EFFECT OF ZEOLITE TYPES LTX AND LTA ON PHYSICOCHEMICAL PARAMETERS OF DRINKING WATER SAMPLES IN GHANA, ASSISTED BY LIGHT TRANSMISSION EXPERIMENT

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Abstract

In this study, the effect of zeolite types LTX and LTA, assisted by laser light transmission experiment on the physico-chemical parameters of drinking water samples have been investigated. Water samples were collected from rivers, streams, and wells from Central and Volta regions of Ghana, and zeolite masses of 0.2 and 0.5 g were added to 100 ml portions of the samples in turn. Laser light intensities transmitted through the samples before and after zeolite addition were measured and recorded. The results obtained showed raw water turbidity of 33.8 NTU and treated water turbidity of 3.0 NTU (WHO recommends the limit of 5 NTU for drinking water); transmitted light intensity for the raw and treated water samples of 0.3122 AU and 0.3345 AU, respectively. Our results also showed that water turbidity highly correlates the transmitted light intensity, and water conductivity depends on dissolved metal concentrations and temperature.

Key Words: *Zeolite LTX, Zeolite LTA, turbidity, light transmission, colour*

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1. INTRODUCTION

The lack of clean drinking water and sanitation systems is a severe public health concern in sub-Saharan Africa, and as a result, households without access to clean water are forced to use less reliable and hygienic sources and often pay more for the consequences of not drinking good and potable water [5, 11, 13 and 21]. Physico-chemical parameters such as turbidity, colour, total suspended solid (TSS) and conductivity are integral in the quality of drinking water [1, 3 and 15]. According to the world health organisation, WHO, the pH of drinking water should be in the range 6.5 – 8.5, turbidity of drinking water should be at most 5 NTU, whereas the colour of such water should not be more than 15 HU [17, 18]. A complete treatment system may consist of the application of a number of physical, chemical and biological processes to the water sources. Zeolites are known adsorbents that have been used in the treatment of water. They are crystalline hydrated aluminosilicates whose framework structure consists of cavities or pores that could be occupied by cations or water molecules. Both the cation and the water molecule have considerable freedom of movement and this permits ion exchange and reversible dehydration [6 – 12, 19 – 20]. The zeolite frameworks are typically anionic which are counterbalanced by the positive charges of cations resulting in a high cation exchange capability [19, 20]. There are over 40 naturally occurring and 160 synthetic zeolites that have been documented. The aim of the work was to study the effect of zeolite type LTA and zeolite type LTX (both synthetic), assisted by laser light transmission experiment on the physical properties such as, turbidity, colour, TSS and conductivity and pH on some drinking water samples obtained in Ghana.

2. EXPERIMENTAL

2.1 Materials and Methods

In this study, water samples were collected from two streams and a hand dug well in the Volta region of Ghana (see Plate 1). Most people living in the communities where these water sources are use the water for drinking, cooking, washing and they also use them for other household chores and for their animals. Water samples fetched were kept in clean and very neat containers for storage and transportation to avoid any interference.

The study took place in three institutions in Ghana, comprising scientists and researchers at the Physics Department (LAFOC) at UCC, Centre for Scientific and Industrial Research (CSIR) in Accra, and the Material Science unit of the Department of Physics, KNUST. Laser light transmission experiments were performed at UCC, physicochemical analyses including, water turbidity, pH/conductivity were conducted at CSIR, and the zeolites application and measurements, at KNUST.

(a) Stream 1

(b) Stream 2

(c) Hand dug well

Plate -1: Pictures of water sources used in this study

2.2 Light transmission experiment

The experimental set up used for the light transmission experiment is as shown in Fig -1.

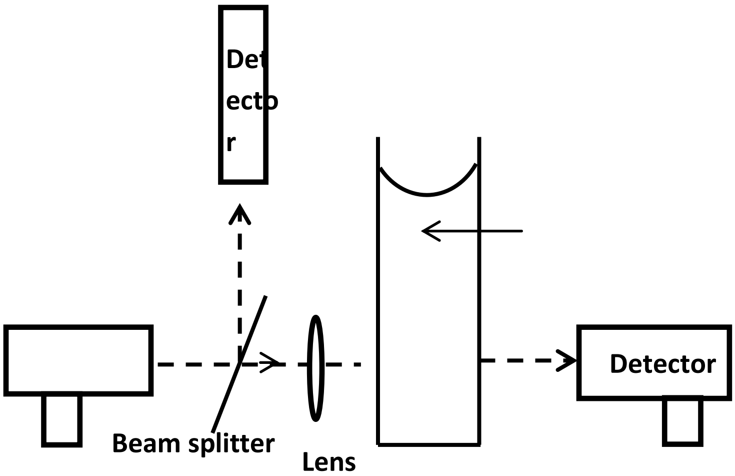

Fig -1: Experimental set up for the light transmission experiment

For accurate measurements, the sample cell (tank) was placed on a variable stage (not shown in diagram) to allow for adjustments to be made at four different depths marked A, B, C and D, at equal intervals of 3 cm. Marked level A was very close to the bottom of the water cell, and in that order up the cell to marked D. This was to ensure that water sample sediments which affect light transmission intensity I was captured. The average transmitted intensity was calculated and tabulated. To ensure integrity of our measurements, during each light transmission experiment, the sample under test was shaken a bit (not frequently, though) to not allow turbidity-causing particulates to settle and change sample temperature. Both of these conditions alter sample turbidity, resulting in a non-representative measurement. Also the outside of the sample cell was wiped clean with laboratory tissue before placing the water cell in the 633nm laser beam (line width of 0.03nm) for measurements. This was to dry clean any moisture (or fogging) and to remove any debris from the outside of the sample cell.

In each experiment, the laser source was put on for about ten minutes to allow the laser light to be stable. The reference transmitted intensity I_0 beyond the empty cell was taken as a reference value for each water sample, before any further readings are measured.

2.3 Determination of Physicochemical parameters

(a) (b) (c)

Plate-2: Photographs of TSS: (a) Stream 1 (b) Stream 2, and (c) Hand dug well

Physicochemical parameters that were measured include temperature, turbidity, total suspended solids (TSS), water colour, conductivity and pH. Turbidity test was carried out first to prevent temperature changes and particle flocculation and sedimentation from changing sample characteristics. Samples were agitated gently (e.g. to prevent settling of coarse sediment) before examination to ensure a representative measurement. However, since there was no apparent flocculation no agitation was done. The samples were placed in the Turbidimeter and their turbidity values taken and recorded. For TSS analysis, a vacuum pump was connected to the side arm of a vacuum flask and a filter holder was seated on top of the flask. Three filter papers were weighed and recorded as W_1 which were then placed on a filter holder. Suction was done and the volume of water filtered recorded for each sample. The three filters were then placed back into their pans which were then placed in a drying oven which was set at 104±1 °C for one hour. The pan/filter was then placed in a desiccator until it cooled to room temperature. The filter was then taken out of its pan, weighed to the nearest 0.0001 g and recorded. The TSS was calculated using equation:

$$TSS = \frac{(\text{Residue+filter})/\text{mg} - (\text{filter})/\text{mg}}{\text{volume filtered}/\text{ml}} \times 10^6 \qquad \text{Eq. 1}$$

The TSS and the Turbidity values obtained in this study have been shown in Table 1below.

Table 1: TSS and Turbidity values for raw water samples

Water Sample	TSS(mg/L)	Turbidity/NTU
Stream 1	38.333	33.8
Well	38.333	18.2
Stream 2	17.800	7.2

A Lovibond Nessleriser Colour Disc was used in the measurement of water colour. This was done by matching the column of sample to that of distilled water by adjusting the cell compartment. The readings were taken and recorded for all water samples. The pH and conductivity of all samples (raw, filtered and treated) were also measured three times with the pH conductivity meter and the averages taken and recorded, as shown in Table -1.

2.4 Exposure of water samples to zeolite types

The batch technique was utilized to monitor the effect of the mass of zeolite LTX and LTA on the physicochemical parameters. Starting with zeolite LTX, for each water sample, six portions were obtained (i.e. three raw samples and three filtrate samples) and these were further divided into two, making twelve samples in all. An equal volume of 100 ml of each sample was measured into each flask after which 0.2 g of zeolite LTX was added. The flasks were placed on a rotary shaker at an average speed of 200 rpm at room temperature for one hour. Each sample was filtered using 0.45µm nanofibre filter paper. The procedure was repeated for zeolite LTX mass of 0. 5g. the same process was conducted with zeolite LTA.

3. RESULTS AND DISCUSSIONS

3.1 Conductivity and temperature of water samples

Water shows significant conductivity when dissolved salts are present. In particular, for drinking water samples the conductivity is dependent on the environmental conditions. For example, according to the USEPA, (2012) water conductivity in streams and rivers is affected primarily by the geology of the area through which the water flows. Streams that run through areas with granite bedrock tend to have lower conductivity because granite is composed of more inert materials that do not ionize (dissolve into ionic components) when washed into the water. On the other hand, streams that run through areas with clay soils tend to have higher conductivity because of the presence of materials that ionize when washed into the water. Ground water inflows can have the same effects depending on the bedrock they flow through. The conductivity of water is also dependent on temperature. Over most ranges, the amount of conductivity is directly proportional to the amount of salts dissolved in the water as shown in equation (Eqn. 2) [22].

Table 2: Results of pH, conductivity and temperature measurements

TDS (ppm) = Conductivity {(µS/cm) x 0.67} Eqn. 2

In Table 2, all the water samples showed conductivity values less than 800 $\mu S/cm$, which is the limit for good drinking water for humans (provided that there is no organic pollution and not too much suspended clay materials. It is also suitable for all live stock.

3.2 Water Colour

The colour values in the drinking water samples as shown in Fig.-3 show that stream 1 recorded the highest value of 37.5 HU. However, no change in the colour value when the raw sample of stream 1 was filtered. This implied that the value obtained was the true colour of the water sample because the colour was due to the dissolved substances and not suspended substances.

Sample of water	**pH**	**Conductivity (μS)**	**Temperature (^{O}C)**
Raw Stream 1	6.95	445.0	26.8
Raw Well	6.96	100.8	26.3
Raw Stream 2	6.94	190.8	26.8
Filtrate of Stream 1	6.94	436.0	26.7
Filtrate of Well	6.95	108.7	26.5
Filtrate of Stream 2	6.97	490.0	26.7
Treated Stream 1	6.98	759.0	28.9
Treated Well	6.96	400.0	29.2
Treated Stream 2	6.99	576.0	29.1

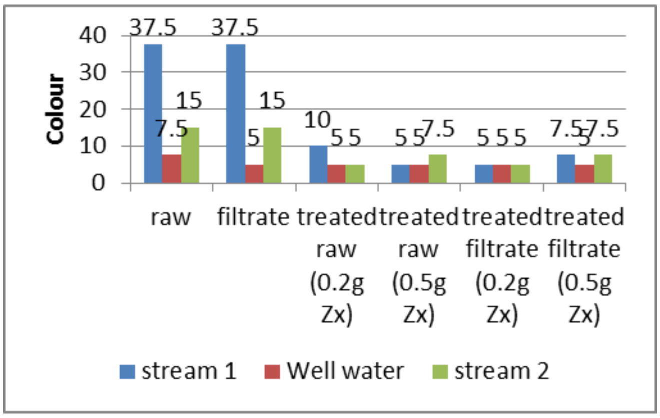

Fig. - 2: Comparison bar chart showing water colour of the various samples

There was an overwhelming improvement in this value as treated samples recorded values as low as 5HU which is well below the acceptable value of 15HU for drinking water. The other raw water samples, however, recorded values 15 HU and 7.5HU. But there were further improvements in their colour values after zeolite ZX treatments (see Fig.-2).

The colour values obtained using zeolite LTA, are as follows: Stream 1 (5 HU), Well (10 HU) and Stream 2 (10 HU). Hence, the effect of the zeolites shows better water colour codes, hence better quality drinking water after treatments.

3.3 Optical Turbidity and TSS

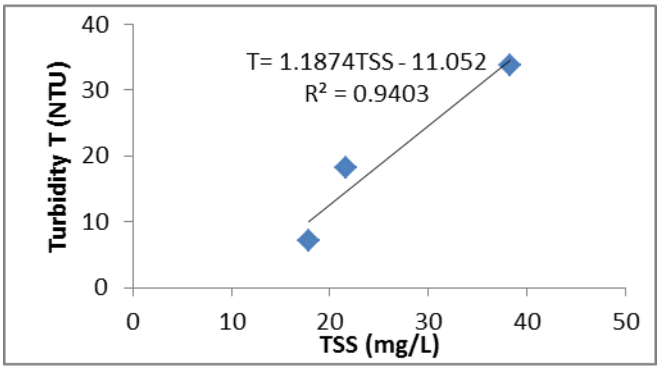

Fig.- 3: Correlation between Total Suspended Solids (TSS in mg/L) and Turbidity level (NTU) in the raw samples, using Table 3.

From Fig.-3, it is evident that optical property expressed as turbidity is affected by the interaction between light and suspended particles in water. Therefore, turbidity could provide a good estimate of the concentration of TSS in a water sample even though turbidity is not a direct measure of suspended particles in water. In this study, the plotted data in Figure 4.6 shows a correlation coefficient of R^2 of 0.9403. Hence, measuring turbidity level in drinking water samples has shown a potential cost- saving option to estimate TSS concentration at an approximate TSS concentration of 38.3 mg/L. We, however, suggest that that in water sample containing suspended solids or particles, the light transmittance depends on factors such as; surface texture, size, shape, colour, and reflectivity of the particles.

3.4 Laser light transmission experiment

The results showed that, the raw sample from stream 1 recorded the least light transmitted intensity value of 0.3122 AU, predicting the highest amount of scattering centres (and highest turbidity) in the water sample than the other two water samples. Therefore, the sample showed highest turbidity. For the treated water samples, average light transmitted values recorded indicated that 0.2g ZX treated sample water of stream 2 showed the highest light transmission value of 0.3368 AU, very close to the incident light intensity of 0.3378 AU. In all, the average transmitted light intensities of the three raw sample waters were lower than their respective filtrates and zeolite treated samples. This indicates that, as the impurities such as the suspended and dissolved substances were removed, the light transmissions through the samples were enhanced. Also, the filter pore-size used for the filtrations, was small indicating no interference from the zeolites during the treatments.

The light transmission intensity values recorded in Table 2 was compared with their corresponding turbidity values obtained during the physicochemical tests. Fig.-4 to Fig.-7 are linear graphs establishing the inverse relationship between light transmission intensity and turbidity. The graphs give negative slopes, indicating negative correlation between transmitted light intensity and water turbidity. This means, highest turbidity corresponds to lowest light transmission due to the greatest ability of scattering centers in the water sample scattering the incident light. All three drinking water samples recorded turbidity values greater than 5 NTU (WHO, 2004). It can however be seen that, stream 1 recorded the highest turbidity value of 33.8 NTU which corresponds with the least transmitted light intensity value of 0.3122 AU, as predicted previously. However, there appeared to be some effect on the filtrate samples as a result of dissolved coloured matter. The effect of colour on light transmission (i.e. turbidity) was not seen with the zeolite treated samples

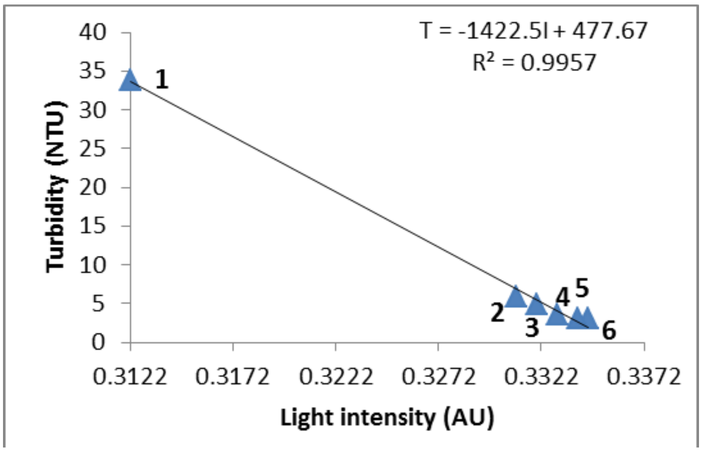

Fig.- 4: A graph of turbidity (NTU) as a function of transmitted light intensity (AU) for sample stream 1, (1) raw sample (2) filtrate, (3) treated raw sample with 0.5gZX, (4) treated raw sample with 0.2g ZX, (5) treated raw sample with 0.2g ZX, and (6) treated filtrate with 0.5g ZX.

The high turbidity value of sample water 1 was drastically reduced to 5.84 NTU after undergoing a filtration with 0.45µm nanofibre. This was further reduced to as low as 3.01NTU which is in the range that is recommended by WHO. The turbidity of the raw sample of Stream 2 was the least of 7.2 NTU and corresponded with the highest transmitted light intensity value of 0.3316 AU among the raw samples. The high turbidity value of sample water 1 was drastically reduced to 5.84 NTU after undergoing a filtration with 0.45µm nanofibre. This was further reduced to as low as 3.01NTU which is in the range that is recommended by WHO. The turbidity of the raw sample of Stream 2 was the least of 7.2 NTU and corresponded with the highest transmitted light intensity value of 0.3316 AU among the raw samples.

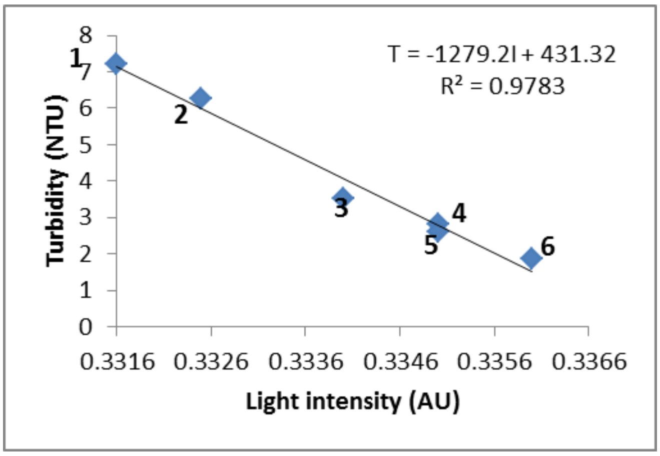

Fig-5: A graph of turbidity (NTU) as a function of transmitted light intensity (AU) for sample stream 2**,** (1) raw water, (2) filtrate, (3) treated raw sample with 0.5g ZX, (4) treated raw with 0.2g ZX, (5) treated filtrate with 0.5g ZX (5) treated raw sample with 0.2g ZX, and (6) treated filtrate with 0.2g ZX

This turbidity value is higher than the WHO accepted value of 5 NTU but was reduced to values below 5 NTU after treatment as shown in Figure 4.4.

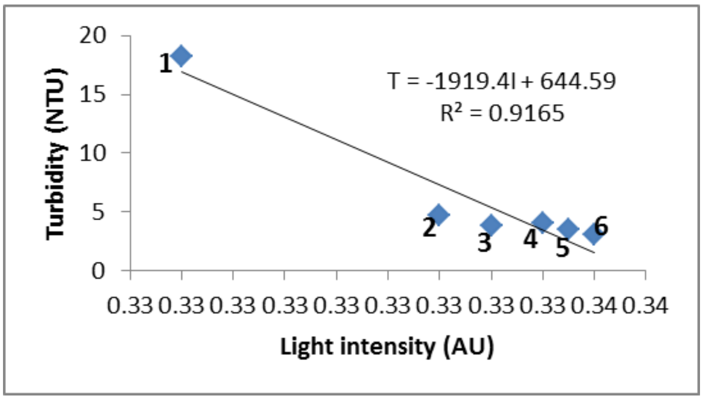

Fig.- 6: A graph of turbidity (NTU) as a function of transmitted light intensity (AU) for sample well water, (1) raw water, (2) filtrate (3) treated raw sample with 0.5g Zx, (4) treated raw sample with 0.2g Zx, (5)treated raw sample with 0.2g Zx, and (6) treated filtrate with 0.5g Zx.

This turbidity value is higher than the WHO accepted value of 5 NTU but was reduced to values below 5 NTU after treatment as shown in Figure 4.4. The raw water sample from the hand dug well recorded a turbidity value of 18.2 NTU. This value was further reduced to 3.11NTU after undergoing 0.45µm nanofibre filtration which falls below the WHO acceptable range. However, the zeolites treated samples of the hand dug well water recorded a turbidity value of 3.47 NTU. This may be due to the fact that the zeolites might have introduced some other coexisting ions which become scattering centers.

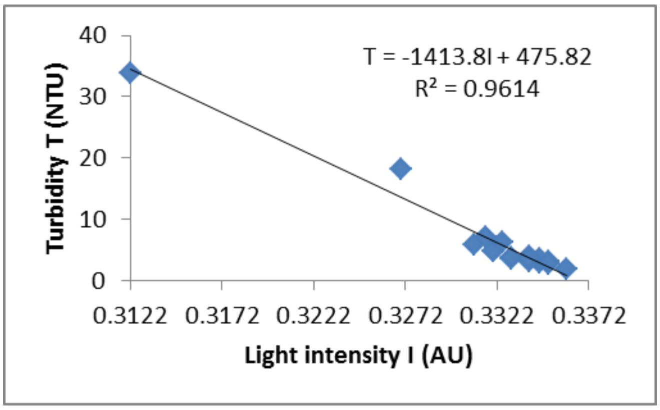

Fig.-7: A graph of Turbidity (NTU) as a function of Transmitted Light Intensity (AU) for all samples of water treated with zeolite LTA

The graphs in Figures 3 – 5 showed a strong negative correlation between turbidity level and transmitted light intensity, with a correlation coefficient of R^2, 0.9614. Hence, the regression line is accurate for interpolation of turbidity values up to 35 NTU. Table 3 shows the TSS and turbidity values for the raw samples:

It can be seen from the Table 2 that, stream 1 had the highest concentration of suspended solids value of 38.33 mg/L and stream 2 had the lowest value of 17.8 mg/L. Their turbidity levels were 33.8 NTU and 7.2NTU respectively. These high TSS concentration values may be due to the activities of humans and animals. As an example, stream 1 recorded the highest TSS concentration because both humans and animals use it as a source of drinking water. Humans enter the stream to fetch the water and some even swim and wash their clothes in. Animals and other livestock drink from the stream, hence debris and other particulates find their way into the water body, hence the source of the high turbidity. The raw sample from hand dug well also had a relatively high TSS concentration of approximately 21.65 mg/L because the mouth of the well is not covered and people fetch or draw water from the well with different kinds of buckets and containers, hence impurities find their way into the well water. Another source of high turbidity may be due to the nature of the walls of the well. As an underground water source, some chemical and organic materials may find their way into the water body. Hence, in view of the variation in turbidity values shown in Table 2, it is prudent to guess that turbidity is often closely correlated to climatological or surface water conditions and changes in turbidity are therefore indicators of differences in environmental conditions. The differences in environmental conditions are evident from the places where the raw samples were obtained. The data points for TSS and their respective turbidity values how that as the TSS value increase, the turbidity also increases showing a good positive correlation between Turbidity and TSS concentration of the drinking water samples (Figure 6). Thus suspended solids have the ability to obstruct the transmittance of light in a water sample and increase TSS concentration intensifies light scatterings. Turbidity has been defined as the optical property of the water sample that causes light to be scattered and absorbed rather than being transmitted in straight lines [2, 3, 5, and 15]. The optical property expressed as turbidity is affected by the interaction between light and suspended particles in water. Therefore, turbidity could provide a good estimate of the concentration of TSS in a water sample even though turbidity is not a direct measure of suspended particles in water. Past studies had been conducted and consistently showing a strong correlation between TSS and turbidity [5, 15] Regression analysis performed on turbidity and TSS data, natural- log transformed, resulted in a strong positive correlation with a R^2 of 0.96 [15].

CONCLUSIONS

The data collected from three drinking water sources from the Volta region of Ghana showed a strong positive correlation coefficient (i.e. R^2 = 0.9614) between transmitted laser light intensity values and turbidity levels. The study has shown that, transmitted light intensity values could be used as a surrogate for turbidity measurement. Hence, it could be an alternative method for determining turbidity values in drinking water samples if turbidimeters are not readily available. The data collected on the drinking water samples further showed a good positive correlation (R^2 = 0.9403) between Turbidity levels and TSS concentrations at a maximum TSS concentration of 40 mg/L. Although, the process of turbidity measurement is simpler and faster than the process of TSS measurement, more information is required to achieve more uniform result. The study also confirmed that measurement of turbidity levels have the potential to replace the measurement of TSS concentrations if the area of study is strictly controlled [5, 13]. Also the present study has shown that water conductivity increases with increasing temperature. Of more important note is the fact that zeolites ZX and LTA effects on the water samples drastically improved light transmissions and greatly reduced water colour. The effect on the water colour may be due to the removal abilities of the zeolites on dissolved substances like humic substances (e.g., humic acids) and contaminants of heavy metal ions.

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Professor Craig Williams is a renowned Professor of Microporous and Mesoporous Materials at the School of Applied Sciences, University of Wolverhampton in the United Kingdom.

Samples	Raw	Filtrate	Treatment with 0.2g ZX		Treatment with 0.5g ZX	
			Raw	Filtrate	Raw	Filtrate
Stream 1	0.3122	0.3311	0.333	0.334	0.332	0.3345
Well	0.327	0.335	0.333	0.334	0.332	0.3345
Stream 2	0.3316	0.335	0.336	0.335	0.3325	0.334