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**Distribution and Fractionation of P, N and C
in the Sediment Cores from
Yamuna River Basin**

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CERTIFICATE

This research work embodied in this Dissertation entitled "Distribution and Fractionation of P, N and C in the Sediment Cores from Yamuna River Basin" has been carried out in the SCHOOL OF ENVIRONMENTAL SCIENCES, JAWAHARLAL NEHRU UNIVERSITY, NEW DELHI. The work is original and has not been submitted in part or full for any other degree or diploma of any University.



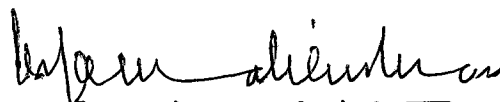
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INTRODUCTION

The river basin and its catchment areas are the most active component of the fresh water part of hydrological cycle. Erosion from the upstream and deposition of the eroded sediments in the catchment areas of downstream are the two very important factors which affect the biogeochemistry and distribution of the nutrients in the river basin. It is estimated that complete cycle of sediments take place in every 250 million years, but individual elements such as Cl, S, Na, Fe, Al etc. are recycled at different rates due to difference in mobility and residence time in the sediment-water system (Garrel and Mackenzie 1971).

Rivers play a major role in global biogeochemical cycling by transporting elements from terrestrial environment to the sea. Many of the transported elements are essential nutrients, and are utilized by river biota. A number of major ions found in river water, such as calcium, magnesium, potassium, sodium, silicon and chloride are often present well in excess of any biological demand, within the river, and may pass through the river system virtually unaffected. Other elements notably, carbon, phosphorus and nitrogen or particulate chemical forms of these elements, are utilized by biota in excess, and may get limited as they pass downstream (Newbold 1992).

Biota remove nutrients from river water, but they also regenerate nutrients to the river water by microbial decomposition of dead tissues. This cycling of nutrients within the river may proceed intensively and yet produce small or negligible net effect on nutrients concentrations. For nutrients such as phosphorus, which does not exchange with atmosphere, biota can not alter the long-run total transport substantially. On the other hand, biota do influence the chemical and physical forms of nutrients, and timing of nutrient transport. The effects may interact, in turn, with physical transport process. For example, the biota might speed downstream transport by converting particulate-bound nutrients to dissolved forms or reducing detrital particulate to smaller, more easily transported sizes. Carbon, nitrogen and, to a limited extent sulphur exchange with the atmosphere. For these elements, biota may strongly influence long term total transport.

The nutrients transport by rivers in the suspended form is far greater than that of in dissolved forms (Berner and Rao, 1994). A major part of eroded sediments from upstream are deposited to the downstream flood-plain areas. And more over, for most of the nutrients, sediments both, act as sink and source. Under certain physico-chemical conditions nutrients get adsorb onto the sediments, and under other sets of physico-chemical conditions desorption occur. Therefore the flood-plain play very crucial role in the biogeochemical cycling of nutrients. At high flow (as in Monsoon) the flood plain becomes part of the surface flow system, and even at low water, the ground return can be a significant base

flow component of river discharge (Lewin, 1992). A high proportion of river sediments are drained from the erosion of flood-plain materials, so that their physical and chemical characteristics are the determinants of the channel material flows. In semi arid system where vertical cut and fill sequences, over period of time, make flood-plain alternatively into source to sink for sediments and nutrients transport. Finally, because flood-plain are primarily constructed through past river sedimentation, they can preserve an extended record of changing sediment characteristics, influenced by climate change, human activities, and deforestation (Lewin 1992). The nutrient studies in the core samples collected from flood-plains can give some very important information for nutrient digenesis, and biogeochemical changes due course of time.

Nutrients are those chemical species present, in soil and sediments, which are utilized by plants and microorganisms for their growth, maintenance and multiplication. For plant growth atleast nineteen elements are needed, although, most of these are required only in very trace amounts. Carbon, hydrogen and oxygen, which are the major components of organisms are called basic components of life. In addition to these elements, the elements which are required in relatively higher quantities are called the macro nutrients (sodium, calcium, potassium, magnesium, silicon, nitrogen, phosphorus and sulphur). The elements which are required in lesser extent are called the micro nutrients (copper, iron, zinc, chlorine, boron, molybdenum, cobalt and vanadium). Insufficiency of any of these nutrients can limit the growth by

that nutrient. In aquatic ecosystem no element other than nitrogen and phosphorus become a limiting factor. Although some times carbon may also be limited but at very low extent. Nutrients in the environment present in the organic and inorganic form.

There is constant recycling between organic and inorganic pools of nutrients. Primary producers are generally using inorganic form of nutrients and convert it to organic form. When organism dies or being consumed by other organisms, these elements again ultimately go to the inorganic reservoir, by the process of microbial decomposition and mineralization; and again enter into the organic pool until again utilized by other organisms.

For the present study, the Yamuna river was chosen, which is the biggest tributary of the Ganges system. Since it flows through diverse climatic and topographic regions, and high anthropogenic activities are taking place in the basin, increased nutrient input into the river system make it an interesting case study for study of nutrient dynamics. To asses the anthropogenic perturbation, three locations were chosen viz. upstream at Saharanpur, midstream at Delhi and downstream at Allahabad, due to logistic reasons, since it covers an area starting from pristine water quality to highly industrially polluted discharge.

Objective of the Present Study

The Yamuna river covers the diverse climatic and topographic areas, from temperate to tropical climatic condition and from plain to hilly areas, the river was chosen for the present study.

1. To evaluate changes in the total phosphorus, nitrogen and carbon with the depth.
2. To measure the increase in C, N, and P loading to the sediments, in recent past by anthropogenic input.
3. To compare the cores of the different climatic, topographic and land use areas.
4. To evaluate the possibility of the water body to be enriched by nutrients, and their role in the Eutrophication.
5. To quantify the different phosphorus reservoirs and there, respective role in phosphorus biogeochemistry.
6. To evaluate the physico-chemical parameters which affect the nutrient dynamics between sediment-water interface.

LITERATURE REVIEW

The rivers play an important role in weathering, erosion and transportation of weathering products to the oceans. Milliman and Meade (1983), and Walling and Web (1983) have estimated river transport of sediments to the oceans as $15-16 \times 10^6$ tonnes per year. The sediment transport from Indian sub-continent to the ocean is estimated to be 1.2×10^6 tonnes per year (Subramanian *et al.*, 1979), which is approximately 10 percent of global sediment transport. According to Berner and Rao (1994) and Vaithyanathan *et al.*, (1989) phosphorus transport to the ocean by the rivers in suspended form is higher than that of in dissolved form, which shows key role played by sediments in nutrients transport.

Nutrient Transport

Extensive literature is available on the river transport of nutrients. On the basis of sediment fractionation of the suspended sediment in the Amazon river, Berner and Rao (1994) calculated the phosphorus flux by the river as 28×10^{10} grams per year. Wafer *et al.*, (1989) on the basis of their work in Brittany river, France, has reported that the nutrient transport in dissolved form is much higher than in particulate form i.e. POC, PON and POP. Horrigen *et al.*, (1990) also observed the higher dissolved flux for nitrogen than particulate phase in the Chesapeake Bay.

Vaithyanathan *et al.*, (1989) and Subramanian (1994) worked out the phosphorus transport of Indian rivers to the ocean. In their

studies the average phosphorus concentration in the sediments of Indian river was found to be between 700-1400 $\mu\text{g/g}$ and average to be about 1100 $\mu\text{g/g}$, the flux of dissolved phosphorus and sediment bound phosphorus to the ocean is 6.6×10^{10} and 13×10^{12} grams per year, (8 and 6 percent of total flux) respectively. The 95 percent flux of the total phosphorus is carried by the sediments. Subramanian and Ittekkot (1991), reported that the organic carbon transport from Himalayan drainage system to the ocean is about 57×10^{12} grams per year. The particulate Organic Carbon content about 0.7 percent (w/w).

Nutrient adsorption-desorption process

The pH and oxidation-reduction potential are two very important factors affecting the adsorption-desorption process (Smayda, 1990). Krom and Berner (1980) observed that under aerobic condition nutrients adsorption on the sediment surface occur while under anaerobic condition desorption takes place. Montimer (1971) has concluded that as long as oxygen concentration in the sediment is greater than 2 mg l^{-1} , release of the nutrient (desorption) from the sediments is nil, below 2 mg l^{-1} of oxygen major amounts of ammonium, phosphorus and silicon are released. Decrease in pH is reported to increase the desorption process (Redshaw et al., 1990).

Carbon, Nitrogen and Phosphorus in the Sediments

Very limited literature is available on the behavior of Carbon, Nitrogen and Phosphorus in the river sediments. Subramanian et al., (1980) gave the geochemical modelling for phosphorus mineralization in the marine sediments. Fluoride was found to be a

key factor influencing the apatite formation. Mineralization of phosphorus was studied by many workers, notably Gale et al., (1992) in the lake sediments and Parkers and Sommer (1983) in sludge affected soils. For lake sediments in the laboratory under anaerobic condition Gale et al., (1992) reported mineralization of 8.6 percent unconsolidated flocculent (UCF) to carbon dioxide and methane for lake sediments under anaerobic condition. They observed the following decomposition order under anaerobic condition:

UCF (unconsolidated flocculent material) > CF (consolidated flocculent material) > peat.

Nitrogen and phosphorus mineralization process may contribute to the nutrient loading to the overlying water (Gale et al., 1992). Simon (1989) on the basis of the study in Potomac river stated that, during suspension and deposition of the sediments, ammonia is liberated from the sediments and enriches the overlying water bodies. Organic nitrogen is the predominant nitrogen species in the sediments (Simon 1989 and Simon & Kennedy 1987). Under anaerobic condition carbon mineralization is very slow, net mineralization of nitrogen is 1.5 to 3 fold higher than carbon mineralization, indicating that the nitrogen is not a limiting factor for microorganisms in the lake sediments (Gale et al., 1992). Parker and Sommers (1993) concluded that the nitrogen mineralization rate is proportional to the Carbon content in the sediments. Nitrogen immobilization is very high when the C/N ratio is above 20:1. Mesnage and Picot (1995) reported that, Fe-bound phosphorus decreases with the depth and apatite is dominant phosphorus bearing mineral.

Phosphorus fractionation

Comprehensive literature exists on the fractionation of phosphorus in the sediment, and data interpretation of the fractionation result (Chang and Jackson 1957; Hiltey and Lijklema 1980; Williams *et al.*, 1971; Chang *et al.*, 1983; Yamada and Kayama 1987; Pettersson *et al.*, 1988 Lucotte and D'Anglejan 1985; Stone and English 1993; Forsgren and Jansson 1993; Ruttenberg 1992; Balchand and Nair 1994; and Berner and Rao, 1994). However, very limited work is done on the fractionation of the river sediments, as most of the work is done on either marine or lake sediments and soil. The first attempt towards working out analytical techniques for the fractionation, was developed by Chang and Jackson (1957). Later Hiltey and Lijklema (1980) has given a very simplified technique to separate the phosphorus into:

- loosely bound phosphorus
- iron and aluminum bound phosphorus
- calcium bound phosphorus
- the rest of phosphorus consisting of inorganic and organic by the difference.

Mayer and Williams (1981) have given a modified procedure for the phosphorus fractionation applicable to a variety of sediments. Pettersson *et al.*, (1988) compared five published fractionation schemes, i.e. Chang and Jackson (1957); Williams *et al.*, (1971); Williams *et al.*, (1976); Hieltjes and Lijklema (1980) and Psenner *et al.*, (1985). He tested the above five fraction schemes, several systematic errors have been detected and the schemes have been modified and simplified accordingly. He also summarized and

discussed the method for sediment phosphorus determination, chemical fractionation and mineralogical identification.

A very prominent work to develop a sequential extraction technique was done by Ruttenberg (1992) in marine sediments. He established the SEDEX method to separately quantify five sedimentary phosphorus reservoirs:

- loosely sorbed phosphorus or exchangeable phosphorus.
- ferric iron-bound phosphorus
- authigenic carbonate fluoro apatite phosphorus plus biogenic apatite phosphorus plus calcium carbonate associated phosphorus
- detrital apatite phosphorus
- organic phosphorus.

SEDEX method successfully separate two of the main categories of authigenic phosphorus phases called most often as a sedimentary sink for diagenetically mobilized phosphorus: ferric oxyhydroxide-associated phosphorus and authigenic carbonate fluoro apatite (Ruttenberg 1992). Berner and Rao (1994) further modified the Ruttenberg's SEDEX scheme.

In Indian scenario, very limited work has been done in the river sediment. Vaithyanathan et al., (1993) worked on the distribution of phosphorus in the Hooghly estuary. They separated the phosphorus into two groups: Non Apatite Inorganic Phosphorus (NAIP) and Apatite Inorganic Phosphorus (AIP). Subramanian (1993) gave the distribution of phosphorus, silicon and some trace contaminants in Ganges estuary. A major work on the phosphorus transport and genesis of ancient phosphorites was done by

Subramanian (1984). Balchand and Nair (1994) has compared eight fractionation schemes on the Cochin estuary sediment samples.

Kinetics of phosphorus in sediment-water interface

Phosphorus exchange between sediment-water interfaces important for quantitative analysis of phosphorus concentration in overlying water (Furumai and Ohgaki 1989). The factors influencing phosphorus exchange between sediment-water interface was worked by many authors i.e. Foy (1986); Sondergaard (1988); Istvanovics et al., (1989); Furumai and Kondo et al., (1989) Furumai and Ohgaki (1989); Redshaw et al., (1990); Sundby et al., (1992); Raaphorst and Kloostering (1994); McGlathery et al., (1994) and Zwolsman (1994). Foy (1986) reported that application of nitrate to the sediments suppress phosphorus release, since nitrate decreases ferric ion reduction to the ferrous (Fe^{+3} to Fe^{+2}). Furumai, Kondo et al., (1989) used phosphorus isotope P^{32} to observe the phosphorus kinetics, and reported that at pH 7, 80 percent exchangeable phosphorus was iron-bound. Iron-bound phosphorus positively influences the phosphorus uptake to the sediments (Istvanovics, et al., 1989; Sundby et al., 1992; Redshaw et al., 1990; Danen-Louwerse and Lijklema 1993 and Raaphorst and Klustehuis 1994. Furumai and Ohgaki (1989) reported the release of phosphorus from sediments under anaerobic condition. The eutrophication of the water bodies result into anaerobic condition (decrease in DO) and sediment release of phosphorus increases (McGlathery et al., 1994 and Zwoslman 1994).

Rate of sedimentation

Rate of sedimentation and elemental accumulation largely depend on the rate of supply at any given time. Geochronology of modern sediments have been determined by using one of the most commonly employed geochronological methods (Pb^{210} methods). Robbins and Edington (1975) have shown that the measurement of Cs^{137} and Pb^{210} provide an independent method for establishing time scale within the sediment column. Geochronology with Pb^{210} is a commonly used technique. The determination of accumulation rate does not involve the identification of the horizon, but it is based on the continuous decay of isotope ($t_{1/2} = 22.3$ years) after burial (Robbins et al., 1978). Pb^{210} method has been employed primarily in lakes, eg. Robbins and Edington (1975); Robbins et al., (1977); Krishnaswamy et al., (1971) estuary and ocean eg., Joshi and Ku (1979); Sarin et al., (1979) and more recently in rivers by Subramanian et al., (1985); Ramesh and Subramanian (1988); Vaithyanathan et al., (1988); and Ramanathan (1993). The first use of Pb^{210} in river sediment was reported by Rama et al., (1961). Subramanian et al., (1985); Ramesh and Subramanian (1988); Vaithyanathan et al., (1988) and Ramanathan (1993) have successfully used Pb^{210} method for determining the sediment and elemental accumulation rates in Yamuna, Krishna and Cauvery river basins, respectively.

THE YAMUNA RIVER BASIN

The main stream of the river Yamuna originates from the Yamunotri glacier near Badan Punch ($30^{\circ}58' N$, $78^{\circ}27' E$) in the Mussoorie Range of the lower himalayas at an elevation of about 6320m above mean sea level (MSL) in Uttarkasi of Uttar Pradesh. In the course of its first 200 and odd kilometers, when the river flows through series of curves and rapids to emerge into the Indo-Gangetic plains , it draws water from the Rishi Ganga an upland tributary which rises 3 km North-West Yamunotri on the right bank near Banas. While two other streams, the Untar and Hanuman Ganga rising respectively from the Jakhal glacier and the Chhamian glacier meet the main river on its left bank further South-West. The Yamuna receives several other tributaries from the lower Himalayan ranges and ridges. The Tons which rises from the North Eastern slope of Badan punch at an elevation of 3900m above MSL meets the river below Kalsi on the South-West fringe of the Mussoorie range. The Tons is the principal source of water in the mountainous range. Another important tributary, the Giri, rises further north-west of the Tons in the hilly track to meet the river. The combined stream then forces its way through the Sivalik range of hills and emerges into the plains in the Saharanpur district of UP at Tajewala (370 m above MSL) to be used for beneficial purposes it is joined by a number of tributary hill streams, the most significant of which are the Tons, The Giri and The Absan. From Tajewala the river sluggishly meanders to its confluence with the Ganga at Allhabad at about 100 m above MSL to

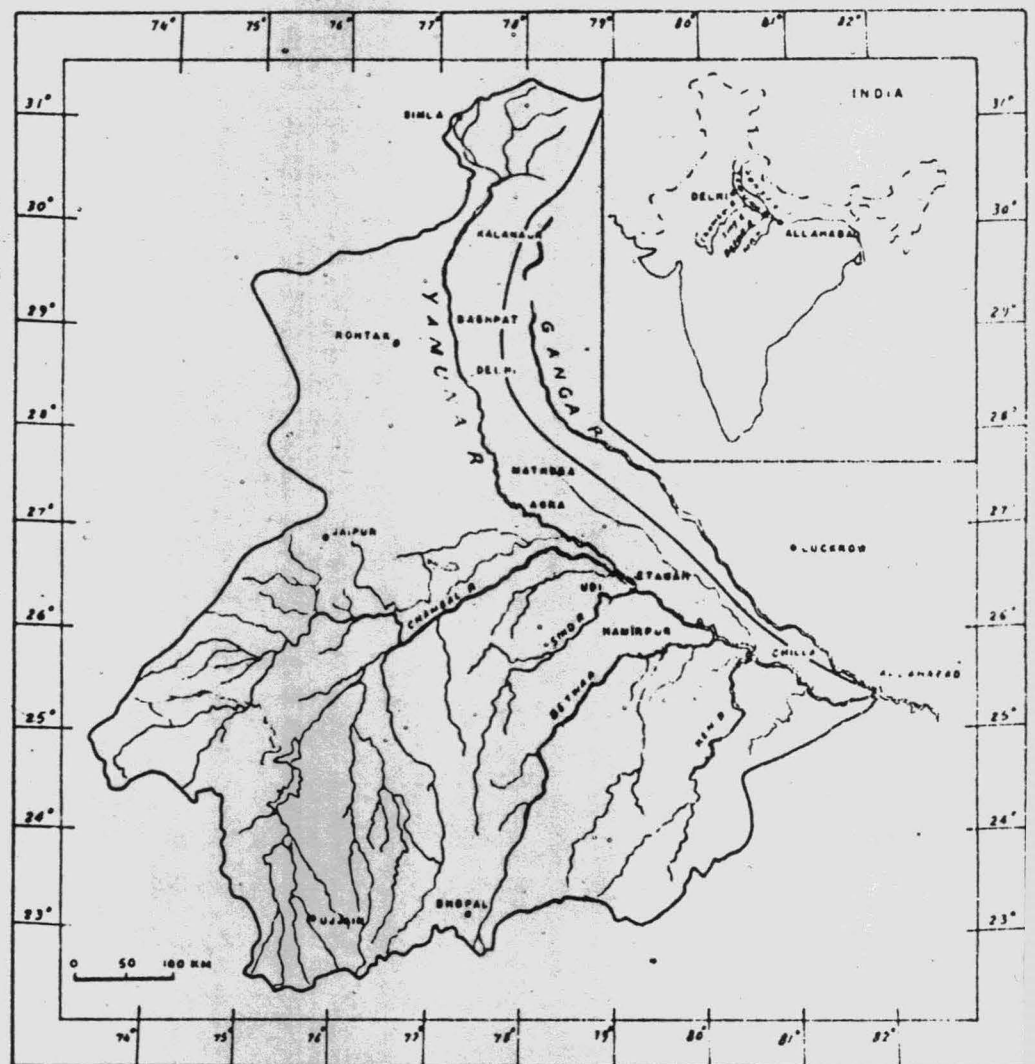


Fig. 1 Drainage basin map of the Yamuna River
 Fig. 1 Drainage basin map of the Yamuna River

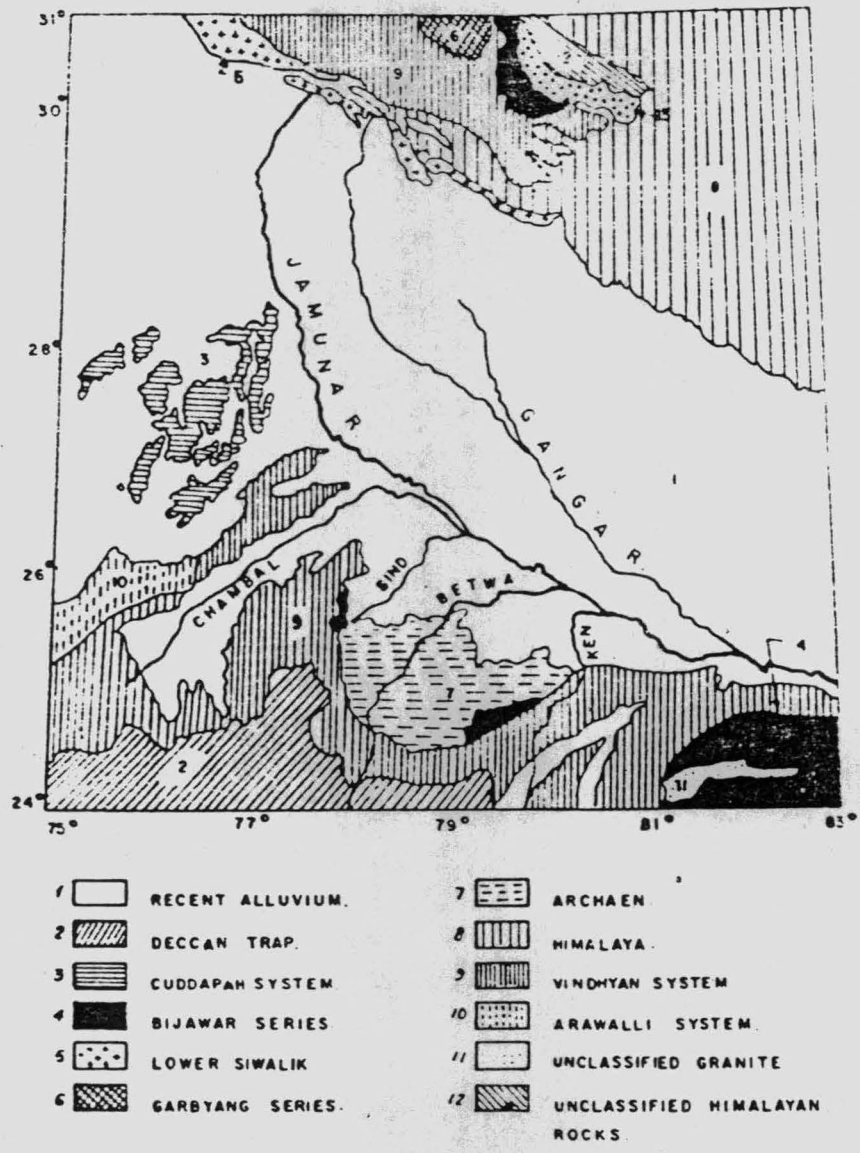


Fig. 2 Geological map of the Yamuna River Basin

Table 1

SUB-BASIN AND STATEWISE CATCHMENT AREAS*

State	Total area in Yamuna Catchment (Sq. Km.)	Area in the major sub basins (Sq.Km)				
		Hindon	Chambal	Sind	Betwa	Ken
Uttar Pradesh	74,208	7,083	452	748	14,438	3,336
Himachal Pradesh	5,799					
Haryana	21,265					
Rajasthan	102,883		79,495			
Madhya Pradesh	140,208		59,838	25,131	33,502	21,090
Delhi	1,485					
Total	345,848	7,083	139,785	25,879	47,940	24,426
Percent	100	2	40.5	7.5	13.9	7.0

* Central Board for prevention and control of water pollution, publication (1980-81).

traverse a route length of around 800 Kms. The main tributaries joining in this reach include the Hindon from the right and the Chambal, the Sind, the Betwa and the Ken from the left. Each one of these major tributaries, in turn, has its own system of tributary streams. Besides these a number of smaller rivers and streams directly join the Yamuna and some of these are not insignificant in terms of stream length, catchment area of flow etc.

The catchment of Yamuna river system covers parts of Uttar Pradesh, Himachal Pradesh, Haryana, Rajasthan, Madhya Pradesh and Delhi.

Topography

According to the publication of Central Board for the Prevention and control of water pollution (1980-81), the ground level in the basin varies from 6,330 m above Mean Sea Level (MSL) near the Yamunotri Glacier to about 100 m above MSL near the confluence with the Ganges at Allahabad. The various tributaries have different relief. For the convenience the basin can be classified into three topographic units, viz hilly, foot hills, plateau region and plains & valleys as tabulated in table (2.). The hilly region constitutes a marginal area (3.38 %), whereas plains & valleys occupy 46.62 % of the basin, and about 50 % of basin is foot hill and plateau.

Lithology

The lithology of Yamuna basin shows diversity both in composition and chronology. The basin consists of extrapeninsular region (Lower Himalaya), alluvial plains and the peninsular region (mainly Deccan Trap).

Table 2.

TOPOGRAPHIC CLASSIFICATION IN YAMUNA BASIN (SQ.KM.) *				
Classification		Hilly	Foot Hills & Plateau region	Plains & valleys
State	Height above	600m	300m - 600m	100m - 300m
Uttar Pradesh		4,900	4,400	64,908
Himachal Pradesh		5,200	599	-
Haryana		-	800	20,465
Rajasthan		1,600	55,610	45,673
Madhya Pradesh		-	111,508	28,700
Delhi		-	-	1,485
	Total	11,700	172,917	161,231
	Percent	3	50	47

* Central Board for prevention and control of water pollution,
Publication 1980-81)

Table 3.

LITHOLOGICAL CLASSIFICATIONS OF SOIL *

Lithological classification	Age Group	% Total Basin-area covered	Locations
Recent Alluvium, clay, silt, sand	Quaternary & upper Tertiary	40	Entire plains and foot hills in UP, Haryana, Delhi and Himachal Pradesh, part of plains in MP and Rajasthan
Greisses complex with intrusion	Archean	7	Northern part of Betwa (and Dhasar) sub-basin
Slate, Schist, Gneiss, Marble, Phyllite etc.	Pre-Cambrian	12	Most of the Baras catchment in the Chambal sub-basin
Basalt with intertrappean clay	Paleozoic and Mesozoic	25	Most of the plateau region in MP
Sand stones Lime stones Dolomite	Tertiary and Pre-Cambrian	16	Hilly regions, northern part of Chambal sub-basin in MP, part of Sind, Betwa and Ken sub-basins

* Central Board for prevention and control of water pollution, Publication (1980-81)

The Siwalik foot hills cover a good part of Himachal Pradesh, Haryana, and UP. They are sedimentary deposits consist of micaceous sand stone, clay, shale and conglomerates. The alluvial plain is the part of vast Indo-Gangetic plain. The alluvium from almost flat ground with little variation in lithology. The composition of alluvium is clay, sand and gravel with thin belt of calcareous Kankar. It has the origin from soft dolomite rock of Himalayas (Mehrotra, 1972). The Vindhyan and Kaimur rocks of basin consist of sand stone, lime stone, mixed conglomerates, calcareous shale, haematite, slates, schist, quartzite and lime stone with frequent bands of marble and granite, constitute the rock system of Aravali range of Rajasthan and Delhi.

The Decan trap consisting of Basalt and inter trappean clay, occupies the greater part of basin in Madhya Pradesh. The table (2) gives the summary of lithological variation in basin.

Soil Types

The distribution of the source rock types have given rise to distinct pedological characteristics in the basin as shown in table (3).

Alluvium have been mainly deposited by Yamuna and its tributaries. It constitute the most extensive soil formation in the basin. The alluvium is generally very deep, except riverine areas where, the alluvium get washed annually. The alluvium has been divided into, (a) older alluvium and (b) newer alluvium. Older alluvium consists of massive beds of clays of pale reddish-brown colour, which become yellow on exposure of air. Pea size

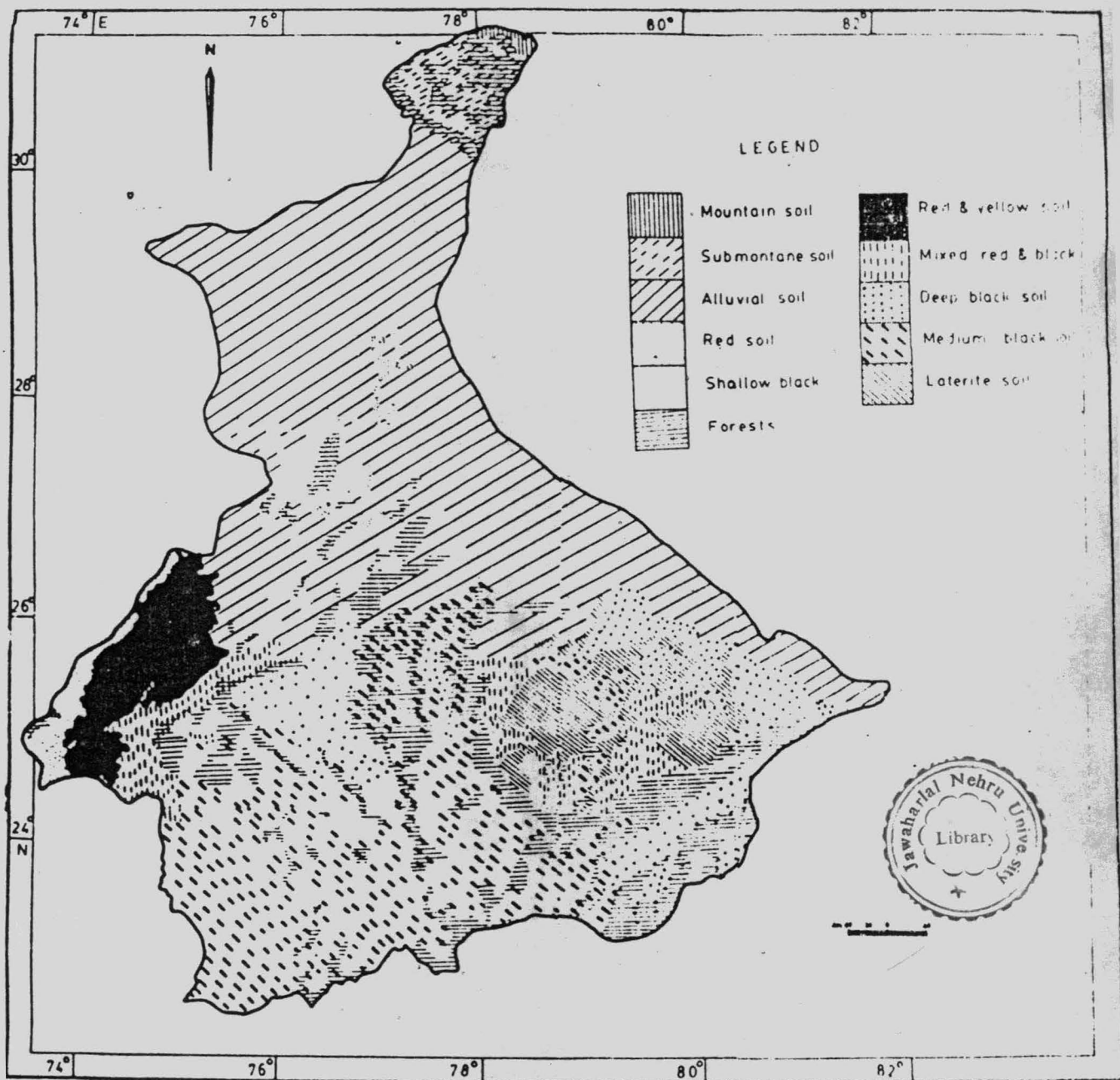


Fig. 3 Distribution of Soil types in the Yamuna drainage.

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Table 4.

SOIL TYPES IN THE BASIN *

Type of Soil	% of total Basin Area covered	Locations
Red Sandy	2.5	Along UP-MP border in district of Jhansi, Hamirpur, Chattarpur etc.
Red & Yellow	5.0	Parts of Jaipur, Alwar and Sawai Madhopur districts and Banda and Panna districts and along western boundry of basin in Rajasthan.
Calcareous Seirozemic	0.5	Parts of Mohindergarh and Bhiwani districts in Haryana.
Deep Black	5.5	On the Southern boundry of the basin in Sehore, Bhopal, Raisen Vidisha, Sagar and Damoh districts.
Medium Black	25.5	Most of basins in MP and strips north of River Chambal in Rajasthan.
Mixed Red and black	15.0	Chittaurgarh, Bhilwara, Banda, Mandasaur, Shivpur, Lalitpur, Tikamgarh, Panna and Chattarpur Districts.
Brown Hill	4.0	Hills and foot-hills in the north.
Alluvial	42.0	Plains and Valleys.

* Central Board for prevention and control of water pollution, publication (1980-81)

nodules of ferric oxide are some time found imbeded in the soil. The older alluviums generally found above the present flood level of the rivers.

Newer alluvium consists of coarse gravel (near the Siwalic hills), clay, sand (river channel), and fine silt in the remaining part of flood plains of the river. Brown soil are calcareous in nature and most cases 'Kankar' layer occur at the depth of 1-15 m (Sidhu et al, . 1972).

Though the nature of soil differ widely from region to region. Still certain characteristics are very common at all the places. The Yamuna soil differs from Ganges soil both in the morphological feature of soil profile and the agricultural behavior. The Ganges brings much of its sediments from Himalaya, where as the Yamuna, apart from Himalayan source bring the sediments also from the Central Indian hills dominated by basaltic rocks. The fully mature soil of Ganges family is called as 'Brown Earth', where as soil of Yamuna is called 'tropical tshernozems'.

Climatic features

Since Yamuna basin extends between 23° latitude to nearly 31° latitude. Upstream at the height of 6330 m above MSL, the climate is temperate, where as at 100 m above MSL at Allahabad climate is tropical. The june is hottest month with the average temperature rising upto 42°C, and January is the coldest month temperature falling down to an average of 6.7°C. Even as the season wise basin goes extreme temperature variations.

Table 5.

Land Use Pattern in the Basin *

State	Total area included in basin sq. Km	Non-arable land %	Forest land %	Cultivable land %	Land sown %	Land under habitational use %
Himachal Pradesh	5,799	25.0	59.4	15.6	14.2	1.5
Haryana	21,265	18.1	2.4	79.5	59.9	3.6
Delhi	1,485	51.0	1.0	48.0	46.5	43.7
Uttar Pradesh	74,208	14.5	7.4	78.1	65.3	4.8
Madhya Pradesh	140,208	26.0	18.0	56.0	50.7	1.8
Grand Total	345,848	27.5	12.5	60.0	51.9	2.9

* Central Board for Prevention and Control of water Pollution, publication (1980-81).

Table 6.

Annual Application of Chemical Fertilizers *

State	Total Consumption Tonnes per year			Rate of application, Kg/hect. Gross cultivable area		
	N	P	K	N	P	K
Himachal Pradesh	1,433	554	488	10.7	4.1	3.6
Haryana	44,139	7,127	3,641	19.2	3.1	1.6
Delhi	14,090	5,590	411	141.0	56.0	4.1
Uttar Pradesh	67,088	15,747	7,394	11.3	2.7	1.2
Rajasthan	33,767	9,067	2,101	6.0	1.8	0.4
Madhya Pradesh	33,549	14,407	2,375	4.4	1.9	0.3

* Central Board for Prevention and Control of Water Pollution, publication (1980-81)

Table 7. Brief Hydrological Characteristics of the Yamuna River Basin *

River	Station	Length of the river (km)	Area of catchment (Km ²)	Elevation above MSL	Mean Annual rain fall	Mean run-off 10 ⁶ m ³			
						Monsoon	Summer	Winter	Total
Yamuna									
		1376		630					
	Tajewala		9572		1430	8.2	1.4	0.9	10.5
	Delhi		28988		875	11.0	1.8	1.1	13.9
	Okhla		30013		867	11.2	1.8	1.2	14.2
	Etawah		81997		720	13.3	2.0	1.6	16.9
	Pratappur		345848		810	87.9	3.5	4.7	96.1
Triutries									
Chambal	Udi	965	139785	766	755	29.8	0.6	1.0	31.4
Hindon	Galata	-	7083	-	830	0.8	0.1	0.2	1.1
Sind	Seondha	415	25879	543	745	4.3	0.1	0.2	4.6
Betwa	Sahijna	590	49940	470	960	17.3	0.2	0.3	17.8
Ken	Chilla	360	28224	-	-	11.3	-	-	11.3

* Compiled after Rao (1975) and Central Board for Prevention and Control of Water Pollution publication (1980-81).

Monsoon season: June to September, Winter season: October to February and Summer Season : March to May.

Mean annual rain fall

Nearly 90 % of the total precipitation in Yamuna basin occurs during June to September. The maximum precipitation in the basin 1600 mm yr⁻¹ or more, occur along a narrow strip running from Solan via Sirmur towards Tehri town . From this intensity in the rain fall steeply decreases towards north and south both to reaches 800 mm yr⁻¹ with in a distance of abut 100 km. The minimum rain fall occur in western most part of basin about 400 mm yr⁻¹. The south-eastern part of the basin receives rain fall over 1000 mm Yr⁻¹, while the northern half of the basin exclusive of hills and foot hills receives only 500-800 mm yr⁻¹ rain fall.

Rate of evaporation

The actual rate of evaporation varies from place to place, however a generalized view is that. The December-January is marked by lowest evaporation rate. From mid-February steep increase in evaporation takes place which reaches its peak during May. On the onset of rain in June bring steep fall in rate leading to local minimum in August. After the monsoon in September-October a slightly increase in rate has been observed which finally declines to low winter rate. The peak monthly evaporation during May is around 450 mm for Ujjain, between 350-400 mm for Jaipur and Delhi around 300 mm for Hissar, Allahabad and below 200 mm for Simla (Central Board for the Prevention and Control of Water Pollution, 1980-81).

Yamuna basin, classified as non-arable, under forest and

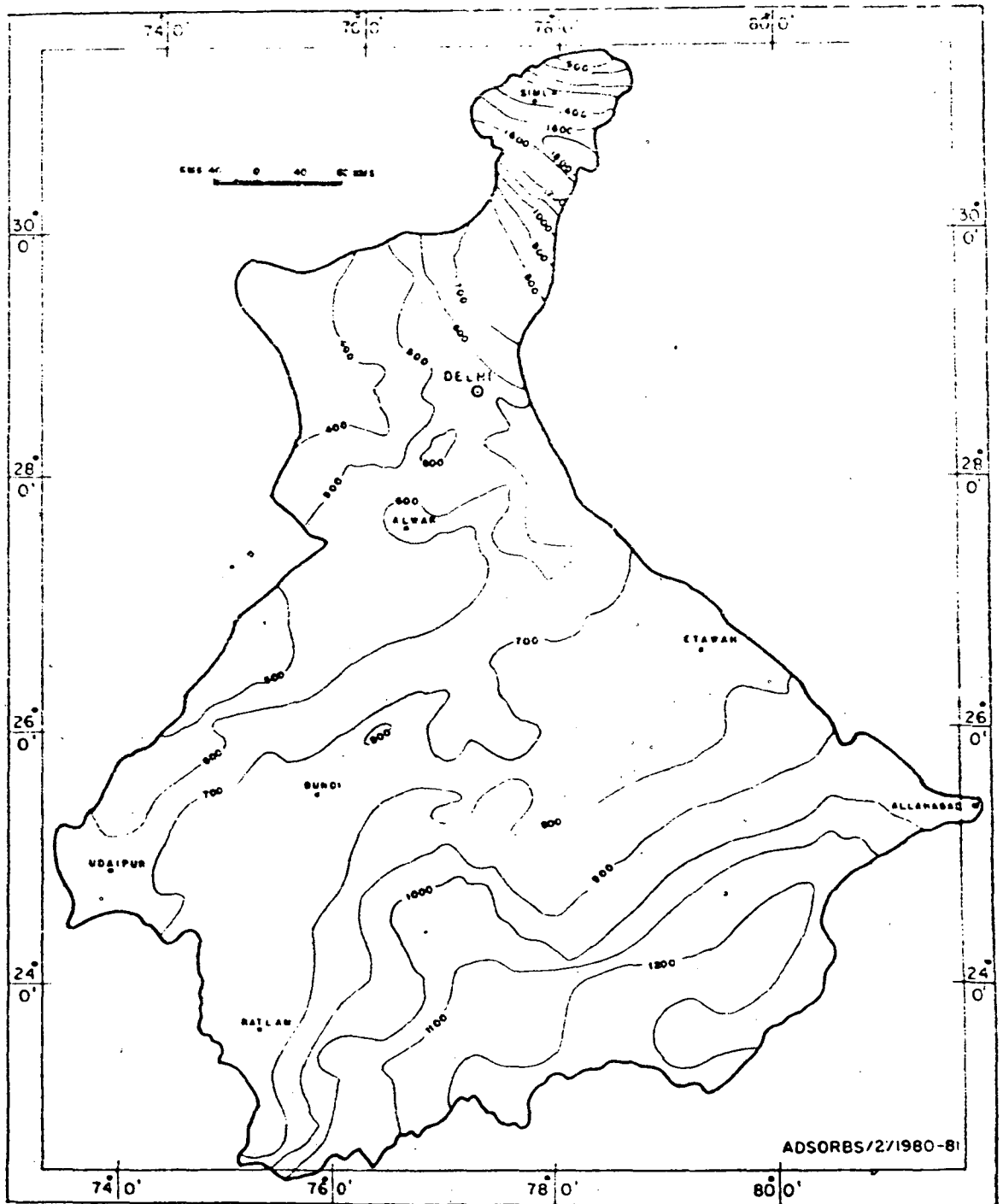


Fig. 4 Map Showing variation of average rainfall in the Yamuna Catchment Area.

Land use pattern in basin

On the basis of land record available, the entire land in the basin is cultivable. The non-arable land constitutes about 27.5 % of the basin area, whereas the cultivable land is 60 % and forest occupy only 12.5 %.

The mining activities in the Yamuna basin includes mining of lime stone in Dehradun district of UP and several districts in Rajasthan, building stones in Delhi, Jhansi, Lalitpur, of zinc and copper Udaipur and Khetri and of diamond in Panna. The mining activities are confined to non-arable land of the basin.

No reasonable assessment of land use habitation, urban and rural, industrial establishments, roads, railways, airport and other modes of transportation and other community uses is available. However, in future, the growth of population and industrial activities are likely to put an expanding demand of land use.

Water discharge

For any meaningful analysis, reliable and detailed information about the discharge at various points are essential. The Yamuna system is a part of Ganges-Brahmaputra system and all data on flows has been declared as 'Secret' by Government of India. This caused constraint on the computation of load (dissolved/sediment) and restricted to the data for a few stations only. The discharge values used in table (7), is indicative only.

A number of medium and large scale irrigation projects, (Eastern and Western Yamuna canal at Tajewala, Agra canal at Okhla,

storage projects on Chambal, Sind, Betwa, Ken etc), some based on storage and some on mere diversion, draw water from the Yamuna and its tributaries. While water drawn for municipal and industrial purposes, largely return to the river system in the form of waste water. It has been observed that the water withdrawals by the canal at Tajewala and Okhla, during non monsoon period almost empties the entire stream run off and leaves a little flow in the channel. The storage project on the other hand do not generally reduce fair-weather flows and may even increase them through seepage an intentional release.

MATERIALS AND METHODS

a) Field Method

The sediment samples were collected from the Yamuna river basin at three locations, i.e. in upstream at Saharanpur, in midstream at Delhi and in downstream at Allahabad. Pits were dug at river flood-plain for about 2.0 to 2.5 m, and samples were taken from the wall of the pits at every 10 cm depth interval. The samples were packed and sealed in plastic bags, brought to the laboratory, and kept in cold room at 4°C until analysis could be performed.

b) Laboratory Methods

Samples were taken out from the cold room and were oven dried at 60°C for 24 hrs (Raaphorst 1994). Homogenization was done by quartering. The following chemical analysis of sediments was carried out:

1. Analysis for the major elements
2. Kjeldahl Nitrogen analysis
3. Carbon analysis
4. Phosphorus fractionation

1. Analysis for the major Element

Finely ground homogenized sediments were taken in the beaker and boiled with 30% (v/v) H₂O₂ (Jackson 1973) for the removal of

organic matter. The treatment was done repeatedly until the emission of CO₂ stopped.

Analysis for the major elements were carried out by the two solution method (Shapiro 1975). Solution 'A' was used for Silica and Phosphorus analysis, where as Metals were analyzed by solution 'B'.

(a) Solution A

0.025 gm of finely ground samples were taken in 50 ml nickel crucible and 3-4 pellets of NaOH were added. The crucible was gently heated for 5 minutes on electric burner, in order to mix molten pellets with the sediments, and then heated to dull redness for 30 minutes. The crucible was allowed to cool down at room temperature, 10 ml distilled water was added and kept over night. The solution was transferred to 250 ml volumetric flask and the crucible was rinsed two-three times. 5 ml of 50% (v/v) HCl was added and boiled till the solution gets clear, and the total volume was made upto 250 ml with distilled water.

Determination of Silica

0.80 ml of solution A, standard solution (Canadian soil standards ie S01, S02, S03, S04) and reagent blank were transferred to 50 ml teflon beaker. 20 ml of distilled water was added to each beaker. 0.20 ml of ammonium molybdate solution was added and kept for 10 minutes. 0.40 ml of 10% (w/v) tartaric acid was added by swirling the beaker. 0.10 ml of reducing reagent was added. The samples were stirred properly and kept for 30 minutes.

Optical density was measured at 650 nm by Cecil Spectrophotometer 594.

Ammonium molybdate solution was prepared by dissolving 1.875 gm ammonium molybdate in 19 ml distilled water and by adding 6 ml 20% (v/v) H_2SO_4 . The reducing reagent was prepared by dissolving 0.07 gm sodium sulphite in 1.0 ml distilled water and then 0.015 gm 1-amino-2-naphthol-4-sulphonic acid was added and stirred well until dissolved. 9.0 ml of 10% (w/v) sodium bisulphite solution was added to it and mixed well.

Determination of Phosphate

Phosphate concentrations were determined by ascorbic acid method (APHA 1985). Phosphate standards ranging from 0.05 ppm to 0.5 ppm were prepared from KH_2PO_4 . 20 ml of each sample, standard solutions and reagent blank were pipetted out in 25 ml volumetric flask and 2.5 ml antimony molybdate solution was added and stirred well. Then 1.0 ml 1% (w/v) ascorbic acid solution was added, mixed well and the solution was diluted to 25 ml with distilled water. The optical density was measured at 650 nm by Cecil spectrophotometer (594). The concentrations were calibrated by soil standards (S01, S02, S03, S04).

Antimony molybdate solution was prepared by dissolving 4.8 gm ammonium molybdate and 0.10 gm potassium antimony tartrate in 400 ml 4N H_2SO_4 and making the total volume was made to 500 ml with the same acid.

(b) Solution 'B'

0.10 gm finely ground sample were transferred to the teflon

crucibles, and 2 ml aqua regia (HNO_3 and HCl ratio 1:3) and 5 ml HF were added to each crucible, and were sealed in metallic case. The crucible was heated for 90 minutes at 100°C , and allowed to cool down at room temperature. The final volume was made upto 100 ml by distilled water, using 100 ml plastic volumetric flask.

The digested sample were used for elemental analysis, by using GBC (902) double beam Atomic Absorption Spectrometer(AAS). Sodium and potassium were analyzed in the emission mode and other elements were analyzed in the absorption mode.

2. Kjeldahl Nitrogen analysis

Nitrogen was analysed by Kjeldahl digestion method of Anderson (1993). 0.20 gm sediments were taken in digestion tube (min 100 ml size). 4.4 ml digestion mixture was added to each tube, and digested at 360°C until the solution became colourless (approximately 2 hrs). The solution was allowed to cool down at room temperature. 50 ml distilled water was added in each tube and stirred continuously till the dissolution stopped. The final volume was made upto 100 ml with distilled water. The tubes were kept for some time for sediment settling. Clear solution was used for analysis.

Digestion mixture was prepared by dissolving 0.42 gm selenium powder and 14 gm lithium sulphate to 350 ml 30% (v/v) H_2O_2 and mixed thoroughly. In this mixture 420 ml H_2SO_4 was added carefully while cooling in an ice bath. The digestion mixture was kept at 4°C for further use.

Nitrogen was determined by steam distillation. Free ammonia is

liberated from the solution by steam distillation in the presence of excess alkali. The distillate is collected in a receiver containing excess boric acid with an indicator, and nitrogen determined by acid titration.

Distillation process was done by transferring 25 ml of aliquot to reaction chamber and addition of 12 ml alkali mixture and distillation was started immediately. 25 ml distillate was collected in 5 ml boric acid-indicator solution. The distillate was titrated against N/140 HCl to a grey end point using microburette. Nitrogen was calculated by following formula.

$$\text{Total N (\%)} = (T \times S \times 0.01) / (A \times W)$$

Alkali solution was prepared by dissolving 500 gm NaOH and 25 gm sodium thiosulphate in water and final volume was made upto 1000 ml with distilled water.

Boric acid-indicator solution was prepared by Okalebo (1993) method. 0.30 gm bromoceroil green and 0.165 gm methyl red were dissolved in 500 ml of 95 % ethanol called mixed indicator. Now 20 gm boric acid was dissolved in 700 ml of distilled water, after cooling it, 200 ml of 95 % ethanol was added. 20 ml of mixed indicator was added to it and mixed well by shaking. Continuously 0.05 N NaOH (2 gm NaOH in 1000 ml of distilled water) was added until when 1 ml of the content was treated with 1 ml of distilled water changes the color from pink to pale green. The solution was diluted to 1000 ml.

3. Carbon analysis

The carbon was analyzed by Using Coulomat (702) Carbon

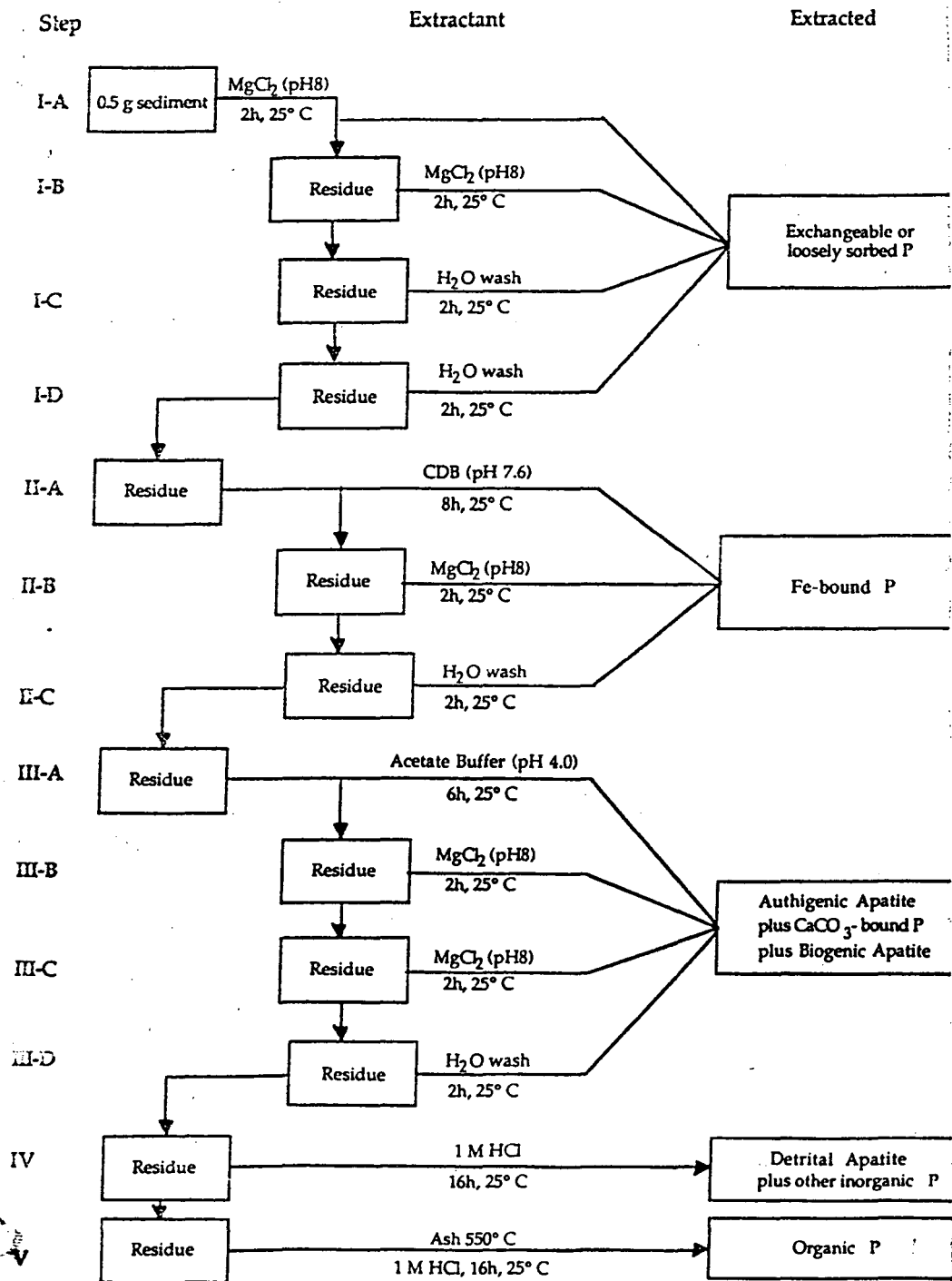
analyzer. Untreated samples were used for total carbon, where as H_2O_2 treated samples were used for inorganic carbon. The difference is considered as organic carbon.

4. Phosphorus fractionation

The phosphorus fractionation was done by sequential extraction method (Ruttenberg 1992). Method depends upon the reactivity of particular phosphorus phase in a particular extractant. By using a series of extractants five different phases were extracted.

0.5 gm finely ground oven dried sediments were taken in 100 ml centrifuge tubes. 50 ml of 1 M $MgCl_2$ (pH 8.0) was added in each tube and shaken for 2 hrs in rotatory shaker. Centrifuged at 4000 rpm for 10 minutes, aliquots were taken out in 250 ml volumetric flasks. Again shaken with 50 ml of same extractant for 2 hrs and aliquots were transferred to respective volumetric flasks. Washing of sediments were carried out by 50 ml distilled water while shaking for 2 hrs. Centrifuged at 4000 rpm for 10 minutes and aliquots were transferred to respective flasks. The washing process was repeated and aliquots were again transferred to respective flasks. The extracted solutions were mixed well and analysed for exchangeable or loosely sorbed phosphorus. The residues were used for next fraction.

45 ml Citrate-Dithionite-Bicarbonate (pH 7.6) solution was added in each centrifuge tube and shaken for 8 hrs in rotatory shaker, aliquots were transferred to 250 ml flasks after centrifuging at 4000 rpm for 10 minutes. 1M $MgCl_2$ (pH 8.0) was added in each tube and shaken for 2 hrs. After centrifuging,



SEDEX fractionation scheme for phosphorus (Ruttenberg, 1992)

aliquots were transferred to respective flasks. The sediments were washed by distilled water while shaking in rotatory shaker for 2 hrs and aliquots were transferred to respective flasks. The extract was diluted to 250 ml in order to check the denaturation of the sample and analyzed immediately for Fe-bound fraction. Residues were taken for next fractions.

Citrate-Dithionite-Bicarbonate (CDB) solution was prepared by making solution containing 0.30 M tri sodium-citrate and 1 M sodium bicarbonate adjusting pH to 7.6, in this solution 11.25 gm sodium dithionite was added in 450 ml of the above solution.

50 ml acetate buffer (pH 4.0) was added in each tube and shaken for 6 hrs, centrifuged it at 4000 rpm for 10 minutes and aliquots were transferred into 250 ml volumetric flasks. 50 ml $MgCl_2$ was added in each tube, shaken for 2 hrs, centrifuged and were transferred to respective flasks. $MgCl_2$ treatment was repeated. 50 ml of distilled water was added in each tube, shaken for 2 hrs, centrifuged it for 10 minutes at 4000 rpm and the extracts were transferred to respective flasks. The extracts were mixed thoroughly and analyzed for phosphorus representing Authigenic Apatite plus Calcium Carbonate bound P plus Biogenic Apatite fraction. The residues were used for next fraction.

50 ml 1M HCl solution was added in each tube, shaken for 16 hrs and centrifuged at 4000 rpm for 10 minutes. Aliquots were analyzed for phosphorus representing Detrital Apatite plus other Inorganic phosphorus. The residues were used for next fraction.

Sediments were transferred to nickel crucible and ashed at 550°C for 2 hrs, extracted by 1M HCl while shaking in a shaker for

16 hrs. After centrifuging at 4000 rpm for 10 minutes extract was analyzed for phosphorus representing Organic Phosphorus.

All the phosphorus concentrations except for fraction II were analyzed by single solution phosphomolybdate blue method (Koroleff 1976). Fraction II was analyzed by Olsen (1962) method, after reacting it with 1 % (v/v) 1.0 M FeCl_3 (Lucotte and D'Anglejan 1985). The treatment is necessary to avoid the interference of citrate, which can reduce the molybdate complex. All the extracts except for fraction II were acidified to pH 1 just after collection.

In the Koroleff (1976) method, 35 ml of extracted samples and standard solutions were transferred into 50 ml volumetric flasks 1 ml mixed reagent II was added in each flask and mixed well, followed by 1 ml 7 % (w/v) ascorbic acid solution. Solutions were mixed and optical densities were measured at 880 nm after 5 minutes using Jasco Spectrophotometer (7800). Mixed reagent II was prepared by, mixing 45 ml molybdate solution (prepared by dissolving 9.5 gm ammonium heptamolybdate $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24}\cdot 4\text{H}_2\text{O}$, in 90 ml of distilled water and diluted to 100 ml) in 120 ml of 9.0N H_2SO_4 and 5 ml of tartrate solution (prepared by dissolving 3.25 gm potassium antimony tartrate in 100 ml of distilled water) and 70 ml of distilled water.

In Olsen (1962) method, 25 ml of FeCl_3 treated solutions were transferred to 125 ml separatory funnel and 5 ml molybdate reagent, 20 ml distilled water and 10 ml 1-butanol were added and shaken for 2 minutes and aqueous phase was discarded. 10 ml 1N H_2SO_4 was added, shaken for 2 minutes and aqueous phase was discarded. 15

ml stannous chloride reagent was added, shaken for 1 minute and aqueous phase was discarded. 1-butanol phase was transferred to 25 ml volumetric flask, separatory funnel was rinsed with 10 ml ethanol, and transferred to the volumetric flask. Solution was diluted to 25 ml by ethanol. The absorbance was measured at 725 nm by Cecil spectrophotometer. In this process molybdate reagent was prepared by dissolving 50 gm ammonium molybdate in 500 ml of distilled water, 400 ml of 10 N H_2SO_4 was added and final volume was made upto 1000 ml by distilled water. Stannous chloride reagent was prepared by diluting 1 ml of stannous chloride stock solution to 200 ml of 1N H_2SO_4 immediately before use(stannous chloride stock solution was prepared by dissolving 10 gm of $SnCl_2 \cdot 2H_2O$ in 25 ml concentrated HCl).

RESULTS AND DISCUSSION

Sediment core samples from three locations of Yamuna flood plain (viz. upstream at Saharanpur, midstream at Delhi and downstream at Allahabad) representing the entire Yamuna basin were analyzed. The USGS rock standards (Sco-1, MAG-1, G-2) and Canadian soil standards (SO-1, SO-2, SO-3, SO-4) were also analyzed as reference material along with the chemical standards.

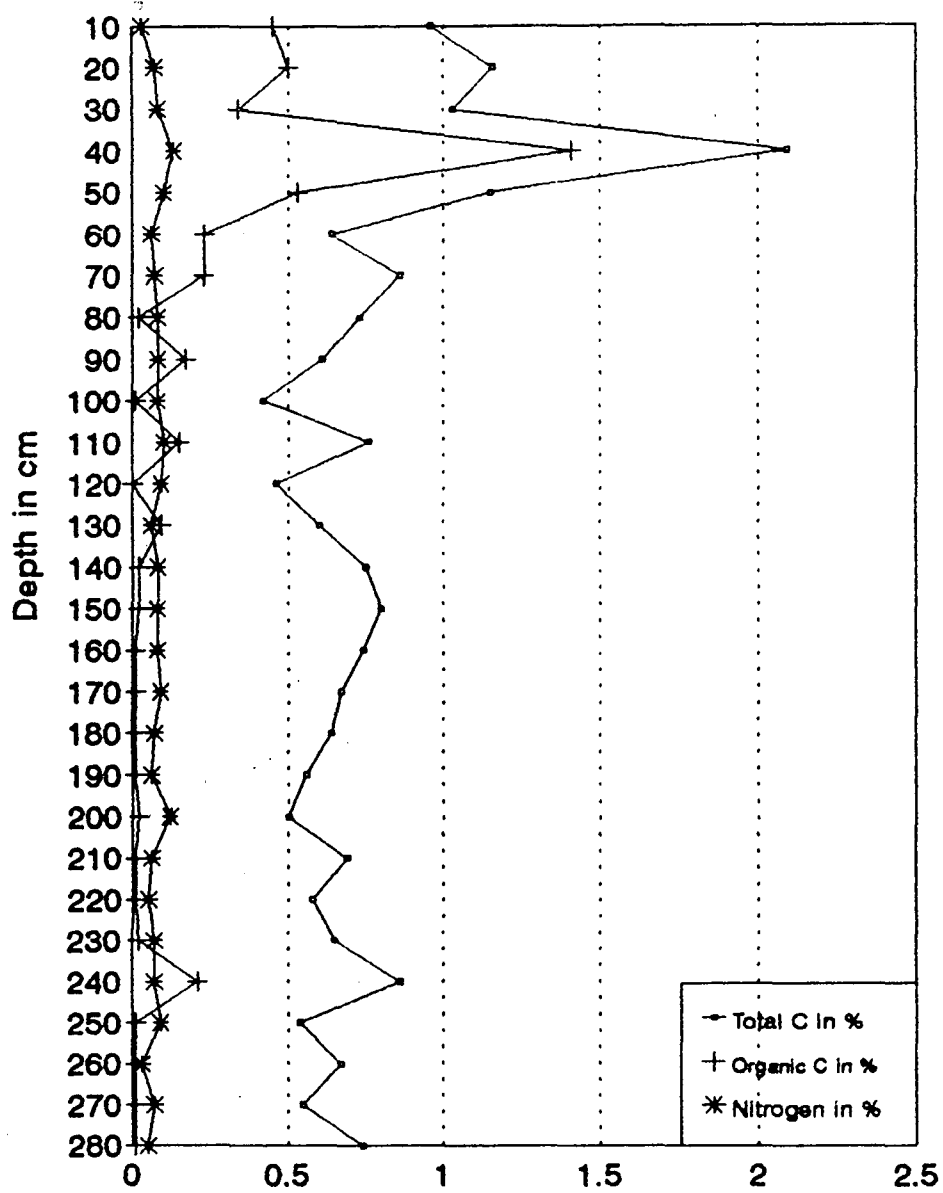
Distribution of Total Phosphorous, Nitrogen and Carbon in the Core.

Saharanpur

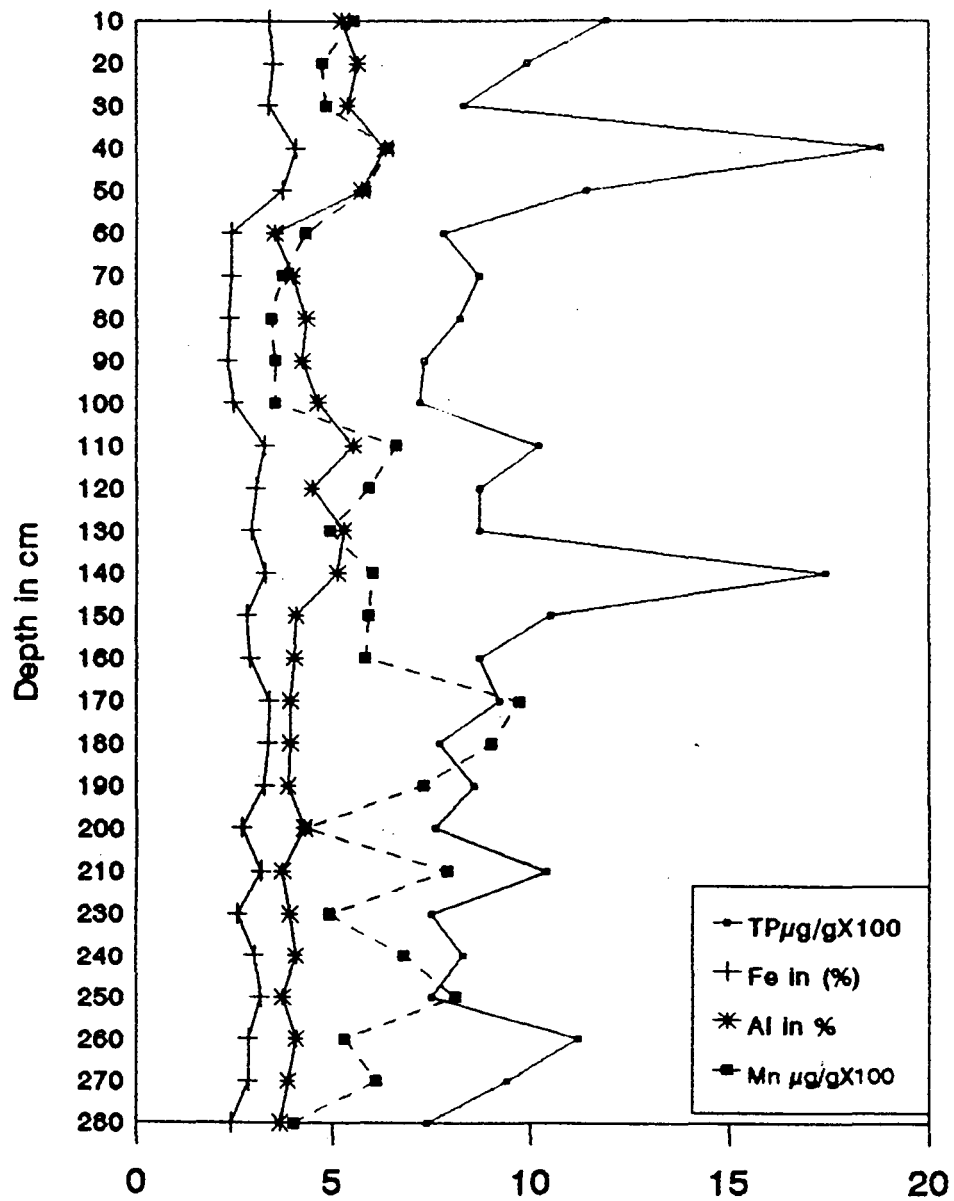
Result and Discussion

The distribution of Total phosphorous, carbon and nitrogen in the vertical profile of Saharanpur is shown in graph (1,2) and in the table¹⁴. The total phosphorous was found to be showing negative correlation with depth ($r = -0.30$) suggesting gradual decrease of phosphorus with depth. The reason for the decrease could be the release of exchangeable and iron-bound phosphorous under anaerobic condition of the deep sediments, as burial and compaction leads to anoxic condition which cause release of the exchangeable and iron bound phosphorous. (Furumai and Ohgaki 1989) Some local anomalies were also found in the core, eg. at depths of 30-40 and 140-150 cm., there are sudden increase in total phosphorous concentrations, (i.e. 1880 μ g/g and 1740 μ g/g

Graph-1
 Variation of TC, OC and TN in the core sediment samples from Saharanpur, with depth



Graph-2
 Variation of TP, Fe, and Mn of Saharanpur in the core sediment samples from Saharanpur, with depth



respectively against its normal trend). The exceptionally high value at 30-40 cm. could be due to the enrichment by anthropogenic input or the grain size effect, since at that depth total carbon, organic carbon, aluminum and iron were also found to giving relatively higher values than their normal behaviour in the core. The other higher value which was observed at a depth of 140-150 cm. was not coinciding with the higher values of aluminum and iron. Showing that enrichment could be due to the organisms which take up phosphorus and enriches at that profile.

Total phosphorus was found to be giving good positive correlation with aluminum, iron, zinc and potassium (0.60, 0.56 and 0.50 respectively). Such positive correlations with aluminum and iron were recorded by several workers (eg. Danen-Louwerse *et al.*, 1993; Yamda and Kayama 1987 and Vaithiyathan *et al.*, 1989). The good correlation with zinc and potassium could be due to mineralogical effect. Positive correlation was also found with total carbon and organic carbon (0.67 and 0.62) respectively. The possible reason of its positive correlation could be calcium, because in total carbon major part of calcium is there, the correlation of calcium with total phosphorous was observed by Vaithiyathan *et al.*, (1989).

The nitrogen concentrations in the Saharanpur core sediments were found to be very low ranging between 0.03 to 0.13 percent. Some lower values are obtained at the upper sediments upto the depth of 20 cm, could be due to the plant uptake. The low value indicates that in the Saharanpur core microbial decomposition (mineralization) of organic matter high, in comparison to the

deposition of organic matter, due low rate of sedimentation.

The total carbon and organic carbon was found to be giving good negative correlation with depth (i.e. $r = -0.51$ and -0.59 , respectively). The decrease in organic carbon concentration with the depth is due to microbial decomposition of the organic matter. The inorganic carbon was not found to be giving any correlation with the depth, giving a constant value with a narrow range (0.41 to 0.78 percent), therefore indicating close association of total carbon with organic matter and aluminum. Good correlation also exist for total carbon with inorganic carbon and iron ($r = 0.52$ and 0.61 , respectively).

The organic carbon in the vertical profile is very low, ranging between 0.0 to 0.53 percent excluding a single exceptional higher value at depth 30-40 cm. This high value is coinciding with the exceptionally high value of phosphorus, further strengthening the possibility of enrichment due to the organisms.

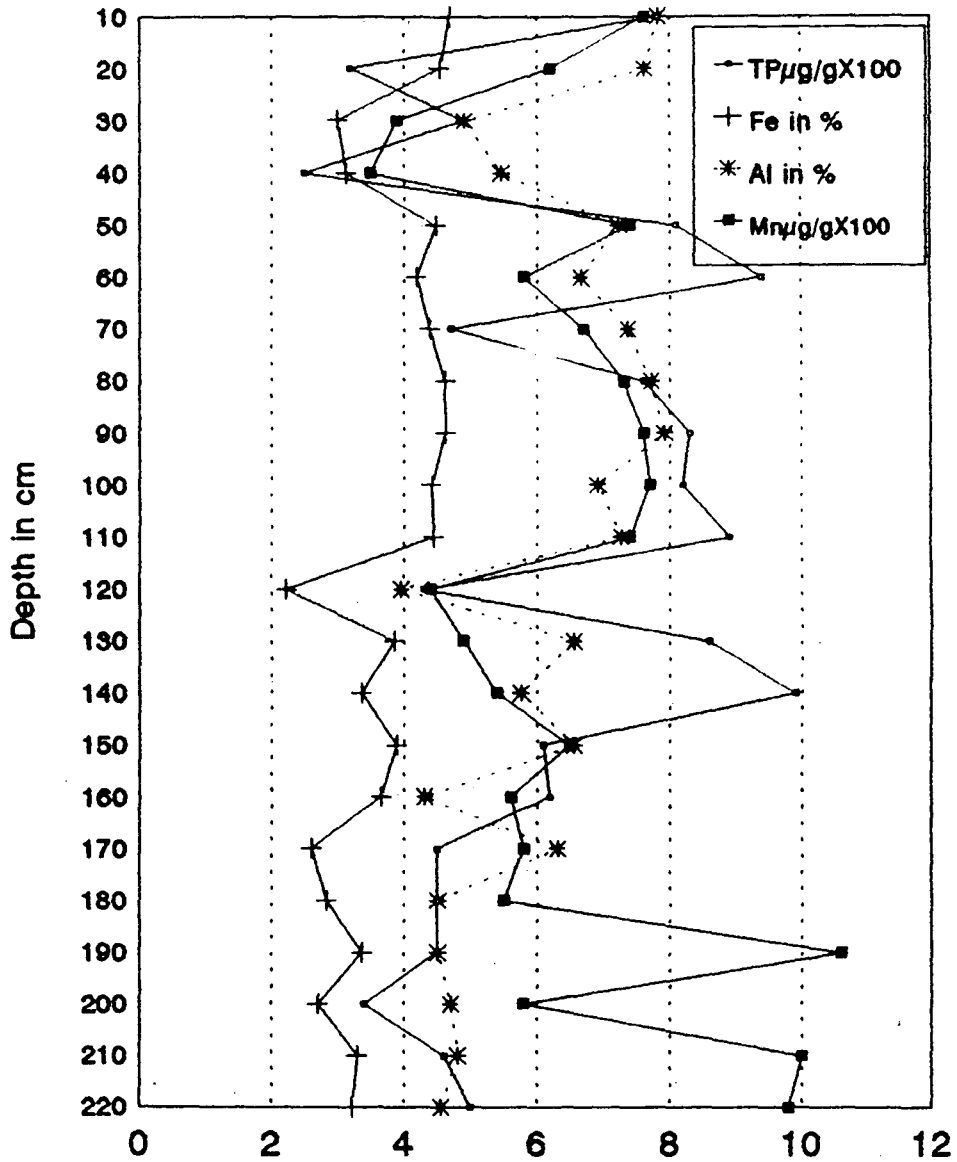
Delhi

Result and Discussion

The total phosphorus concentration in the Delhi sediment core was found to be fluctuating with the depth. No specific pattern is observed in vertical profile. It suggests that in the vertical profile sediment is possibly disturbed due to high anthropogenic activities, which are going on in the flood plain areas of the Yamuna river at Delhi. The overall concentrations were found to be lower than that of in the sediments at Saharanpur, the values ranging between 250 $\mu\text{g/g}$ and 990 $\mu\text{g/g}$. The lower values are solely

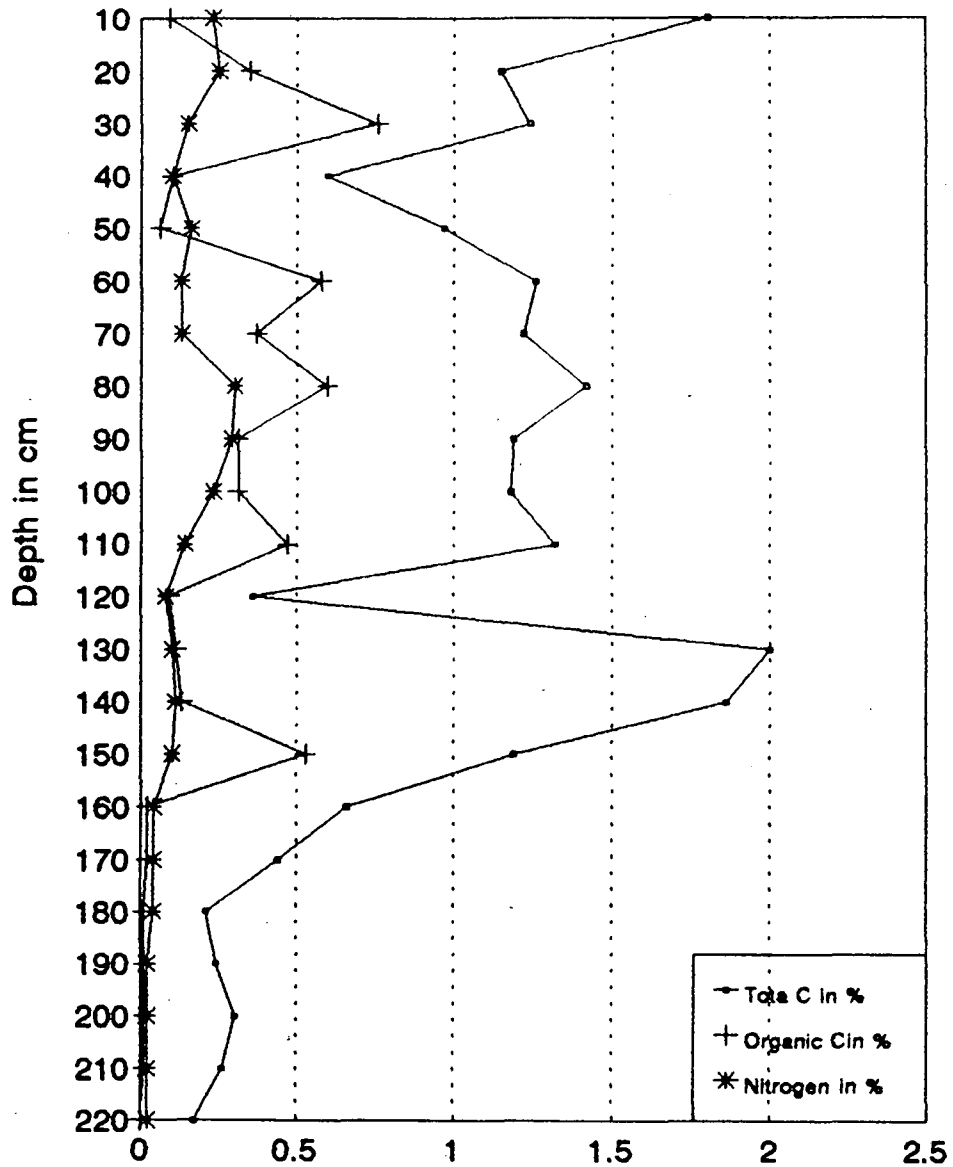
Graph-3

Variation of TP, Fe, Al and Mn in the core sediment samples from Delhi, with depth



Graph-4

Variation of TC, OC and TN in the core sediment samples from, Delhi with depth



due to mineralogical composition. Total phosphorus was found to be giving good correlation with total carbon inorganic carbon (0.72 and 0.68 respectively) and also with aluminum, iron, zinc and potassium. A moderate negative correlation was observed with silicon. Similar observations were found by Stone and English 1993 and Vaithiyanathan *et al.*, 1989 for iron, and aluminum.

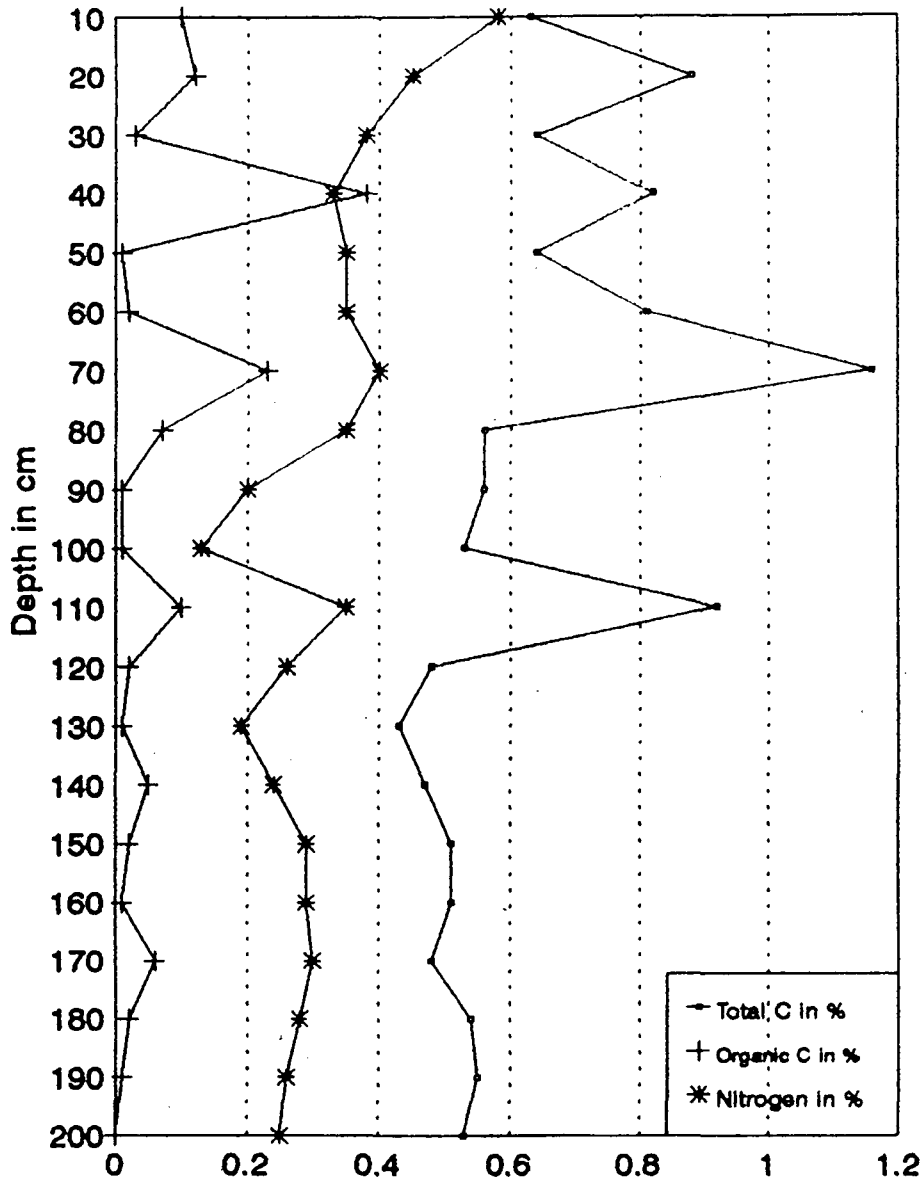
Nitrogen was found to be giving very good negative correlation with the depth ($r = -0.75$) indicating that with the depth, in anaerobic condition nitrogen got decomposed. The positive correlation of nitrogen with the organic matter reveals that a major part of nitrogen is derived from organic matter. Zinc, aluminum and potassium were also found to be giving good correlation nitrogen indicates the affinity of these elements to the nitrogen.

The total carbon in the Delhi core sediment was found to be higher than that at Saharanpur, and was found to be fluctuating in the vertical profile. Lack of any specific trend further strengthen the possibility of the profile being disturbed by anthropogenic activities. The same feature was also observed for the total phosphorous distribution. The high value of total carbon is possibly due to anthropogenic activity, since lot of organic matter is dumped into the river flood plain.

The total carbon in the Delhi core sediment was found to be highly fluctuating with the depth. There was no trend observed in vertical profile, and it further strengthens the possibility of the sediment disturbance in vertical profile by anthropogenic activities, which are very much prevalent in the flood plains of

Graph-5

Variation of TC, OC and TN in the core sediment samples from Allahabad, with depth



Yamuna at Delhi. The total carbon concentration was found to be higher than that at Saharanpur, the reason being the dumping of solid waste in the flood plain, and high sediment deposition. A high value at surface sediment could be an indication of its enrichment due to above mentioned reason. The concentration of the total carbon was found to be varying between 0.17 and 2.0 percent. A higher value of the total carbon (2 percent) was observed, which is also possibly due to solid waste dumping.

The organic carbon was found to be decreasing in vertical profile with increasing depth. The higher values were obtained at upper profile of the sediments, where as lower values were obtained at lower profile; the decrease in the concentration is due to the microbial decomposition of organic matter. The total carbon was found to be giving good negative correlation with silicon, indicating that both have very different sources of origin. The total carbon was found to be giving very good positive correlation with inorganic carbon, since major part of total carbon is the inorganic carbon. It was also found to be giving good positive correlation with aluminum ($r = 0.09$), iron ($r = 0.65$) and organic carbon ($r = 0.50$), indicating their relation with the total carbon.

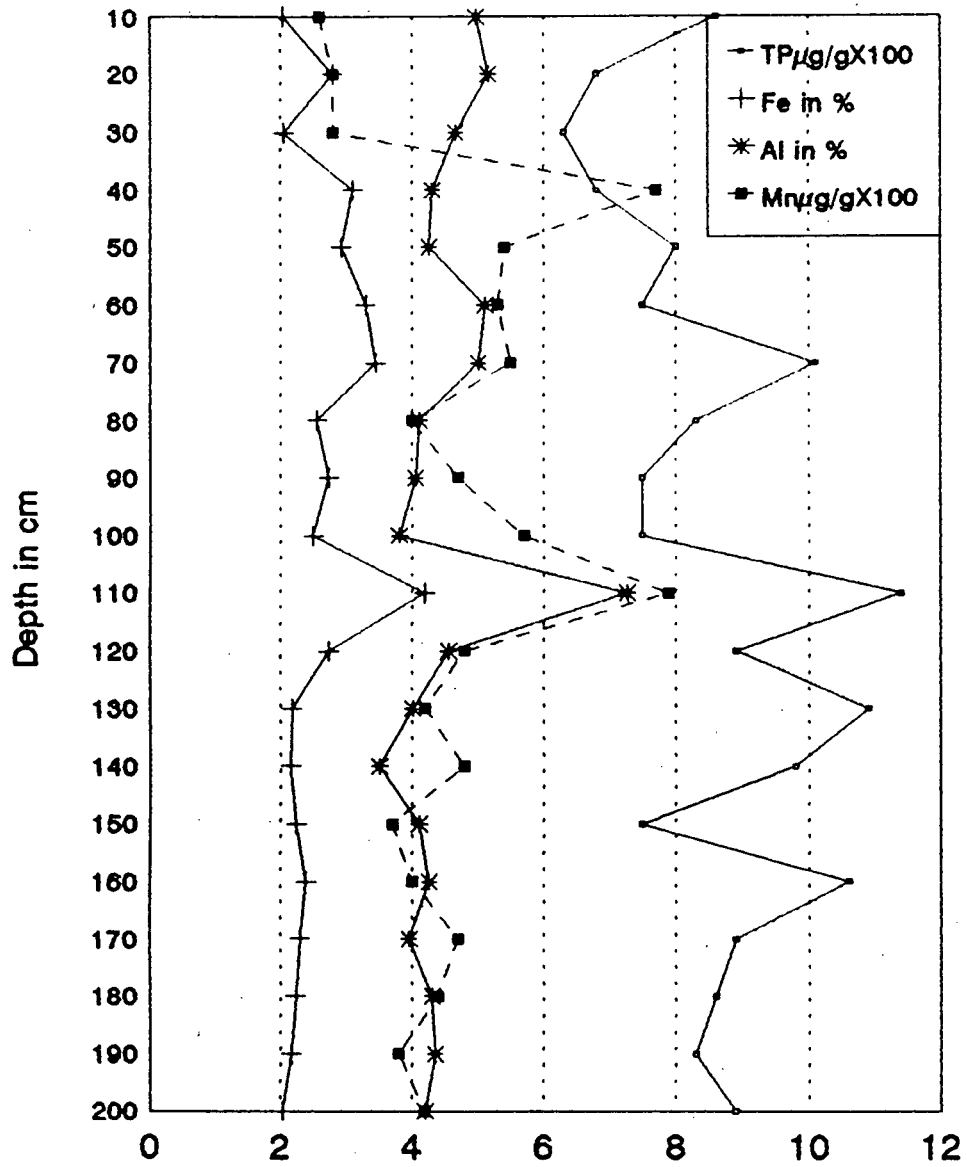
Since inorganic carbon makes up a major part of the total carbon, the correlation of inorganic carbon and total carbon with different elements is similar.

Allahabad

Result and discussion

Graph-6

Variation of TP, Fe, Al and Mn in the core sediment samples from Allahabad, with depth



Total phosphorus in the Allahabad core sediments were found to be having low positive correlation with the depth. With increasing depth, the total phosphorus gradually increases. The increase is due to high concentration of iron bound phosphorus which increases with the depth. The total phosphorus was found to be exceptionally high at four places (i.e. at depth 60-70, 100-110, 120-130 and 150-160 cms.) in the vertical column, against its normal trend. The value could be due to the grain size effect (Stone and English 1993). The total phosphorus concentration ranges between 630 $\mu\text{g/g}$ (at depth 20-30 cm) and 1140 $\mu\text{g/g}$ (at depth 100-110 cm). The low values of the sediments at higher level could be due to the plant uptake of phosphorus. The high value observed at depth of 100-110 cm is possibly due to grain size effect, since, aluminum, iron and manganese were also found to be higher at this particular profile.

Nitrogen concentrations were found to be higher than that in the samples at Saharanpur and Delhi. Since in flood plain areas extensive agriculture practice is going on, the high value could be due to the nitrogen enrichment by the agriculture run off. This possibility of enrichment is further supported by high value at upper part of sediments. A very good negative correlation was found with the depth indicating that with the depth, concentration decreases sharply due to the mineralization of nitrogen. Positive correlation with the organic carbon suggests that a substantial part of nitrogen is derived from the carbon only. The organic origin of the nitrogen at lower profile of the sediment is also proved by the vertical distribution of carbon, as at lower profile the line graph for Carbon distribution (as evident in the graph

50) with the nitrogen is almost parallel to each other. In the upper profile, the nitrogen concentration fluctuates, further strengthening the possibility of nitrogen enrichment of the sediment by anthropogenic input (possibly from agriculture runoff). In the vertical column nitrogen concentration varies between 0.50 percent at top to a lowest value of 0.20 percent.

Phosphorus fractionation

The phosphorus fractionation results for Saharanpur, Delhi and Allahabad core samples are shown in table (8,9,10) and graph (7,8;10;11,13,14)

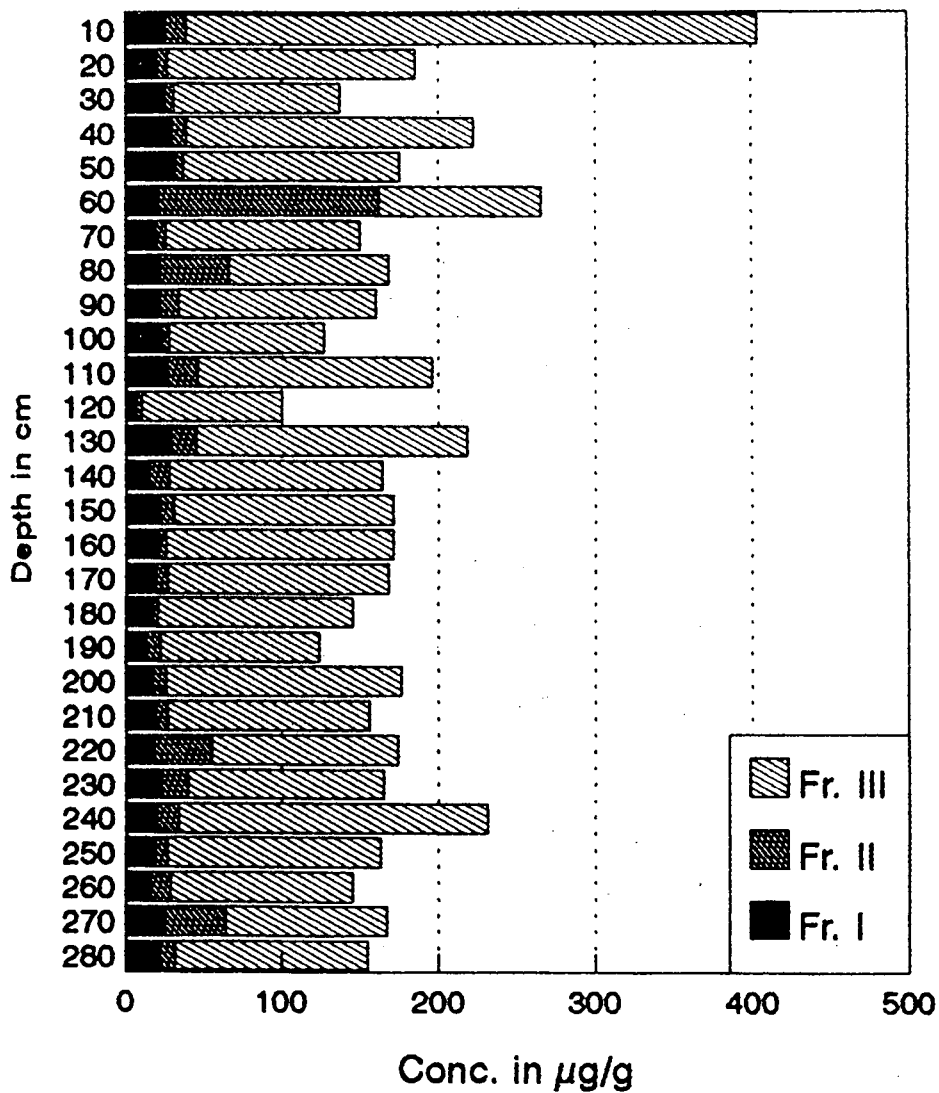
Result and Discussion

Saharanpur

Exchangeable or loosely sorbed phosphorus (fraction I) decreases slowly with depth. ($r = -0.30$). The reason for its decreases with the depth could be the desorption during compaction and burial of the sediment. The burial and compaction leads to anaerobic condition and in anaerobic condition phosphorus release from the sediment increases (Furumai and Ohgaki, 1989 and Redshaw et al., 1990). The concentration of this fraction is very low, ranging between 7 $\mu\text{g/g}$ and 32 $\mu\text{g/g}$. A comparatively low value was observed at a depth of 110-120 cm, which could be due to plant uptake of phosphorus from sediments or possibly due to different nature of sedimentary environment. Good positive correlation was obtained with total carbon, organic carbon and aluminum. Similar results were also observed by Stone and English (1993). Correlation

Graph-7

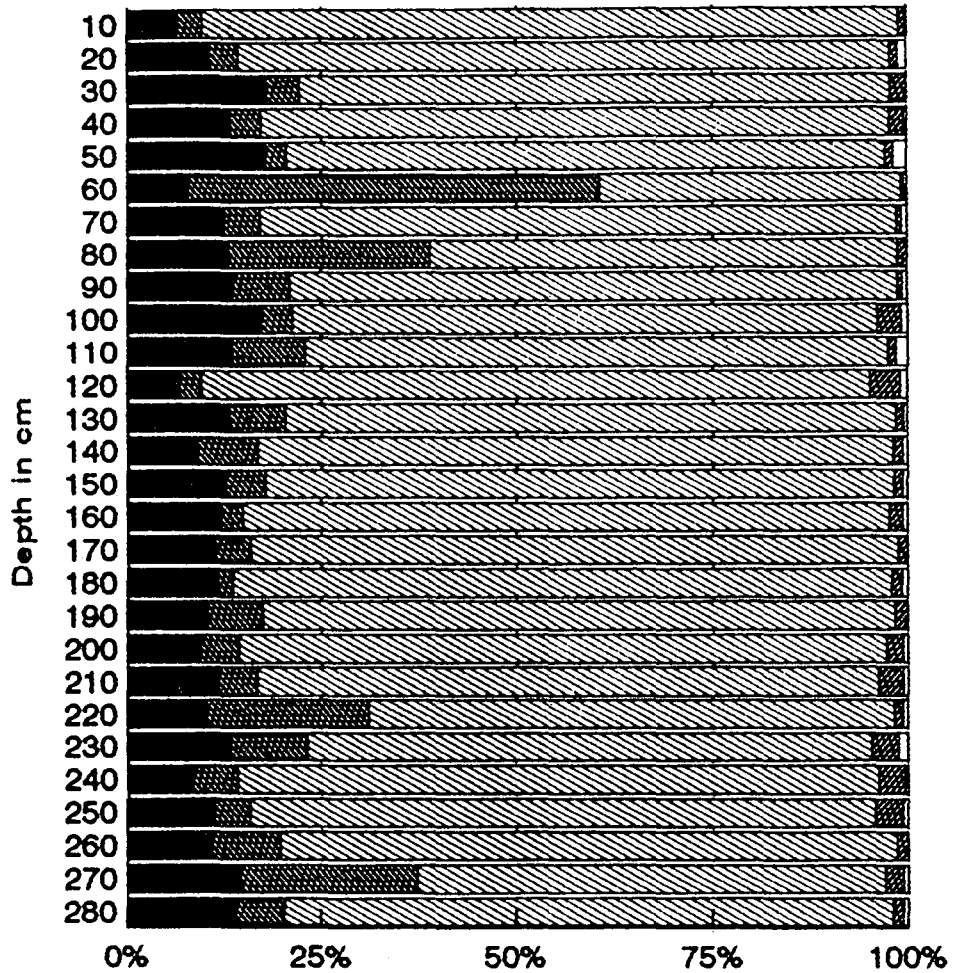
Phosphorus fractionation in the core sediment samples from Saharanpur



Fr. I represents Exchangeable P, Fr. II Fe-bound P
Fr. III Authigenic apatite + Carbonate-bound P + biogen. apatite
Detrital apatite & organic P together contribute <2% and not shown in fig.

Graph-8

Phosphorus fractionation in the core sediment samples from Saharanpur



Fr. I represents Exchangeable P, Fr. II Fe-bound P, Fr. III Authigenic apatite + Carbonate-bound P + biogenic apatite, Fr. IV Detrital apatite and Fr. V Organic P

Graph-9

Variation of Fe-bound P, Fe and Al in the core sediment samples from Saharanpur, with depth

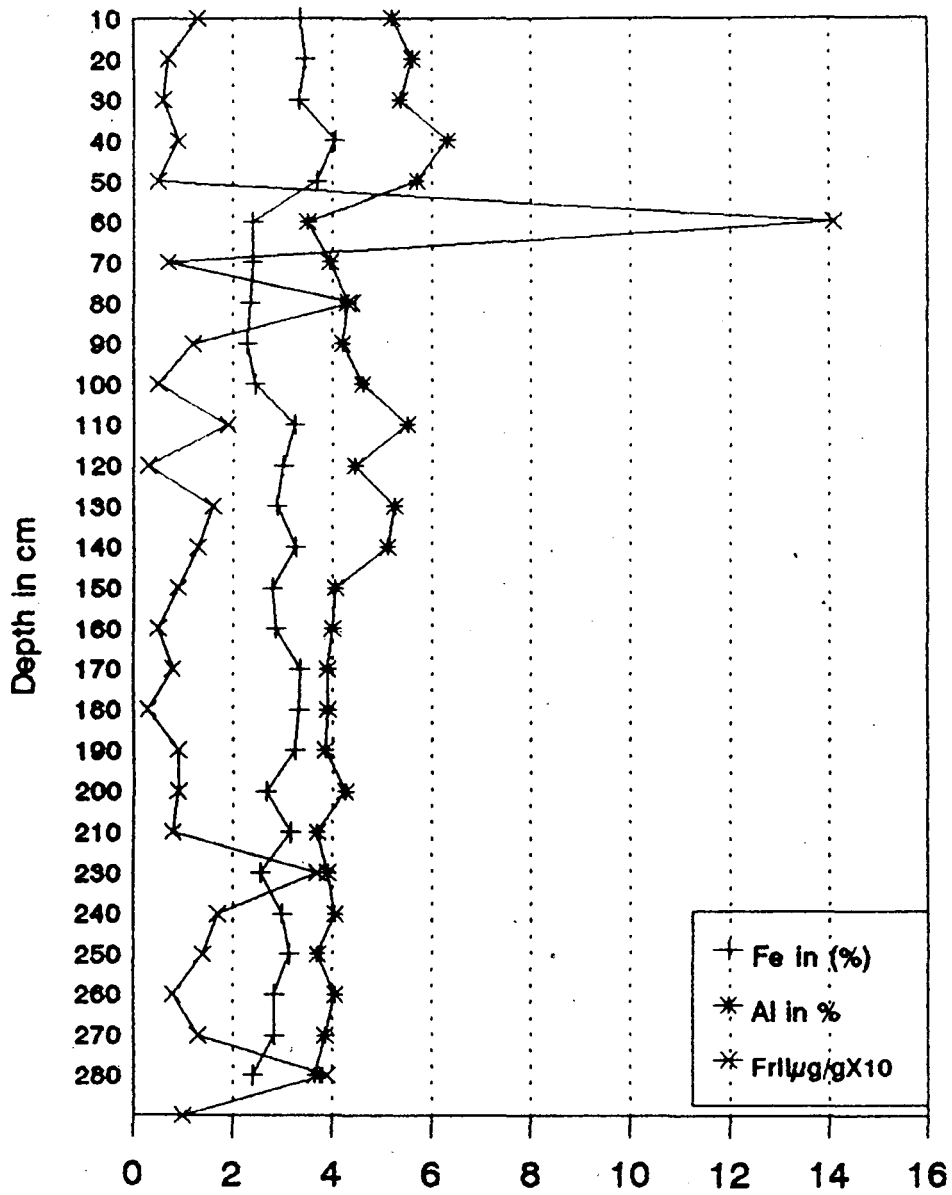


Table 8, Phosphorous fractionation of Saharanpur core

Depth in cm	Fr. I P µg/g	Fr. II P µg/g	Fr. III P µg/g	Fr. IV P µg/g	Fr. V P µg/g	SUM(I.V) µg/g	Total P µg/g	% of P Extracted	% of fr. I	% fr. II	% fr. III	% fr. IV	% fr. V
10	26	13	365	3	1	408	1190	34	6	3	90	1	0
20	20	7	158	2	2	189	990	19	11	4	84	1	1
30	25	6	106	3	0	140	830	17	18	4	75	2	0
40	30	9	183	4	1	227	1880	12	13	4	81	2	0
50	32	5	138	2	3	180	1140	16	18	3	77	1	2
60	21	141	103	1	1	267	780	34	8	53	39	0	0
70	19	7	124	1	1	152	870	17	12	5	81	1	1
80	22	44	102	2	0	170	820	21	13	26	60	1	0
90	22	12	126	1	1	162	730	22	14	7	78	1	1
100	23	5	99	4	1	132	720	18	17	4	75	3	1
110	27	19	150	2	3	201	1020	20	13	9	75	1	1
120	7	3	90	4	1	105	870	12	7	3	86	4	1
130	29	16	173	2	1	221	870	25	13	7	78	1	0
140	15	13	136	2	1	167	1740	10	9	8	81	1	1
150	22	9	140	2	1	174	1050	17	13	5	80	1	1
160	21	5	145	3	1	175	870	20	12	3	83	2	1
170	19	8	141	2	0	170	920	19	11	5	83	1	0
180	17	3	125	2	1	148	770	19	12	2	85	1	1
190	13	9	102	2	0	126	850	15	10	7	81	1	0
200	17	9	150	4	1	181	760	24	9	5	83	2	1
210	19	8	129	5	1	162	1040	16	12	5	80	3	1
220	18	37	119	2	1	177	750	24	10	21	67	1	1
230	23	17	125	6	2	173	830	21	13	10	72	4	1
240	20	14	197	8	1	240	750	32	8	6	82	3	0
250	19	8	136	6	1	170	1120	15	11	5	80	3	1
260	16	13	116	2	0	147	940	16	11	9	79	1	0
270	25	39	103	4	1	172	740	23	15	23	60	2	1
280	22	10	123	2	1	158	750	21	14	6	78	1	1

of the organic carbon and total carbon reveals that phosphorus is very much associated with total carbon and organic carbon (Furumai *et al.*, 1989; Raaphorst and Kloosterhuis 1994). Fraction I phosphorus accounts for about 6 to 18 percent of total phosphorus extracted.

Iron-bound phosphorus constitutes the second phosphorus fraction (Fraction II). The iron-bound phosphorus in Saharanpur core shows very small concentration (most of the samples less than 5 percent of total phosphorus extracted). The concentration ranges between 3 and 19 $\mu\text{g/g}$, with few exceptions. Two prominent exceptionally higher values were obtained at depths of 50-60 cm, and 70-80 cm having concentrations 141 $\mu\text{g/g}$ and 44 $\mu\text{g/g}$ respectively. Since the concentrations are so less no significant relationship can be established with any parameters. At the depth of 110-120 cm iron-bound phosphorus was found to be very less coinciding with the low value of exchangeable phosphorus in vertical column. This further strengthens the possibility of phosphorus being taken up by the plants, since iron-bound phosphorus is the most easily available form of phosphorus to the plants (Bostrom *et al.*, 1988).

Detrital apatite phosphorus plus other inorganic phosphorus constitute fourth fraction (Fraction IV) of phosphorus. In riverine environment this fraction is very negligible, indicating that detrital apatite does not contribute much phosphorus to the total phosphorus pool.

Organic phosphorus forms fifth fraction (Fraction V) of the phosphorus. Since the organic matter itself is very small, organic

phosphorus was also found to be very small. Fraction IV and fraction V contribute together less than 3 percent of the total phosphorus extracted.

In the Saharanpur core samples, between 10 and 34 percent of total phosphorus was extracted by using Ruttenberg's SEDEX method.

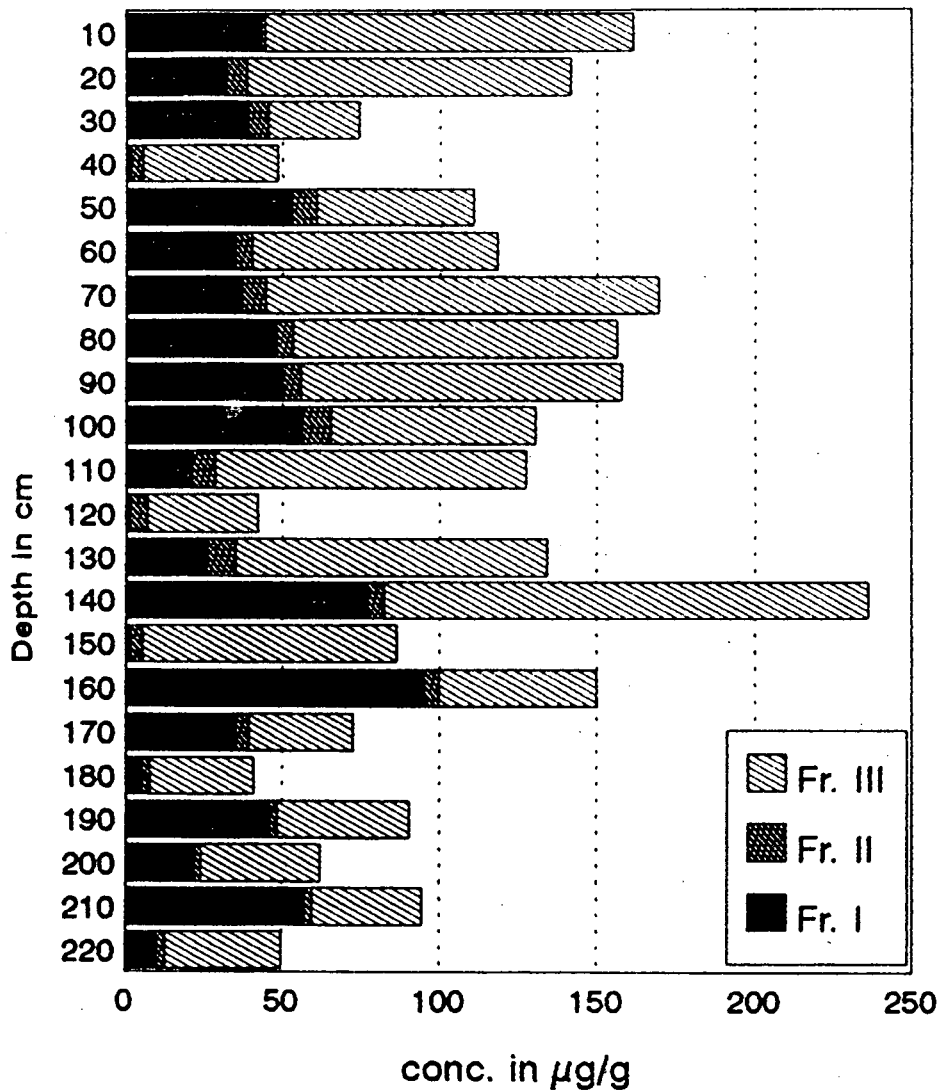
Delhi

In Delhi core samples, exchangeable phosphorus is higher than that in the Saharanpur samples. The reason for higher values of exchangeable phosphorus could be anthropogenic enrichment of the sediments, by the agricultural runoff, solid waste disposal and detergents coming from sewage. The distribution graph shows the fluctuation in concentrations with the depth. The fluctuating values indicate that the sediments in the vertical column is highly disturbed, since fluctuation was observed for the total phosphorus, and nitrogen. Disturbance of the sediment is also revealed by the aluminum, iron and manganese, variations, the same sort of fluctuations were also observed even for these stable elements.

Iron-bound phosphorus contributes only a very small part to the total phosphorus extracted (between 0.8 and 13.0 percent). The concentration varies between 1.3 $\mu\text{g/g}$ and 9.3 $\mu\text{g/g}$. Lower value for the top sediments could be due to plant uptake of the phosphorus, since iron-bound phosphorus is the most easily available phosphorus to the plants (Bostrom et al., 1988). Iron-bound phosphorus was found to be giving good correlation with iron and aluminum, and similar results were observed by Yamada and Kayama (1987); Danen-Louwerse (1993) and Stone and English (1993). Good positive

Graph-10

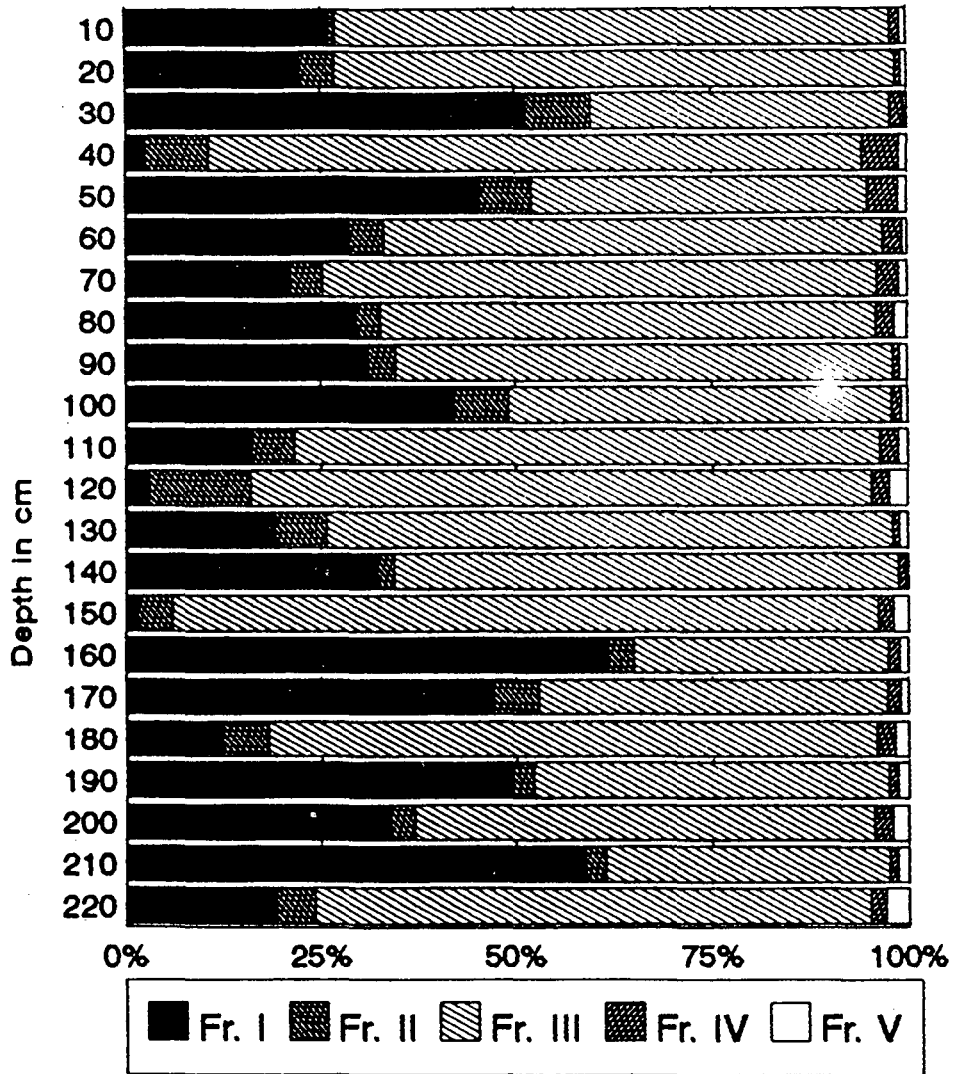
Phosphorus fractionation in the core sediment samples from Delhi



Fr. I represents Exchangeable P, Fr. II Fe-bound P
Fr. III authigenic apatite + carbonate-bound P + biogenic apatite
Detrital apatite & organic P together contribute <2% & not shown in fig.

Graph-11

Phosphorus fractionation in the core sediment Samples from Delhi



Fr. I represents Exchangeable P, Fr. II Fe-bound P
Fr. III Authigenic apatite + carbonate-bound P + biogenic apatite
Fr. IV Detrital apatite and Fr. V Organic P

Graph-12

Variation of Fe-bound P, Fe and Al in the core sediment samples from Delhi, with depth

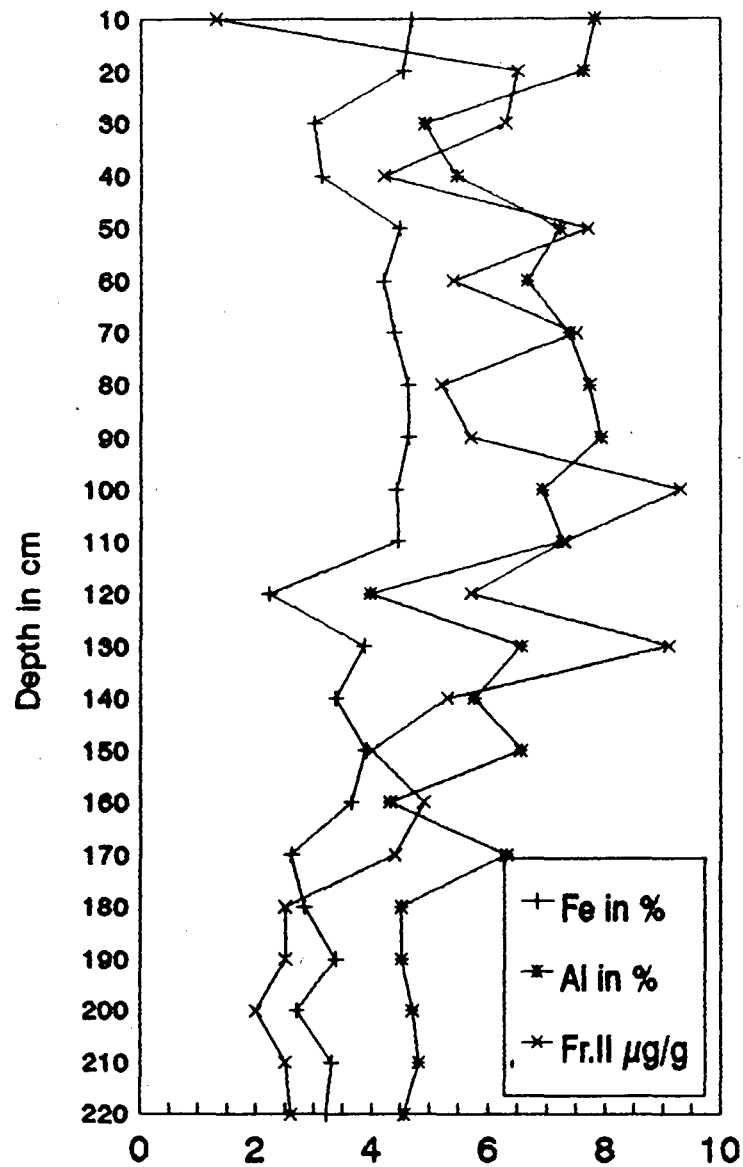


Table 9. Phosphorus fractionation of Delhi core.

Depth in cm	Fract. I P (µg/g)	Fract. II P (µg/g)	Fract. III P (µg/g)	Fract. IV P (µg/g)	Fract. V P (µg/g)	SUM (I.V) P (µg/g)	Total P µg/g	% of P Extracted	% of Fr. I P	% of Fr. II P	% of Fr. III P	% of Fr. IV P	% of Fr. V P
10	43.0	1.3	117.0	2.0	1.3	164.6	780.0	21.1	26.1	0.8	71.1	1.2	0.8
20	32.0	6.5	103.0	1.0	1.0	143.5	320.0	44.8	22.3	4.5	71.8	0.7	0.7
30	39.0	6.3	29.0	1.3	0.3	75.9	490.0	15.5	51.4	8.3	38.2	1.7	0.4
40	1.3	4.2	43.0	2.4	0.5	51.4	250.0	20.6	2.5	8.2	83.7	4.7	1.0
50	53.0	7.7	50.0	4.5	1.2	116.4	810.0	14.4	45.5	6.6	43.0	3.9	1.0
60	35.0	5.4	78.0	3.0	0.7	122.1	940.0	13.0	28.7	4.4	63.9	2.5	0.6
70	37.0	7.5	125.0	4.8	1.8	176.1	470.0	37.5	21.0	4.3	71.0	2.7	1.0
80	48.0	5.2	103.0	3.8	2.5	162.5	760.0	21.4	29.5	3.2	63.4	2.3	1.5
90	50.0	5.7	102.0	1.3	1.6	160.6	830.0	19.3	31.1	3.5	63.5	0.8	1.0
100	56.0	9.3	65.0	1.6	1.0	132.9	820.0	16.2	42.1	7.0	48.9	1.2	0.8
110	21.0	7.3	99.0	3.0	1.6	131.9	890.0	14.8	15.9	5.5	75.1	2.3	1.2
120	1.3	5.7	35.0	1.0	1.0	44.0	430.0	10.2	3.0	13.0	79.5	2.3	2.3
130	26.0	9.1	99.0	1.0	1.5	136.6	860.0	15.9	19.0	6.7	72.5	0.7	1.1
140	77.0	5.3	154.0	2.1	0.7	239.1	990.0	24.2	32.2	2.2	64.4	0.9	0.3
150	1.3	4.0	81.0	1.7	1.7	89.7	610.0	14.7	1.4	4.5	90.3	1.9	1.9
160	95.0	4.9	50.0	2.1	1.7	153.7	620.0	24.8	61.8	3.2	32.5	1.4	1.1
170	35.0	4.4	33.0	1.2	0.7	74.3	450.0	16.5	47.1	5.9	44.4	1.6	0.9
180	5.2	2.5	33.0	1.0	0.7	42.4	450.0	9.4	12.3	5.9	77.8	2.4	1.7
190	46.0	2.5	42.0	1.0	1.3	92.8	450.0	6	49.6	2.7	45.3	1.1	1.4
200	22.0	2.0	38.0	1.5	1.3	64.8	340.0	19.1	34.0	3.1	58.6	2.3	2.0
210	57.0	2.5	35.0	1.0	1.3	96.8	460.0	21.0	58.9	2.6	36.2	1.0	1.3
220	10.0	2.6	37.0	1.0	1.5	52.1	500.0	10.4	19.2	5.0	71.0	1.9	2.9

correlations were observed with inorganic carbon, organic carbon and nitrogen also. The association of iron-bound phosphorus with the organic matter could be a reason for giving good correlation (Yamada and Kayama 1987).

Authigenic apatite phosphorus plus calcium carbonate-bound phosphorus plus biogenic apatite phosphorus (Fraction III), contributes major fraction of the phosphorus. It contributes between 32.5 and 90.3 percent of total phosphorus extracted. In vertical profile it gives a negative correlation, indicating its gradual decrease with the depth. An abnormally high value was observed at the depth of 130-140 cm against its normal trend. A negative correlation was observed for phosphorus fraction III with silicon, because silicon is associated with larger grain size sediments where as this fraction could have been associated with finer grain. Very good positive correlations were also observed with total carbon, organic carbon, inorganic carbon and aluminum. The positive correlation with total carbon, organic carbon, and inorganic carbon, suggest that fraction III phosphorus is strongly associated with carbonate, since carbonate contributes major chunk of the total carbon. Iron, zinc and potassium are found to have good correlation with fraction III phosphorus, indicating that the minerals incorporating phosphorus fraction III are probably same as that of iron, zinc and potassium, probably a clay mineral.

Fraction IV forms detrital apatite phosphorus and other inorganic phosphorus, which gives very low concentrations. The phosphorus fractions V contributes organic bound phosphorus which is very low. Since organic carbon is very small, less organic

phosphorus could be expected. Fraction IV phosphorus and fraction V phosphorus contribute together less than 3 percent of total phosphorus.

The total extracted phosphorus ranges between 9.4 and 44.8 percent of the total phosphorus, by using Rutteberg's SEDEX method for phosphorus extraction.

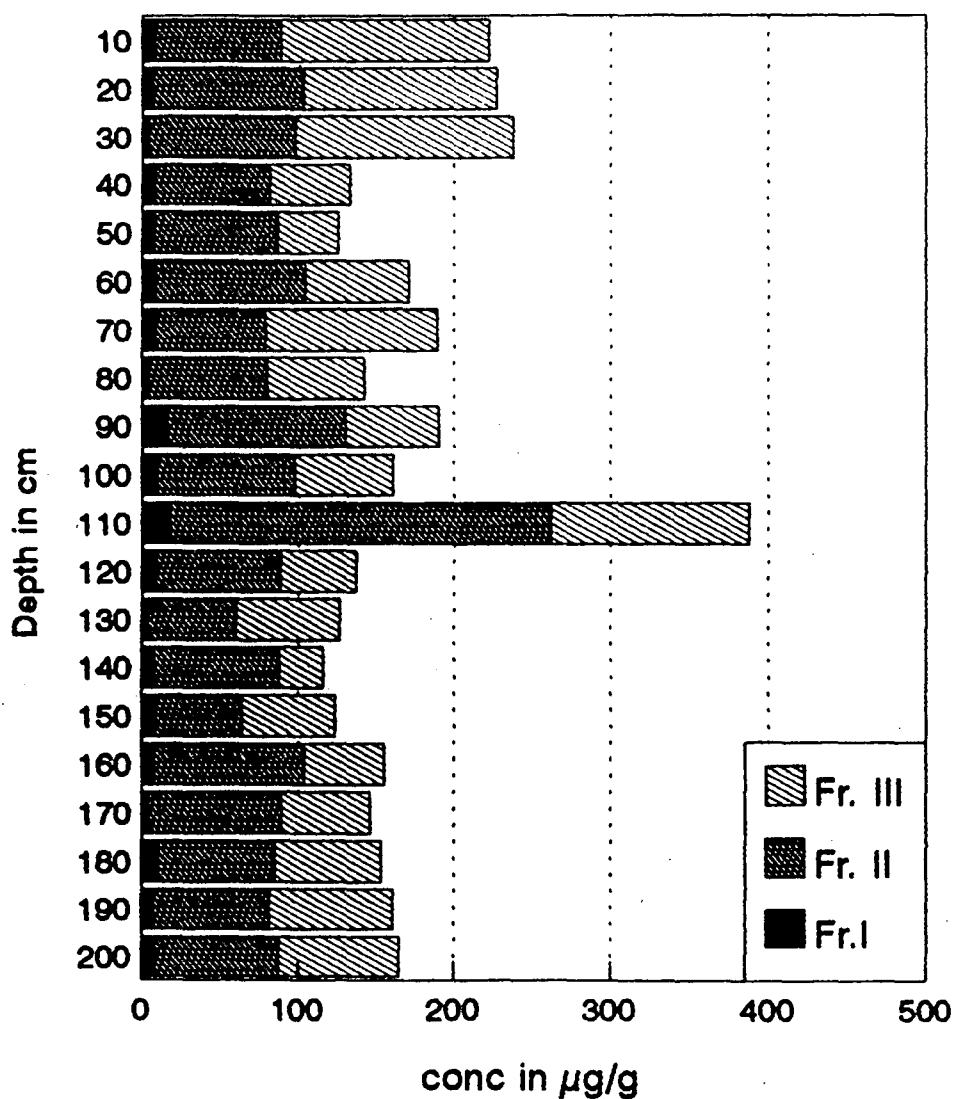
Allahabad

In Allahabad core sample exchangeable phosphorus was lower than that of Saharanpur and Delhi. The exchangeable phosphorus was found to be constant with increasing depth. The values range between 4.1 and 17.9 $\mu\text{g/g}$. It contributes between 11.6 and 37.9 percent of total phosphorus extracted. Good positive correlation was found with Fe-bound phosphorus ($r = 0.74$), showing that Fe-bound phosphorus having very good affinity with exchangeable phosphorus. Similar observations were also made by, Istvanovics (1989); Sundby et al., (1992) and Raaphorst and Kloosterhuis (1994). It suggests that either exchangeable phosphorus fraction is a part of Fe-bound phosphorus as observed by Furumai et al., (1989), or the minerals which bear Fe-bound phosphorus have strong affinity to adsorb phosphorus as observed by Redshaw et al., (1990). Since iron, aluminum and manganese are closely related in the sedimentary environment, exchangeable phosphorus is giving good correlation with Al, Fe and Mn ($r = 0.54, 0.56$ and 0.50 respectively).

Authigenic apatite phosphorus plus calcium carbonate-bound phosphorus plus biogenic apatite (fraction III) makes major part of the total phosphorus extracted. The concentration varies between

Graph-13

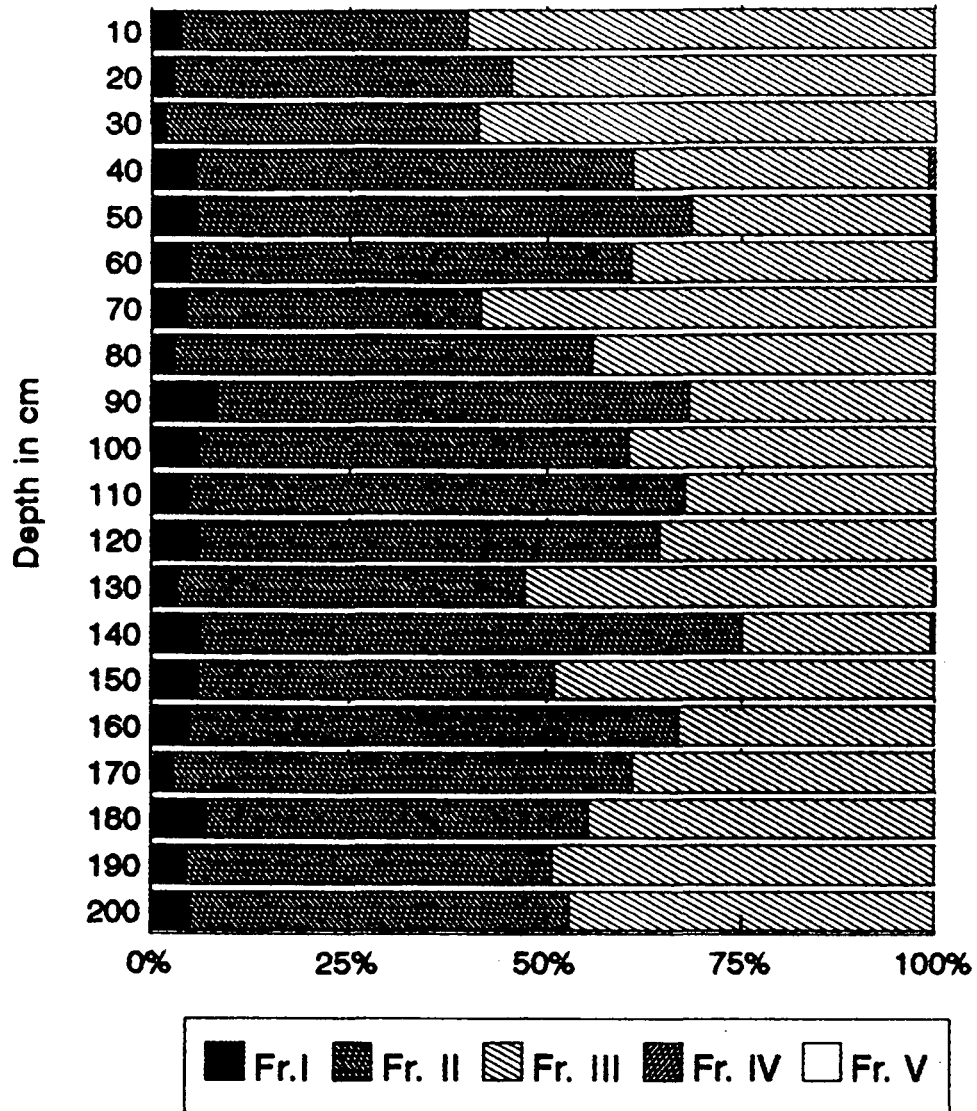
Phosphorus fractionation in core sediment samples from Allahabad



Fr. I represents Exchangeable P, Fr. II Fe-bound P
Fr. III authigenic apatite + carbonate-bound P + biogenic apatite
Detrital apatite & organic P together contribute <2% and not shown in fig.

Graph-14

Phosphorus fractionation in the core sediment samples from Allahabad



Fr. I represents Exchangeable P, Fr. II Fe-bound P
Fr. III Authigenic apatite + carbonate-bound P + biogen. apatite
Fr. IV detrital apatite and Fr. V organic P

Graph-15

Variation of Fe-bound P, Fe and Al in the core sediment samples from Allahabad, with depth

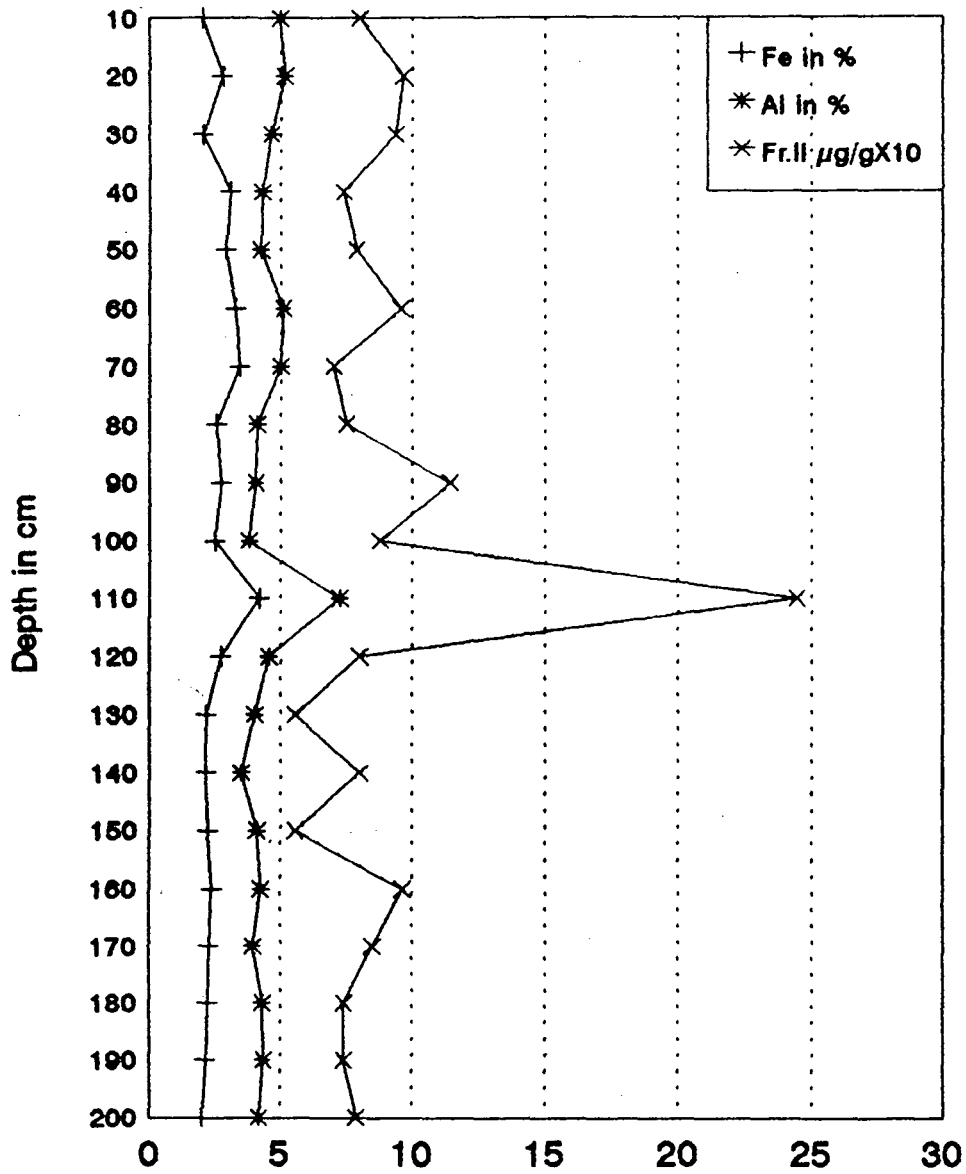


Table 10. Phosphorus fractionation of the Allahabad core.

Depth in cm	Frac. I P (µg/g)	Frac. II P (µg/g)	Frac. III P (µg/g)	Frac. IV P (µg/g)	Frac. V P (µg/g)	SUM(ItoV) P (µg/g)	Total P µg/g	% of P Extracted	%ofFr. I.P	%ofFr. II	%ofFR. III	% ofFr. IV	%ofFr. V
10	8.2	80.2	133.7	0.0	0.1	222.1	860.0	25.8	3.7	36.1	60.2	0.0	0.0
20	6.5	96.8	123.9	0.2	0.1	227.5	680.0	33.5	2.9	42.6	54.5	0.1	0.1
30	4.1	93.9	140.8	0.0	0.1	238.9	630.0	37.9	1.7	39.3	59.0	0.0	0.0
40	7.3	74.3	51.3	1.0	0.1	134.1	680.0	19.7	5.5	55.4	38.3	0.7	0.7
50	7.3	79.2	39.1	0.5	0.1	126.2	800.0	15.8	5.8	62.8	31.0	0.4	0.4
60	8.2	95.8	66.8	0.3	0.1	171.2	750.0	22.8	4.8	56.0	39.0	0.2	0.2
70	8.2	70.4	110.8	0.0	0.1	189.6	1010.0	18.8	4.3	37.1	58.5	0.0	0.0
80	4.1	75.3	62.8	0.0	0.1	142.3	830.0	17.1	2.9	52.9	44.1	0.0	0.0
90	15.5	114.4	60.3	0.0	0.1	190.3	750.0	25.4	8.1	60.1	31.7	0.0	0.0
100	9.4	88.0	63.6	0.0	0.1	161.0	750.0	21.5	5.8	54.7	39.5	0.0	0.0
110	17.9	244.5	125.5	0.3	0.1	388.3	1140.0	34.1	4.6	63.0	32.3	0.1	0.1
120	8.2	80.2	48.9	0.0	0.1	137.3	890.0	15.4	5.9	58.4	35.6	0.0	0.0
130	4.1	55.7	66.8	0.0	0.2	126.8	1090.0	11.6	3.2	43.9	52.7	0.0	0.0
140	7.3	80.2	28.5	0.5	0.1	116.7	980.0	11.9	6.3	68.7	24.4	0.4	0.4
150	7.3	55.7	60.3	0.0	0.1	123.5	750.0	16.5	5.9	45.2	48.8	0.0	0.0
160	7.3	96.5	51.3	0.0	0.1	155.3	1060.0	14.7	4.7	62.1	33.1	0.0	0.0
170	4.1	85.1	57.1	0.0	0.2	146.5	890.0	16.5	2.8	58.1	39.0	0.0	0.0
180	10.6	74.3	68.5	0.0	0.1	153.5	860.0	17.9	6.9	48.4	44.6	0.0	0.0
190	7.3	74.3	79.1	0.0	0.2	160.9	830.0	19.4	4.6	46.2	49.1	0.0	0.0
200	8.2	79.2	77.4	0.0	0.2	165.0	890.0	18.5	4.9	48.0	46.9	0.0	0.0

Table 11. Elemental deposition rates for the Saharanpur core

Year of deposition	P dep. mg/cm ² /yr	N dep. mg/cm ² /yr	TC dep. mg/cm ² /yr	Al dep. mg/cm ² /yr	Fe dep. mg/cm ² /yr	Mn dep. mg/cm ² /yr	Si dep. mg/cm ² /yr	Na dep. mg/cm ² /yr	K dep. mg/cm ² /yr	Zn dep. mg/cm ² /yr
1995-77	0.39	0.10	3	17	11	2	93	3	6	0.03
1977-59	0.32	0.23	4	18	11	2	96	3	6	0.03
1959-41	0.27	0.26	3	17	11	2	94	4	6	0.03
1941-24	0.61	0.42	7	20	13	2	99	3	7	0.04
1924-06	0.37	0.32	5	19	12	2	101	3	6	0.03
1906-1888	0.25	0.19	2	11	8	1	112	3	4	0.02
1888-70	0.28	0.23	3	13	8	1	93	3	4	0.02
1870-52	0.27	0.26	2	14	8	1	124	3	5	0.02
1852-34	0.24	0.26	2	14	7	1	120	3	5	0.02
1834-16	0.23	0.26	1	15	8	1	112	3	5	0.02
1816-1799	0.33	0.32	2	18	11	2	118	3	6	0.03
1799-81	0.28	0.29	1	14	10	2	110	3	5	0.03
1781-63	0.28	0.19	2	17	9	2	100	3	6	0.03
1763-45	0.58	0.26	2	17	11	2	109	3	6	0.04
1745-27	0.34	0.26	3	13	9	2	116	3	4	0.03
1727-09	0.28	0.26	2	13	9	2	130	3	5	0.03
1709-1691	0.30	0.29	2	13	11	3	93	3	4	0.04
1691-74	0.25	0.23	2	13	11	3	133	2	4	0.03
1674-56	0.28	0.19	2	13	11	2	129	3	4	0.03
1656-38	0.25	0.39	2	14	9	1	133	3	5	0.04
1638-20	0.34	0.19	2	12	10	3	126	2	4	0.03
1620-02	0.24	0.16	2	13	8	2	109	3	4	0.03
1602-1584	0.27	0.23	2	13	10	2	115	3	4	0.03
1584-66	0.24	0.23	3	12	10	3	128	2	4	0.03
1566-45	0.36	0.29	2	13	9	2	127	3	5	0.03
1545-27	0.31	0.10	2	13	9	2	111	2	4	0.03
1527-09	0.24	0.23	2	12	8	1	135	3	4	0.03
1509-1491	0.24	0.16	2	14	8	1	132	3	5	0.03

Table 12. Elemental deposition rates for the Delhi core

Year of Deposition	P dep. mg/cm2/yr	N dep. mg/cm2/yr	TC dep. mg/cm2/yr	Al dep. mg/cm2/yr	Fe dep. mg/cm2/yr	Mn dep. mg/cm2/yr	Si dep. mg/cm2/yr	K dep. mg/cm2/yr	Na dep. mg/cm2/yr	Zn dep. mg/cm2/yr
1995-93	3	9	67	289	173	3	998	84	31	0.50
1993-90	1	9	43	282	168	2	979	83	28	0.48
1990-88	2	6	46	181	111	1	1364	61	37	0.20
1988-85	1	4	22	202	116	1	1024	62	38	0.27
1985-83	3	6	36	267	166	3	865	84	34	0.34
1983-81	3	5	47	246	155	2	1064	79	36	0.36
1981-78	2	5	45	272	162	2	839	79	31	0.32
1978-76	3	11	52	285	171	3	702	84	29	0.38
1976-74	3	11	44	293	171	3	1114	83	32	0.45
1974-71	3	9	44	256	163	3	1081	83	31	0.34
1971-69	3	5	49	269	164	3	865	79	33	0.43
1969-66	2	3	13	146	82	2	1478	44	33	0.11
1966-64	3	4	74	242	143	2	1161	73	33	0.52
1964-62	4	4	70	213	125	2	798	62	33	0.30
1962-59	2	4	44	242	144	2	991	73	36	0.38
1959-57	2	1	27	159	135	2	1016	65	37	0.32
1957-55	2	1	16	233	96	2	1283	46	33	0.20
1955-52	2	1	10	167	105	2	1324	44	33	0.23
1952-50	2	1	11	167	125	4	1109	44	44	0.20
1950-47	1	1	13	174	100	2	1116	48	33	0.20
1947-45	2	1	11	178	122	4	1268	45	35	0.25
1945-43	2	1	6	169	119	4	1216	42	36	0.23

Table 13. Elemental deposition rates for the Allahabad core.

Year of deposition	P dep. mg/cm ² /yr	N dep. mg/cm ² /yr	TC dep. mg/cm ² /yr	Al dep. mg/cm ² /yr	Fe dep. mg/cm ² /yr	Mn dep. mg/cm ² /yr	Si dep. mg/cm ² /yr	K dep. mg/cm ² /yr	Na dep. mg/cm ² /yr	Zn dep. mg/cm ² /yr
1995-94	6	42	52	360	147	2	2948	112	96	1.08
1994-93	5	33	72	373	202	2	2543	137	94	0.90
1993-91	5	27	53	337	148	2	2507	118	96	1.18
1991-90	5	24	67	311	224	6	2254	98	125	1.18
1990-89	6	25	53	308	212	4	2904	112	90	0.79
1989-88	5	25	67	369	238	4	2478	134	74	1.13
1988-86	7	29	95	362	249	4	1994	125	82	0.68
1986-85	6	25	46	297	185	3	2276	100	76	0.96
1985-84	5	14	46	293	198	3	2001	107	82	0.68
1984-83	5	9	44	275	181	4	1763	94	79	0.39
1983-82	8	25	76	525	303	6	1828	116	69	0.79
1982-80	6	19	39	329	198	3	1972	101	85	0.73
1980-79	8	14	35	290	158	3	2363	98	87	0.68
1979-78	7	17	39	254	156	3	1922	98	87	0.96
1978-77	5	21	42	297	163	3	1640	108	83	0.56
1977-75	8	21	42	308	173	3	1691	103	90	0.68
1975-74	6	22	39	286	167	3	2139	96	89	1.18
1974-73	6	20	44	311	162	3	1626	108	85	0.56
1973-72	6	19	45	315	157	3	2110	112	85	1.08
1972-71	6	18	44	304	147	3	2131	107	87	1.02

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Table 14. Elemental composition of the core sediment sample collected from Saharanpur.

Concentrations of P fractions are in ug/g.

Depth cm	Si %	TC %	Inor. C %	Org. C	Nitr. %	P µg/g	P.fr.I µg/g	P.fr.II µg/g	P.fr.III µg/g	Al %	Fe %	Mn µg/g	Zn µg/g	Na %	K %
10	27.78	0.96	0.51	0.45	0.03	1190	26	13	365	5.21	3.36	550	80	1	1.85
20	29.52	1.16	0.66	0.5	0.07	990	20	7	158	5.61	3.47	470	92	0.98	1.95
30	29.07	1.03	0.69	0.34	0.08	830	25	6	106	5.36	3.34	480	98	1.28	1.85
40	30.44	2.09	0.68	1.41	0.13	1880	30	9	183	6.31	4.05	640	129	0.95	2.13
50	31.17	1.45	0.92	0.53	0.1	1140	32	5	138	5.71	3.7	580	104	0.88	1.98
60	34.47	0.64	0.41	0.23	0.06	780	21	141	103	3.51	2.41	430	61	0.78	1.25
70	28.6	0.86	0.63	0.23	0.07	870	19	7	124	3.96	2.41	370	67	0.9	1.35
80	38.13	0.73	0.71	0.02	0.08	820	22	44	102	4.31	2.35	340	61	0.9	1.5
90	36.85	0.61	0.44	0.17	0.08	730	22	12	126	4.21	2.3	350	61	0.93	1.48
100	34.48	0.42	0.41	0.01	0.08	720	23	5	99	4.61	2.45	350	61	0.95	1.6
110	36.48	0.76	0.61	0.15	0.1	1020	27	19	150	5.51	3.25	660	92	0.83	1.7
120	33.92	0.46	0.46	0	0.09	870	7	3	90	4.46	3.02	590	80	0.93	1.48
130	30.79	0.6	0.51	0.09	0.06	870	29	16	173	5.26	2.9	490	92	0.95	1.7
140	33.55	0.75	0.73	0.02	0.08	1740	15	13	136	5.11	3.27	600	123	1	1.78
150	35.75	0.8	0.78	0.02	0.08	1050	22	9	140	4.06	2.8	590	92	0.85	1.33
160	40	0.74	0.73	0.01	0.08	870	21	5	145	4.01	2.87	580	86	0.93	1.4
170	28.6	0.67	0.66	0.01	0.09	920	19	8	141	3.91	3.36	970	117	0.78	1.25
180	40.8	0.64	0.63	0.01	0.07	770	17	3	125	4.26	2.67	430	110	0.85	1.4
190	37.79	0.56	0.55	0.01	0.06	850	13	9	102	3.86	3.25	730	92	0.8	1.3
200	41.07	0.5	0.48	0.02	0.12	760	17	9	150	3.71	3.17	790	98	0.75	1.33
210	38.68	0.69	0.68	0.01	0.06	1040	19	8	129	3.91	2.57	490	86	0.78	1.38
220	33.55	0.58	0.57	0.01	0.05	750	18	37	119	4.06	3	680	98	0.93	1.38
230	35.39	0.65	0.63	0.02	0.07	830	23	17	125	3.71	3.14	810	86	0.75	1.33
240	39.42	0.86	0.65	0.21	0.07	750	20	14	197	4.06	2.84	530	86	0.8	1.48
250	39.23	0.54	0.58	0.01	0.09	1120	19	8	136	3.86	2.84	610	86	0.75	1.38
260	34.28	0.67	0.66	0.01	0.03	940	16	13	116	3.66	2.41	400	98	0.78	1.3
270	41.61	0.55	0.54	0.01	0.07	740	25	39	103	3.91	3.34	900	98	0.75	1.3
280	40.5	0.74	0.73	0.01	0.05	740	22	10	123	4.21	2.47	390	104	0.83	1.48

Table 15. Elemental composition of the core sediment sample collected from Delhi. Concentrations of P fractions are in $\mu\text{g/g}$.

Depth cm	Si %	TC %	Inor. C %	Org. C %	Nitr. %	P $\mu\text{g/g}$	P fr. I	P fr. II	P fr. III	Al %	Fe %	Mn $\mu\text{g/g}$	Zn $\mu\text{g/g}$	Na %	K %
10	27	1.8	1.71	0.09	0.23	780	43	1.3	117	7.82	4.69	760	135	0.85	2.28
20	26.5	1.15	0.8	0.35	0.25	320	32	6.5	103	7.62	4.54	620	129	0.75	2.25
30	36.9	1.24	0.48	0.76	0.15	490	39	6.3	29	4.91	3	390	55	1	1.65
40	27.7	0.6	0.5	0.1	0.1	250	1.3	4.2	43	5.46	3.13	350	73	1.03	1.68
50	23.4	0.97	0.91	0.06	0.16	810	53	7.7	50	7.22	4.48	740	92	0.93	2.28
60	28.8	1.26	0.68	0.58	0.13	940	35	5.4	78	6.66	4.19	580	98	0.98	2.15
70	22.7	1.22	0.85	0.37	0.13	470	37	7.5	125	7.37	4.39	670	86	0.85	2.15
80	19	1.42	0.82	0.6	0.3	760	48	5.2	103	7.72	4.62	730	104	0.78	2.28
90	30.15	1.19	0.88	0.31	0.29	830	50	5.7	102	7.92	4.63	760	123	0.86	2.25
100	29.25	1.18	0.87	0.31	0.23	820	56	9.3	65	6.92	4.42	770	92	0.85	2.25
110	23.4	1.32	0.85	0.47	0.14	890	21	7.3	99	7.27	4.45	740	117	0.9	2.15
120	40	0.36	0.27	0.09	0.08	430	1.3	5.7	35	3.96	2.22	440	30	0.88	1.18
130	31.4	2	1.89	0.11	0.1	860	26	9.1	99	6.56	3.86	490	141	0.9	1.98
140	21.6	1.86	1.73	0.13	0.11	990	77	5.3	154	5.76	3.37	540	80	0.9	1.68
150	26.8	1.19	0.66	0.53	0.1	610	1.3	4	81	6.56	3.89	650	104	0.92	1.98
160	27.5	0.73	0.71	0.02	0.04	620	95	4.9	50	4.31	3.65	560	86	1	1.75
170	34.7	0.44	0.42	0.02	0.04	450	35	4.4	33	6.31	2.6	580	55	0.88	1.25
180	35.82	0.26	0.25	0.01	0.04	450	5.2	2.5	33	4.51	2.83	550	61	0.88	1.18
190	30	0.29	0.28	0.01	0.02	450	46	2.5	42	4.51	3.37	1060	55	1.2	1.18
200	30.2	0.35	0.34	0.01	0.02	340	22	2	38	4.71	2.7	580	55	0.9	1.3
210	34.3	0.31	0.3	0.01	0.02	460	57	2.5	35	4.81	3.3	1000	67	0.95	1.23
220	32.9	0.17	0.17	0	0.02	500	10	2.6	37	4.56	3.22	980	61	0.98	1.13

Table 16. Elemental composition of the core sediment sample collected from Allahabad.
Concentrations of P fractions are in ug/g.

Depth cm	Si %	TC %	Inor. C %	Org. C	Nitr. %	P Tot. µg/g	P fr. I	P fr. II	P fr. III	Al %	Fe %	Mn µg/g	Zn µg/g	Na %	K %
10	45.3	0.63	0.53	0.1	0.58	860	8.2	80.2	133.7	4.98	2.04	260	149	1.33	1.55
20	39.1	0.88	0.76	0.12	0.45	680	6.5	96.8	123.9	5.16	2.8	280	125	1.3	1.9
30	38.5	0.64	0.61	0.03	0.38	630	4.1	93.9	140.8	4.66	2.05	280	164	1.33	1.63
40	34.7	0.82	0.44	0.38	0.33	680	7.3	74.3	51.3	4.31	3.1	770	164	1.73	1.35
50	44.7	0.64	0.63	0.01	0.35	800	7.3	79.2	39.1	4.26	2.93	540	109	1.25	1.55
60	38.1	0.81	0.79	0.02	0.35	750	8.2	95.8	66.8	5.11	3.3	530	156	1.03	1.85
70	30.7	1.16	0.93	0.23	0.4	1010	8.2	70.4	110.8	5.01	3.45	550	94	1.13	1.73
80	35	0.56	0.49	0.07	0.35	830	4.1	75.3	62.8	4.11	2.56	400	133	1.05	1.38
90	30.8	0.56	0.55	0.01	0.2	750	15.5	114.4	60.3	4.06	2.74	470	94	1.03	1.48
100	27.1	0.53	0.52	0.01	0.13	750	9.4	88	63.6	3.81	2.5	570	54	1.1	1.3
110	28.1	0.92	0.82	0.1	0.35	1140	17.9	244.5	125.5	7.27	4.2	790	109	0.95	1.6
120	30.3	0.48	0.46	0.02	0.26	890	8.2	90.2	48.9	4.56	2.74	480	101	1.18	1.4
130	36.3	0.43	0.42	0.01	0.19	1090	4.1	55.7	66.8	4.01	2.19	420	94	1.2	1.35
140	29.5	0.47	0.42	0.05	0.24	980	7.3	80.2	25.5	3.51	2.16	480	133	1.2	1.35
150	25.2	0.51	0.49	0.02	0.29	750	7.3	55.7	60.3	4.11	2.25	360	78	1.15	1.5
160	26	0.51	0.5	0.01	0.29	1060	7.3	96.5	51.3	4.26	2.39	400	94	1.25	1.43
170	32.9	0.48	0.42	0.06	0.3	890	4.1	85.1	57.1	3.96	2.31	470	164	1.23	1.33
180	25	0.54	0.52	0.02	0.28	860	10.6	74.3	68.5	4.31	2.24	440	78	1.18	1.5
190	32.4	0.55	0.54	0.01	0.26	830	7.3	74.3	79.1	4.36	2.17	380	149	1.18	1.55
200	32.8	0.53	0.53	0	0.25	890	8.2	79.2	77.4	4.21	2.04	420	141	1.2	1.48

28.5 and 140.8 $\mu\text{g/g}$. Its contribution to total extracted phosphorus is between 24.4 and 60.2 percent. In vertical profile it gives a negative correlation, indicating its gradual decrease with the depth. Higher values were obtained in the top 40 cm of the sediments, due to the low diagenesis at top of sediment than deeper part of sediments. Positive correlations were observed with the total carbon and inorganic carbon, suggests that fraction III phosphorus is associated with the carbonate, since carbonate contributes major part of the total carbon as well as organic carbon. Good correlation with aluminum and potassium suggests that it is also associated with aluminosilicate minerals.

The iron-bound phosphorus in the Allahabad sediment samples are comparatively very high. It contributes a major chunk of total phosphorus extracted, i.e. between 36.1 and 68.7 percent. The values are ranging between 55.7 and 244.5 $\mu\text{g/g}$. An exceptionally high value (ie. 244.5 $\mu\text{g/g}$) was observed at a depth of 100-110 cm. Fe-bound phosphorus show a relatively constant value with depth. The iron-bound phosphorus was found to be giving good correlation with aluminum (0.81) and iron ($r = 0.67$), showing the association of iron and aluminum with the Fe-bound phosphorus. Similar result were obtained by Yamada and Kyama (1987); Danen-Louwerse *et al.*, (1993) and Stone and English (1993). It shows that in minerals which are responsible for iron-bound phosphorus Fe and Aluminum forms an integral part.

Fraction III (authigenic apatite plus carbonate bound phosphorus plus biogenic apatite) concentration in the core varies between 28.5 and 140.8 $\mu\text{g/g}$. It contributes between 24.4 and 60.2

percent of total phosphorus extracted. It indicate that during digenesis this fraction is released. The fraction III phosphorus shows very good correlation with total carbon and inorganic carbon.

The phosphorus of fraction IV and V contribute together less than three percent.

By using Ruttenberg's SEDEX method for phosphorus extraction, between 11.6 and 37.9 percent of total phosphorus was extracted.

Rate of Elements Deposition

Sedimentation rate is a necessary tool to determine elements deposition rate. Rate of sedimentation was taken from the Subramanian *et al.*, (1985). In the present study, the samples were taken from the flood plain, which have different nature of sedimentation compared to river bed. Since no data is available on the sedimentation rate for flood plain, this data is used to give an over all idea regarding deposition. Average sedimentation rate of Delhi i.e 42 mm Yr⁻¹ (the range was between 5.6 mm Yr⁻¹ and 82.1 mm Yr⁻¹) was used for the calculation.

The sedimentation rate at Wazirabad (Entry point of river Yamuna to Delhi) was used as sedimentation rate for Saharanpur i.e 5.6 mm Yr⁻¹ assuming that there is no major difference in sedimentation rates between the two places. However in several aspects these two places are different (eg topography, urbanization etc.). Since no data is available on sedimentation rate at Saharanpur, this data had to be relied on.

Sedimentation rate at Okhala (exit point of river Yamuna from Delhi) was taken as sedimentation rate for Allahabad. i.e 82.1 mm

Yr^{-1} , assuming that the high sedimentation rate at Okhala is comparable with that of Allahabad. Subramanian *et al.*, (1985), reported that urbanization is a major factor which affect the sedimentation, and the urbanization around Allahabad is much lesser than that of Delhi. However the joining of tributaries downstream to Delhi may cause high sedimentation rate at Allahabad, which may be comparable to that of Okhala. Keeping these limitations in mind deposition rate was calculated to give a picture regarding the deposition of elements.

In situ density of sediments were considered as 0.88 gm cm^{-3} (Joshi and Ku 1979). The deposition rates of the elements are given in table (11, 12 & 13). The rate calculated in the present study assuming a constant supply of material over a period of time. However it is known that sediment supply changes significantly. Therefore, the sedimentation rate which is at to- day may not be same as which was 50 years ago. Hence, element accumulation rate presented here are likely to be altered in the course of time as the sedimentation rate changes.

Deposition rate of the elements are summarised in the table 11, 12 and 13. The result indicates that the deposition rates at Delhi and Allahabad are approximately two order higher than Saharapur. The higher value is due to the high sedimentation rate due to anthropogenic activities. The high sedimentation rate at Delhi could be due to the exessive solid waste load to the river basin where as the high value at Allahabad may be due, the tributaries which join the mainstream of Yamuna, downstream to the Delhi.

Table 17. Correlation matrix for the Saharanpur core

	Depth	Si	TC	Inor. C	Or. C	Nitrogen	Tot. P	P fr. I	P fr. II	P fr. III	Al	Fe	Mn	Zn	Na	K
Depth	1.00															
Si	0.69	1.00														
TC	-0.51	-0.46	1.00													
Inor. C	0.02	-0.07	0.52	1.00												
Or. C	-0.59	-0.49	0.94	0.19	1.00											
Nitrogen	-0.23	0.05	0.37	0.13	0.38	1.00										
Tot. P	-0.31	-0.36	0.67	0.37	0.62	0.35	1.00									
P fr. I	-0.36	-0.26	0.56	0.26	0.53	0.18	0.21	1.00								
P fr. II	-0.10	0.06	-0.14	-0.34	-0.03	-0.20	-0.18	0.06	1.00							
P fr. III	-0.29	-0.33	0.34	-0.01	0.39	-0.18	0.34	0.35	-0.16	1.00						
Al	-0.66	-0.54	0.72	0.27	0.72	0.34	0.60	0.56	-0.28	0.37	1.00					
Fe	-0.26	-0.37	0.61	0.28	0.59	0.45	0.56	0.32	-0.25	0.33	0.63	1.00				
Mn	0.34	0.05	-0.04	0.02	-0.05	0.31	0.12	-0.03	-0.08	0.05	-0.11	0.64	1.00			
Zn	0.22	-0.09	0.43	0.49	0.30	0.26	0.55	0.08	-0.35	0.10	0.36	0.66	0.50	1.00		
Na	-0.66	-0.56	0.34	0.09	0.34	0.01	0.21	0.20	-0.21	0.15	0.63	0.22	-0.38	0.03	1.00	
K	-0.01	-0.04	0.00	0.32	-0.13	0.06	0.50	-0.16	-0.07	-0.01	0.09	0.07	0.05	0.30	0.14	1.00

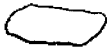


Table 18. Correlation matrix for Delhi core.

	Depth	Si	TC	Inor. C	Or. C	Nitrogen	Tot. P	P fr. I	P fr. II	P fr. III	Al	Fe	Mn	Zn	Na	K
Depth	1.00															
Si	0.34	1.00														
TC	-0.59	-0.55	1.00													
Inor. C	-0.41	-0.50	0.91	1.00												
Or. C	-0.54	-0.28	0.50	0.09	1.00											
Nitrogen	-0.75	-0.47	0.64	0.46	0.57	1.00										
Tot. P	-0.20	-0.45	0.72	0.68	0.29	0.43	1.00									
P fr. I	-0.04	-0.36	0.29	0.36	-0.05	0.19	0.43	1.00								
P fr. II	-0.42	-0.24	0.51	0.39	0.41	0.43	0.42	0.16	1.00							
P fr. III	-0.40	-0.71	0.83	0.80	0.32	0.58	0.59	0.28	0.32	1.00						
Al	-0.63	-0.63	0.69	0.57	0.46	0.82	0.51	0.13	0.44	0.70	1.00					
Fe	-0.56	-0.72	0.65	0.54	0.43	0.77	0.57	0.33	0.41	0.67	0.86	1.00				
Mn	0.38	-0.14	-0.23	-0.16	-0.21	-0.03	0.10	0.23	-0.28	-0.01	0.09	0.31	1.00			
Zn	-0.49	-0.55	0.77	0.73	0.31	0.66	0.56	0.17	0.36	0.71	0.81	0.85	0.06	1.00		
Na	0.32	0.24	-0.40	-0.34	-0.23	-0.60	-0.17	0.04	-0.31	-0.48	-0.59	-0.37	0.19	-0.44	1.00	
K	-0.75	-0.68	0.78	0.62	0.56	0.84	0.58	0.26	0.58	0.68	0.89	0.92	-0.06	0.83	-0.48	1.00

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Table 19. Correlation matrix for the Allahabad core.

	Depth	Si	TC	Inor. C	Or. C	Nitrogen	Tot P	P fr. I	P fr. II	P fr. III	Al	Fe	Mn	Zn	Na	K
Depth	1.00															
Si	-0.68	1.00														
TC	-0.54	0.18	1.00													
Inor. C	-0.41	0.15	0.88	1.00												
Or. C	-0.46	0.12	0.66	0.21	1.00											
Nitrogen	-0.63	0.61	0.54	0.44	0.40	1.00										
Tot P	0.44	-0.32	-0.01	0.05	-0.10	-0.14	1.00									
P fr. I	0.05	-0.36	0.28	0.37	-0.01	-0.12	0.23	1.00								
P fr. II	-0.08	-0.16	0.36	0.45	0.02	0.09	0.33	0.74	1.00							
P fr. III	-0.45	0.32	0.54	0.58	0.18	0.64	-0.07	0.13	0.36	1.00						
Al	-0.30	0.10	0.67	0.72	0.23	0.49	0.26	0.55	0.81	0.66	1.00					
Fe	-0.34	-0.04	0.76	0.71	0.44	0.17	0.21	0.56	0.67	0.16	0.73	1.00				
Mn	0.00	-0.27	0.39	0.20	0.47	-0.26	0.25	0.50	0.50	-0.26	0.34	0.75	1.00			
Zn	-0.24	0.56	0.12	-0.04	0.29	0.46	-0.27	-0.37	-0.02	0.21	0.09	-0.09	-0.10	1.00		
Na	-0.29	0.32	0.04	-0.34	0.61	0.27	-0.36	-0.43	-0.39	-0.02	-0.25	-0.24	0.00	0.43	1.00	
K	-0.44	0.35	0.69	0.84	0.08	0.59	-0.23	0.13	0.21	0.60	0.58	0.39	-0.19	0.18	-0.16	1.00

Table 20. Correlation matrix for the Yamuna basin on the basis of three core samples.

	<i>Depth</i>	<i>Si</i>	<i>TC</i>	<i>Inor. C</i>	<i>Or. C</i>	<i>Nitrogen</i>	<i>Tot. P</i>	<i>P fr. I</i>	<i>P fr. II</i>	<i>P fr. III</i>	<i>Al</i>	<i>Fe</i>	<i>Mn</i>	<i>Zn</i>	<i>Na</i>	<i>K</i>
Depth	1.00															
Si	0.04	1.00														
TC	-0.45	-0.32	1.00													
Inor. C	-0.22	-0.28	0.81	1.00												
Or. C	-0.48	-0.19	0.68	0.12	1.00											
Nitrogen	-0.31	-0.10	0.02	0.07	-0.06	1.00										
Tot. P	-0.05	-0.05	0.33	0.20	0.30	0.05	1.00									
P fr. I	-0.06	-0.28	0.48	0.46	0.23	-0.30	-0.02	1.00								
P fr. II	-0.07	-0.09	-0.26	-0.15	-0.25	0.62	0.14	-0.41	1.00							
P fr. III	-0.28	0.07	0.35	0.24	0.29	-0.15	0.49	0.12	-0.15	1.00						
Al	-0.39	-0.42	0.70	0.57	0.47	0.10	0.00	0.47	-0.23	0.15	1.00					
Fe	-0.30	-0.39	0.71	0.57	0.49	-0.08	0.08	0.57	-0.33	0.18	0.85	1.00				
Mn	0.20	-0.21	0.23	0.19	0.15	-0.23	0.06	0.39	-0.24	0.05	0.38	0.68	1.00			
Zn	-0.17	-0.04	0.26	0.29	0.08	0.61	0.30	-0.18	0.28	0.11	0.19	0.14	0.02	1.00		
Na	-0.15	-0.05	-0.27	-0.26	-0.13	0.56	0.03	-0.39	0.46	-0.24	-0.33	-0.44	-0.32	0.39	1.00	
K	0.12	0.12	-0.02	0.06	-0.11	-0.14	0.42	-0.03	-0.11	0.14	-0.06	0.00	0.06	0.07	-0.07	1.00

An Overall Behaviour of the Nutrients in the Yamuna Basin

A correlation matrix was made on the basis of the samples from three locations representing a wide range of variation in topography, urbanization, temperature etc. to get an idea about the general behaviour of the nutrients in entire basin (table-20). The total carbon was found to be decreasing with the depth. A good correlation was observed for aluminum with total carbon and inorganic carbon, giving an idea that carbonate minerals are closely associated with the alumino-silicate minerals, in the basin. Inorganic carbon was found to be giving good correlation with iron. Iron was also found to be giving good correlation with total carbon and inorganic carbon. Aluminum was observed to be giving good correlation with iron, and manganese was found to be giving correlation with iron showing that they have been originated from the same source i.e. weathering product of silicate minerals.

Comparative distribution of Nutrients in the three core samples

The organic carbon in Saharanpur sediments varies between 0.01 and 0.45 percent (excluding a very high exceptional value i.e. 1.41 percent), whereas in Delhi it varies between 0 and 0.58 percent, and at Allahabad it ranges between 0.43 and 0.93 percent. The low value at Saharanpur is may be due to a slow sedimentation rate, which cause total oxidation of organic matter before its burial along with the sediments. Similarly much higher values at Allahabad could be due to high rate of sedimentation, which protect the decomposition of organic matter.

Nitrogen was also found to be very low may be due to mineralization, before it could bury in the sediments, since the

sedimentation rate is very low. The higher value at Allahabad may be due to the burial of nitrogen before it could be completely mineralized due to a high rate of sedimentation. The high exchangeable phosphorus is may be due to grain size effect.

Distribution of Si, Al, Fe, Mn, Zn, Na and K in the sediments

The element distribution is shown in table (14,15,16). In the major elements the natural input is seems to be higher than anthropogenic, evident by relatively constant value along the depth in the core.

Factor analysis

Factor analysis was done to simplify numerous inter-element correlations among different variables. It is a technique by which a data set is simplified by creating one or more new variables or factors, each representing a cluster of inter related variables within the data set. Twelve factors were obtained but only two factors were considered which have eigen values more than 2.

Saharanpur

In Saharanpur sediment core analysis two factors explain 58.3 percent of variance. The factor 1 alone explains 42.3 percent of variance, having variables such as depth and silicon. This factor is possibly controlling the physico-chemical environment of the sediments. The correlation value also suggests the reason for their inclusion in single factor. The depth is very important parameter which controls the mineralization of nitrogen and phosphorus. It is also possibility affectind chemical potential of the element, since burial and compaction are related phenomenon which leads to anoxic

Table 2) Factor analysis- Saharanpur

Variables	Factors	
	1	2
Depth	0.654	0.528
Si	0.525	0.330
Total carbon	-0.900	-0.020
Organic carbon	-0.908	-0.086
Nitrogen	-0.426	0.486
Total phosphorus	-0.715	0.324
P fr.I	-0.647	-0.177
P fr.II	0.185	-0.357
P fr.III	-0.508	-0.185
Al	-0.878	-0.112
Fe	-0.747	0.514
Mn	-0.042	0.842
Eigen value explained	5.078	1.921
Percent variance	42.3	16.0
Cumulative percent of variance	42.3	58.3

condition affecting the distribution iron-bound phosphorus along with the nitrogen and carbon mineralization. Inclusion of silica with the depth in a same factor indicates that depth also controls the weathering of silicate minerals.

Factor 2 explains 16 percent of the variance. The variables in this factor are depth, aluminum and manganese. This factor is likely to be controlling weathering processes of the elements and their interrelationships. Since aluminum and manganese are very much associated with the phosphorus in their oxide forms, thus this factor is also very important for the phosphorus distribution.

Delhi

In Delhi core analysis, two factors explain 66.3 percent variance, such as depth and silicon, similarly like Saharanpur core. The factor 1 alone explains 50.4 percent of the variance. This factor is likely to be controlling the physico-chemical environment of the sediments. The correlation value also suggests the reason for their inclusion in single factor. The inclusion of silica with the depth in a single factor is explained in the discussion of Saharanpur.

Factor 2 explains 15.9 percent of the variance. The variables in this factor are depth and manganese. This factor is likely to be controlling weathering pattern of the elements and their relationships. Since the depth controls the behaviour of Manganese, at the lower profile manganese exists in reducing stage, which is more labile, and thereby affecting phosphorus distribution behaviour. Depth was found to be very important factor controlling nitrogen and carbon behavior.

Table 22 Factor analysis Delhi

Variables	Factors	
	1	2
Depth	0.691	0.518
Si	0.733	-0.328
Total carbon	-0.875	-0.093
Organic carbon	-0.591	-0.440
Nitrogen	-0.842	-0.185
Total Phosphorus	-0.714	0.397
P fr.I	-0.345	0.555
P fr.II	-0.565	-0.325
P fr.III	-0.816	0.154
Al	-0.891	0.004
Fe	-0.891	0.240
Mn	0.022	0.801
Eigen value explained	6.049	1.91
Percent variance	50.4	15.9
Cumulative percent Variance	50.4	66.3

Table 23 Factor analysis - Allahabad

Variables	Factors	
	1	2
Depth	0.546	0.667
Si	-0.188	-0.782
Total carbon	-0.867	-0.165
Organic carbon	-0.548	-0.213
Nitrogen	-0.542	-0.690
Total phosphorus	-0.115	0.567
P fr.I	-0.534	0.604
P fr.II	-0.713	0.471
P fr.III	-0.590	-0.429
Al	-0.895	0.109
Fe	-0.856	0.323
Mn	-0.505	0.597
Eigen value explained	4.540	2.97
Percent variance	44.3	29.0
Cumulative percent variance	44.3	73.4

Allahabad

In Allahabad core analysis two factors explain 73.4 percent of variance. The factor 1 alone explains 44.3 percent of the variance. The only variable in this factor which is having considerable effect is the depth. This factor is likely to be affecting oxidation-reduction environment. The control of depth over other parameters are explained in the section of Delhi and Saharanpur.

Factor 2 explains 29.0 percent of variance. The variables in this factor are depth, total phosphorus, exchangeable phosphorus and manganese. This factor seems to be controlling weathering pattern of elements and their relationships. It is further proved by correlation values. The total phosphorus and exchangeable phosphorus are very much related to the manganese. The manganese in higher oxidation state cause uptake of phosphorus, and in reduced stage dissolution of manganese bound phosphorus occur.

On the basis of factor analysis of the three core samples it was observed that depth and silica are two important variables which affect the system considerably and are put together in one factor.

The factor 2, in comparison to factor 1 represents quite smaller variance. In most of the case the variables are depth, aluminum and manganese.

CONCLUSION

Sediment core samples from three locations of Yamuna flood plain (viz. upstream at Saharanpur, midstream at Delhi and downstream at Allahabad), representing the entire Yamuna river basin were analysed, for the distribution and fractionation of phosphorus, nitrogen and carbon. The salient features which were observed are given below.

Phosphorus concentrations were found to be comparable at all three core samples. In Saharanpur and Allahabad core phosphorus concentrations were found to be not much varying depth. In Delhi core samples phosphorus was found to be highly fluctuating with the depth. Fluctuation behaviour of other elements, besides phosphorus suggest that the sediment core at Delhi, is disturbed by anthropogenic activities.

Nitrogen and organic carbon were found to be very small at Saharanpur core samples, due to their low deposition rates. The nitrogen and organic carbon concentrations at Delhi and Allahabad were fairly high, due to high deposition rate of these elements, their rate of mineralization. Nitrogen concentrations at Allahabad were high due to agriculture run off, since in lower sediment samples concentrations were comparatively low. Nitrogen and organic carbon were found to be giving good negative correlation with depth, suggest its decrease in depth due to the mineralization process.

Authigenic apatite plus calcium-carbonate-bound phosphorus plus biogenic apatite (fraction III), was the only phosphorus

fraction, found to be dominant in total phosphorus pool. However in Allahabad core sediment samples iron-bound phosphorus was also found to be considerably higher. In most of the cases iron, aluminum and manganese were found to be giving good correlation with the total phosphorus, indicating the association of these elements with the total phosphorus.

The element deposition rates at Delhi and Allahabad were found to be approximately two order higher than that at Saharanpur. The sedimentation rate of Saharanpur was also assumed to be very low on the basis of speculation made from data of Subramanian et al., (1985).

The aluminum, iron and manganese were found to be nearly constant in the vertical profile, except samples from Delhi core. The value suggests that there is no much anthropogenic input for these elements, except at the upper sediments. Its relatively constant value in the lower profile suggests that very recently anthropogenic contribution of these elements, intensified.

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