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Annual Sedimentation Yield and Sediment Characteristics of Upper Lake, Bhopal, India

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Abstract

Sedimentation in lentic and lotic water resources is the outcome of the land erosion in their catchment area. Land erosion ultimately affects the physical and chemical properties of soils and resulting on-site nutrient loss and off-site sedimentation and nutrients enrichment of water resources. The off-site effects of erosion in the form of sedimentation and nutrients enrichment are usually more pricey and severe than the on-site effects on land resources. Many empirical equations and procedures have been developed for estimating sediment yield at the outlet of a catchment. These regression equations for estimation of annual sediment yield are linked with catchment area, land use patterns, meteorological conditions and runoff generated within the catchment. These equations are widely accepted and used for prediction of sediment yield from the un-gauged catchment area. In the present study Upper Lake, Bhopal and its catchment area is taken as a test case and entire study was aimed with two main objectives, first, to estimate and compare the annul sedimentation yield using different empirical equations and second, to determine the sediment characteristics deposited in the bottom of the Upper Lake. The study results revealed that significant annual sedimentation yield were observed which were found in between 0.22-5.6 Mcum/year. As far as, sediment characteristic is concern, it was also found rich in nutrient and organic loads which may be the significant nutrient contributors to hypo-limnetic lake environment. Therefore, an integrated catchment area plan is imperative which can manage on-site effect of soil erosion that could reduce the risk and negative impacts on downstream Upper Lake ecosystem.

Keywords: Sedimentation, lentic, lotic, land erosion.

Introduction

Soil erosion is a complex dynamic process by which productive soil surface is detached, transported, and accumulated at a distant place. It produces exposed subsurface where the soil has been detached and deposited in low-lying areas of the landscape or in water bodies downstream in a process known as sedimentation. Soil erosion and sedimentation are concurring environmental processes with varied negative and positive impacts. The negative impacts include the removal of nutrient rich topsoil in upland areas and subsequent reduction of agricultural productivity in those areas and at the same time if deposited in Lake or River bed than enhance the nutrients enrichment and reduce the storage volumes[1].

In India, an area of about 175000 km^2 out of the total land area of 328000 km^2, accounted near 53% of the total land area is prone to soil erosion[2].The accelerated soil erosion has irreversibly converted vast tracts of land into infertile surface over the country. These degraded land surfaces have also become a source of pollution of the natural water. Deposition of soil eroded from upland areas in the down streams reaches into the lakes and river has caused degradation. In some cases, sediment is responsible for the transport of essential nutrients as well pollutants for any lentic and lotic water resources that is why non-point sources of pollution accounted more responsible for water quality degradation. Sediment has an important role in the nutrient cycle of aquatic environment. This has resulted reduction in the water submergence area and sedimentation in lentic and lotic water resources.

Over the years, there has been a considerable growth in the awareness of environmental pollution problems and it has become a major national and international political issues[3]. In case of lake and wetlands, as discussed earlier non-point sources may alone responsible for more than 50% of the total pollution load. In many areas non-point pollution, such as runoff from crop land, urban storm water and runoff from industrial sites are becoming major issues for degradation of water quality. Apart from this, several other anthropogenic activities are also responsible for water quality degradation. In line with that hydro chemical changes in two eutrophic lakes of Central India after immersion of Durga and Ganesh idol were also studied to understand the impacts of religious activities on the limnetic environment[4]. Agriculture is often considered as the largest contributor to non-point sources pollution of both surface and subsurface systems. In this context, discharges of nitrogen and phosphorous are mainly responsible for degradation of lentic and lotic water resources. Increased nutrient loads from natural and anthropogenic sources have led to eutrophication of many aquatic systems worldwide[5]. In eutrophic lakes in particular, fluxes of nitrogen (N) and phosphorus (P) from the sediments to the water column often represent an important source of nutrients for primary productivity[6,7]. Although these effects were caused by high nutrient loading, restoration of the former macrophyte-dominated clear-water state often could not be achieved by external load reduction alone because eutrophic lakes often show resistance to recovery.

Apparently, once the system has switched from a clear to a turbid state, this switch cannot simply be reversed[8,9,10]. In such cases, eutrophication and an accumulation of nutrients in the lake sediment plays an important role. In fact, sediment nutrient release can account for up to 80% of total nutrient inputs to some lakes[12] and if external nutrient loadings are reduced in an effort to restore surface-water quality, lake recovery can be significantly retarded by persistently high sediment release rates[11,12].

Therefore, sedimentation in case of lentic water resources considered more important as compare to lotic water resources because of high retention time and water stagnation. There are several factors that lead to high level of sedimentation transport from the catchment or watershed area to the lakes and reservoirs such as steepness of the terrain, soil quality, low vegetative cover and high intensity of rainfall. Runoff and soil loss are significant in lake sedimentation. These both attributes are inversely related to ground cover although the exact form of the relationship is most likely curvilinear[13]. Therefore, land uses and land management practices which maintain a high ground cover will reduce both runoff and soil losses.

There are several studies have been conducting in India regarding the estimation of annual sedimentation yield in various reservoirs, lakes and rivers. Based on a screening analysis of the available data, Morris[14] concluded that few reservoirs in India have lost as much as 50% of their capacity to date. By 2020 it is expected that 27 of the 116 reservoirs will have lost half their original capacity and by the year 2050, only about 20% of India's existing reservoirs will not have lost 50% of their capacity.

In this paper, we have considered the Upper Lake of Bhopal and its catchment area as a test case. The Upper Lake is located in Bhopal which is a capital of Madhya Pradesh, India and is the only source of water for the city. Economic as well as recreational activities of the city are also heavily dependent on the availability of water in the lake, which is received as surface runoff during monsoon period which hold large volume of silt containing plant nutrients. Therefore, present study is carried out to achieve following targets: Assessment of annual sediment yield from Upper Lake basin. Comparison the annual sediment yield derived from different empirical methods used in India. Assessment of sediment characteristics deposited in Upper Lake.

Material and Methods

The Study Site: Historic Upper Lake was created by Raja Bhoj of Dhar in the 11th Century A.D. by constructing an earthen dam on the River Kolans by virtue of which it is also known as Bhoj Wetland. Subsequent to being declared as state capital of Madhya Pradesh, the Bhopal city witnessed an exponential growth of population and the resultant anthropogenic pressures on water resources. Dense human population in catchment area, urbanization and various anthropogenic activities in the watershed caused increased inflow of silt, untreated sewage, nutrients and pesticides from urban and rural areas, thus adversely affecting both - the water quality and quantity. However, in view of its ecological importance, the Ministry of Environment and Forests, Government of India has recognized this lake along with another lake (Lower lake) located downstream of Upper Lake as wetland of national importance and designated them as ‘Bhoj Wetland’ in 1998 and later declared as Ramsar site in year 2002. Majority of conservation works for Upper Lake was started from year 1995 under Bhoj Wetland Conservation Project through financial assistance of Japan Bank for International Corporation of Japan and completed in year 2004.

Morphological Features of Upper Lake: The Upper Lake is an east-westerly elongated manmade lake and luxuriant growth of aquatic vegetation can be observed in western portion of the lake. Some of the important salient features[15] of the lake are given in Table 1.

Table-1
Salient features of the study site[7]

S. No.	Features	Upper Lake of Bhopal
1	Period of Formation	11th Century A.D.
2	Longitude	77^{0} 18’- 17^{0} 23`E
3	Latitudes	23^{0} 12’- 23^{0} 16`N
4	Catchment area	361 sq. km
5	Submergence area at FTL	36.54 sq. km
6	Storage capacity	117.05 M.cum
7	Maximum Depth	11.7 m
8	Maximum Water level (R.L)	508.65 m
9	Main water uses	Potable water supply
10	Source of water	Rain water

Catchment Area: Catchment of the Upper Lake displays a complete range of urban and rural activity with varying intensities that contribute nutrients and pollution load through point and non-point pollution sources. As shown in Figure-1, majority of the catchment area is under agricultural activities followed by scrub or without scrub and built-up area.

Attributes and Analytical Procedure: Assessment of Sediment Yield: Many empirical equations and procedures have been developed for estimating sediment yield at the outlet of a watershed or a catchment. These regression equations for estimation of annual sediment yield are linked to catchment area; land uses patterns, meteorological conditions and runoff generated within the catchment area. The present study deals with the estimation of sediment yield for the Upper lake Basin located in Madhya Pradesh at central part of India. Three empirical equations viz. Khosla equation[16], Dhurv Narayan equation[17] and Garde and Kothyari equation[18] are used which were commonly used in India for the estimation of annual sediment yield. Details of considered empirical equations (1,2, 3) are described below:

Khosla Equation[16], The annual sediment yield on the volume basis is related to the catchment area as:

$$Q_{sv} = 0.00323A^{0.72} \quad Mm^3/year \qquad (1)$$

Where: Qs = Volume of sediment yield rate in tons per year from the catchment area

A= catchment area in KM^2

Dhruvnarayan et.al. equation[17] , In this annual sediment rate is related to annual runoff as:

$$Q_s = 5.5 + 11.1\,Q \qquad (2)$$

Where: Qs = Volume of sediment yield rate in tons per year from the catchment area

$\mathrm{Q} = $ Annual runoff volume in $\mathrm{M.ha.m}$

Garde & Kotyari[18], The most detailed study to estimate the sediment yield from large catchment is the work of Garde and Kothyari (1987). An analysis of the data from 50 catchments with area ranging from 43 km^2 to 83 880 km^2 produced the following equation for mean annual sediment yield:

$$\mathrm{S_a} = 1.182 * 10^{-6} * \mathrm{P}^{1.29} * \mathrm{A}^{1.03} * \mathrm{D_d^{0.40}} * \mathrm{H}^{0.08} * \mathrm{F_c^{2.42}} \qquad (3)$$

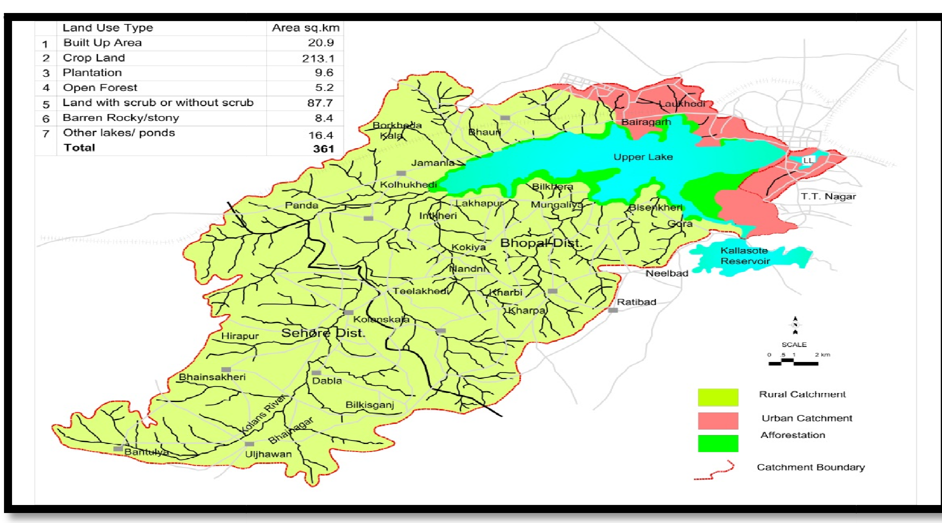
With

$$Fc = (0.8\,FA + 0.6\,FG + 0.3\,FF + 0.1\,F_J/A)$$

Where A is catchment area (km^2), H is catchment slope, D_d is drainage density, Fc is vegetation cover factor, P is annual mean precipitation (mm) and S_a is annual sediment yield (Mm^3). *Fc* is defined as the erosion factor (vegetative cover factor) and *FA* is the area of arable land in the catchment, *FG* is the area occupied by grass and scrub while *Fw* is the area of waste land and *FF* is the forested area. In the present work, analogue data were converted into digital form and a database was created in GIS. Various inputs viz land uses, stream ordering, numbers, length, drainage density and slope etc. which are required for calculating drainage parameters estimated using GIS technique.

Assessment of Lake Sediment Samples: Sediment sampling network was designed to cover a wide range of determinates of key sites, which reasonably represent the shallow and deeper zone of lake. Quarterly sampling of sediment was carried one year from October 2009 to September 2010. Four sampling points were identified in shallow zone while three sampling points were identified in deeper zone. These sediment samples were collected with the help of Eckmen's dredger. All the collected samples from the field brought to the Ministry of Environment and Forests (MoEF), Government of India recognized laboratory for analysis of seven parameters viz. Sediment Texture, Moisture contents, Total Nitrogen (TN), Nitrate-Nitrogen, Total Phosphorous, Total Organic Carbon (TOC), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Sodium (Na^{+}) and Potassium (K^{+}). The collected soil samples were air-dried and crushed into powder in a porcelain mortar and sieved through a nylon sieve (Pore size, 0.45 mm). Total organic carbon content of the air dried sample was determined by following Walkley and Black's wet digestion method[19] using silver sulphate to overcome the influence of chloride ion. Total Nitrogen (TKN) of the air-dried sample was estimated by Kjeldahl method[20].Total phosphorous (TP) was extracted in a weak acid solution of H_2SO_4 and analyzed by using spectrophotometer. Other parameters such as sediment texture, Nitrate-N, Calcium, Magnesium, Sodium and Potassium were analyzed by employing standard methods[21,22]. The graphical representation and statistical analyses were performed using Microsoft Excel and Statistical Packages for the Social Sciences (SPSS).

Figure-1
Catchment of Upper Lake



Results and Discussion

Annual Sediment Yield: The theoretical calculation of the sediment yield is accomplished by estimating various catchment parameters such as area, land use patterns, runoff, and vegetative cover factor etc. The calculated data and factors that were considered in the present estimation of annual sedimentation yield are summarized in table- 2.These parameters are substituted in the various empirical formulas namely, Khosla equation, Dhurv Narayan et.al. equation and Garde and Kothyari equation. The results revealed that, there is significant differences were found in the annual sedimentation yield calculated by these three different methods. A highest annual sedimentation yield of 5.6 Mm^3/year was estimated by Dhurv Narayan et.al. equation while minimum annual sedimentation yield was estimated by Khosla equation. A much more comprehensive and detailed equation for annual sedimentation yield estimation was developed by Garde and Kotyari in 1987. In the contest of Upper Lake, Bhopal with the application of this equation, annual sediment yield was found 1.4 Mm^3.

Empirical equation of Garde and Kotyari considered several additional parameters such as catchment slope, drainage density and vegetation cover factors which were not covered in the equation of Khosla and Dhurv Narayan. Therefore, Garde and Kotyari estimation of annual sediment yield may be more accurate as compare to other two considered equations. On the basis of annual sedimentation yield derived from these three equations, annual reduction of water storage capacity and life of Upper Lake were also estimated which is summarized in table-3.

Table-3
Annual sedimentation yield, reduction of water storage capacity and life of Upper Lake, Bhopal

Method of estimation	Annual sediment yield of Upper Lake, Bhopal (Mm^3/year)	Reduction of lake water storage capacity/ annum (%)	Life of the lake (Years)
Khosla Equation	0.22	0.18	532
Dhruvnarayan et.al.	5.6	4.78	21
Garde & Kotyari	1.4	1.19	83

Assessment of Sediment Characteristics: Assessment of sediment is an important part of limnetic-chemistry to understand the realistic status of the lake. Due to sedimentation, organic matters and nutrients rich soil particles enters in the water body finally settles down in the lake under the influence of gravity. Therefore, the lake sediments are generally rich in nutrients and having important role in lake ecosystem. In case of present study, seasonal variation in different sediment quality parameters is presented in figure-2 to figure-19. Apart from this, there was significant correlation were noted in between most of the sediment quality parameters which are summarized in table-4.

Table-4
Correlation coefficient between sediment quality parameters developed by SPSS software

Correlations

		MC	TN	Nitrate	TP	TOC	Ca	Mg	Na	K
MC	Pearson Correlation	1	.463*	.851**	.669**	.614**	.745**	.388*	.264	.758**
	Sig. (2-tailed)		.013	.000	.000	.001	.000	.041	.174	.000
	N	28	28	28	28	28	28	28	28	28
TN	Pearson Correlation	.463*	1	.653**	.834**	.781**	.826**	.906**	.620**	.557**
	Sig. (2-tailed)	.013		.000	.000	.000	.000	.000	.000	.002
	N	28	28	28	28	28	28	28	28	28
Nitrate	Pearson Correlation	.851**	.653**	1	.770**	.756**	.822**	.612**	.529**	.848**
	Sig. (2-tailed)	.000	.000		.000	.000	.000	.001	.004	.000
	N	28	28	28	28	28	28	28	28	28
TP	Pearson Correlation	.669**	.834**	.770**	1	.898**	.872**	.863**	.680**	.660**
	Sig. (2-tailed)	.000	.000	.000		.000	.000	.000	.000	.000
	N	28	28	28	28	28	28	28	28	28
TOC	Pearson Correlation	.614**	.781**	.756**	.898**	1	.917**	.802**	.749**	.621**
	Sig. (2-tailed)	.001	.000	.000	.000		.000	.000	.000	.000
	N	28	28	28	28	28	28	28	28	28
Ca	Pearson Correlation	.745**	.826**	.822**	.872**	.917**	1	.776**	.600**	.726**
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000	.001	.000
	N	28	28	28	28	28	28	28	28	28
Mg	Pearson Correlation	.388*	.906**	.612**	.863**	.802**	.776**	1	.607**	.581**
	Sig. (2-tailed)	.041	.000	.001	.000	.000	.000		.001	.001
	N	28	28	28	28	28	28	28	28	28
Na	Pearson Correlation	.264	.620**	.529**	.680**	.749**	.600**	.607**	1	.419*
	Sig. (2-tailed)	.174	.000	.004	.000	.000	.001	.001		.026
	N	28	28	28	28	28	28	28	28	28
K	Pearson Correlation	.758**	.557**	.848**	.660**	.621**	.726**	.581**	.419*	1
	Sig. (2-tailed)	.000	.002	.000	.000	.000	.000	.001	.026	
	N	28	28	28	28	28	28	28	28	28

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

SPSS Processor is ready

Sediment Texture and Moisture Content: Texture of the sediment samples collected from shallow and deeper zone found same as black cotton soil containing which contains more clay material. As shown in figure-2 & figure-3, more than 50% of moisture content was recorded in all the collected samples.

Total Nitrogen (TN): In the sediment samples collected from shallow portion of the Upper Lake, Total Nitrogen was recorded in the range of 527-712 mg/kg with an average concentration of 633 mg/kg. Higher concentration was recorded in the month of January while low concentration was recorded in the month of April. In the deeper zone sediment samples, Total Nitrogen was found in between 472-626 mg/kg with an average concentration of 565 mg/kg. In the deeper zone samples higher concentration was observed during January while lower concentration was found in the month of October. As shown in figure-4 and figure-5.

Nitrate Nitrogen (Nitrate-N): In shallow portion of the Upper Lake, Nitrate-N was recorded in the range of 108-186 mg/kg with an average concentration of 142 mg/kg. Higher concentration was recorded in the month of January while low concentration was recorded in the month of April. In the deeper zone sediment samples, Nitrate-N was found in between 126-158 mg/kg with an average concentration of 143mg/kg. In the deeper zone samples higher concentration was observed during January while lower concentration was found in the month of April. As shown in figure-6 and figure-7

Total Phosphorous (TP): In shallow portion of the Upper Lake, TP was recorded in the range of 100-210 mg/kg with an average concentration of 155 mg/kg. Higher concentration was recorded in the month of January while low concentration was recorded in the month of April. In the deeper zone sediment samples, TP was found in between 92-170 mg/kg with an average concentration of 127 mg/kg. In the deeper zone samples higher concentration was observed during January while lower concentration was found in the month of October. As shown in figure-8 and figure-9.

Total Organic Carbon (TOC): In shallow portion of the Upper Lake, TOC was recorded in the range of 890-1388 mg/kg with an average concentration of 1099 mg/kg. Higher concentration was recorded in the month of January while low concentration was recorded in the month of April. In the deeper zone sediment samples, TOC was found in between 944-1108 mg/kg with an average concentration of 996 mg/kg. In the deeper zone samples higher concentration was observed during January while lower concentration was found in the month of April. As shown in figure-10 and Figure-11.

Calcium (Ca): In the sediment samples collected from shallow portion of the Upper Lake, Calcium Ions was recorded in the range of 2614-3398 mg/kg with an average concentration of 3037 mg/kg. Higher concentration was recorded in the month of January while low concentration was recorded in the month of April. In the deeper zone sediment samples, It was found in between 2846-3008 mg/kg with an average concentration of 2912 mg/kg. In the deeper zone samples higher concentration was observed during January while lower concentration was found in the month of October. As shown in figure-12 and figure-13.

Magnesium (Mg): In the sediment samples collected from shallow portion of the Upper Lake, Magnesium Ions was recorded in the range of 304-496 mg/kg with an average concentration of 386 mg/kg. Higher concentration was recorded in the month of January while low concentration was recorded in the month of April. In the deeper zone sediment samples, It was found in between 218-366 mg/kg with an average concentration of 300 mg/kg. In the deeper zone samples higher concentration was observed during in the month of January. As shown in Figure-14 and figure-15.

Sodium (Na): In the sediment samples collected from shallow portion of the Upper Lake, Sodium Ions was recorded in the range of 28-46 mg/kg with an average concentration of 35 mg/kg. Higher concentration was recorded in the month of January while low concentration was recorded in the month of April. In the deeper zone sediment samples, It was found in between 26-36 mg/kg with an average concentration of 31 mg/kg. In the deeper zone samples higher concentration was observed during January while lower concentration was found in the month of October. As shown in figure-16 and Figure-17.

Potassium (K): In the sediment samples collected from shallow portion of the Upper Lake, Potassium Ions was recorded in the range of 14-30 mg/kg with an average concentration of 21mg/kg. Higher concentration was recorded in the month of January while low concentration was recorded in the month of April. In the deeper zone sediment samples, it was found in between 18-28 mg/kg with an average concentration of 21.4 mg/kg. In the deeper zone samples higher concentration was observed during January while lower concentration was found in the month of April. As shown in figure-18 and Figure-19.

Conclusion

In conclusion, this study showed that annual sediment yield of the Upper Lake were relatively high. Therefore, necessary steps towards reduction of soil erosion in the catchment of Upper Lake and sedimentation in lake bottom must be initiated again which were started during Bhoj Wetland Project. Sedimentation in Upper lake is not only reducing the water holding capacity of lake but also degradation of deposited soil sediment releasing the nutrients in hypo-limnetic environment which ultimately affecting the water quality and trophic status of the Upper lake. As the sediment analysis also revealed that significant concentration of Total organic carbon, Total Nitrogen and total Phosphorous were recorded in both shallow and deeper zone sediment samples. As reported by Upadhyay[23], particulates and phytoplantonic turbidity along with higher concentration of Total phosphate were the main reasons of higher trophic status of Upper Lake. Various programmes for soil conservation and silt reduction were taken at priority in the Bhoj Wetland project till year 2004. However, it seems to be a difficult task to control erosion over vast tracts of lands by soil conservation practices alone. Therefore, an Integrated Lake Basin Management Plan is required to prevent and control over siltation and water quality improvement which comprise In-Lake Treatment and Catchment Area Treatment both. Land uses and land management practices which maintain a high ground cover will reduce both runoff and soil losses in Upper Lake catchment. Nevertheless, the problem of lake sedimentation can also be brought under control by construction of upstream silt arresting structures, sediment traps through biological fencing, shore stabilization and by developing effective procedures for sediment routing.

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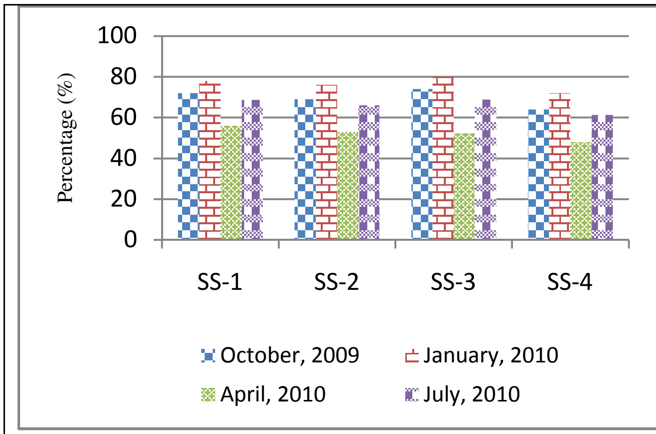

Figure2
Variation of moisture content in sediment samples collected from shallow zone

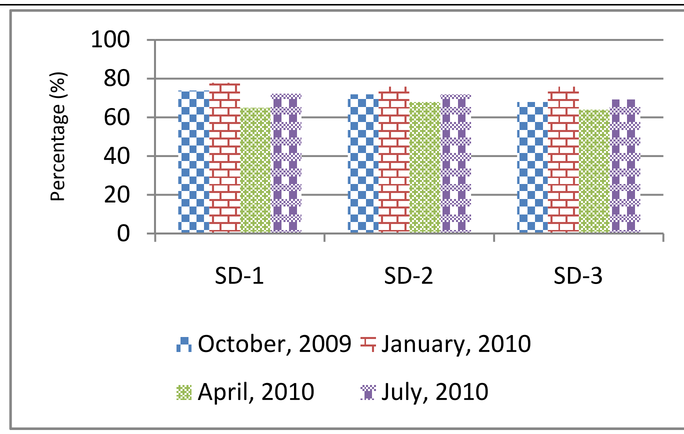

Figure-3
Variation of moisture content in sediment samples collected from deeper zone

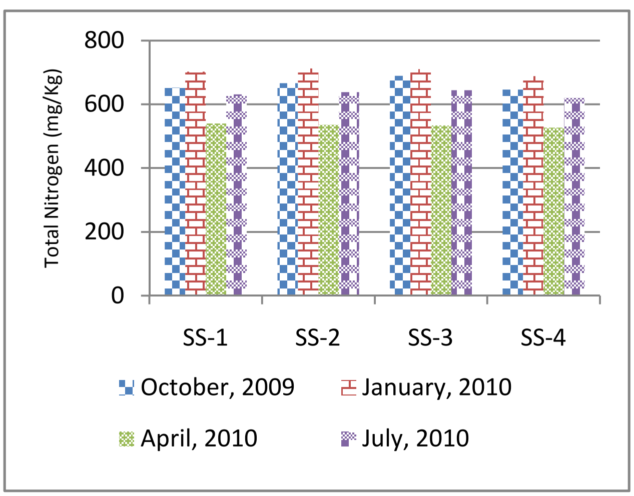

Figure-4
Variation of total nitrogen in sediment samples collected from shallow zone

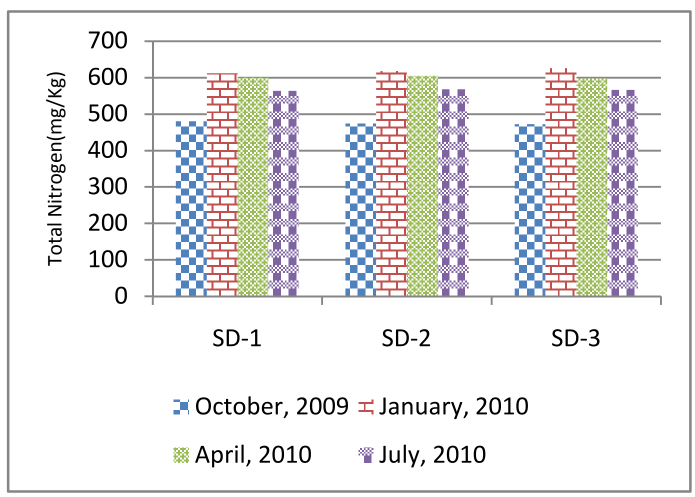

Figure-5
Variation of total nitrogen in sediment samples collected from deeper zone

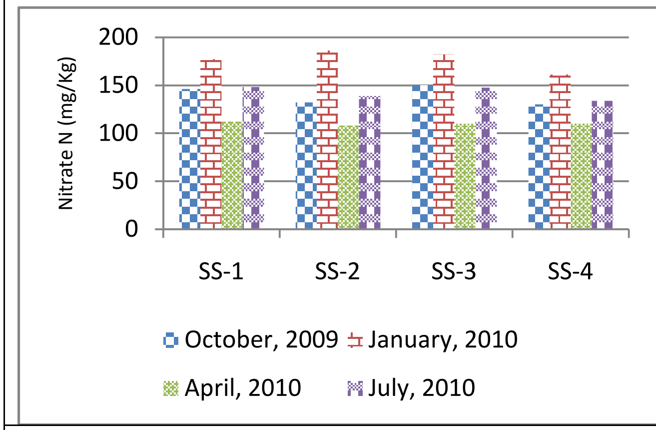

Figure-6
Variation of nitrate-n in sediment samples collected from shallow zone

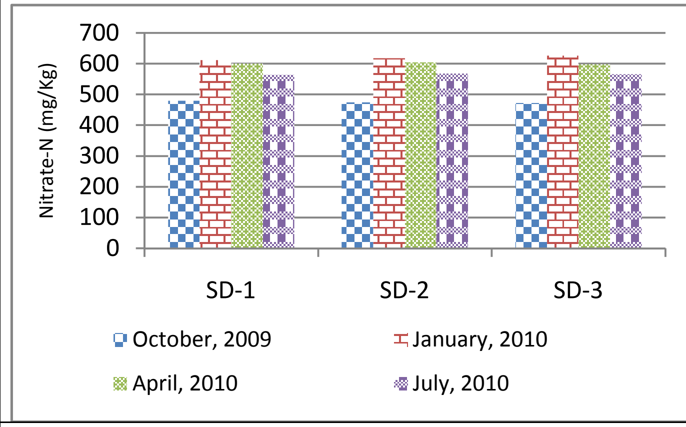

Figure-7
Variation of nitrate-n in sediment samples collected from deeper zone

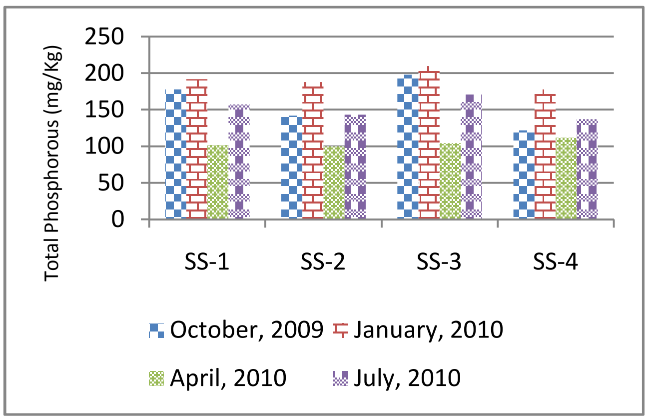

Figure-8
Variation of total phosphorous in sediment samples collected from shallow zone

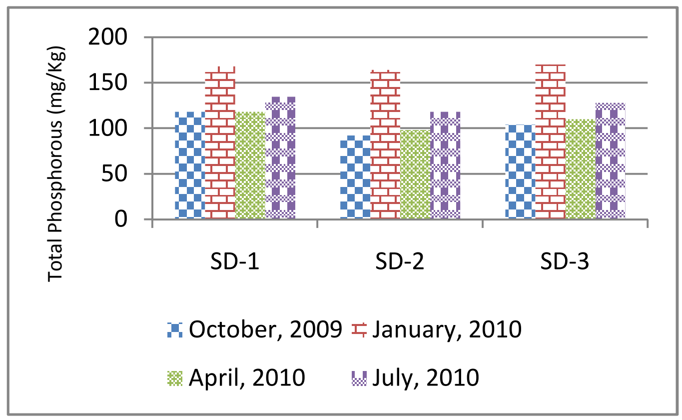

Figure-9
Variation of total phosphorous in sediment samples collected from deeper zone

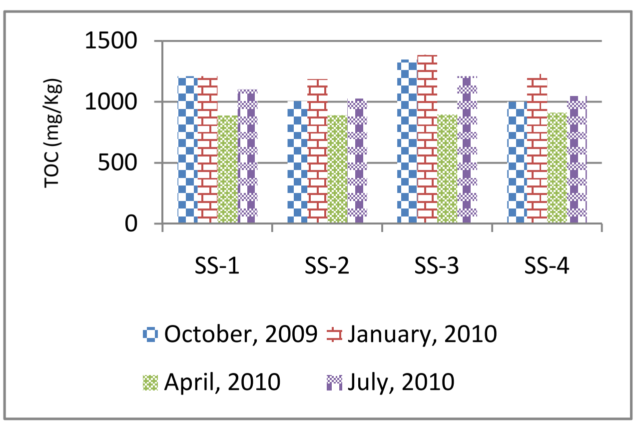

Figure-10
Variation of total organic carbon in sediment samples collected from shallow zone

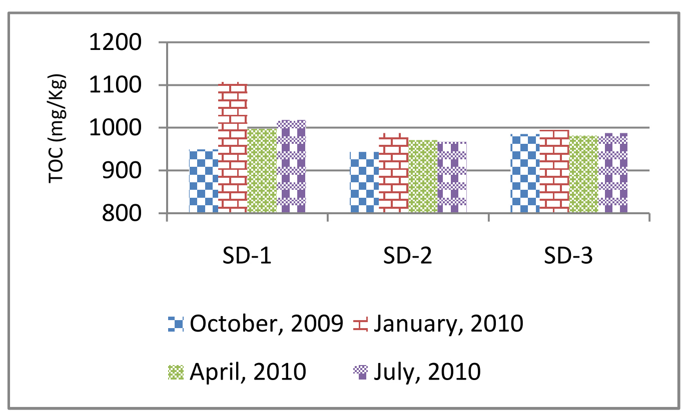

Figure-11
Variation of total organic carbon in sediment samples collected from deeper zone

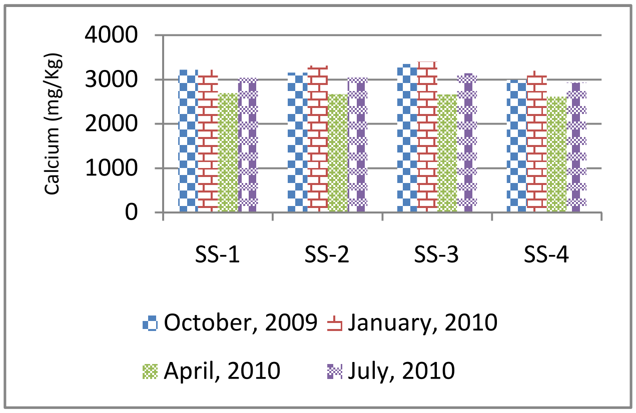

Figure-12
Variation of calcium in sediment samples collected from shallow zone

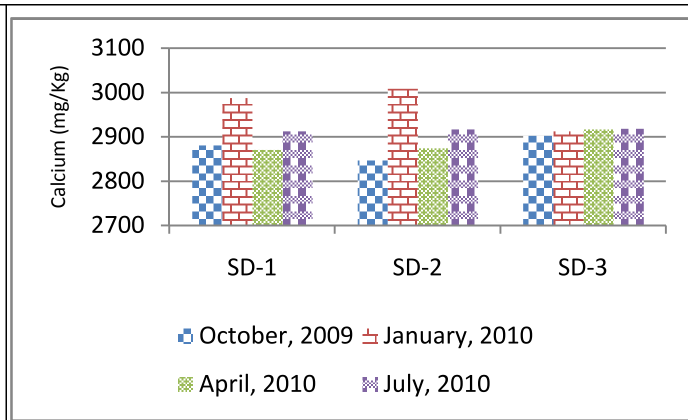

Figure-13
Variation of calcium in sediment samples collected from deeper zone

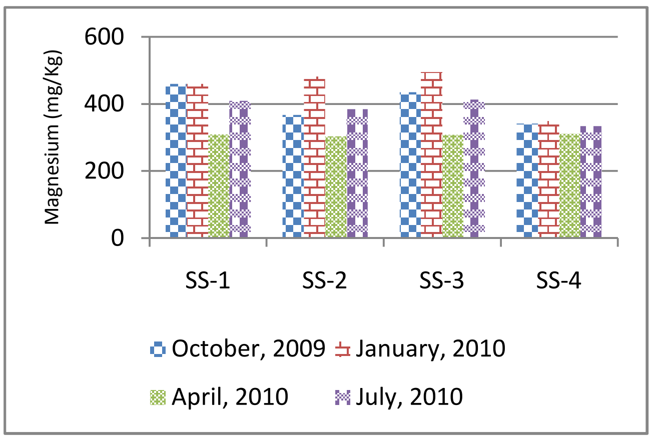

Figure-14
Variation of magnesium in sediment samples collected from shallow zone

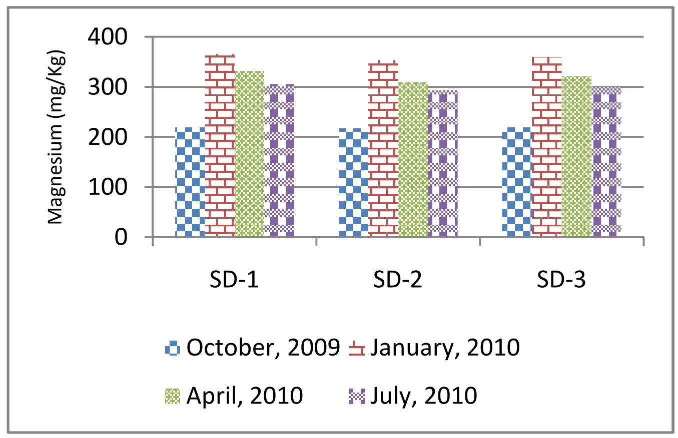

Figure-15
Variation of magnesium in sediment samples collected from deeper zone

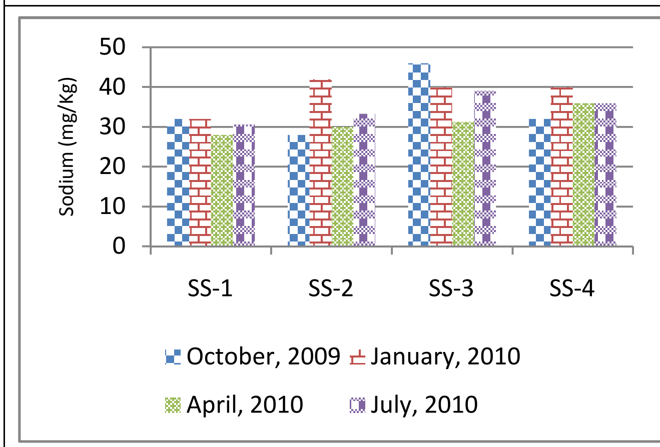

Figure-16
Variation of sodium in sediment samples collected from shallow zone

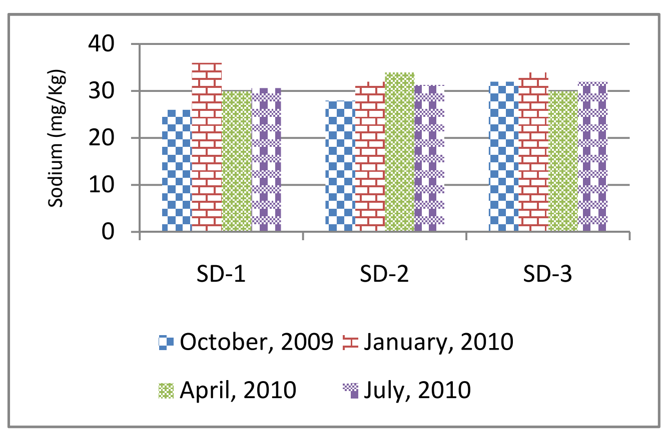

Figure-17
Variation of sodium in sediment samples collected from deeper zone

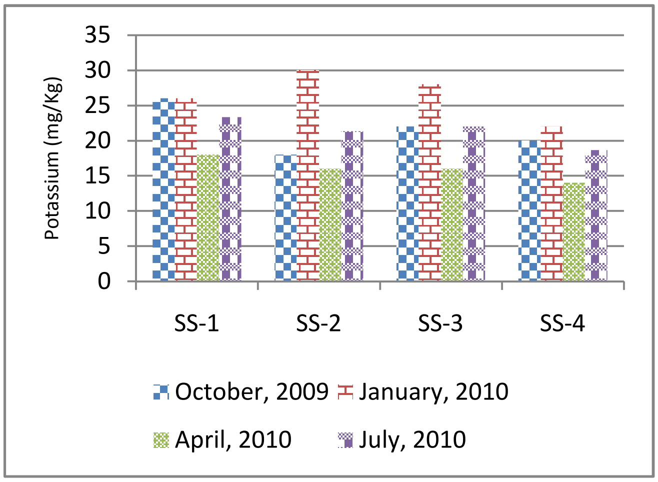

Figure-18: Variation of potassium in sediment samples collected from shallow zone

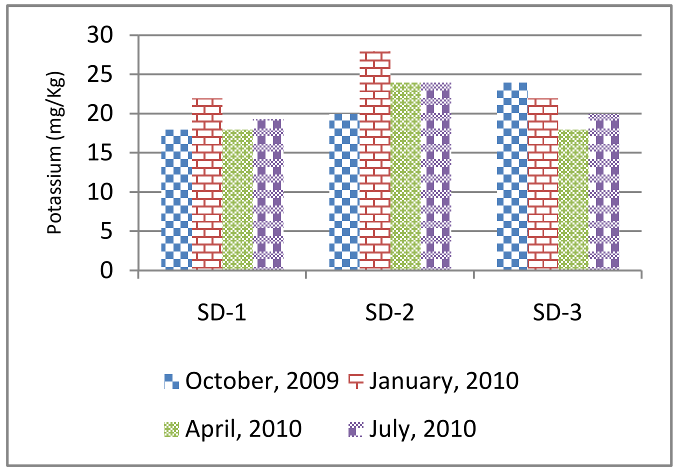

Figure-19: Variation of potassium in sediment samples collected from deeper zone