Acta Scientific AGRICULTURE (ISSN: 2581-365X)

Volume 7 Issue 12 December 2023

Research Article

Predicting Total Suspended Solids from Turbidity for different types of Soil Particles

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DOI: 10.31080/ASAG.2023.07.1323

Received: August 01, 2023

Published: November 27, 2023

Abstract

Physical, chemical, and biological factors are used in water quality assessments to assess the water's appropriateness for a certain purpose. The total suspended solids and turbidity, out of all of these variables, are the most crucial for determining the general quality of the water from the perspective of agricultural applications. TSS measurements have a variety of applications, such as observing erosive processes in a landscape or irrigation systems. On the other hand, it is challenging to quickly monitor the TSS content in the water and to address urgent problems. Turbidity may be measured swiftly with the help of a turbidity meter. Given the correlation between turbidity and TSS, one may estimate the water's TSS using the turbidity value. Turbidity is affected by various types of soil solids that are present in the soil. The aim of this study was to determine the correlation between TSS and turbidity, based on this develop regression models, compare the performance of the regression models for vertisols that was segregated into sand, silt, clay, mixed soil and natural soil solids. The data on TSS and turbidity were preprepared for 5 different soil fractions in the laborartary conditions through the sedimentation process. Using the known methods, TSS through the gravimetric method and turbidity through the turbidity meter at different concentration levels from 1 to 1500 mg/L, it is the possible minimum to maximum turbidity values for agricultural applications. These values were used to develop the linear regression model for the study. The results showed a strong positive relationship between turbidity and the TSS for all types of soil fractions. The correlation coefficient was found to be over 0.9 for these soils, which have demonstrated a high correlation. While monitoring, sand-sized percentage of soil fractions were immediately dropped below the turbidity-meter-monitored zone, which had an impact on the TSS value. However, it was discovered that the percentage of sand in black cotton soil were quite low; therefore, the established relationship can be helpful for TSS assessment. It is concluded that the generated models presented with good adjustments can be able to be used for predicting the concentration of TSS as a function of turbidity.

Keywords: TSS; Turbidity; Water Quality; Black Cotton Soils; Vertisol

Abbreviations

APHA: American Public Health Association; CIAE: Central Institute of Agricultural Engineering; ICAR: Indian Council of Agricultural Research; NTU: Nephelometric Turbidity Units; TSS: Total Suspended Solids; WHO: World Health Organization

Introduction

The acceptability of water for a particular purpose based on physical, chemical, and biological factors is referred to as water quality. The WHO has published standards for evaluating water quality based on the physical quality of the water, which is primarily determined by the physical elements and organic matter present in the water, such as TSS, turbidity, and colour [19,21]. Among these different parameters, TSS and turbidity are essential in the agricultural uses. TSS measurements have a variety of uses, including monitoring soil erosion from a landscape and quantifying the amount of soil lost during the erosion process. Similarly, in micro irrigation systems, particularly drip and sprinkler irrigation, the amount of soil trapped by the filter will help to determine whether the system is choked or not. This aids in the proper cleaning and maintenance of the irrigation system. Other applications of the measurement of above parameters were found in water quality management, agricultural practices, and environmental protection.

Filter paper is common practice used to measure TSS in water. The TSS in the water are measured by their dry weight as they were trapped by the filter paper. TSS and water turbidity are interrelated [15]. TSS and Turbidity are caused by suspended particles in the water, such as clay, silt, finely divided organic material, plankton, and other inorganic elements. However TSS is a quatitive parameter, wheras turbity is a qualitative parameter. The turbidity of the water is a gauge of its purity. Water with a high turbidity is musky, while water with a low turbidity is clear. A glass of water can readily show turbidity more than 5 NTU, which is objectionable for aesthetic reasons [15]. The TSS of the water may be examined using turbidity measurements. However, suspended particles, particularly in natural water, contain a wide range of material that may include clays, silts, inorganic matter, organic matter, vegetation, and living organisms. This results in a wide range of particle sizes and optical characteristics and ultimately different turbidity values. As a result, there is no definite relationship between TSS and turbidity.

It is challenging to rapidly and easily monitor the TSS content in the water, making it difficult to use TSS to make timely decisions and address short-term problems. A turbidity meter may be used to measure turbidity rapidly and with little effort. Numerous researches have also found relationships between turbidity and TSS; as a result, by monitoring turbidity, we can monitor the TSS in water. The arduous effort involved in the TSS estimate may be lessened as a consequence. Sand, silt, and clay make up the majority of the total suspended solids in water, whereas algae are made up of of inorganic solids [15]. The relationship between TSS and turbidity is influenced by a number of factors, most notably the shape and optical properties of suspended particles [9]. Similar to suspended sediment concentration, turbidity is influenced by water colour, particle size, shape, and content, as well as suspended sediment concentration [14]. Therefore, the relationship between turbidity and suspended sediment concentration may be biassed as a result of particle size, shape, composition, and watercolour. So, neither unique nor consistent is this relationship [14]. However, average relationships between the TSS and turbidity may be determined; this may help in the monitoring of real-time TSS wherever it is required [6]. Although, turbidity and suspended sediment concentration may not always correlate well, there is often a good correlation for regionally specific observations. For instance, in several streams, a log-linear model demonstrated a strong positive correlation between TSS and turbidity with $R^2 = 0.96$. [13,16].

Regional-specific investigations are required since wide variety of literature indicate that the TSS and Turbidity may not always correlate. black cotton soils in central India (Vertisols) are a type of clay soil that exhibits unique properties, including high shrink-swell potential and a tendency to form cracks. The relationship between turbidity and TSS for vertisols and its soil fractions may differ from that of other soil types due to their distinct physical and chemical characteristics. Based on this the present study was aimed to develop the the relationship between TSS and turbidity for vertisols separated into different fractions: sand, silt, clay, mixed soil, and natural soil solids. The specific objectives were to

- Determine the correlation between turbidity and TSS for each soil fraction.
- Develop regression models to estimate TSS based on turbidity measurements for each soil fraction.
- Compare the performance of the regression models for different soil fractions.

Materials and Methods

The details of the methodology have been presented in the following sub-headings.

Description of study area

Bhopal is a district in the Madhya Pradesh state, located between the latitudes 23º05'- 23º54'N and longitudes 77º10'- 77º40' E with an average altitude of 500 m above mean sea level. The Bhopal district experiences a humid subtropical climate with hot summers and cold, dry winters typical of the Vindhya plateau's agro-climatic zones. The warmest month is May, with a mean maximum temperature of 40.7°C, while the coldest month is January, with a mean minimum temperature of 11.3°C. The Bhopal district receives 1132 mm of rainfall on average each year, 95% of which is received during the southwest monsoon season. In general, August has been recorded as being the wettest month, with a mean monthly maximum rainfall of 374 mm. In the summer, the mean relative humidity is as low as 26% and as high as 88% during the monsoon season.

Collection and preparation of soil samples

Soil samples have been collected from the ICAR-CIAE research farm and processed accordingly. Following that, 0.8 kilogramme of soil from the samples was added into the bucket with 20 liters of water. The sample bucket was agitated for thirty minutes and the sedimentation procedure was used to separate the sand, silt, and clay. The sand was separated from the above solution after 40 sec, the silt separated after 2 h and the clay was separated after 2 days. After collecting the samples, they were subjected to oven drying for 24 hours, to ensure the complete removal of moisture present in the soil sample. Clay, Silt, Sand, Mixed soil and Natural soil were the five different soil fractions selected for the study. For each type ofsoil fractions, 22 samples were prepared in the lab by adding a known quantity of soil to 1L of distilled water. Mixed soil was prepared based on the known texture of the soil in that region and this texture was decided based on the previous literatures.

The designated concentrations for various soil fractions were set at 1500mg/L, 1250mg/L, 1000mg/L, 900mg/L, 800mg/L, 700mg/L, 600mg/L, 500mg/L, 400 mg/L, 300mg/L, 250mg/L, 200mg/L, 150mg/L, 125mg/L, 100mg/L, 80mg/L, 60mg/L, 50mg/L, 10 mg/L, 5mg/L, 3mg/L, and 1mg/L across different soil categories. To achieve these concentrations, a precise amount of soil was added to a one-liter water bottle. The weight of the solids was measured using an analytical balance with readings accurate to one-tenth of a milligram (mg). Both the initial weight of the solids on the paper sheet and the final weight inside the bottle were recorded to ensure no loss occurred during transfer. Subsequently, the bottle was filled with one liter of de-ionized water. Rigorous control was maintained over the concentrations of solids in the prepared water samples, with an acceptable variation of less than two percent (±2%), even at the lowest concentration of 20 mg/L. (Figure 1). After that for each categories of soil fractions TSS and Turbity measured in the lab conditions for generation of the regression equation and calibration of the generated model. Detailed procedure of the TSS and turbity measurement is described below.

Figure 1: Separation process of each type of solids.

Total suspended solids (TSS)

In this TSS (Total Suspended Solids) determination method, a carefully mixed and precisely measured volume of a water sample undergoes filtration using a pre-weighed glass fiber filter. The filtration process involves passing the water through the filter, which effectively captures suspended particles such as sand, silt, and clay. The glass fiber filter is initially weighed before the filtration process.

Following filtration, the filter, now containing the suspended solids from the water sample, undergoes a heating process. The filter is heated to a constant mass at a specific temperature of 104 ± 1º C for a duration of 24 hours. This prolonged heating period ensures the complete removal of moisture from the filter and the suspended solids.

After the heating process, the filter is weighed again. The dry mass of the suspended solids, which are now captured on the filter, is determined by the difference between the final weight of the filter paper with the dry soil sample and the initial weight of the filter paper alone.

The formula used to calculate the Total Suspended Solids (TSS) concentration in the water sample is.

TSS = (Final weight of filter paperwith dry soil sample-Initial weight of filter paper only) ÷ Sample Volume

This equation expresses the TSS concentration in milligrams per liter (mg/L), providing a quantitative measure of the dry mass of suspended particles present in the water per unit volume. The entire process ensures accurate and standardized measurements of TSS in the water sample.

Turbidity

The method is based upon a comparison of the intensity of light scattered by the sample under defined conditions with the intensity of light scattered by a standard reference suspension. The higher the intensity of scattered light, the higher the turbidity. Readings, in NTUs, are made in a nephelometer designed according to specifications. A primary standard suspension is used to calibrate the instrument. A secondary standard suspension is used as a daily calibration check and is monitored periodically for deterioration using one of the primary standards. Formazin polymer is used as a primary turbidity suspension for water because it is more reproducible than other types of standards previously used for turbidity analysis.

The above samples were separated for our study through sedimentation analysis. In the laboratory, 22 samples for each type of solids were prepared in the lab by adding a known quantity of soil to 1L of distilled water. These samples, spanning TSS concentrations from 1500 ppm to 1 ppm, were meticulously prepared, and their respective turbidity levels were examined using a turbidity meter. EUTECH TN 100 portable turbidity meter was used to measure turbidity on samples within a small duration. Bottles were shaken thoroughly before filling turbidity meter sample cells once and then refilled for immediate turbidity measurement. Filtration procedure followed by standard methods [1] Whatman No.1 filter paper was cleaned using distilled water and then it was oven dried for 30min at 104°c. Filters were then dried at 104°C for 1 hour in a hot air oven and reweighed. All masses were measured using an analytical balance accurate to 0.0001 grams. An empirical model was developed and calibrated to establish the relationship between the TSS and Turbidity. The developed model was validated to confirm the relationships.

Figure 2: Turbidity measurement and TSS measurement of samples by gravimetric method.

TSS and Turbidity relationship

Total suspended solids (TSS) represent the dry weight of inorganic particles (sand, silt, and clay) suspended in water. Turbidity, on the other hand, measures the clarity of a water sample, indicating its cloudiness or haziness. TSS and turbidity are interrelated; the suspended particles or chemical dissolvents in water cause turbidity. However, TSS is a quantitative parameter, while turbidity is qualitative. The gravimetric method, a time-consuming process, is generally employed to measure TSS, requiring more man-hours compared to the turbidity measurement with a turbidity meter. Numerous studies have explored the relationship between TSS and turbidity, often established regression equations based on local conditions. However, these studies often fail to create a lasting connection between TSS and turbidity. In this study we developed empirical models for various soil samples-Clay, Silt, Sand, Mixed soil, and Natural soil-gathered from black cotton soils in central India (Figure 2). In excel sheet we generated the linear regression models between TSS and tudbity. After generation of the model, calibration of the model were done by creationing the relationship between the observed values and predicted values.

Results

This chapter highlights the findings of the investigation along with the relevant interpretations. The results are presented under the following heads.

Correlation between total suspended solids (TSS) and turbidity

The tables (Table 1,3,5,7,9) display the TSS values and associated turbidity for various soil fraction concentrations under laboratory settings. The turbidity values for clay soils fluctuated between 0.69 to 560 NTU, while the turbidity values for sand were less, between 1.875 NTU to 402.33 NTU. The turbidity values for silt were in between sand and clay, spanning from 6.83 NTU to 472.33 NTU. In the specific instance of mixed soil fractions 4.58 and 596.33 NTU and 6.35 to 409 NTU in natural soil. The subsequent tables (Table 2,4,6,8,10) provide more thorough observations of predicted value of TSS and measured values of TSS used for the calibration of the established models.

TSS (mg/L)	Turbidity(NTU)
1500	472.33
1300	444.33
1200	382.33
1000	296.00
900	271.33
700	277.00
600	194.67
500	161.33
400	123.00
300	76.70
250	66.90

200	54.53
150	36.57
125	32.13
100	26.13
80	22.87
50	13.73
10	6.83

Table 1: Turbidity and TSS relationship for silt.

Total Solids (mg/L)	Measured value of TSS (mg/L)	Predicted value of TSS (mg/L)
1500	1398	1256
1000	926	790
500	428	569
300	264	256
200	148	206
100	62	123

Table 2: Measured value of TSS and predicted value of TSS for silt.

TSS (mg/L)	Turbidity (NTU)
1500	402.33
1200	261.00
1000	203.67
900	178.33
800	180.33
700	131.00
600	107.33
500	87.27
400	63.30
300	46.50
250	40.90
200	28.93
150	19.24
125	17.39
100	14.04
80	9.55
60	7.76
50	7.09
10	1.875

Table 3: Turbidity and TSS relationship for sand.

Total Solids (mg/L)	Measured value of TSS (mg/L)	Predicted value of TSS (mg/L)
1500	1638	1715
1000	1004	1203
500	538	432
300	290	250
200	218	229
100	88	141

Table 4: Measured value of TSS and predicted value of TSS for sand.

TSS (mg/L)	Turbidity (NTU)
1500	560.00
1000	404.50
500	183.50
400	118.00
300	96.90
250	76.35
200	70.55
150	51.30
125	46.40
100	27.05
80	20.30
60	16.74
50	13.53
40	11.38
30	7.74
25	5.83
20	5.25
15	4.87
10	3.115
5	1.62
3	1.03
1	0.69

Table 5: Turbidity and TSS relationship for clay.

Total Solids (mg/L)	Measured value of TSS (mg/L)	Predicted value of TSS (mg/L)
1500	1392	1475.37
1000	840	1070.29
500	395	494.58
300	293	268.99
200	158	200.35
100	39	87.04

Table 6: Measured value of TSS and predicted value of TSS for clay.

TSS (mg/L)	Turbidity (NTU)
1500	409.00
1300	423.00
1200	366.33
1000	292.67
900	250.00
800	200.33
700	164.33
600	142.33
500	107.33
400	85.60
300	63.53
250	54.50
200	41.53
150	29.37
125	21.09
100	18.71
80	15.74
60	9.58
50	8.68
10	6.35

Table 7: Turbidity and TSS relationship for natural soil.

Total Solids (mg/L)	Measured value of TSS (mg/L)	Predicted value of TSS (mg/L)
1500	1378	1354
1000	940	1039
500	448	667
300	268	392
200	162	275
100	64	181

Table 8: Turbidity and TSS relationship for natural soil.

TSS (mg/L)	Turbidity (NTU)
1500	596.33
1300	515.00
1200	467.67
1100	384.33
1000	369.67
900	333.33
800	306.00
700	257.00
600	216.33
500	169.00
400	131.67
300	87.83
250	73.67
200	60.13
150	44.63
125	35.80
100	29.37
80	22.53
60	16.28
50	12.57
10	4.58

Table 9: Turbidity and TSS relationship for mixed soil.

Theoretical value of TSS (mg/L)	Actual value of TSS (mg/L)	Predicted value of TSS (mg/L)
1500	1422	1433.24
1000	900	743.06
500	418	505.17
300	228	332.64
200	166	221.93

Table 10: Turbidity and TSS relationship for mixed soil.

Establishment of the regression models between TSS and turbidity

The study covered five different sets of samples and both turbidity and TSS parameters were recorded and analyzed. The number of samples tested in each type of solids were 25 levels. The regression analysis has been carried out to relate Turbidity with TSS. Following heads the established empirical relationship for the given samples are given for black cotton soils.

- **Silt:** The correlation between turbidity and total suspended solids for the silt particles as a whole gives a positive relationship and it is as follows
- TSS (mg/l) = 3.019 * Turbidity (NTU) + 23.95, and the Coefficient of determination (R^2) was 0.987.
- The relationship between the predicted and actual value for the silt particles was also found to be in a good correlation value with the predicted value of TSS (mg/l) = 0.823* the measured value of TSS (mg/l) + 90.69, and the Coefficient of determination (R^2) as 0.975 (Figure 3).
- **Sand:** The correlation between turbidity and total suspended solids for the sand particles as a whole gives a positive relationship and it is as follows
- TSS (mg/l) = 3.998 * Turbidity (NTU) + 89.29, and the Coefficient of determination (R^2) was found to be 0.969. The relationship between the predicted and actual value for the sand particles was also shown as a good correlation with the predicted value of TSS (mg/l) = 1.081* and the measured value of TSS (mg/l) – 18.82, and the Coefficient of determination (R^2) as 0.979 (Figure 4).
- **Clay:** The correlation between turbidity and total suspended solids for the clay particles as a whole gives a positive relationship and it is as follows
- TSS (mg/l) = 2.605 * Turbidity (NTU) + 16.57, and the Coefficient of determination (R^2) as 0.994. The relationship between the predicted and actual value for the clay particles was also shown as a good correlation with the predicted value of TSS (mg/l) = 1.078* andthe measured value of TSS (mg/l) + 39.26, and the Coefficient of determination (R^2) as 0.981 (Figure 5).
- **Natural soil:** The correlation between turbidity and total suspended solids for the sand, silt and clay particles combined in the natural soil as a whole gives a positive relationship and it is as follows
- TSS (mg/l) = 3.266 * Turbidity (NTU) + 68.7, and the Coefficient of determination (R^2) as 0.98.
- The relationship between the predicted and actual value for the natural soil particles also shows a good correlation withthe predicted value of TSS (mg/l) = 0.897* Measured value of TSS (mg/l) + 163.6, and the Coefficient of determination (R^2) is 0.984 (Figure 6).
- **Mixed soil:** The correlation between turbidity and total suspended solids for the mixed soil particles as a whole gives a positive relationship and it is as follows
- TSS (mg/l) = 2.522 * Turbidity (NTU) + 42.78, and the Coefficient of determination (R^2) is 0.995. The relationship between the predicted and actual value for the mixed soil particles was also shown as a good correlation with the predicted value of TSS (mg/l) = 0.893* measured value of TSS (mg/l) + 87.23, and the Coefficient of determination (R^2) is 0.965 (Figure 7).

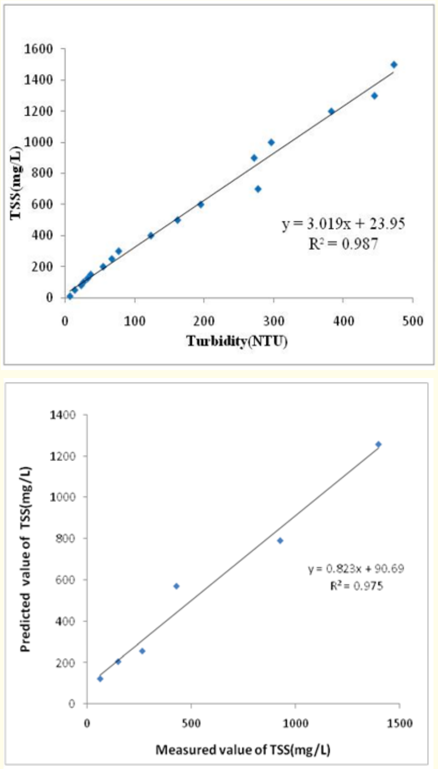

Figure 3: Relationship between TSS & Turbidity for silt.

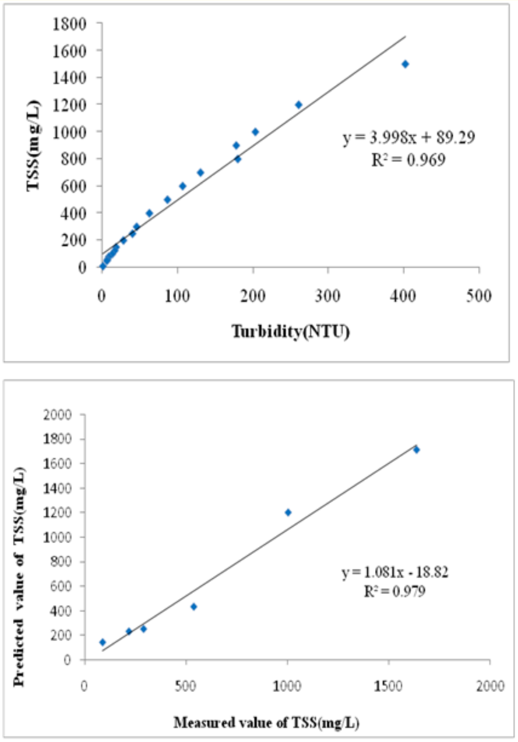

Figure 4: Relationship between TSS & Turbidity for sand.

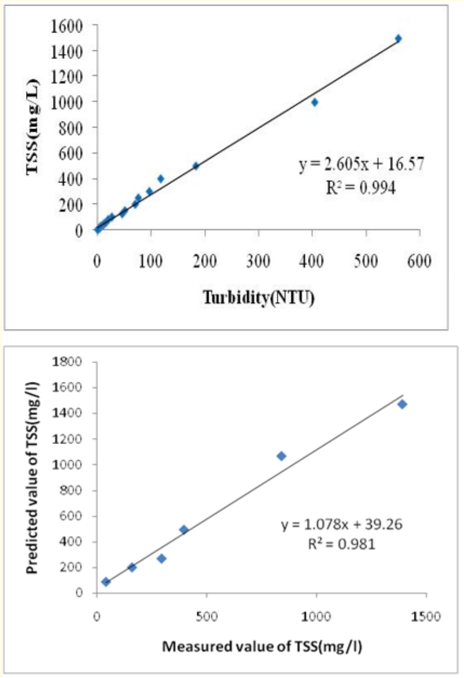

Figure 5: Relationship between TSS & Turbidity for clay.

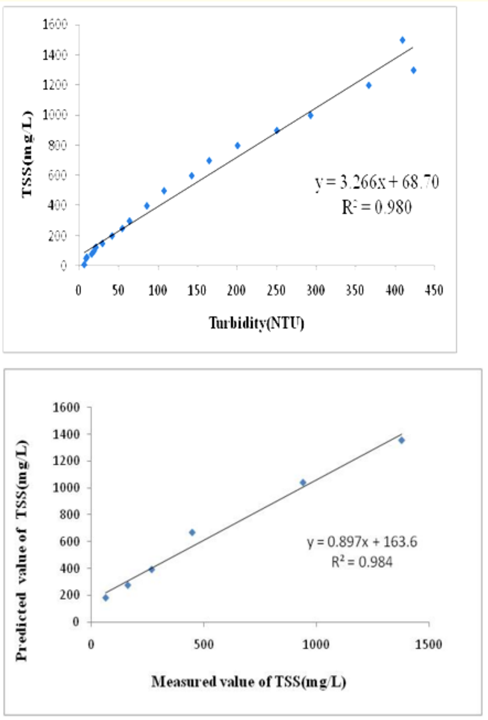

Figure 6: Relationship between TSS & Turbidity for Natural soil.

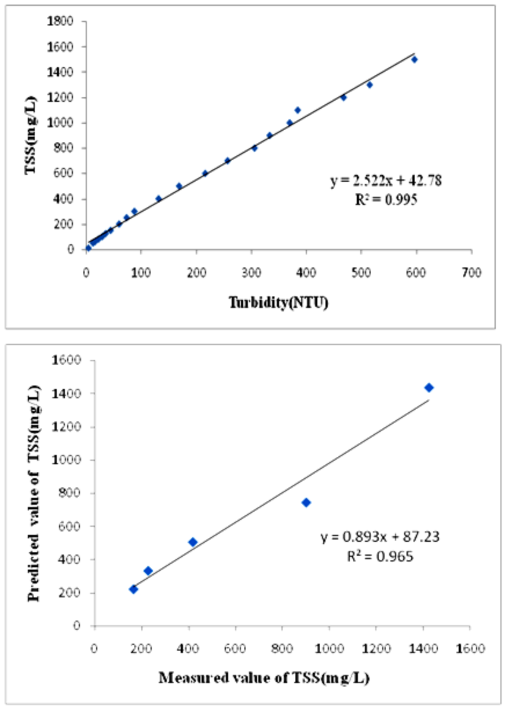

Figure 7: Relationship between TSS & Turbidity for mixed soil.

Discussion

Strong positive correlations were observed between colour and turbidity of the water, when the colour is increasing turbidity values were observed high. When, the particle size were smaller the colour was observed more and corresponding turbidity was also observed high. This is because, in a water sample, if the colour was more, then more light was absorbed and scattered, this caused higher turbidity values [4,17,20]. Also, different sizes of grain particles produced different turbidity values, when particle size was reduced in size the turbidity values were found more [2,12]. The turbidity increased due to a decrease in the mean diameter of the suspended particles because fine silt has a higher surface area that reflects light per unit mass [5]. Similarly, when the number of particles increased, for example, in this experiment, the number of particles were observed higher in the case of clay as compared to sand particles, this has also had an effect on the turbidity values as the number of particles increased higher values of turbidity was observed, this linear relationship was observed up to some extent after that no trend was observed [3,8,18,22]. The size of the particles also influences the turbidity values, the geometry of the particles is influencing the scattering of the light in a suspension when comparing the clay and sand particles the sizes were different and this is affecting the scattering of light as compared to small particles, bigger particles have less turbidity values, were observed [11].

TSS and turbidity values are dependent on the time of sampling, especially during the turbidity measurement. After the shaking of the sample, by using a mechanical shaker, sampling within 10 seconds gives some variation in the turbidity values because of air trapping in the sample, the same way sampling after one min also gives a wrong result because it causes settlement of bigger particles due to gravity. In this study, we found that a strong positive correlation exists between the TSS and turbidity of the five different sets of samples, all these samples have a coefficient of determination (R^2) higher than 0.900. Similarly, a strong positive relationship was observed in the case of TSS and turbidity relationships by many other researchers [7,10,20]. If the sand fraction is more, then immediate measurement of the turbidity is necessary (within the first 15sec turbidity should be measured), as, if the clay fraction is more then the suspension can stay for a longer time [9,14]. Similarly, there was an observation that different compositions of particles respond differently to this linear relationship, so there is a need for the development of the linear relationship on a regional basis, the developed relationships may help to reduce the time and effort for TSS measurement in experimentations.

Conclusion

A strong positive relationship between turbidity (NTU) and the total suspended sediment concentration (TSS, mg/l) was observed for all the soil solids under study. The coefficient of determination (R^2) was found more than 0.9 for all different soil solids under study. But, the factors that affect the turbidity measurement also influence the measurement of TSS. For example, if the sand-sized fraction is more, then particles in the sand fraction will settle down soon due to their bigger sizes and higher masses. Sand-sized fraction quickly settles even below the zone of monitoring of turbidity meter, this influences the turbidity measurements. Turbidity responds to factors other than just suspended solids concentrations. This was one of the drawbacks observed in this study. The developed relationships for TSS estimation using Turbidity may directly be used under control conditions for similar soils.

Acknowledgement

The authors would like to acknowledge the ICAR-Central Institute of Agricultural Engineering (ICAR-CIAE), Bhopal for providing laboratory facilities, technical and other support and ICAR-Indian Institute of Sugarcane Research (ICAR-IISR), Lucknow for allowing the first author to undergo professional attachment training at ICAR-CIAE for three months duration.

Conflict of Interest

All the authors declare no conflicts of interest.

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