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Investigation of turbidity and suspended solids behavior in storm water run-off from different land-use sites in South Korea

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ABSTRACT

Turbidity is known to be the quickest and cost effective characteristic to evaluate the eroded sediment amount in urban and construction sites run-off. In Korea, the focus towards the storm water run-off from the construction site is limited and therefore, this research investigates storm water run-off pollution effects and quantifies the turbidity–suspended solids relationship from various land-use areas including the construction site in Yongin watershed Korea. In this study, precipitation, discharge, and water quality data were collected and analyzed between June 2011 and December 2012. It was found that the construction site showed high turbidity concentration levels in all storm water events compared to other monitoring sites. Overall mean turbidity level in the construction site was 4, 27, and 70 times higher than mix catchment, agriculture, and urban sites, whereas, mean turbidity level in mix catchment site was 17 times higher than urban site, therefore, hydro–pollutograph can be described in clear flow and turbid flow period portions. Results obtained in this study showed a strong correlation between suspended particles and turbidity specifically in the construction site compared to other monitoring sites. These findings will support managers to plan, manage, and monitor storm water pollution according to specific land-use type.

Keywords: Turbidity; Storm water run-off; Hydro–pollutograph; Suspended solids

1. Introduction

Over the last 40 years, management of point source end-of-pipe controls were mainly focused on preserving the water quality in Korea but were unable to meet clean water demand target due to nonpoint-source pollution discharge into water bodies from various land-use areas. It occurs from agricultural, urban, forest, mining, construction sites, livestock, fertilizer, herbicides, generates numerous nonpoint pollutants including pesticides, oil, grease, chemicals, sediments, acidic sewage, bacteria, nutrients, and others [1]. Monitoring of storm water run-off quality needs a comprehensive literature review, detailed survey of watershed area, collection of hydrological and site characteristics data, and specific target water pollutants data according to land-use characteristics.

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Land-use change impact from vegetation and forest cover to urban development disturbs the natural water environment and aquatic ecosystem severely. Replacement of ground cover of any catchment area affects the water quality, run-off volume, and flow characteristics within the watershed [2]. In Korea, Urban storm water run-off and its potential threats to receiving water bodies have been focused and highlighted in many studies over the last two decades [3–7]. Although many restoration programs and treatment methods were initiated to improve the water quality, it could not meet the established standards as per National Environmental Policy Act of Korea.

In a newly urban development project, monitoring of storm water run-off from pre-during-post construction phases is utmost important. Apart from other storm water pollution sources such as agriculture, industrial, and forests, an unmanaged and uncontrolled construction industry storm water run-off can significantly impair and pollute the water quality due to onsite land-disturbing activities such as cutting of trees, clearing, digging, and grading. These pollutants include sediments, debris, nutrients, and chemicals which have negative impact on aquatic environment. Erosion is considered as a natural phenomenon but the construction sites produce higher erosion rate compared to natural erosion rate because of the removal and disturbance of natural vegetative cover. In previous studies, it was found that sediment levels in the construction sites are 10–20 times higher than agricultural lands and from 1,000 to 2,000 times higher than forest lands [8]. These sediments affect the clarity of water and cause high turbidity which can result in diminishing of aquatic ecosystem.

In recent years, turbidity is considered as a substitute for suspended solids (SS) because they can only be measured in laboratory on samples collected during rain events and there is no continuous measuring device [9]. Turbidity is related to the scattering of light by fine and suspended particles that cause water to have a cloudy appearance and is measured by a turbidity meter in nephelometric turbidity units (NTUs) as the intensity of light scattered at one or more angles to an incident beam of light [10]. Direct automated measurement of turbidity can provide representative temporal measurements, avoid discrete sample collection, reduce the laboratory cost, and save the time and labor. Previous studies found that turbidity measurements may correlate closely with sediment concentrations during storm water run-off events [11,12]. It has been suggested that turbidity and SS relationship is site-specific as well as time based, therefore a relationship varies for a particular catchment and within a particular period of time [13].

The objective of this study is to investigate the pollutant concentration behavior on storm water discharge quality and to determine the relationship between turbidity and SS so that the storm water discharge effects on turbidity–sediment relationship can be observed.

2. Research methodology

2.1. Study area description and sampling criteria

Total of five land-use categories were selected as pilot areas according to run-off and site-specific characteristics considering the ease in accessibility and maintenance within the Yongin watershed that ultimately drain to guem-hak stream as shown in Fig. 1. In the year 2011, forest, construction, and mix catchment (construction and urban) sites were selected, whereas, in the year 2012, construction, mix catchment, urban, and agricultural sites were selected to monitor storm water run-off pollution. Forest site was converted into bare soil land; therefore, it was not monitored in the year 2012. It was selected to observe the site-specific natural storm water background characteristics. Construction site was selected outside the construction area boundary because of continuous land disturbance and new urban development activities. Mix catchment site is the outlet discharge towards the stream from the construction site and surrounding urban land-use categories. Agriculture site represents the discharge from crop field. Discharge from urban site includes commercial, residential, and others was also monitored. Total of 15 storm water events were monitored considering hydrological and site-specific conditions. Manual grab sampling was conducted for all monitoring sites considering time and flow throughout the storm water event. Multiple grab samples are discrete samples and can be collected at any time and flow change during the storm water event. The time of sampling and the intervals between the samples throughout the storm event is of great importance due to flushing and pollutants wash-off characteristics depending on topographical, hydrological, and site-specific characteristics. Sampling strategy and methodology were modified according to the site-specific characteristics. Sampling interval time was set as 15–30 min for initial 2 h run-off and 1–2 h thereafter except for later peak flow time. Sufficient number of samples was collected from each storm water event to provide representative data.

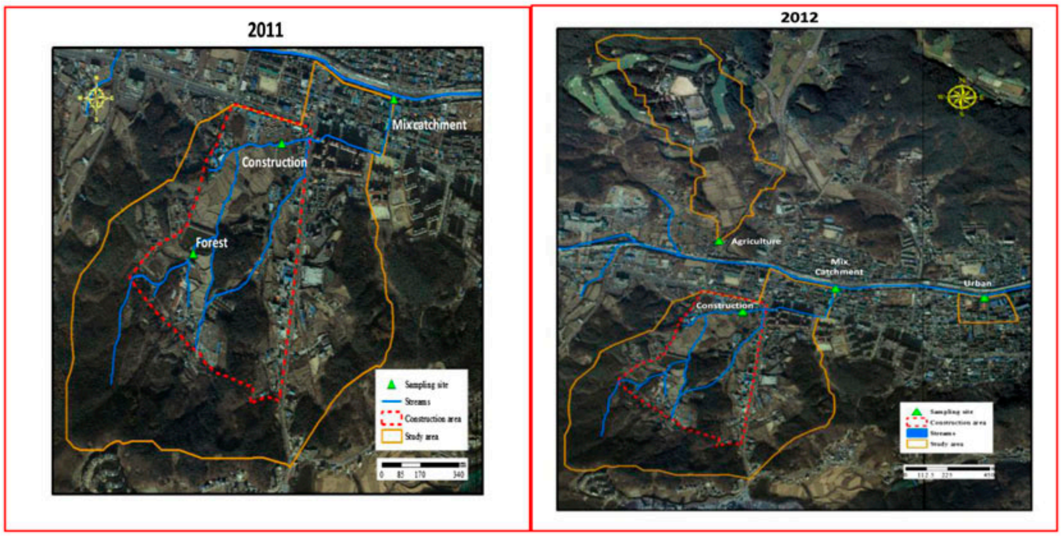

Fig. 1. Study area location map.

2.2. Field investigation and turbidity–SS analysis

In this study, precipitation and discharge were investigated between June 2011 and December 2012. Rainfall data are important to characterize conditions for monitoring events selection. Rainfall records showed daily event analysis throughout the year and were categorized in five different categories, i.e. 1–4, 4–10, 10–30, 30–50, and >50 mm. Rainfall gage was installed in the field to measure and record the rainfall data. Discharge data were collected by using manual current velocity meter or automatic flow meter according to the ease and approach at each monitoring site throughout the storm water period.

Collected samples were analyzed for turbidity and SS in laboratory within one day of the collection. Onsite turbidity measurement was conducted using Horiba sensor but high turbid and unclear samples were analyzed in laboratory due to limited range of field equipment analysis. Manual shaking of samples was made to ensure well mixing and also samples were diluted due to large sediment quantity. They were immediately investigated using turbidity meter and were reported in NTU. SS were analyzed using filtration procedure according to Korea standard method guidelines.

3. Results and discussion

3.1. Rainfall data and hydrological characteristics

Rainfall data of last 10 years (3–12) were collected from national meteorological department to find out the rainfall pattern in the local monitoring area using data of nearby station to the study area. The data survey shows an average annual rainfall of 1,483 mm, the highest annual rainfall of 1,973 mm (2011), and the lowest annual rainfall of 1,215 mm (2004) as shown in Table 1. Monthly average rainfall data show greater than 100 mm from May to September, which is approximately 80.6% of the total annual rainfall due to monsoon season.

Table 2 summarizes the hydrological characteristics of individual storm water events. In the year 2012, they were characterized considering minimum 4 mm of rainfall intensity and 3 days antecedent dry period for all events because it was observed that storm water events with less number of dry days and small rainfall intensity events could not represent a comprehensive data for the characterization of water pollution in 2011 due to infiltration capacity, underground water flow, base flow, and other site-specific characteristics. Event features such as rainfall intensity, run-off duration, rainfall depth, run-off volume, and peak flow rate were also summarized in Table 2.

3.2. Time-flow-concentration trend plots

The trend for pollutant concentration in each of the storm water event was observed through time-flow-concentration graphs (hydro–pollutographs). It was found that, these graphs can be described in clear flow and turbid flow period portions as it can be seen in Fig. 2 for most of the monitoring sites. Overall forest site showed variations in constituent concentration

Table 1
10 years local rainfall data

Year	Yearly rainfall	Jan	Feb	Mar	April	May	June	July	Aug	Sep	Oct	Nov	Dec
2003	1,511	10	46	28	182	85	159	341	294	271	30	51	14
2004	1,215	18	42	14	64	125	136	382	157	183	2	67	25
2005	1,426	6	15	25	85	89	161	252	357	315	70	39	12
2006	1,362	39	19	7	60	133	157	755	66	22	18	61	25
2007	1,323	9	15	135	24	147	74	269	295	269	18	57	11
2008	1,341	13	9	55.9	42	93	198	541	217	102	35	18	17
2009	1,540	8	27	59	45	102	119	766	207	56	64	68	19
2010	1,471	27	57	79	58	101	116	207	373	376	30	18	29
2011	1,973	11	50	23	186	74	391	794	315	33	38	46	12
2012	1,674	10	0.7	43	125	67	16	562	418	229	88	66	47
Average	1,483	15	28	47	87	102	153	487	270	186	39	49	21
Maximum	1,973	39	57	135	186	147	391	794	418	376	88	68	47
Minimum	1,215	6	1	7	24	67	16	207	66	22	2	18	11

Table 2
Hydrological characteristics

Rainfall run-off event	Antecedent dry hours (h)	Average rainfall intensity (mm/h)	Run-off duration (min)	Rainfall depth (mm)	Run-off volume (m^3)	Peak flow (m^3/h)
6/22/2011	216	4.08	360	24.5	322	341
7/7/2011	72	9.9	300	49.5	22,167	6,141
7/26/2011	24	10.06	340	57	20,003	8,845
8/3/2011	19.2	0.33	180	1	4,542	6,505
8/12/2011	24	9.79	340	55.5	11,906	4,746
9/29/2011	216	1.42	700	16.55	1,499	310
10/14/2011	336	1.4	300	7	1,044	723
12/2/2011	24	0.4	600	4	98	14
6/29/2012	744	5.1	960	63.7	14,727	2,358
7/19/2012	72	2.64	510	33.5	11,240	2,824
8/12/2012	552	2.24	700	28.5	11,716	4,723
9/4/2012	91.2	5.69	775	65.7	21,610	5,670
9/13/2012	96	2.63	400	11	5,181	1,638
10/22/2012	264	5.68	490	47.5	4,779	1,522
11/16/2012	72	0.94	480	7.5	1,079	215

and were not highly affected by peak flow or time interval, whereas, agriculture site was strongly correlated with flow rate because peak concentration co-exhibited with peak flow rate. In mix catchment area peak concentrations were observed in the initial and middle period for the year 2011, whereas, the later period of storm water event exhibited peak concentration in the year 2012. It may be due to the increase in soil disturbance activities within construction boundary. Pollutants peak concentration occurred in 1st hour of run-off from urban land-use site and then gradual decrease was observed in concentration levels. Early flushing peak concentration was observed due to high imperviousness in urban land-use. In case of the construction site, pollutants concentration varied significantly. In 2011, peak concentration was observed in the middle and later period of event due to background flow dilution and minimum soil disturbance activities, whereas, in 2012, peak concentration levels were observed within first two hours of rainfall event due to the increase in digging, transportation, and deposition of soil and also diversion of drainage

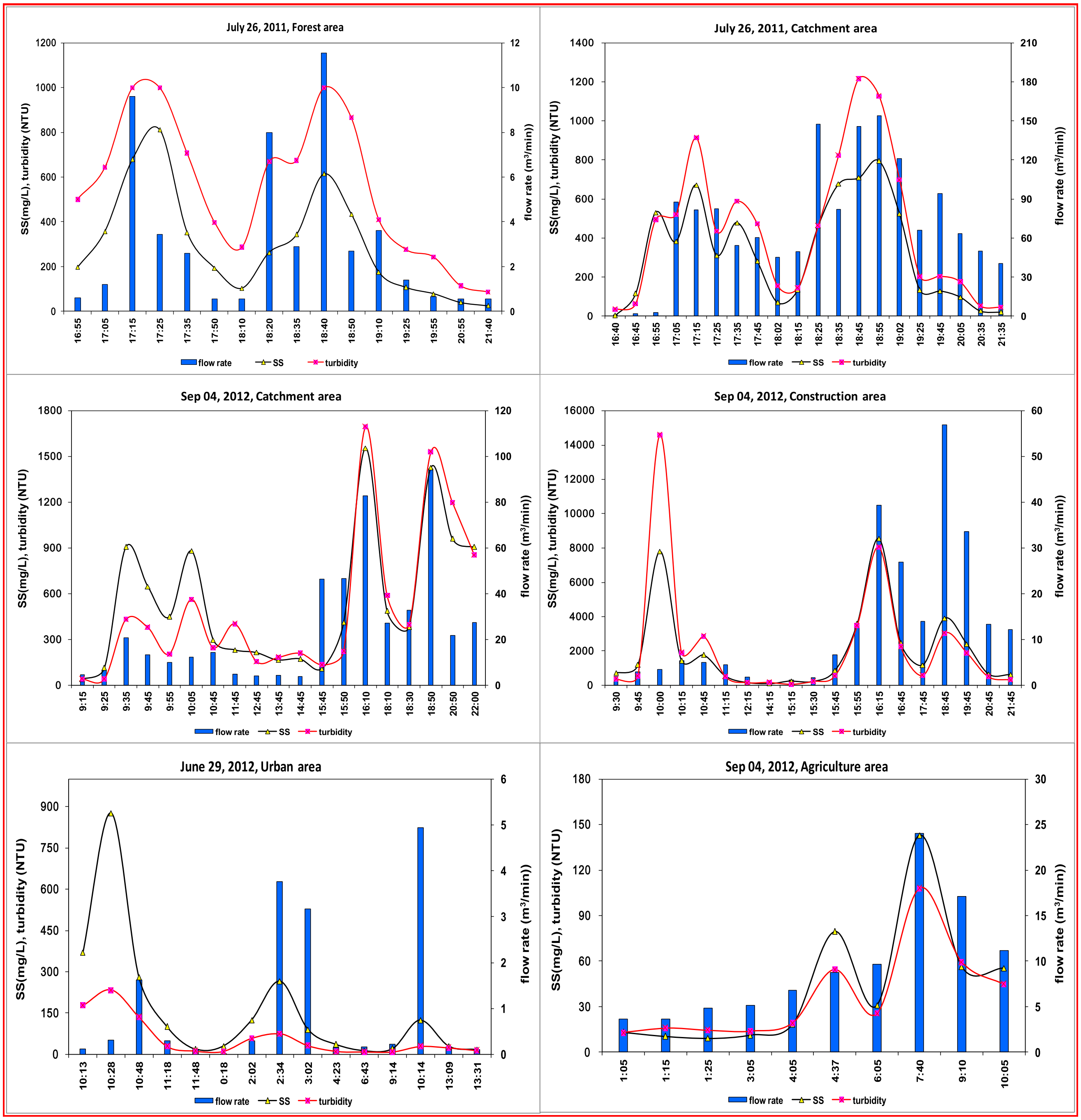

Fig. 2. Hydro–pollutographs.

pathway. It was observed that an increase in SS concentration resulted in an increase in turbidity levels in most of the monitoring sites. In past study, [14] similar results of SS with turbidity were also found. Overall the pollutographs graphs showed similar trend of rise and fall peak concentrations and no correlation was observed between pollutants concentration and peak flow rate in most of the storm events for all monitoring sites.

Tables 3 and 4 represent comparison of turbidity and SS ranges in each monitoring site. The maximum concentration level during 2012 was 5–10

Table 3
Concentration ranges in 2011

	SS (mg/L)			Turbidity (NTU)		
Rainfall run-off event	Forest	Construction	Mix catchment	Forest	Construction	Mix catchment
6/22/2011	11–862	4–194	3–458	21–1,089	7–221	7–559
7/7/2011	2–410	4–208	4–535	4–642	6–341	8–662
7/26/2011	26–812	4–484	3–795	86–1,120	5–985	34–1,218
8/3/2011	23–1,560	16–456	24–532	63–1980	55–994	45–1,221
8/12/2011	2–589	23–172	4–380	30–890	6–333	2–820
9/29/2011	–	2–174	2–118	11–862	4–443	5–169
10/14/2011	–	–	9–948	–	–	10–1,284
12/2/2011	–	–	5–113	–	–	32–414

Table 4
Concentration ranges in 2012

	SS (mg/L)				Turbidity (NTU)			
Rainfall run-off event	Construction	Mix catchment	Agriculture	Urban	Construction	Mix catchment	Agriculture	Urban
6/29/2012	186–11,300	2.4–3,340	17.5–382	12–877	80–7,632	4.5–4,749	22–157	8–233
7/19/2012	485–5,250	23.7–703	48–134	7–109	473–6,654	24 –675	44–76	6–83
8/12/2012	990–16,120	30 –9,220	22–81	6–286	1,432–12,320	10 –6,816	10 –55	5.8–94
9/4/2012	90–8,546	38–1,553	9.2–143	2–27	45–14,500	39.7–1,694	13–108	5.4–14.5
9/13/2012	11–37	–	–	–	6–47	–	–	–
10/22/2012	–	17.3–1,220	26–258	8–116	–	5.2–1,134	15–127	7.7–98.8
11/16/2012	–	27–470	–	–	–	33–290	–	–

times higher than the results in 2011 for construction and mix catchment sites. Overall the construction site showed highest mean pollutant concentration levels in all storm water events followed by mix catchment site from all monitoring sites. It was found that mean turbidity levels in the construction site was 4, 27, and 70 times higher than mix catchment, agriculture, and urban sites whereas, mean turbidity in mix catchment site was 17 times higher than urban site. Forest site is considered as the representative site for background concentration but in this study the results showed significantly higher levels than expected. It may be due to the interference of surrounding anthropogenic activities such as agriculture, run-off from road surface, devegetation, and cutting of trees but the pollution source were mostly leaves, debris, and eroded soil. Similar results were observed in previous study in which organic pollutants concentration was higher than expected [15]. Developed countries such as USA proposed numeric turbidity limits as 50 NTU daily sediment discharges limit from the construction sites to the water bodies [16]. According to one study, SS desirable concentration should not exceed 25 mg/L in fresh water [17] and also in Singapore the maximum allowable limit to discharge SS into drainage system is 50 mg/L [18].

In previous studies, linear correlation was found between turbidity and SS regardless of change in physical properties with respect to time during rainfall events [19,20]. In this study a Pearson correlation analysis was performed and in result a linear regression analysis was confirmed between SS and turbidity for all monitoring sites. Strong correlation was observed in the construction site with a correlation coefficient of R^2 of 0.91, suggesting that turbidity can be used as a substitute to predict SS concentration within this watershed. For forest, urban, mix catchment, and agriculture sites, the R^2 values were observed as 0.75, 0.84, 0.80, and 0.82, respectively, as shown in Fig. 3. The regression method and formulae can be used to accommodate further SS monitoring without considering the water samples and laboratory analysis cost.

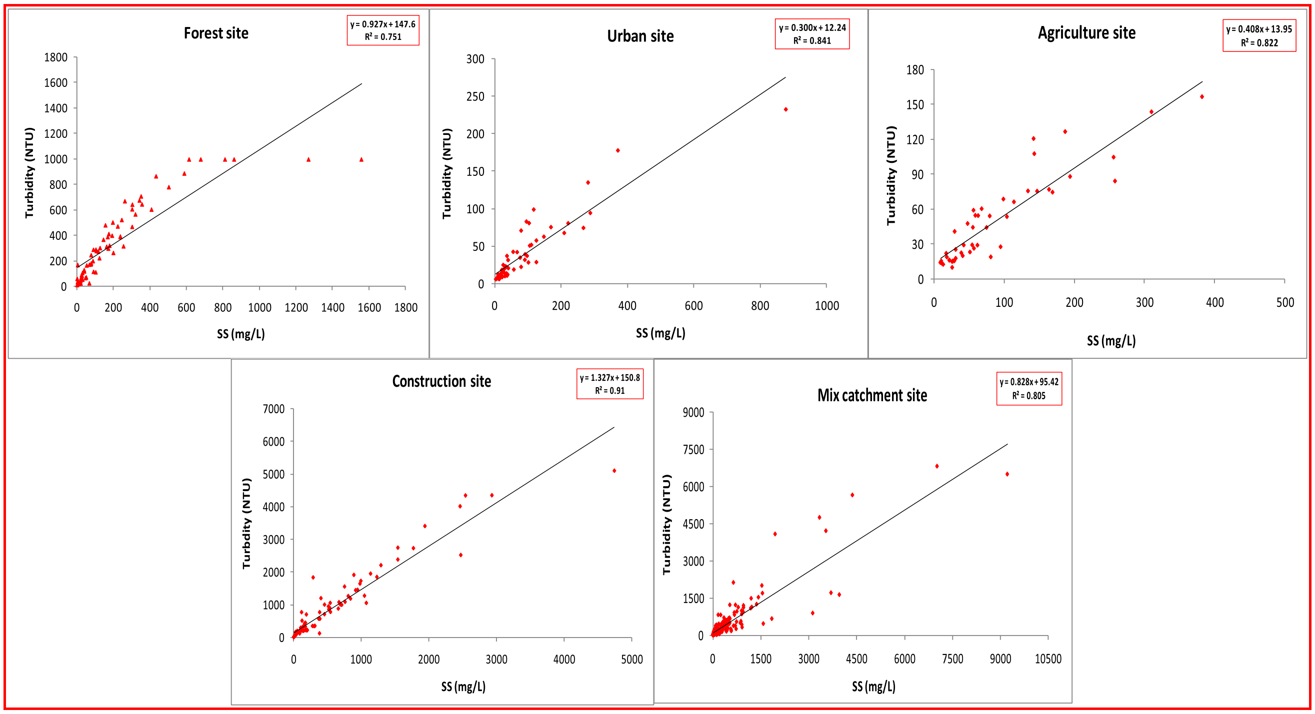

Fig. 3. Correlation analysis graph.

4. Conclusions

This study has provided the basis for comprehensive investigation of nonpoint source pollutants effects on run-off water quality from different land-use sites, specifically the construction site impact. Results show the temporal change in hydro–pollutograph in all monitoring sites. It was concluded that peak concentration preceded or followed the peak flow rate and does not correlate with each other. Construction site showed highest turbidity level as compared to other monitoring sites. A strong positive linear relationship was examined between turbidity and SS. This measurement can be used as a substitute for the sediment concentration determination within the catchment area according to the site-specific characteristics. Although the turbidity measurement is cost effective and quicker than SS measurement, there is a need to collect more representative data and best collection time in order to establish good correlation. The findings from this study can be employed to develop management strategies to control storm water pollution at the specific catchment level.

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