ORIGINAL ARTICLE

TREATMENT OF POLLUTED WATER USING NATURAL ROCK MATERIAL AT THE HOUSEHOLD LEVEL

Esayas Alemayehu, BSC, MSC (ENG.); Wondwossen Birke, BSC

ABSTRACT

BACKGROUND: *In rural and semi-urban communities of developing countries, including Ethiopia, adequate water treatment procedures are almost non-existent, mainly for economic reasons as well as settlement characteristics of the people. Hence, a technology that does not demand much financial resource at household level is required. The aim of this study was to test the filtering capacity of natural rock material obtained in the rift valley of Ethiopia.*

METHODS: *The rock material "Pumice" was collected from Metehara and Awash-7 Kilo areas, the rift valley of Ethiopia and then designed into rock vessels which were 2cm, 4cm and 6cm, cylindrical and hemispherical shapes at the top and bottom, respectively.*
Three experimental cycles were under taken. Polluted water samples that had initial average concentration of 497 Most Probable Number (MPN) per 100mL of faecal coliforms, 93. 2 Formazine Turbidity Unit (FTU) of turbidity, 83.3 True Color Unit (TCU) of color, 1.405 mg/L of fluoride, 0.63 mg/L of iron, 0.028 mg/L of manganese and a pH of 6.74 at a temperature of 20.5^{0}C were passed through the rock vessels.

RESULTS: *There was a very good reduction of contaminants in which faecal coliforms became 96.4%, 97.6% and 98.4%; turbidity 96.5%, 96.7% and 96.9%; color 88%, 89.2% and 92.8%; temperature 5.9%, 6.15% and 6.3%; fluoride 22%, 38.6% and 67.5%; Iron 79.4%, 87.3% and 88.9%; manganese 67.9%, 89.3% and 92.9%; but, the mean averages for the hydrogen ion concentration (P^H value) increased gradually to 6.53%, 8.2% and 6.7% in 2cm, 4cm and 6cm rock filters, respectively.*
The study has revealed that, as the filter run increased, the efficiency to eliminate the contaminants was positively significant (p>0.05). It was also observed that there is a declining trend in filtration rate as the frequency of the filter run increased.

CONCLUSION: *Natural rock filter has the capacity to filter impurities from contaminated water. It is a relatively simple technology for household water treatment. Further studies also need to be done on other removal mechanism (adsorption capacity of the rock), characterization of the rock and the application of this natural rock as a conventional water treatment media, which are not included in this study.*

KEY WORDS: *Natural rock water filter vessels, Physiochemical, Microbial Impurities, filtering capacity, household level, polluted water.*

Correspondence:Esayas Alemayehu, Address: Jimma University, Public Health Faculty, School Of Environmental Health, P.O.Box 388; Tel. 111432; Fax 111450,
E-mail: esayas16@yahoo.com

INTRODUCTION

Water must be contaminated with associated disease causing organism or hazardous chemicals to act, as a vehicle for the spread of a specific disease. Disease causing organism can survive for periods of days to years depending upon their form, environment and treatment given to the contaminated water. All sewage-contaminated water is presumed to be potentially dangerous. Other impurities such as inorganic and organic chemicals and heavy concentration of decaying organic matter may also find their way into water supply, making the water hazardous, destructive or otherwise unsuitable for domestic use (1).

More than 80 percent of the communicable diseases, some of them in an epidemic form, are caused due to lack of safe and adequate water supply and inappropriate disposal of waste. Provision of potable water supply for prevention of water borne and other related disease is the most important consideration in the field of public health. This is also expressed as an essential component of primary health care.

Water, which is safe for drinking, must be free from pathogenic organisms, toxic substances, excess minerals and organic matters to be attractive to consumer. It should be free from color, turbidity, odor; and it should contain sufficient oxygen and an acceptable test (1). Based on the above facts, some methods are required to make water suitable for human consumption.

Although safe and reliable water supply is badly needed, a number of factors have made it impossible to utilize the conventional engineering solution of extending the municipal water system (2). In this case small-scale treatment processes seem to be suitable methods of providing relatively clean water for those who draw their water supplies from unprotected wells, ponds and streams.

Boiling, straining (by cloth), storage to remove silt load, the use of natural coagulant such as chitosan, moringa and nirmaliseeds (3, 4), up flow - down flow filters (6), ceramic candles and home-made sand filters (7) are some of the options that are applicable at household level in different parts of the world.

Although there is no clear information on the extent of the Natural Rock Water Filter, its use as a means of household level water purification is known in some parts of Ethiopia such as among the people living in the Rift valley rural and urban areas of Metehara, Awash - 7- kilo and other parts of the country. The purpose of this study was therefore directed towards evaluating the physico-chemical and bacteriological-filter capacity of the natural rock material.

MATERIALS AND METHODS

An experimental study to evaluate the effectiveness of natural rock water filter was conducted in Environmental Health School Laboratory, Jimma University.

The natural rock was collected from Metehara and Awash – 7 – Kilo areas, the rift valley of Ethiopia for the study purpose. The amorphous rock (Pumice), locally known as "BEHA", was then cut and shaped into three vessel (pot) like structures of 2cm, 4cm, and 6cm side and bottom thickness using locally available hand tools. The filter medium was designed to have a shape of right circular cylinder at the top and semi-circular (hemispherical) at the bottom with an internal diameter of 18cm and a 20cm height for the cylindrical part. The radius of the spheroid part was the same as the top cylindrical portion and the depth (height) was taken to be as suitable as possible, but the same depth was kept for the three pots see figure 1.

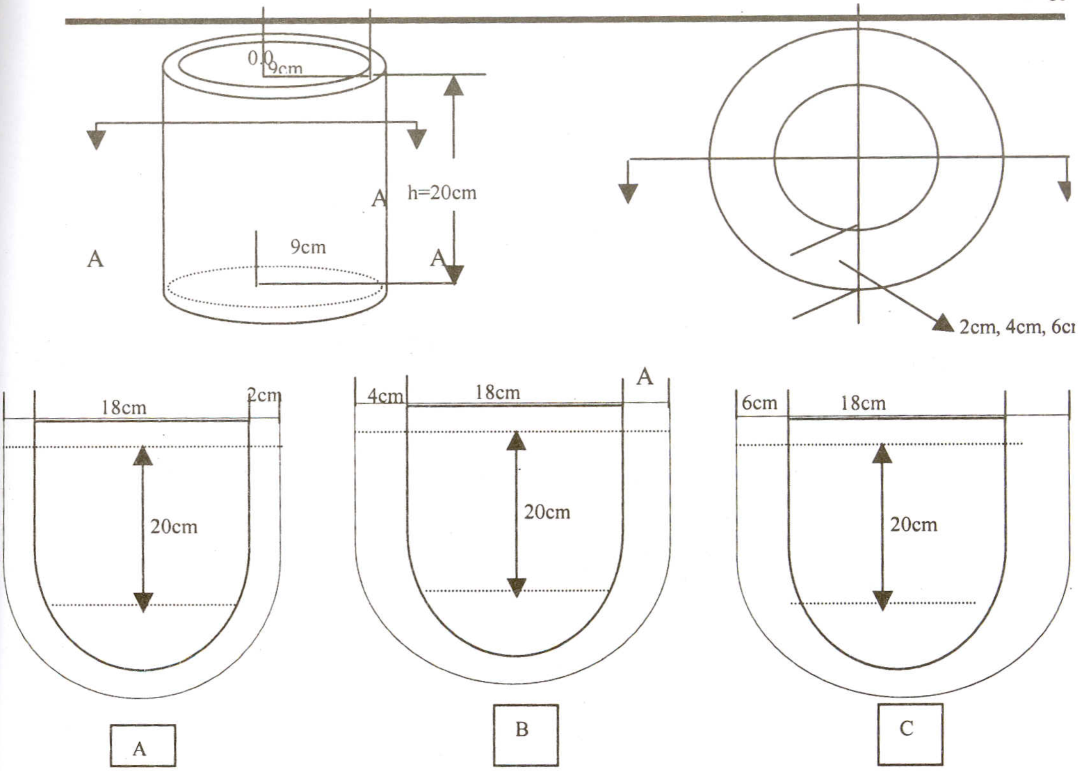

Figure 1: Top, isometric view and section A-A' of the rock filter vessel 2cm, 4cm, and 6cm side and bottom thickness (A, B and C respectively), (not drawn to scale)

Shaping of the rock in such a way would enable to facilitate its operation under the influence of gravity since it was assumed to ooze out liquid (water) in its entire body surface. The cylindrical portion of the rock that remained above the filtered water holding tank (a plastic bucket shaped like a frustum of a cone with a capacity of 10 liters in volume was utilized) was covered and guarded from extraneous forces (agents) by plastic sheets see figure 2. In so doing the plastic sheets was glued only at the top rims of the cylindrical portion of the rock.

The raw water holding capacity (internal volume) of each pot was found to be; Volume (by volume postulate) = the volume of right circular cylinder + the volume of the Spheroid part. Therefore, each pot had approximately a capacity to hold 7 liters of raw water at a time.

Filter media and tanks might come in contact with foreign agents while they were prepared. This contamination thus had a direct influence on the findings of bacteriological tests. Therefore, both were disinfected with a liquid bleach of 5% NaOCl at a 50 PPM to minimize the occurrence (outcome) of false results.

In disinfecting each medium and tank, the inside parts of both as well as the outer part of the medium was cleaned thoroughly by brushing and flushing. The solution was poured in to them when they were half-full of water (water from piping system) and left for at least 12 hours. And then, they were emptied and the water was let to run to waste.

The disinfection operation might be expected to have an effect on the bacteriological findings and hence the continuation of the bactericidal action that might be occurred of the halogen (chlorine) was controlled (avoided) by using a dechlorinating agent called sodium thiosulphate ($Na_2S_2O_3$, 0.88mg/L) (12) with the addition of water from a tap before the on set of the pretest and cycles of the experiment. Aseptic condition made in such a manner was counter checked by adding distilled and sterilized water (sterilization was made with the help of an autoclave) in to the medium and then bacteriological tests was carried out.

Consequently, the filter medium was inserted into the tank until the portion of the medium went down. The plastic sheet glued at the top rim of the medium was extended over the tank to cover the space between the medium and the tank in order to avoid the entrance of foreign agents during filtration operation.

Deterioration in the real quality of the raw water (i.e., the raw water quality that was already known before filtration) might have been expected to occur as a result of some droppings from the top to the medium and hence the problem was tackled by preparing a cover (lid) made of timbered wood (lumber; plank). During the filtration operation, the filter media and the filtered water holding tankers were undisturbed through out the experiments (i.e. no washing and rinsing of them after each cycle of the experiment was occurred) in order not to cause re-suspension of any of the settled matters available there. The users' of the rock also have a trend of not washing it for a period of a month or more. Drying of filter bed was prevented between cycles of the experiment to avoid cracks that act as a conduit allowing short-circuiting of raw water by adding distilled and sterilized water.

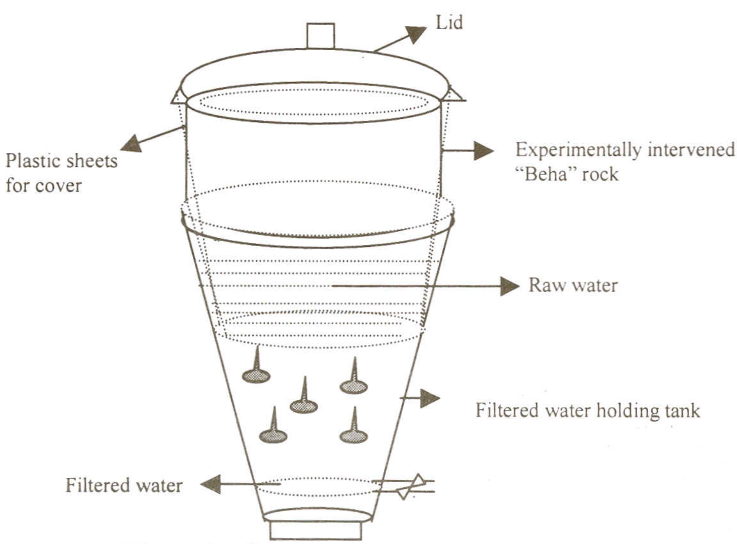

Figure 2: Filter arrangement using the intervened rock.

Water Samples for study and analysis were collected from River Awetu, crossing Jimma town, and 2km from the research area. The river was subjected to different pollutants such as solid and liquid wastes. The indiscriminate disposal of town wastes created aesthetically unsightly conditions by being washed down with storm water and sewage. There are more than ten open ditches in which sewage from different sources is collected and continuously ends up in the stream course by gravitational pulls (13). The river water had a large bacteriological load (about 1100 faecal coliforms per 100 ML of untreated water), which makes it an ideal source for the experiment.

Fecal coliforms were analyzed by using multiple tube fermentation technique for the easy availability of chemicals. Samples were taken aseptically from the Jerycan (raw water) and from the outlet tap of the filter units. Standard laboratory procedures w ere u sed d uring the analysis. Turbidity of the samples was measured using Absorptometric method. Visual colorimetric method, thermometer (Digital probe), Electrometric method, Alizarine photometric method, and Palintest Photometric methods were used to measure color, temperature, P^H, fluoride, iron and manganese, respectively.

The experiment was done in three phases. In each phase the water sample was brought with a 20L plastic Jerycan. From this, five liters were allotted for the analyses of the selected water quality parameters and the rest voluminous amount was equally shared and poured in to the filter media.

RESULTS

Faecal Coliform test:

Faecal coliform count using Most Probable Number (MPN) method was conducted from samples before and after filtration. Results before filtration indicated that 240, 150 and 1100 MPN/100mL for sample I, II and I II, r espectively, t he m ean a verage of which is about 497 MPN per 100mL. The mean average measurements of the three composite samples per rock thickness were became 18 (96.4%), 12 (97.6% and 8 (98.4%) reductions of MPN per 100 mL of faecal coliform counts for the rock thickness of 2cm, 4cm and 6cm, respectively (Table 1).

Physical Tests and P^H:

Parameters used for physical test were; turbidity, color and temperature. All of the samples showed pattern of changes for the physical parameters and P^H while they were passed through the rocks.

Samples which had an initial concentrations of 14.5FTU, 120FTU and 145FTU of turbidity; 50HU, 75HU and 125HU of color; and 19.57^{0}C, 21.14^{0}C and 20.8^{0}C of temperature were reduced in the 2cm thick filter vessel to 82.8%, 96.83% and 97.7% of turbidity; 74%, 90% and 92.5% of color; and 0.72%, 12.2% and 4.81% of temperature, respectively. But, the P^H measurements with initial values of 6.8, 6.5 and 6.93 were increased to 0.74%, 13.85% and 5.1% respectively. In the 4cm filter medium with the above initial concentrations, the impurities were reduced in the filtrates to 83.45%, 97% and 97.7% of turbidity; 80%, 90.7% and 93.2% of color; 0.87%, 12.3% and 4.9% of temperature, respectively. With the above initial P^H values in the 4cm, they were increased to 0.4%, 15.4% and 8.95%, respectively. With the same initial values for all parameters, the contaminants in the 6cm were reduced to 84.83%, 97.2% and 97.9% of turbidity; 90%, 92.7% and 94.9% of color; 1%, 12.5% and 5.05% of temperature, respectively. The P^H measurement values increased to 0.15%, 17.2% and 3.2%, respectively (Table 1).

Chemical Tests:

Fluoride tests:

From table 1, it can be seen that filtering raw water samples through the rocks had a reduction effect on the concentrations of fluoride.

The mean average concentration changes observed in the 2cm, 4cm and 6cm rock thicknesses were; from 1.405 mg/L to 1.10mg/L (22% reduction), 0.863 mg/L (38.6% reduction) and 0.456mg/L (67.5% reduction), respectively (Table 1).

Iron tests:

The calculated mean averages (Table1 above) of iron concentrations showed that, filtering the raw water samples through 2cm, 4cm and 6cm rock thicknesses decreased the concentration from 0.63mg/L to 0.13mg/L (79.4% reduction), 0.08mg/L (87.3% reduction) and 0.07mg/L (88.9% reduction) respectively (Table 1).

Manganese tests:

Manganese also greatly reduced when filtering the raw water samples through the intervened rocks.

The mean average concentrations of manganese showed a decline from 0.028mg/L to 0.009mg/L (67.9% reduction), 0.003 mg/L (89.3% reduction) and to 0.002mg/L (92.9% reduction) in the 2cm, 4cm and 6cm respectively see table 1.

Table 1. Mean values of the selected water quality parameters, for three samples taken for three days per rock thickness

Rock thickens and Mean Value	Day and Sample No.	FC (MPN/ 100mL)		Turbidity (FTU)		Color (HU)		Temperature (^{0}c)		pH		Fluoride (mg/L)		Iron (Mg/L)		Manganese (mg/L)	
		BF	AF	BF	AF	BF	AF	BF	AF	BF	AF	BF	AF	BF	AF	BF	AF
	D_1S_1	240	11	14.5	2.5	50	13	19.57	19.43	6.8	6.85	1.232	0.651	0.33	0.16	0.03	0.012
2cm	D_2S_2	150	14	120	3.8	75	7.5	21.14	18.57	6.5	7.4	1.487	1.322	0.72	0.11	0.028	0.002
	D_3S_3	1100	28	145	3.4	125	9.4	20.8	19.8	6.93	7.28	1.495	1.312	0.83	0.12	0.027	0.012
Mean		496.67	17.67	93.17	3.23	83.33	9.97	20.5	19.27	6.74	7.18	1.405	1.1	0.63	0.13	0.028	0.009
	D_1S_1	240	7	14.5	2.4	50	10	19.57	19.4	6.8	6.83	1.232	0.427	0.33	0.05	0.03	0.004
4cm	D_2S_2	150	9	120	3.6	75	7	21.14	18.55	6.5	7.5	1.487	0.888	0.72	0.09	0.028	0.004
	D_3S_3	1100	21	145	3.3	125	8.5	20.8	19.78	6.93	7.55	1.495	1.274	0.83	0.11	0.027	0.002
Mean		496.67	12.33	93.17	3.10	83.33	8.5	20.5	19.24	6.74	7.29	1.405	0.863	0.63	0.08	0.028	0.003
	D_1S_1	240	4	14.5	2.2	50	5	19.57	19.38	6.8	6.81	1.232	0.232	0.33	0.03	0.03	0.003
6cm	D_2S_2	150	7	120	3.4	75	5.5	21.14	18.5	6.5	7.62	1.487	0.195	0.72	0.08	0.028	0.002
	D_3S_3	1100	14	145	3.10	125	6.4	20.8	19.75	6.93	7.15	1.495	0.942	0.83	0.10	0.027	0.001
Mean		496.67	8.33	93.17	2.9	83.33	5.63	20.5	19.21	6.74	7.19	1.405	0.456	0.63	0.07	0.028	0.002

D1S1: day one sample one; D2S2: day two sample two; D3S3: day three sample three
BF: Before Filtration; AF: After Filtration

From table one, it can be seen that measurements of the mean average values of faecal coliforms, turbidity, color, temperature, fluoride, iron and manganese showed a general trend of decreasing in magnitudes after filtering the three raw water samples in the 2cm, 4cm and 6cm rock thicknesses, respectively. On the other hand, the mean average values for pH showed a general trend of increasing in magnitudes while filtering the three composite samples in the 2cm, 4cm and 6cm rock thickness.

Table 2. Determination of "time of operation"/ Filtration rate (for the entire cycles of the experiment) while filtering a total of 15 liters of raw water per rock thickness.

	Time of Operation in hours			
Rock Thickness (in cm)	1st day sample	2nd day sample	3rd day sample	Average
2	3:04	3:06	3:55	3:22
4	3:10	3:11	4:10	3:44
6	3:15	3:20	4:25	3:53

DISCUSSIONS

Among the "Beha" rock thickness used in this study, the 6cm was much better than the 4 cm and this in turn was better in removing faecal coliform organisms than the 2cm thickness. The reductions achieved according to their increasing level were 96.4%, 97.6% and 98.4% (Table 1 and figure3).

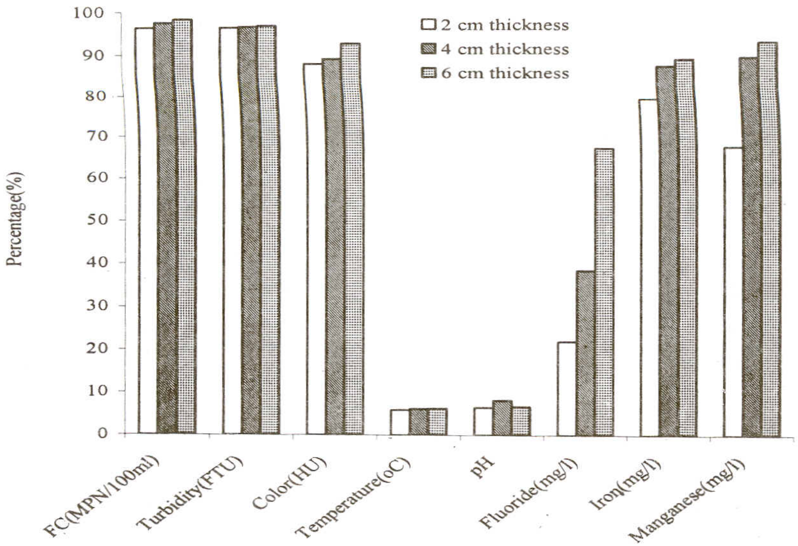

Figure 3: Comparison of percentage reduction of the net mean values of the selected water quality parameters per rock thicknesses.

were observed to reduce iron and manganese below the recommended level of WHO (8), which is 0.3 mg/L for iron

and 0.1mg/L for manganese, while filtering all of the samples (Table 1).

According to the study findings the initial hydrogen ion concentration (PH) of the sample varies between 6.5 to 6.93pH; but after filtration, which have met the WHO recommended standard value of pH for drinking water supply (8), i.e. between 6.81 – 7.62pH (table 1). This is probably because in most natural water treatment processes, pH is controlled by the carbonate-carbonate equilibrium system (16, 18).

Samples which had an initial average temperature of 20.5°C been lowered to 19.27°C (5.9% reduction), 19.24°C (6.15% reduction) and 19.21°C (6.3% reduction) in the 2cm, 4cm and 6cm respectively (Table 1 and 5). This is probably because as the adsorptive of the rock material as well as the rate of filtration and sedimentation increases as the temperature drops (19).

Generally, in all of the "Beha" rock filters a significant association, $P(x^2 \geq 23.685)=0.05$, was observed between the filtration frequency and the concentrations of the selected water quality parameters. This effect could possibly be due to an involvement of uninterrupted operations of the filter media, which encourage the formation of schmutzdecke, which in turn promotes the efficiency of the media (7).

An observation was also made to determine the filter operation period before cleaning is required. At a variable raw water turbidity of 14.5 FTU, 120FTU and 145FTU, the filtration rate showed a declining trend in each of the rock thicknesses.

The mean average time taken to filter 15 liters of raw water per 2cm, 4cm and 6cm "Beha" filters were 3 hours and 22, 44 and 53 minutes respectively (Table 2). The declining trend observed could possibly be due to an increase on the head loss (that is, the water emerging from the filter comes slowly and lacking the pressure of its own weight), that resulted from an increase in the efficiency of the filter media due to the formation of schmutzdecke ("cover of filth") (7).

Typical water demand assessments for rural and suburban communities collecting water from surface sources show that the average per capita consumption is usually below 15 liters per day (16). Each time the filter medium can accommodates about 7 liters, totaling to 36, 32 and 31 liters per 2cm, 4cm and 6 cm per day (24 hours), respectively, which is sufficient for an average family size of 4.3 persons (5) at the demand indicated above. The WHO's minimum recommended level and the USAID's (United States for International Development Agency) for water project development per day per capita consumption (9) was best satisfied by the "Beha" filters.

IMPLICATIONS AND RECOMMENDATIONS

The use of "Beha" rock is a relatively simple technology for household water treatment. The filter can be used to treat raw water from surface sources. This is a great improvement for those who have no alternative to consuming the raw water.

For sufficient treatment through the "Beha" rock, it is advisable to increase the thickness. Although the filtration frequencies decline the filtration rate (filter run), it can bring a dramatic change on physicochemical and microbial impurities and hence can best suit the recommended water quality requirements of the WHO.

The major areas of application can include households, emergency water supplies, temporary lodgings, and concentration camps where it is economically not possible to provide clean water for domestic use by conventional water supply or other means. Above all, the rural people who do not have access to protected water sources are the beneficiaries of the findings of this study. To appreciate the outcomes of this study, the users must know the danger associated with the use of untreated water from contaminated sources.

Further studies need to be done:

- On the selection of different rock thicknesses and their effect of reduction on different contaminants;
- Determination of the efficiency of the natural rock to remove other contaminants, namely chromate, cadmium, phosphate, nitrate, etc.
- Identify the adsorption capacity of the rock by using different models
- Determine the physical and chemical characteristics of the natural rock
- Application of this natural rock as a conventional water and wastewater treatment plant

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