Correlation between Turbidity and Total Suspended Solids in Singapore Rivers

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ABSTRACT
Sediments in the rivers, expressed as suspended solids, are depending on the discharge. In recent years, Singapore has several numbers of construction projects. The construction activities may result an increase of river water pollution, especially sediment concentration, in some Singapore rivers near construction sites. As part of control strategy, silts and sediments can be discharged in stormwater drainage system with the maximum allowable limit of 50 mg/L of total suspended solids. Continuous direct measurement of total suspended solids can be conducted during river water sampling in various river streams. However the method is very time consuming due to a large number of water samples needed for the analysis. A random study was conducted from January 2010 to July 2011 in several river streams in Singapore. In this study each of total suspended solids measurement was paired with relatively fast turbidity measurement at a preliminary defined location of 50-100 m away from any construction sites. The correlation between TSS and turbidity was established to offer more efficiency in predicting total suspended solids concentration in a river. A positive relationship between total suspended solids concentration and turbidity level suggested that the measurement of turbidity is possibly the most economic option for estimating total suspended solids concentration in a river.

Keywords: Constructions; River; Total Suspended Solids; Turbidity

1. INTRODUCTION
Singapore is geographically located between latitudes N 1° 09’ and N 1° 29’ and longitudes E 103° 36’ and E 104° 25’ with the total area of 694 km². Figure 1 shows the geographical location of Singapore. Being located near the equator, Singapore experiences tropical climate with relatively stable temperature throughout the year. The average temperatures throughout the year are approximately between 24.7 to 31.1°C (NEA, 2007). Due to its maritime exposure, Singapore climate is also characterised by high humidity and abundant rainfall. The mean annual humidity is 84.2% and may reach 100% frequently during periods of rain (NEA, 2007). Although rain falls throughout the year, the wettest months are usually starting from November to January and the driest periods of the year are from May to September.

1.1 Description of Singapore Rivers and Singapore River with Its Background History
Singapore is an island country with no natural aquifers and lakes. Providing sustainable water supply to meet daily’s water demand is a need for the country. Stormwater harvesting through local catchment of storage reservoirs is considered one of the important methods in
providing clean water. At the moment, Singapore uses two separate systems to collect rainwater and reclaimed water. Rainwater is collected through a network of drains, canals, rivers and stormwater collection ponds before it is channelled to the current 17 storage reservoirs in the country. At the moment the newly completed reservoir, the 15th storage reservoir, is called Marina Reservoir. It is considered the largest and most urbanised catchment with the total area of 10,000 ha. The catchment area was designed to collect surface waters from the major rivers of Singapore River and Kallang River and also Rochor Canal. It is expected to supply 10% of Singapore’s current water needs (PUB, 2011a). Overall, Singapore is considered one of the few countries in the world to harvest urban stormwater on a large scale for its water supply.

In this study Singapore rivers refer to any river in Singapore that are used to supply water to storage reservoirs. They are named as Jurong River, Ulu Pandan River, Singapore River, Rochor River, Kallang River, Bedok River, Loyang River, Changi River, Mandai River and some other rivers which can be seen in Figure 2. The most famous river in Singapore, known as “Singapore River” or "The River", spans 3.2 km from the sea to its upper land site reaches in Kim Seng Road. Back in the 1800s, many of the early immigrants made their first settlement on the banks of Singapore River. Some of them set up their businesses there and lived by the waterway. Over the years, the economic opportunities attracted more immigrants to settle in the surrounding Singapore River. At the later date the Singapore River became the focal point of a flourishing trading port with subsidiary trading areas emerging in Rochor and Kallang Rivers. By 1880s, Singapore River became the heart of trading and business activities. There was heavy traffic on the river due to expanding trade and rapid urbanization. As a result, Singapore River became polluted by oil spills from boats and the disposal of waste, sewage and other by-products from industries located along the river. By 1977, Singapore River was filled with black water with foul odour. Since then, many efforts were made for the development of infrastructure, massive resettlement of squatters, relocating industries, street hawkers, pig and duck farms and phasing out of pollutive activities. It took ten years of operation before the cleanup of Singapore River was completed. Today, Singapore River is home to the Central Business District, famous night spots and also a part of the first urban reservoir in Singapore. Figure 3 shows the collections of four photographs of Singapore River’s views, which were taken in the early 1970s and the recent year of 2010.

![Figure 1 Geographical location of Singapore](image-url)
Figure 2 Location of river water sampling points around Singapore as dotted in the map

Figure 3 Photographs of Singapore River’s views which were taken in early 1970s (2 upper photographs) and recent year of 2010 (2 bottom photographs)
1.2 Water Demand And River Clean Up In Singapore

Providing clean water to the populace has always been a key issue for the government of Singapore. Currently, Singapore supplies water through the 4 national taps, with sources from imported water, local catchment, desalinated water and reclaimed water, known as NEWater. Since the early 1960s, Singapore has been importing water from neighbouring state of Johor, Malaysia based on two long term agreements. With one contract already expired in 2011 and the other will be expiring in 2061, Singapore aims to become a water self-sufficient country by increasing the water security through continuous researches and investments in water treatment infrastructures and technologies. Achieving water self-sufficiency cannot solely depend on water supply management and an efficient water demand management must also be run concurrently. The Public Utilities Board (PUB), a statutory board under the Ministry of the Environment and Water Resources, had hence adopted a two-pronged approach to effectively manage Singapore’s water demand through the implementation of water conservation measures and the management of effective water networks.

In most countries, rivers have always been an important source of water, food and energy. However, due to continuous urbanization near water sources, rivers faced increasing degradation in water quality. One particular area of urbanization would be construction works. Construction works usually involve replacement of top soils with impervious surfaces which may disturb existing ground cover. Much bare surfaces are being exposed causing an increase in the amount of sediments discharge especially during rain. Sediments introduced in rivers can cause environmental pollution and browning the rivers. This would lead to the decrease in water quality, which is generally reflected by an increase of particulate matter in river streams (Mulliss et al., 1996; Webb and Walling, 1992). As a result, many countries have begun to take notice of this environmental hazard.

Back in 1977, Singapore started a ten years of action plan to clean up two major rivers of Singapore River and Kallang River. The plan included the development of infrastructure such as housing, industrial workshops and backyard trades, re-sitting of street hawkers to food centres and phasing out of pollutive activities.

1.3 Meeting The Growing Construction Industry And The Objective Of River Study

In recent years, Singapore’s construction demand had increased by 14% year-on-year from $22.5 billion in 2009 to $25.7 billion in 2010 (BCA, 2011). In the year of 2011, Singapore’s construction demand is projected to reach between $22 billion and $28 billion, with public sector projects covering about 55% of the overall construction demand (MTI, 2011). With more property developments such as Gardens by the Bay being planned near waterways, maintaining the quality of our water could be a challenging issue.

Under the current regulation, Sewerage and Drainage (Surface Water Drainage) Regulation 4(1), Public Utilities Board (PUB, 2011b) has set a maximum allowable limit of 50 mg/L of Total Suspended Solids (TSS) to be discharged into the storm water drainage system to tackle the issue on sediment discharge. As an action, continuous water sampling from storm water drainage to determine the concentration of TSS is critical.

TSS concentration can be measured directly or indirectly. Direct measurement in determining the concentration of TSS is commonly
conducted by fast filtering a water sample. The filtered water were then dried and weighed following the two common standard methods, namely the American Public Health Association (1998) and American Society for Testing and Materials (2000). However, both of the APHA and ASTM standard methods are time consuming and require large suspension volume, especially when the suspended solids concentration is low (Sadar, 1998; Ginting and Mamo, 2006). A common indirect measurement of determining the concentration of TSS would be the nephelometric turbidity method. Turbidity is a commonly used parameter to determine water quality and is used to quantify water clarity. Turbidity can be easily measured using turbidimeter and the turbidity reading is simple and fast. The nephelometric turbidity method of determining TSS concentration is based on the theory that light scattering increases with the concentration of particles (Sadar, 1998). Thus, turbidity level has the potential to estimate the concentration of TSS. However, turbidity is also dependent on other factors such as the size, shape, (Clifford et al. 1995; Gippel, 1988) and colour (Malcolm, 1985) and reflectivity of the particles (Bhargava and Mariam, 1991). Hence, the correlation between turbidity and TSS is unique in each location or situation at a different time because equal concentrations of TSS do not scatter the same amount of light (Pavanelli and Pagliarani, 2002).

The objective of this study is to give a better understanding on the general characteristics of river water for young generations in Singapore. This study would be concurrently link to PUB’s ABC (Active, Beautiful, and Clean) Water Programme in the current water campaign (PUB, 2011a). While measuring several TSS concentration and turbidity levels in the same collection points of river streams, the project was also studying whether the correlation between TSS concentration and turbidity level for the river streams can be established. In a good and solid correlation between the two water parameters, TSS concentration and turbidity level, a TSS concentration of a river water sample could be easily estimated using its turbidity measurement within a short time period.

2. MATERIALS AND METHODS

2.1 River Water Sampling

Fourteen river streams in Singapore were randomly selected from January 2010 to July 2011. Figure 2 illustrates the random locations of the river water collection. These sites were specifically selected for sampling due to ongoing construction activities along the river streams. Points of river water collection are at proximity of 50 to 100 metres downstream from the construction sites’ discharge points. Two sets of river water samples, “before and after rain” were drawn from each location at mid-depth of flow using clean plastic water bottles. Rain water samples “before rain” mean river waters which were randomly collected any time in any day during a dry season. River water samples “after rain” mean river waters which were randomly collected after one rainy day throughout the year, at approximately the same spotted location when collecting the river water samples before rain. A total of forty eight river water samples had been collected for further laboratory test in one or two days after river water collection.

2.2 TSS And Turbidity Measurement Of River Water Samples

Turbidity was measured using Eutech TN-100 portable turbidimeter. The turbidity unit were reported in Nephelometric Turbidity Units (NTU), which is a measurement of the intensity of light being scattered when light is transmitted through a water sample. All the bottles containing river water samples were
manually shaken thoroughly for a couple of seconds to ensure uniform mixing. The river water samples were poured in a vial glass and immediately measured the turbidity level using the calibrated turbidimeter. The procedure was repeated for all the river water samples.

The TSS concentration was determined using a filtration method. Porcelain crucible was oven dried at 103°C to remove all the water vapours. The mass of the porcelain crucible plus a glass fibre filter with pore size of 0.6 µm were weighed using 4 digits analytical balance. Series of the collected river water sample of 25 mL were filtered through the porcelain crucible with a glass fibre filter with pore size of 0.6 µm using Gelman Sciences vacuum filter pump. The filter tank was washed thoroughly with deionised water to ensure that the entire river water sample was washed through the glass fibre filter. The fibre filter of 0.6 µm was then dried in a crucible in an oven at 103°C for 60 minutes to remove all the moisture. The dried filtrate in porcelain crucibles was immediately placed in a desiccator for 60 minutes to avoid water vapours absorption from its surrounding environment. The dried filtrate and crucible were reweighed using 4 digits analytical balance to measure the weight of the suspended solids. The TSS concentration was calculated by taking the difference between the total mass of dried porcelain crucible, a fibre filter and its filtrate and the empty dried porcelain crucible and its fibre filter over the volume of river water samples of 25 mL.

3. RESULTS AND DISCUSSION

The TSS concentration and turbidity level were measured at the same collection point of river showing a large variance for the two parameters. The lowest and the highest TSS measurements were measured approximately at 0.6 and 3,752 mg/L respectively. The lowest and the highest turbidity levels were recorded approximately at 1.95 and 249.67 NTU respectively.

As an example, at Tampines River, the TSS concentration of 0.6 mg/L and turbidity level of 30.2 NTU during a dry season but the figures were reduced down to 0.2 mg/L and 11.06 NTU respectively after a rainy day. This might be occurred due to fast flushing of stormwater in a short canalised river after raining in reasonably new residential development area. Whereas in an old river, such as Kallang River, the TSS and turbidity figures would be much higher due to the different characteristics of the river streams and the original used of a river.

The full data sets were plotted in Figure 4(a) and analysed. As the TSS increases the turbidity uncertainty also increases. Out of the 48 data sets, the result shows higher consistency at an approximate maximum TSS concentration of 50 mg/L as shown in Figure 4(b). However, this finding did not mean the construction works were adhering to the 50 mg/L of TSS of the stated PUB discharge limit. Rather, those were the measures of the TSS levels in the river streams after dilution by the river water. As aforementioned, the selected data were then plotted in Figure 4(b). Correlation between TSS concentration (in y-axis) and turbidity level (in x-axis) of river streams was established after applying a linear regression model.

In general, the graph in Figure 4(a, b) show that an increase in TSS concentrations affecting in an increase in turbidity levels. Suspended solids have the ability to obstruct the transmittance of light in a water sample, when TSS concentration increases; light scattering intensifies (Sadar, 1998). APHA defines turbidity as the optical property of the water sample that causes light to be scattered and absorbed rather than being transmitted in straight lines. 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 (Gippel, 1995). For example, in a research conducted by the University of Washington, 13 river streams had been sampled in the Puget Lowlands in Washington State to determine the feasibility of using turbidity to estimate TSS concentrations. Regression analysis performed on turbidity and TSS data, natural-log transformed, resulted in a strong positive correlation with a $R^2$ of 0.96 (Packman et al., 1999).

There may be a case of obtaining a zero value of turbidity number that paired up with a certain TSS concentration from a river water sample. At low TSS concentration this might be due to a fine sand-size fraction in the river samples which was quickly settles below the zone monitored by turbidimeter (Holliday et al., 2003). The fine sand-faction was trapped together with other suspended solids during filtration using 0.6 µm glass fibre filter when measuring the TSS concentration.

Overall the plotted data in Figure 4(b) shows a good positive correlation between TSS concentration and turbidity level, with a correlation coefficient of $R^2$ of 0.7992. Hence, measuring turbidity level in river water samples has shown a potential cost-saving option to estimate TSS concentration at an approximate TSS concentration of 50 mg/L.

However, using turbidity measurement to serve as a surrogate for TSS measurement was not recommended. The main possible reason was, in water sample containing suspended solids, the light transmittance is depending on the abovementioned factors such as surface texture, size, shape (Clifford et al. 1995; Gippel, 1988), colour (Malcolm, 1985) and reflectivity of the particles (Bhargava and Mariam, 1991).

**Figure 4** Correlation between Total Suspended Solids (TSS in mg/L) and Turbidity level (NTU) from: (a- left) 48 river water samples and (b- right) selected river water samples at lower TSS concentration range, which were collected from various river streams in Singapore between Jan 2010 to July 2011.
The occurrence of rain was expected to change the river characteristics based on the TSS and turbidity measurements in river streams. Figure 5 shows the TSS concentrations “before rain” and “after rain” in the river streams. At a limited $R^2 = 0.7073$ and an approximate ratio of TSS concentration “before rain” and “after rain” 1:1.8, the result might suggest that a raining event may eventually add more sediments in the river due to some erosion of river sites that carried some sediments from the upstream and increase the TSS concentration in the downstream. In the previous study it was reported that rainfall could cause soil erosion upstream, bringing loads of suspended solids into the rivers (Bakar et al., 2007). The increased discharge or flow rate caused by the storm would also keep lighter materials in suspension than in a stable flow in the river during a dry period. The result was hardly confirmed with the recorded turbidity data using the same river water samples due to the poor relationship between pairs of turbidity levels “before rain” and “after rain”. The possible reasons could be explained by several limitations when the study was carried out. Firstly, the sample timing was not consistent. Lag time from the start of rainfall to the time of collection of our water samples were not fixed. Limited data collection from each river stream compared to the large number of river streams available in Singapore could result a lack of data accuracy. In addition, large variance of river size, rainfall intensity and unknown upstream site characteristics might result the large variance of TSS and turbidity measurement too.

CONCLUSIONS

The data collected from 14 river-streams around Singapore shows a fairly good correlation ($R^2 = 0.8$) between Turbidity levels and TSS concentrations at a maximum TSS concentration of 50 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 occurrence of rain may change the river characteristics based on the TSS. It showed that the TSS records “after rain” fairly increase approximately 1.8 times
higher than TSS records “before rain” at the river streams. Smaller scope of area of study, more data collections and controlled time of collection and analysis are required to better establish the correlation between TSS and turbidity in river streams. In case, a good correlation between turbidity level and TSS can be established, the relationship can change spatially and temporarily due to variations in sediment composition in river streams. Overall the results suggest that the measurement of turbidity levels have the potential to replace the measurement of TSS concentrations if the area of study is strictly controlled.

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