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Advanced Characterizations of Earth Materials for Cost Effective Wastewater Treatment

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ABSTRACT

Water pollution has been identified as affecting the environmental balance, including the ecosystem. Textile industry has also been identified as a source of wastewater. Depending on the nature of the pollutant, treatment methods such as chemical treatment, physical treatment or biological treatment are selected. Research and development of some cost-effective earth materials for water treatment applications is becoming an important chapter in the modern research world. Clay is the dominant material of the earth, which has versatile properties that are solutions to most of the scientific and technological problems and currently different types of clay are being tested for different water treatment purposes. As part of the present study, it was planned to characterize the chemical properties of three selected clays based on the disclosure of their important properties. The clay samples were collected from three different regions of Sri Lanka and these clays were named as ant nest clay, brick clay and tile clay according to their uses. The clay samples were characterized chemically using X-ray fluorescence (XRF), Fourier transform infrared (FT-IR) spectroscopy and X-ray diffraction (XRD) spectroscopy. According to the study results, each clay contained at least 75% Fe, at most 6% Ti, at most 5.30% Ba, at most 13% K which was present only in ant nest clay and ant nest clay and only 7.5% Ca in brick clay. According to the X-ray fluorescence (XRF) spectroscopy results, the presence of kaolinite, muscovite and quartz as minerals in each clay according to the available associations based on Fourier transform infrared (FT-IR) spectroscopy and mineralogical results was determined. This was confirmed by X-ray diffraction (XRD) spectroscopy results. According to recent research, kaolinite and muscovite are strong adsorbents for some other metals such as heavy metals and dyes and it was also studied that K^+ and Ca^{2+} are strong exchange ions. Therefore, these clays can be recommended for textile wastewater treatment experiments and applications based on the task of removing heavy metals, removing some pathogens, dyes and removing some unnecessary dissolved cations.

1. Introduction

Environmental pollution has been identified as an acrimonious accomplishment because of the anthropogenic activities and a few of natural circumstances. According to the further concerns and categorizations of the environment pollution, it is even handed to study that massive topic under a few of specific categories.

When considering the various pollution aspects in different states, the water pollution obtained a leading attention among other pollution categories because the water plays a dominant role on the life of human beings, animals, plants and the equilibrium of the ecosystems. As the most pertinent reasons for the water contamination or the pollution, the following activities and processes can be emphasized.

- Increasing of water consumption
- Irrigation and agricultural activities
- Industrial activities
- Unsystematic waste disposal
- Natural processes
- Urbanization
- Global warming
- Deforestation

Ensuring the preservation of water quality and the mitigation of water pollution should be regarded as a crucial matter, as water has been recognized as a finite resource globally, particularly when considering the portion that is suitable for consumption. Numerous water quality regulations and frameworks have been implemented in different parts of the world, taking into account specific conditions and risks. Consequently, the conservation and treatment of water have gained immense importance in industries, households, and for individuals. The most common wastewater treatment methods can be listed as follows.

- Physical treatment methods
- Chemical treatment methods
- Biological treatment methods
- Sludge treatment methods

When considering physical and biological treatment methods, it is important to note the relatively higher costs associated with installation and operation, as well as the need for technical expertise. As a result, most of these treatment methods are primarily used for large-scale or industrial wastewater treatment purposes [1-12].
Based upon the modern research studies of waste water treatments, there can be found some developments and applications in following materials.

- Clay minerals (kaolinite, montmorillonite, smectite)
- Dolomite

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- Zeolite
- Activated carbon
- Charcoal
- Saw dust
- Risk husk
- Plant materials

The objective of the previous study was to develop a wastewater treatment system using natural substances such as clays, dolomite, feldspar, river sand, and activated carbon made from burnt coconut shells.

2. Materials and Methodology

According to the selections of materials for the existing research activity, the following criteria were followed.

- Current industrial applications of the clays (primitive/ advanced)
- Publicity of the clay deposit
- Locations of the clay deposit

The list of selected materials is given in the below.

- Three different clay types
- A selected dolomite variety
- A selected feldspar variety
- A selected variety of river sand
- A variety of burnt coconut shells/ activated carbon
- A variety of vein graphite

Three different types of clays were selected for the existing research component as follows.

- Clay type 1- No industrial application and using in the building of anthill by termite
- Clay type 2- Manufacturing of bricks for building construction
- Clay type 3- Manufacturing of roof tiles for buildings

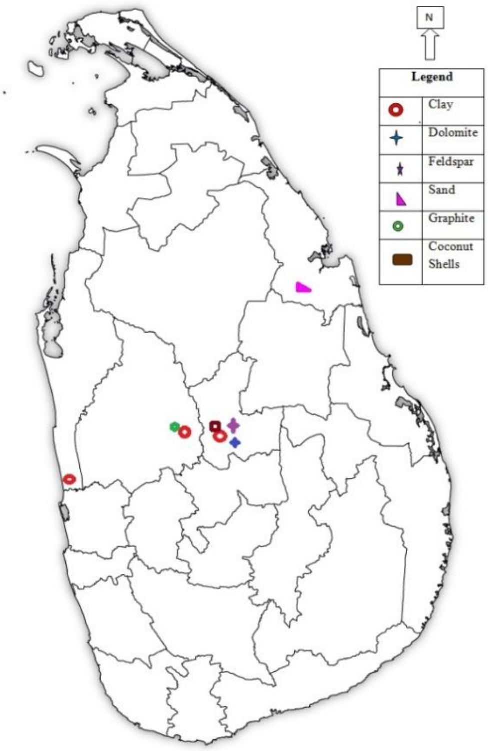

Fig. 1. Sampling locations in Sri Lanka

According to the scope and the objectives of the existing research, the methodology part has been sub-divided in to following sections.

- Finding/ providing of earth materials
- Experimentations of the general and essential characteristics of those earth materials and synthesis of some alteration forms of raw materials
- Designing and manufacturing of the water treatment system using above earth materials (optional)
- Collecting of different types of wastewater samples and experimentations of a few of water quality parameters of those wastewater samples (optional)
- Experimentation of the impact of the manufactured waste water treatment system on the qualities of wastewater (further recommendation).

The characterizations of materials were performed as mentioned in the Table 1.

Table 1: The summary of the characterizations of materials

Earth Material	Clay	Dolomite	Feldspar	Burnt Coconut Shells	River Sand	Vein Graphite
Primary Physic-Chemical Analysis	√					
Strength Analysis (Bricks)	√					
X-ray diffraction (XRD) Analysis	√					
X-ray fluorescence (XRF) Analysis	√	√	√	√	√	
Fourier Transform Infrared (FT-IR) Analysis	√	√				
Optical Microscopic Analysis	√	√	√	√	√	
Scanning Electron Microscopic (SEM) Analysis	√	√	√	√	√	√
Atomic Absorption Spectroscopic (AAS) Analysis	√					

3. Results and Discussion

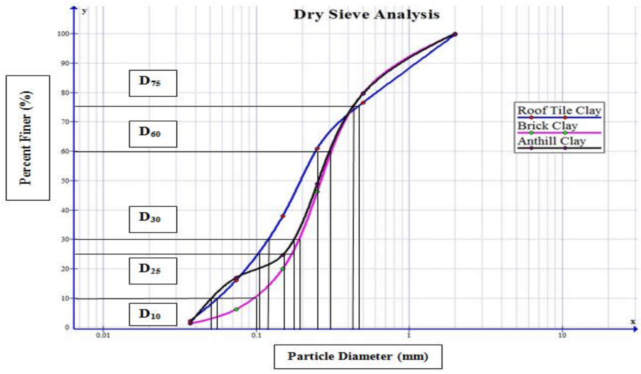

Fig. 2. Particle size distribution curves of three different clays

Analyzing the curve helps understand the soil's gradation and organization, providing data for calculating coefficients that evaluate properties like porosity, permeability, and hardness. Roof tile clay has a well-graded distribution of particles with lower porosity and permeability, along with a higher proportion of fine particles. Anthill clay has a gap-graded arrangement of particles, as indicated by a discontinuity in the curve, showing an uneven distribution of particle sizes due to the absence of particles in specific intervals. Brick clay has a poorly graded and organized particle distribution, revealed by a continuous, smooth curve with a steep incline in its particle size distribution curve [5-9].

Table 2: The important determinations on soil parameters

Type of Clay	Effective Size / D_{10} (mm)	Uniformity Coefficient /C_u	Coefficient of Gradation /C_c	Sorting Coefficient / S_0	Skewness/ S_K
Anthill Clay	0.051	5.78	2.04	1.71	0.248
Brick Clay	0.096	3.23	1.24	1.60	0.273
Roof Tile Clay	0.055	4.45	1.05	2.12	0.255

The findings suggest significant implications for the physical and chemical properties of different clays. The effective size (D_{10}) influences soil characteristics like permeability. There is a correlation between D_{10} and a soil's permeability. Brick clay has the highest D_{10} value, while anthill clay has the lowest. As a result, brick clay is expected to have higher hydraulic conductivity. However, hydraulic conductivity is not solely determined by D_{10}. Brick clay has poor grading compared to other clays based on its uniformity coefficient. Any clay with a significantly different uniformity coefficient from 4 is considered poorly graded. Roof tile clay has a coefficient of gradation (Cc) value closer to 1, indicating balanced particle distribution.

Anthill clay deviates from a balanced distribution like poorly graded brick clay. Roof tile clay has a higher sorting coefficient, suggesting it is well graded, while brick clay has a lower sorting coefficient. Average grain size can represent the particle size distribution of a series of clays. Brick clay particles are relatively larger. All clay types are fine skewed based on their skewness values. Anthill clay has a more symmetrical particle distribution. Roof tile clay shows good grading and sorting, while brick clay shows poor grading. Anthill clay exhibits irregular fluctuations in key parameters. Based on grain sizes and sorting, brick clay is more suitable for water treatment [2-13].

Table 3: Important physic-chemical characteristics of clays

Physic-Chemical Characteristic	Anthill Clay	Brick Clay	Roof Tile Clay
Moisture Content (%)	15.49	21.45	25.97
Splitting Tensile Strength (MPa)	0.44	0.31	1.30
Compressive Strength (MPa)	20.88	17.25	>31.68
Water Absorption (%)	24.93	19.88	17.30
Bulk Density (g/cm^3)	2.62	3.15	2.00
Apparent Porosity (%)	65.28	62.70	34.59
Acidity (pH)	5.56	6.57	5.68

Analysis showed anthill clay with lowest acidity and brick clay with highest. All samples had acidity below neutral pH of 7, ranging from 5.5-7. These clays pose minimal risk in food and water applications. Acidity levels in clay can vary due to external factors. Anthill clay brick had highest water absorption, while roof tile clay had lowest. Water absorption is key for evaluating clay's properties. Roof tile clay bricks had higher compressive strength than brick clay despite lower water absorption. Anthill clay bricks had highest water absorption and average compressive strength, while brick clay bricks had lower strength and absorption.

Table 4: The summary of XRD analysis of clays

Mineral	Chemical Formula	Observations for 2Θ	Reference Values for 2Θ
Kaolinite	$Al_2(Si_2O_5)(OH)_4$	$14^0, 20^0, 26^0, 45^0, 65^0$	$12^0, 25^0, 37^0$
Muscovite	$KAl_2(Si_3Al)O_{10}(OH)_2$	$20^0, 35^0, 55^0$	$9^0, 18^0, 27^0, 46^0$

Quartz	SiO_2	$21^0, 23^0, 32^0$	$21^0, 27^0, 36^0, 39^0, 43^0, 50^0$

The main peaks at 14, 20, 26, 45, and 65 degrees indicate the presence of kaolinite in small amounts. Aluminum is the main element in kaolinite. Kaolinite is common in the three types of clay. Muscovite is the second most abundant clay mineral. Muscovite was inconclusive in brick clay. Quartz traces were found in the clay samples. These clays are useful for wastewater treatment due to kaolinite's adsorption properties. Kaolinite has a high specific surface area and can adsorb pollutants. Different clays have varying adsorption capabilities [6-12].

Table 5: Elemental chemical compositional analysis results of earth materials

Earth Material	Fe (%)	Ti (%)	Ba (%)	K (%)	Zr (%)	Ca (%)	Zn (%)
Anthill Clay	82.08	4.84	0.79	12.28	-	-	-
Brick Clay	84.38	5.92	2.14	-	-	7.56	-
Roof Tile Clay	75.72	2.95	5.30	12.67	3.36	-	-
Dolomite	-	-	-	0.54	-	99.46	-
Feldspar	5.14	-	-	52.98	-	41.43	0.45
Burnt Coconut Shells	68.85	-	-	31.15	-	-	-
River Sand	26.16	2.66	14.10	31.91	-	25.18	-

Ca^{2+} is a common substitute cation in ion exchange, which is essential for managing wastewater. Brick clay has potential for ion exchange. Clays in roof tiles contain Fe and other useful elements for water treatment. No harmful elements were found in clay samples. Dolomite samples primarily contain Ca and a small amount of K, improving their properties. Ca^{2+} can effectively replace toxic ions in ion exchange. CaO in dolomite is heat-resistant. $CaCO_3$ is effective at adsorbing heavy metals. Mg was not detected in dolomite samples, likely due to the experiment. Activated carbon from burnt coconut shells has Fe, K, and carbon with no hazardous elements. It is recommended for treating contaminated water, especially leachate from landfill sites. Leachate characteristics include smell, metallic content, organic pollutants, color, and natural organic matter. Activated carbon effectively removes odor and taste from water. Feldspar varieties are strong adsorbents due to potassium and calcium content, making them suitable for water treatment. River sand composition does not contain harmful elements, but further analysis is recommended before industrial uses [4-15].

4. Conclusion and Recommendations

The study found different geological materials, including clay, dolomite, feldspar, graphite, river sand, and burnt coconut shells. The clay types anthill and roof tile have fine clay particles suitable for filtration. Clays like kaolinite, muscovite, and montmorillonite can absorb heavy metals and pathogens. High calcium dolomite can adjust water pH levels. Burnt coconut shells can absorb particulate matter and heavy metals. Feldspar is non-toxic and can remove pathogens from water. River sand is safe and good for filtration. Vein graphite can absorb oil contaminants. The research can help in wastewater treatment by removing pollutants and adjusting properties. Certain clays and burnt coconut shells can also be used as catalysts. Future research should explore these materials further for various applications in wastewater treatment. Advanced analysis of clays, dolomites, feldspar, burnt coconut shells, river sand vein graphite, analysis of three types of clay using Neutron Activation Analysis. Manufacturing of activated carbon using coconut shells and creating a wastewater treatment system using earth materials will be suggested further. Testing the system with different types of wastewaters, experimenting with different earth materials for better performance, using nano-materials for improved adsorption, adjusting parameters for optimal performance, monitoring pollutant removal over time and the experimenting with backwashing methods using natural compounds are further recommendations for some advanced researches.

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