. P. *Evaluating the Suitability of Shallow Aquifer for Irrigational Purposes in Some Parts of Kelantan, Malaysia.* Bulletin of the Geological Society of Malaysia, **66**(1), 57–64 (2018)
6. Department of Irrigation and Drainage Malaysia (2020)
7. Tan, P. Y., & Rohasliney, H. *Status of Water Quality Subject to Sand Mining in the Kelantan River, Kelantan. Tropical Life Science Research*, **24**(1), 19-34 (2013)
8. Hutchison, C., & Tan, D. *Geology of Peninsular Malaysia.* University of Malaya & Geological Society of Malaysia. (ISBN 978-983-44296-6-9.) (2009)
9. MacDonald, S. *Geology and Mineral Resources of North Kelantan and North Terengganu*. District Memoir **10**, Geological Survey West Malaysia, p. 202 (1967).

10. Cobbing, E. J., Pitfield, P.E.J., Darbyshire, D. P. F. & Mallick, D.I.J. *The Granites of the South-East Asian Tin Belt.* British Geological Survey Overseas Memoir, **10**, Her Majesty's Stationery Office, London, 369 pp (1992)
11. Malaysian Water Association. Malaysia Water Industry Guide. Kuala Lumpur: MWA (2011)