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Influence of Fine-Grained Layer on Groundwater Quality Parameters in Johor's Rural Cathments

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ABSTRACT

Soil testing can be used to characterize clay layers and assess their influence on groundwater quality. The mineral composition of soils plays a significant role in determining groundwater characteristics. In Batu Pahat District, the presence of soft clay and high organic matter content in the soil affects key groundwater parameters. This study aimed to identify the dominant chemical elements in clay soil samples obtained from the RECESS borehole using X-ray fluorescence (XRF) and X-ray diffraction (XRD) techniques, and to examine the correlation between the clayey layer and groundwater quality. The analysis revealed that SiO_2 was the primary component detected in both XRF and XRD results, followed by Al_2O_3 as the second most dominant oxide. K_2O was present at various depths, while other oxides such as Fe_2O_3 and MgO were detected at different levels. Correlation analysis showed a strong positive relationship ($r = 0.90$) between dominant soil elements and clay soil characteristics. However, the correlation between groundwater quality parameters and clayey soil composition was relatively low ($r = 0.43$). The findings contribute to the understanding of clay soil properties in the Johor region, particularly in Parit Raja, and provide valuable insights into the relationship between soil mineralogy and groundwater quality.

1. Introduction

Nowadays, four districts in Johor are experiencing water shortages that could lead to scheduled water rationing. Due to this crisis, groundwater is a suitable option to supply water for consumers. With the availability of this alternative, it can help users get their water supply. As a first step to solving this problem, there are several groundwater wells have been constructed in the Research Centre for Soft Soil (RECESS), Parit Raja, Johor (Figure 1). Batu Pahat District is an area with soft clay and organic matter content in the soil influences the groundwater parameters [1]. Groundwater is one of the natural resources that is not vulnerable to contaminants. However, rising activities of

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municipal, industrial, agricultural, or extreme land-use activities have resulted in groundwater contamination, as occurred at RECESS, Universiti Tun Hussein Onn Malaysia (UTHM) [2].

Raw groundwater quality has been monitored to be considered an alternate water source at a level beneath the water supply-demand [2]. The hydro-chemical characteristics and the type of groundwater were identified in order to investigate the elements of major ions in groundwater samples collected at the hydro-meteorology station located at Parit Raja, Johor [3]. Therefore, the understanding of the hydro-geochemical process and water quality status is a significant component in addressing effective protection measures and implementing sustainable management of shallow groundwater, which has been discussed in previous studies [4,5].

The study focuses on XRD and XRF analysis of clayey soil to discover the most dominant chemical components that affect groundwater quality. The characteristics of soil layers that affect the quality of groundwater are of concern in the field of water engineering. The data were examined to identify the correlation between the clayey layer and groundwater quality. The reason for using XRD and XRF analysis is that XRD identifies and measures the presence in amounts of minerals and their species in the sample, as well as phases, whereas XRF produces an assay by providing information on the chemical composition of the sample without indicating which phases are present.

Fig. 1. The location of the groundwater source at RECESS, Parit Raj

1.1 Groundwater Quality

Natural clay minerals have been known and used by humans since the dawn of civilization. Clay minerals are attractive prospects as adsorbents due to their inexpensive cost, abundance on most continents, high sorption capabilities, and potential for ion exchange. Clay materials are called host materials because they have a layered structure. The distinctions in their layered architectures are used to classify them. Clays include smectites (montmorillonite, saponite), mica (illite), kaolinite, serpentine, pylophyllite (talc), vermiculite, and sepiolite, among others [6].

Groundwater and base flow are also regarded as a stream flow portion of groundwater discharge. It is typically calculated by means of conceptual formulas, recursive filters, or variations. It's rough but validate these approaches regardless of the latest field estimation problems. A simulation of a plaster reaction in a synthetic catchment is conducted using a fully developed water flow model on the surface of the groundwater. The spectrum of different dynamics in stream flow development is known to cover a sequence of rainfall events with different recovery times and various antecedent humidity conditions [7].

Groundwater in soil, sand, and rock is the water that is found underground. The purpose of this study was to identify the principal elementary components of the samples and link the results with mineral kinds and compare them with clays from other studies. XRF on clay sample had a combination of kaolinite (two-layered structure) and illithe in comparison to oxides of the main elements in earlier research three-layered structure [8].

The soil type usually affects groundwater quality and is naturally contaminated because of the soil characteristics. This study intends to investigate the effectiveness of a single treatment using dual Soil aquifer therapy (SAT) and therapeutic-electrolyse procedures for decreasing the pollution of groundwater. The SAT was applied with a deep clay medium physical charging well (REWES). The filters in the well were also well constructed to handle discharges and to clean up the abstraction. Therapeutic electrolysis approaches have treated other contaminants such as fluoride, nitrate, chloride, and groundwater turbidity [3]. Without altering the mineralogy this treatment process eliminates more than 64 % of contaminants. Consequently, these dual treatments have the finest way to decrease unnecessary contamination without harming the purity of groundwater. In terms of economic process and ecological usage for water distribution plants, an eco-distributor system is suitable for implementation. There has been no detailed examination of the scientific basis for the usage of mounds as possible places to locate groundwater structures [9].

1.2 Clay Mineral

Natural clay minerals have been well-known to mankind since the beginning of history (Figure 2). Because of their inexpensive cost, they are abundant on most of the world's continents. In addition to the textural information that may be acquired by optical, microwave, and electron microscopy, the minerals present in the clay are generally based on XRD investigations of clay fractions. X-ray diffraction (XRD) has become one of the leading analytical techniques for the qualitative and quantitative analysis of geological materials throughout the past century [10].

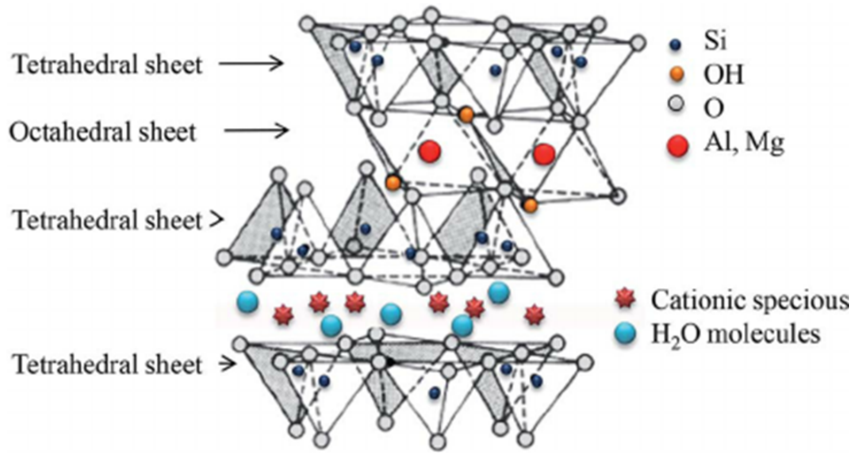

Fig. 2. Clay mineral showing two tetrahedral structures [10]

Clay minerals are silicate layer minerals that are typically generated as a result of the chemical weathering of other silicate minerals near the earth's surface. They are most frequently found in shales, the most common sedimentary rock type. Clay minerals are relatively stable in cool, dry, or temperate regions and are a major component of soil, which is the reason Quartz became the dominating mineral. High concentrations of SiO^2 and Al_2O_3 were contributed by clay minerals [11].

2. Method and Materials

This study area is located at RECESS, UTHM, as shown in Figure 1. There are 4 drilled wells were built in 2013 for groundwater research purposes. The flowchart, as shown in Figure 3, illustrates the study's major phases. Phase 1 identifies the geochemical analysis of the clayey soil layer by using XRD and XRF techniques. Phase 2 was to correlate XRD and XRF results and groundwater characteristics taken from previous studies. Then, the final stage is phase 3, which includes data analysis, discussion, and conclusion of the study.

This study is concerned with the correlation analysis of the clayey layer effect on groundwater quality by using XRD and XRF analysis on RECESS well at UTHM campus. The 13 samples were collected from 1.5 m to 48 m deep during the construction well. The soil tests were performed to examine soil characteristics. The character of soil can indicate the quality of subsurface water [12]. In this study, clayey soil samples were assessed by XRF and XRD analysis. The groundwater quality parameters were collected from a prior study done by Jing *et al.* [4] and Goa *et al.* [5]. The correlation coefficient value is determined using Pearson's method. Knowing the dominant element is important for correlating groundwater characteristics. Other researchers may be able to apply the findings from this study to conduct future research that will have a significant influence, particularly in the soil and water quality sector.

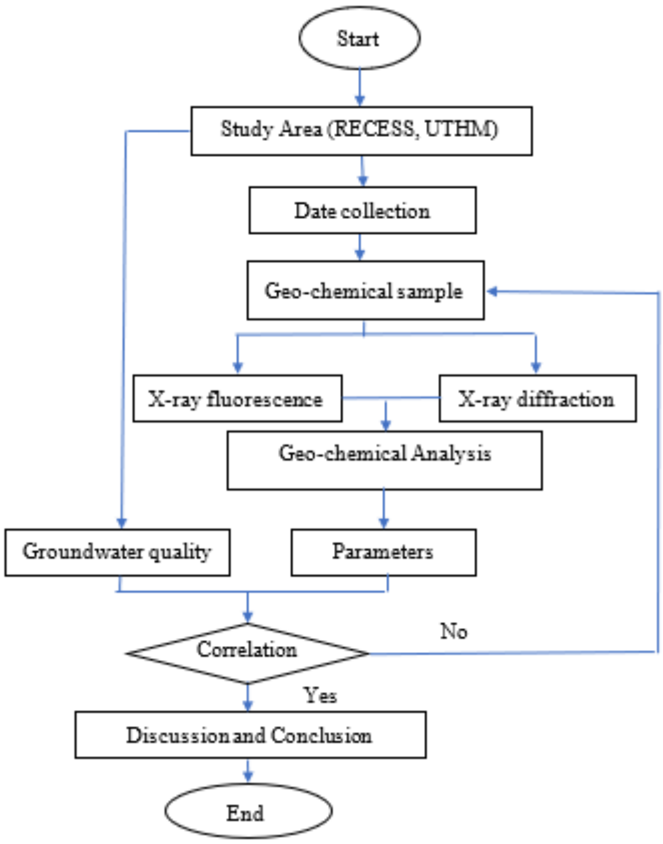

Fig. 3. The groundwater analysis for this scope

2.1 Data Collection

There are several drilled wells were built for groundwater research in the local region. Soil samples were collected from the well (N 1°51’6.92900”, E 103°4’52.65880”) for soil characteristics, XRF, XRD, and water quality analyses (Figure 4). Table 1 from previous studies by Jing *et al.,* [4] and Goa *et al.,* [5] showed that the quality of groundwater in the RECESS borehole and UTHM campus Parit Raja was identified. The water quality properties listed in Table 1 were used during the data analysis to find the correlation between the clay layer and groundwater quality.

Fig. 4. The pumped well was built in 2013 and is located at RECESS, UTHM

Table 1
The content of contaminants in groundwater parameters [3]

Parameters	Study area (UTHM)	KKM Standard	Groundwater quality Standard (raw water criteria)	MOH Drinking Water Standard
pH	7.81	6.6-9.0	5.5-9.0	6.5-9.0
Dissolved Oxygen (DO), (mg/l)	6.70	8.0-10.0	n.a	n.a
Turbidity (NTU)	7.26	5.0	1000	15
Manganese (mg/l)	1.2	0.1	150	150
Chloride (mg/l)	1518.46	250	250	250
Sulfate (mg/l)	1389.49	250	250	250
Nitrate (mg/l)	13.06	10	10	10

2.2 Geochemical Phase

The two methods used were analyses to characterize the relationship among soil samples and to determine their respective compositions, especially in the clay minerals aspect. The soil samples were collected at depths of 1.5 m to 48 m. To analyze the elements and minerals, the samples were dried, crushed, and powdered using the crusher at the UTHM laboratory. The powdered samples were then compressed and molded for scanning of chemical and mineralogical distributions. Geochemical analysis was conducted on the chemical elements through the X-ray fluorescence (XRF) scanning method. To identify the secondary minerals in the soil, the X-ray diffraction (XRD) method was carried out in layers through the XRF composition outputs.

2.3 X-ray Fluorescence

A set of 13 soil samples was selected for the analysis of their chemical content with X-ray fluorescence. These samples were collected from 1.5 m to 48 m soil depth were located at the UTHM campus in Parit Raja, Johor, Malaysia. The raw data from the laboratory were analyzed to identify the chemical compositions of the clay soil.

2.4 X-ray Diffraction

X-ray Diffraction is the most common technique used in soil mineralogical analysis is the x-ray diffraction. X-ray diffraction is a device that produces detailed information about the atomic structure of crystalline materials, which have long been a key factor in soil mineral identification.

The XRD of the heavy mineral fraction was done at the laboratory to identify the crystalline phase in the clay soil and to determine the mineralogical composition of the raw material components, as well as the qualitative and quantitative phase analysis of multiphase mixtures. An X-ray diffractometer was used for this analysis.

2.5 Correlation Phase

The correlation coefficient is a statistical measure that determines the degree of the relationship between two variables' relative movements (dependent and independent variables). When the movement of one variable is followed by the movement of another variable, the variables are said to be correlated. Correlation, on the other hand, is a statistical method for determining the degree of association between two variables [13]. Table 2 shows the rule of thumb for interpreting the size of a correlation coefficient by Haldun [14].

Table 2
Study rule of thumb for interpreting the size of a correlation coefficient [14]

Size of correlation	Interpretation
0.90 to 1.00	Very high positive
0.70 to 0.90	High positive
0.50 to 0.70	Moderate positive
0.30 to 0.50	Low positive
0.00 to 0.30	Little if any correlation

The correlation between the parameters is characterized as strong; when it is in the range of $\pm$0.8 to $\pm$1.0, moderate in the range of $\pm$0.5 to +-0.8, weak when in the range of 0.0 to $\pm$0.5 [15]. Correlation refers to the mutual relationship between two variables. A direct (positive) correlation occurs when an increase or decrease in the value of one parameter is associated with a corresponding increase or decrease in the value of the other. Conversely, a negative correlation occurs when an increase in one parameter results decrease in the other. The correlation coefficient *(r)* ranges from +1 to -1. A correlation is considered strong when *r* falls within the range of ±0.8 to ±1.0, moderate when within ±0.5 to ±0.8, and weak when within 0.0 to ±0.5 [15]. The correlation coefficient (r) among various water quality parameters was calculated, and the values of the correlation coefficients are given in Table 2.

3. Results

The purpose of XRD was to determine the crystal structure of a material (X-ray crystallography) or to detect and quantify crystalline phases in a clay soil sample. X-ray fluorescence (XRF) was used non-destructive technique to determine the elemental composition of the clay soil. XRD provided information about the crystalline phases present in the clay sample and can distinguish between compounds. The correlation between XRF and XRD results is shown in Table 3. The statistical analysis showed that the $p > 0.05$ correlation is significant, as shown in Table 4. Therefore, the correlation between XRD and XRF calculated is equal to 0.9, which shows a highly significant correlation as $p = 0.9 > 0.05$.

The comparison between XRD and XRF data is shown in Table 4. The SiO_2 is the sample's main component in both XRD and XRF analysis. Al_2O_3 is the second most abundant component in XRF analysis, whereas Fe_2O_3 is the second most abundant compound in XRD analysis, although there is minimal difference in XRF analysis. Both XRD and XRF analyses reveal different amounts of K_2O were 1.6 % and 0.9 % respectively. SO_3 accounts for about 0.8 % in XRF analysis but almost half (0 %) in XRD analysis. MgO and TiO_2 were detected at 0.9 % in XRF analysis, but only 0.1 % were detected in XRD.

Table 3
Correlation of XRD and XRF for each depth

Sample for XRD and XRF at the depth	Correlation coefficient
1.5 m	0.91
3.0 m	0.905
9.0 m	0.91
10.5 m	0.92
13.5 m	0.89
15.0 m	0.905
16.5 m	0.89
18.0 m	0.89
21.0 m	0.87
22.5 m	0.85
25.5 m	0.88
28.5 m	0.987
48.0 m	0.987

Table 4
Chemical concentration in soil

Parameters	XRF (%)	XRD (%)	Correlation (%)
SiO_2	66	81.5	24
Al_2O_3	31.4	3.1	-28
SO3	0.8	0	89.7
Fe_2O_3	1.7	0.5	1
K_2O	1.6	0.9	34
MgO	0.9	0.1	-9
TiO_2	0.4	0.3	-9

The result found that many researchers, in line with previous studies by Nayak and Sigh [6], stated that clay is composed mainly of silica, and [12] found a high concentration of Silicon dioxide (SiO_2) (43.90 %) and Aluminium Oxide (Al_2O_3) (12.10 %). High concentrations of SiO_2 and Al_2O_3 were contributed by clay minerals such as illite [11], and quartz was the most dominant in all the samples.

Correlation is a statistical tool that helps to measure and analyze the degree of relationship between chemical concentration in soil and raw water parameter quantity. The overview result of the XRD and XRF was correlated with groundwater quality in the study area, as shown in Table 5, which indicated a low positive correlation value.

Table 5
The correlation between soil chemical and groundwater (raw water) content

Formula	Soil (%)	water (mg/L)	r
Silicon dioxide (SiO_2)	24	1518.460	
Aluminium oxide (Al_2O_3)	-28	0	
Potassium oxide (K_2O)	34	0	0.43
Iron oxide (Fe_2O_3)	1	0	
Magnesium Oxide (MgO)	-9	1.2	

4. Conclusions

Based on soil sampling and XRD analysis, a detailed map was created identifying each location in the field where subsamples were collected. The composite sample consisted of 48 soil concentrations from the study area. A total of 13 cores were extracted at depths of 1.5 m, 3 m, 9 m, 10.5 m, 13.5 m, 15 m, 16.5 m, 18 m, 21 m, 22.5 m, 25.5 m, 28.5 m, and 48 m. The analyzed components included silicon dioxide (SiO_2), aluminium oxide (Al_2O_3), potassium oxide (K_2O), iron oxide (Fe_2O_3), and magnesium oxide (MgO). XRD and XRF analyses were performed on clay soil samples from the 13 different depths obtained from the RECESS borehole. The results indicated that the dominant oxides were SiO_2, Al_2O_3, and K_2O, followed by Fe_2O_3 and MgO. The correlation coefficient between soil composition and groundwater quality was calculated to be 0.43, indicating a low positive correlation. It can be concluded that the soils in the study area contain both major and minor metallic oxides, with their concentrations varying according to depth.

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