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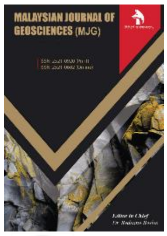

RESEARCH ARTICLE

GEOLOGICAL ASSISTED ON WATER RESOURCES PLANNING IN MOUNTAINOUS CATCHMENTS IN KUNDASANG, SABAH, MALAYSIA

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ABSTRACT

Based on geological mapping and geohydrologic data, water resources planning in mountainous catchment areas in Kundasang are outlined. The area is underlain by thick Paleogene clastic sediment and old Quaternary gravels. These rock units are carved by numerous lineaments with complex structural styles developed during series of regional Tertiary tectonic activities. The tectonic complexities reduced the physical and mechanical properties of the rock units and produced intensive displacements and discontinuities among the strata, resulting in high degree of weathering process and instability. The weathered materials are unstable and may cause subsidence and sliding induced by high pore pressure subjected by both shallow and deep hydrodynamic processes. Evaluation of 60 boreholes data in the study area reveals that the depth of the groundwater table ranges from 1.90 m (6 feet) to 11.20 m (35 feet) deep. The groundwater level in the study area fluctuates even within a short period of any instability of climatic change. The Quaternary sand and gravel layers with variable thickness defined the major shallow aquifers within the underlying weathered materials while the highly fractured sedimentary rocks defined the major deep aquifers. Most of the aquifers within the top unconsolidated weathered clastic material are under unconfined condition. The sedimentary formations are coarse-grained clastic materials generally contain fractured porosity and exhibit higher permeability. However, below subsurface, much of the groundwater is partially confined. Movements of groundwater are sufficiently restricted area to cause slightly different in head depth zones during periods of heavy pumping. During periods of less draught, the various groundwater levels will be recovered to their respective original level. This condition resulted from discontinuous nature of sediments where zones of permeable sand and gravel are layered between less permeable beds of silt and clay. Aquifer characterization and geological data are given to assist the local agencies on the water resources planning of the study area.

KEYWORDS

Geology, Water Resources, Mountainous Catchments, Hydrology, Sabah, Malaysia.

1. INTRODUCTION

The population growth in Malaysia has resulted in an increase in water demand, greater shortage of water supply and pollution of water resources. Decisions affecting the utilization of groundwater resources must be based on knowledge of the geologic and geohydrologic aspects of the study area and its surrounding areas. The geology as it pertains to groundwater can be perceived by examining the physiographic setting, geologic history, and nature and water-bearing characteristics of the underlying rocks. The tropical climate in Sabah provides abundant rain (>2000 mm annually) but the present water is hardly sufficient to cover the need of the population because most of the rain consumed by evapotranspiration and generally there is poor management of water resources discharge in most of the area. The water shortage problem in Sabah demands that all possible sources should be studied, analyzed and developed for optimum utilization.

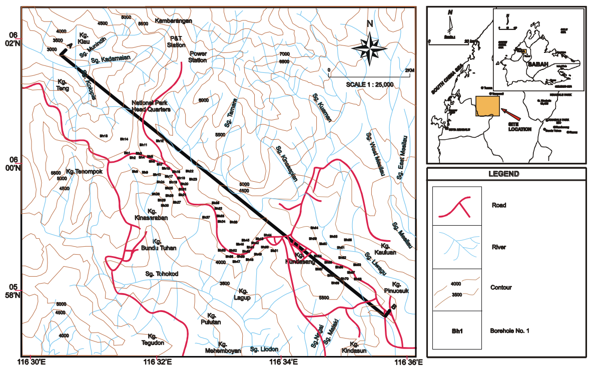

Figure 1. Location of study area

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Groundwater has been identified, as an alternative source of water supply, due to its economic importance. Managing of groundwater resources including monitoring its quality has become important as preparatory steps in facing water supply problem as experience during the drought in 1998. The study area covers an area of about 100 km^2. It is bounded by longitude E 116° 30.946' to E 116° 39.268' and latitude N 06° 00.598' to N 05° 56.635' (Figure 1). The study area is part of the largest catchment areas in Sabah and can contribute a large amount of water to the state of Sabah.

2. Methodology

Soil and rock samples from the study area were collected during field mapping for detailed analysis. The laboratory works such as classification tests (grain size, atterberg limit, specific gravity and moisture content) and permeability test were carried out in compliance and accordance to British Standard Code of Practice BS 5930-1981 (Site Investigation) and British Standard Code of Practice BS 1377-1990 (Method of Test for Soils for Civil Engineering Purposes). Sixty boreholes log data were obtained from the J.W. Geotechnical Consultant Sdn Bhd, which were reinterpreted and correlated in order to have clearer idea of the subsurface soil profile and lithological units.

3. Physiography and Landuse

The major geomorphologic regions distinguished are the summit dome of Mount Kinabalu above 9,000 feet; the steepness slopes and cliffs of the mountain from 2,500 to above 9,000 feet; the areas of partly dissected solifluction material; the foothills of dissected ultrabasic rocks; and the foothills of dissected sedimentary rocks, the accordant summits of which probably formed part of the early Pleistocene erosion surfaces.

The land use area in the study area consists of 3 categories: state land and agricultural area (50.0 %), protected and commercial forest reserve (36.0 %) and parks (14.0 %). Most of the villagers are farmers. Other activities include handicraft, selling agricultural products, animal husbandry, forestry, administrative services and tourism. The business centers are Kundasang and Ranau towns, while the tourism is active along the Sabah Parks at Mt. Kinabalu to Ranau area.

4. Climatology

Sabah is located within the equatorial belt and enjoys a warm and wet tropical climate. Generally, the seasons are divided into the northeast monsoon (November to March) and the southwest monsoon (May to August). Daily temperature of the lowland area ranges from 25°C to 30°C with significantly cooler at higher altitude areas. There is no record of typhoons passing through Sabah, but unexpected tropical storms are unavoidable. There are five climatic regions in Sabah based on dry and wet seasons, which in turn are induced by minimum and maximum rain periods (Figure 2). Regionally, the study area belongs to the third type (100" – 120"). The driest seasons occurs during the northern monsoon and the wettest seasons during the southwest monsoon. The maximum temperature is 30°C and the minimum is 15°C, although the usual range is from 23°C to 32°C at the lowland areas.

Inland, the climate is somewhat colder due to altitude changes. In order to understand the climatologic setting of the study area, some statistical analysis was applied for this study (Figure 3). Rainfall provides the major source of inflow to the Kinabalu basin while surface runoff, evapotranspiration, groundwater extraction, spring discharge and other constitute the out-flow component (Faisal et al., 1997). The average annual rainfall in the study area (1971 – 2003) is ranging from 1220.0 mm to 3358.8 mm with total wet days ranging from 49 mm to 233 mm (half of the days), most of which falls in second half of the year. Rainfall is heavy during the inter monsoon season, drenching the slopes with more than 1400 mm of rains in a single month. Apart from the monsoon rains, due to its altitude also receives regular mountainous rain, especially in the afternoon. Deep weathering profiles seen in this study area is attributed to the heavy rainfall. Analysis of the rainfall data (Figure 3) shows that there is a noticeable decrease rainfall in the early 90's compared to the high rainfall of the late 80's.

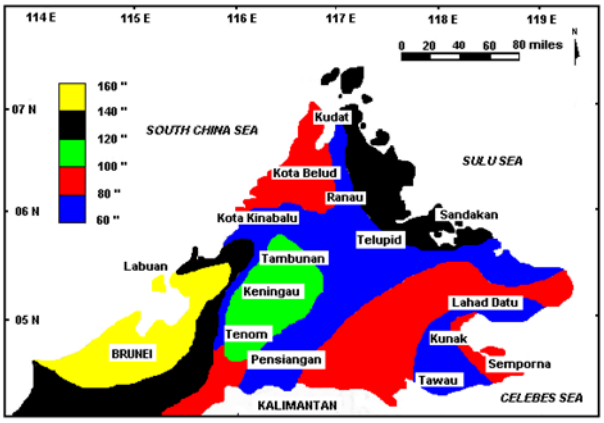

Figure 2. Distribution of Sabah means annual rainfall data Climatologic Services (After Faisal, et al. 1997)

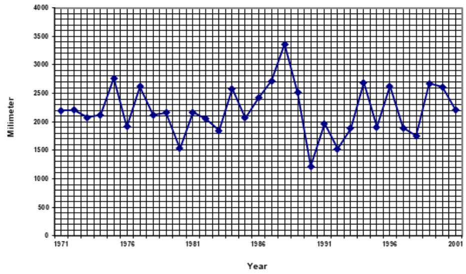

Figure 3: Total annual (Source after Sabah Department)

5. Hydrologic and Geohydrologic Setting

The study area and its surrounding areas are controlled by heavy drainage system of different patterns (Trellis, Annular and Parallel) (Figure 1). The region has a high drainage density, being the cradle and origin of major rivers in the study area. The watershed of the Mount Kinabalu region feeds rivers like the Kinasaraban, Liwagu, Mesilau, Kuaman and countless other drainage basins surrounding the mountain, those flow either to the South China Sea or to the Sulu Sea. Structurally, a number of linear river segments belong to different watershed systems indicate the existence of major tectonic fractures. The structural control of the river tributaries of the area is evidenced by the physical characteristics of sedimentary rocks; highly fractured areas and less competent shale beds. The sedimentary rocks are more intensely dissected by fault zones than the ultrabasic rocks and formed trellis drainage pattern. Groundwater occurs and moves through interstices or secondary pore openings in the rock formations. Such openings can be the pore spaces between individual sedimentary grains, open joints and fractures in hard rocks or solution and cavernous opening in brecciated layers and cataclasites. The amount of water that can be stored by a rock is measured by its porosity and permeability. However, the amount of water that can be withdrawn from the rock depends largely on its permeability. Therefore the more permeable a rock is, the better aquifer it is. The factors that control the above coefficients are the size or degree of openings, interconnection of the openings and molecular attraction between the grains and the water. The direction of subsurface water movement is generally under the influence of gravity. Within the zone of aeration, movement is generally vertical until the water reaches the water table, which defines the upper surface of the zone of saturation. Within the zone of saturation, the subsurface water is now referred to as groundwater. Here, the direction of groundwater movement is generally toward the point of lines of discharge, also influenced by gravity but at a greater horizontal component. In artesian aquifers, where the groundwater is confined between two impermeable layers, movement can go against the pull of gravity depending on the shape of the confined aquifer. Since the water is under hydrostatic pressure, the elevation to which the water level rises is usually above the top of the aquifer and in some cases above the ground surface.

6. GEOLOGY

The geology of the study area is made up of three sedimentary rock formations: the Trusmadi Formation (Palaeocene to Eocene age), the Crocker Formation (Late Eocene age) and the Pinousuk Gravel (Late Pleistocene to Holocene age) (Figure 4). The Trusmadi Formation consists of interbedded dark shale and sandstone. The Trusmadi Formation is exposed at the foot of the Mount Kinabalu and Ranau area. Low-grade metamorphism has occurred in some of the rocks of the Trusmadi Formation. The rock associations are highly sheared and brecciated with some cataclasites. The dark argillaceous rocks are thickly bedded or interbedded with sandstone and siltstone beds. The thickness of the argillaceous beds is about 100 feet, whereas the sandstone beds are about 120 feet at the foot of Mount Kinabalu area. Some volcanic rocks mainly spilite, extruded through the Trusmadi Formation. Quartz veins are quite common in this Formation. The Trusmadi Formation can be divided into 4 main lithological units: shale, interbedded sandstone and shale (turbidities), cataclasites and thick sandstones. The Crocker Formation forms the main exposure in the area where outcrops can be found along road-cuts, paths and excavations. Major exposures are moderately to highly weathered materials. The sedimentary rocks of the area are partly made up of the Crocker Formation to the southwest of Mount Kinabalu and partly consist of the Trusmadi formation, forming part of the Crocker Range and Trusmadi Range respectively, were mapped as the Crocker Formation on the basis of their lithological features (Collenette, 1958). The Crocker Formation is characterized by monotonous rock facies, repetition of interbedded sandstone and shale strata, by isoclinal foldings and faults. The rough structure has been determined from statistical analysis of various structural elements and by the analysis of aerial photograph (Kasama et al., 1970). The Crocker Formation can be divided into four main lithological units; namely thick bedded sandstone, thinly bedded sandstone and siltstone, red and dark shale and slumped deposits. The Pinousuk Gravels are preserved south and west of Mount Kinabalu in three main areas: the Pinousuk Plateau, the Tohubang Valley, and near Tenompok. It is proposed to regard as the type section exposures those along Mantaki River, Mesilau River, Tawaras River and Bambangan River, flow through the Pinousuk Plateau at east - southern. The solifluction material is continuously distributed within the alluvium in which terraces have been developed along the Liwagu Valley and in the Tohubang Valley near Ranau. The angular to rounded clasts found in the Pinousuk Gravels are mainly granites and sedimentary rocks, embedded in a light brown to red brown matrix of sandy, silty and clayey materials. Rare wood fragments are also found in the Pinousok Gravels. The Pinousok Gravels unconformable overlies the above discussed rock units and reach a maximum thickness of about 450 feet. The beds consist of poorly cemented gravel of various compositions and are considered as tilloid deposits. Division is possible into a lower unit consisting of silty to sandy gravel of angular to subangular clasts of either sedimentary or ultra-basic rocks, and an upper unit that is composed of clayey to sandy gravel of angular to rounded clasts of varied composition. The lower and upper units have been interpreted as pre-glacial solifluction deposits and as probable mudflow sediment containing reworked till, respectively (Tjia, 1974). Laboratory analysis for petrography was conducted on selected 17 sedimentary rock samples in order to study the mineralogy and porosity of the rock samples by using polarized microscope (Table 1). From this laboratory analysis, a thin – section was used as a delineation of the mineral constituents to show the mineral characteristics. The petrographic study of rock samples in the study area revealed only slight differences between the sedimentary rocks of Trusmadi Formation and Crocker Formation.

Table 1: Modal analysis for sedimentary rocks from Trusmadi Formation and Crocker Formation

ROCK UNIT	ROCK TYPE	LOCA-TION	SAM-PLE NO.	DETRITAL GRAINS (%)						MATRIX & CEMENT (%)	PORO-SITY (%)
				QUARTZ	PLAGIO-CLASE	K - FELD-SPAR	MICA	ROCK FRAG - MENT	CHERT		
TRUS-MADI FORM-ATION	Quartz Wacke	11	RSL 11	58.00	1.80	1.80	0.45	0.70	0.90	24.35	12.00
		12	RSL 15	62.00	1.50	2.00	0.30	0.75	1.05	21.40	11.00
		13	RSL 13	48.50	2.00	1.60	0.50	0.90	1.20	32.80	12.50
		15	RSL 15	48.00	2.50	1.75	0.65	0.85	1.05	32.70	12.50
		18	RSL 18	53.50	2.85	1.85	0.55	0.80	1.35	27.60	11.50
		19	RSL 19	52.00	2.65	1.95	0.60	0.80	1.20	27.80	13.00
		23	RSL 23	58.50	2.55	1.85	0.55	0.90	1.15	22.00	12.50
AVERAGE				**54.36**	**2.26**	**1.83**	**0.51**	**0.81**	**1.13**	**26.95**	**12.15**
CROC-KER FORM-ATION	Quartz Wacke	1	RSL 1	42.00	4.50	0.80	0.45	3.50	3.50	32.75	12.50
		2	RSL 2	48.50	3.00	0.95	0.55	2.50	4.00	27.50	13.00
		3	RSL 3	45.00	5.50	1.00	0.50	3.00	4.00	27.00	14.00
		4	RSL 4	48.00	3.50	0.95	0.45	2.00	4.50	28.10	12.50
		7	RSL 7	47.50	5.00	0.75	0.40	1.50	3.00	28.35	13.50
		8	RSL 8	46.50	6.00	0.80	0.60	2.50	2.50	26.60	14.50
		9	RSL 9	49.50	4.00	0.90	0.45	1.50	4.50	25.15	14.00
		10	RSL 10	51.00	4.00	0.95	0.50	2.00	2.50	22.50	16.50
		26	RSL 26	55.00	5.00	0.90	0.45	1.85	3.50	17.80	15.50
		27	RSL 27	50.00	5.50	0.85	0.55	2.00	3.00	22.60	15.50
AVERAGE				**48.30**	**4.60**	**0.89**	**0.49**	**2.24**	**3.50**	**25.84**	**14.14**

7. GEOLOGICAL CHARACTERISTICS AND WATER RESOURCES

Table 2 indicates the aquifer types in the study area with their water bearing properties, engineering properties and physical characteristics. Two aquifer types are present in the study area; the unconsolidated aquifers and consolidated aquifers (Figure 5). The unconsolidated aquifers consist of unconsolidated sediments, chiefly sand and gravel. These deposits are usually found along watercourses, plains or valley, buried or abandoned river channels and sand lenses. They are commonly covered by interlayered with clay and silt (Table 2). Being unconsolidated, the permeability of sand and/or gravel is generally higher than other natural material. In unconsolidated aquifers, groundwater occurs in the pore openings between the granular material and within individual porous grain. In the study area, large portions of the developed aquifers are found in the unconsolidated aquifers. The consolidated aquifer can be divided into four types based on host rocks (Figure 5): aquifer within karstic rocks, aquifer within sandstones rocks, aquifer within sandstone and associated volcanic rocks and aquifers within igneous and metamorphic rocks.

Table 2: Types of Aquifer with their Water Bearing Properties, Engineering Properties and Physical Characteristics

Rock Formation	Rock Unit	General Character	Water-Bearing Properties	Engineering Properties	Physical Characteristics			
					Soil Types	Porosity, n_p (%)	Specific Yield (%)	Permeability, K (m/day)
Alluvium (Quaternary)	-	Unconsolidated gravel, sand and silt with minor amounts of clay deposited along the rivers or streams and their tributaries. Includes natural levee and flood plain deposit.	Gravelly and sandy, portions are highly permeable and yield large quantities of water. Important to groundwater development.	Generally poorly consolidated. Hence not suitable for heavy structures and subsidence under heavy load.	Gravelly SAND	15 to 25	16 to 18	52 to 8.20 X 10 $^{-2}$
Pinousuk (Gravel Upper Pleistocene to Holocene)	-	Poorly consolidated tilloid deposits. Unconformable overlie ultrabasic granitic and Tertiary sedimentary rocks.	Good aquifer present in poorly fractures consolidated deposit.	Poorly consolidated. Not suitable for heavy structure. Born to be heavy sliding.	Fine SAND	25 to 32	22 to 25	16 to 1.92 X 10 $^{-2}$
Crocker Formation (Late Eocene to Early Miocene)	Shale	This unit composed two types of shale red and grey. It is a sequence of alteration of shale with siltstone of very fine.	It has no significant to groundwater development due to its impermeable characteristic.	Very dangerous site for heavy structures and the main causes of mass movement.	Silty CLAY	40 to 45	3 to 5	1.82 to 9.25 X 10 $^{-5}$
	Shale-Sandstone Inter bedded	It is a sequence of interlayering of permeable sediment sandstone with impermeable sediment of shale. The permeability of this unit is quite variable. Groundwater in this unit tends to be under semi-confine to confine system.	Little importance to groundwater provides some water but not enough for groundwater development.	Dangerous site for heavy structures and high potential for mass movement.	Sandy CLAY	30 to 35	2 to 8	5.68 X 10 $^{-4}$ to 7.95 X 10 $^{-7}$
	Sandstone	Light grey to cream colour, medium to coarse -grained and some time pebbly. It is highly folded, faulted, jointed, fractured occasionally cavernous, surfically oxidized and exhibit spheriodal weathering.	Importance to groundwater.	Good site for heavy structures with careful investigation. Stable from mass movement and provide some modification like closing of continuous structure.	Gravelly SAND	12 to 20	8 to 10	482 to 6.32 X 10 $^{-2}$
Trusmadi Formation (Paleocene to Eocene)	Trusmadi Slate and Trusmadi Phylites	Comprise of dark colored argillaceous rock either in thick bedded or interbedded with thin sandstone beds reported along with isolated exposures of volcanic rock is a common feature of this formation.	Fracture bed of sandstone has significant to groundwater.	Dangerous site for heavy structure. Improvement should be conducted before any project.	Sandy GRAVEL	18 to 25	15 to 20	565 to 1.35 X 10 $^{-2}$

The karstic rock covers only very limited areas in the study area. It has little importance to groundwater resources. The sandstone aquifers cover large areas in study area. Their potential to groundwater depends on it porosity, specific yield and permeability (Table 2), cementing materials and presence or absence of geologic discontinuities. Partly cemented fractured sandstone can be a good aquifer, especially if the deposits are sufficiently thick and widely distributed. Individual beds are commonly thin, (between a few centimeters to a few feet) but in some instances, they could be sufficiently thick (more than 65 feet). The sandstone and associated volcanic aquifer types vary widely in porosity and permeability depending upon the degree of consolidation, degree of association and/or the development of permeable zones after deposition. The drilling of successful production wells in this type of aquifer depends very much on the borehole penetrating fracture zones. Igneous and metamorphic rocks are relatively impermeable and are generally poor aquifers. Appreciable porosities and permeability however can be developed through fracturing and weathering of both types of the rocks. Limited yields for low production, domestic purposes may also be obtained from leached or highly fractured zones of both rock types. The porosity and permeability of igneous and metamorphic rocks, generally, decreases rapidly with depth of emplacement and the crystallization period.

The rock formations exhibit a high degree of weathering and covered by thick residual soil, that extends to more than 65 feet in thickness. Evaluation of more than 60 boreholes drilled (Figure 1) and the cross-section constructed (Figure 6) from those boreholes in the study area indicated that the groundwater table in the study area is shallow and ranges from 6 feet to about 35 feet. It is also indicated that the water table following the topography from highland toward the road and the valley side. The weathered materials are weak and may cause sinking, subsidence and sliding due to high pore pressure subjected by both shallow and deep groundwater. Faults and joints (fractures) will tend to close at depth due to compaction of overburden. The occurrence of groundwater in the study area is greatly influenced by these geologic discontinuities due to faulting or fracturing control and enhancing the secondary porosity and permeability.

The effect of faulting activity can be observed on the lithologies of the study area. This was confirmed by the existence of transformed faulted material consisting of angular to sub angular sandstone fragments, with fine recrystallized quartz along the joint planes, poorly sorted sheared materials and marked by the occurrence of fault gouge with fragments of subphyllite and slickened sided surfaces. The geometry of these fault lines is not well known but is expected to be complex due to the fact that there are intersection zone of different type (Figure 7). Highly fractured and sheared sandstones indicate the result from long history of tectonic activities; most of faulting shears exist within the interbedded sandstone-shale. Breaks and fractures were developed by shearing stresses that caused the rapid disintegration and weathering of the rocks into relatively thick soil deposit. As a corollary to this, in rock bodies, the surface roughness of joint are generally smooth to rough planar. A relatively smooth surface decreases the frictional resistance to expose the fractures, therefore effected the possibility of ground water movement in study area.

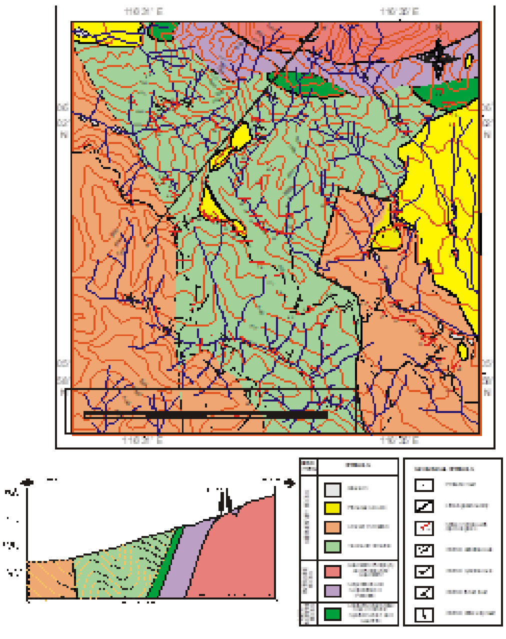

Figure 4: Regional geologic map of the area (Modified after Jacobson, 1970)

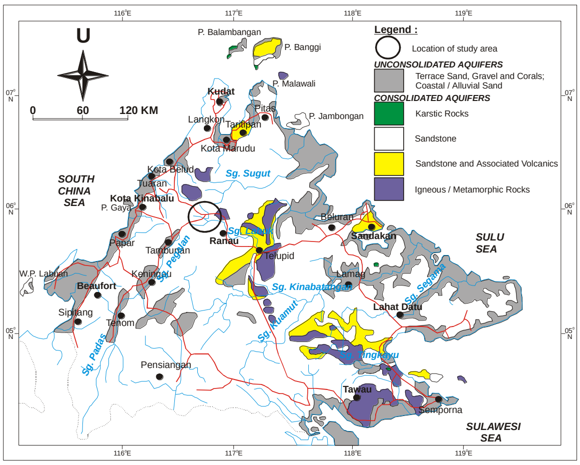

Figure 5: Types of aquifers in Sabah (After Faisal et al., 2001)

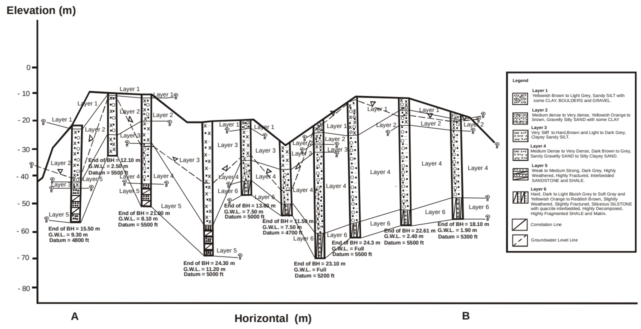

Figure 6: Cross – sectional of groundwater table (From Figure 1)

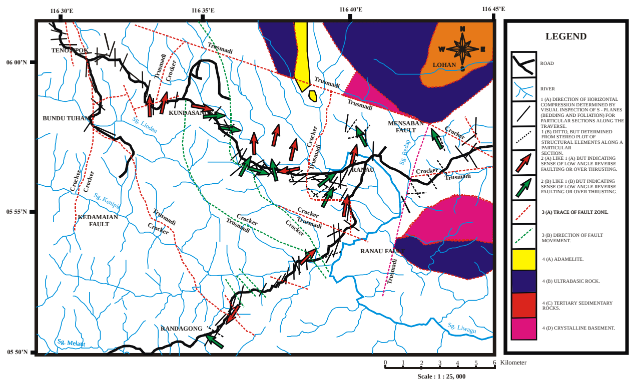

Figure 7: Structural geology map (Modified after Tjia, 1974)

8. Conclusions

Based on evaluation of the studies, the followings were concluded:

1. The geologic and topographic setting controlled the groundwater occurrences and movements in Kundasang Mountainous area. Various combinations of geologic discontinuities and stratigraphy resulted in different groundwater systems. The general movement of groundwater flow in the study area is from highland to lowland. Groundwater level in the study area is ranging between 6 feet to 35 feet depth.

2. The geology of the study area indicates that the sandy layers of sedimentary rocks and the Quaternary sediments can be considered as important groundwater reservoirs. Sand and gravel of varying thickness define the major aquifers within the unconsolidated sediments. The older rocks are highly compacted layers at which groundwater development is not economically feasible. Shallow clay beds occasionally act as aquicludes resulting in semi-confined conditions in some unconsolidated sediments.

3. The other groundwater reservoir in the study area is the confined permeable bed that occurs as irregular masses of sandstones intercalated with impervious beds of shale, clay and silt. Shale beds or lenses locally interbedded with sandstone might be extensive enough to separate water-bearing layers into general aquifers.

RECOMMENDATIONS

This study recommends some suggested measures as stated below to facilitate the understanding of groundwater system and provide water resources planning for the future in Kundasang Mountainous area:

1. Continuous monitoring of groundwater level to determine actual response of water level to climatic change.

2. Monitoring of groundwater system to avoid the adverse impact.

3. Detailed geophysical survey to delineate the geological structures those are suspected to act as groundwater conduit from the watershed toward the valley.

4. The identification of individual layers within the sedimentary succession gave overall planning and management of groundwater resources in the study area.

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