# Measurement Of Optical Turbidity Of Drinking Water Samples,Using Nephelometric And Laser Light Techniques

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***Abstract***

*The specific objective of this study was to directly measure drinking water turbidity of six (6) groundwater samples of surface rivers, streams and hand-dug wells from Ghana, for sustainable national development. These measurements were carried out in two research laboratories by using laser light techniques of light scattering and light transmission experiments to assist nephelometric measurements.*

*The nephelometric studies showed a strong positive correlation with a R2 value of 0.9285 between optical turbidity (NTU) and the concentration of the suspended solids (mg/L) of the water samples. Thus, indicating that environmental conditions do affect water turbidity and suspended solids. Furthermore, polar diagrams of light scattered by high turbidity and low turbidity water samples could be distinguished. Indeed, the polar graphs of all the drinking water samples were noticeably the same shape for the most turbid to the least, for the measuring light wavelength $\lambda=633$ nm (in air). The study also showed that light transmission measurements can be used to complement the fractional reduction in light intensity per metre length due to scattering of the inhomogeneities in the water samples.*

***Keywords*** *: Turbidity, Groundwater, Nephelometric, Physicochemical, Water resources*

## I. INTRODUCTION

Water turbidity is a measure of the lack of transparency or clearness of water, which is caused by biotic and abiotic suspended or dissolved substances in the water column (ISO, 1999 and BCMOELAP, 1997). Nonetheless, according to European Communities Regulation (2007), turbidity is not a direct measure of suspended particles, but rather a general measure of the scattering and absorbing effect that suspended particles have on light. To this end, optical turbidity is commonly measured with nephelometric turbidimeter in nephelometric units (NTU). Clesceri et al., (1998) contended that, worldwide, the nephelometer (a turbidimeter with scattered-light detectors located at 90 degrees to the incident light beam) is known to be sensitive, precise, and applicable over a wide range of particle size and concentration. Similarly, laser-based light sources are versatile, have higher selectivity and sensitivity to small changes in turbidity and are often used to monitor filtration performance for clean to ultrapure water (Haas et al., 1983).

The specific object of this study was to directly measure turbidity in laboratory by using laser light techniques of light scattering and light transmission experiments to assist nephelometric measurements of optical turbidity of six (6) groundwater samples of surface rivers, streams and hand-dug wells. The samples were collected for analysis on three different campaigns within the month of February 2013, the lean season of rainfall.

In Ghana, water resources include natural groundwater bodies, such as, rivers, streams, lakes and wells. In particular, in towns and villages access to good water for drinking and for other household chores is scarce and the quality of the water used by the communities is not known. Presently, deterioration of groundwater quality has been attributed to human disturbances including industrial activities, especially illegal mining of gold (aka, “Galamsey”) and the impacts of climate change. Sometimes these activities potentially produce turbidity above the natural background conditions. As a consequence, women and children have to travel long distances (mostly by foot) in search of portable water for consumption. To this end, the lack of clean drinking water is a severe public health concern, and it is affecting the sustainability of the national development.

For drinking water, past studies have shown that water turbidity is a health-related function and it is quite demanding. It is therefore known that the existence of turbidity in drinking water may affect the water quality; its acceptability, chemistry implications, and turbidity particles (depending on the precise composition of the turbidity-causing materials) may safeguard pathogenic organisms and may cause health hazards to consumers (Wilson, 2010 & Jacobs Engineering Group Inc., 2010). The WHO (2004) and EU DWD (2007) recommend that drinking water turbidity value must not exceed (i.e. “never to exceed”) 1 NTU. However, the appearance of water with a turbidity of less than 5 NTU is usually acceptable for drinking.

Therefore, the present study could provide source water protection measures for the public health departments of the communities in which the water samples were collected. In this regard, this work is to safeguard public health. Significantly, the present research could be used to ensure that groundwater wells, for example, are properly built and maintained, and are located in areas where there is least possible contamination.

## II. MATERIALS AND METHODS

### *A. Collection of water samples*

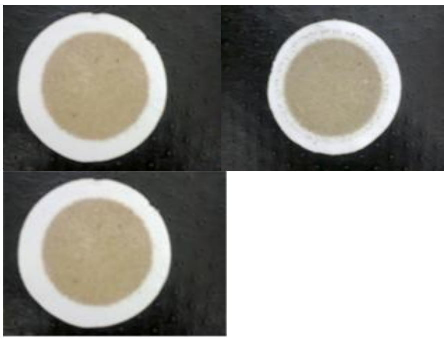
Six groundwater samples were collected from two streams (herein known as stream 1 and stream 2); two hand- dug wells (herein known as well 1 and well 2) and two rivers (herein known as river 1 and river 2), from two selected regions in Ghana. These two regions are well noted of their geographical differences.

To avoid any interference the water samples were kept in well-rinsed, clean non-wettable polythene bottles (containers) for storage and transportation for studies in our laboratories. All samples were stored at 27 ± 2 oC during transportation to our laboratories before being analysed within 6 hours.

B. Physicochemical analysis of water turbidity

At the Centre for Scientific and Industrial Research (CSIR) in Accra, Ghana, the following well calibrated equipment, a portable turbidimeter, desiccator, weighing dish, measuring cylinder, clips, vacuum pump, weighing balance, pH-meter, conductimeter, Nessleriser, and an electric oven were used for physicochemical tests.

(a) River 1 (b) River 2 (c) Well 1



(d) Stream 1 (e) Stream 2 (f) Well 2

Figure-1: Some photographs of TSS of the raw water samples

To prevent possible effects such as temperature changes, biochemical action, particle flocculation and sedimentation from changing the characteristics of the water samples, the turbidity of each water sample was first determined. For this reason, each sample water under test was agitated gently before turbidity test, to prevent settling of coarse sediment to ensure a representative measurement.

To measure turbidity in nephelometric units (NTU), a well calibrated portable turbidimeter was used. The sensitivity of the instrument was good and allowed for detecting turbidity differences in the water samples. Also, another parameter which can be used as a substitute for turbidity, the total suspended solids (TSS) was measured. The TSS includes all suspended particles (e.g. the discharge of silt and other colloidal material washings) in water which would not pass through membrane filters of 0.45 μm (Wilson, 2010). Drying the "suspended solids" in an oven set at a temperature of 105 oC for one hour (photographs of TSS as shown in Figure1 were obtained and in Table 1, the TSS values are quoted with temperature and pH). The TSS is a measure of the dry weight of the suspended solids per unit volume of water in milligrams of solids per litre (mg/L), using equation (2).

After the physicochemical analysis of the turbidity in NTU of the water samples (raw and filtered) at CSIR, the remaining portions of the samples were transported to the laser and fibre optics centre (LAFOC) at the university of Cape Coast, Ghana for the laser light techniques to be carried out.

C. *Laser light Technique: Light scatterig experiment*

The samples; river 1, river 2 and well 2 collected in the central region of Ghana, were analysed using He-Ne laser, wavelength (in air) of 633 nm and beam size of 0.4 mm at the centre of the sample cell in a light scattering experiment. In the work of Giovando (1959), the narrowness of the incident laser beam was of three important reasons: (1) to allow the measurement of scattering down to very small angles from the forward direction, (2) to permit a clear definition of the scattering volume, and (3) to minimize the distortion that might arise from the curvature of the sample cell. The laser light scattering method involved the measurement of the intensity of light scattered at an angle away from the attenuated or transmitted light (i.e., forward direction), using a high sensitive photomultiplier (or photo detector) tube. In each measurement, about 200 ml of the sample water under test was poured into, a round-bottomed flask (sample cell) of about 3.6 cm in diameter along the incident light path (see Figure 2). Giovando (1959) opined that spherical sample cell minimizes instrumental errors arising from refraction effects in the glass flask. The flask was always covered during each measurement to prevent any effect of dust or moisture to interfere the readings.

Scattered light intensities between 10 degrees below the attenuated or transmitted light and 10 degrees below the incident laser light beam were measured for all samples. In other words, within scattering angle of 10 degrees and 170 degrees, inclusive (at intervals of 10 degrees), polar diagrams of scattered light intensities were obtained (see Figs- 4 and 5).

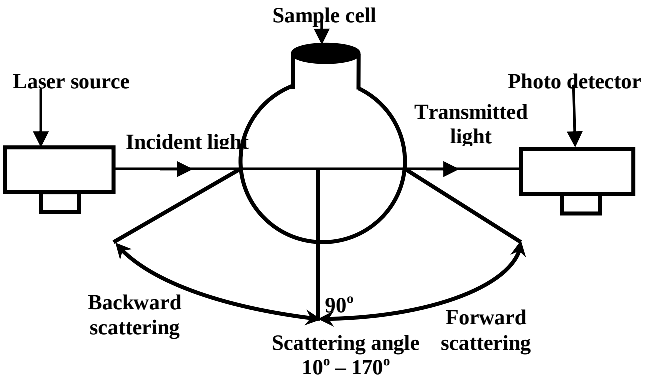


Figure-2: Schematic diagram of the light scattering experimental set-up

Throughout the light scattering experiment, the sample under test was shaken a bit (not frequently though), to not allow turbidity-causing particulates to settle and change sample temperature. Also, it was ensured that the outside of the sample cell was wiped clean with laboratory tissue before placing it in the laser beam for measurement. This was to dry clean any moisture (or fogging) and to remove any debris from the outside of the sample cell. Also, to always ensure that the sample cell was clean for accurate measurements, the neck of the sample cell was held to remove it from the sample stage, either to shake the sample to make sure it was well mixed or to change the sample for a new measurement.

### D. *Laser light Technique: Light transmission experiment*

With this method, about 500 ml of each raw and filtered water sample of streams 1, 2 and well 1, obtained from the Volta region of Ghana were analysed using the set-up shown in Figure 3. In fact, for each water sample, transmitted light intensity was measured at four equally spaced marked/graduated levels A, B, C and D, marked on the rectangular tank to hold the sample (not shown in Figure 3); with mark A close to the bottom of the tank, and in that order up the tank. Then the average transmitted light intensity of each sample was taken and recorded, based on the Beer-Lambert’s equation, which expresses turbidity as µ (m-1) values in accordance with;

$$I=I0e-\mu x$$

(1)

In equation (1), I is the transmitted light intensity, x is the path length, Io is intensity of the incident light, and e is the base of natural logarithm = 2.71828……During each experiment, the laser source was put on for about ten minutes to allow the laser light to be stable before taking readings. The reference transmitted light intensity I0 was taken for empty water tank (beyond the empty cell). As a practice, 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.

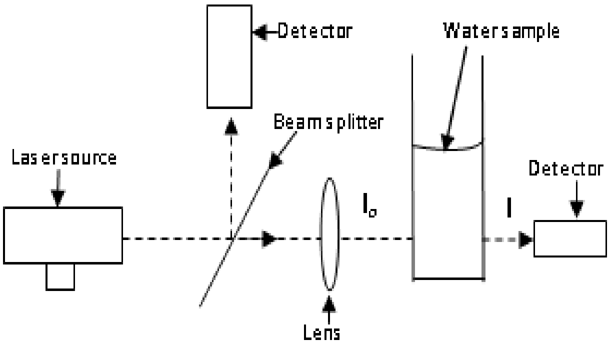


Figure 3: A set-up of the light transmission experiment

## III. RESULTS AND DISCUSSIONS

### A. *Nephelometric Turbidity measurement*

The amount of dispersed suspended solids in water is an important indicator of water quality. These solids obstruct the transmittance of light through water and impart a qualitative characteristic known as turbidity (Thus, the optical turbidity of water sample generally increases as the total suspended solid increase.

Table-1 shows that the turbidity values of the “raw water” samples collected were much higher than the allowable turbidity limit of 5 NTU for drinking water (WHO, 2004 & EU DWD, 2007). The turbidity value for well 2 water sample was the highest, and that of stream 2, the least. Table 1, also shows that turbidity correlate positively with TSS, as depicted graphically in Fig- 3. The high regression value R2 of 0.9285, indicates a strong correlation between water turbidity and TSS. In this regard, the net effect of the TSS data may be the apparent turbidity of the samples, shown in Table-1. We therefore, speculate that the high concentration of TSS calculated using equation (2), may be largely due to organic and inorganic constituents due to human disturbances, including industrial activities near the groundwater sources.

$$\text{TSS (mg/L)} = \frac{(Residue+filter)/mg-(filter)/mg}{volume\ filtered/ml} * 1000000 \qquad (2)$$

For example, stream 1 recorded the second highest TSS value, because apart from humans using it for drinking, it is also used for swimming (or bathing) and washing of clothes. Birds and other livestock drink from the stream; debris and other particulates find their way into the water body from the banks of the stream, hence its high turbidity. With the wells, the high turbidity values may be due to the fact that the mouth of the wells are usually not covered, thereby exposing them to dirt. Usually, some people fetch or draw water from the wells with dirty buckets and containers, therefore, solid suspended substances find their way into the wells to dirty or contaminate the waters. Another source of high turbidity may be due to the nature of the walls of the wells. We have noted that, the wells are not properly maintained, and are located in areas where there is high possible contamination. As groundwater sources, some chemicals and organic materials may find their way into the water bodies through the well walls. We also point out that the walls of the wells have very weak cement works all down to the bottom; hence clay or other soil types may cause the high turbidity. The net effect of the above mentioned reasons is that, the TSS of the wells could lead to the apparent turbidity of the well water samples. However, we are very careful to be explicit in this sense, since it is important to remember that turbidity is not in itself a measure of the quantity of suspended solids in a sample, but instead, an aggregate measure of the combined scattering effect of the suspended particles on an incident light source (European Communities Regulation, 2007).

Table-1: Physicochemical values of TSS and Turbidity for the raw water samples with their pH and Temperature values

| Raw Water Sample | TSS(mg/L) | Turbidity/NTU | Temperature/ °C | pH |
|---|---|---|---|---|
| Stream 1 | 38.333 | 33.8 | 26.8 | 6.74 |
| Well 1 | 21.647 | 18.2 | 26.3 | 5.63 |
| Stream 2 | 17.8 | 7.2 | 26.8 | 6.71 |
| River 1 | 3.429 | 15.0 | 29.1 | 5.65 |
| Well 2 | 103.6 | 240.0 | 28.4 | 5.17 |
| River 2 | 9.2 | 18.0 | 29.0 | 5.62 |

In Table-2, certain contaminant parameters distinctive of the water samples analysed have been shown. These include the pH, conductivity, and turbidity; in particular, the conductivity values of the stream samples were very much different from those of the river samples. Basically, this is due to the geology of the area through which the water flows. Similarly, the conductivities of the water samples of the wells depend on the type of the bedrock the water flows through. Generally, these parameters help in order to establish water quality, and they do discriminate between the water sample sources.

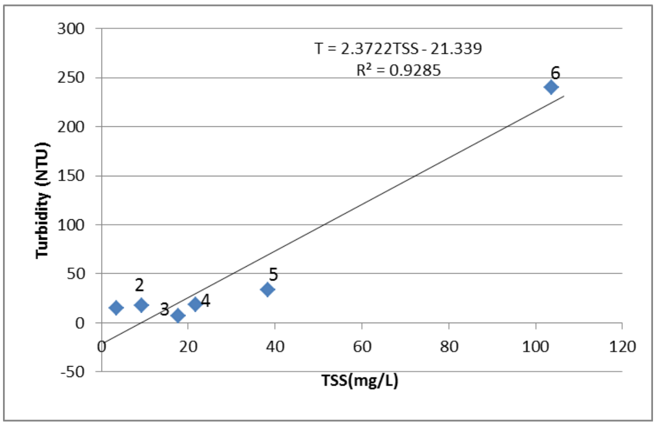


Figure 4: Graph of Turbidity (NTU) as a function of TSS (mg/L) for all raw water samples (1) river 2 (2) river 1(3) stream 2 (4) Well 1(5) stream 1 (6) Well 2

Table-2: Physicochemical values of conductivity, pH, temperature and turbidity of the water samples

| Sample | pH | Conductivity (µS) | Temperature (°C) | Turbidity (NTU) |
|---|---|---|---|---|
| **Stream 1 (raw)** | 6.74 | 445.00 | 26.80 | 33.80 |
| **Well 1 (raw)** | 5.63 | 100.80 | 26.30 | 18.20 |
| **Stream 2 (raw)** | 6.71 | 190.80 | 26.80 | 7.20 |
| **River 1 (raw)** | 5.62 | 82.10 | 29.00 | 15.00 |
| **River 2 (raw)** | 5.68 | 177.00 | 29.10 | 18.00 |
| **well 2 (raw)** | 5.17 | 126.80 | 28.40 | 240.00 |
| **Stream 1 (filtrate)** | 6.98 | 436.00 | 26.70 | 5.84 |
| **Well 1 (filtrate)** | 6.02 | 98.70 | 26.00 | 3.11 |
| **Stream 2 (filtrate)** | 6.97 | 190.00 | 26.70 | 2.82 |
| **River 1 (filtrate)** | 6.62 | 77.90 | 26.80 | 2.58 |
| **River 2 (filtrate)** | 6.64 | 175.60 | 27.00 | 8.59 |
| **well 2 (filtrate)** | 6.28 | 114.60 | 27.80 | 86.60 |

### *B. Laser light scatterig measurements*

In this section, the results of the laser light scattering method of measuring optical turbidity of the water samples are presented. In the scattering technique, we assumed that narrow portions of the incident and scattered light beams have been used, and that ions of dissolved salts do not absorb significantly at wavelengths greater than about 340 nm (Wilson, 2010). A single distilled water sample was used to calibrate the set-up shown in Fig.-1.

### *Polar diagram of scattered light*

Polar diagrams were obtained based on the interpretation of scattering light intensity, Isc ≡ Isc (scattering angle, ϴ, etc.) in water at intervals of 100 in scattering angle. Generally, the scattered light intensity Isc is a function of the scatter angle ϴ, the particle size, shape of the suspended material, the wavelength of the incident light, the optical properties of the particle and the medium such as, the refractive index n. Here it should be noted that the spatial distribution of scattered light depends on the ratio of particle size to wavelength of incident light (Hulst, 1957). Figs- 4, 5a and 5b, respectively, show the polar graphs of average scattered light intensity for the single distilled water, “raw water” samples and the “filtrate water” samples. These graphs show that the average light intensities of the scattered light was largely due to forward scattering with broad minimum at 900 (for rivers 1 and 2 water samples) and 1000 (for well 2 water sample), and the single distilled water whose minimum occurred sharply at 900, respectively (see Table 3). Therefore, we posit that the type of light scattering used in this study was dependent on the water molecules itself, by suspended particles, and by dissolved matter.

Table-3: Minimum polar points of scattered angle and average scattered light intensity of water samples

| | **Raw sample** | | **Filtrate sample** | |
|---|---|---|---|---|
| **Sample** | **Angle (deg.)** | **Intensity (a.u)** | **Angle (deg.)** | **Intensity (a.u)** |
| **River 1** | 90 | 0.0296 | 100 | 0.010 |
| **River 2** | 90 | 0.0393 | 100 | 0.014 |
| **Well 2** | 100 | 0.0745 | 100 | 0.016 |

Basically, we have used the following premise: that passing light through the sample is reduced by extinction to exponential (-τ) of its original value (Pickard & Giovando, 1960). Furthermore, if the optical path τ (the product of optical turbidity, μ and geometrical light path x in the sample) is less than 0.1, single scattering prevails; in-between 0.1 and 0.3 (not included), a correction for double scattering may be necessary. For τ greater than 0.3, multiple scattering becomes a factor (Van de Hulst, 1957, p. 6). Accordingly, in this study, the optical path τ for each sample of water analysed was 0.0152 (river 1), 0.0550 (river 2), and 0.0966 9 (well 2). These values of τ are all less than 0.1; hence, we postulate that our scattering experiment was single scattering measurement. Therefore, the polar plots (see Figures 5, 6a and 6b) show that the well 2 (raw water) had the highest turbidity, and river 1(raw sample) had the lowest turbidity. The intensity Io shown on the graphs represents the transmitted light intensity through the empty water cell. This was the same for all samples. Therefore, we think that the high scattered light intensity values pertaining to the forward scattering of the raw samples (see Figures 6a and 6b) suggest that a great number of the suspended solid materials in the various samples were relatively transparent of size large compared to the wavelength of light used. We also postulate that some of the back scattered light are results of multiple internal reflection of light in the transparent materials (Pickard and Giovando, 1960).

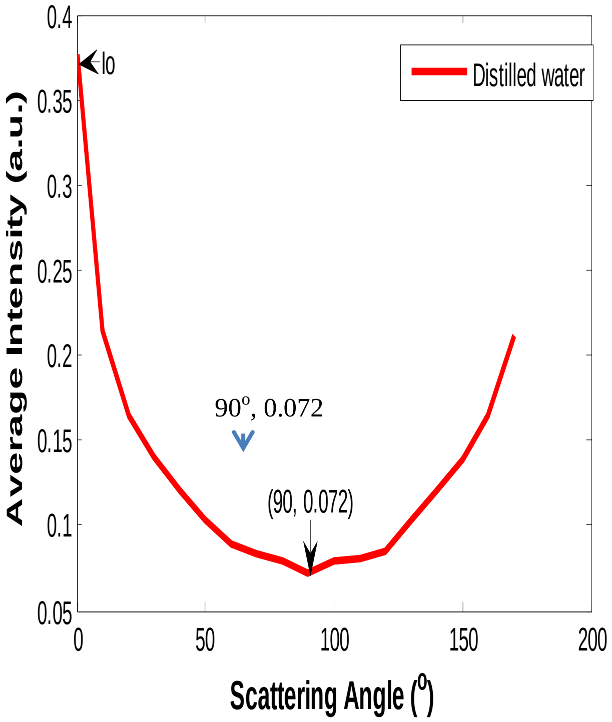
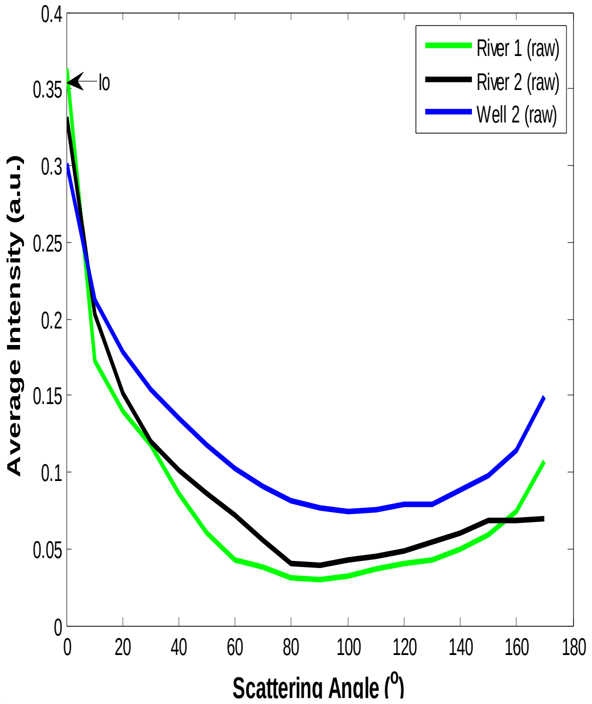
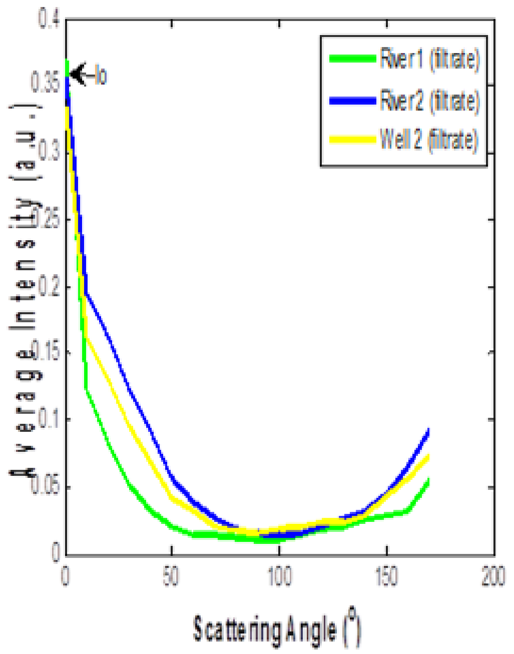


Figure 5: Polar diagram of light intensity (average) scattered at angle ϴ by single distilled water sample. Wavelength λ of laser light (in air) of 633 nm and approx. 475.94 nm (in water)



(a)



(b)

Figure 6: Polar diagrams of average light intensity scattered at angle ϴ by (a) the “raw water” samples (high turbidity), (b) “filtered water” samples (low turbidity). Wavelength λ of laser light (in air 633 nm) and approx. 475.94 nm (in water)

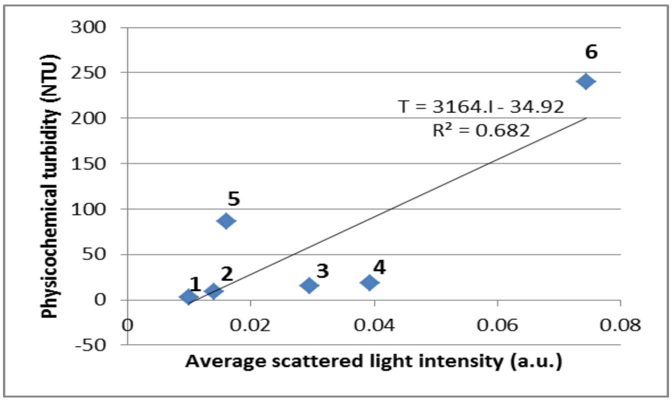


Figure 7: A regression line of physicochemical turbidity (NTU) against average scattered light intensity (a.u.) of the (raw, filtered) water sample pairs (3, 1), (4,2) and (6, 5) of River 1, River 2 and Well 2 sample sources, respectively.

It is interesting to note that the scattering intensity of the single distilled water was more than 5% of the filtrate samples, indicating that the filtrates had finer particles than the single distilled water. Therefore, we think that the scattering in the distilled water may be from both suspended particulates and the water molecules themselves, causing the apparent turbidity. Comparatively, the relatively low suspended particles in the “filtrates” allowed much higher transmission intensity values than that of the raw samples. In other words, the “raw” samples do scatter light better than the “filtrate” samples; hence, the apparent high turbidity values of the “raw water” samples. In other words, the scattering of light increases as the concentration of suspended particulates in the water increases. In Figure 7, a linear regression of R2 value of 0.682 shows a good positive correlation for physicochemical turbidity (NTU) and average scattered light intensity (a.u.) for the water samples studied under laser light scattering.

### *C. Laser light transmission measurements*

In Table-3, the average light transmitted intensity values of the water samples analysed are shown. The results showed that, the raw sample from stream 1 recorded the least transmitted light intensity value of 0.3122 a.u., predicting the highest amount of optical turbidity. The results shown in Table-4, is graphically displayed in Figure 8.

The plotted data shows a strong negative correlation between the nephelometric turbidity (NTU) and average transmitted light intensity, with a correlation coefficient of R2, 0.9534. Here, we remark that highest turbidity corresponds to lowest light transmission due to the greatest ability of scattering centres in the “raw water” samples than in the “filtrate water” samples. Hence, measuring transmitted light intensity through drinking water samples show a potential cost- saving option to estimate turbidity levels at an approximate turbidity level of 38 ± 2 NTU. In other words, the regression line is accurate for interpolation of turbidity values up to 40 NTU. This is in conformity with the detection limits of an acceptable turbidimeter with a range of 0 to 40 NTU (Wilson, 2010).

Table-4: Average light transmission intensity (a.u.) through the water samples

| | **Average light intensity (a.u.)** | | **Physicochemical Turbidity (NTU)** | |
|---|---|---|---|---|
| **Sample** | raw | filtrate | raw | filtrate |
| | | | | |
| **Stream 1** | 0.3122 | 0.3311 | 33.8 | 5.84 |
| | | | | |
| **Well 2** | 0.3270 | 0.3350 | 7.2 | 6.25 |
| | | | | |
| **Steam 2** | 0.3316 | 0.3350 | 18.2 | 4.72 |

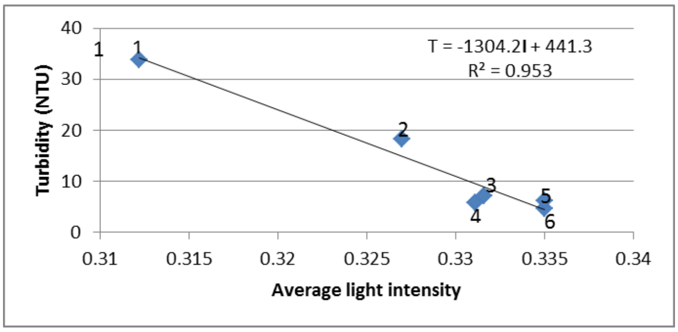


Figure 8: Graph of turbidity (NTU) against average transmitted light intensity (a.u.) for (1) Stream 1 (raw), (2) Well 1 (raw), (3) Stream 2 (raw), (4) Stream 1 (filtrate), (5) stream 2 (filtrate) and (6) Well 1 (filtrate)

### *D. Correlation between* Nephelometric *Turbidity and Calculated Turbidity*

Literature on turbidity (Alinas et al., 2010) reveals that light scattering intensity can be converted to nephelometric turbidity (NTU) using a calibration curve that can be generated from AMCO Clear turbidity standards (GFS Chemicals, Columbus, OH). Nevertheless, in this study the fractional reduction in light intensity per metre length due to scattering of the inhomogeneities in the water samples, using equation (1) has been used in order to measure the optical turbidity µ or the calculated turbidity of the samples.

The object was to complement scattering measurements by transmission measurement of the same water samples. To this end, Table-5 compares calculated turbidity of our "raw water" samples with the nephelometric turbidity (NTU) values. Figures 9 and 10 show that there is a strong positive correlation between the nephelometric turbidity (NTU) and the calculated turbidity due to the laser light techniques for the raw water samples.

Table-5: Comparison of Calculated Turbidity (per metre length) and Nephelometric Turbidity (NTU)

| | ***Calculated turbidity ($m^{-1}$)*** | | **Turbidity/NTU** | |
|---|---|---|---|---|
| **Sample** | Raw | Filtrate | Raw | Filtrate |
| **River 1** | 0.4244 | 0.3699 | 18 | 8.59 |
| **Well 2** | 2.6839 | 0.334 | 240 | 86.6 |
| **River 2** | 1.5304 | 0.3565 | 15 | 2.58 |
| **Stream 1** | 0.6112 | 0.1554 | 33.8 | 5.84 |
| **well 1** | 0.252 | 0.0646 | 18.2 | 4.72 |
| **Steam 2** | 0.1437 | 0.0646 | 7.2 | 6.25 |

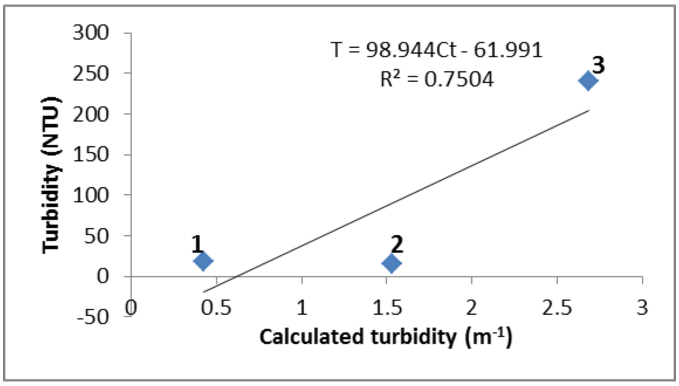


Figure 9: Correlation between nephelometric turbidity and calculated turbidity of raw water samples of, (1) River 1, (2) River 2, and (3) Well 2

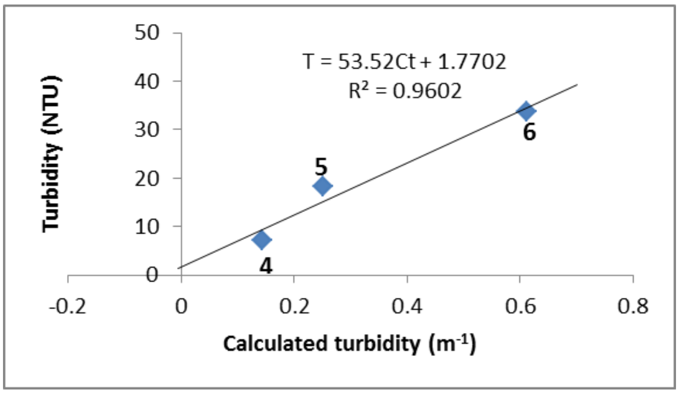


Figure 10: Correlation between nephelometric turbidity and calculated turbidity of water samples of, (4). Stream 2, (5) Well 1, (6) Stream 1

## IV. CONCLUSIONS

We have successfully used nephelometric (physicochemical) analysis and laser light techniques of light scattering and light transmission measurements to establish the optical turbidity of water samples obtained from two rivers, two streams, and two hand-dug wells from two different geographical regions in Ghana. Our results show that the nephelometric studies and laser light techniques compare very well with each other, and they reveal two important relationships.

Firstly, a regression analysis performed on optical turbidity and TSS showed a strong positive correlation with a R2 of 0.9285. A past study conducted by Packman (1999) have shown a strong positive correlation between optical turbidity and TSS. Therefore, we conjecture that turbidity provides a good estimate of the concentration of TSS (total suspended solids) in water, even though turbidity is not a direct measure of suspended particles in water. Nonetheless, it should be remarked that these two parameters may contribute to water-borne disease outbreaks due to microorganisms such as; bacteria, viruses, and protozoans possibly associating themselves with the suspended solids and the organic fractions.

Secondly, the turbidity data obtained with the laser ($\lambda = 633$ nm in air) light techniques of scattering and transmission, correlate strongly with the nephelometric turbidity values of the water samples. In particular, regression coefficient R2 of 0.682 and 0.953, respectively, have been obtained. These show that, the polar graphs of the light scattering experiment were noticeably the same shape from the most turbid to the least, indicating for example, the highest optical turbidity corresponds to the highest average scattered light intensity. Also, lowest light transmission corresponds to highest optical turbidity due to the greatest ability of scattering centres in the water samples scattering the incident light. Therefore, we posit that turbidity is more likely to depend on the total suspended solids.

Furthermore, our transmitted light intensity measurements have shown a potential cost-saving option to discriminate turbidity levels at an approximate turbidity level of 38 ± 2 NTU, in strong conformity with the detection limits (of range of 0 to 40 NTU) of an acceptable turbidimeter (Wilson, 2010). However, we support the view that filtration alone does not reduce the optical turbidity of “raw water” samples, since turbidity may be due to the apparent water colour and dissolved substances (Peterson, 2001). Elsewhere, a treatment plan had been used for the treatment of the water samples analysed in this study (Sefa-Ntiri et al., 2014). We have also shown that transmission measurements can be used to complement the fractional reduction in light intensity per metre length due to scattering of the inhomogeneities in the water samples. Hence, there is a strong positive correlation between the nephelometric turbidity (NTU) and the calculated turbidity (per metre length) due to the laser light techniques.

Finally, in view of the variation in turbidity values shown in Table 1, 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. In this study, the differences in environmental conditions have been shown to be evident based on the geographical places where the “raw water” samples were collected. Hence, we suggest that, the extremely high turbidity of the water samples from the wells may be due to high concentrations of bacteria and nutrients and clay; hence groundwater wells, for example, should be properly built and maintained.

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