SHORT COMMUNICATION

Magnetic Susceptibility Studies of Soils in Delhi

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Abstract : An atlas of magnetic anomalies in soils has been prepared for the first time for the city of Delhi, capital of India and one of the most populous and urbanized city in the world The study reveals that magnetic susceptibility for Delhi top soils (0-15cm) coincide with either industrial sources of pollutants or natural anomalies The result shows low field mass-specific susceptibility value ranging for different observed classes as industrial (3 02 531 $\times 10^{5}$ m^3/kg), traffic areas (0 48 100 67 $\times 10^{5}$ m^3/kg) and natural sections (0 02-6 8 x$\times 10^{5}$ m^3/kg) Frequency dependent susceptibility shows quite high median value of 8 67% for older pit samples (depth samples), followed by 5 88% in present (top soils) and lowest for industrial samples (1 67%) The present study is a preliminary investigation on the environmental magnetic studies of soils in Delhi More detailed rock magnetic studies and assessment of associated contaminations of soils are in progress

Keywords: Magnetic susceptibility, Spatial analysis, Top soil, Delhi

Magnetic susceptibility measures the 'magnetizability' of a material These measurements can be carried out for a whole range of samples and also are economic, quick and non-destructive (Dearing et al 1996, Hay et al 1997, Petrovsky et al 1998, Schloger,1998, Bityukova,1999, Lecoanet et al 1999, Strzyszcz,1999) Magnetic susceptibility in environmental samples is the sum total of magnetic susceptibilities of the ferromagnetic, ferrimagnetic, antiferromagnetic, paramagnetic and diamagnetic susceptibilities Normally, ferromagnetic being absent in natural form and for relatively weak diamagnetic component, the sum of the other three controls magnetic susceptibility (Versob and Roberts,1995, Walden et al 1999) Using low external magnetic field (<1 0 mT), the influence of ferrimagnetic alone can be ascertained, by blocking effect of others

Frequency dependent susceptibility measurement involves, detecting ultrafine viscous ferrimagnetic minerals known as super paramagnetic (SP) by using two or more AC frequencies (0 47 and 4 7 k Hz) at constant low reversible magnetic field The change in frequency of measurement means the change in measurement time for grains to react with applied field Higher frequency (4 7 k Hz) measurement does not allow SP grains to react with applied external field, as it changes more quickly than required relaxation time of SP grains As a result in high frequency susceptibility, lower value of susceptibility is measured Its difference with low frequency measurement represents an estimation of SP amount Mathematically, it can be expressed as (Walden et al 1999), χ fd%= {χ lf $-\chi$ hf) × 100}/ χ lf, where χ lf = low frequency (0 47 kHz) susceptibility, χ hf = high frequency (4 7 kHz) susceptibility at constant low magnetic field (0 1 mT) and χ fd% = frequency dependent susceptibility

The study area, Delhi lies in North India between Latitudes of 28°24'17" and 28°53'00" North and Longitudes of 76°50'24" and 77°20'37" East, with an area of 1,483 km^2 Different land uses include agricultural field, grazing land, rocky areas and city area with green ridge forest and six larger industrial areas namely Anand Parbat Industrial Estate (17 23%), Mayapuri Industrial Area (15 10%), Okhla Industrial Area (11 34%), Narela Industrial Area (9 59%), Wazirpur Industrial Area (7 70%) and Kirti Nagar Industrial Estate (6 82%) (Joshi, 2003, Gupta 2003)

In total, 100 samples were collected with a 2 km grid interval from city area of Delhi (Fig 1) Top soil samples (0-15 cm) were collected, as they are indicative of the most recent deposition site of particulate matters, generated by gaseous emissions from industries and vehicles or domestic sludge through sewages or by dumping Without exception, magnetic susceptibility measurement samples were collected taking full care to avoid any sort of iron contamination Samples were collected by stainless steel

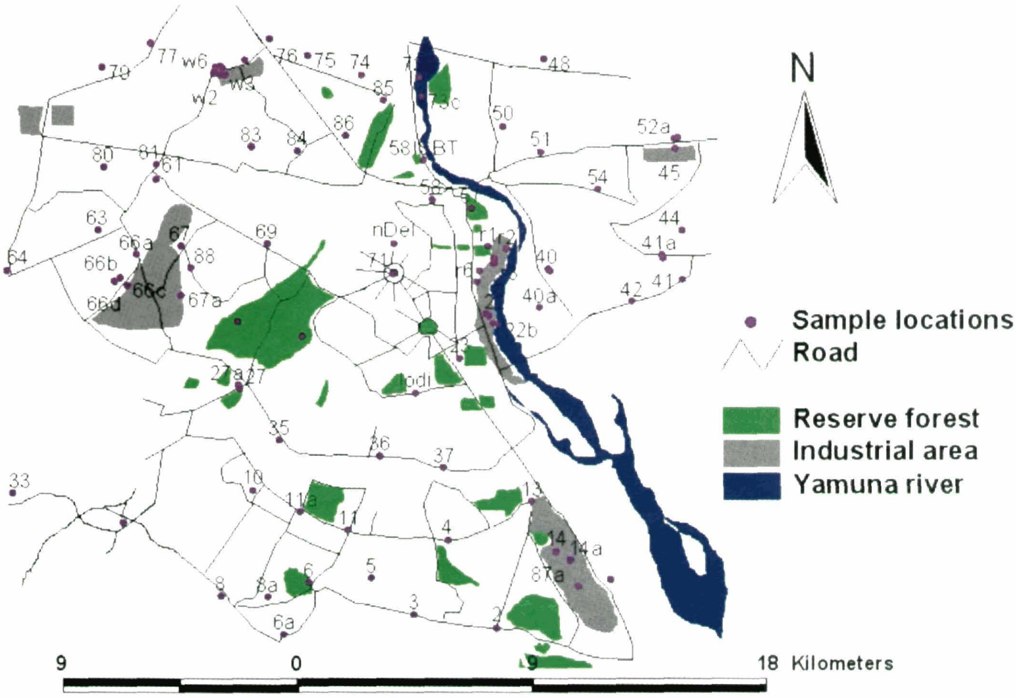

Fig.1. Sample collection sites in Delhi.

spoon and were packed in polythene bags. To avoid area specific influences, from one single location, several samples were gathered, by covering an area of $5m^2$ around that particular location. By coning and quartering method, ten gram samples were taken in box for measurement in Bartington instrument, where magnetic susceptibility was measured for two different frequencies (4.7 kHz and 0.47 kHz) of the applied field. To assess this natural input, depth wise variation of magnetic susceptibility has been studied for a flood bank section (~ 3 m sedimentation by lithogenic processes) and a pit (~5 m soil formation by pedo-genesis), near a metro railway construction site (Fig.2).

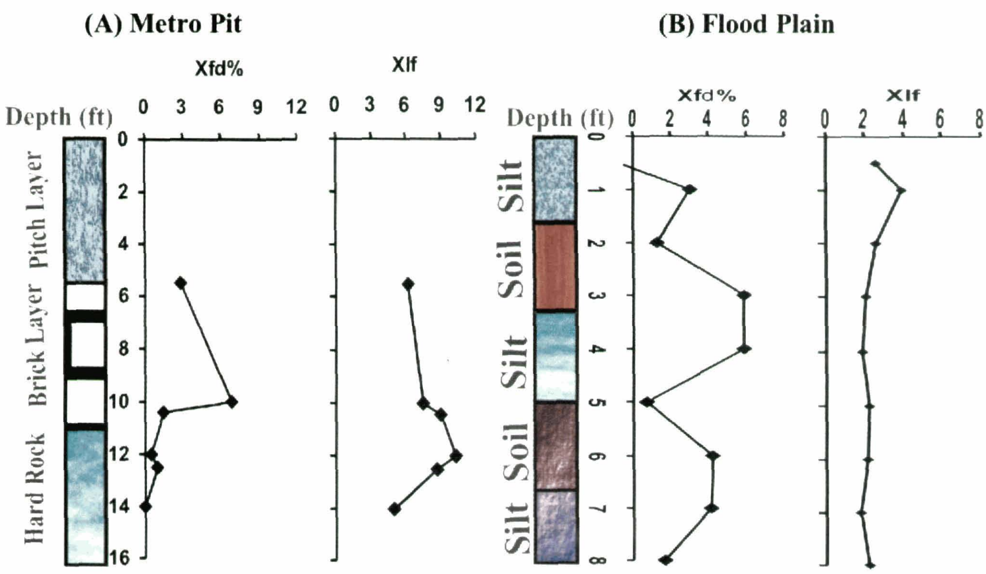

Fig.2. Magnetic susceptibility of (A) metro pit- pedogenic layer χlf is more (χfd% less) due to anthropogenic input. (B) Flood plain- χlf is more in sandy layer (χfd% less) due to natural pedogenesis.

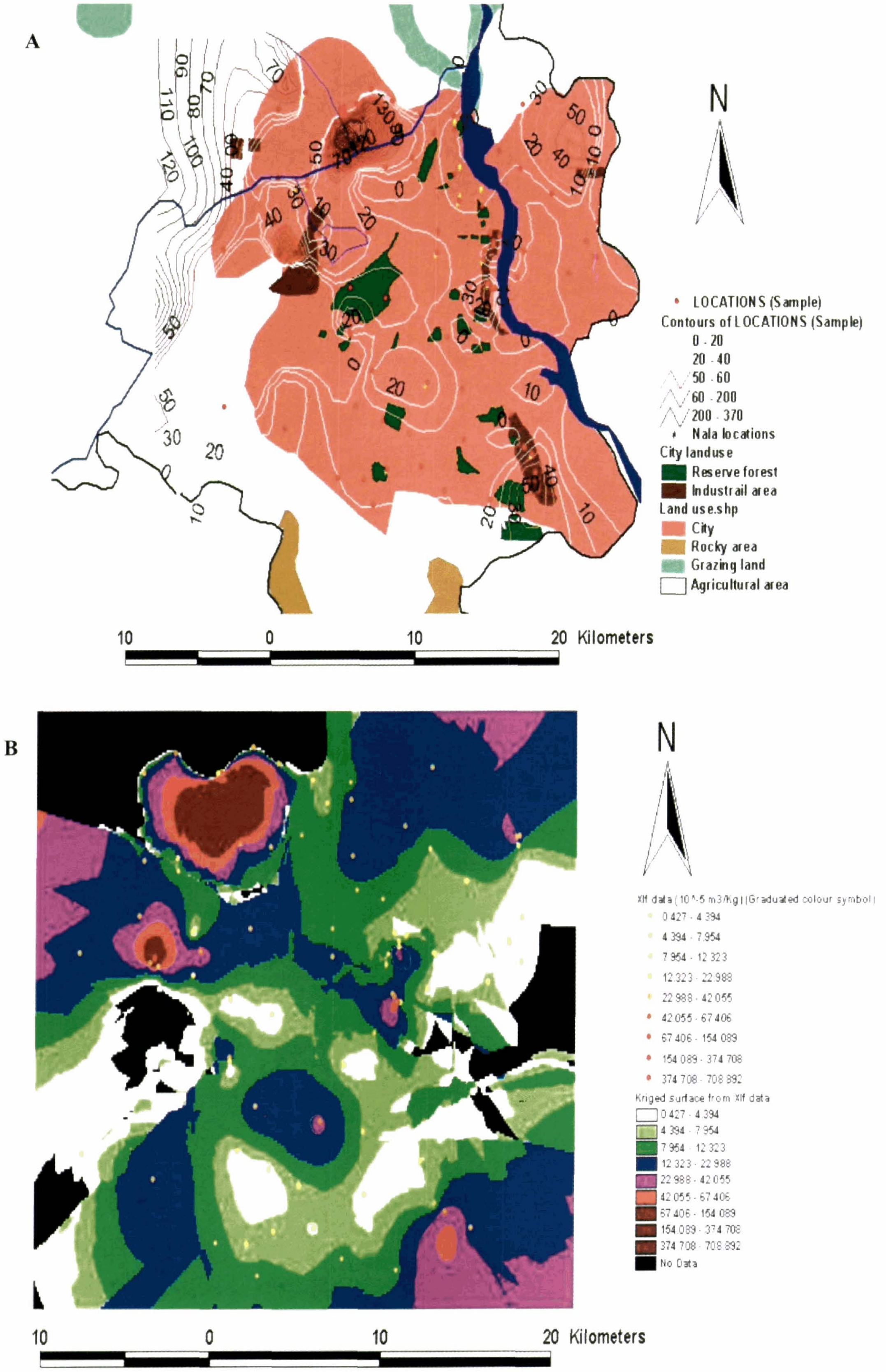

Fig.3. Distribution of low field susceptibility in Delhi soils using GIS, **(A)** χ lf contours and **(B)** kriging surface creation for low field magnetic susceptibility.

A

B

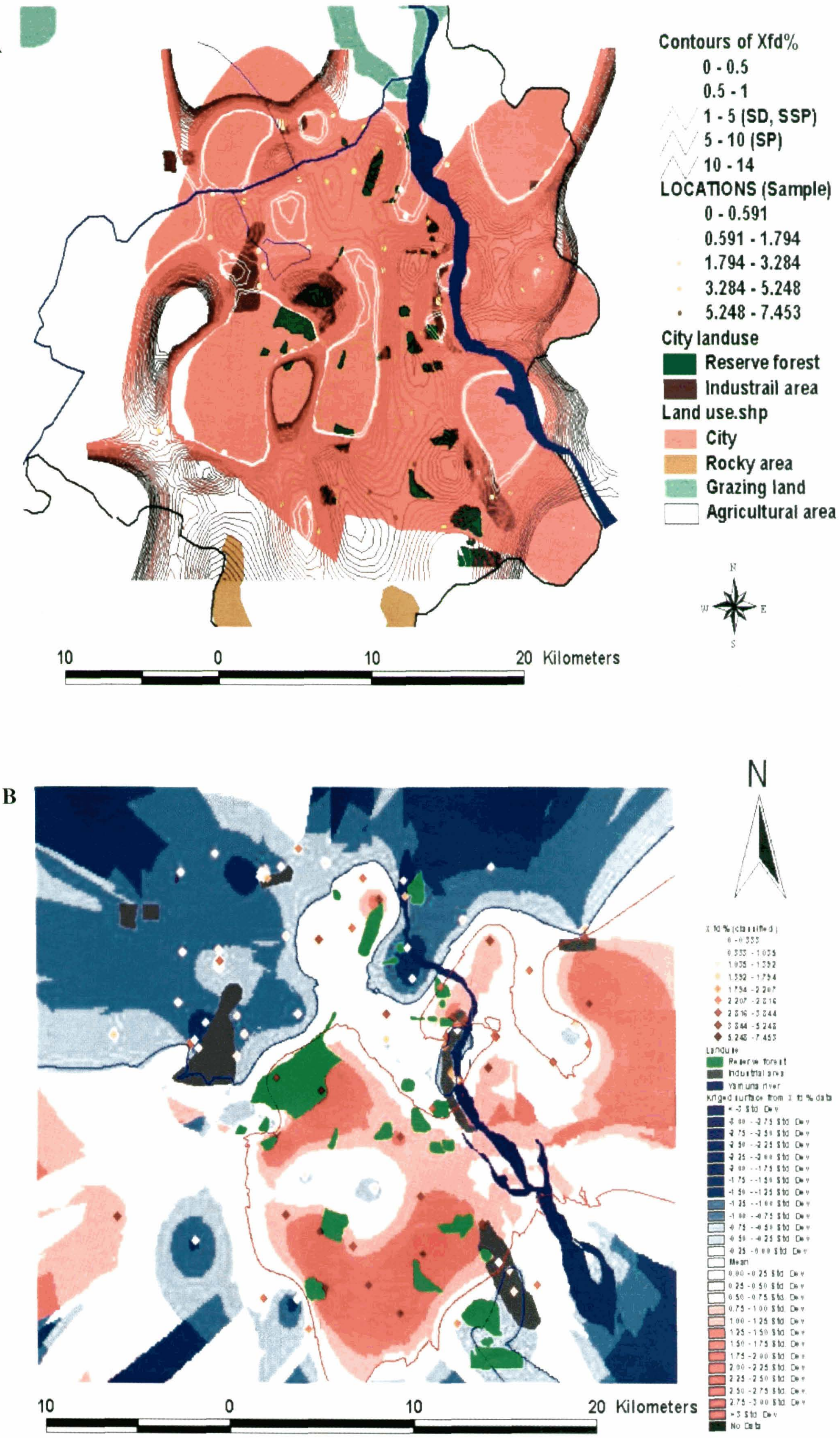

Fig.4. Distribution χ lf percentage in Delhi soils using GIS, **(A)** χ lf% contours and **(B)** kriging surface creation for χ fd% in Delhi soils.

Depth wise, the maximum χlf is seen below the topmost layer for the flood bank section (Fig 2) In the flood plain section the sandy layers show lower χfd% and higher χlf, except for the topmost layer In the absence of significant detrital or anthropogenic input, the χ lf% in the soils increase due to pedogenesis (Maher 1986, Henesh and Scholger, 2003, Flander, 1994, Hoffmann et al 1999), wherein the susceptibility in the topsoils may have been resulted due to authigenic magnetite produced under ponding (reduced) conditions (Maher, 1986, Xie et al 2001) Ponding is a very common feature on the banks of Yamuna river The χlf% values below 5% in the top layer of the flood plain section are suggestive of such contributions although more detailed analysis are required to confirm this On the country, in the metro pit section, the weakly pedogenic layer below the bricklayer shows high χlf but reduced χlf% reflecting anthropogenic input This is evident from the χfd% curve which indicates increasing trend due to weathering of the top most layer of the hard rock, which continues till the initial soil layer, then decreasing further as the anthropogenic loading is increased Overall the anthropogenic sediments show higher susceptibilities and lower χfd% as against the natural/ pedogenic layers

Spatial analysis is a strong technique to distribute source specific observational facts by methods of contouring or by creation of kriging surfaces (Jones et al 1986) This facility is available in Arcview 3 1 software package Measured data of different susceptibility parameters (χ lf and χ fd %) are classed initially in three major divisions, based on kind of sources of heavy metal loading expected, during field survey These classes are point industrial sources, mobile line sources of traffic areas and unpolluted natural source To know the dispersion within low field magnetic susceptibility measurement (χ lf) of different set of classes, quartile analysis has been performed Industrial class ranges between minimum 3 01×10 ^{5}m^{3}/kg to maximum 531×10 ^{5} m^{3}/kg with standard deviation of 126 04 and median value 9 65×10 ^{5} m^{3}/ Kg and average 24 58×10 ^{5} m^{3}/kg In the case of traffic and natural classes, median value 9 9×10 ^{5} m^{3}/ Kg for traffic and 2 09×10 ^{5} m^{3}/kg for natural sources are observed Such high dispersion in industrial class indicates abrupt change in susceptibility value near industrial area It is also evidenced in spatial analysis by contouring and kriging surface creation (Fig 3) The spatial distribution of χ lf shows closed narrow contours with very high value near

Table 1. *Statistical value of different magnetic parameters from total areas and individual source specific areas*

Low Field Magnetic Susceptibility (χ lf) (in unit of 10 ^{5} m^{3}/kg)	Anthropogenic		Natural		
	Industrial	Vehicular	Natural	Pit	Flood bank
No of samples	24	70	14	6	9
Minimum	3 01	0 42	0 02	0 02	1 79
1st quartile	10 01	5 60	1 60	0 56	2 05
Median	25 74	9 90	2 09	1 16	2 21
2nd quartile	66 69	16 62	2 61	2 45	2 60
Maximum	531	100 67	6 85	6 85	3 92
Mean	73 53	12 74	2 25	2 07	2 37
Standard deviation	126 04	13 33	1 59	2 53	0 64
Kurtosis	8 26	26 78	4 59	3 01	4 56
Skewness	2 85	4 34	1 66	1 63	1 98

Frequency Dependent Magnetic Susceptibility (χ fd%)	Anthropogenic		Natural		
	Industrial	Vehicular	Natural	Pit	Flood bank
No of samples	24	70	14	6	9
Minimum	0 33	0 29	0 72	6 18	0 72
1st quartile	0 86	1 28	1 48	6 48	1 30
Median	1 67	2 08	5 88	8 67	3 57
2nd quartile	2 02	4 10	6 79	8 92	4 16
Maximum	5 03	7 72	10 33	10 3	5 88
Standard deviation	0 24	0 22	0 85	0 7	0 70
Kurtosis	2 2	1 08	1 07	-0 43	1 57
Skewness	1 34	1 16	0 05	-0 23	0 05
Mean	1 81	2 57	5 25	8 31	3 34

industrial areas Kriging surface of maximum magnetic susceptibility is found near Wazirpur industrial areas Other industrial areas like Mayapuri, Jhimli, Okhla are also characterized in same way with higher contour value

χ fd% data show standard deviation of 0 245, 0 224, 0 85 and 0 70 respectively for industrial, vehicular, natural and pit samples However, median values are high for natural sources (8 67) and low for industrial (1 67) and traffic sources (2 08) (Fig 4) This implies that the natural samples are with higher amount of ultrafine super para-magnetic particles (SP)

Kriged surface of χ fd% data are classified in standard deviation with break classes of ¼ standard deviation The spatial pattern shows break classes, higher than mean value are concentrated near ridge areas, whereas lower classes are near industrial areas In comparison to South Delhi, North Delhi shows with distinct separation of classes Two possible explanations can be drawn about this observation The first can be attributed to more anthropogenic pollution for North Delhi The second reason could be because of pedogenic contribution in soil formation for South Delhi and more lithogenic in the case of North Delhi This variation of χ fd% is evidenced from the studies of flood bank and pit sections, where median values are 3 03% for lithogenic and 8 03% for pedogenesis

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