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Groundwater quality and hydrogeological characteristics of Malacca state in Malaysia

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Abstract

Groundwater quality and aquifer productivity of Malacca catchment in Peninsular Malaysia are presented in this article. Pumping test data were collected from 210 shallow and 17 deep boreholes to get well inventory information. Data analysis confirmed that the aquifers consisting of schist, sand, limestone and volcanic rocks were the most productive aquifers for groundwater in Malacca state. GIS-based aquifer productivity map was generated based on bedrock and discharge capacity of the aquifers. Aquifer productivity map is classified into three classes, namely high, moderate and low based on discharge capacity. Groundwater potential of the study area is 35, 57 and 8% of low, moderate and high class respectively. Fifty two shallow and 14 deep aquifer groundwater samples were analyzed for water quality. In some cases, groundwater quality analysis indicated that the turbidity, total dissolved solids, iron, chloride and cadmium concentrations exceeded the limit of drinking water quality standards.

Key words: *aquifer productivity, groundwater, Malacca catchment, pumping test, water quality*

INTRODUCTION

Groundwater potential and quality are of major concern to researchers because of increasing demand for fresh water coupled with climate change effects. Large amount of effluents generated from urban population, industries and agricultural activities may pollute soil and groundwater. Groundwater recharge and distribution depend on the underlying geological formations, surface expression, local and regional climate settings [ARSHAD *et al.* 2014; SHIRAZI *et al.* 2010; SHIRAZI *et al.* 2012; SHIRAZI *et al.* 2013; SRIVASTAVA 2002]. Sufficient information and an overview of the present groundwater condition have significant role in the early stages of preparing a sustainable groundwater development plan. Appropriate measures should urgently be undertaken for water resources development due to fast decline of groundwater table and increasing water demand [NAGESWARA, NARENDRA 2006; ZARDARI *et al.* 2014]. Geological data interpretation and field reconnaissance are important at preliminary stages of groundwater investigation. Proper investigation and experiment are needed on borehole water quality, lithology, aquifer media, soil classification, discharge, recharge, land use, topography and rainfall to get an overview on present groundwater quality and potential. Geographic Information System (GIS) is an important tool for classifying, explain, handling, storage and management of large and complex data within short time with a minimum error. The GIS facilitates proper data analysis and interpolation techniques [JHA *et al.* 2007]. It is also an effective tool for interpreting and integration of different thematic map related to land cover [MATTIKALLI 1995]. TEEUW [1995] used GIS for site selection of borehole drilling and found it an effective method for this purpose. The GIS facilitates rapid storage of a large amount of data, quantification and analyses and helps interpreting large hydrogeological data sets with better accuracy. CHOWDHURY *et al.* [2010] reported the significance of GIS for groundwater resources assessment. The State of Malacca in Peninsular Malaysia is very important for agriculture, industry and tourism. An extensive investigation and exploitation are very essential to understand the present groundwater quality and potential of Malacca catchment. Therefore, an attempt was undertaken to investigate the groundwater quality and potential to meet the water demands for domestic, agricultural and industrial purposes.

METHODS

Malacca is ranked the third smallest state in Malaysia with a surface area of 1650 square kilometers. Geographical coordinates of the study area are 1°06' to 2°30' N and 101°58' – 102°35' E (Fig. 1).

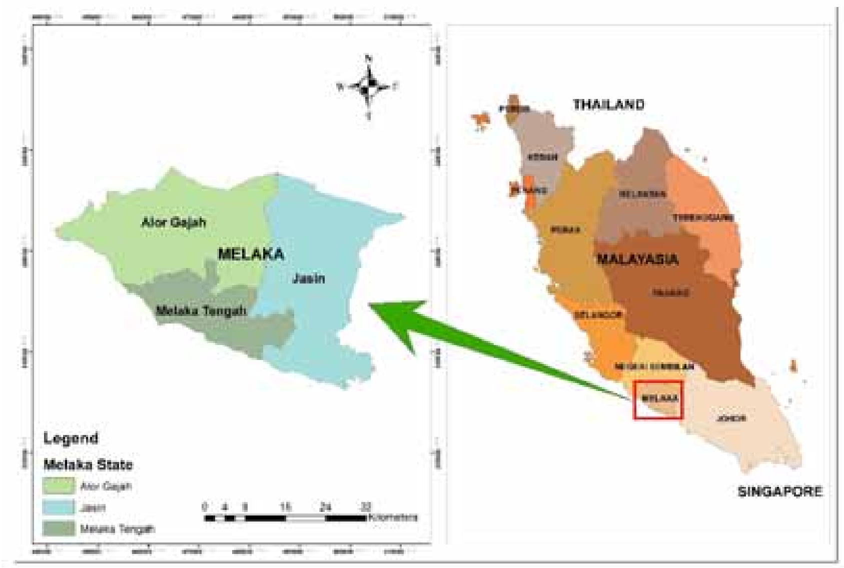

Fig. 1. Malacca state of Peninsular Malaysia; source: own elaboration

In order to understand and identify the groundwater quality and potential geological, hydro-geological, geo-physical, test drilling, pumping test and the hydro-chemical investigations were carried out. In this study we analysed 238 units of shallow aquifers (depth < 20 m) built by the Malacca State Government and spread on the territory of Alor Gajah, Central Malacca and Jasin. We also investigated 20 deep aquifers (depth > 50 m) mostly owned by the private sector under the supervision of Malacca authorities. The upper portion of the deep aquifers were provided with 355 mm diameter steel casing while 200 mm PVC pipe was used in the lower parts.

RESULTS AND DISCUSSION

GEOLOGY OF THE STUDY AREA

The detail geological features were assessed to get an overview of the nature of underlying formations and the capabilities in terms of groundwater potential. Geological formation of the study area was mostly dominated by phyllite, schist and slate. Second major parts consisted of acid intrusive rocks and granite. In the east boundary parts of Jasin district up to Johor geological substratum was formed by schist, sand, limestone, volcanic rocks and alluvium. Sedimentary rock formations showed a storage capacity of groundwater resources in the hard rock region [DIBI *et al.* 2010]. A small part of the study area consisted of sandstone and volcanic rocks. Satisfactory groundwater potential zones were found in the hard rock terrain corresponding to the fracture valleys, pediments and high lineaments. The geological features of Malacca are shown in Figure 2. The annual average rainfall in Malacca ranges between 1430 and 2152 mm·year^{-1}.

RECHARGE

The amount of water penetrating from surface to groundwater table per unit area is called net recharge. It is mostly influenced by land cover, slope, geology,

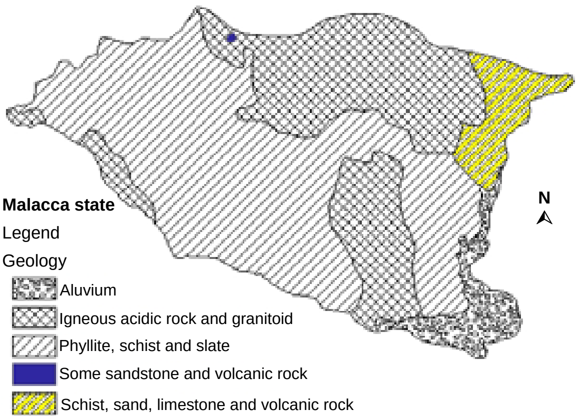

Fig. 2. Geology map of Malacca; source: own elaboration

lithology, permeability of soil and rainfall. In the study area, the shallow aquifers were subjected to high recharge which was mainly governed by precipitation. The groundwater potential depends on recharge rate of infiltration through the faults and fractures [TRAVAGLIA, DAINELLI 2003]. The 22-year mean annual rainfall and evaporation data were used to prepare the recharge map (Fig. 3). The correlation between mean annual rainfall and annual net recharge is presented in Figure 4.

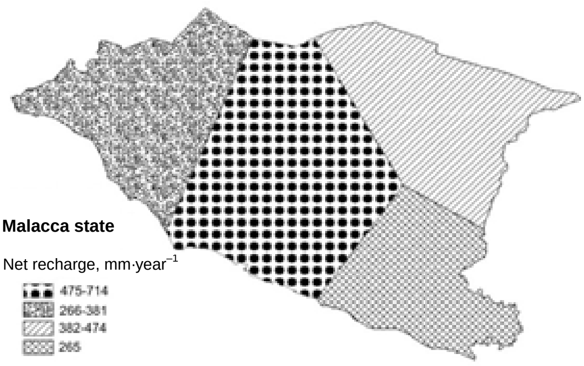

Fig. 3. Net recharge of Malacca; source: own elaboration

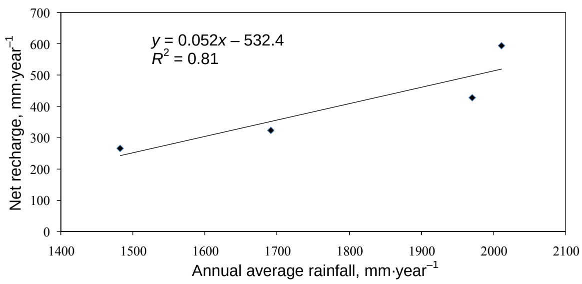

Fig. 4. Correlation between the mean annual rainfall and net recharge; source: own elaboration

LAND USE

Most parts of the Malacca state are dominated by agricultural land, especially palm oil plantations, seasonal crops, forests and urban development [LMDM 2003]. The main economic source of Malacca is tourism and manufacturing. Land use and water demand increases fast because of exponential growth of population, agricultural, industrial and tourism purposes. Groundwater quality, storage and flow paths are significantly hampered by mining operation [VAHT *et al.* 2011]. The combination of land use data with slope, soil texture map, rock properties, drainage map, rainfall, and other factors like evapotranspiration and rainfall distribution was very effective to identify the groundwater potential zone. From Malacca land use classification, it appeared that major parts of the area are used for agricultural activities. Others categories were dominated by urban development, industrialization, orchards, forests, swamps and marsh lands and riparian forests. The land use classification of Malacca state is shown in Table 1.

LITHOLOGY

The detailed well inventory data of 210 shallow boreholes and 17 deep boreholes were collected from Mineral and Geosciences Department of Malaysia.

Table 1. Types and areas of land use in Malacca

Type	Area					
	2007		2008		2009	
	ha	%	ha	%	ha	%
Forest	5,079.66	3.06	5,079.66	3.05	5,079.66	3.05
Agriculture	99,754.00	60.25	99,754.00	59.98	99,754.00	59.98
Urban and industrial	7,033.08	4.25	7,033.08	4.23	7,033.08	4.23
Aborigines' reserve	667.07	0.40	667.07	0.40	667.07	0.40
Federal land	8,159.63	4.93	2,413.76	1.45	2,413.76	1.45
State land	716.83	0.43	706.38	0.42	706.38	0.42
Other	44,157.57	26.68	50,646.05	30.45	50,646.05	30.45
Total	165,567.84	100.00	166,300.00	100.00	166,300.00	100.00

Source: own study.

These data were used to assess the occurrence, movement, quantity and quality of groundwater. Hydro-geological investigations of hard rock aquifers were greatly focused on their structure [TAYLOR, HAWARD 2000; WYNS *et al.* 2004] and on the methodologies for developing aquifer mapping and groundwater management at large scale [DEWANDEL *et al.* 2010; LACHASSAGNE *et al.* 2001; MARECHAL *et al.* 2006]. Hydraulic conductivity, flow path and gradient were greatly controlled by aquifer media. Lithological logs that convey the deep aquifers media were mainly formed by phyllite, schist, shale, coarse sand, medium sand, fine sand, clay, laterite and quartz. The shallow aquifers media were mainly formed by granite, meta-sediment, clay, coarse sand, medium sand, fine sand and peat [RANGZAN *et al.* 2008]. BAHAR and REZA [2010] carried out a study on well site selection in Iran and reported that the most suitable areas for groundwater exploration were the alluvial and sandstone deposits. The typical lithological formations of the study area are presented in Figures 5 and 6 for deep and shallow aquifers, respectively.

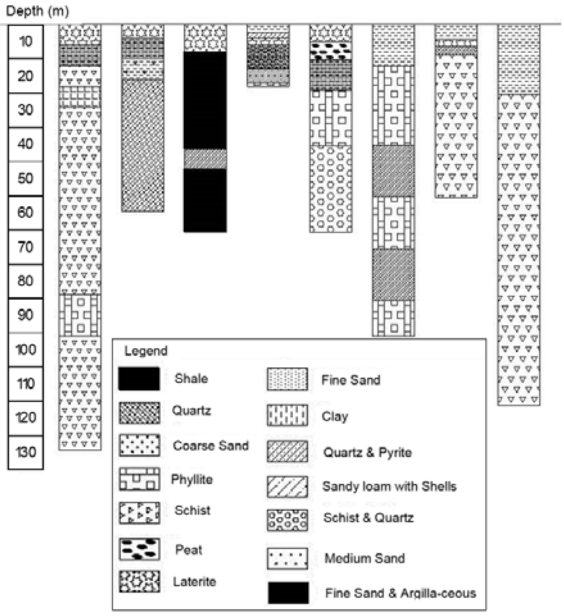

Fig. 5. Typical lithology of deep aquifers at Malacca; source: own elaboration

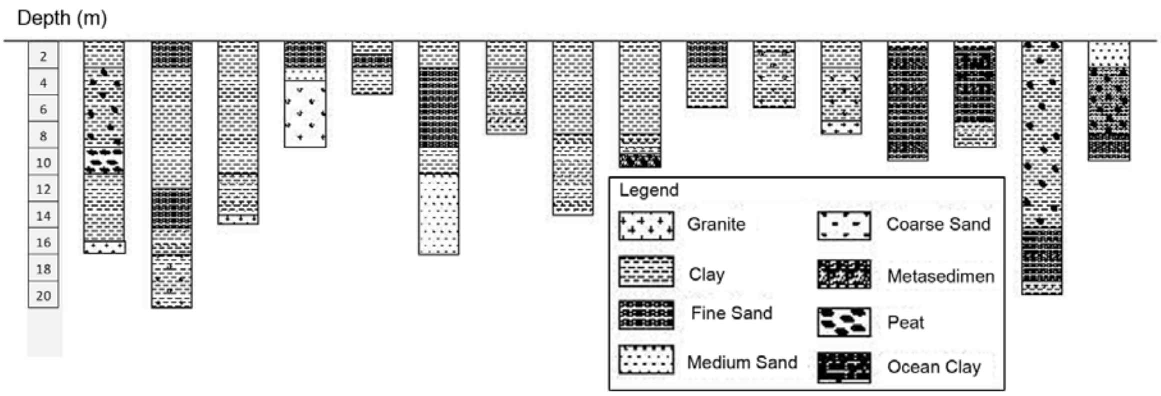

Fig. 6. Typical lithology of shallow aquifers at Alor Gajah; source: own elaboration

PUMPING TEST AND AQUIFER PRODUCTIVITY

Preliminary field survey and collected data help us to provide an overview of groundwater condition of the Malacca State. The productivity of the aquifer in the study area was determined from pumping test and borehole drilling data. The pumping tests data were used to determine the aquifer parameters in order to ensure the aquifer potential. Geological structure of the study area was largely dominated by granite, phyllite, slate and schist. The aquifer productivity classifications are presented in Table 2 based on the judgments of the typical long term discharge rate in cubic meters per hour from a reliable site and constructed borehole. The rock type in each borehole was categorized from the pump test data and hydrogeological map. Aquifers productivity is classified by having a typical yield ranges of <3.6 $m^3 \cdot h^{-1}$ (low), 3.6–12.0 $m^3 \cdot h^{-1}$ (moderate) and >12.0 $m^3 \cdot h^{-1}$ (high).

Investigation in the area of Alor Gajah indicated that the bedrock of shallow aquifers was dominated by phyllite, schist and granite. About 73 units of shallow aquifers gave varying discharge rates. Most of the discharge were 3.6–12 $m^3 \cdot h^{-1}$ and only few shallow and deep aquifers gave satisfactory discharge (>12 $m^3 \cdot h^{-1}$). Groundwater potential was limited in the region of Central Malacca based on lithology data and pump test. From among 107 units, only 53 units of drilling holes discharged 138 $m^3 \cdot h^{-1}$. Aquifers of moderate productivity were located in phyllite, schist and slate, which is a thin layer of metamorphic splitting rock. This layer have lower permeability than the more well-sorted, coarser and high productivity deposits which reduces their potential for yielding large volumes of groundwater. Granite and acid intrusive rocks were dominant in the low productivity aquifer bedrock which was not suitable for groundwater storage.

The high potential of groundwater in Jasin region was found in the schist, sand, limestone and volcanic rocks. From among 63 units of shallow borehole, 50 units were suitable for extracting groundwater. The

Table 2. Aquifer productivity classification of Malacca catchment

District	Total boreholes	Active boreholes	Productivity classes			Area %	Total discharge $m^3 \cdot h^{-1}$
			high (>12 $m^3 \cdot h^{-1}$)	moderate (3.6–12 $m^3 \cdot h^{-1}$)	low (<3.6 $m^3 \cdot h^{-1}$)		
Alor Gajah	80	5	12.3–18			8	274
		31		3.6–12		54	
		22			0.2–3.5	38	
Malacca Tengah	107	2	13.5–18			4	138
		36		4–8.2		68	
		15			0.5–3.5	28	
Jasin	71	5	13.6–18			10	211
		24		4–12		50	
		19			0.5–3.5	40	

Source: own study.

aquifers discharge ranged mostly between 0.5 and 12 $m^3 \cdot h^{-1}$. The capacity of groundwater was tested by drilling deep to find out the value of transmissivity coefficient and hydraulic conductivity. Pumping test was continuously carried out for 10 hours, followed by waiting for the rise of groundwater table. The transmisivity coefficient was 10 $m^2 \cdot day^{-1}$ and hydraulic conductivity 0.63 $m \cdot day^{-1}$. Aquifer productivity results indicated that 35% of area had low, 57% moderate and 8% area had high groundwater potential at Malacca. The aquifer potential zones and existing well locations in the study area are presented in Figure 7.

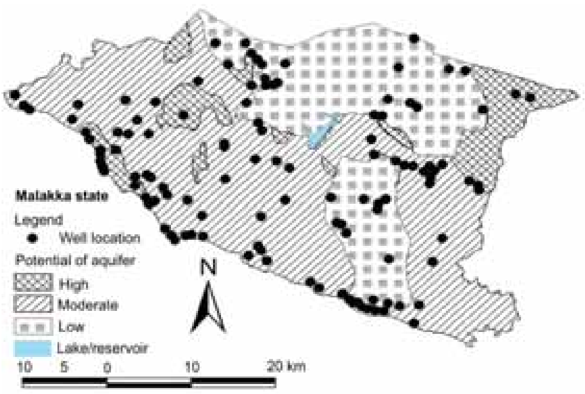

Fig. 7. Well locations and aquifer potential map of Malacca source: own elaboration

GROUNDWATER QUALITY

Water quality is the most important issue for agricultural sectors. Water samples from 52 shallow aquifers and 14 deep aquifers were collected and analyzed for major cations (Ca^{2+}, Mg^{2+}, Na^{+}, Fe^{2+}, Mn^{+2} and K^{+}) and anions (HCO_3^{-}, SO^{2-}_4 and Cl^{-}). Other physical and chemical parameters like conductivity, pH, total dissolved solids and turbidity were also measured. The groundwater quality data for shallow and deep aquifers are presented in Figures 8 and 9, respectively. Groundwater quality of Central Malacca is good and water can be used without any treatment because it was within the limits of drinking water quality standards issued by the Ministry of Health of Malaysia. However, in some places such as Mukim Keeling, Cheng, Ayer Molek and Cage ground waters are salty and brackish as a result of seawater intrusion. Groundwater is affected by brackish character of in the coastal region due to seawater influence and hydro-geochemical processes. The quality of ground water in Alor Gajah district is still eligible as a source of water for residents. The quality of groundwater, particularly in the coastal areas of Kuala Linggi, is diminished by salt water due to intrusion of seawater. Excessive pumping and decreasing recharge rate caused aquifer depletion and led to the intrusion of seawater [MOUSTADRAF *et al.* 2008; PUJARI, SONI 2008; RANGZAN *et al.* 2008; ZHOU 2009]. Coastal areas of this region are often subjected to the brackish and salty inflows both on alluvium stone and hard rock stone.

Groundwater quality analysis indicated that the turbidity, total dissolved solids (TDS), iron, chloride and cadmium concentrations were high in both shallow and deep boreholes. Fifty percent of pH values of shallow boreholes were between 4–6.5 and the other 50% were between 6.5 to 8.2. Similarly, 50% of pH values of deep boreholes were within 4.0–5.2 and the other 50% between 6.7–8.5. High TDS values indicated that groundwater was affected by percolation of agricultural, industrial and residential runoff water.

CONCLUSIONS

The analyses of hydraulic conductivity, transmissivity and aquifers yield indicated that the aquifers formed by sand, alluvium, granite and schist were most productive. In view of aquifer productivity, 35% of the study area had low potential, 57% moderate potential and 8% of the area had high potential for groundwater. Most of the aquifers located on banks of the strait of Malacca showed good potential for groundwater. Groundwater along the bank of Malacca straight is affected by brackish and salty conditions due to the intrusion of seawater while in the inland, there is a great chance to spread contaminants into groundwater by infiltrating wastewater from urban, agricultural and industrial activities. The chemical composition of groundwater in bedrock is often dif-

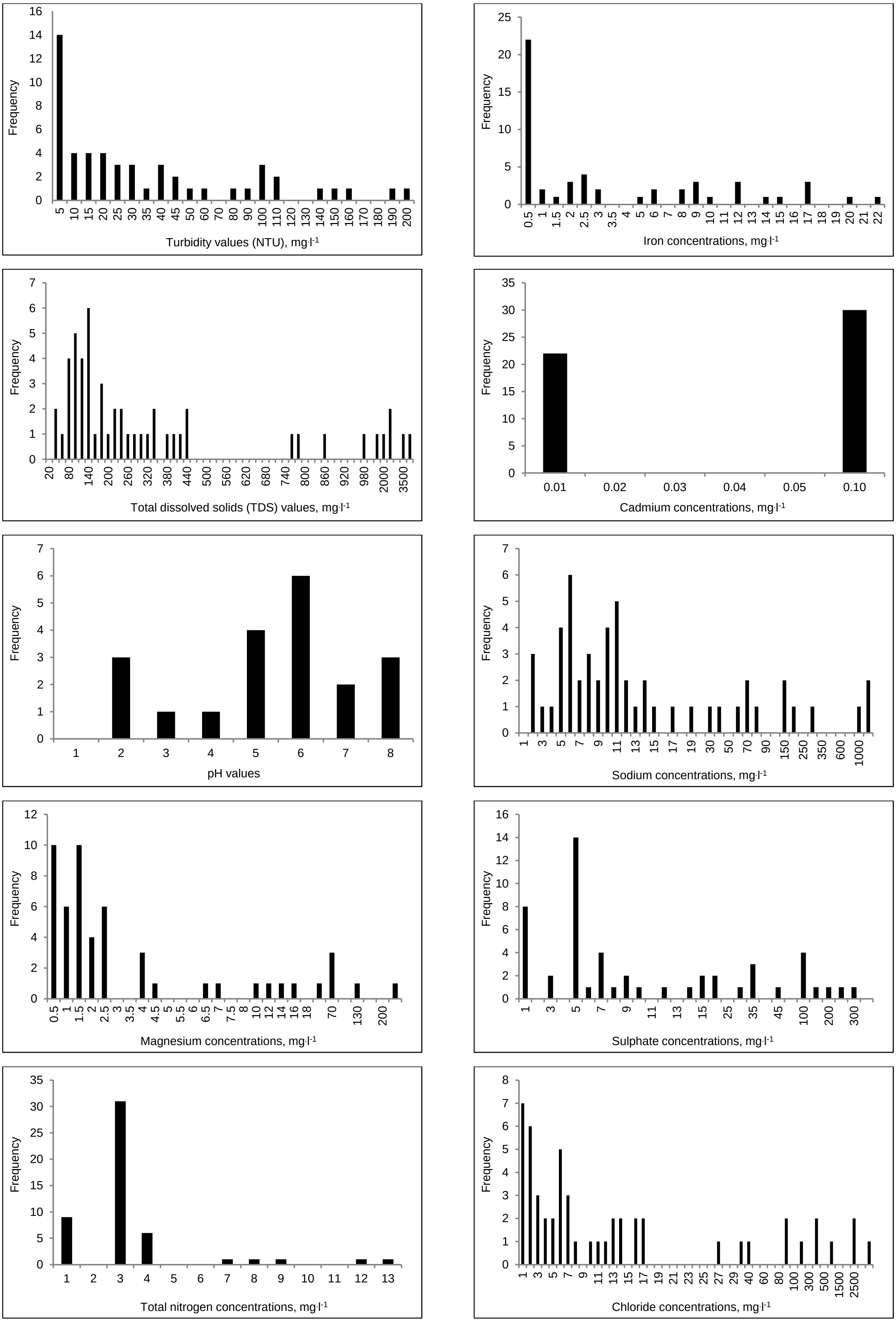

Fig. 8. Quality of groundwater in gauging stations of shallow boreholes; source: own study

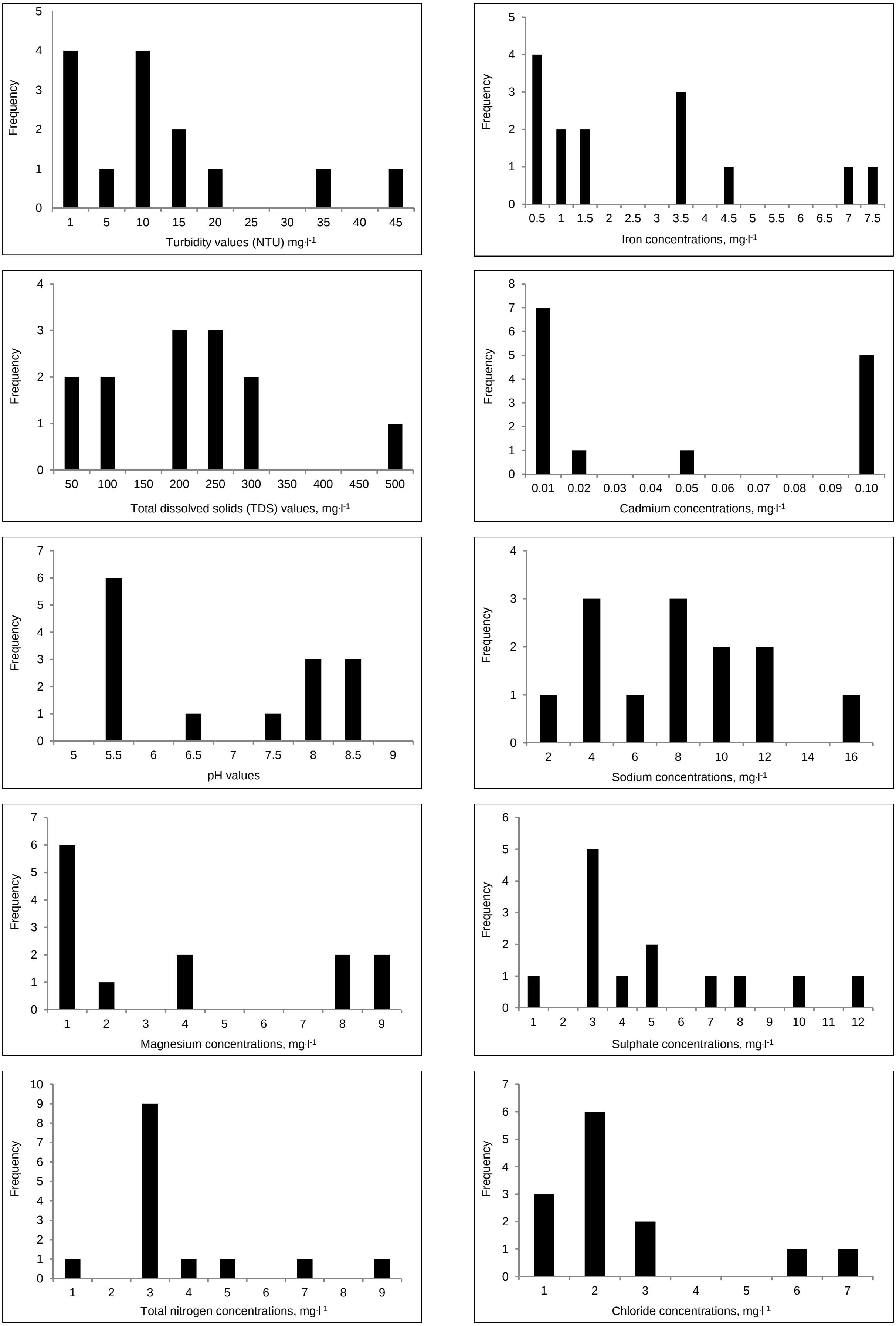

Fig. 9. Quality of groundwater in gauging stations of deep boreholes; source: own study

ferent from that in superficial drift deposit. Groundwater quality analysis indicates that iron, turbidity, total dissolve solids, chloride and cadmium concentrations were high in some cases for both shallow and deep aquifers, and exceeded the drinking water quality standards. The pH values ranged from 4.0 to 8.2 for shallow aquifers and from 5.2 to 8.1 for deep aquifers. Other parameters of groundwater were mostly satisfactory for drinking and others purposes, and did not exceed the drinking water quality standards. Therefore, groundwater of Malacca can be used for drinking and other purposes with major treatment in some cases.

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Jakość wód gruntowych i charakterystyka hydrogeologiczna stanu Malakka w Malezji

STRESZCZENIE

Słowa kluczowe: *jakość wody, pompowanie badawcze, woda gruntowa, wydajność warstwy wodonośnej, zlewnia Malakka*

W artykule przedstawiono jakość wód gruntowych i wydajność warstwy wodonośnej w zlewni Malakka na Półwyspie Malajskim. Do badań zastosowano metodę pompowania badawczego z 210 płytkich i 17 głębokich odwiertów. Najbardziej wydajne okazały się poziomy wodonośne usytuowane w łupkach, piaskowcach, wapieniach i skale wulkanicznej. Na podstawie danych o podłożu i wydajności sporządzono mapę wydajności warstw wodonośnych. Wyróżniono trzy klasy wydajności warstw wodonośnych: wysoka (8%) badanego obszaru, umiarkowana (57%) i niska (35%). Analizom poddano 52 próbki z płytkich warstw i 14 próbek z głębokich warstw. W niektórych przypadkach stężenie zawiesiny, suchej masy, żelaza, chlorków i kadmu przekraczało dopuszczalne wartości dla wody pitnej.