STUDY OF RAINWATER CHEMISTRY IN DELHI

Dissertation submitted to the Jawaharlal Nehru University in partial fulfillment of the requirement for the award of the degree of

MASTER OF PHILOSOPHY

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CERTIFICATE

This is to certify that the research work embodied in this dissertation entitled **"STUDY OF RAINWATER CHEMISTRY IN DELHI"**, has been carried out in this school for the partial fulfillment for the award of the degree of master of philosophy. This work is original and has not been submitted in part or full for any other degree or diploma in any other University.

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Dedicated to……………………

My Late Mother,

whose love and care I will
always miss ……………

CHAPTER – I

INTRODUCTION

INTRODUCTION

1.1 Introduction:

Rainfall provides a major input of several elements to the earth's surface and the importance of the rain input can be determined only if its composition is well known, likewise in attempting to determine the effects of rock weathering or biological processes on the concentration of a given element in a lake, river, or ground water, one must first correct for the concentration of this element in rain water arriving at the ground.

From a practical view point, rainwater composition is of interest to those concerned with air pollution and the role of humans in altering the chemistry of the atmosphere. An outstanding example of this is the formation in recent years, of acid rain downwind from industrial areas.

The water depletes in most clouds average about 5 to 10 µm in diameter with the largest being about 20 µm. because of constant updraft, these sizes are too small for the droplets to fall to the ground. In order to have rain, there must be a process whereby the droplet can become big enough, on the average about 1000 km in diameter to fall as rain drops (Neiburger, Edinger, and Bonner;1973). Further condensation on existing droplets in clouds is not an efficient mechanism. Instead the most commonly collision –coalescence and ice crystal growth followed by melting. For snow formation the major process is ice crystal growth.

The total amount of water vapour in the atmosphere over the globe is $13x10^{15}$ kg (which represents only 0.001% of the total water on the earth). The average residence time of water vapour in the atmosphere is only the length of time the average water vapour molecule spends in the atmosphere between its evaporation and its precipitation as rain or snow. Such rapid turnover is important for the removal of atmospheric pollutants that can be washed out by rain. Because of rapid transport, the amount of water vapour passing over a given landmass can be very large. Because of large–scale transport of water vapour, most continental precipitation does not come from locally evaporated water.

1.2 Rain Formation:

The transformation of water vapour in the atmosphere into rain involves two processes. First, the water vapour gas must condense to form water droplets (or sublimate to form ice crystals).

This is cloud or fog formation. However, condensation does not necessarily lead to precipitation or the fall of water droplets or show flakes. In order for cloud droplets to fall to the ground as rain, they must become large and heavy enough to reach the ground without evaporation. The average lifetime of a cloud is around 1 hour; while on the average water spends 11 hours in the atmosphere in the form of droplets before being removed as rain. Thus, cloud water evaporates and condenses several times before actually forming rain (Pruppacher –1973).

In order for condensation to occur, air, must become supersaturated with water vapour, but this is not enough Nuclei are needed to begin the condensation process. The nuclei can be any one of a member of small bodies suspended in air, chief of which are soil dust particles, combustion products, and saw salt. In air completely free of condensation nuclei, it would be possible to have relative humidities of as high as 800% without condensation taking place, whereas in actuality relative humidities (for condensation never exceed 102% Miller et al. 1983. This is because condensation nuclei promote the formation of water droplets and such nuclear always present.

1.3 Aerosols:

In the atmosphere, water always condenses on a particle or nucleus because the nucleus promotes condensation at a reasonably low relative humidity (a maximum of 102%). Therefore, the rain that forms from these cloud droplets of condensed water will have a chemical composition that reflects the composition of the particles on which it condenses and also the composition of other atmospheric particles that it contacts on the way down.

1.4 Types of Aerosols:

In addition to major and trace gases, the atmosphere contains aerosols, small particles of solid or liquid ranging in size from clusters of a few molecules to about 20 km in radius. Particles larger then 20μm do not remain in the atmosphere very long because they are heavy enough to settle out rapidly. There are two main types of aerosols or particles in the atmosphere.

a) Primary particles emitted directly into the atmosphere (such as dust or sea salt) and

b) Secondary particles formed from gaseous emissions that subsequently condense in the atmosphere. Gas to particle conversion results on the formation of fine particles (< 0.5μ m), whereas directly emitted particles are dominantly coarse (> 0.5 μm)

In chemical composition, aerosols may consist of one or more fractions (Rahn 1976).

i) water soluble ions (such as sulphate, nitrate, ammonium, and several sea-salt-derived ions)

ii) a mostly insoluble inorganic part (silicates, oxides, etc.); and

iii) a carbonaceous part (soluble and insoluble organic matter).

In form, aerosols range form dry dust particles to sea-salt particles which are sometimes drops of salty water (at a high relative humidity). Most continental aerosols are a mixture of soluble an insoluble components (mixed particles) whereas most marine aerosols are soluble sea salt (Junge 1963).

Condensation occurs preferentially on the lager particles (radius 0.1 to 20 μm) and most of the smaller particles are never used in condensation. The type of particle used for condensation is apparently controlled not only by the sizes available, but also by preferential use of certain chemical compositions, such as hygroscopic or soluble particles.

Hygroscopic particles, which are substances that readily absorbs water and are very soluble in it, serve as the best nuclei. They are so efficient that they can initiate condensation at less then 100% relative humidity (Neiburger, Edinger, and Bonner 1973, Pruppacher 1973). Examples are NaCl from sea spray, and H_2SO_4 and HNO_3 from the burning of fossil fuels. Condensation may start at less then 100% because the hygroscopic particles are highly soluble in water and at high concentration they lower the saturation vapour pressure of water (but because of dilution of the salts, continued condensation still requires relative humidities of more than 100%). Thus, hygroscopic nuclei require much lower degrees of super saturation than their non hygroscopic equivalents and it is for this reason that they are more efficient in forming water droplets.

Over the oceans, condensation nuclei are dominated by hygroscopic salt particles derived from land, the nuclei are both hygroscopic and non hygroscopic with the latter being derived from soils and combustion products.The greater concern over land, especially larger particles, results in competition for water and the formation of more but smaller water droplets in clouds. Over the oceans, the few but highly efficient hygroscopic particles produce relatively large droplets. Since larger cloud droplets favour rain formation, rainout over the oceans (and coastal regions) is relatively easier than over land .This aids in the efficient removal of marine aerosols and help explain the high sea-salt content of marine and coastal rain (Junge 1963).

The main sources of particles or aerosols in the atmosphere are as follows (SMIC (1970):

1. Sea salts form the ocean surface (dominantly coarse)
2. Soil and mineral dust from the continents (coarse)
3. Volcanic ask
4. Forest fire and slash burning products, dominantly anthropogenic: both ask and goes converted to particles .
5. Biogenic aerosols (plant exudates) including volatile hydrocarbons. Which are converted to particles as well as direct particle emissions.
6. Gaseous emissions, both natural and anthropogenic, which react in the atmosphere to form fine particles (excluding forest fires)
7. Solid particles from other, anthropogenic activities, e.g. combustion and industry.

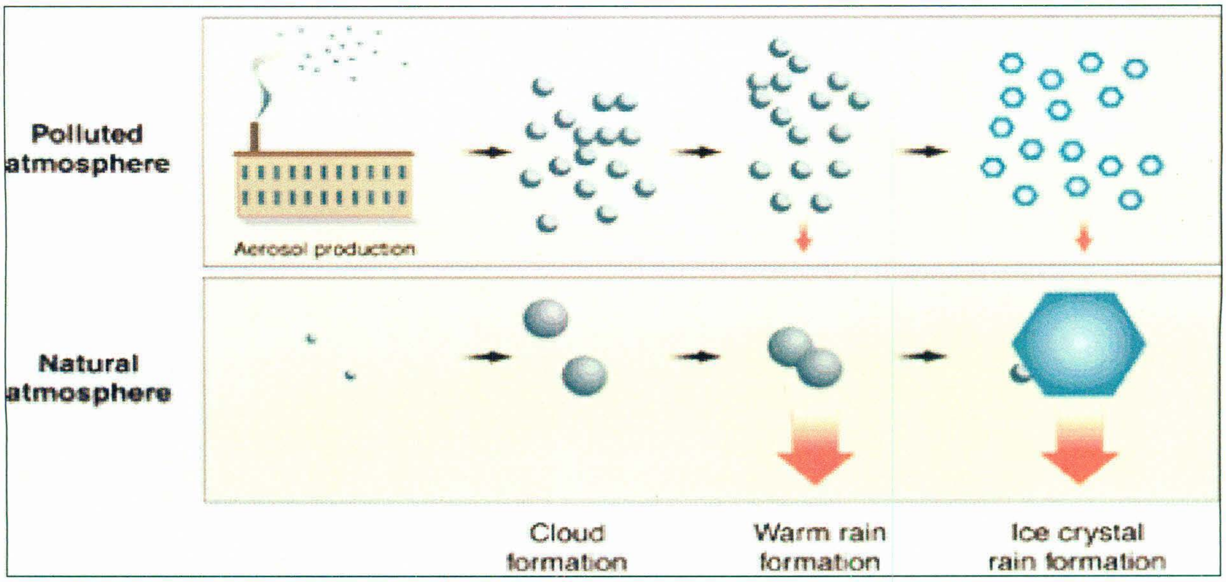

Fig.1.1:**Processes by which aerosols affect clouds**. The polluted cloud contains eight times as many droplets of half the size, twice the surface area, twice the optical depth, and higher reflectivity than the natural cloud.

Table 1.1 Estimates of particles smaller than 20 μ m Radius Emitted into or formed in the Atmosphere (in Tg/yr; Tg=10^{12} g).

	Natural	Anthropogenic	Percent of Total
Soil and rock dust:			
Long transport	500-900	-	35
(Total Production)	(3000-4000)		
Sea Salt:			
Long transport	540	-	27
(Land deposition)	(180)		
(Total production)	(1800)		
Forest fires and slash burning			
Debris	6-11	72-139	6
Volcanic debris	25-150	-	3
Particles form anthropogenic direct emissions: fuel, incinerators, and industry	-	10-90	2
Particles formed from gaseous emissions:			
Sulphate from H_2S	115	-	6
Sulphate from SO_2	-	100	5
Nitrate from NO_x	30	75	5
Ammonium from NH_3	2	26	1
Hydrocarbons: Biogenic aerosols	75-200	-	7
Fossil fuels	-	15-90	3
Approximate total	1293-1948	298-520	-
	80%	20%	100

Although the particle fluxes give in table 1.1 are not well known and represent approximate estimates based in the case of gases it is still apparent that the main particle sources are natural soil dust, which contributes about one-third of the particles and sea salt, which contributes about one quarter. Anthropogenic particles formed in the atmosphere from gaseous emissions (sulphate, nitrate and hydrocarbons) amount to anther 13%. Overall, roughly, about 80% of the particles are natural and 20% are anthropogenic.

The dissolved ions Na^+, K^+, Ca^{2+} and Cl^- in rain come mainly from sea salt and soil dust whereas gaseous emissions (which form secondary particles) give rise to such ions as SO_4^{2-}, NO_3^-, and NH_4^+.

1.5 Chemical Composition of Rainwater:

General Characteristics:

Rainwater can be characterized as being dilute (with average total dissolved salt contents of a few milligrams per litre) and weakly acidic (pH 4-6). Dilution is brought about by the way rain forms. Evaporation into the atmosphere involves extensive separation of water molecules from dissolved salts in surface water the resulting water vapour ultimately condeses to form rain, and the overall process can be viewed as purification by natural distillation. However, rainwater is not totally pure. Solid particles are dissolved by rainwater, which results in a wise range in chemical composition, as well as in variation of PH.

The dissolved chemical components of rainwater can be divided into two groups:

1. those derived primarily from particles in the air (Na^+, K^+, Ca^{2+}, Mg^{2+} and Cl^-, and
2. those derived mainly from atmospheric gases (SO_4^{2-}, NH_4^+ and NO_3^-).

The particles and gases, in turn, have a variety of sources, and the element associations in rain which result from these sources are given in table 1.2.

Table 1.2 Primary Associations in Rain

Origin	Associations
Marine inputs	Cl-Na-Mg-SO_4
Soil inputs	AL-Fe-Si-Ca-(K, Mg, Na)
Biological	NO_3-NH_4-SO_4-K
Burning of vegetation	NO_3-NH_4-P-K-Ca-Na-Mg-SO4
Industrial Pollution	SO_4-NO_3-Cl
Fertilizers	K-PO_4-NH_4-NO_3

Sources: Modified after Stallard 1980; and Lewis 1981.

Table 1.3 Sources of Individual Ions in Rainwater :

Ion	Marine Inputs	Terrestrial Inputs	Pollution Inputs
Na^+	Sea salt	Soil dust	Burning Vegetation
Mg^{2+}	Sea salt	Soil dust	Burning Vegetation
K^+	Sea salt	Biogenic aerosols Soil dust	Burning Vegetation
Ca^{2+}	Sea salt	Soil dust	Fertilizer Burning vegetation
H^+	Gas reaction	Gas reaction	Fuel burning to form gases
Cl^-	Sea salt Gas release from sea salt	-	Industrial HCl
SO_4^{2-}	Sea salt Marine gases (DMS)	H_2S from biological decay Volcanoes Soil dust (Biogenic areas sols)	Burning of fossil fuels to SO_2 lowest burning
NO_3^-	N_2 plus lightning	NO_2 form biological decay N_2 plus lightning	Gaseous auto emissions,combustion of fossil fuels, forest burning,Nitrogen fertilizers
NH_4^+	-	NH_3 from bacterial decay	Ammonia fertilizers and animal wastes combustion
PO_4^{3-}	-	Soil dust Biogenic aerosols Absorbed on sea salt	Burning vegetation, fertilizer
HCO_3^-	-	CO_2 in air soil dust soil dust	Land clearing

Source: Junge 1963; Mason 1971; Miller 1974 Granat, Rodhe, and Hall berg 1973; and Stallard and Edmond 1981.

1.6 Na^+, Mg^{2+}, K^+, Ca^{2+} and Cl^- in Rain :

The primary sources of dissolved Na^+, Mg^{2+}, K^+, Ca^{2+} and Cl^- in rain are marine (sea-salt aerosols, terrestrial (soil dust, biological emissions), and anthropogenic industrial, burning of vegetation, marine sources varies with distance from the coast and levels of at fairly constant low level inland. A "hierarchy of ions" can be established (after Means et al. 1981 and Stallard and Edmond 1981) based on the relative importance of marine sea-salt sources and continental terrestrial of palletized sources:

$$Cl^- = Na^+ > Mg^{2+} > Ca^{2+} > SO_4^{2-} > NO_3^- = NH_4^+$$

Mostly **marine** Mostly **continental**

The contribution of sea salt to Ca^{2+} in continental rain is very small since the Ca/Cl ration in sea salt + only 4% if the Na/Cl ratio. Instead Ca^{2+} comes primarily from the dissolution of $CaCO_3$ in soil dust. Calcium carbonate dissolves in rain to form HCO_3^- and Ca^{2+} by the reaction

$$H^+ + CaCO_3 \leftrightarrows Ca^{2+} + HCO_3^-$$

In this was way neutralization of rain acidity comes about. In the case of strong acids like H_2SO_4 (when SO_2 is present in the air), thus naturalization results in the production of CO_2 and acid anions such and acid anions such as SO_4^{2-}

$$H_2SO_4 + CaCO_3 \rightarrow CO_2\uparrow + H_2O + SO_4^{2-} + Ca^{2+}$$

1.7 Gases and Rain:

a.Gas –Rain water Reactions:

Because atmospheric water droplets and raindrops are small they have large specific surface areas available for the exchange of gases between the droplets and atmosphere. As a result, atmospheric gases become dissolved in rainwater both during the condensation process (rainout) and while the rain is on its way to the ground (washout) washout concurs if the concentration of the gas below a cloud is greater than it is within the could or if the earlier reaction within the cloud is not complete.

The amount which a gas dissolves in rainwater depends upon.

1. its partial pressure or concentration in the atmosphere, and
2. its solubility in water (solubility in turn, is a function of temperature).

The ratio of partial pressure to total pressure is a measure of concentration and is equivalent to the volume fraction of a given gas in air.

Volume fractions (expressed as a percent) for a number of atmospheric gases are listed in table 1.4. The table also shows the concentrations in aqueous solution of some major gases for equilibrium with air at a total pressure of 1 atmosphere (and T=25°C). The dissolved concentration divided by the volume fraction in air a measure of the relative solubility for each gas.

Table 1.4 Concentration of Gases in Air and in Solution

Gas	Volume Percent in Air	Equilibrium Concentration in Solution (Mg/l)
Nitrogen (N_2)	78.084	13.5
Oxygen (O_2)	20.948	6.7
Argon (Ar)	0.934	-
Carbon dioxide (Co_2)	0.035	0.5
Neon (Ne)	0.0018	-
Helium (He)	0.0005	-
Methane (CH_4)	0.0002	0.05
Sulpur dioxide (SO_2)	0-0.0001	-
Nitrogen dioxide (WO_2)	0-0.000002	-
Ammonia (NH_3)	O to trace[b]	-
Krypton (Kr)	0.0001	-
Hydrogen (H_2)	0.00005	-
Ozone (O_3)	0-0.000001	-

Source: Air composition from Turekian 1972

[a] for equilibrium which air at T=25° C and a total pressure of 1 atmosphere

[b] $2x10^{-7}$ (Soderlund and Svensson 1976).

Some gases not only dissolve in water, but also react with H_2O and with other gases, before and after dissolving to form new species. This includes carbon dioxide (CO_2). Ammonia

(NH_3), sulphur dioxide (SO_2) and nitrogen dioxide (NO_2). In the case of CO_2, SO_2 and NO_2 , acids are H_2SO_4 (sulphuric acid) and HNO_3 (nitric acid); whereas for NH_3, a is formed: NH_4OH (ammonium hydroxide). Sulphuruic acid and nitric acids are strong acids that completely dissociate.

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$$

$$HNO_3 \rightarrow H^+ + NO_3^-$$

Whereas carbonic aid and ammonium hydroxide are weak and only partially dissociate.

$$H_2CO_3 \rightleftarrows H^+ + HCO_3^-$$

$$NH_4OH \rightleftarrows NH_4^+ + OH^-$$

Either way, the ions SO_4^{2-}, NO_3^-, HCO_3^-, NH_4^+, and H^+ result and these are major components of rainwater.

b) Gases and Cl^- in Rain

Since the chloride ion (Cl^-) in rain comes primarily from sea salt chloride is frequently used as an indicator of the amount of sea salt present. However, chlorine can also exist as a gas (HCl) in the atmosphere produced by reaction with sea salt or arising from industrial sources. In these cases, the amount of chloride in rain may not be an accurate indication of sea salt content.

Hydrogen chloride (HCl) gas can be formed by the reaction of hygroscopic sea-salt particles ($NaCl$) with polluted air containing either NO_2 or SO_2 gas. The NO_2 and SO_2 ultimately form HNO_3 and H_2SO_4 and the HCl is then formed by the reactions.

The HCl gas escapes to the atmosphere and the chloride content of the sea-salt aerosol is accordingly reduced (Eriksson 1952). However, since HCl gas is highly soluble in water, a good deal of it may be redissolved in precipitation as Cl^- if it is not removed from the areas.

Thus, while the Cl/Na ratio of sea-salt aerosol would be reduced the rain Cl/Na ratio might not be.

Martens et al. (1973) found on average reduction of the sea-salt Cl/Na ratio of around 10% due to the reaction of the chloride in sea salt aerosol with HNO_3 gas. Hence pollutive HCl is found in industrial areas and may raise the Cl/Na ratio of rain above the sea-salt ratio.

c) Sulphate in Rain

Sulphate in rain has three major and roughly equal sources:

1. Sea- salt aerosols;
2. Sulphur dioxide from fossil fuel burning, and
3. Biogenic reduced sulphur gases, such as H_2S and $(CH_3)_2S$ from natural metabolism and organic decay.
4. Volcanic emissions of sulphur dioxide, hydrogen sulphide, and particulate sulphates;
5. forest burning,
6. soil dust; and
7. plant aerosols.

Conversion of Sulphur Dioxide to Sulphate in Rain : These are two main process, where relative importance varies involved in the conversion (oxidation) of SO_2 gas to Sulphate (SO_4^{2-}) which can be removed in rain or dry deposition. First, SO_2 gas reacts with OH radicals in gaseous form in the atmosphere (via intermediate stages) to form sulphuric acid aerosol (CNRC 1983).

$$SO_2 + 2OH \rightarrow H_2SO_4$$

(in liquid cloud droplets)

Sulphuric acid is highly soluble in water and is a strong acid which completely dissociates to hydrogen and sulphate ions.

$H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$

In this way H_2SO_4 contributes to the formation of acid rain

Oxidation of SO_2 does not always result simply in the production of H_2SO_4. when ammonia is also present in polluted air, it reacts with sulphuric aicd droplets to form ammonium sulphate particles, which raise the pH by consuming H^+ ions.

$2 NH_3+2H^++SO_4^{2-} \rightarrow (NH_4)_2 SO_4$

$NH_3+ 2H^++SO_4^{2-} \rightarrow ((NH_4) HSO_4$

Other substances such as $CaCO_3$ can also react to neutralize sulphuric acid.

Rain can also remove SO_2 directly form the air as it falls to the ground (washout). However, it has been found that after in heavily polluted air most of the sulphate in rainwater of sulphate aerosols not washout of SO_2 gas during rainfall (Granvenhorst etal. 1978).

Sulphate Deposition in Rain: Sulphate concentrations in rain vary both with time and with location. The usual range in excess sulphate over land is from loss than 1 to 10 mg/l with higher values being due to pollution. The unpolluted remote land background concentration of excess sulphate in rain has been estimated as 0.5-0.6. mg/l SO_4 (Kramer 1978; Granat et al: 1976) and about 0.5 mg/l SO_4 has been measured in Amazon Basin rain (Stallard and Edmond 1981). These values are considerably less than most North American or European Values, which reflect varying degrees of pollution.

Table 1.5: Estimates of Annual Global Emissions of Gaseous Sulphee rinto the Atmosphere by Natural and Anthropogenic Processes (in Tg S/Yr.)

Natural Emissions[a]	Anthropogenic Emission	Natural as a percent of Total	Reference
92	50	65	Kellogg et al 1972
108	65	62	Friend 1973
98	64	60	Robinson and Robbins 1975
35	65	35	Granat, Rodhe, and Hallbery, 1976
5-100	69	42-59	Moller, 1984
100	100	50	Andrae and Galbally, 1984
51	77-77[b]	40	Berner and Berner, 1996

[a] Includes biological decay and volcanism but does not include sea salt.

[b] Includes anthropogenic forest burning of 7 Tg S/Yr.

The pollutive contribution of the total atmospheric sulphur input is large, about 40% (75% over the land alone) and illustrates, as in the case for nitrogen, the importance of human activities as they affect the composition of major reservoirs and fluxes at the earth's surface, in this case the atmosphere pollution is a global as well as a local problem. Pollution also plays a major role as it affects sulphur in continental waters and in the oceans.

d) Nitrate in Rain:

Natural Sources :

Nitrate (NO_3^-) in rain results both from natural processes and from human activities. Most nitrate in rain comes form nitrogen oxide gases (NO_x), directly from nitrogen dioxide (NO_2) and indirectly from nitric oxide can be formed by the reaction of nitrogen and oxygen in the air at high temperatures in excess of 2000°C. This process occurs in lightning, and during combustion, and can be summarized as

$$N_2 + O_2 \rightarrow 2\ NO\ \text{(Nitric oxide)}$$

Nitric oxide is quite reactive and combines easily in the atmosphere with ozone (O_3), or with peroxides (HO_2 or organic peroxides) to form nitrogen dioxide (NO_2)

$$NO + O_3 \rightarrow NO_2 + O_2$$

or

$$NO + HO_2 \rightarrow NO_2 + OH$$

NO_2 in turn reacts with OH, in he air (catalytically) to form nitric acid (HNO_3) (Logan 1983).

$$NO_2 + OH \rightarrow HNO_3$$

Nitric acid is then removed in rain Cor surface deposition). Nitric acid is a strong acid and completely dissociates in rain water to form NO_3^- and H^+

$$HNO_3 \rightarrow H^+ + NO_3^-$$

In this way nitric acid can lower the pH of rain.

The conversion of NO_x to HNO_3 in the air is fairly rapid, being less than one to two days in summer and about ten days in winter according to Logan (1983), and the HNO_3 is removed from the air in rain or surface deposition. After only a few days.

The sources of NO_3^- in rain, or essentially the sources of NO_x gas, include the following.

1. Lightning
2. Photochemical oxidation in the stratosphere of N_2O gas to NO and NO_2
3. Chemical oxidation of NO by microbial processes

4. Social production of No by microbial processes
5. Fossil fuel combustion by humans
6. Forest burning

The first four of these processes are predominantly natural and the last two predominantly anthropogenic.

Anthropogenic Sources: Human undoubtedly provide the largest sources of nitrate in rain (50%) by the production of nitrogen oxides NO and No_2 from Foss fuel combustion, mainly in automobile engines and power plants. The NO_x gases are formed by the high temperature reaction between atmospheric N_2 and O_2.

Reactions involving pollutant nitrogen oxides are particularly obvious in photochemical smog, where automobile exhausts accumulate as a result of a temperature inversion.

Another important source of rain nitrate (28%) in from forest and grass fires, most of which are set by humans for land clearing in tropical areas such as South America and Africa. In addition some wood is used as a fuel. Wild fires set by lightning amount to only 4% of the biomass burning is anthropogenic (Logan et al. 1981). Lewis (1981) found combustion of vegetation on a large scale in Venezuela during the dry season caused on accumulation of nitrogen oxides in onset of the rainy season as nitric acid, in some cases acid run. The amount of NO_x-N released to the atmosphere from biomass burning is estimated as 12 Tg N/Yr by Logan (1983). This is derived from estimates of the amount of biomass fuel burned annually, the nitrogen content of the biomass burned, and the assumption that only 25% of the nitrogen is converted to NO. Thus, the combination of forest burning and fossil fuel combustion accounts for the 75% of NO_x-N in the atmosphere, which is anthropogenic in origin.

Table 1.6 Production of Nitrogen Oxides from Fossil Fuel combustion and Industry in 1979 (in Tg NO_x- N/Yr; Tg=10^{12} g)

Source	U.S. and Canada	Europe[a]	Rest of World	Total
Power and heating combustion:				
Coal	1.6	2.4	2.4	6.4
Oil	0.8	1.3	1.1	3.2
Gas	1.1	0.9	0.3	2.3
Subtotal Power + heating	3.5	4.6	3.8	11.9
Transportation[b]	2.5	2.8	2.5	8.0
Industrial sources	0.2			12.
Total				

Source: After J.A. Logan. “Nitrogen oxides in the troposphere:Global and regional budgets”:, J. of Geophysical Research, 88 (C15), 10792.

Note: NO_x is the sum of NO_2 and NO.

[a] Europe includes 80% of US.S.R. fuel

[b] Total includes 0.2 Tg from air traffic.

[c] Petroleum refining and manufacture of nitric acid and cement in the United states.

(e) Ammonium in Rain

Ammonium (NH_4^+) is the other major nitrogen containing ion found in rain, ammonium ion results form the reaction of ammonia gas (NH_3) with water:

$$\mathbf{NH_{3\,gas} + H_2O \rightarrow NH_4^+ + OH^-}$$

This reaction tends, because of the production of hydroxyl ions (OH^-), to raise the pH of rainwater and partly counteract the acid effects of CO_2, NO_2, NO_x and SO_2. Ammonia is the only atmospheric gas that can do this .Junge (1963) has calculated that, in the absence of other gases, the average concentration of NH_3 in the air of3 μ g/m^3 would result in a high pH for rainwater, about 8.5. however, since most rainwater has a pH of 4 to 6, ammonia obviously does not control its pH, the acidic gases CO_2, NO_x, and SO_2 are more important. In fact, since most rainwater is acid, NH_3 should be very soluble in rain, (the above reaction also shows why alkaline soils tend to give off NH_3 and acid soils to take it up). NH_3 gas remains in the atmosphere around one to four days before being converted to NH_4^+ (Soderlund and Svensson, 1976), and once NH_4^+ is formed, it is removed in rain in about a week.

There are four sources of ammonia in the air.

1. Bacterial decomposition of domestic animal and human excreta;
2. Bacterial decomposition of natural nitrogenous organic matter in soils;
3. Release from fertilizers (and fertilizer manufacture), and
4. Burning of coal (which conations organic nitrogen compounds).

All the above sources are continental in nature. This helps to account for the observations of higher concentrations of NH_4^+ in rain over the continents (0.03-1.0 mg/l NH_4^+). In addition, the above sources are seasonal, the first three being at a maximum in the spring and summer and the last in winter. The increase in NH_4^+concentrations is rain (and NH_3 concentrations in the air) in warmer weather has been noted by several authors (Junge 1963, Freyer 1978; and Lenhard and Gravenhorst 1980).

Table 1.7 Fluxes of Ammonia: The atmospheric Ammonia Cycle

Process	Flux (Tg NH_4-N/Yr)	Percent of Total	Anthropogenic as percent of Total
Input Sources :			
Domestic animal and human waste decomposition :	15	65	65
Net soil loss from organic matter decomposition (excluding fertilizer):	6	26	17
Fertilizer release :	2	9	9
Fossil fuel combustion :	0.03	<1	<1
Total inputs :	23	100	91
Removal:			
Conversion in atmosphere to NOx :	<1		
Land – rainfall :	15		
Ocean –rainfall :	7		
Dry deposition –particulate NH_4 :	1		
Total removal :	23		

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$(NH_4)_2SO_4$ Aerosol formation: Interaction of N and S cycles:

NH_3 gas in the atmosphere reacts very readily with aqueous H_2SO_4 aerosols to form $(NH_4)_2SO_4$ aerosols. This reaction partiality neutralizes the aid H_2SO_4 and converts gaseous NH_3

to NH_4^+ aerosol, which can be transported or removed in rain or by dry deposition. It also provides a link between the atmospheric does of N and S, (Galbally, Farquhar, and Ayers 1982). In the atmospheric NH_3-N cycle, as pointed ot by Galbally, Farquhar and Ayers, there are essentially two competing processes regulating the atmospheric concentration of NH_3.

(1) the tendency of plants to take up or give of atmospheric NH_3 gas, maintaining a concentration of NH_3 around 1 mg/m^3, due to their internal chemistry ;

(2) the reaction of NH_3 with $H_2 SO_4$, which converts gaseous NH_3 to NH_4^+ in aerosols and prevents NH_3 form being recycled by plants. Thus, conversion of gaseous NH_3 to NH_4^+ in sulphate aerosol essentially removes ammonia gas from the biogenic N cycle and reduces the amount of atmospheric N available for plants. Also, NH_4^+in aerosol can be transported long distances (up to 5000 Km) before removal in rain and dry deposition. Thus, the net effect of the formation of $(NH_4)_2SO_4$ aerosols is to spread NH_4^+- N around and probably increase NH_4^+ concentrations in rain in areas far from sources of NH_3 gas.

The other important effect of the formation of $(NH_4)_2 SO_4$ aerosols is the neutralization of $H_2 SO_4$ acidity in rain.

1.8 Acid Rain

Besides bringing about change in the concentration of NO_3^-, SO_4^{2-}, and Cl^- in rain, the gases NO, NO_2, SO_2, and HCl also produce hydrogen ions, H^+. The result is called acid rain. Acid, rain is rain that is more acid than it would be in the absence of these gases, and much of it is pollutive in origin. The pH of a solution is defined as the negative logarithm (base 10) of the hydrogen ion concentration; in other words

$$\mathbf{pH = - \log [H^+] = \log (1/[H^+])}$$

Here the brackets refer to the concentration in moles per litre. Solutions having a pH greater than 7 are referred to as being basic (or alkaline); conversely, those with a pH less than 7 are referred to as being acidic.

The pH of Natural Rainwater :

Pure water containing no dissolved substances should have a pH of 7, in which case it is referred to as being neutral (neither acidic nor basic). Natural rain water, however, is not pure water. First of all, as a result of the solution of atmospheric carbon dioxide (to equilibrium), rainwater becomes moderately acidic with a pH of 5.7. This comes about from the reaction of CO_2 with H_2O which results in the formation of carbonic acid (H_2CO_3), which in turn partly dissociates to produce hydrogen and bicarbonate ions:

$$\mathbf{CO_2\,gas \leftrightarrows CO_2\,soln.}$$

$$\mathbf{CO_2\,sols. + H_2O \leftrightarrows H_2CO_3}$$

$$\mathbf{H_2CO_3 \leftrightarrows H^+ + HCO_3^-}$$

(Further dissociation of HCO_3^- to CO_3^+ and H^+ is negligible at the ph[3] of rain.) From the latter two reactions, it can be seen that CO_2 reacting with H_2O results in the formation of H^+ and HCO_3^- in equal amounts.

By using equilibrium expression for the above reactions and the fact that the concentrations of H^+ and HCO_3^- are equal one can readily calculate that at equilibrium:

$$\mathbf{[H^+] = 2.1 \times 10^{-6}\ moles\ per\ litre = 10^{-5.67}}$$

This is equivalent to a **pH** of about **5.7**. Since the concentration of carbon dioxide in the some, one would, therefore, expect that natural rainwater, if no other reaction were involved, would exhibit a **pH** close to **5.7**; that is, it would be moderately acidic.

Under a variety of circumstances however, the pH of natural (unpolluted) rainwater can be higher or lower than 5.7. Higher pH is a less common situation on a worldwide basis and comes about mainly in arid regions where air pollution is absent) as the result of the dissolution of windblown dust, which contains high concentrations of $CaCO_3$ (Kramer 1987. The reaction is:

$$CaCO_3 + H^+ \rightarrow Ca^{2+} + HCO_3^-$$

This reaction not only results in neutralization of acidity via the consumption of hydrogen ions but also in the production of Ca^{2+} in rain HCO_3^- ions. Thus, Ca^{2+} in rain in excess of sea-salt concentrations often indicates that the rain has reacted with $CaCO_3$ dust.

Neutralization of natural acidity in unpolluted rain over land can also take place by reaction with ammonia gas (NH_3). In regions where ammonia is emitted to the atmosphere. From biological decay, agricultural activity, and so forth, there may be enough to bring about a slight rise in pH via the reaction

$$NH_3 + H^+ \rightarrow NH_4^+$$

Charlson and Rodhe (1982) calculate that in the absence of sulphate aerosol, NH_3, at the lowest concentrations formed in continental areas (0.13 ug/m^3), could raise the pH of CO_2^- containing rain to 6.2. Since NH_3 gas or fine aerosol NH_4^+ can travel further than coarse soil dust containing $CaCO_3$, the neutralization effect of NH_3 may be important in areas further from the source. The relative importance of NH_3 and soil dust in neutralizing acidity varies from areas to areas but on the average about one-third of the acid neutralization is due to NH_4^+ (Munger and Eisenreich 1983).

Natural rainwater can also have a pH less than 5.7 in which case it falls in the category of acid rain. This is due to the presence of naturally of biogenic reduced sulphur gases (Charlson and Rodhe 1982). In order for "naturally acid" rain to occur there must be a lack of neutralizing

$CaCO_3$ soil dust and NH_3. Charlson and Rodhe (1982) suggest that theoretically an average pH of about 5 might occur in pristine areas (which lack neutralizing substances) because of emissions of natural sulphur gases. This is based on an annual global release of 65 Tg of non-sea-spray natural sulphur spread evenly over the globe. Locally, because of variations in natural sulphur emissions, pH values in natural rain might range from 4.5 to 5.6 with the lower pH values being favoured by high SO_4^{2-} aerosol concentrations and low liquid water content of clouds. Low natural pH values might occur over the oceans because of considerable emissions of reduced sulphur gases there (provided sea-salt neutralization is minimal) and the absence of continentally derived bases (NH_3 and $CaCO_3$ dust).

Weak organic acids, such as acetic acid or formic acid also have been suggested as an additional source of natural acidity in some local areas (Galloway et al. 1982). These acids could come either from natural volatilization from vegetation or from the sea surface.

Acid Rain from Pollution:

Acid rain is defined, more precisely, as that having a ph less than 5.7 due to reactions with acidic gases other than CO_2. The acidic gases are SO_2 , NO_2 , NO, and (to a lesser extent) HCl, and they result in the formation in the atmosphere and in rain clouds of sulphuric, nitric, and hydrochloric acids respectively overall reactions are:

$$SO_2 + OH \rightarrow \ldots\ldots\ldots\ldots \rightarrow H_2\,SO_4 \text{ (sulphuric acid)}$$

$$SO_2 + H_2\,O_2 \rightarrow H_2\,SO_4 \text{ (sulphuric acid)}$$

$$NO_2 + OH \rightarrow HNO_3 \text{ (nitric acid)}$$

$$HCl_{gas} \rightarrow HCl \text{ (hydrochloric acid)}$$

Followed by the dissociation of these acids in rain to form H^+ ions:

$$H_2SO_4 \rightarrow 2\,H^+ + SO_4^{2-}$$

$$HNO_3 \rightarrow H^+ + NO_3^-$$

$$HCl \rightarrow H^+ + Cl^-$$

Thus, as more and more of the precursor gases are added to the atmosphere by human activities, more and more hydrogen ions are produced and the ph of rainwater drops.

Acid rain was first reported in northwest Europe in the early 1950s. Barett and Brodin (1955) found that precipitation in southern Sweden had a pH was lowest in the winter when the air flow is from the south, bringing pollution from central and western Europe.

1.9 The Monsoon Season:

The rainy season in India starts with the onset of the southwest monsoon in June and continues till the middle of September. This is also called the monsoon season, the southwest monsoon season, the wet season and the hot-wet season. The weather conditions all over the country change with the onset of the monsoon winds. High heat, high humidity extensive clouding and several spells of moderate to heavy with strong surface winds are the chief characteristics of this season.

(a) **Temperature:** There is a significant fall in temperature with the beginning of rainy season. The June temperature in south India is 3°C to 6°C lower than the May temperature.

Similarly, July temperature in northwest India is 2° to 3°C lower than the June temperature. But once the temperature falls from its dry summer level, it remains more or less uniform throughout the rainy season. However, the temperature rises again in September with the cessation of rains and secondary maximum temoperature period is experienced all over the country. Also, there is rise in temperature whenever there is break in the monsoons and rainfall does not occur for a number of days. Night temperatures are more uniform than the day temperatures. The diurnal range of temperature is small due to clouds and rains. It ranges between 4°C and 8°C when the monsoon is fully established.

The highest temperature of over 32°C is experienced in the Thar desert of Rajasthan. At places especially west of the Aravali the temperature may be as high as 38° C to 40 ° C. This is due to lack of clouds and the predominance of continental air mass. The remaining parts of north-west India also have temperatures above 30 ° C. The temperatures are quite low over the western Ghats due to high elevation and also due to very heavy rainfall, but the rain shadow area is comparatively warmer on account of low elevation and scanty rainfall. The coastal areas of Tamil Nadu and adjoining parts of Andhra Pradesh have temperatures above 30 ° C because they receive little rainfall during this season.

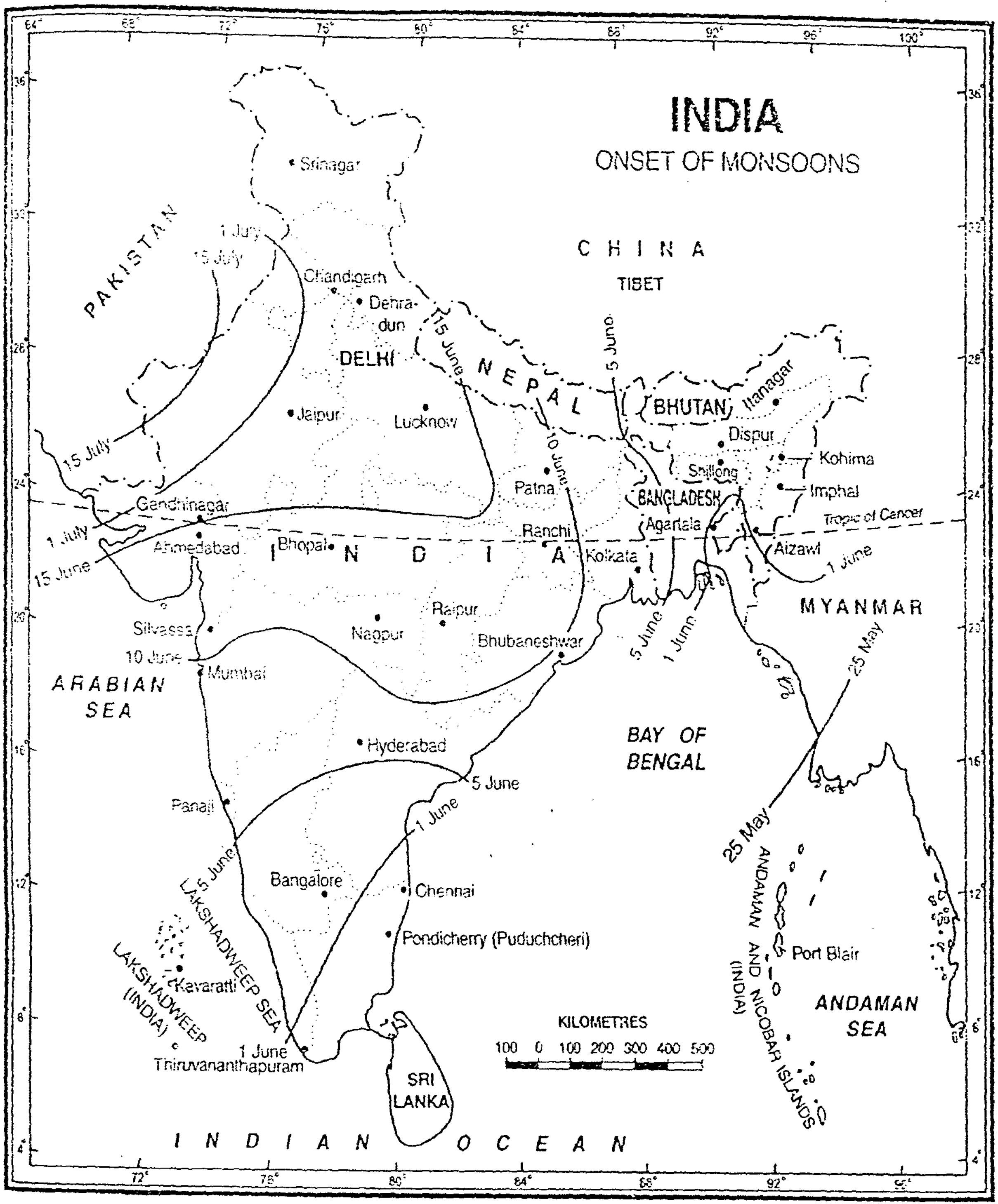

Fig 1.2 Normal dates of Arrival of Monsoon .

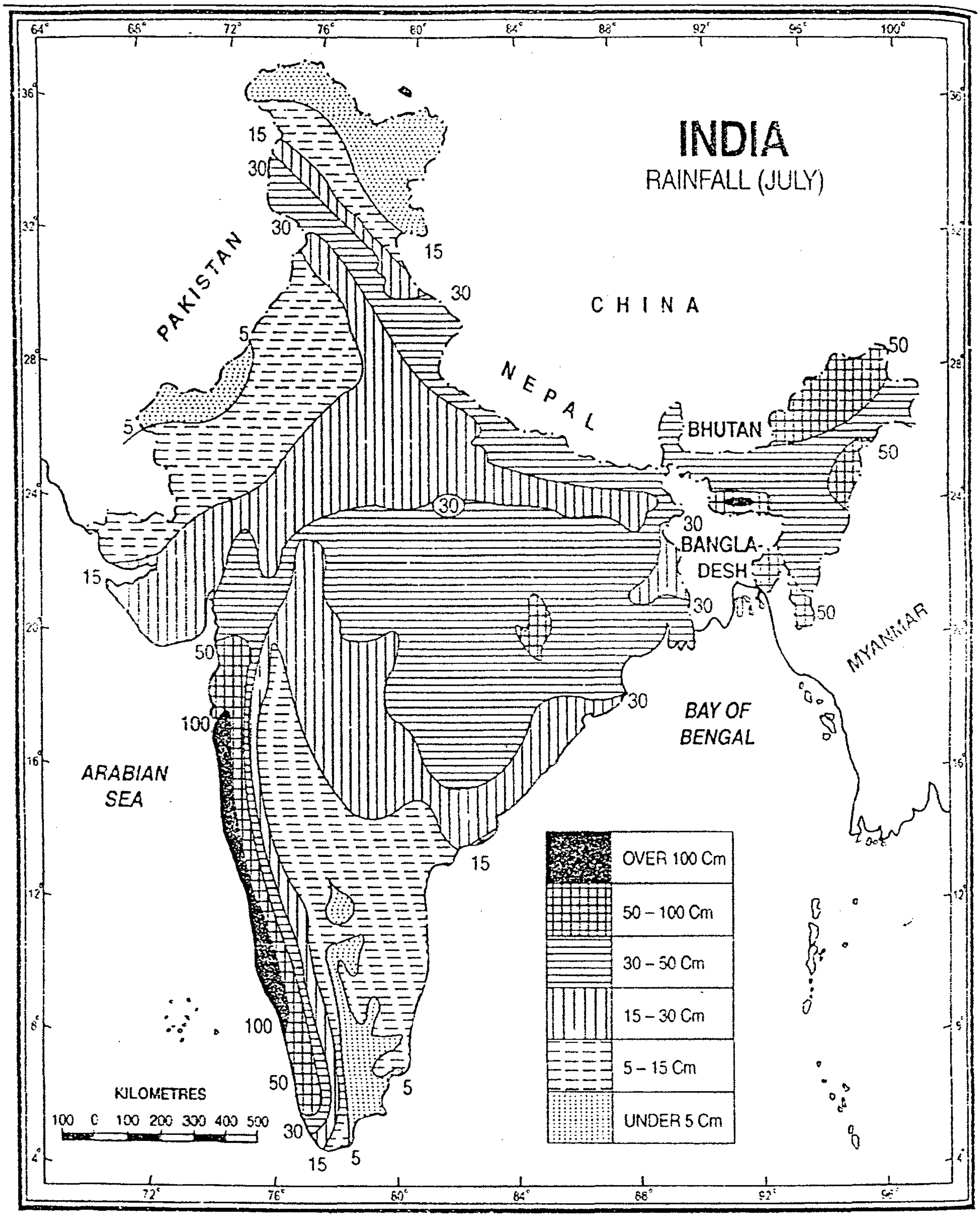

Fig.1.3 India Rainfall July

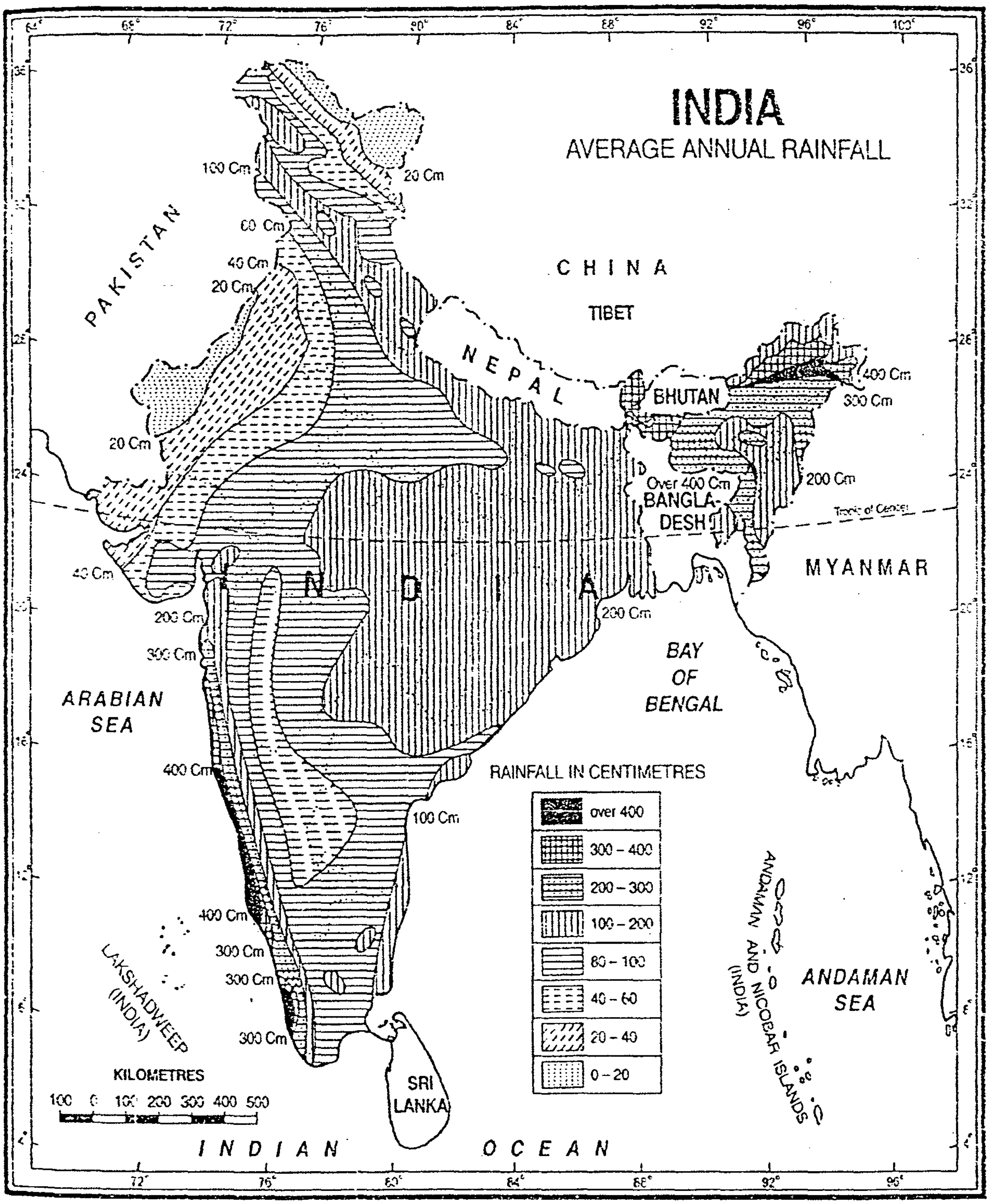

Fig. 1.4 India Average annual Rainfall.

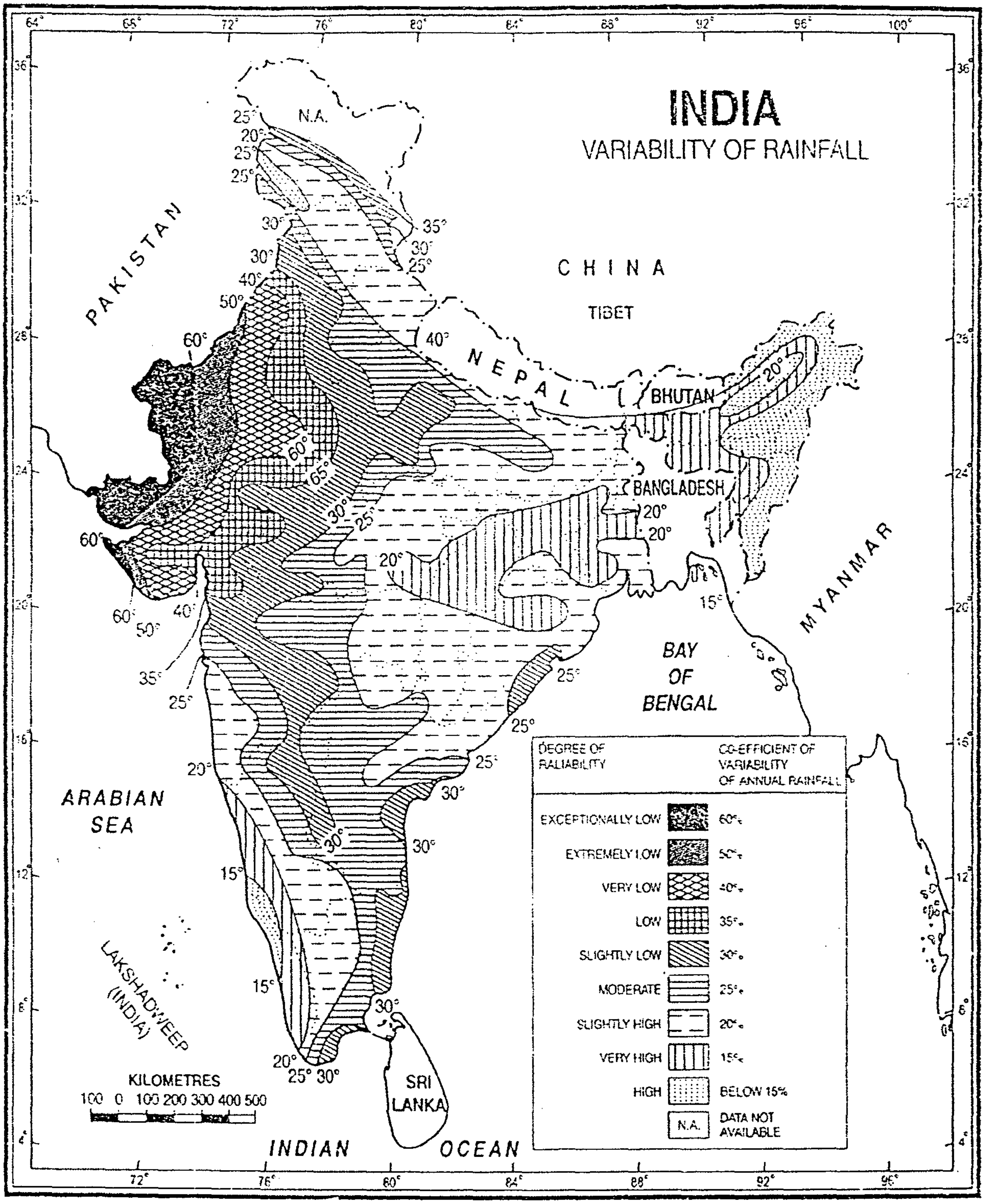

Fig.1.5 : Coefficient of variation of monsoon rainfall.

(b) **Pressure and Winds:-** the temperatures in northwest India as still very high as a result of which low pressure conditions prevail there. The most conspicuous feature of the surface pressure distribution during this season is an elongated trough across the Ganga right up to the head of Bay of Bengal. This is called the monsoon trough. There are frequent changes in its location and intensity depending upon the weather conditions. The atmospheric pressure in most parts of north India is less than 1, 000 mB. It increases steadily southwards where it ranges between 1, 008 mB, and 1, 010 mB. The isobar of 1, 009 mB crosses parts of Kerala and Tamil Nadu besides Arabian Sea and the Bay of Bengal.

Under the influence of the above mentioned pressure distribution, winds blow in a southwest to northeast direction from Arabian Sea and Bay of Bengal. They maintain this direction throughout peninsular India. But their direction undergoes a change in Indo-Gangetic plain where they move from east to west.

(c) **Rainfall:** India's three fourths of the total annual rainfall is received during this season. In some areas it is much more than this average. For example, the average rainfall over the plains of India in this season is about 92 cm., or about 87 percent during the remaining part of the year only 14 cm. of rainfall occurs. This season has maximum number of rainy days as a result of which it is called the 'wet season'.

Rainfall during this season all over the country is caused by southwest monsoons coming form the Indian Ocean. Figure 1.2 show isolines of normal dates of arrival of the monsoon in different parts of the country. It is clear from this map that the normal date of arrival of the monsoon is 20th May in Andaman and Nicobar Islands. It is worth mentioning that the advance of the monsoon is much more in the Bay of Bengal than in the Arabian Sea. This is evident from the pronounced curve shown by isolines of the monsoon onset in figure 1.1. The monsoon current advance to nearly 20 ° N lattitude in Bay of Bengal by the third week of May, when it is still south of Kerala at about 7 ° N latitude in the Arabian Sea. The normal, date of onset of the southwest monsoon over Kerala i.e. the first place of entry in the main land of India is 1st June. The monsoons advance with startling suddenness accompanied with a lot of thunder, lightning and heavy downpour. This sudden onset of rain is termed as monsoon burst. Although the normal date of onset of the southwest monsoon on the southern tip of the peninsula is 1st June, the actual onset may be earlier or later than this date. On 60 % occasions, the onset occurs between 29th May and 7th June. The earliest onset was on 11th May in 1918 and 1955, while the most delayed onset was on 18th June in 1972. Satellite imagery is used to identify the advance of the monsoon on a day to day basis.

The progress of the monsoon winds beyond with Kerala is in the form of two branches viz. the Arabian Sea branch and the Bay of Bengal branch. The Arabian Sea branch gradually advances north-wards. It reaches Mumbai by 10th June and spreads over Saurashtra Kuchchh and central parts of the country by 15th June. The progress of the Bay of Bengal branch is no less spectacular. It spreads rather rapidly over most of Assam. The normal date of its arrival at Kolkata is 7th June. On reaching the foot hills of the

Himalayas the Bay branch is deflected westward by the Himalayan barrier and it advances up the Gangetic plain. The two branches meet roughly along the line running through Agra and Ferozpur and merge with each other to form a single current. The combined current gradually extends to west Uttar Pradesh, Haryana, Punjab, Rajasthan and finally to Himachal Pradesh and Kashmir. By the end of June, the monsoon is usually established over most parts of the country. By middle July, the monsoon extends into Kashmir and the remaining parts of the country, but only as a feeble current because, by this time, it is often difficult to say whether the Arabian Sea branch or the deflected Bay of arrive. For example, at a place like Delhi, the first showers are sometimes brought by the Bay of Bengal branch from the east but on a number of other occasions it is the Arabian Sea branch which brings the first monsoon rain from the south. It is interesting to note that the Arabian Sea branch of the monsoon is much more powerful than the Bay of Bengal branch for two reasons.

(i) The Arabian Sea is larger than the Bay of Bengal, and

(ii) The entire Arabian Sea current advances towards India, whereas only a part of the Bay of Bengal current enters India, the remainder proceeding to Myanmar, Thailand and Malaysia.

(d) **Monsoon Depressions:** A major part of the monsoon rainfall is generated by depressions originating in the Arabian Sea but more so in the Bay of Bengal. Some depressions develop over land also. About 3-4 depressions are formed per month from June to September. Almost all of them are sacked inward through the deltas of great rivers, the

Ganga, the Mahanadi, the Godawari, the Krishna and the Cauvery and cause heavy rain in these areas.

In June the depressions in the Bay of Bengal originate between 16 ° N and 21 ° N and west of 92 ° E. The majority of them move towards north-west. During July and August they originate north-westerly direction. In September, the Bay storms originate to the north of 15 ° N and to the west of 90 ° E. majority of cyclones move along the monsoon trough and most of them merge with the seasonal low over north-west India.

In the Arabian Sea the formation of depression in June is between 17 ° N and 20 ° N. They move either in north-west or in northerly direction and may affect Gujarat or Maharashtra. Storms during August and September are rare and are formed close to Maharashtra – Gujarat coast.

Most of the rainfall in central and northern parts of the country is caused by these depressions. The satellite imagery shows thick clouds associated with these depressions. Sometimes they give excessive rainfall, as much as 60 cm. in a single day, resulting in heavy loss of life and property. The absence of depression or a change in their tracks result in deficit or no rain.

1.10 Ambient Air Quality Monitoring in Delhi

The Central Pollution Control Board (C.P.C.B) has been conducting ambient air quality monitoring at seven locations in Delhi. The locations have been categorized based on land use; i.e. residential, industrial and traffic intersection. The comparison of air quality data (average annual mean values) from the year 2000 to 2005 as shown in table 5.1 and graph 5.1 reveal that:

Concentration of all regulatory pollutants in ambient air of Delhi has been reducing during the period 2000 to 2005 except for NO_2 concentration.

- Average annual SO_2 concentration for all monitoring sites in Delhi came down to 8.88 $\mu g/m^3$ in the year 2005 from, 17.83 $\mu g/m^3$ in the year 2000.
- Annual average value of NO_2 concentration for all monitoring sites raised to 48.69 $\mu g/m^3$ in 2005 from 35.69 in the year 2000.
- Annual average value of PM 10 for all sites came down to 140.30 $\mu g/m^3$ in 2005 from 158.95 $\mu g/m^3$ in the year 2000.
- Annual average SPM concentration for all monitoring sites in Delhi come down to 335.11 $\mu g/m^3$ in the year 2005 from 404.77 $\mu g/m^3$ in the year 2000.

Besides mandating the use of CNG, a number of other policy instruments have been enacted that has helped improve the air quality in Delhi. The Honourable Supreme Court of India took the initiative and passed an order for converting the public transport into CNG mode, which has been implemented in Delhi Since 2001. The table below shows the ambient air quality of Delhi after implementation of CNG in Delhi.

Table 1.8: Table showing Delhi Ambient Air Quality for year 2000-2005,(annual average mean values) ; (All values are in μ gm/m^3) .

Year / Location	SO_2 (Mean 24 hourly avg.)	NO_2 (Mean 24 hourly avg.)	SPM (Mean 24 hourly avg.)	PM10 (Mean 24 hourly avg.)
2000	17.83	35.94	404.77	158.95
2001	13.81	34.35	347.80	137.47
2002	11.50	37.64	424.36	165.95
2003	9.56	45.25	337.30	143.94
2004	9.18	47.08	340.63	143.99
2005	8.88	48.69	335.11	140.30

Source- C.P.C.B.

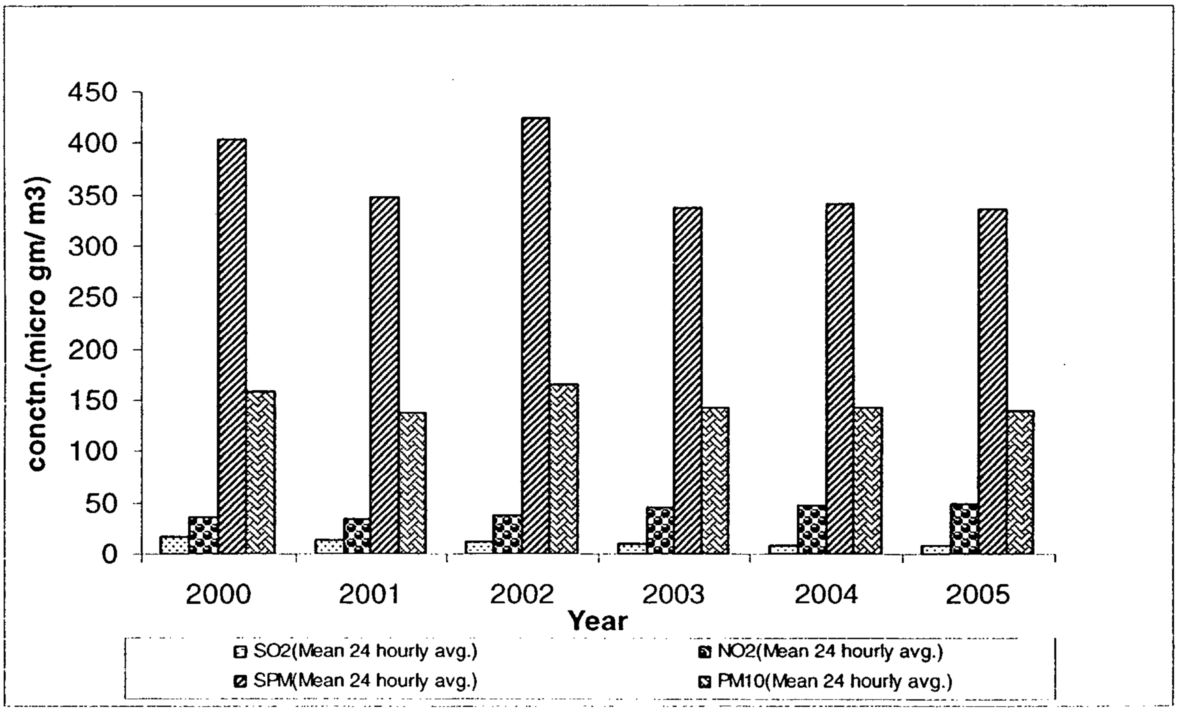

Fig. 1.6: Variation of air quality parameters in Delhi;source C.P.C.B

The table below shows the statistics about the number of vehicles as on 31.05.2006 in Delhi.

Table 1.9: Statistics about the number of vehicles as on 31.05.2006 in Delhi

Sl. No.	Category	No. of Vehicles
1	Two wheelers	14,86,934
2	Four wheelers	31,05,892
3	Bus	25,705
4	Goods Vehicle	1,59,981
5	Taxis	2,09,73
6	Auto Rickshow	74,183
	Total	48,73,668

Source: Transport Department Govt. of Delhi

Table 1.10: Estimated vehicular emission load in Delhi.

Name of the City	Vehicular Pollution load (Tonnes Per day)					
	Particulates	SO_2	Oxides of Nitrogen (NO_x)	Hydro-Carbons	CO	Total
Delhi	10.30	8.96	126.46	249.57	651.01	1046.30

Source: C.P.C.B., New Delhi "Urban Statistics" October, 1996, Town and Country Planning Organization, Ministry of Urban Affairs and Employment, Govt. of India.

Table 1.11: Total Annual Emission under BAU (thousand tones) in Delhi

Pollutant	1990/91	1995-96	2000/01	2005/06	2010/2011
CO	132.31	169.47	193.76	191.91	200.62
HC	53.79	70.2	81.96	80.63	82.48
NO_x	22.49	30	40.16	50.42	65.56
SO_2	3.03	4.11	6.01	8.03	10.49
TSP	6.03	8.11	10.3	11.59	13.39
Pb	0.078	0.102	0.111	0.104	0.098

Source: WWF

Table 1.12 : Percentage share of air pollution by various sources in Delhi.

	1970-71	1980-81	1990-91	2000-01
Industrial	56	40	29	20
Vehicular	23	42	63	72
Domestic	21	18	8	8

Source: WWF

Table1.13: Annual energy demand in thousand tones of oil equivalent for Delhi.

Fuel / Type	1990/91	1995/96	2000/01	2005/06	2010/11
Gasoline	399	524	629	670	721
Diesal	203	280	450	649	893
Total	602	804	1079	1319	1614

Source: Automotive energy use and emission control: a simulation model to analyze transport strategies fro Indian metropolises Bose R.K. 1998.Energy Policy 26(13): 1001-1016.

The above data shows that transport sector in Delhi is the biggest pollution of Delhi air. In Delhi the situation deteriorated in the 1990s as vehicle growth has, outpaced population growth and economic development, vehicles numbers had risen to 4.87 million by 31/05/2006. During the period, Delhi's population increased from 9.5 to 13.8 million and road length from 22,000 to 25,000 km. The World Bank estimated that a person who dying every70 minutes. In Delhi 1995 from air pollution (Brandon and Hommann, 1995). The Supreme Court (SC) of India ruled in 1998 that all the public transport diesel to CNG by 31st March 2001 and by December 1,2002 all the buses were converted to CNG.

The assertion that the conversion to CNG reduces the particulates levels has not been established. A look at trend figures, significant shows that after every pollution levels do fall but not in a sustained manner. The NO_x, has risen after the conversion conversion SPM and PM_{10} have shown only marginal fall; CO has shown a significant decline. One of the reasons for this transitory impact could be that almost 200,000 vehicles join the existing fleet annually.

CHAPTER – II

LITERATURE REVIEW

LITERATURE REVIEW

There is general agreement that the acid rain is a serious problem. There are very good reasons to consider acidification as one of the most serious environmental problems facing industrialized tropical countries where significant rate of pollution growth and current emphasis on agriculture and economic development virtually course that large increases in SO_2 and NO_2 emission will occur in the decades to come.

Acid rain is defined, as that having a pH less than 5.6 due to reactions with acidic gases other than CO_2. The acidic gases are SO_2, NO_2, NO, and (to a lesser extent) HCl.Acid rain was first noted in northwest Europe in the early 1950s. Barett and Brodin (1955) found that precipitation in southern Sweden had a pH between 4 and 5 and that the pH was lowest in the winter when the airflow is from the south, bringing pollution from central and western Europe. In 1968, Oden found that the acidity of Northern European rain had increased since 1956; rain in some part of Scandinavia was zoo times more acidic than in 1956. By 1947, most of the northwestern Europe was receiving acid precipitation ($pH < 5.6$) (Likens 1978).

To understand the possible impact of atmospheric constituents on ecosystems and to estimate the involved flux rates, it is necessary to know the both ways the ecosystem. Input of acidity by rain to aquatic and terrestrial ecosystems has gained considerable public and scientific interest.

The problem of acid rain has not yet been widely acknowledged in India. However, potential effects of recent industrialization and coal based power generation over the last decades, warrants a closer examination of the impacts of emissions of SO_2 from various large sources and the overall long range transport and deposition of SO_2 / SO_4^{2-}on some sensitive receptors in northern India (Sharma et al. 1995).

At normal concentration and pressure of carbon dioxide in the atmosphere the equilibrium value of pH of rain would be 5.56 at 20°C. But Mukherjee and Krishnanand (1981) suggest that in tropical countries where atmospheric temperature is high, lower solubility and dissolution rate of carbon dioxide added with rapid process of cloud formation and precipitation results in higher pH, and concluded that pH of rain water over India should be close to 7.0 which is the neutral value of pure distilled water.

Subramanian and Saxena (1980) collected rainwater samples from various locations in Delhi throughout the monsoon of 1978 and analysed for Na, K, Ca, Mg, Cl, HCO_3, SO_4, PO_4 and SiO_2, pH and conductivity were also measured. The alkaline rain water of Delhi has total dissolved solids (T.D.S.) ranging from 35 – 170 p.p.m., depending on space and time. Sisterson and Shannon (1990) and Marquardt and Ihle (1988) have shown that drizzle and snow has more concentrations of all rains than normal rain and drizzle falling from lower clouds and very small droplets is very effective in capturing the air pollutant.

Ahmed et al. (1990) deduced that the H^+ increases with increase in rain depth. Both sulphates and nitrates in precipitation are due to rain – out process incorporated in the clouds where as magnesium and calcium are due to wash out. Ravichandran and Padmanabhamurthy (1994) showed that after complete wash out of cations the acidity is due to the rainout of sulphate and nitrate picked up.

Khemani et al. (1987) studied the ionic composition of cloud and rain water samples along with pH value at Pune region in India. They have shown that pH is influenced by alkaline properties of soil oriented components (Ca^{2+}, K^{+}, Mg^{2+}) present in high concentrations in cloud and rainwater samples. The effect of acidic components (SO_4^{2-} and NO_3^{-}) are negligible and are completely neutralized by the alkaline components.

In India, the study of chemical composition of precipitation was started long ago by Narayanswamy (1939),Mukherjee (1957); Khemani et. al. (1968); Handa (1969), and only during the last two decades extensive work has been done by Sequeria (1976), sadasivam (1979); Subramaniam and Saxena (1980); Krishnanand (1984); Mahadevan (1984); Mukherjee et.al. (1986); Varma (1989a); Khemani et. al. (1989a, 1989b) deduced that elsewhere in India occurrence of acid rain is ruled out due to higher concentration of soil derived particles.

In India, first occurrence of acid precipitation was reported by Mahadevan et. al. (1984) at Chembur, an isolated pocket in Mumbai and also in Delhi by Khemani (1989a) Ravichandran and Padmanabhamurthy (1994), and decreasing trend in pH was observed by Varma (1989a) in BAPMoN (Background Air Pollution Monitoring Network) stations like Kodaikanal, Port Blair, Minicoy, Nagpur, and Mohanbari, while Das (1988) reported that in Kolkata most rainwater samples have a tendency towards being slightly acidic in character.

The atmosphere of India has a high dust load and the dust from acid and semi – acid tracts of Rajasthan have their additional impact in northern India (Khemani et al 1985) and also surface erosion of soil appears to be the major contributor for many areas studied by Mahadehaven et al (1983). High pH value together with high concentration of $Ca^{2+}$and NH_4^+ had been observed by Munger (1982); Loye Pilot et. al. (1986) while Mukherjee et al. (1985); Chan et al. (1987); Khemani et al. (1989a, b), Ahmed et al. (1990); Verma et al (1990); Ravichandran and Padmanabhamurthy the (1994). Al – Momani et al. (1995); Sanusi et al. (1996), deduced that the pH of the precipitation is determined not only by the concentration of cations in the atmosphere which neutralizes the acidity by forming salts.

It is well documented that the dust load in the atmosphere over north western parts of India is higher and significant amount of dust incorporates into rainfall either as condensation nuclei or by collision with falling rain drops. Significant research work by Khemani et al (1985, 1987), Applin and Jarsak (1986) and Barnard et al. (1986) has shown the reason for pH values greater than 5.6, which reflects the possible neutralization effects of airborne dust.

The dust particles play an important role in deciding the pH of rainwater (Mukhapadhyay et al., 1992). When the dust load increases, the pH increases, the main reason being the presence of more Ca^{2+} and K^+ in dust, which originate from the soil and vegetations and alkalinity of rain decreases with increasing distance from the desert areas.

Rainwater chemistry studied over a one year period at a regional representative urban site, Tirupati showed that the acid neutralization is brought about by crustal ions particularly calcium in the region. The ionic composition of rainwater in the region was strongly influenced by terrestrial sources rather than anthropogenic and marine sources (Chandra Mouli, et al; 2004)

The pH of the rainwater was found to be more than 5.6 showing alkalinity during the early phase of monsoon in Delhi, but during the late phase of monsoon pH tendency was towards acidity due to lack of proper neutralization of acidic ions. In the late monsoon the concentration of cations gets reduced because of heavy rainfall and relatively unfavorable condition for their transport from the adjoining areas, whereas the anion concentration remains unchanged owing to their continuous emission (S. Balachandran and P.S. Khillare; 2001)

The atmosphere is recognized as a major vector for pollutants (Heitzenborg, 1989; Leaitch and Isaec, 1989). The residence time of airborne contaminants in the atmosphere various depending on numerous factors such as the contaminant itself, its physical and chemical states and the environmental conditions (wind, atmospheric and stability, rainfall intensity, etc.). However, the micro chemical and micro physical processes involved are still only partly understood (Bachmann et. al., 1992). It has been estimated that the two major mechanism, rain–out (in-cloud scavenging) and wash-out (scavenging below the cloud), together remove about 75-80 % of the atmospheric pollutants from the atmosphere to the Earth (Radke et al., 1980; Beattie and Whelpdale, 1989). However, this account is highly dependent on the chemical species, on the location of sampling in relation to emission sources and on the frequency of rain events. Concentration of race in organic elements in rainfall in the Montreal Island had high variance, indicating diversified sources and illustrating the complexity of the process involved. In addition to Al, only Ti, Fe, Ru, Y, Zr, and Cs can be classified as natural. On the other hand, seven elements are clearly related to human activities; B, Cu, Zn, Mo, Cd, Sb and Pb. Correlation Between elements indicated that some elements have similar behaviour, which can be partly explained by sorption phenomena or chemical bonding in the same compound (Poissant, et al., 1993).

Cloud water sampled in Sequoia National Park, California had pH values ranging from 4.4 to 5.7. The advance of cold fronts into the Park appeared to lead to higher aerosol and gas phase concentrations that are seen under normal mountain- valley circulations, producing higher cloud-water concentrations than might otherwise be expected. Estimates of annual deposition rates of NO_3^-, SO_4^{2-}, NH_4^+ and H^+ due to cloud water impaction were comparable to those measured in precipitation (Collett Jr.et al.; 1988).

A study of the sources of acid precipitation in Ontario, Canada found three factors reproduce the concentrations observed in precipitation. Those factors represent the acid gas sources (SO_2 and NO_x sources), Ca and Mg sources, and Na and Cl sources (marine aerosol). The acid gas sources were responsible for the acidity of the precipitation. Factor analysis was applied to the combined chemical and end point variable data sets. The results showed the relationship between the chemical nature of the sources and the geographic regions that the air parcels passed (Y. Zheng,and P.K. Hopke; 1988).

Although rainwater is a very dilute solution and its content of ions in solution is among the lowest of natural waters, its composition is the result of complex processes involving the atmosphere, hydrosphere and lithosphere. Rainwater acquires its chemical characteristics through dissolution of the solids and gases with, which it comes into contact during its descent. Since human activities influence rainwater chemistry is more correct to say that rainwater reflect the rain-air-rock-life interaction. The quantitative relationship between the pH of rainwater and its chemical composition is defined by the formulation of a geochemical model, which allows the initial pH of rainwater to be identified before that contamination, such as the addition of substances with high buffering capacity, changed their hydrogen ion composition (G. Dongarra, and S.Francofonte; 1995).

For almost all events, the concentrations of chemical species Cl^-, NO_3^-, SO_4^{2-}, NH_4^+, K^+, Ca^{2+} and Mg^{2+} decreased with rainfall duration, H^+ ion concentration showed an increasing trend in eight rain events sampled sequentially on time and volume basis in Uji, Kyoto, Japan. Thus even for the same event, the chemical species concentrations in rainwater varies greatly due to the change of sampling time and sampling duration (Luo Wanqing, 2001).

The orverall regional effect on rain chemical composition was related to the transitional zone from large deserts to Mediterranean climate in Israel. In a longitudinal section through Israel, there is a progressive change from basic (with a mean ph of 7.45) and no acid rains in the south to more acid (a mean pH of 5.49) and approximately 65 % acid rains in the north (Herut,et al.; 2000).

The most abundant ion was H^+ and rain acidity was significant at all sampling sites (average pH of 4.4-4.5). The sources of this free acidity differ among sites and appear to be correlated to the different land-uses. The composition of rainwater appeared to be controlled mostly by three sources: soil dust, sugarcane burning and industrial emission (Lara, et al. ; 2001)

Landuse and industrial activities are considered the most important driving forces in the ongoing process of atmospheric chemistry alteration. Most of these anthropogenic influences in the atmospheric chemistry are due to emissions of N, ammonia, and sulphur

(Munger and Eisenreich, 1983; Galloway et al. ; 1995; Puxbaum et al. , 1998). The oxidation of these chemicals and subsequent scavenging by precipitation has caused, mainly in northern Europe and north eastern United States, wide spread acidification of precipitation and an extra input of N to terrestrial and aquatic systems, with several deleterious consequences to the environment, such as decline of forests and crop productivity, increase of lake and soil acidification, and loss of biodiversity (Zhang, 1994; Wilson and Skeffington, 1994; Vitousek et al., 1997, Furiness et al., 1998, Kuylenstierna et al., 1998; Torseth and Semb, 1998). However increasing development and industrialization worldwide has been the problem of acidic deposition extend in recent times to other areas, such as East Asia.

Numerous studies on atmospheric chemistry have been published for the Northern thermosphere (Keene et al., 1983; Munger and Eisenreich, 1983; Puxbaum et al.1998; Sequeira and Lai, 1998). In contrast, there are few studies on the rainwater chemistry of tropical countries (Moreira – Nordemann, 1988; Ayers et al. 2000; Gillett et al., 2000), and many of these have been concentrated in more pristine areas, such as the Amazon Basin (Stall and Edmond, 1981; Lesack and Melock 1991; Williams et al., 1977). Relatively little information is available for developing regions of tropical and sub-tropical areas, where land are changes are intense and followed by rapid urbanization, associated with a large industrial expansion (Moreira – Nodermann et al., 1988). Such information is relevant, since recent estimates show that in a near future more than half of N inputs related to energy consumption in the Earth will take place in tropical and subtropical regions (Galloway et al., 1994). In addition, tropical, terrestrial and aquatic systems appear to function differently from temperate systems, where N limitation is more severe than in the tropics (Martinelli et al., 1999a). Therefore, conclusions based only in studies conducted in temperate regions may not be valid for tropical and sub-tropical regions.

Comparison of the chemical composition of fog water and that of rain water were collected during three conductive winters form the year 2000 to 2003 in Delhi, indicated that nearly all the chemical constituents were higher in fog water than those in rain water except for one case of rainwater. Concentration of nitrate both in fog and temporally nearest rain water samples was nearly the same except for the single rain sample, which indicated that while fog water drags only the lower tropospheric NO_3, rainwater collects an appreciable amount of NO_3^- from aloft as well (Ali, Momin, Safai et al., 2004).

In recent years SO_2, SPM, and NO_x levels over metropolitan cities of India are increasing. Any new industrial sitting powered by coal or fuel oil is likely to contribute further to the ambient levels of these pollutants. During clouding and sub-sequent rain formation sufficient mixing actually takes place in the atmosphere, where by the soluble components of these soil-derived aerosols dissolve in the cloud column influencing the pH value of rainwater. Khemani et al. (1987) took some aeroplane observations and noticed that the raindrops immediately coming out from the cloud possess relatively low pH, but when they reach the earth's surface, the pH decreases. Therefore, the environment through which the rain drops travel plays an important role in deciding the rain acidification at each location. In the tropics, the atmosphere has a high dust load almost through out the year except the coastal belt. Therefore the dust is considered to be an important factor in influencing the pH of the rainfall.

The rainfall weighted pH values of last 11 years in respect of 10 Indian $BAPM_ON$ stations where used along with the pH values and on that basis, iso-pH curves were drawn and finally pH regionalization was made (G.S. Varma, 1989). Thus, on the basis of this study the entire country can be divided into four such zones as follows:

(1) Highly sensitive pH zone (S1);

(2) Moderately sensitive pH zone (S2);

(3) Normal pH zone (N);

(4) High pH zone (H).

Several initiatives were taken to reduce extremely high levels of pollutants present in the ambient air of Delhi. One of the initiatives was to move public transport to CNG, which has been implemented in Delhi since April, 2001. A relative comparison of ambient air concentrations of pollutants, e.g. carbon monoxide (CO), sulphur dioxide (SO_2), suspended particulate matter (SPM), and oxides of nitrogen ($NO_{x\_}$, emitted from transport sector, during the years 1995-2000 (without CNG) and the year 2001 (with CNG) had been made in order to asses the impact of CNG vehicles on ambient air quality in Delhi. It was found that concentration contribution of above pollutants had reduced considerably (P. Goyal, and Sidhartha; 2003).

Daily ambient air quality data from June 1999 to September 2003 from the busiest crossings in Delhi do not indicate an all-round improvement in ambient quality. The NO_x had risen after the conversion whereas SPM and PM_{10} had shown only marginal fall; CO had shown a significant decline (Vinish Kathuria, 2004). Present study is therefore focused to find out whether there has been any change in the rainwater quality vis-à-vis the implementation of CNG as transport fuel in Delhi.

Objective of the study are:

- To study the spatial variation of various chemical parameters of rain water at different locations during monsoon season in Delhi.
- To gain a clear understanding of the rain water chemistry.
- To identify possible sources contributing the chemical composition of rain water.
- To compare the rain water quality before and after the implementation of CNG in Delhi.

CHAPTER – III

STUDY AREA

STUDY AREA

The area of Delhi is extended from 28°53' North latitude and 76°50' east to 77°22' east longitude with total geographical area of 1483 sq km. Delhi is bounded in east by the state of U.P and the remaining three sides are surrounded by the state of Haryana.

The Yamuna River and terminal part of the Aravali hill ranges are the two main geographical features of the city. Delhi is the dividing the between two major river plains of the country, the Ganga-Yamuna plain in the east and the Satluj-Ravi plain in the north.

The Union Territory of Delhi consists of flat and level plains interrupted by cluster of sand dunes and a long continuous chain of rocky ridges. The sand dunes are of varying dimensions and in general trend northeast – southwest. The crests of the dunes generally lie between 6 and 15 meters above the surrounding plains. They are more or less fixed in this area and support vegetation. It appears that they are of longitudinal type and are oriented parallel to the prevailing wind directions.

Physically the National capital territory of Delhi can be divided into 3 segments – the Yamuna flood, plain, the Ridge and the Plain. The Yamuna flood plains are somewhat low-lying and sandy and are subject to recurrent floods. This area is also called Khadar. The ridge constitutes the most dominating physiographic features of this territory. It originates from the Aravali hills of Rajasthan and entering the union territory from the south extends in a northeastern direction. It encircles the city on the north-west. The point near Bhatti has a height of 1045 ft. Tughlaquabad fort is located on one of the highest spurs of ridge. Leaving aside the Yamuna flood plain (khadar) and the ridge, the entire area of the national capital territory of Delhi is categorized as Bangar or the plain.

A major proportion of the area of Delhi is plain and on this are located Delhi, New Delhi and Delhi cantonment along with a vast stretch of numerous villages. The land of the plain is mostly fertile.

The drainage network of Delhi is controlled by River Yamuna. On the east side of river Yamuna there are two drains called eastern Yamuna canal and Hindon cut. The Agra canal originates from river Yamuna in the Southeastern part of Delhi and flows towards Haryana. The Bangar area of Delhi has a major drain named Najafgarh drain, which almost divide the main territory in Northern and Southern parts. Several smaller drains and nalas join the Najafgarh drain at various stages. The Western Yamuna canal, which flows from North to South supports drinking water requirement of citizens of Delhi.

Depending upon the land use pattern the geographical area can be classified into following part:

TABLE 3.1 LAND USE CLASSIFICATION OF DELHI

LAND USE	AREA IN '000 ha	PERCENTAGE
Total geographical area	148	
Reporting area for land utilization	147	100.00
Forests	1	0.68
Not available for cultivation	83	56.46
Permanent pasture and other grazing lands	a	0
Land under misc. tree crops & groves	1	0.68
Culturable wasteland	7	4.76
Fallow land other than current fallows	8	5.44
Current fallows	a	0
Net area sown	47	31.97

a: Below 500 ha

Source: Land use statistics At a Glance 1996-97, Ministry of Agriculture, GOI, 2000

Soil type:

There are four main geographical region of Delhi on the basis of the distribution of soils. In North-West calcareous, silty clay loam is found. In Southern part rocky Aravali ridge and dissected land spreads, while sandy loam is found in southern western part, and in north-east the mixed calcareous, silty, clayey, and sandy-loam is found.

Vegetation:

Hardy evergreen and spinous xerophytic trees and shrubs are most common in the vegetation of the ridge. They are *Prosopis spicigera* ; *Acacia Arabica* wild, *Balanties* *roxburghii, Butea monosperma, Anogeissus pendula, Cassia fistula, Albizia lebbek* e.t.c. *Capparis sepiaria* . is common among larger thorny shrubs. Other shrubs or undershrubs are *Grewia tenax* and *Adhatoda vasica*.

In the alluvial plains, the only timber is Dalbergia sissoo. Other tree such as *Acacia arabica, Ficus benghalensis, Prosopis juliflora, Eucalyptus sp.* etc. are being planted in a big way on the road sides and in new colonies. In the soils covered by recent alluvium tree like *Salvadora persica* and *Eruca sativa* and shrubs like *Calotropis procercera* and grasses like *Erianthus ravennae* and *Saccharum spontaneum* are commonly observed. The common weeds are *Avena fatua* (wild oast), *Cinchrus sp.* (Anjan), *Cypercus rotundus* (Motha), *Phalaris minor* (Chiria) and *Chenopodium album* (Bathua).

Climate and Rainfall:

The climate of the Delhi region is semiarid type, with three well defined seasons. The cold season begins at the end of November, and extends to in early July and continues upto September. The hot summer extends from the end of March to the end of June. The temperature is usually between 21.1°C to 40.5°C during these months. Winters are usually cold and night temperature often fall to 6.5°C during the period between December and February. The average annual temperature recorded in Delhi is 31.5°C based on the records over the period of 70 maintained by the Meteorological Department.

The normal rainfall in Delhi is 611.8mm. The rainfall increases from south west to north east, about 81% of the annual rainfall is received during three monsoon months of July, August, and September, while balance annual rainfall is received as winter rains and as thunderstorm rain during pre and post-monsoon months.

Table 3.2 Average conditions New Delhi, India

Month	Average Sunlight (hours)	Temperature				Discomfort from heat and humidity	Relative humidity		Average Precipitation (mm)	Wet Days (+0.25 mm)
		Average		Record						
		Min	Max	Min	Max		am	pm		
Jan	7	7	21	-1	29	-	72	41	23	2
Feb	9	9	24	0	32	-	67	35	18	2
March	8	14	31	7	39	Medium	49	23	13	1
April	9	20	36	12	46	Medium	35	19	8	1
May	8	26	41	18	46	High	35	20	13	2
June	6	28	39	19	46	Extreme	53	36	74	4
July	6	27	36	22	45	Extreme	75	59	180	8
Aug	6	26	34	22	40	Extreme	80	64	173	8
Sept	7	24	34	18	41	High	72	51	117	4
Oct	9	18	34	11	39	Medium	56	32	10	1
Nov	10	11	29	5	34	Medium	51	31	3	0.2
Dec	9	8	23	1	28	-	69	42	10	1

Table 3.3 : Average rainfall at Delhi

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mm	22.7	20.1	14.5	10.1	15.0	67.9	200.4	200.3	122.5	18.5	3.0	10.0	706.4
Inches	0.9	0.8	0.6	0.4	0.6	2.7	7.9	7.9	4.8	0.7	0.1	0.4	270.8

Source: NEW DELHI / SAFDARJUNG data derived from GHCN 1. 1390 months between 1875 and 1990

Table 3.4: Annual rainfall (in cm) in Delhi (1990-2005).

Year	Rainfall in (cm)
1990	121.1
1991	79.6
1992	43.5
1993	87.4
1994	79
1995	96.6
1996	92.4
1997	75.4
1998	92.6
1999	37.2
2000	69.8
2001	70.3
2002	55.8
2003	115.3
2004	56.8
2005	72.4
Average	**77.825**

Source: IMD (Indian Meteorological Department)

Table 3.5: Rainfall (in mm) in Delhi (July-Sept.,2005).

July	**06/07/2005**	**11/07/2005**	**12/07/2005**	**13/07/2005**	**29/07/2005**
Rainfall(mm)	**62.7**	**75.1**	**20.9**	**133.4**	**19.6**

August	**04/08/2005**	**05/08/2005**	**06/08/2005**	**16/08/2005**	**19/08/2005**	**21/08/2005**
Rainfall(mm)	**9.7**	**13.0**	**1.3**	**4.7**	**0.5**	**3.1**

August	**09/09/2005**	**12/09/2005**	**13/09/2005**	**14/09/2005**	**15/09/2005**	**16/09/2005**	**23/09/2005**	**24/09/2005**
Rainfall(mm)	**1.8**	**0.7**	**5.5**	**14.6**	**37.0**	**28.8**	**16.6**	**17.6**

Source: IMD (Indian Meteorological Department)

Air pollution problem in Delhi

Delhi, the capital city of India, is one of the 10 most polluted cities of world and the third most populated city in India with 13.8 million inhabitants spread over 1483 km^2 (Aneja et al,2001). The population density has increased in last 10 years from 6352 per km^2 in 1991 to nearly 9500 per km^2 in 2005. Its length of 51.9 km and width of 48.5km gives it a circular structure. The transportation network in Delhi is predominantly road based with 1284 km of road per 10 km^2. Its urban area has quadrupled from 182km^2 in 1970s to more than 750 km^2 in 1999 with the number of industries from 26,000 in 1971 to 137,000 in 1997 ([Nils Olof Nylund and Allex (2000)].

The steep increase in vehicular population has resulted in corresponding increase in pollutants emitted by these vehicles. Presently, more than 1300 tonnes of pollutants are emitted by the vehicles plying in Delhi. However, Delhi had six lakhs vehicles in 1982 that became 20 lakhs in 1992, accounting for about 60% of total pollutants being generated in Delhi. Motor vehicles registration rose by 51 times between 1961 and 1991, whereas, the population is increased 4 times over the same period. It has been estimated in 1993, that 2.1 million vehicles have registered in Delhi. The vehicles are expected to touch 26 millions in 2011.

Air pollution is a complex problem as it contains so many known and unknown parameters. The pollutants are added to the environment through various known and unknown natural processes as well as anthropogenic sources viz. industrial process, auto exhaust and domestic sources.

According to the White Paper on the pollution prepared by Ministry of Environment and Forests (MOEF), Government of India, the ambient air quality data of Delhi shows very high values of suspended particles which have been beyond the permissible limits from last several years continuously.

At all monitoring stations set up by Central Pollution Control Board (CPCB), the concentrations of SO_2, NO_x and particulates have been found to be consistently much higher than permissible limits. As things stand, air pollution in the city is largely due to vehicles. Delhi now has more vehicles than Mumbai, Chennai and Calcutta put together. Industries have also been targeted for tacking air pollution in Delhi.

After tacking the issue of industries described as 'hazardous', the Supreme Court directed the Delhi Pollution Control Committee (DPCC) to draw a list of industries that were set up in areas categorized as 'non-conforming' and residential areas. The DPCC submitted its list of 97,600 industries before the court in 1997. The court directed Delhi Government to either shift them to an alternative side or close them down. In addition to shifting of industries, a combination of setting up individual Effluent Treatment Plants (ETPs), methods of control pollution at different levels of production, fiscal measure have been followed in the industrial units.

CPCB points out that the three main thermal power plants use electrostatic precipitators. The emission is controlled. There might be a bit of particulate matter and oxides of sulphur that are released into the air but the problem of pollution from thermal power emission is not acute. Industrial emission too is not alarming. CPCB claims. Delhi does not have any big industries were there in Delhi earlier have been closed down now. Of course, there are about a lakh of small scale industries. The emission levels of these industries, is not much of a problem ([Gulati (2001)].

It is the vehicular pollution, both diesel and well petrol-induced, which continues to be the major problem for the capital, which has the highest number of automobiles in the country.

With the number of vehicles, especially two wheelers, increasing at an unprecedented rate, vehicular pollution has become a major contributor to deteriorating air quality in Delhi. According to White Paper (MOEF), vehicular pollution contributes to 64% of the total pollution in Delhi in 1991 and 70% in 2000-2001.

Geological Details:

The ground water availability in the territory is controlled by the hydrogeological situation characterized by occurrence of alluvial formation and quartzitic hard rocks. The hydrologeological set up and the groundwater occurrence is further influenced by the following distinct physiographic unit:

(1) Alluvial plain on eastern and western sides of ridge

(2) Yamuna river flood plain deposits

(3) Isolated and nearly closed Chattarpur alluvial basin

(4) NNE-SSW trending Quartzitic Ridge.

The Delhi ridge, which is the northern most extension of Aravali mountain range consists of quartzite rocks and extends from southern part of the territory to western bank of river Yamuna for about 35 kms. The alluvial formation overlaying the quartzitic bed rock have different nature on either of the ridge. The Yamuna flood plain contain a distinct river deposits. The nearly closed Chattarpur alluvial basin covers an area of about 48km^2, is occupied by alluvial derived from the adjacent quartzite ridge. The general stratigraphic sequence of the rock formation in Delhi is presented in Table 3.2

Table 3.6 Stratigraphic sequence of rock formation in Delhi

Quaterny	Newer Alluvium	Unconsolidated, interbedded lenses of sand, silt, gravel and clay in narrow flood plain of Yamuna river
	Older Alluvium	Unconsolidated, interbedded lenses of sand, silt, gravel and clay and kankar, moderately sorted. Thickness variable, at places more than 300 meters
Pre-Cambrian	Alwar Quartzits	Well stratified, thick bedded, brown to buff color, hard and compact, intruded locally by pegmatite and quartz veins inter-bedded with mica schist

Fig.3.1: Geology and rock types of Delhi

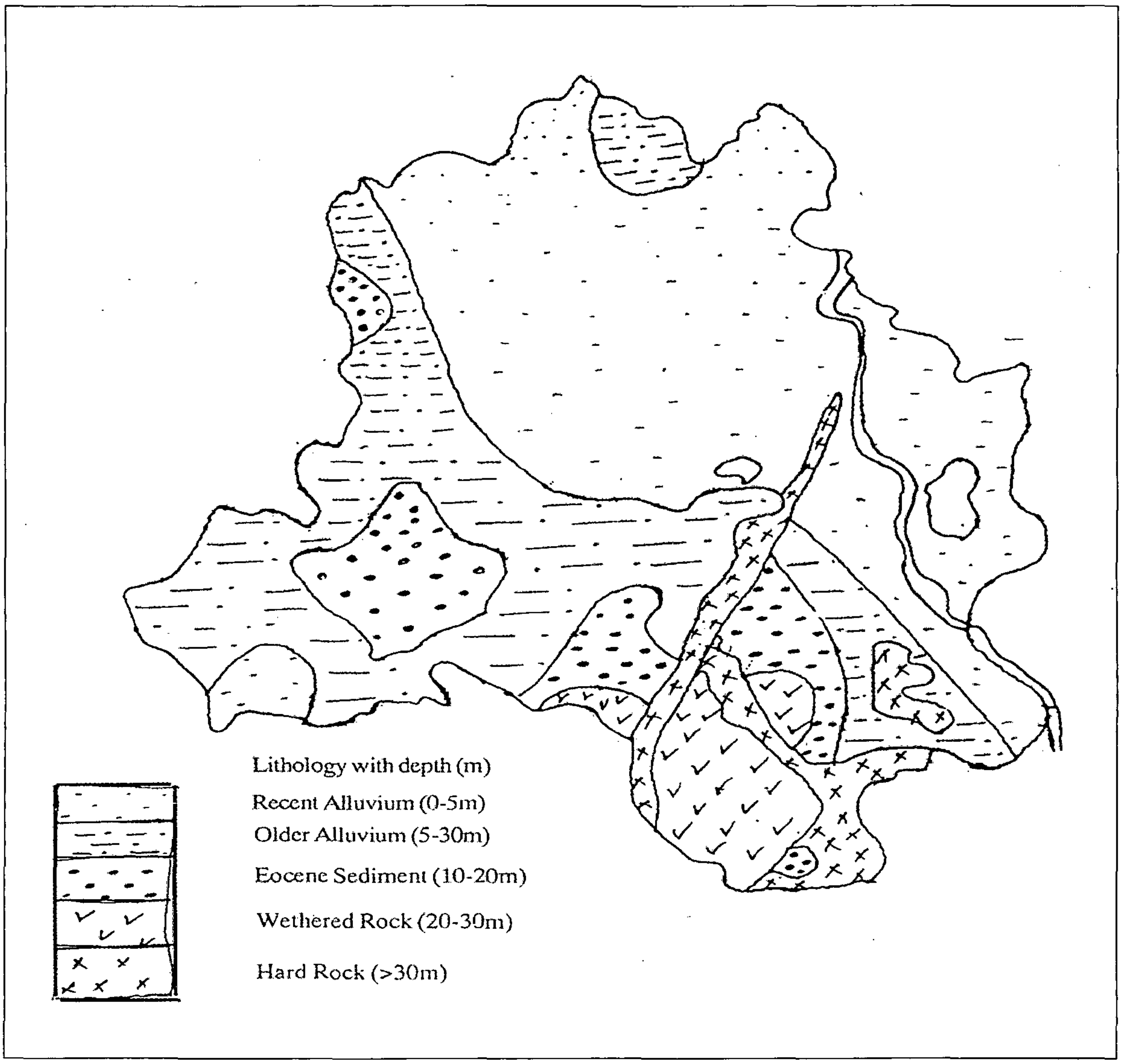

Table 3.7: Description of Sampling Area:

Site	Delhi North	Delhi South	Delhi East	Delhi West	Delhi Central
Name of Location	Mukherjee Nagar, Rohini	J.N.U., A.I.I.M.S., Badarpur,	Shadara, Laxmi Nagar, Okhla	Dwarka	Paharganj, Rajinder Nagar

Table 3.8: Classification of Sampling Location:

Site No.	Area of Study	Specific activity of the area
1.	J.N.U	Institutional area
2.	A.I.I.M.S.	Health Care Centre/Hospital area, Traffic intersection
3	Badarpur	Thermal power plant
4	Okhla	Industrial Area
5	Laxmi Nagar	Residential area
6	Shahdara	Industrial Area
7	Paharganj	Residential/ Commercial area, Heavy Traffic
8	Mukherjee Nagar	Residential cum institutional area
9	Rohini	Residential area
10	Rajinder Nagar	Residential/Commercial area
11	Dwarka	Residential area

Fig. 3.2: Sampling Locations

CHAPTER – IV

MATERIALS AND METHODS

MATERIALS AND METHODS

4.1 Sample Collection

The rainwater samples were collected on event basis with wet only collectors (Khemani et al. 1989), for a period of three monsoon months (July 2005 to September 2005). Care was taken that the collection procedure results in sampling of wet deposition only and not bulk samples. In order to achieve this the collector was opened only during the period of precipitation and closed tightly at other times. Precipitation samples were collected on volume basis. Te collector consists of conical flask (2000 ml), funnel (20 cm diameter) and mesh, to prevent the insects from falling inside. These components were assembled as a single unit. The whole assembly was kept one meter above the ground level to prevent plashing of rain water from the ground. During the dry spell, the funnel was covered to avoid dry deposition.

Rainwater was brought to the laboratory immediately after the collection and pH was determined digital pH meter (Cyberscan 510^{pH}). The pH meter was calibrated after and before each measurement using buffer solution of pH 4.0 and 7.0 respectively. Sample collection equipments used on an event basis were washed with 10% cl and then rimed with double distilled water (D.D.W.). conductivily and T.D.S. of the samples were also measured immediately. The samples were then filtered by whatman No. 41 filter paper and stored in a cold room at 4^0C.(Balachandran and Khillare; 2001, Singh et al., 2001). In precleaned poly propylene bottles, after preconditioning the filter and filter device by rinsing with 20 ml DDW. In order to remove the inorganic contaminants filters were prewashed with 200 ml DDW (Bagchi and Haddad, 1986) and dried at 100^0C, and the filter blanks showed no contamination. The samples were then analysed for major inorganic ions.Samples were collected from 11 location in Delhi described in Chapter III.

pH ,Conductivity And TDS

The pH and conductivity were measured in unfiltered water samples. The pH was measured by (Cyberscan 510 ^{pH}) pH meter. The glass electrode was conditioned (4M KCl as filling solution) and calibrated with buffer solution of pH 4, 7and 9.2. The temperature knob was set in accordance with the temperature of the rain water samples. The samples were stirred continuously in order to maintain homogeneity before noting down the pH.

Conductivity was measured in micro-Siemens/cm (µS/cm) using 'Systronics'Conductivity meter. The instrument was calibrated and set for 0.01m KCl solution (1.413µS/cm at 25°C).

TDS (Total Dissolved Solids) was analyzed by Soil and Water Analysis Kit. The instrument was calibrated and set for 0.01m KCl solution (1.413µS/cm at 25°C).

BICARBONATE

The bicarbonate content was determined following the **potentiometric titration method** (APHA-1995). Bicarbonate standards ranging from 100-1000ppm were prepared from $NaHCO_3$. 50 ml sample and a series of bicarbonate standards were titrated against 0.02N HCl. The end point was noted at pH 4.5. A standard graph was plotted between bicarbonate standards and volume of the acid consumed. The reading of samples was noted down from the graph.

CHAPTER – V

RESULTS AND DISCUSSION

ANION (Chloride, Nitrate and Sulphate)

These anions were analyzed using Metrohm 732 Ion Chromatography.

CATION (Sodium, Potassium, Calcium, Magnesium and Ammonium)

These cations were analyzed using Metrohm 732 Ion Chromatography.

Plate1: CNG vehicles in Delhi

1(a):CNG bus in Delhi

1(b): CNG three-wheelers in Delhi

Plate2:Faulty CNG conversion in Delhi Buses

2(a)CNG Cylinder next to exhaust. 2(b) No stress loops/piping 2(c)Too rigid/Unsupported piping

Plate3:Rainfall in Delhi

Plate 4: Sampling apparatus

RESULTS AND DISCUSSION

5.1 Chemical Composition of Rainwater:

- The measured concentration of major ions in rainwater at various locations in Delhi is given in table 5.1 (a) – (k).
- The correlation between rainwater constituents at various locations has been shown in table 5.2 (a) – (k).
- Sampling events and day are shown in table 5.3.
- Time of sampling at various locations in Delhi for different sampling events has been shown in table 5.4.
- The variation of different chemical constituents with days at various locations has been shown in figure 5.1(a) to 5.11(b).
- Variation of average pH, E.C., and T.D.S. at different location figures in Delhi has been shown in figures 5.12, and 5.13 respectively.
- Percentage occurrence of acidic events over Delhi has been shown in figure 5.14.
- Correlation between T.D.S. and E.C. has been shown in figure 5.15.
- Correlation between (Ca^{2+} + NH_4^+) and (NO_3^- +SO_4^{2-}) has been shown in fig. 5.16.
- Correlation of total cation (tz+) and total anion (tz-) has been shown in fig. 5.17.
- Variation of total cation total anion and ratio of anion & cation ,NO_3^- /SO^{2-}_4 and (Ca^{2+} + NH_4^+)/-(NO_3^- +SO_4^{2-}) has been shown in table 5.5.
- Mean concentration (μeq/l) of major inorganic ions in rainwater at selected sites worldwide along with pH (in pH units) is shown in table 5.6.

Table 5.1(a): Concentration of major ions at J.N.U. (all values are in **μeq/l**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+	[a] tz+	[b] tz-	[c] Ch. Ba.
1	6/7/2005	6.40	158.0	94.3	246.0	61.4	281.0	392.0	612.5	144.0	133.8	113.5	19.8	1023.6	980.4	2.2
2	11/7/2005	6.98	115.2	68.1	58.7	153.0	175.5	350.0	403.5	124.7	121.1	119.1	52.1	820.5	737.2	5.3
3	12/7/2005	6.34	91.8	52.3	42.6	91.3	158.8	265.5	451.3	53.5	11.6	18.2	36.8	571.4	558.2	1.2
4	13/7/2005	6.85	97.0	55.6	73.8	94.9	160.1	277.4	254.5	115.8	191.1	116.5	39.3	717.2	606.2	8.4
5	29/7/2005	6.33	98.2	58.9	46.9	71.7	195.3	286.5	361.5	112.3	70.5	106.0	17.0	667.3	600.4	5.3
6	4/8/2005	7.16	91.6	50.3	13.9	81.2	186.0	248.0	295.6	105.6	108.3	47.4	29.2	586.1	529.1	5.1
7	5/8/2005	7.01	84.5	49.3	92.3	81.8	144.1	209.9	352.8	56.0	85.0	60.8	31.2	585.8	528.1	5.2
8	6/8/2005	6.93	88.3	50.3	60.6	43.9	153.0	272.0	285.8	68.5	187.7	80.4	17.3	639.7	529.5	9.4
9	16/8/2005	6.57	96.5	56.3	95.1	76.8	200.2	228.7	388.9	62.4	129.4	36.8	42.8	660.3	600.8	4.7
10	19/8/2005	6.32	90.5	53.1	95.1	70.8	214.2	190.9	382.4	75.6	85.0	48.8	30.0	621.8	571.0	4.3
11	21/8/2005	6.70	69.0	37.3	13.9	45.6	115.6	198.3	252.3	43.3	65.0	43.9	18.7	423.2	373.4	6.2
12	9/9/2005	6.01	73.2	42.8	105.2	108.0	106.4	168.4	229.2	75.4	78.8	68.7	36.6	488.7	488.0	0.1
13	12/9/2005	6.31	42.0	26.8	43.9	43.5	98.3	83.2	202.4	29.5	57.7	17.8	4.1	311.5	268.9	7.3
14	13/9/2005	5.92	40.2	23.4	73.4	28.7	60.2	99.4	150.6	63.5	12.7	23.3	11.7	261.8	261.7	0.0
15	14/9/2005	6.26	34.3	19.2	32.5	50.3	54.8	62.5	128.0	39.2	26.6	21.7	7.2	222.7	200.0	5.4
16	15/9/2005	6.47	39.0	21.0	44.6	25.4	68.2	83.5	152.6	34.1	30.3	12.3	8.5	237.8	221.7	3.5
17	16/9/2005	5.51	39.8	23.9	90.5	30.1	37.3	122.3	105.6	60.8	37.2	66.0	9.6	279.2	280.2	-0.2
18	23/9/2005	6.18	25.3	15.2	49.2	32.0	42.0	37.7	109.0	44.2	13.8	16.3	8.0	191.3	160.9	8.6
19	24/9/2005	6.20	27.6	16.9	36.2	45.6	40.6	78.4	85.1	93.3	15.0	13.9	18.7	226.0	200.9	5.9
	Max.	7.16	158.0	94.3	246.0	153.0	281.0	392.0	612.5	144.0	191.1	119.1	52.1	1023.6	980.40	
	Min.	5.51	25.3	15.2	13.9	25.4	37.3	37.7	85.1	29.5	11.6	12.3	4.1	191.30	160.88	
	Average	6.44	73.8	42.9	69.2	65.1	131.1	192.3	273.9	73.8	76.9	54.3	23.1	501.89	457.71	
	S.D.	0.42	35.2	20.7	50.8	32.5	69.6	102.4	140.0	33.2	56.5	37.5	13.9	235.11	216.29	
	Kurt.	0.00	0.1	0.4	8.1	1.5	-0.6	-0.9	0.2	-0.6	-0.3	-1.0	-0.8	-0.48	0.18	
	Skew.	-0.16	0.4	0.6	2.4	1.1	0.3	0.2	0.6	0.7	0.7	0.6	0.5	0.36	0.51	

[a] tz+ = total cation

[b] tz- = total anion

[c] Ch.. Ba. = Charge Balance = (tz+ - tz-)/(tz+ + tz-)* 100

Table 5.1(b): Concentration of major ions at A.I.I.M.S. (all values are in **μeq/l**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+	[a] tz+	[b] tz-	[c] Ch. Ba.
1	6/7/2005	6.02	145.2	84.8	118.0	160.5	247.0	384.5	433.5	183.9	195.3	144.8	55.4	1012.9	910.0	5.4
2	11/7/2005	5.25	138.8	76.4	174.4	101.2	244.5	327.7	404.5	167.6	145.3	102.8	25.3	845.5	847.8	-0.1
3	12/7/2005	6.15	106.2	63.8	103.1	81.8	204.1	291.0	352.6	156.9	95.5	80.8	31.2	717.0	680.0	2.6
4	13/7/2005	6.23	110.0	67.5	172.1	83.9	175.0	287.7	333.0	169.7	109.3	84.4	112.9	809.3	718.7	5.9
5	29/7/2005	6.02	108.0	62.6	111.4	70.9	226.8	235.7	292.6	115.6	135.0	101.7	49.3	694.2	644.8	3.7
6	4/8/2005	5.88	98.8	57.8	83.3	67.9	178.7	291.9	298.2	117.2	109.1	76.0	26.3	626.8	621.8	0.4
7	5/8/2005	5.85	88.6	51.2	124.6	50.0	151.5	207.4	251.6	110.6	101.0	66.9	46.6	576.7	533.5	3.9
8	6/8/2005	6.10	88.8	46.0	134.9	61.0	116.0	177.0	261.8	115.8	60.5	62.2	35.9	536.2	488.9	4.6
9	16/8/2005	5.98	56.0	33.3	36.1	38.5	105.0	169.6	186.0	68.5	73.3	53.4	13.4	394.6	349.2	6.1
10	19/8/2005	6.39	62.0	39.0	80.9	43.9	136.0	147.1	195.6	91.2	60.5	42.1	38.9	428.3	407.9	2.4
11	21/8/2005	6.89	60.3	36.8	87.8	36.3	101.9	165.5	185.2	81.4	51.6	68.2	31.8	418.2	391.5	3.3
12	9/9/2005	5.93	60.1	35.6	133.9	39.3	95.2	119.0	175.2	72.5	46.1	72.6	26.5	392.9	387.4	0.7
13	12/9/2005	6.37	42.0	23.9	31.1	42.2	88.5	72.5	87.6	69.5	35.6	46.9	16.2	255.8	234.3	4.4
14	13/9/2005	5.65	34.0	19.4	25.6	38.8	51.4	96.7	74.6	43.5	26.7	50.0	14.6	209.4	212.5	-0.7
15	14/9/2005	6.34	35.6	18.8	24.6	51.0	38.3	92.9	71.2	89.2	8.1	41.2	18.6	228.3	206.8	4.9
16	15/9/2005	6.75	27.9	13.6	13.9	21.5	53.2	45.6	64.6	43.6	11.7	14.6	9.2	143.7	134.2	3.4
17	16/9/2005	6.06	30.6	15.9	38.5	11.2	40.0	69.8	45.3	41.0	26.6	26.9	29.9	169.7	159.5	3.1
18	23/9/2005	6.17	39.6	19.2	14.9	16.8	64.2	95.0	128.4	16.8	12.5	10.8	31.2	199.7	190.9	2.2
19	24/9/2005	6.12	17.5	8.9	7.4	16.9	31.5	29.0	11.5	40.5	10.2	24.8	5.7	92.7	84.8	4.5
	Max.	6.89	145.2	84.8	174.4	160.5	247.0	384.5	433.5	183.9	195.3	144.8	112.9	1012.9	910.0	
	Min.	5.25	17.5	8.9	7.4	11.2	31.5	29.0	11.5	16.8	8.1	10.8	5.7	92.7	84.8	
	Average	6.11	71.0	40.8	79.8	54.4	123.6	174.0	202.8	94.5	69.2	61.6	32.6	460.6	431.8	
	S.D.	0.36	38.7	23.0	54.9	35.5	71.9	104.0	127.1	49.2	52.9	33.4	23.6	268.9	250.6	
	Kurt.	1.56	-0.9	-1.0	-1.3	3.4	-1.1	-0.8	-1.0	-0.8	0.1	0.7	7.2	-0.8	-0.9	
	Skew.	-0.01	0.5	0.4	0.2	1.5	0.4	0.5	0.2	0.4	0.8	0.6	2.3	0.5	0.4	

[a] tz+ = total cation

[b] tz- = total anion

[c] Ch.. Ba. = Charge Balance = (tz+ - tz-)/(tz+ + tz-)* 100

Table 5.1(c): Concentration of major ions at Badarpur (all values are in **μeq/l**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+	[a] tz+	[b]tz-	[c]Ch. Ba.
1	6/7/2005	4.93	152.2	80.5	196.2	150.3	316.0	394.2	505.5	184.7	226.7	97.0	79.0	1092.8	1056.7	1.7
2	11/7/2005	5.20	128.0	72.0	174.9	91.3	355.8	227.7	485.5	157.2	187.3	73.4	29.8	933.2	849.7	4.7
3	12/7/2005	6.00	85.6	45.2	106.5	91.7	188.9	171.3	300.1	101.3	106.1	81.2	31.4	620.1	558.4	5.2
4	13/7/2005	6.72	90.2	47.8	145.9	80.9	178.9	210.6	265.5	99.3	172.3	87.1	62.3	686.5	616.3	5.4
5	29/7/2005	5.99	103.0	54.4	118.0	116.2	223.3	276.9	308.5	125.6	177.7	77.8	49.5	739.1	734.4	0.3
6	4/8/2005	5.81	88.0	47.6	91.8	91.8	210.2	229.2	355.6	100.8	109.4	66.8	40.0	672.6	623.0	3.8
7	5/8/2005	5.95	73.2	39.5	19.7	56.8	207.5	184.5	252.8	77.8	80.6	75.2	21.7	508.1	468.5	4.1
8	6/8/2005	6.77	71.8	41.7	80.3	91.0	176.2	216.4	292.8	77.8	101.3	51.3	49.8	573.0	563.9	0.8
9	16/8/2005	6.81	69.2	40.9	91.8	39.5	184.0	200.9	298.4	65.9	95.5	80.8	31.8	572.4	516.2	5.2
10	19/8/2005	6.90	68.4	37.5	102.6	118.4	109.2	200.6	258.6	85.2	78.8	65.3	46.5	534.4	530.8	0.3
11	21/8/2005	6.81	69.8	35.3	90.2	93.9	116.0	177.1	226.7	61.2	80.5	82.7	38.9	490.0	477.2	1.3
12	9/9/2005	6.11	59.6	29.6	141.5	35.5	91.4	101.7	231.6	43.7	75.6	43.6	14.1	408.6	370.1	4.9
13	12/9/2005	6.39	39.6	22.7	29.5	48.0	102.7	84.2	153.7	26.2	89.4	17.8	9.3	296.4	264.4	5.7
14	13/9/2005	5.78	38.0	24.0	94.3	30.4	93.8	72.2	147.3	48.8	50.0	42.6	10.8	299.5	290.7	1.5
15	14/9/2005	6.08	34.8	17.1	68.9	30.8	41.8	81.9	153.3	17.4	21.2	23.3	28.3	243.5	223.4	4.3
16	15/9/2005	6.82	28.8	15.0	24.6	15.5	74.4	60.9	121.6	23.7	31.6	13.4	3.1	193.4	175.4	4.9
17	16/9/2005	5.31	30.0	18.0	41.8	25.4	75.2	113.5	152.6	34.0	51.2	12.7	9.5	260.0	255.9	0.8
18	23/9/2005	5.73	28.5	17.0	5.7	33.0	76.6	108.0	121.2	22.2	30.5	16.2	39.9	230.0	223.3	1.5
19	24/9/2005	5.80	25.2	14.9	13.0	52.3	56.8	90.0	126.7	23.1	23.8	27.8	19.8	221.2	212.1	2.1
	Max.	6.90	152.2	80.5	196.2	150.3	355.8	394.2	505.5	184.7	226.7	97.0	79.0	1092.8	1056.7	
	Min.	4.93	25.2	14.9	5.7	15.5	41.8	60.9	121.2	17.4	21.2	12.7	3.1	193.4	175.4	
	Average	6.10	67.6	36.9	86.2	68.0	151.5	168.5	250.4	72.4	94.2	54.5	32.4	503.9	474.2	
	S.D.	0.59	35.3	18.7	54.8	37.9	86.6	84.7	113.1	47.6	59.0	28.7	19.8	252.2	239.3	
	Kurt.	-0.76	0.4	0.4	-0.5	-0.7	0.4	1.2	0.5	0.3	0.0	-1.5	0.2	0.1	0.4	
	Skew.	-0.24	0.8	0.8	0.3	0.5	0.9	0.9	0.9	0.9	0.8	-0.3	0.6	0.7	0.8	

[a] tz+ = total cation

[b] tz- = total anion

[c] Ch.. Ba. = Charge Balance = (tz+ - tz-)/(tz+ + tz-)* 100

Table 5.1(d): Concentration of major ions at Okhla (all values are in **μeq/l**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+	[a] tz+	[b]tz-	[c]Ch. Ba.
1	6/7/2005	5.70	182.3	93.1	195.1	152.3	281.2	346.1	600.2	159.7	160.8	94.7	58.4	1073.8	974.7	4.8
2	11/7/2005	4.90	123.5	69.9	144.1	113.5	189.7	329.3	413.0	120.1	127.5	84.7	49.7	795.0	776.6	1.2
3	12/7/2005	5.98	98.9	55.4	108.2	113.4	158.5	211.9	313.2	86.5	137.2	83.9	42.5	663.3	592.0	5.7
4	13/7/2005	5.83	97.5	56.7	139.3	61.0	110.8	336.7	292.5	100.3	85.7	96.4	69.2	644.1	647.8	-0.3
5	29/7/2005	5.83	97.9	48.1	97.4	81.2	180.6	148.1	251.2	107.7	78.3	80.3	29.2	546.7	507.2	3.7
6	4/8/2005	5.34	101.4	53.5	123.0	85.3	121.2	249.6	261.2	104.7	81.1	89.1	48.2	584.3	579.1	0.5
7	5/8/2005	6.15	85.7	47.1	81.5	75.0	151.5	203.3	225.6	65.6	112.0	56.8	42.6	502.6	511.3	-0.9
8	6/8/2005	6.89	67.3	40.6	83.6	67.7	143.0	133.5	212.8	63.2	62.3	80.0	28.4	446.7	427.8	2.2
9	16/8/2005	5.81	71.2	41.1	78.7	29.9	130.2	188.7	202.6	72.8	79.4	46.8	41.0	442.6	427.5	1.7
10	19/8/2005	6.80	66.1	35.5	70.5	67.7	103.0	133.5	195.6	57.2	62.2	36.0	27.4	378.4	374.7	0.5
11	21/8/2005	6.88	72.7	38.3	94.6	61.4	102.6	174.2	234.2	51.3	84.5	20.7	35.8	426.5	432.8	-0.7
12	9/9/2005	6.15	62.6	33.5	57.5	51.7	101.9	141.3	125.0	61.4	86.1	55.2	39.4	367.1	352.4	2.0
13	12/9/2005	5.95	40.8	22.5	38.2	61.9	68.1	73.2	78.8	78.2	21.6	45.6	23.2	247.4	241.4	1.2
14	13/9/2005	6.08	38.5	22.7	37.7	42.3	88.5	72.9	96.9	73.7	43.2	25.8	16.2	255.8	241.4	2.9
15	14/9/2005	6.56	41.2	21.8	37.7	49.0	84.7	64.2	93.0	63.2	61.4	40.8	18.3	276.7	235.6	8.0
16	15/9/2005	6.58	45.9	23.5	34.1	51.9	82.2	91.0	98.4	52.8	71.6	30.8	12.3	265.9	259.2	1.3
17	16/9/2005	5.93	28.0	15.6	36.9	23.7	46.5	60.6	65.1	49.1	38.6	16.8	8.7	178.3	167.6	3.1
18	23/9/2005	6.05	27.6	14.1	5.0	13.0	36.8	90.0	56.7	45.8	13.8	17.8	21.8	155.9	144.8	3.7
19	24/9/2005	6.09	18.3	11.8	24.1	10.4	38.8	52.2	31.1	48.8	18.0	22.6	11.8	132.3	125.5	2.6
	Max.	6.89	182.3	93.1	195.1	152.3	281.2	346.1	600.2	159.7	160.8	96.4	69.2	1073.8	974.7	
	Min.	4.90	18.3	11.8	5.0	10.4	36.8	52.2	31.1	45.8	13.8	16.8	8.7	132.3	125.5	
	Average	6.08	72.0	39.2	78.3	63.8	116.8	163.2	202.5	77.0	75.0	53.9	32.8	441.2	422.1	
	S.D.	0.51	39.8	20.9	48.7	35.6	59.5	95.8	140.5	29.8	39.8	28.5	16.7	240.0	225.4	
	Kurt.	0.51	1.9	1.0	0.2	0.9	1.9	-0.4	2.3	1.9	0.0	-1.6	-0.4	1.2	0.5	
	Skew.	-0.23	1.1	0.9	0.7	0.8	1.1	0.8	1.3	1.4	0.4	0.2	0.4	1.0	0.8	

[a] tz+ = total cation

[b] tz- = total anion

[c] Ch.. Ba. = Charge Balance = (tz+ - tz-)/(tz+ + tz-)* 100

Table 5.1(e): Concentration of major ions at Laxmi Nagar (all values are in µeq/l, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+	[a] tz+	[b] tz-	[c] Ch. Ba.
1	6/7/2005	6.26	185.2	101.9	121.3	159.3	386.6	325.1	435.4	219.0	208.8	169.5	66.1	1098.8	992.3	5.1
2	11/7/2005	6.92	129.2	74.4	249.2	155.6	147.5	284.5	395.6	181.9	187.7	100.8	28.4	894.4	836.8	3.3
3	12/7/2005	6.62	91.2	48.0	41.0	110.0	151.4	206.1	252.6	115.6	112.2	76.9	51.6	608.9	508.5	9.0
4	13/7/2005	6.87	95.7	48.1	73.0	45.5	125.8	267.1	222.5	104.3	134.4	90.0	55.7	606.9	511.4	8.5
5	29/7/2005	4.98	87.2	46.7	111.3	56.8	127.5	236.2	205.8	151.9	90.0	75.2	17.7	540.6	531.8	0.8
6	4/8/2005	5.91	90.0	47.3	127.8	61.8	116.2	226.4	212.8	105.1	113.3	81.3	42.0	554.5	532.2	2.1
7	5/8/2005	6.18	79.7	44.2	82.9	52.6	144.4	200.3	192.8	100.6	108.0	61.0	41.0	503.4	480.2	2.4
8	6/8/2005	6.13	75.4	43.7	111.5	91.7	119.4	171.2	229.8	116.4	76.1	75.2	36.4	533.9	493.7	3.9
9	16/8/2005	6.13	67.6	38.5	71.0	48.4	109.8	190.0	256.0	75.4	43.8	67.8	18.8	461.8	419.2	4.8
10	19/8/2005	6.73	70.4	39.6	84.9	36.3	116.0	177.1	181.9	71.2	60.5	82.7	37.9	434.2	414.3	2.3
11	21/8/2005	6.85	11.5	5.9	4.1	6.7	14.2	32.7	34.2	11.7	8.8	1.8	1.3	57.8	57.7	0.1
12	9/9/2005	5.80	65.7	38.5	64.0	92.3	106.8	165.5	245.3	98.5	35.6	58.2	18.8	456.4	428.6	3.1
13	12/9/2005	5.75	60.2	32.3	59.0	46.2	108.6	108.0	156.0	65.2	28.3	57.4	31.2	338.1	321.8	2.5
14	13/9/2005	6.18	46.0	27.4	58.7	54.0	83.3	92.5	158.1	41.2	21.1	61.3	18.6	300.3	288.5	2.0
15	14/9/2005	6.81	36.7	18.8	48.5	27.0	58.6	46.4	164.0	49.2	25.5	28.6	9.3	276.6	180.5	21.0
16	15/9/2005	6.83	40.2	22.8	38.7	50.7	73.2	87.1	125.2	28.4	36.6	44.3	18.0	252.5	249.7	0.6
17	16/9/2005	6.05	15.4	9.7	22.8	11.8	23.8	40.3	76.5	10.6	5.6	8.3	4.4	105.4	98.7	3.3
18	23/9/2005	5.85	28.5	15.7	26.2	21.7	49.3	65.8	89.2	22.6	18.3	29.2	12.4	171.7	163.0	2.6
19	24/9/2005	6.00	24.8	12.8	19.7	12.2	31.5	72.6	67.3	13.5	8.5	36.9	17.2	143.4	136.0	2.7
	Max.	6.92	185.2	101.9	249.2	159.3	386.6	325.1	435.4	219.0	208.8	169.5	66.1	1098.8	992.3	
	Min.	4.98	11.5	5.9	4.1	6.7	14.2	32.7	34.2	10.6	5.6	1.8	1.3	57.8	57.7	
	Average	6.26	68.4	37.7	74.5	60.0	110.2	157.6	194.8	83.3	69.6	63.5	27.7	438.9	402.4	
	S.D.	0.51	41.9	23.0	55.3	44.0	79.1	88.8	101.7	58.6	60.7	37.2	17.9	262.8	240.4	
	Kurt.	0.47	2.2	2.3	4.7	0.8	8.4	-1.1	1.0	0.1	0.2	2.8	-0.4	1.0	0.9	
	Skew.	-0.6	1.1	1.2	1.8	1.1	2.4	0.2	0.8	0.7	1.0	0.9	0.6	0.8	0.8	

[a] tz+ = total cation

[b] tz- = total anion

[c] Ch.. Ba. = Charge Balance = (tz+ - tz-)/(tz+ + tz-)* 100

Table 5.1(f): Concentration of major ions at Shahadara (all values are in **μeq/l**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+	[a] tz+	[b]tz-	[c]Ch. Ba.
1	6/7/2005	4.95	164.6	79.5	124.6	110.8	327.5	304.5	413.2	157.7	203.6	125.2	22.7	922.4	867.4	3.1
2	11/7/2005	5.35	105.6	64.4	71.6	116.7	205.6	287.7	313.5	110.3	148.6	91.8	48.7	712.9	681.6	2.2
3	12/7/2005	6.98	91.6	49.9	86.5	103.2	137.3	194.5	253.6	103.8	103.6	85.4	39.5	585.9	521.5	5.8
4	13/7/2005	6.02	101.2	53.2	59.0	80.7	187.7	233.2	249.9	118.8	79.4	85.3	61.7	595.1	560.6	3.0
5	29/7/2005	5.63	77.2	42.8	57.4	82.8	155.5	150.7	255.6	85.8	68.3	67.4	29.2	506.3	446.4	6.3
6	4/8/2005	6.02	68.0	44.1	18.0	71.8	163.0	203.5	281.8	77.2	62.2	60.0	28.4	509.6	456.3	5.5
7	5/8/2005	5.32	79.6	47.6	41.0	31.2	180.6	248.0	278.8	51.9	78.2	67.3	28.2	504.4	500.8	0.4
8	6/8/2005	6.56	69.2	43.4	93.3	38.8	173.5	142.2	220.6	102.0	53.1	45.2	31.7	452.6	447.8	0.5
9	16/8/2005	6.15	65.0	39.3	11.1	35.4	174.4	168.9	241.6	53.7	51.6	53.4	12.2	412.5	389.8	2.8
10	19/8/2005	6.88	60.3	37.4	68.0	41.7	109.6	171.7	181.9	92.0	66.1	55.0	35.4	430.4	391.0	4.8
11	21/8/2005	6.16	63.2	35.2	44.3	41.2	108.5	172.5	192.5	63.7	80.5	56.9	13.2	406.8	366.5	5.2
12	9/9/2005	5.83	50.2	30.0	48.4	51.0	115.3	92.9	191.2	42.5	31.1	27.3	21.6	313.7	307.6	1.0
13	12/9/2005	6.15	52.1	31.0	10.7	45.3	129.2	141.3	202.2	48.3	42.2	37.4	17.5	347.6	326.4	3.1
14	13/9/2005	6.25	56.8	32.9	36.1	41.5	117.7	154.2	181.3	51.7	36.7	74.3	31.7	375.7	349.5	3.6
15	14/9/2005	6.67	35.8	19.9	12.3	28.7	62.2	109.4	85.6	43.9	32.7	49.1	11.0	222.3	212.6	2.3
16	15/9/2005	5.06	45.2	26.1	13.9	14.7	79.6	150.0	89.2	42.5	47.7	45.6	39.7	264.7	258.2	1.2
17	16/9/2005	6.18	35.6	17.1	19.7	7.2	52.9	71.8	43.2	42.6	28.8	30.5	11.9	157.0	151.6	1.8
18	23/9/2005	6.35	20.2	12.5	9.5	16.9	35.4	69.0	45.2	29.3	32.2	24.7	5.7	137.1	130.8	2.4
19	24/9/2005	6.56	19.6	11.3	8.2	20.3	47.5	34.9	28.7	19.3	29.2	31.7	8.2	117.1	110.9	2.7
	Max.	6.98	164.6	79.5	124.6	116.7	327.5	304.5	413.2	157.7	203.6	125.2	61.7	922.4	867.4	
	Min.	4.95	19.6	11.3	8.2	7.2	35.4	34.9	28.7	19.3	28.8	24.7	5.7	117.1	110.9	
	Average	6.06	66.4	37.8	43.9	51.6	134.9	163.2	197.3	70.4	67.1	58.6	26.2	419.7	393.5	
	S.D.	0.58	33.8	17.3	33.7	33.2	69.1	72.0	101.6	35.9	44.7	25.8	14.8	203.2	189.5	
	Kurt.	-0.49	2.9	0.6	0.1	-0.5	2.1	-0.2	-0.2	0.2	4.2	1.0	0.3	0.7	0.9	
	Skew.	-0.42	1.3	0.6	0.8	0.8	1.0	0.3	-0.1	0.8	2.0	0.9	0.7	0.6	0.7	

[a] tz+ = total cation

[b] tz- = total anion

[c] Ch.. Ba. = Charge Balance = (tz+ - tz-)/(tz+ + tz-)* 100

Table 5.1(g): Concentration of major ions at Paharganj (all values are in **μeq/l**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+	[a] tz+	[b]tz-	[c]Ch. Ba.
1	6/7/2005	4.88	150.6	85.1	95.7	81.0	313.3	392.9	515.2	115.8	184.7	101.3	18.6	935.6	882.9	2.9
2	11/7/2005	5.78	129.8	69.2	124.6	59.5	281.0	227.4	475.5	102.7	107.2	78.6	22.5	786.5	692.5	6.4
3	12/7/2005	5.77	81.0	45.5	59.8	91.7	109.9	171.3	252.9	82.4	56.7	55.2	36.4	483.6	432.7	5.6
4	13/7/2005	6.11	99.6	59.7	121.3	70.2	222.7	223.5	294.5	80.2	106.1	107.8	51.2	639.8	637.7	0.2
5	29/7/2005	6.21	73.4	43.2	37.7	71.7	152.3	198.5	196.2	72.4	90.5	76.4	25.0	460.5	460.2	0.0
6	4/8/2005	5.6	72.0	41.5	19.7	65.3	145.2	199.0	185.8	82.5	96.1	92.6	23.5	480.5	429.2	5.6
7	5/8/2005	5.58	80.6	48.2	63.9	68.5	195.8	177.0	256.6	62.8	64.4	70.0	60.7	514.5	505.2	0.9
8	6/8/2005	7.08	75.0	44.0	80.3	61.9	168.1	143.2	291.6	63.5	61.6	58.2	22.8	497.7	453.5	4.6
9	16/8/2005	6.88	74.2	41.1	65.9	46.7	136.2	187.1	245.0	78.2	56.6	64.3	18.0	462.1	435.9	2.9
10	19/8/2005	6.71	68.0	37.8	59.3	48.4	109.8	190.0	212.7	82.0	53.8	67.8	18.8	435.1	407.5	3.3
11	21/8/2005	6.96	61.2	35.9	114.6	28.0	105.4	128.4	185.2	86.4	68.8	52.7	22.6	415.7	376.4	5.0
12	9/9/2005	6.37	56.2	34.4	59.0	11.4	126.5	136.5	161.8	42.1	79.4	42.4	31.1	356.8	333.4	3.4
13	12/9/2005	5.93	29.0	13.8	4.3	16.9	45.4	59.0	82.0	9.3	32.2	4.7	5.6	133.8	125.6	3.2
14	13/9/2005	6.45	24.0	13.1	47.4	10.8	34.8	40.3	81.8	10.5	30.5	14.3	3.4	140.5	133.3	2.6
15	14/9/2005	6.71	26.2	14.1	4.4	16.9	36.4	89.0	65.7	29.3	32.2	31.7	5.7	164.6	146.8	5.7
16	15/9/2005	5.87	30.2	18.1	27.7	21.8	56.2	86.7	85.1	25.5	43.3	27.3	5.6	186.8	192.4	-1.5
17	16/9/2005	5.87	36.2	20.8	38.5	41.2	66.6	78.0	86.2	21.8	88.8	27.3	4.2	228.3	224.3	0.9
18	23/9/2005	6.05	17.6	8.8	43.3	16.8	13.2	21.6	55.3	12.5	18.8	8.2	3.0	97.8	94.9	1.5
19	24/9/2005	5.81	15.1	7.9	15.6	18.6	16.9	32.0	41.6	14.3	11.4	18.3	1.4	87.0	83.1	2.3
	Max.	7.08	150.6	85.1	124.6	91.7	313.3	392.9	515.2	115.8	184.7	107.8	60.7	935.6	882.9	
	Min.	4.88	15.1	7.9	4.3	10.8	13.2	21.6	41.6	9.3	11.4	4.7	1.4	87.0	83.1	
	Average	6.14	63.2	35.9	57.0	44.6	122.9	146.4	198.5	56.5	67.5	52.6	20.0	395.1	370.9	
	S.D.	0.56	37.1	21.2	37.1	26.4	85.9	89.3	133.5	34.2	40.3	31.4	16.4	235.5	219.0	
	Kurt.	-0.05	0.4	0.1	-0.6	-1.4	0.0	1.9	0.9	-1.4	2.8	-1.0	0.9	0.1	0.1	
	Skew.	-0.10	0.7	0.6	0.5	0.2	0.7	0.9	1.0	-0.1	1.3	0.1	1.0	0.6	0.6	

[a] tz+ = total cation

[b] tz- = total anion

[c] Ch.. Ba. = Charge Balance = (tz+ - tz-)/(tz+ + tz-)* 100

Table 5.1(h): Concentration of major ions at Mukherjee Nagar (all values are in μeq/l, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+	[a] tz+	[b] tz-	[c] Ch. Ba.
1	6/7/2005	6.40	160.8	85.0	124.6	98.3	357.0	287.7	485.2	107.2	247.7	105.3	23.8	969.2	867.6	5.5
2	11/7/2005	6.60	120.6	65.9	79.7	81.7	289.8	215.8	285.5	112.8	238.3	74.7	21.4	732.7	667.0	4.7
3	12/7/2005	6.80	136.6	77.6	122.9	157.4	271.8	304.8	308.0	193.5	258.3	85.2	60.7	905.7	856.9	2.8
4	13/7/2005	6.05	148.0	83.5	221.3	75.6	336.5	275.8	254.5	191.3	286.1	92.4	58.0	882.3	909.2	-1.5
5	29/7/2005	7.38	103.2	60.1	108.3	61.7	208.9	251.8	252.8	119.4	206.1	85.2	38.4	701.9	630.7	5.3
6	4/8/2005	6.57	105.0	64.6	95.6	56.7	265.6	217.7	381.6	105.4	91.6	66.8	41.7	687.1	635.6	3.9
7	5/8/2005	5.82	91.2	48.7	85.6	78.7	151.9	219.3	258.2	185.3	56.1	25.7	39.4	564.7	535.5	2.7
8	6/8/2005	6.98	75.2	44.7	141.0	41.3	109.8	190.0	265.6	75.8	73.8	87.8	18.8	521.8	482.1	4.0
9	16/8/2005	6.83	72.4	43.7	84.5	59.5	141.0	177.4	234.9	112.7	64.2	78.6	22.4	512.8	462.4	5.2
10	19/8/2005	5.65	68.0	40.6	59.8	63.0	138.1	173.2	212.8	91.5	81.6	45.4	21.0	452.3	434.1	2.0
11	21/8/2005	7.13	63.2	39.7	57.9	19.7	155.9	171.3	248.5	81.5	76.1	35.3	18.4	459.8	404.8	6.4
12	9/9/2005	6.27	60.2	36.5	57.8	65.9	148.0	113.2	238.1	50.5	71.6	35.6	22.8	418.6	384.9	4.2
13	12/9/2005	6.79	44.0	28.8	66.4	23.7	84.6	110.6	151.1	49.2	71.1	28.7	8.7	308.8	285.3	4.0
14	13/9/2005	5.81	40.8	24.0	44.4	21.9	66.0	127.7	149.0	44.2	43.8	31.2	7.2	275.4	260.0	2.9
15	14/9/2005	5.81	33.6	22.5	53.1	18.6	66.9	91.2	116.5	34.3	49.4	28.2	6.4	234.8	229.8	1.1
16	15/9/2005	5.87	31.1	21.4	45.7	17.5	58.9	94.2	111.5	11.2	79.4	21.3	6.5	229.9	216.3	3.1
17	16/9/2005	6.18	31.7	22.8	32.1	25.3	93.1	85.2	172.3	16.4	48.3	12.7	8.5	258.2	235.7	4.5
18	23/9/2005	6.36	28.6	17.2	13.8	20.3	61.5	79.3	138.4	13.2	26.6	4.8	8.2	191.2	174.9	4.5
19	24/9/2005	6.06	21.6	12.9	25.7	15.2	29.8	66.1	98.5	14.4	13.0	8.3	5.8	140.0	136.8	1.1
	Max.	7.38	160.8	85.0	221.3	157.4	357.0	304.8	485.2	193.5	286.1	105.3	60.7	969.2	909.2	
	Min.	5.65	21.6	12.9	13.8	15.2	29.8	66.1	98.5	11.2	13.0	4.8	5.8	140.0	136.8	
	Average	6.39	75.6	44.2	80.0	52.7	159.7	171.2	229.6	84.7	109.6	50.2	23.1	497.2	463.7	
	S.D.	0.50	43.2	22.8	48.9	36.6	100.3	76.0	97.2	59.6	87.7	32.3	17.1	257.1	243.0	
	Kurt.	-0.91	-0.8	-0.9	2.7	2.3	-0.7	-1.2	1.4	-0.6	-0.4	-1.5	0.2	-1.0	-0.8	
	Skew.	0.31	0.6	0.5	1.4	1.3	0.7	0.3	0.9	0.6	1.1	0.2	1.0	0.4	0.5	

[a] tz+ = total cation

[b] tz- = total anion

[c] Ch.. Ba. = Charge Balance = (tz+ - tz-)/(tz+ + tz-)* 100

Table 5.1(i): Concentration of major ions at Rohini (all values are in **μeq/l**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S	HCO_3	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+	[a] tz+	[b] tz-	[c] Ch. Ba
1	6/7/2005	6.82	187.2	97.8	124.0	169.3	306.6	365.2	503.0	182.8	228.3	136.5	66.1	1116.7	965.1	7.3
2	11/7/2005	6.82	147.2	79.0	106.6	169.3	278.8	310.5	303.0	283.7	208.3	106.5	46.1	947.6	865.1	4.6
3	12/7/2005	5.82	106.2	63.0	94.5	67.9	228.7	272.0	275.5	167.4	183.3	87.6	28.3	742.1	663.1	5.6
4	13/7/2005	6.35	116.2	68.4	106.6	105.6	233.7	291.6	345.6	175.9	176.6	76.4	41.7	816.2	737.5	5.1
5	29/7/2005	6.25	96.0	61.6	83.6	96.4	212.5	274.1	312.5	156.0	153.3	60.0	36.1	717.9	666.6	3.7
6	4/8/2005	6.15	92.0	56.1	74.1	71.4	206.4	236.4	296.8	92.1	139.4	93.5	23.1	644.9	588.3	4.6
7	5/8/2005	6.33	78.6	44.3	113.1	95.4	112.5	174.2	206.8	91.2	133.3	69.6	31.1	532.0	495.2	3.6
8	6/8/2005	6.85	80.2	46.7	168.0	67.8	101.8	165.4	182.8	78.2	111.6	167.8	38.8	579.2	503.0	7.0
9	16/8/2005	6.90	67.2	38.1	91.1	31.5	114.4	163.5	171.6	53.7	151.6	43.0	13.1	433.0	400.5	3.9
10	19/8/2005	7.11	70.6	42.7	118.0	34.5	113.8	191.6	196.0	86.5	76.6	69.6	38.7	467.4	457.9	1.0
11	21/8/2005	7.35	56.4	32.7	36.1	30.2	107.3	155.2	213.5	44.0	67.2	46.5	10.6	381.8	328.8	7.5
12	9/9/2005	6.14	68.3	38.0	86.7	35.1	116.6	148.0	236.0	61.5	33.3	77.4	33.2	441.4	386.4	6.6
13	12/9/2005	6.45	60.5	32.3	59.3	28.4	86.5	136.5	152.8	52.1	59.4	43.7	28.1	336.1	310.7	3.9
14	13/9/2005	5.91	55.2	27.6	87.7	25.3	73.1	103.2	152.6	44.1	68.7	33.5	8.2	307.1	289.3	3.0
15	14/9/2005	6.89	52.2	28.1	93.9	19.7	74.7	101.3	176.6	31.5	56.1	39.0	11.1	314.3	289.6	4.1
16	15/9/2005	6.08	11.3	6.6	9.8	6.8	14.2	31.6	51.2	2.3	12.8	2.5	2.1	70.9	62.4	6.3
17	16/9/2005	6.21	35.2	21.0	44.3	11.9	78.2	73.2	128.3	8.6	28.6	29.7	25.6	220.8	207.6	3.1
18	23/9/2005	6.25	36.2	23.2	54.6	18.7	78.2	89.3	198.4	24.0	12.7	10.0	11.0	256.1	240.8	3.1
19	24/9/2005	5.92	37.6	23.9	36.1	14.0	93.0	103.3	148.5	22.9	41.1	21.5	21.6	255.6	246.4	1.8
	Max.	7.35	187.2	97.8	168.0	169.3	306.6	365.2	503.0	283.7	228.3	167.8	66.1	1116.7	965.1	
	Min.	5.82	11.3	6.6	9.8	6.8	14.2	31.6	51.2	2.3	12.7	2.5	2.1	70.9	62.4	
	Average	6.45	76.5	43.7	83.6	57.9	138.5	178.2	223.8	87.3	102.2	63.9	27.1	504.3	458.1	
	S.D.	0.44	41.7	22.6	37.4	49.7	80.2	90.7	99.5	73.9	68.2	42.2	15.8	270.6	238.2	
	Kurt.	-0.8	1.7	0.4	0.4	0.8	-0.4	-0.6	2.4	1.2	-1.2	0.8	0.5	0.0	-0.2	
	Skew.	0.45	1.1	0.8	0.1	1.2	0.8	0.5	1.1	1.2	0.4	0.9	0.6	0.7	0.6	

[a] tz+ = total cation

[b] tz- = total anion

[c] Ch.. Ba. = Charge Balance = (tz+ - tz-)/(tz+ + tz-)* 100

Table 5.1(j): Concentration of major ions at Rajinder Nagar (all values are in µeq/l, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+	[a] tz+	[b] tz-	[c] Ch. Ba
1	6/7/2005	5.55	179.2	104.0	131.1	169.3	396.6	316.5	518.6	185.8	208.8	146.5	66.2	1125.9	1013.5	5.3
2	11/7/2005	5.68	159.6	79.7	124.6	98.9	286.8	295.2	415.6	145.4	185.0	108.7	48.3	903.0	805.5	5.7
3	12/7/2005	6.75	119.8	64.4	106.5	60.9	208.9	310.6	290.0	128.3	172.7	97.2	45.1	733.3	686.9	3.3
4	13/7/2005	6.84	82.4	52.9	24.6	48.7	189.6	280.0	301.2	106.1	77.7	85.6	35.7	606.3	542.9	5.5
5	29/7/2005	5.55	79.2	46.3	131.1	69.3	96.6	216.5	248.6	95.8	108.8	71.5	36.2	560.9	513.5	4.4
6	4/8/2005	6.20	89.8	50.9	24.6	48.7	173.5	242.2	286.2	81.9	83.8	70.7	28.7	551.3	489.0	6.0
7	5/8/2005	6.15	74.4	44.2	127.8	38.0	102.6	214.8	251.9	95.1	74.4	64.3	21.9	507.6	483.2	2.5
8	6/8/2005	6.78	69.6	40.7	123.0	49.2	108.3	162.5	212.8	85.6	84.6	54.7	23.0	460.7	443.0	2.0
9	16/8/2005	6.78	55.4	29.3	41.0	60.9	88.1	113.2	148.0	62.8	71.6	55.6	21.8	359.8	303.2	8.5
10	19/8/2005	6.21	70.5	38.4	90.2	51.7	85.0	209.0	256.8	55.5	60.0	50.4	22.5	445.2	435.9	1.1
11	21/8/2005	6.85	61.0	34.5	48.9	44.6	108.3	162.6	203.2	33.8	49.4	64.8	15.0	366.2	364.4	0.3
12	9/9/2005	6.01	35.8	20.2	36.1	30.4	52.2	91.7	101.1	38.8	30.4	32.6	11.8	214.7	210.4	1.0
13	12/9/2005	6.54	37.2	21.1	29.5	41.2	62.6	88.0	81.2	71.8	31.3	37.4	11.2	232.9	221.3	2.6
14	13/9/2005	6.20	34.5	21.2	52.5	31.2	51.2	96.7	91.4	36.6	19.0	67.8	19.5	234.3	231.6	0.6
15	14/9/2005	6.75	30.8	19.7	30.7	11.5	68.7	91.6	99.5	26.5	16.6	49.5	10.7	202.8	202.5	0.1
16	15/9/2005	6.06	22.0	14.0	22.9	17.0	52.6	46.5	74.1	25.2	15.6	25.6	10.3	150.8	139.0	4.1
17	16/9/2005	5.86	23.0	12.4	14.3	20.2	51.0	44.0	64.1	29.0	15.0	21.2	11.3	140.6	129.5	4.1
18	23/9/2005	5.45	21.2	12.3	5.7	18.8	50.2	46.7	74.6	13.6	16.1	20.0	4.6	128.9	121.4	3.0
19	24/9/2005	6.15	18.6	10.40	10.7	11.6	30.6	51.2	56.2	15.8	8.3	17.4	9.2	106.9	104.0	1.4
	Max.	6.85	179.2	104.0	131.1	169.3	396.6	316.5	518.6	185.8	208.8	146.5	66.2	1125.9	1013.5	
	Min.	5.45	18.6	10.4	5.7	11.5	30.6	44.0	56.2	13.6	8.3	17.4	4.6	106.9	104.0	
	Average	6.23	66.5	37.7	61.9	48.5	119.1	162.1	198.7	70.2	70.0	60.1	23.8	422.7	391.6	
	S.D.	0.48	45.8	25.0	47.2	36.6	94.5	96.3	129.4	47.6	60.9	33.2	16.1	279.9	250.1	
	Kurt.	-1.2	1.1	1.4	-1.5	6.2	3.2	-1.4	0.5	0.3	0.5	1.2	1.2	0.8	0.6	
	Skew.	-0.1	1.2	1.2	0.5	2.2	1.8	0.3	0.9	0.9	1.2	0.9	1.2	1.0	1.0	

[a] tz+ = total cation

[b] tz- = total anion

[c] Ch.. Ba. = Charge Balance = (tz+ - tz-)/(tz+ + tz-)* 100

Table 5.1(k):Concentration of major ions at Dwarka (all values are in μeq/l, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+	[a] tz+	[b] tz-	[c] Ch. Ba.
1	6/7/2005	6.02	170.50	95.9	95.9	164.5	308.5	351.3	540.0	208.7	173.8	102.8	83.0	1108.3	998.1	5.2
2	11/7/2005	6.25	158.00	73.4	73.4	115.7	255.0	309.0	451.0	180.5	120.7	90.4	39.4	882.0	788.6	5.6
3	12/7/2005	6.05	167.20	74.4	74.4	81.2	280.6	308.0	395.6	131.8	118.3	70.4	62.3	778.4	764.2	0.9
4	13/7/2005	6.21	110.23	62.8	62.8	91.7	208.3	262.6	381.5	116.5	94.4	84.7	31.0	708.1	650.0	4.3
5	29/7/2005	6.15	101.20	62.3	62.3	91.7	218.3	282.5	335.6	106.5	104.4	84.7	29.0	660.2	685.0	-1.8
6	4/8/2005	6.25	89.80	55.7	55.7	45.7	185.0	209.0	251.0	120.5	120.7	90.4	39.4	622.0	588.7	2.8
7	5/8/2005	6.11	78.70	48.1	48.1	30.8	148.7	221.9	249.8	117.4	103.3	66.8	28.3	565.6	500.3	6.1
8	6/8/2005	7.32	75.60	44.3	44.3	26.0	131.9	198.2	216.8	71.2	114.8	48.2	39.8	490.8	445.4	4.8
9	16/8/2005	7.13	76.20	40.4	40.4	34.7	110.5	180.0	196.6	80.2	107.7	55.6	38.7	478.8	403.0	8.6
10	19/8/2005	7.17	69.20	39.4	39.4	55.9	79.5	168.5	162.8	123.2	94.4	41.5	64.6	486.5	425.5	6.7
11	21/8/2005	6.78	48.60	30.5	30.5	32.1	97.3	95.2	123.2	43.8	87.2	41.8	31.6	327.6	311.9	2.4
12	9/9/2005	5.75	42.40	27.0	27.0	38.8	88.7	96.7	124.3	63.6	66.1	30.0	15.7	299.7	262.6	6.6
13	12/9/2005	6.15	54.56	32.1	32.1	38.0	85.4	168.4	112.4	56.4	118.8	32.1	36.6	356.3	323.3	4.9
14	13/9/2005	6.24	43.60	26.2	26.2	41.8	73.5	142.2	123.8	32.0	83.8	20.4	31.7	291.7	270.0	3.9
15	14/9/2005	6.11	48.00	24.6	24.6	34.8	69.7	100.0	113.4	16.2	77.7	25.2	37.7	270.2	247.0	4.5
16	15/9/2005	6.16	31.22	18.5	18.5	13.5	55.3	74.2	91.9	21.5	59.6	18.8	5.1	196.9	181.2	4.2
17	16/9/2005	5.79	32.25	17.8	17.8	35.4	72.4	61.0	101.6	23.7	35.0	13.2	12.1	185.6	187.4	-0.5
18	23/9/2005	6.62	30.20	17.9	17.9	12.2	67.5	72.6	117.6	12.5	30.5	16.9	17.2	194.7	174.2	5.6
19	24/9/2005	6.12	33.80	21.0	21.0	10.5	71.5	108.0	126.1	18.5	53.3	13.4	15.6	226.9	213.1	3.1
	Max.	7.32	170.5	95.9	95.9	164.5	308.5	351.3	540.0	208.7	173.8	102.8	83.0	1108.3	998.1	
	Min.	5.75	30.2	17.8	17.8	10.5	55.3	61.0	91.9	12.5	30.5	13.2	5.1	185.6	174.2	
	Average	6.34	76.9	42.7	42.7	52.4	137.2	179.4	221.8	81.3	92.9	49.9	34.7	480.5	443.1	
	S.D.	0.45	45.9	22.6	22.6	39.7	80.7	90.3	135.8	57.6	34.4	30.1	19.2	260.4	241.5	
	Kurt.	0.32	0.1	0.0	0.0	2.3	-0.4	-1.0	0.1	-0.3	0.6	-1.3	1.2	0.2	-0.2	
	Skew.	1.12	1.1	0.8	0.8	1.5	1.0	0.4	1.1	0.6	0.1	0.4	0.9	0.9	0.8	

[a] tz+ = total cation

[b] tz- = total anion

[c] Ch.. Ba. = Charge Balance = (tz+ - tz-)/(tz+ + tz-)* 100

Table 5.2(a): Correlation of J.N.U. data

	pH	*E.C.*	*T.D.S.*	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
pH	1											
E.C.	0.49	1										
T.D.S.	0.47	0.99	1									
HCO_3^-	0.12	0.71	0.71	1								
Cl^-	0.49	0.92	0.91	0.64	1							
SO_4^{2-}	0.47	0.97	0.95	0.73	0.29	1						
NO_3^-	0.51	0.96	0.95	0.73	0.08	0.99	1					
Ca^{2+}	0.35	0.68	0.70	0.23	0.31	0.59	0.59	1				
Mg^{2+}	0.33	0.69	0.72	0.22	0.23	0.59	0.59	0.77	1			
NH_4^+	0.40	0.53	0.56	0.53	0.40	0.46	0.49	0.95	0.24	1		
Na^+	0.47	0.69	0.74	0.26	0.03	0.60	0.60	0.56	0.53	0.54	1	
K^+	0.47	0.94	0.93	0.76	0.06	0.99	0.99	0.53	0.52	0.46	0.52	1

Table 5.2(b): Correlation of A.I.I.M.S. data

	pH	*E.C.*	*T.D.S.*	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
pH	1											
E.C.	-0.15	1										
T.D.S.	-0.17	0.99	1									
HCO_3^-	0.16	0.77	0.79	1								
Cl^-	-0.13	0.83	0.86	0.65	1							
SO_4^{2-}	-0.21	0.85	0.87	0.64	0.51	1						
NO_3^-	0.00	0.92	0.90	0.82	0.63	0.81	1					
Ca^{2+}	-0.34	0.75	0.81	0.43	-0.02	0.51	0.39	1				
Mg^{2+}	-0.38	0.83	0.84	0.56	0.46	0.64	0.43	0.83	1			
NH_4^+	-0.46	0.80	0.81	-0.02	0.50	0.75	0.55	0.84	0.32	1		
Na^+	-0.47	0.79	0.80	0.45	0.64	0.13	-0.02	0.56	0.89	0.56	1	
K^+	0.00	0.87	0.85	0.79	0.14	0.34	0.39	0.40	0.59	0.48	0.44	1

Table 5.2(c): Correlation of Badarpur data

	pH	*E.C.*	*T.D.S.*	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
pH	1											
E.C.	-0.29	1										
T.D.S.	-0.22	0.98	1									
HCO_3-	0.46	0.42	0.43	1								
Cl^-	0.18	0.66	0.70	0.74	1							
SO_4^{2-}	0.04	0.77	0.78	0.46	0.67	1						
NO_3^-	0.31	0.63	0.67	0.76	0.76	0.80	1					
Ca^{2+}	-0.51	0.84	0.85	0.48	0.25	0.55	0.19	1				
Mg^{2+}	-0.50	0.81	0.84	0.37	0.27	0.50	0.31	0.98	1			
NH_4^+	-0.47	0.88	0.89	0.06	0.36	0.60	0.71	0.87	0.57	1		
Na^+	-0.38	0.90	0.89	0.13	0.37	0.44	0.43	0.54	0.42	0.45	1	
K^+	-0.27	0.88	0.94	0.18	0.57	0.32	0.53	0.48	0.62	0.52	0.67	1

Table 5.2 (d): Correlation of Okhla data

	pH	*E.C.*	*T.D.S.*	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
pH	1											
E.C.	-0.44	1										
T.D.S.	-0.48	0.97	1									
HCO_3^-	0.12	0.66	0.58	1								
Cl^-	-0.39	0.91	0.93	0.73	1							
SO_4^{2-}	-0.28	0.76	0.83	0.38	0.67	1						
NO_3^-	-0.40	0.90	0.92	0.72	0.79	0.78	1					
Ca^{2+}	-0.41	0.82	0.91	0.43	-0.05	0.44	0.47	1				
Mg^{2+}	-0.54	0.72	0.82	0.30	0.39	0.59	0.39	0.92	1			
NH_4^+	-0.49	0.81	0.90	0.30	0.43	0.60	0.71	0.76	0.47	1		
Na^+	-0.51	0.75	0.83	0.36	0.44	0.35	0.34	0.58	0.48	0.46	1	
K^+	-0.40	0.88	0.91	0.69	0.39	0.22	0.49	0.75	0.65	0.40	0.72	1

Table 5.2(e): Correlation of Laxmi Nagar data

	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
pH	1											
E.C.	0.12	1										
T.D.S.	0.04	0.99	1									
HCO_3^-	0.27	0.82	0.81	1								
Cl^-	0.15	0.96	0.95	0.86	1							
SO_4^{2-}	-0.06	0.84	0.86	0.49	0.75	1						
NO_3^-	0.14	0.98	0.96	0.84	0.56	0.79	1					
Ca^{2+}	0.10	0.90	0.91	0.40	0.31	0.52	0.43	1				
Mg^{2+}	-0.03	0.93	0.95	0.41	0.45	0.40	0.57	0.92	1			
NH_4^+	0.09	0.92	0.92	0.34	0.32	0.79	0.85	0.77	0.53	1		
Na^+	0.01	0.91	0.93	0.23	0.53	0.35	0.47	0.59	0.88	0.84	1	
K^+	0.15	0.87	0.84	0.30	0.58	0.39	0.40	0.69	0.75	0.72	0.83	1

Table 5.2 (f): Correlation of Shahdara data

	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
pH	1											
E.C.	-0.34	1										
T.D.S.	-0.42	0.99	1									
HCO_3^-	0.13	0.78	0.73	1								
Cl^-	-0.25	0.93	0.93	0.79	1							
SO_4^{2-}	-0.29	0.74	0.76	0.45	0.74	1						
NO_3^-	-0.13	0.84	0.83	0.80	0.90	0.92	1					
Ca^{2+}	-0.35	0.64	0.65	0.26	0.41	0.56	0.34	1				
Mg^{2+}	-0.47	0.79	0.80	0.44	0.65	0.58	0.54	0.77	1			
NH_4^+	-0.47	0.57	0.59	0.19	0.30	0.28	0.24	0.79	0.68	1		
Na^+	-0.39	0.73	0.76	0.36	0.54	0.55	0.52	0.83	0.73	0.84	1	
K^+	-0.22	0.94	0.93	0.81	0.99	0.74	0.89	0.41	0.63	0.30	0.53	1

Table 5.2 (g): Correlation of Paharganj data

	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
pH	1											
E.C.	-0.39	1										
T.D.S.	-0.39	0.99	1									
HCO_3^-	0.16	0.68	0.72	1								
Cl^-	-0.21	0.63	0.69	0.60	1							
SO_4^{2-}	-0.32	0.92	0.94	0.70	0.61	1						
NO_3^-	-0.55	0.94	0.96	0.69	0.69	0.83	1					
Ca^{2+}	-0.34	0.82	0.80	0.44	0.28	0.77	0.72	1				
Mg^{2+}	-0.01	0.71	0.69	0.35	0.28	0.69	0.54	0.85	1			
NH_4^+	-0.51	0.78	0.73	0.27	0.17	0.68	0.71	0.60	0.42	1		
Na^+	-0.18	0.80	0.76	-0.05	0.42	0.79	0.41	0.45	0.91	0.47	1	
K^+	-0.04	0.64	0.70	0.24	0.75	0.40	0.45	0.46	0.52	0.23	0.61	1

Table 5.2 (h): Correlation of Mukherjee Nagar data

	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
pH	1											
E.C.	0.34	1										
T.D.S.	0.33	0.98	1									
HCO_3^-	0.13	0.88	0.85	1								
Cl^-	0.27	0.84	0.78	0.67	1							
SO_4^{2-}	0.29	0.96	0.95	0.87	0.89	1						
NO_3^-	0.32	0.96	0.91	0.82	0.78	0.89	1					
Ca^{2+}	0.22	0.50	0.64	0.25	0.39	0.26	0.48	1				
Mg^{2+}	0.35	0.90	0.85	0.13	0.18	-0.02	-0.05	0.77	1			
NH_4^+	0.40	0.80	0.82	-0.05	0.66	0.84	0.67	0.86	0.32	1		
Na^+	0.27	0.83	0.87	-0.11	0.58	0.41	0.34	0.52	0.71	0.58	1	
K^+	0.34	0.94	0.89	0.31	0.43	0.36	0.29	0.42	0.73	0.33	0.73	1

Table 5.2 (i): Correlation of Rohini data

	pH	E.C.	T.D.S	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
pH	1											
E.C.	0.27	1										
T.D.S	0.27	1.00	1									
HCO_3^-	0.42	0.88	0.88	1								
Cl^-	0.19	0.88	0.86	0.70	1							
SO_4^{2-}	0.20	0.96	0.97	0.81	0.80	1						
NO_3^-	0.33	0.92	0.92	0.82	0.85	0.82	1					
Ca^{2+}	0.09	0.85	0.87	0.60	0.34	0.53	0.44	1				
Mg^{2+}	0.14	0.87	0.87	-0.25	0.57	0.55	0.32	0.63	1			
NH_4^+	0.27	0.86	0.87	0.43	0.62	0.68	0.76	0.70	0.42	1		
Na^+	0.35	0.58	0.61	0.24	0.57	-0.02	0.39	0.55	0.55	0.45	1	
K^+	0.34	0.90	0.90	0.41	0.41	0.29	-0.02	0.62	0.51	0.35	0.44	1

Table 5.2 (j): Correlation of Rajinder Nagar data

	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
pH	1											
E.C.	-0.18	1										
T.D.S.	-0.25	0.98	1									
HCO_3^-	-0.08	0.61	0.61	1								
Cl^-	-0.26	0.90	0.90	0.63	1							
SO_4^{2-}	-0.30	0.88	0.90	0.59	0.90	1						
NO_3^-	0.09	0.89	0.84	0.63	0.70	0.77	1					
Ca^{2+}	-0.38	0.86	0.91	0.33	0.50	0.42	0.39	1				
Mg^{2+}	-0.22	0.93	0.94	0.39	0.45	0.50	0.34	0.93	1			
NH_4^+	-0.15	0.87	0.89	0.34	0.81	0.72	0.71	0.71	0.46	1		
Na^+	-0.13	0.91	0.93	-0.02	0.52	-0.02	0.29	0.41	0.65	0.45	1	
K^+	-0.18	0.85	0.88	0.28	-0.01	-0.04	0.42	0.57	0.33	0.57	0.64	1

Table 5.2 (k): Correlation of Dwarka data

	pH	*E.C.*	*T.D.S.*	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
pH	1											
E.C.	0.07	1										
T.D.S.	0.01	0.99	1									
HCO_3^-	0.46	0.54	0.50	1								
Cl^-	-0.22	0.90	0.92	0.68	1							
SO_4^{2-}	-0.17	0.86	0.89	0.75	0.89	1						
NO_3^-	0.14	0.85	0.86	0.68	0.68	0.84	1					
Ca^{2+}	-0.21	0.88	0.88	0.20	0.45	0.55	0.56	1				
Mg^{2+}	0.01	0.89	0.91	0.37	0.36	0.89	0.70	0.84	1			
NH_4^+	-0.21	0.81	0.86	0.15	0.66	0.96	0.59	0.81	0.38	1		
Na^+	-0.17	0.84	0.88	0.26	0.57	0.91	-0.01	0.44	0.40	0.48	1	
K^+	0.18	0.83	0.83	-0.16	0.39	0.73	0.28	0.35	0.63	0.35	0.60	1

Table 5.3: Sampling Event and Day :

Sampling Event	Day
1	6/7/2005
2	11/7/2005
3	12/7/2005
4	13/7/2005
5	29/7/2005
6	4/8/2005
7	5/8/2005
8	6/8/2005
9	16/8/2005
10	19/8/2005
11	21/8/2005
12	9/9/2005
13	12/9/2005
14	13/9/2005
15	14/9/2005
16	15/9/2005
17	16/9/2005
18	23/9/2005
19	24/9/2005

Table 5.4: Table showing time of sampling (IST) at different locations for different sampling events:

Sampling event/Location	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	1
J.N.U.	845	1600	1200	1400	2000	1300	1500	700	600	1615	1215	1430	1200	830	930	530	630	930	10
AIIMS	530	2100	1400	1400	645	1200	930	530	1700	1430	1530	1630	1700	730	930	1000	1030	1330	21
Badarpur	930	2100	1200	1400	830	1430	1000	630	600	1400	1500	930	2130	830	730	1230	1230	1430	20
Okhla	630	2000	1530	1430	930	1530	1400	730	600	1430	1300	730	2000	930	800	1400	1100	1530	22
Laxmi Nagar	730	2200	1430	1500	1000	1630	1200	830	1800	1200	1500	830	2030	830	900	1500	1130	1300	23
Paharganj	830	2000	1330	1500	1100	1500	1500	930	1500	1200	630	830	1830	600	600	1600	1230	1200	930
Mukherjee Nagar	1030	2200	1530	1630	1200	730	1600	1000	1200	1900	1800	1000	1700	700	830	1400	1530	1330	15
Rohini	1100	1630	1630	1830	1230	1500	1800	1030	1300	1800	1900	1000	1400	530	930	1430	1630	1000	12
Rajinder Nagar	1200	2030	1600	1900	1300	1530	1800	1200	1600	2130	1830	1600	1500	630	630	630	1400	1230	15
Dwarka	1530	2130	1900	1630	1330	1630	1900	1500	1900	2100	1830	1530	1530	530	700	830	1300	1430	16

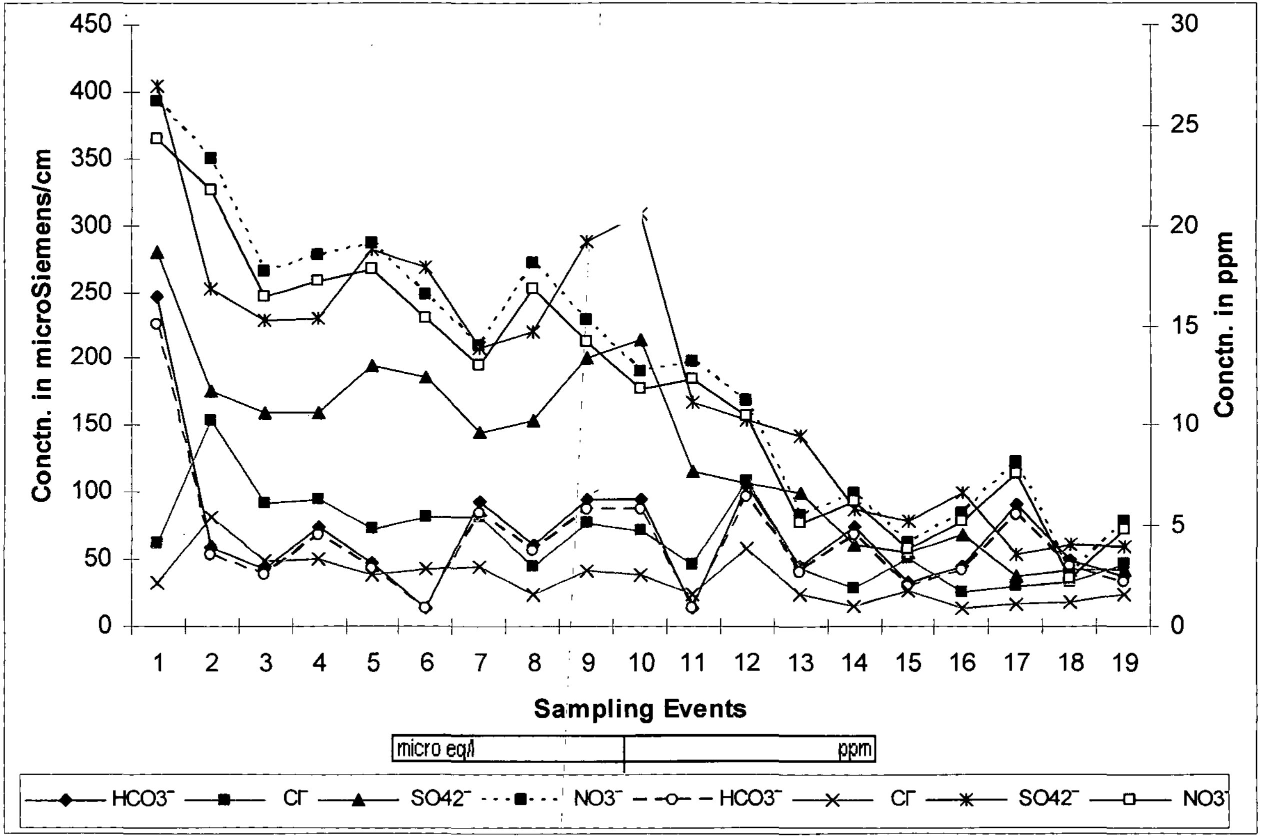

Fig. 5.1(a):Variation of different chemical constituents with days at J.N.U

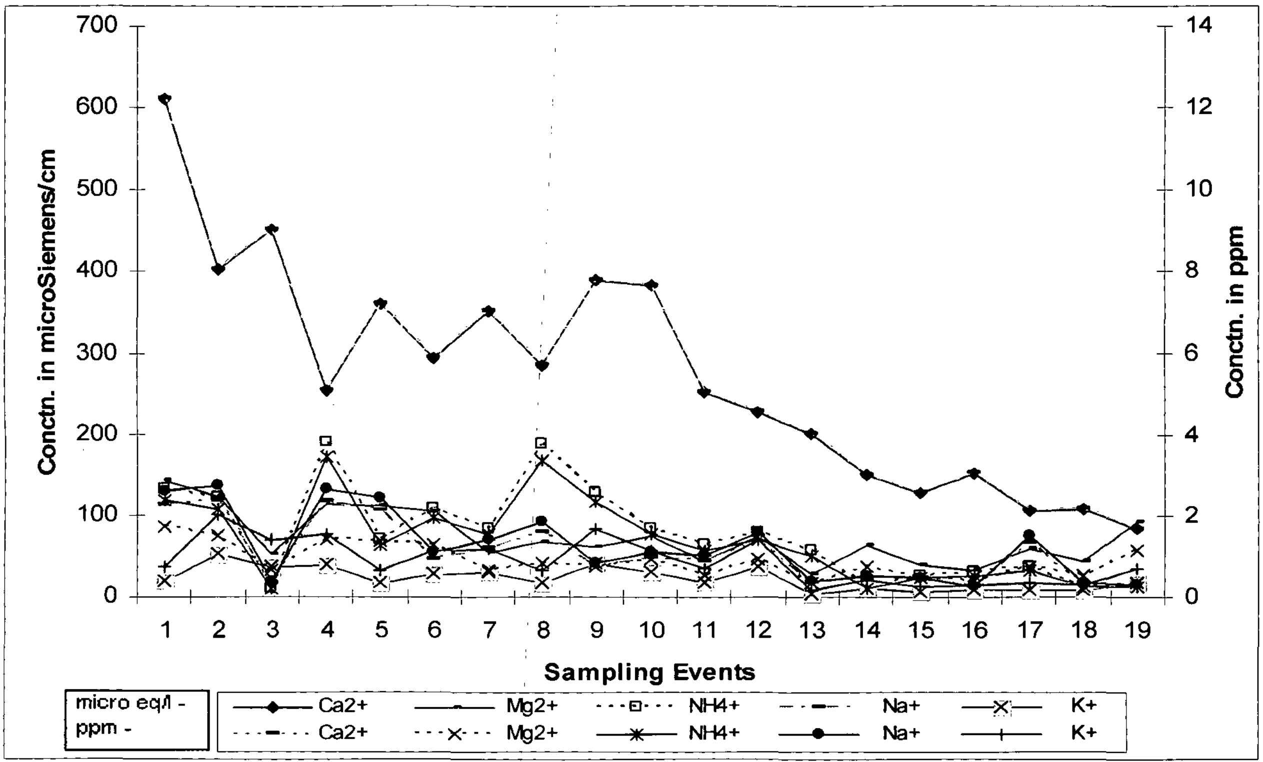

Fig. 5.1(b): Variation of different chemical constituents with days at J.N.U.

Note: Sampling Event 1- 06/07/2005……………………………….,Sampling Event 19 – 19/09/2005.

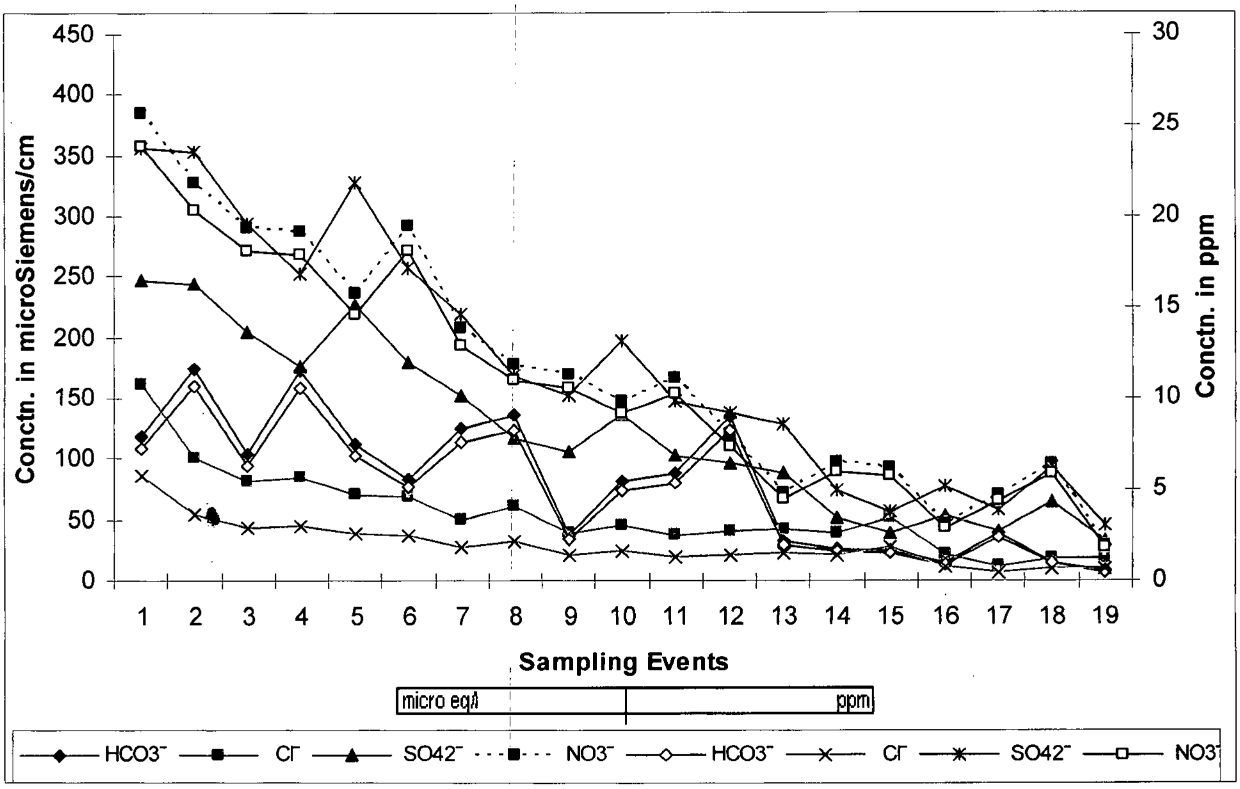

Fig. 5.2(a): Variation of different chemical constituents with days at AIIMS.

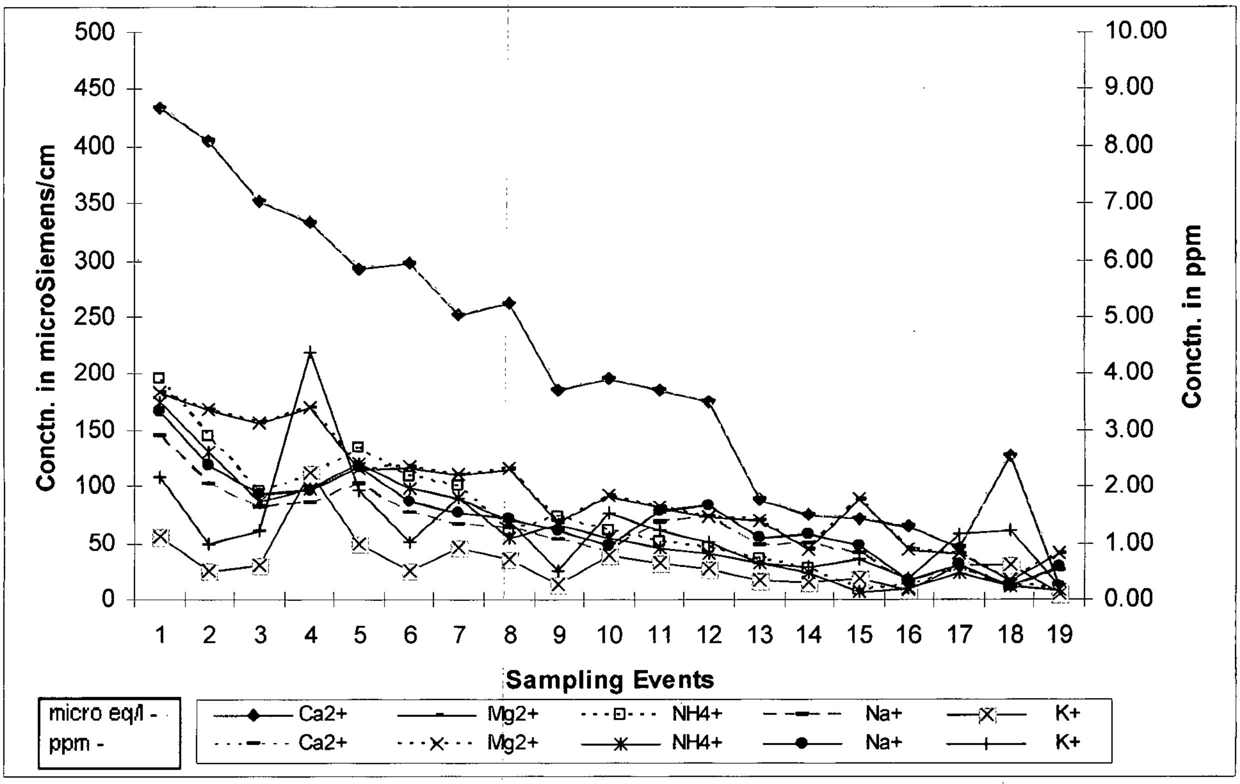

Fig. 5.2(b): Variation of different chemical constituents with days at AIIMS.
Note: Sampling Event 1- 06/07/2005............................,Sampling Event 19 – 19/09/2005.

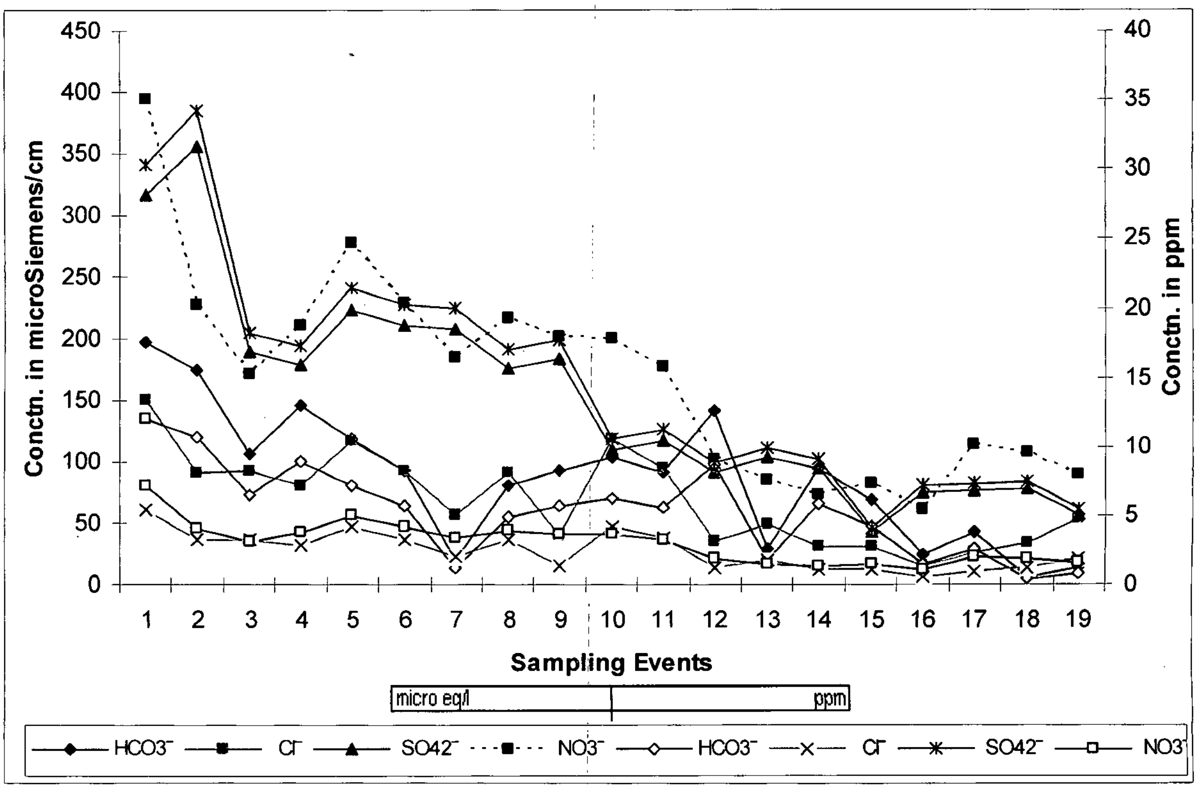

Fig. 5.3(a): Variation of different chemical constituents with days at Badarpur.

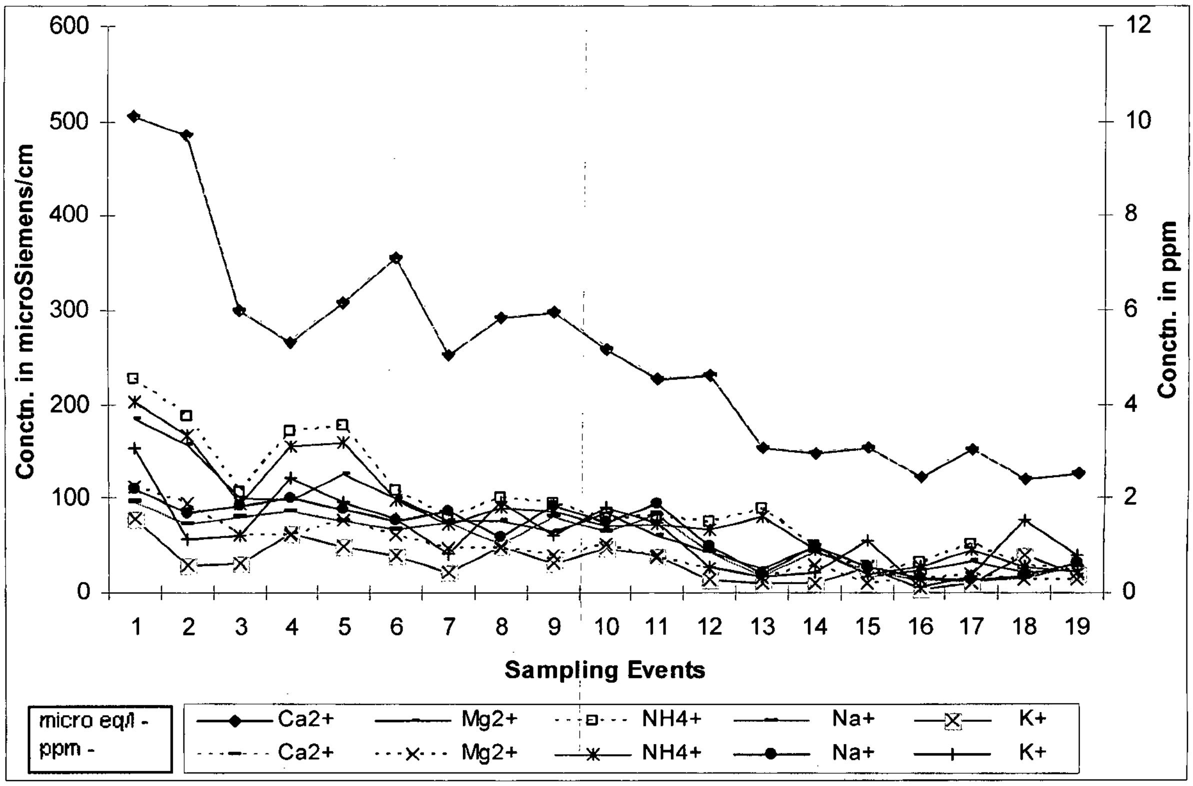

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Fig. 5.3(b): Variation of different chemical constituents with days at Badarpur.
Note: Sampling Event 1- 06/07/2005…………………………….,Sampling Event 19 – 19/09/2005.

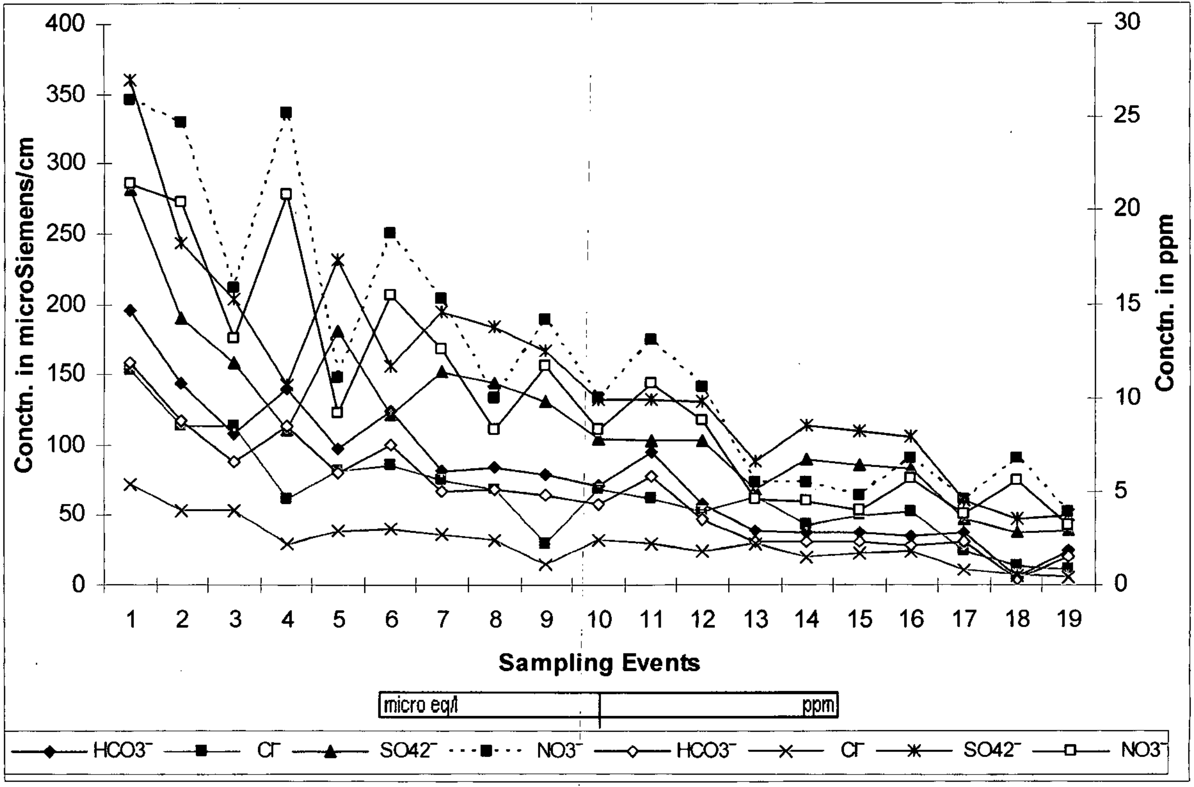

Fig. 5.4(a): Variation of different chemical constituents with days at Okhla.

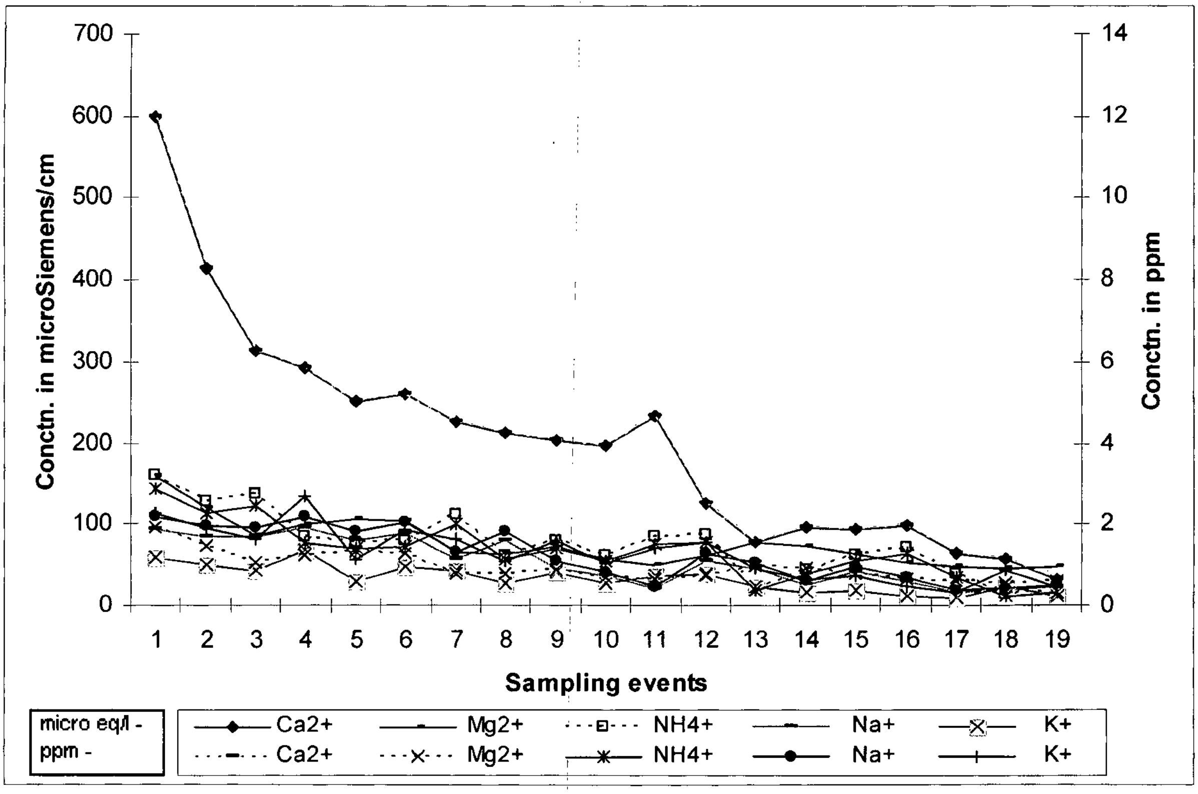

Fig. 5.4(b): Variation of different chemical constituents wih days at Okhla

Note: Sampling Event 1- 06/07/2005.............................., Sampling Event 19 – 19/09/2005.

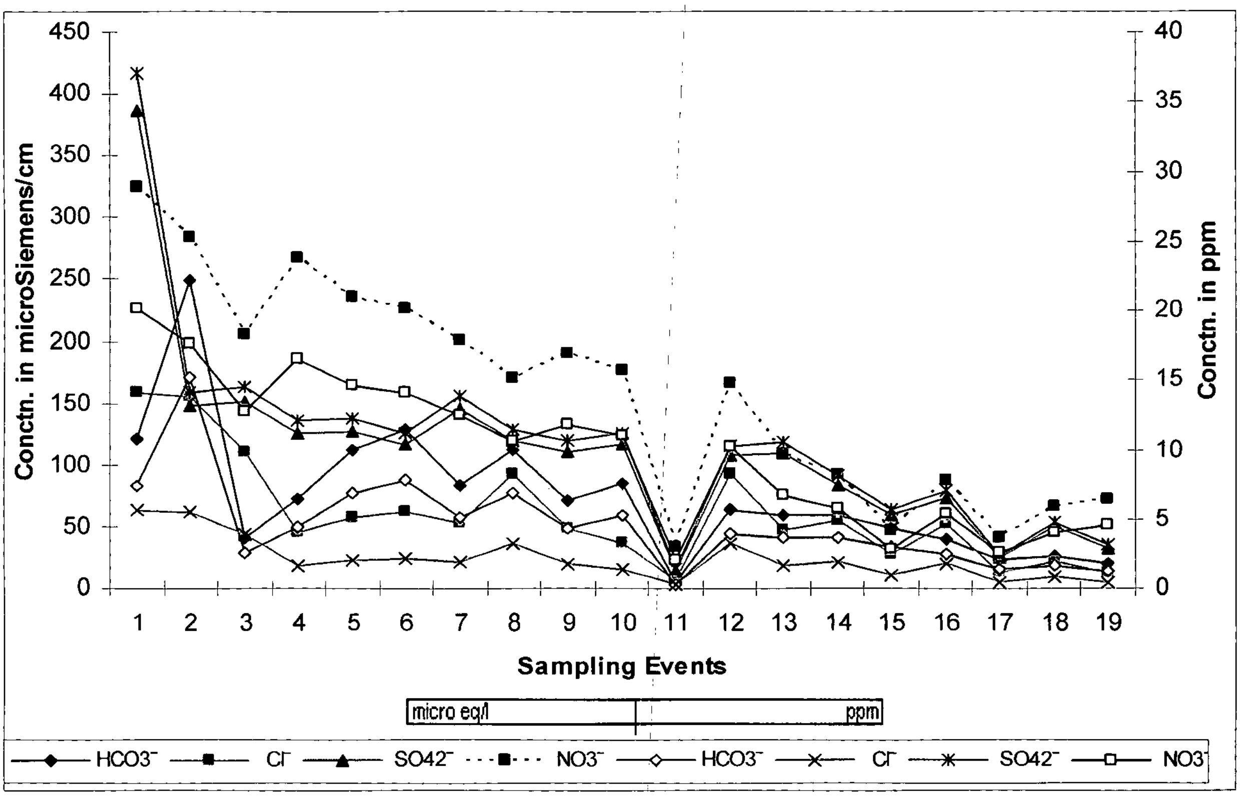

Fig. 5.5(a): Variation of different chemical constituents with days at Laxmi Nagar.

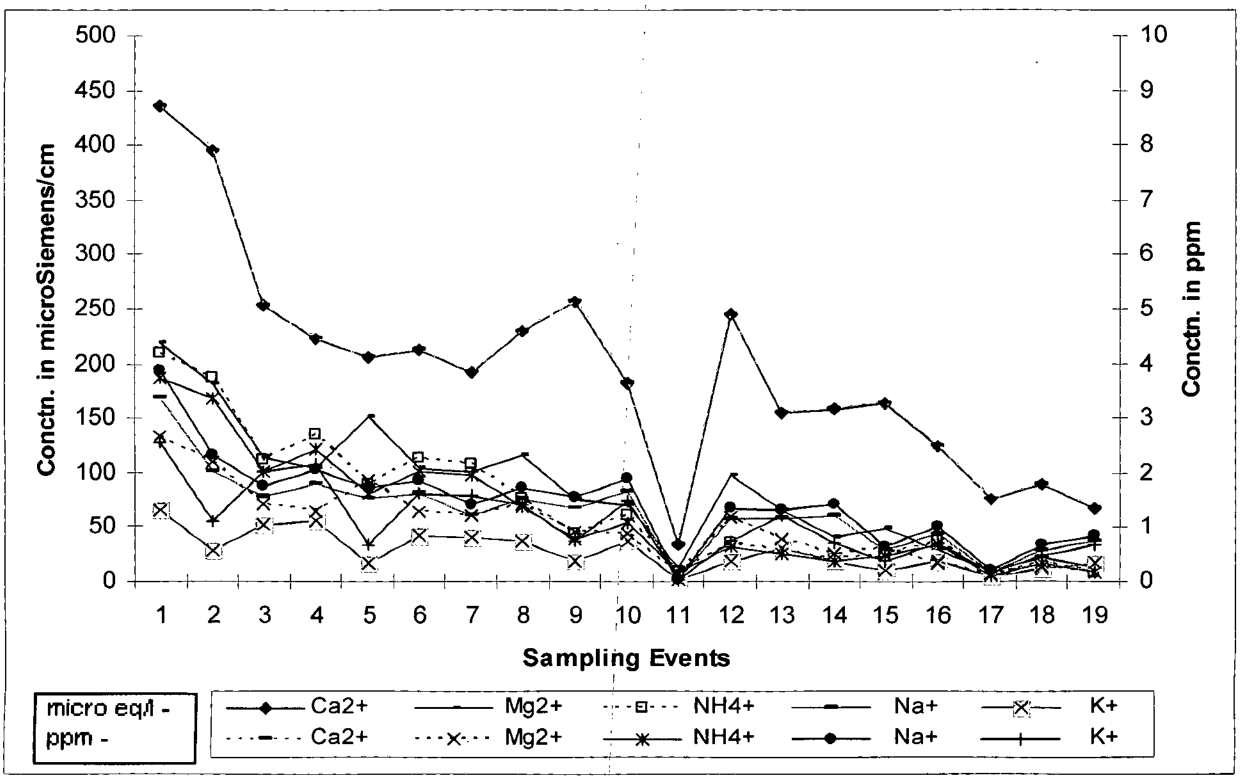

Fig. 5.5(b): Variation of different chemical constituents with days at Laxmi Nagar.
Note: Sampling Event 1- 06/07/2005……………………………,Sampling Event 19 – 19/09/2005.

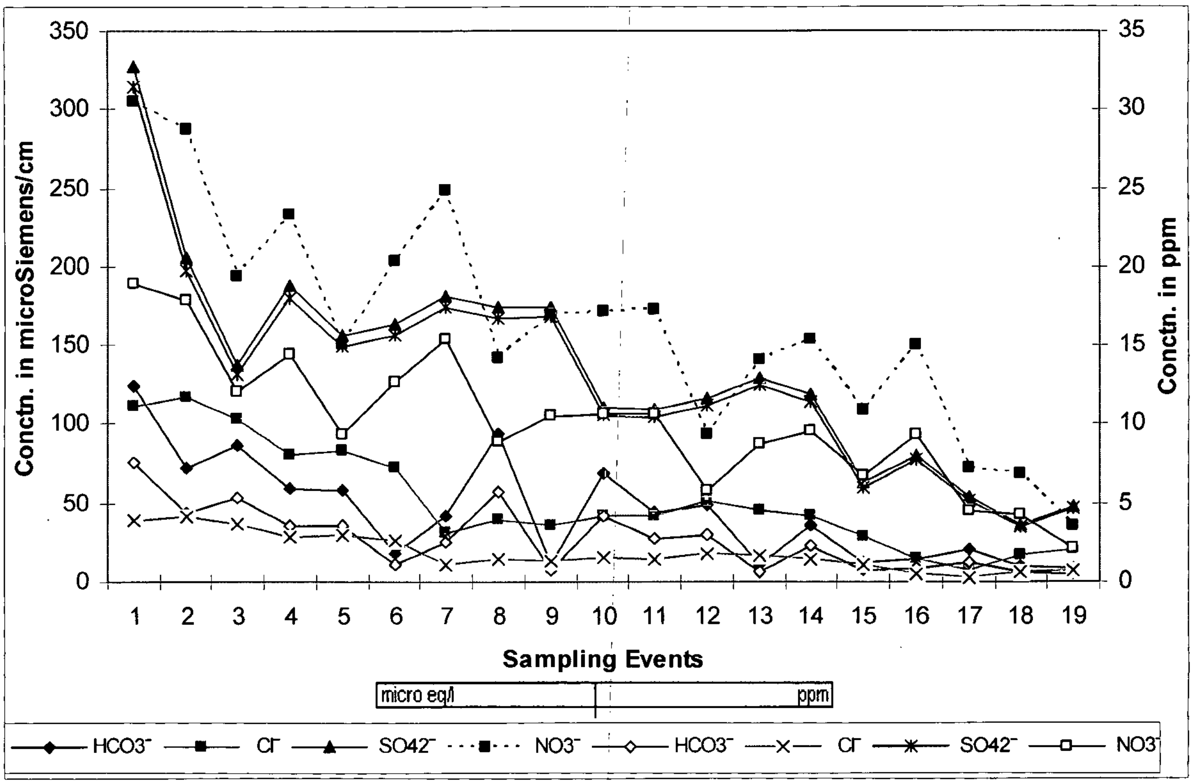

Fig. 5.6(a): Variation of different chemical constituents with days at Shahdara.

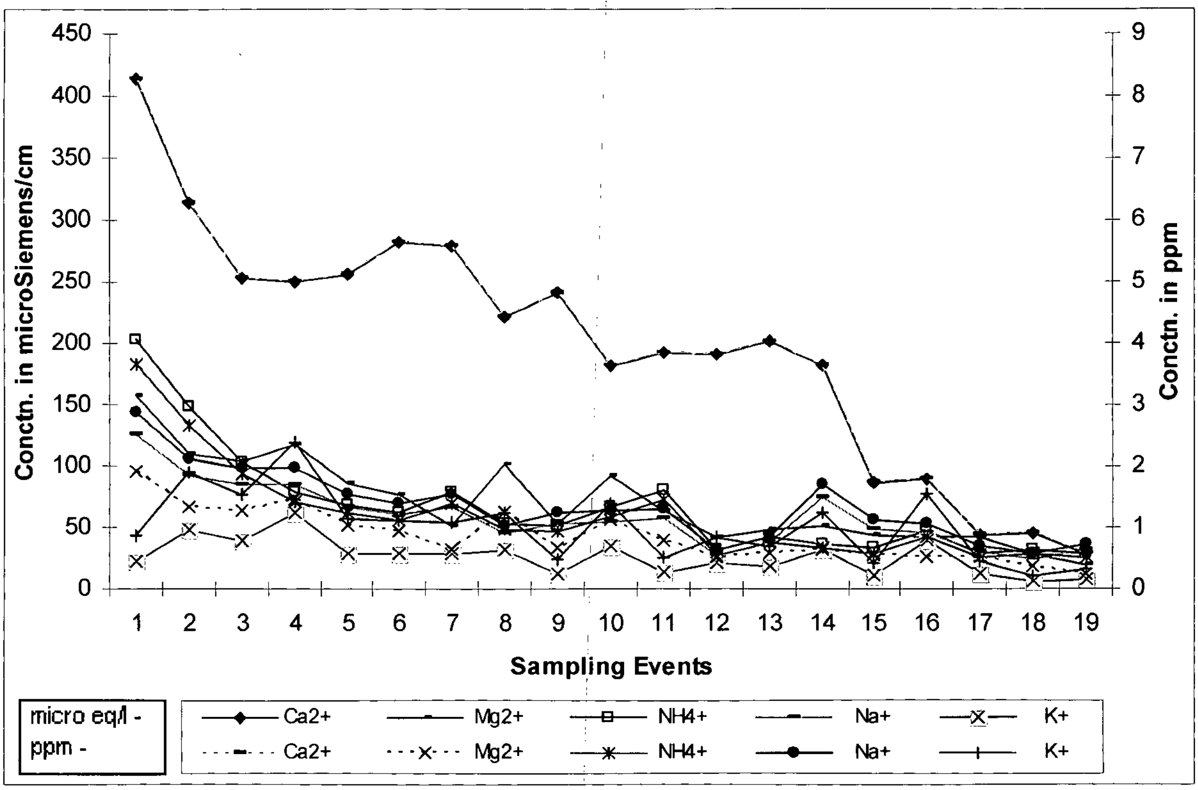

Fig. 5.6(b): Variation of different chemical constituents with days at Shahdara.
Note: Sampling Event 1- 06/07/2005................................,Sampling Event 19 – 19/09/2005.

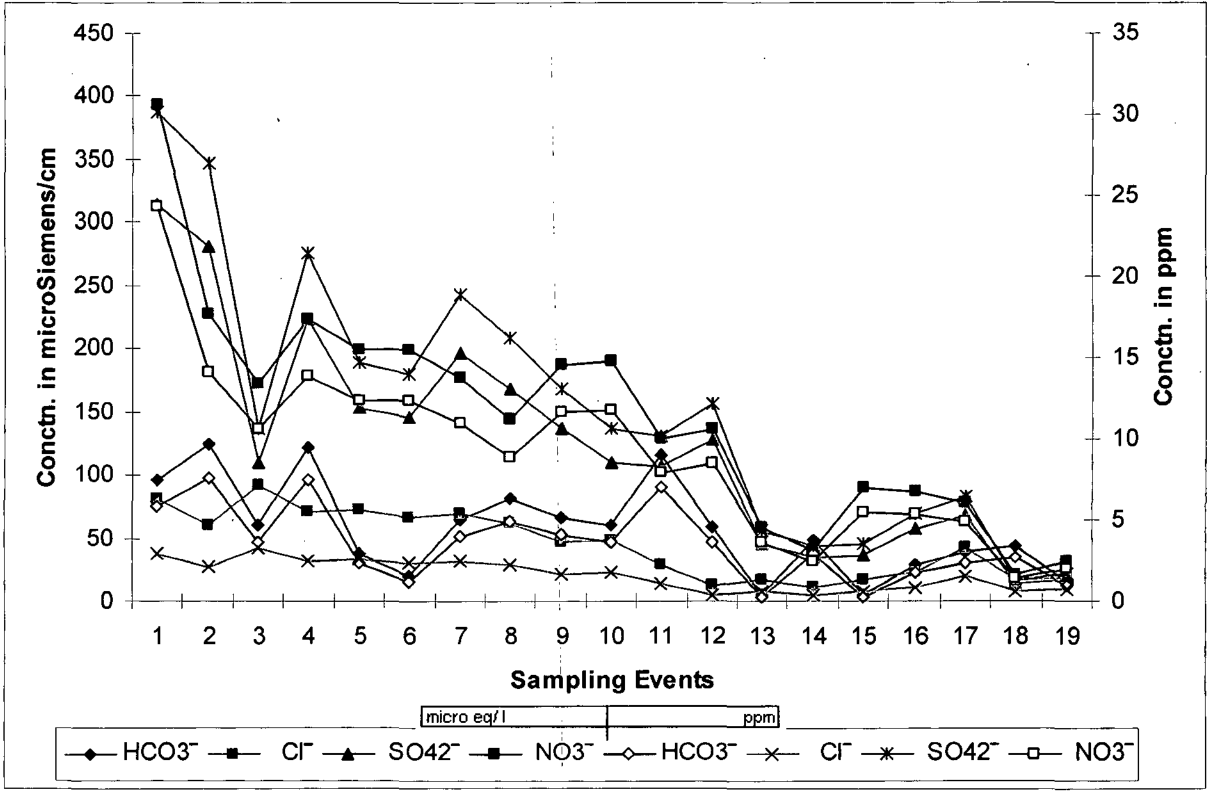

Fig. 5.7(a): Variation of different chemical constituents with days at Paharganj.

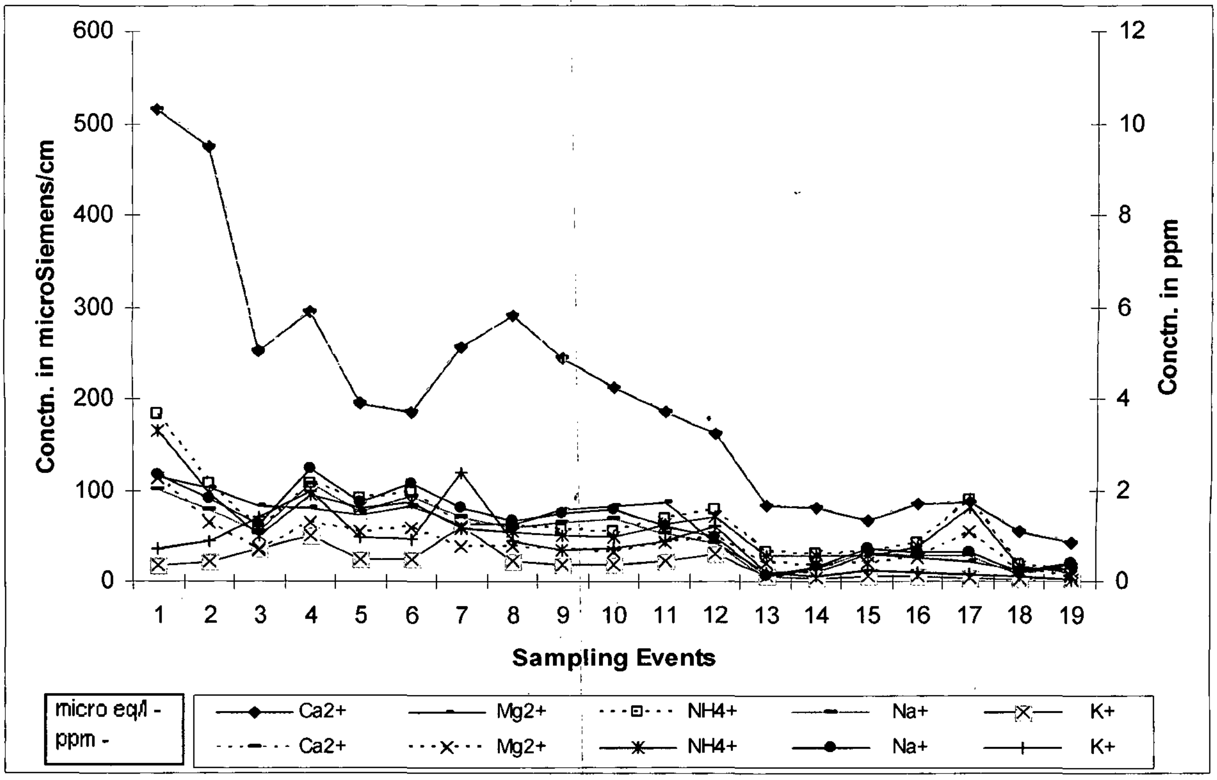

Fig. 5.7(b): Variation of different chemical constituents with days at Paharganj.
Note: Sampling Event 1- 06/07/2005…………………………….,Sampling Event 19 – 19/09/2005.

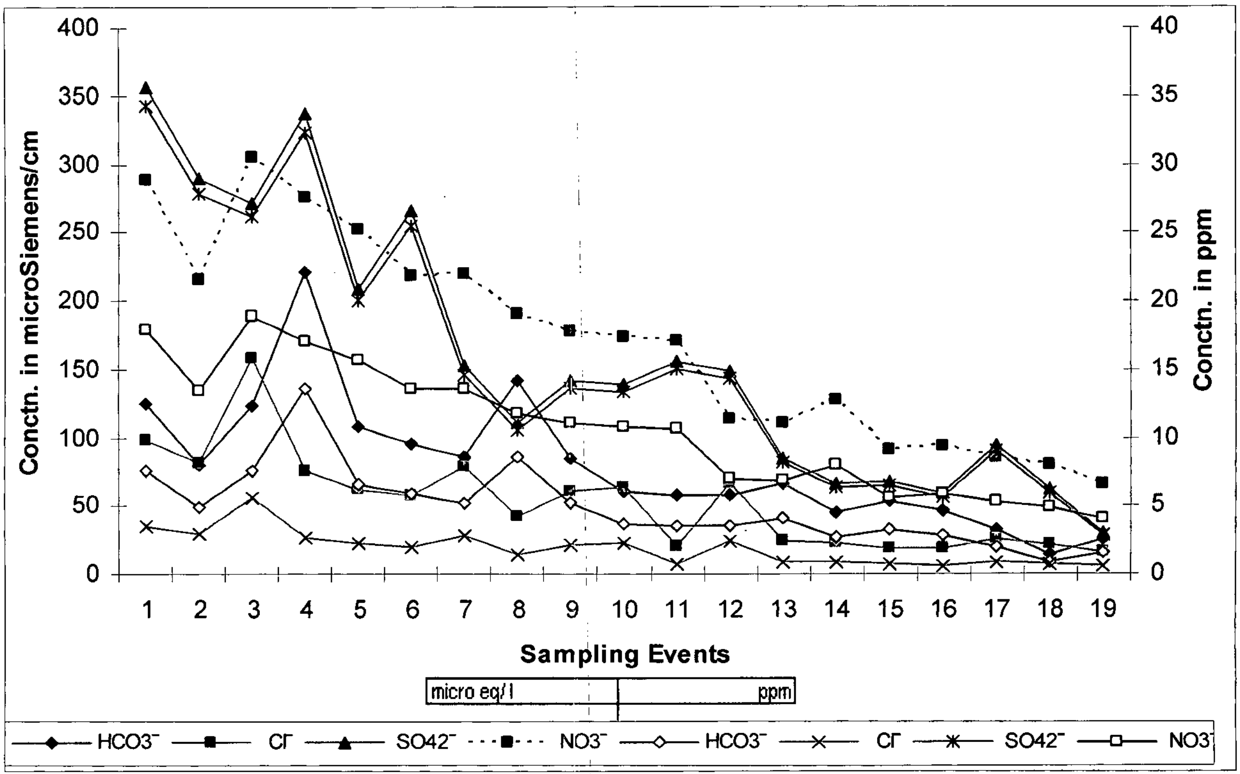

Fig. 5.8(a): Variation of different chemical constituents with days at Mukherjee Nagar.

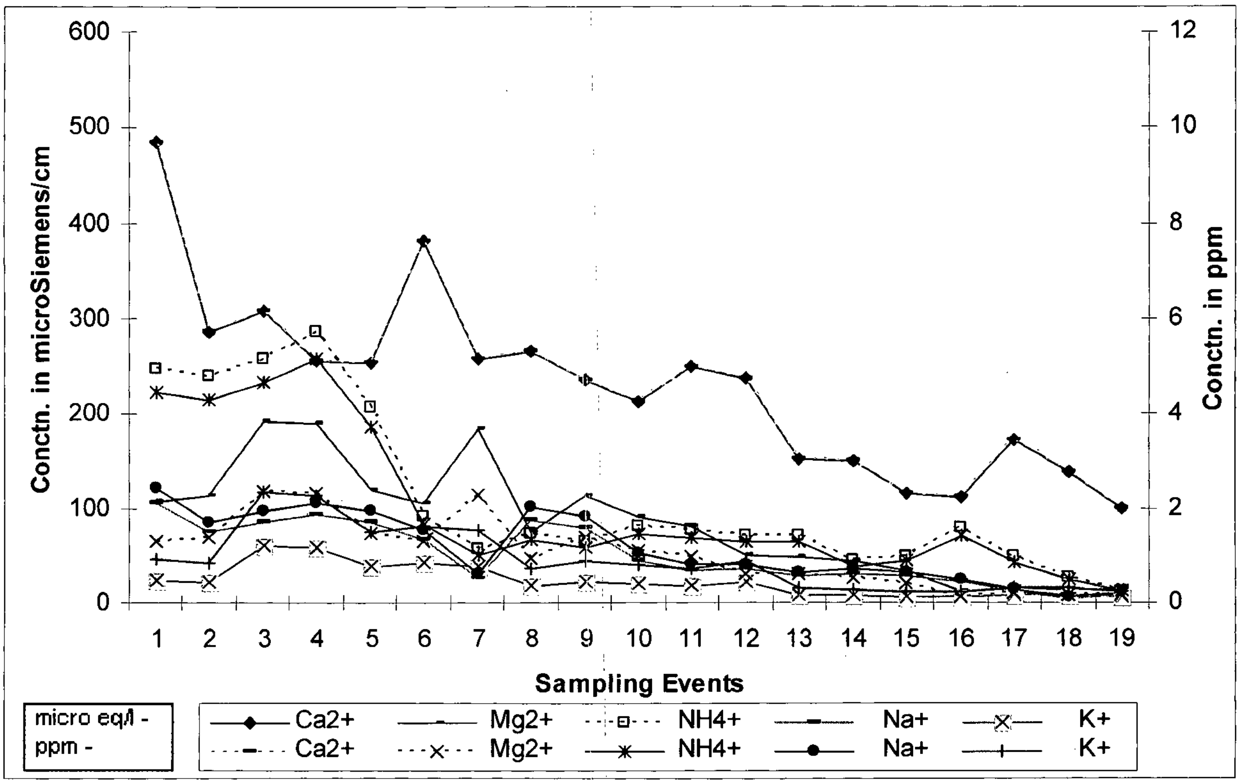

Fig. 5.8(b): Variation of different chemical constituents with days at Mukherjee Nagar.
Note: Sampling Event 1- 06/07/2005..,Sampling Event 19 – 19/09/2005.

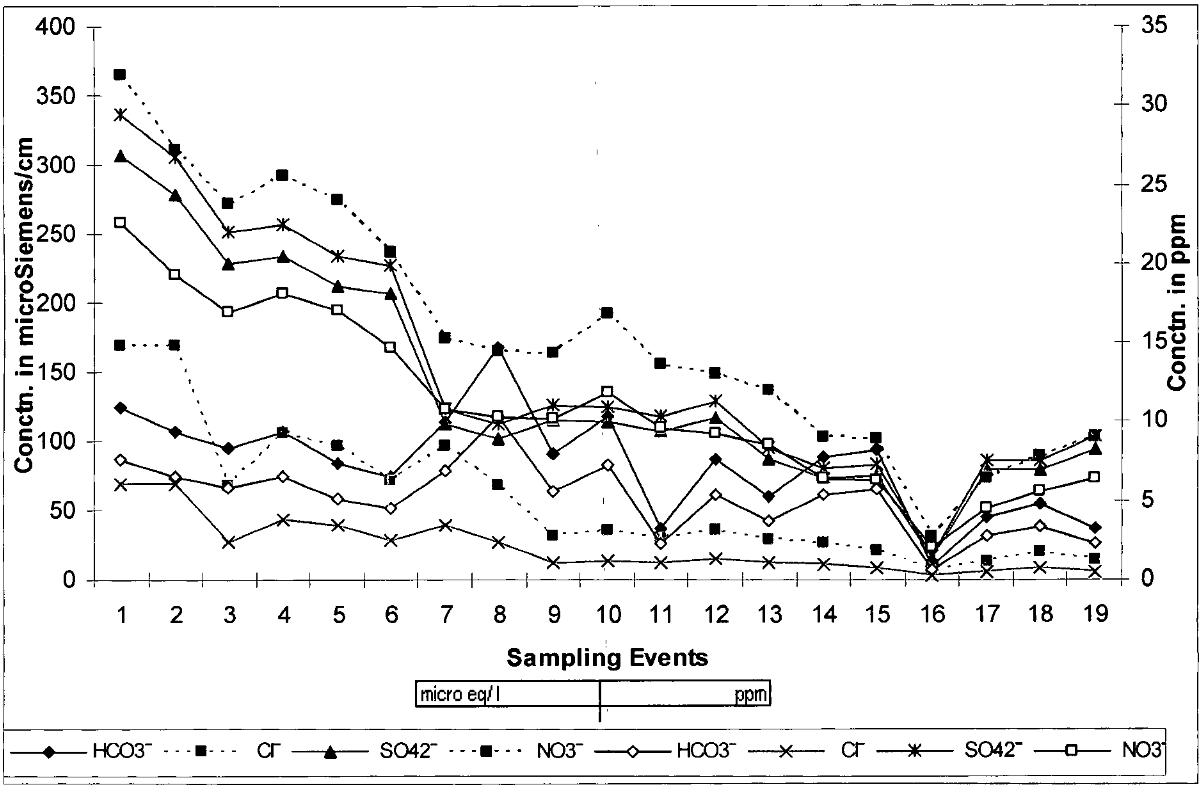

Fig. 5.9(a): Variation of different chemical constituents with days at Rohini.

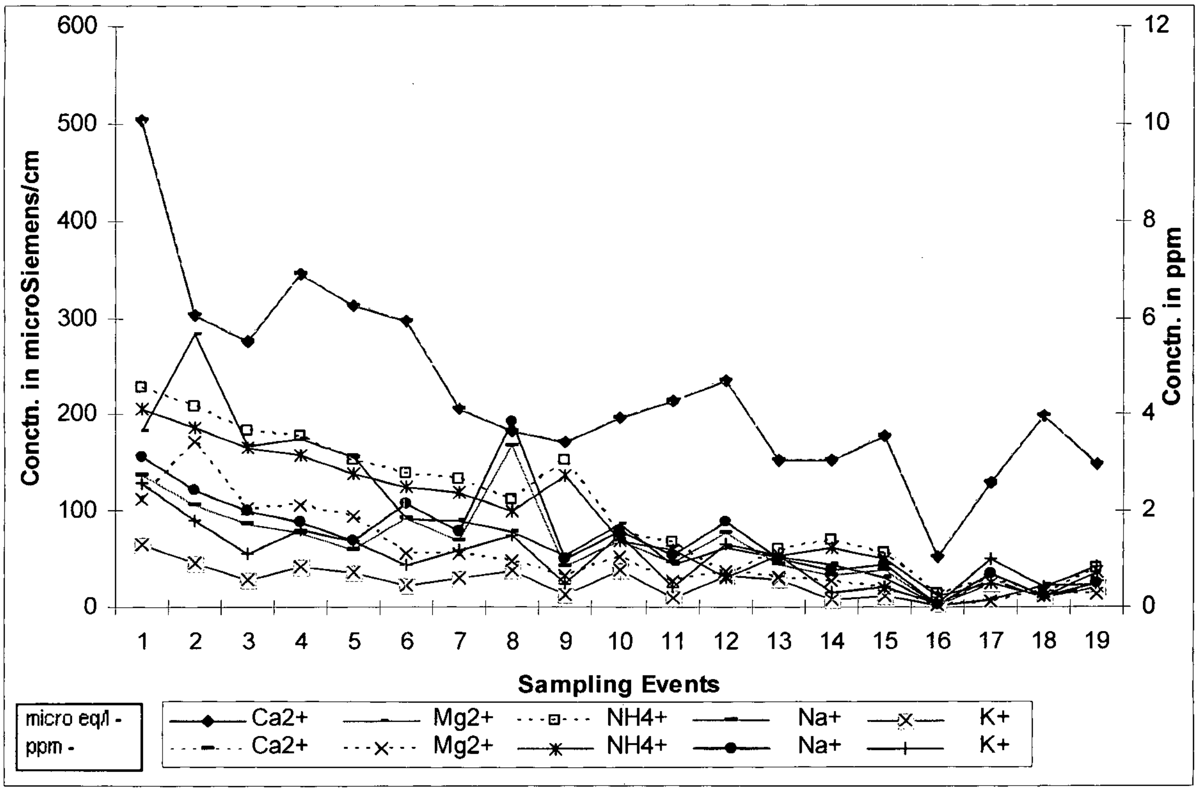

Fig. 5.9(b): Variation of different chemical constituents with days at Rohini.

Note: Sampling Event 1- 06/07/2005................................,Sampling Event 19 – 19/09/2005.

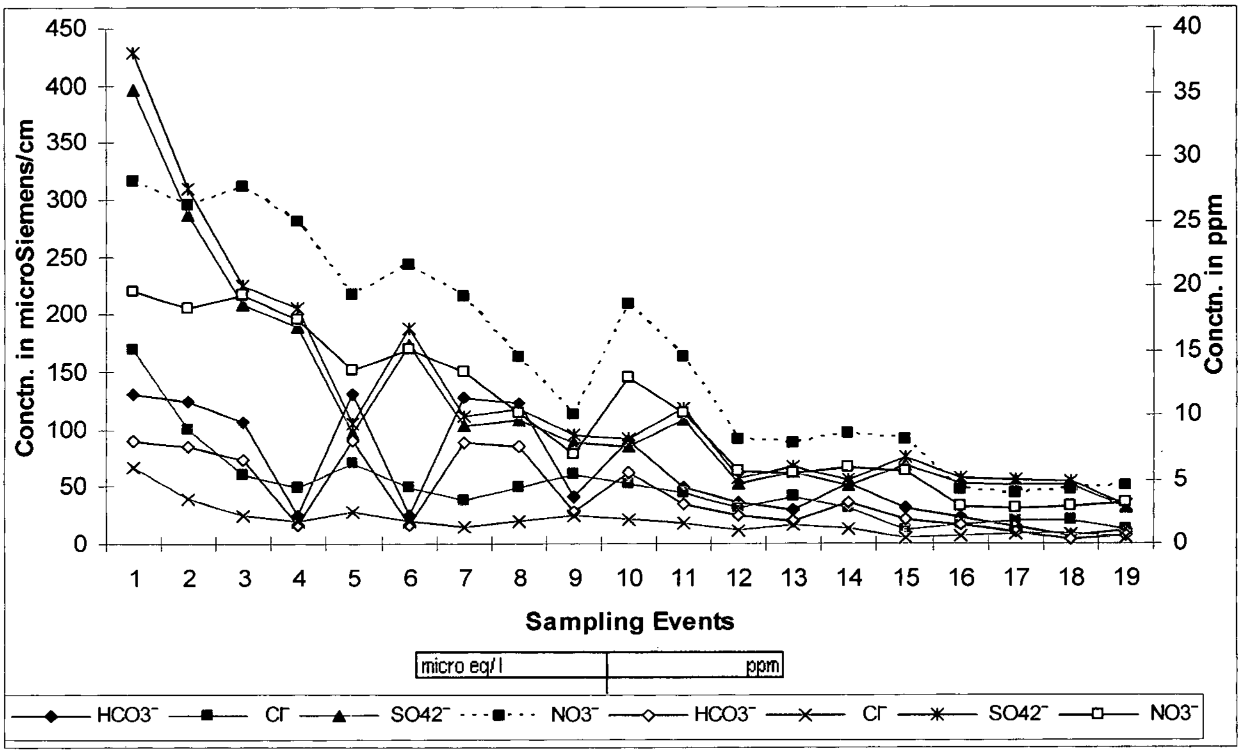

Fig. 5.10(a): Variation of different chemical constituents with days at Rajinder Nagar

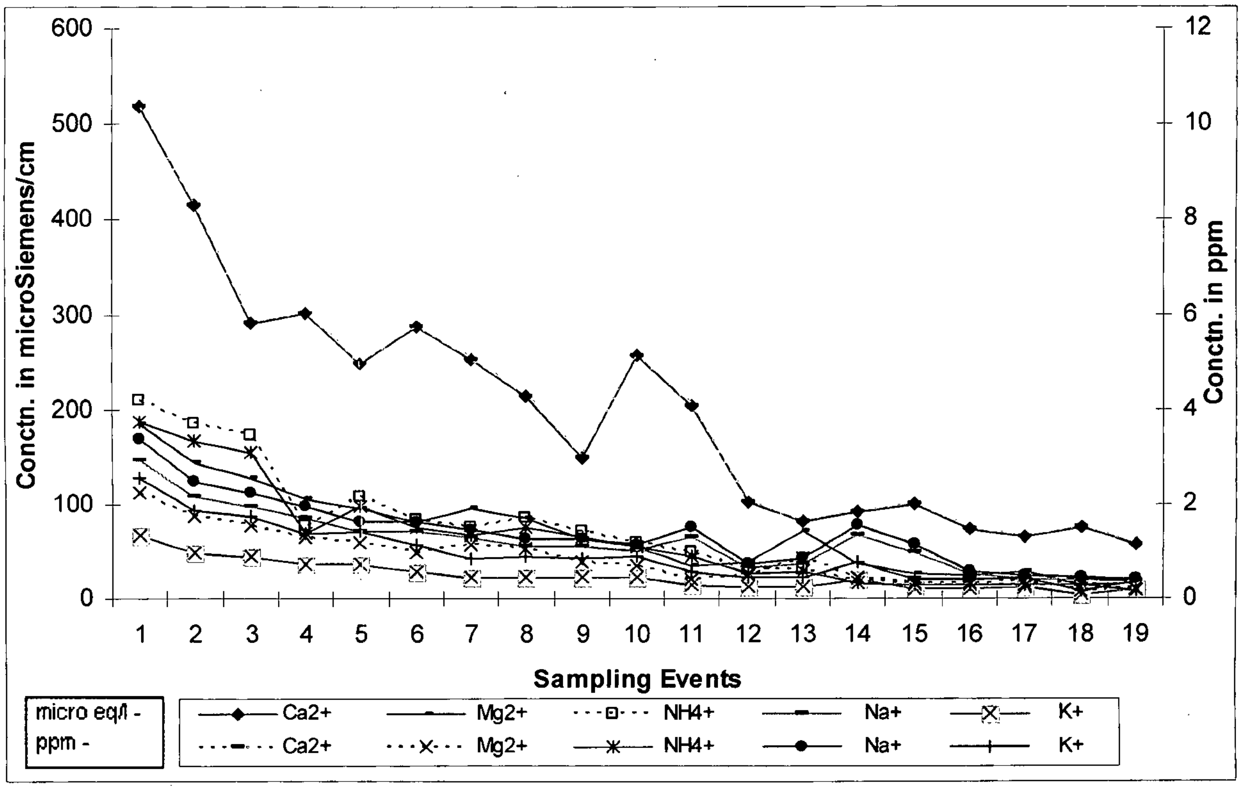

Fig. 5.10(b): Variation of different chemical constituents with days at Rajinder Nagar
Note: Sampling Event 1- 06/07/2005..............................,Sampling Event 19 – 19/09/2005.

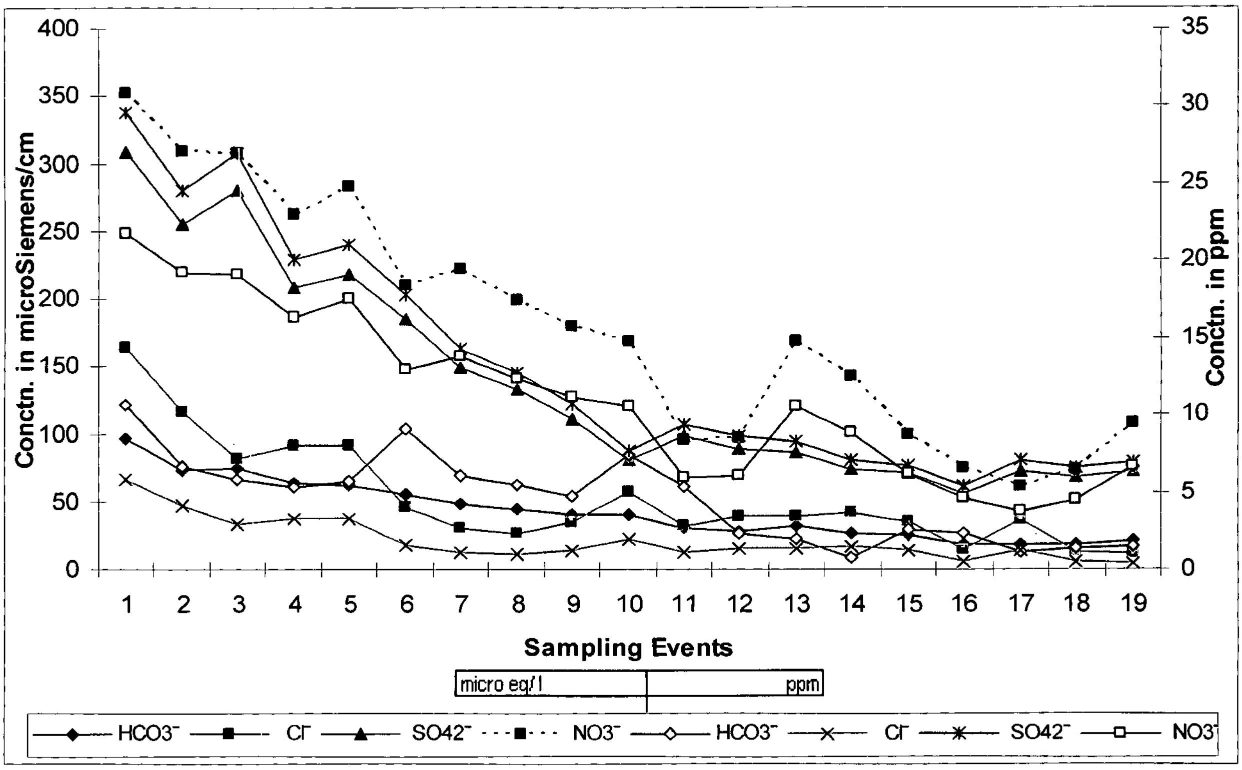

Fig. 5.11(a): Variation of different chemical constituents with days at Dwarka.

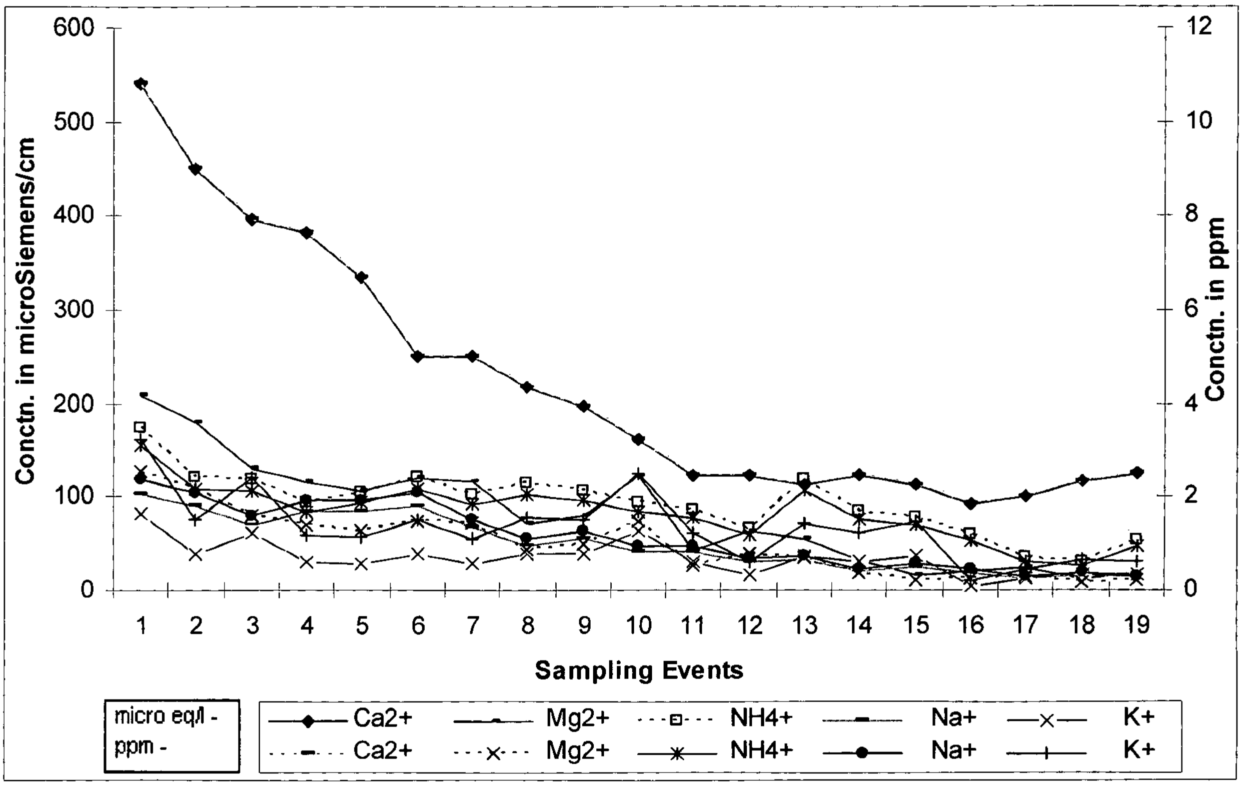

Fig. 5.11(b): Variation of different chemical constituents with days at Dwarka.
Note: Sampling Event 1- 06/07/2005.............................,Sampling Event 19 – 19/09/2005.

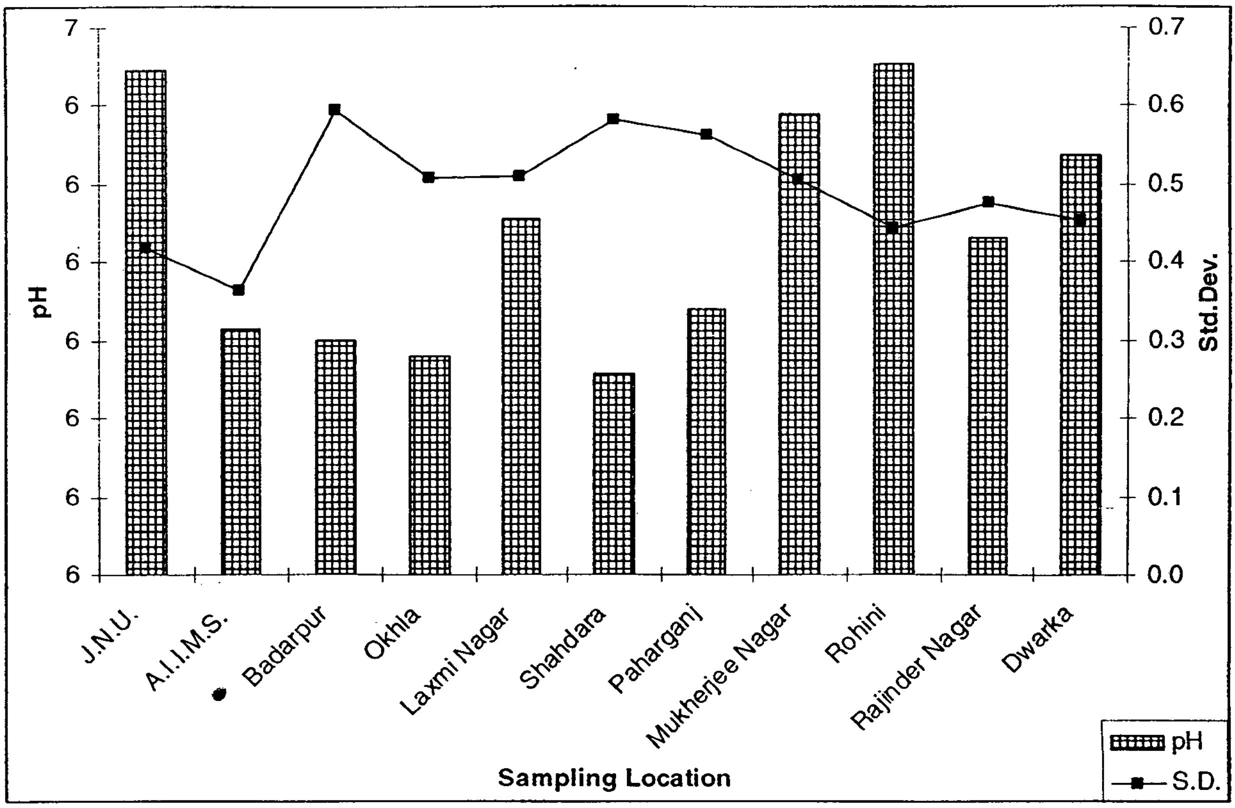

Fig.5.12: Variation of average pH at different locations in Delhi

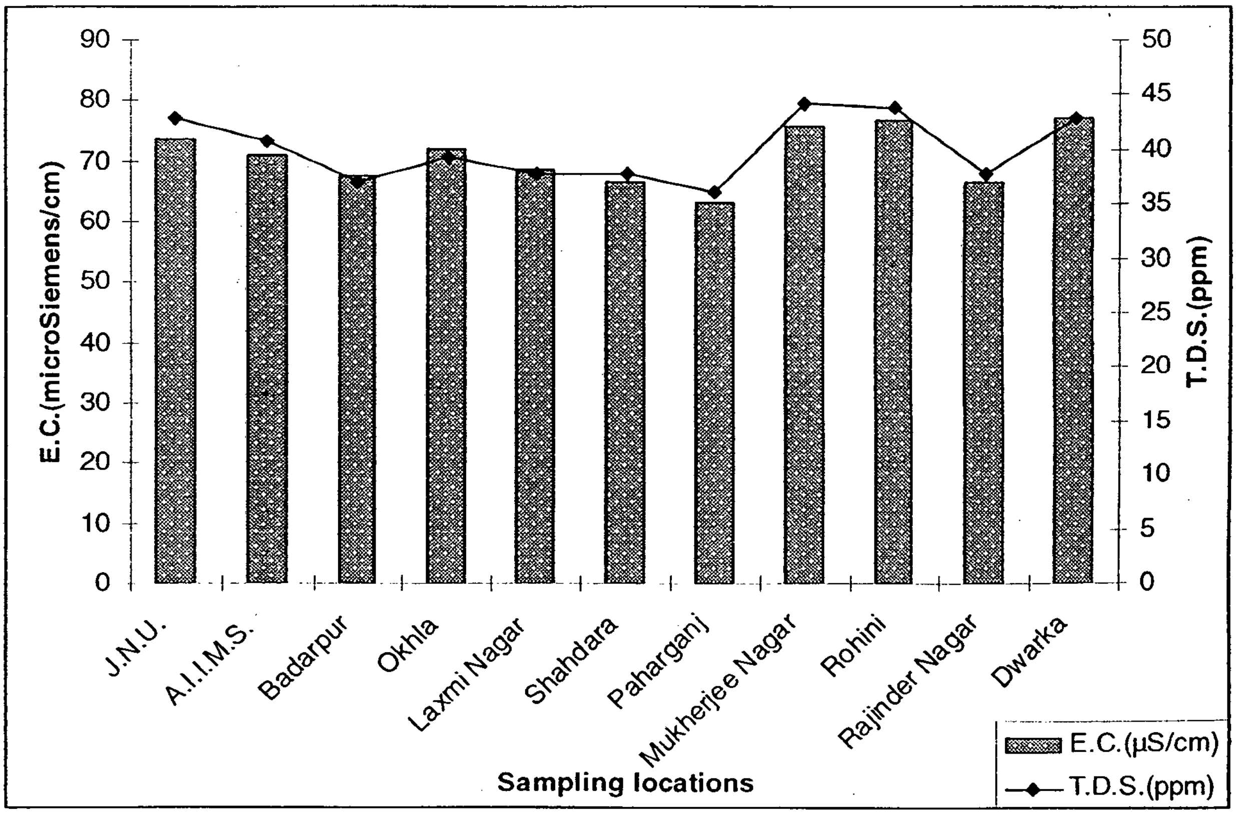

Fig.5.13: Variation of average E.C. & T.D.S. at different locations in Delhi.

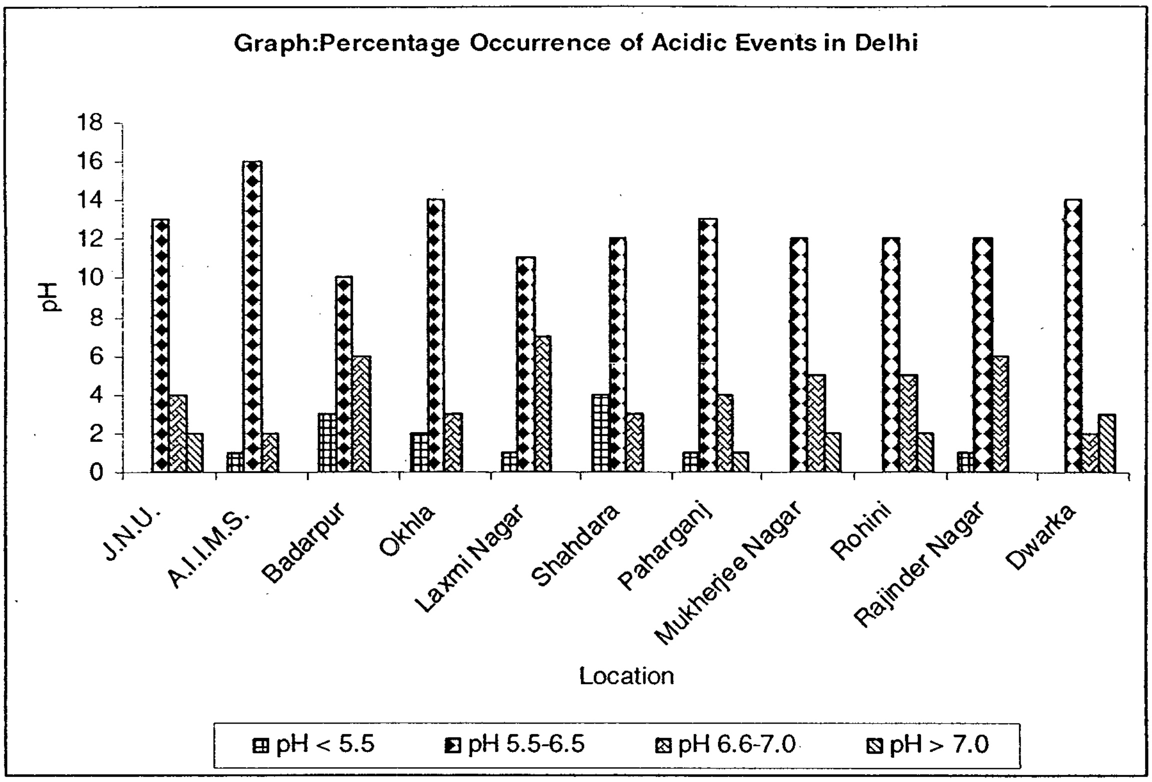

Fig.5.14: Percentage Occurrence of Acidic Events in Delhi.

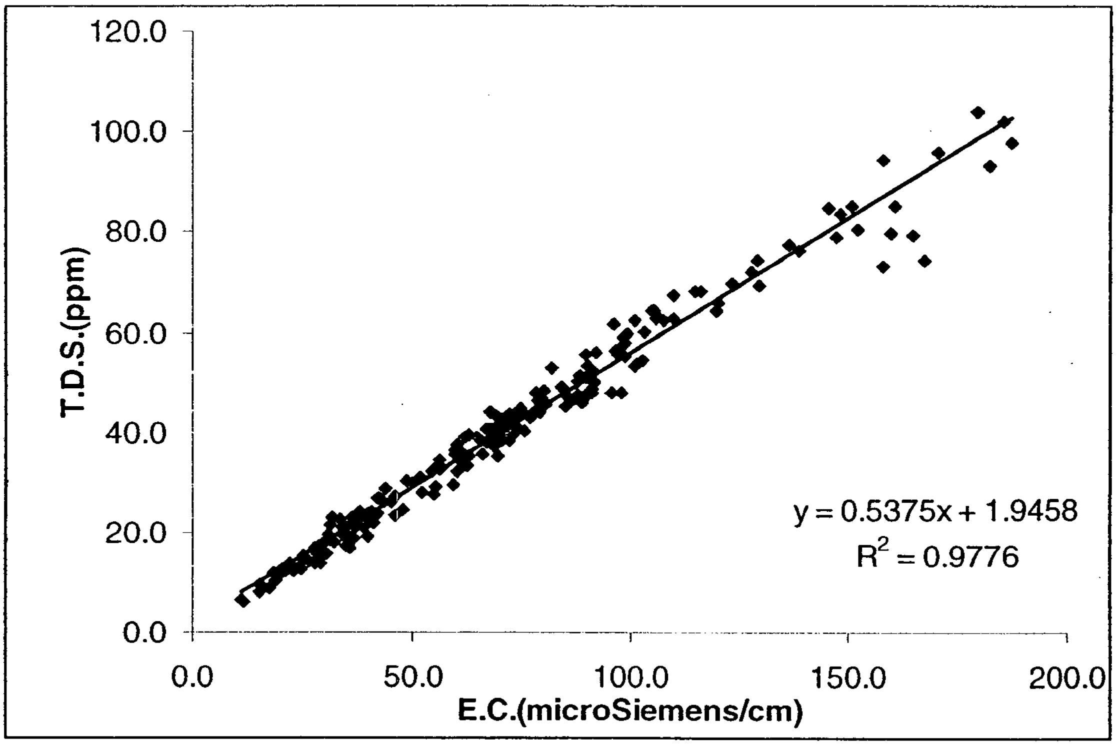

Fig.5.15: Correlation of E.C. & T.D.S.

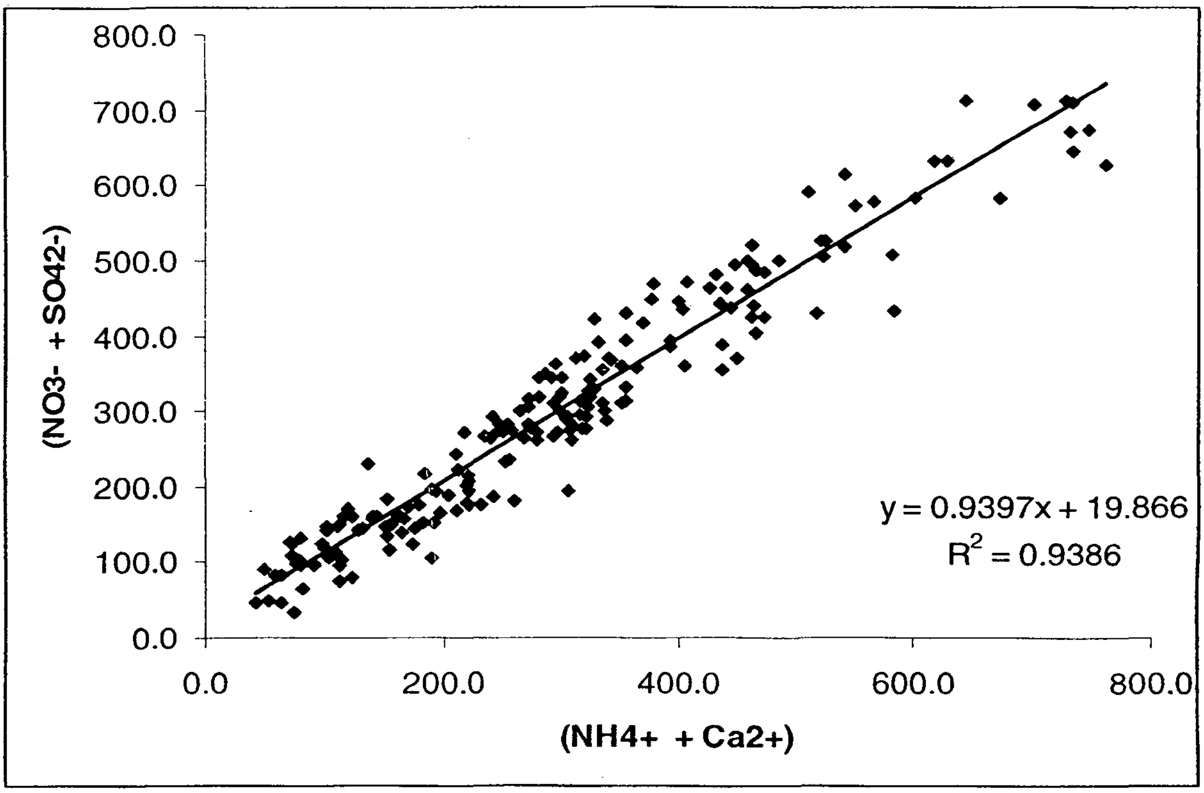

Fig.5.16: Correlation of (NH_4^+ + Ca^{2+}) and (NO_3^- + SO_4^{2-}).

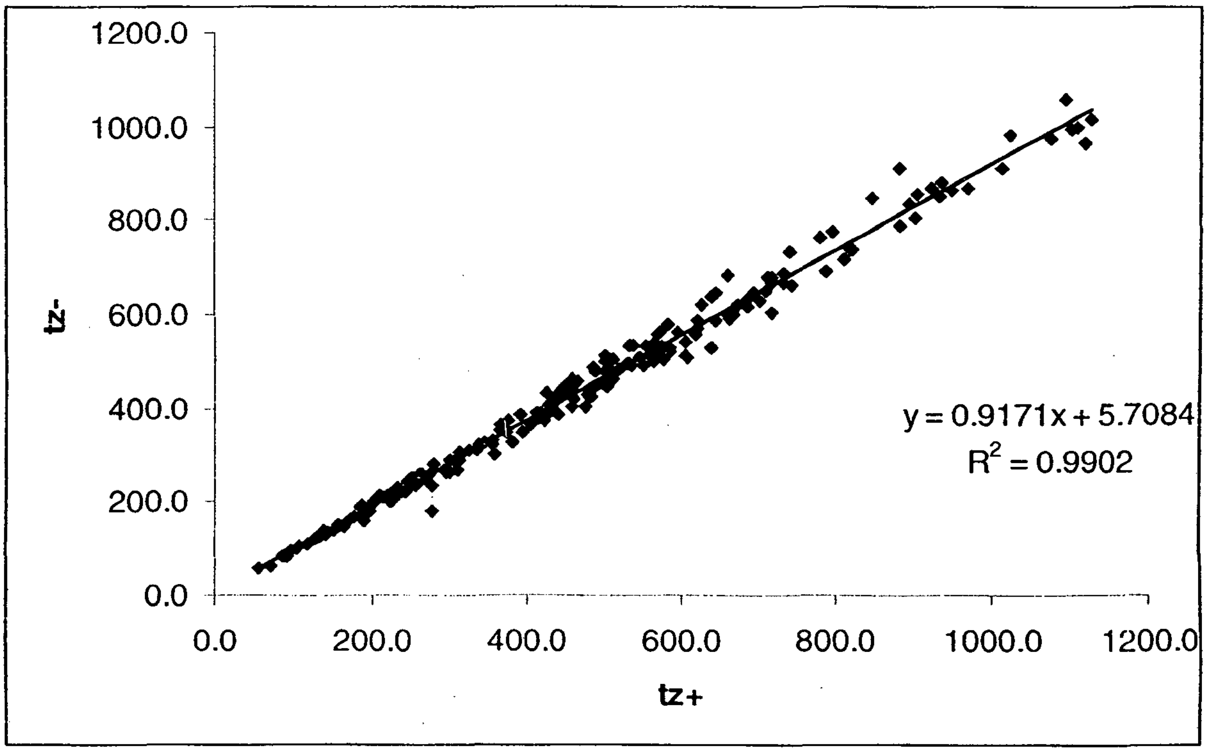

Fig.5.17: Correlation of total cation (tz+) and total anion (tz-).

Table 5.5: Variation of ratio of anion/cation, NO_3^-/SO_4^{2-} , $(Ca^{2+}+NH_4^+)/(NO_3^-+SO_4^{2-})$.

Location / Ratio	Anion / Cation			NO_3^-/SO_4^2			$(Ca^{2+}+NH_4^+)/(NO_3^-+SO_4^{2-})$		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
J.N.U.	0.92	1.04	0.84	1.37	2.12	0.84	1.01	1.17	0.87
A.I.I.M.S.	0.94	1.00	0.84	1.47	2.46	0.80	0.93	1.14	0.72
Badarpur	0.91	0.98	0.86	1.37	2.23	0.94	1.08	1.40	0.87
Okhla	0.96	1.02	0.85	1.43	3.04	0.76	0.94	1.22	0.54
Laxmi Nagar	0.92	1.00	0.65	1.55	2.31	0.79	1.01	1.80	0.73
Shahdara	0.94	0.99	0.88	1.29	1.95	0.73	0.86	1.08	0.58
Paharganj	0.94	1.03	0.88	1.35	2.45	0.81	1.07	2.13	0.78
Mukherjee Nagar	0.93	1.03	0.88	1.25	2.22	0.74	1.06	1.25	0.85
Rohini	0.91	0.98	0.86	1.37	2.23	0.94	1.08	1.40	0.87
Rajinder Nagar	0.94	1.00	0.84	1.47	2.46	0.80	0.93	1.14	0.72
Dwarka	0.92	1.04	0.84	1.37	2.12	0.84	1.01	1.17	0.87

5.2 Rainwater Chemistry:

Rainwater Chemistry at J.N.U.

J.N.U. is located in south Delhi. Being situated on the outskirts it has rural, suburban surroundings like Mahipalpur, Masudpur, Mehrauli, Vasant Kunj etc. The Delhi ridge runs parallel to its boundary.J.N.U. has greenery spread through out the length and breadth of its campus. All these factors are affecting the rainwater quality here.The concentration of all the ions were maximum in the beginning of the monsoon. The rainwater was alkaline in nature in J.N.U.Yet, the effect of pollution can't be denied. There was one instance of acid rain in J.N.U. on 16.09.2005.

This is probably due to the fact that at the end of rainy season when most of the Ca^{2+} and NH_4^+ ions are washed out, then acidic ions are not properly neutralized. The ridge surrounding the J.N.U. area plays an important role in neutralization of acidic ions providing input of aerosols. The rural area in the backyard of J.N.U. where a number of farm houses are located prove to be a rich source of NH_4^+ ions since there is a large use of fertilizers. The green zone surrounding J.N.U. like Sanjay Van also gives NH_4^+ ions. There is a distinct trend in pH. The pH is alkaline to begin with but decreases gradually and it ranges between 7.16 and 5.51.

Rainwater Chemistry at A.I.I.M.S.

A.I.I.M.S. is a health care and hospital area. It is situated in a heavy traffic area .The anthropogenic input has a telling effect on the rainwater chemistry here. Though there were only 2 acidic events here, the acidity in rainfall was comparatively higher than nearby J.N.U. There were two acidic events at A.I.I.M.S.On 11.07.2005 due to heavy rainfall pH was 5.25 because when rainfall amount increases more ions dissolve in rain by rainout and wash out. The previous rainfall on 06.07.2005 was also a heavy one which washed out basic cations leaving the anions unneutralised later on. The pH ranges between 5.25 and 6.89.

Rainwater Chemistry at Badarpur

The chemistry of rainwater here is influenced heavily by the thermal power plant located here.Badarpur power plant is the largest power plant in Delhi with an installed capacity of 725 MW. There is a heavy load of SO_2 and CO_2 in the air due to the burning of coal in the power plant, though SPM levels have decreased due to installation of electrostatic precipitator. There are three acidic events in Badarpur. The first two rain events are acidic to begin with. This is because of high concentration mainly of SO_4^{2-}, HCO_3^- and NO_3^- which are acidic ions, and comparatively low concentration of Ca^{2+} and NH_4^+. The pH then shows an increasing trend till 16.09.2005 when basic cations are thoroughly washed out while anthropogenic input of NO_3^- and SO_4^{2-} are still on the rise. The pH ranges between 6.90 and 4.93.

Rainwater Chemistry at Laxmi Nagar

Laxmi Nagar has trans-Yamuna location. The Yamuna River takes a left turn beyond the Nizamudding Bridge. The river being the worst polluted one is a source of input of pollutants into the air by evaporation. The high traffic volume between trans-Yamuna and the Central Business District is another source of pollutant influx. Besides, the industries in NOIDA, Shahibabad and Ghaziabad are close also to this area are also contributing to pollution load. The pH is basic in the beginning but gradually turns acidic. Lowest pH was recorded on 29.07.2005 due to lack of complete neutralization. Anthropogenic inputs are the chief culprits for pH behviour.The concentration of all the major ions is the lowest on 21.08.2005. This is probably because of trace amount of rainfall there due to which ions could not dissolve completely. The rainfall on 09.09.2005 has a high concentration of major ions because of high amount of rainfall there resulting in rain out and wash out of ions. The pH ranges between 4.98 and 6.92.

Rainwater Chemistry at Okhla

Okhla is primarily an industrial location. Mathura Road located on NH-2 is a busy road. Both industries as well as vehicles are contributing to the pollution load. The Yamuna River being the worst polluted one is a source of input of pollutants into the air by evaporation. Here also the acidic and basic cations are progressively washed out as the monsoon progresses. On 11.07.2005 the pH is lowest. This is because of the high amount of rainfall because when the volume of rain fall is higher more ions dissolve causing acidic precipitation. Due to anthropogenic inputs the pH is on the lower side in Okhla and it ranges between 6.89 and 4.9.

Rainwater Chemistry at Shahdara

Shahdara in East Delhi is the most polluted location in Delhi. Out of 19 sampling events, there are 5 which have a pH of less than 5.67. During the Monsoon season the wind direction is from E/SE.

Shahdara is surrounded by industrial areas. The pollutants emitted by Sahibabad Industrial area, Patparganj Industrial area as well as Ghaziabad area are focused towards eastern direction and their combined pollution load is causing acid precipitation in Shahdara. Besides the heavy traffic on G.T. Road is another factor. The lowest pH in Shahdara was recorded on 29.07.2005. This is because probably the basic cations were washed out in heavy rain on 13.07.2005 and subsequently there was a build up of acidic ions which went unneutralised on 29.07.2005. The pH ranges between 6.89 and 4.95. It has maximum number of acidic events (5) among all the locations. Shahdara has lowest average pH of 6.06.

Rainwater Chemistry at Paharganj

Paharganj in Central Delhi is located close to Connaught Place and New Delhi Railway Station. Clearly, the main source of air pollution in Paharganj is vehicular traffic. Being surrounded on all sides by roads converging from all sides to the Central Business District and also the Ring Road encircling the area, pollutants are entering from all sides. There was substantial acidity in the precipitation in Paharganj. The Ring Road acts as a store house for pollutant gases like SO_2 and NO_x. The lowest pH was recorded on 06.07.2005 which was mainly because of rainout and washout of acidic ions and a lack of neutralizing effect. The pH ranges between 4.88 and 7.08

Rainwater Chemistry at Mukherjee Nagar

Mukherjee Nagar in North Delhi is residential and institutional area. The Delhi ridge extends close to the Delhi University area and ends at Majnu Ka Tila close to Mukherjee Nagar. The ridge is having influence on the rainwater chemistry, since it adds basic cations into the atmosphere. The fallow land behind Mukherjee Nagar is a source of dust and biogenic NH_4^+ ions. The Yamuna River upstream from Wazirabad Bridge is relatively unpolluted and is therefore not a source of acidic gases. The lowest pH was recorded on 19/08/2005. This is probably due to low amount of rainfall due to rainfall after a long gap and a lack of basic cations in the air. The pH ranges between 7.38 and 5.65. There is only one acidic event and in general the rain water is alkaline.

Rainwater Chemistry at Rohini

Rohini is situated in North West Delhi. It is primarily a residential area. Cultivated areas on the northern fringe of Rohini are a source of NH_4^+ ion influx into the atmosphere. Anthropogenic inputs are mainly from vehicular pollution. Industrial areas in Ashok Vihar and Mangolpuri in South East and South of Rohini input pollution load into the atmosphere. Additionally Najafgarh drain running from Southeast to north east direction is also a contributing factor. Yet the basic cations are far in excess in Rohini. That is the reason why acidic events were not recorded at Rohini. The rainwater is alkaline in Rohini and it ranges between 7.35 and 5.82.

Rainwater Chemistry at Rajinder Nagar

Rajinder Nagar in Central Delhi is a residential cum commercial area. It is in close proximity to market places such as Karol Bagh and Connaught Place. The vehicular traffic is high and is thus contributing to acidic gases. The Pusa hill forest to the South of Rajinder Nagar is a source of biogenic inputs such as NH_4^+ ions. The basic ions did not effectively neutralize the acidic gases due to which 4 acidic events were reported. There were three acidic events in the beginning of rainy season. The first rainfall is acidic at Rajinder Nagar which is similar to the rainfall at Paharganj. This may be due to the fact that factors affecting acidity at Paharganj and Rajinder Nagar are same as discussed earlier. The pH ranges between 6.85 and 5.45.

Rainwater Chemistry at Dwarka

Dwarka in South West Delhi in a residential area. Farm houses are scattered everywhere on the fringe of Dwarka. Agricultural operations are a source of NH_4^+ ions. Vehicular traffic is less intense compared to other locations. The Indira Gandhi International Airport located near Dwarka has heavy air traffic which might be contributing to NO_x emitted by Jet planes. The rainwater at Dwarka is alkaline. The pH ranges between 7.32 and 5.75. The pH is basic in the beginning and then decreases later on.

On the basis of pH the 11 sampling locations can be classified into three zones as follows:

1) Zone of high pH(average pH<6.30): Dwarka, Rohini,J.N.U.,Mkherjee Nagar
2) Zone of intermediate pH(6.2<average pH<6.3) : Rajinder Nagar,Laxmi Nagar
3) Zone of low pH(average pH<6.2): Shahdara, Paharganj,Badarpur,AIIMS,Okhla,

Thus, we see that central and east Delhi has low pH while north west and southwest Delhi has high pH.

Statistical Analysis

1. **Standard Deviation of Data:** It indicates the deviation of the data from the mean value.
2. **Kurtosis:** It is an indicator of the relative sharpness or flatness of then peak compared to normal distribution. Positive Kurtosis indicates a sharp distribution while negative Kurtosis indicates a flat one.
3. **Skewness:** It typifies level of asymmetry of a distribution around its mean. Positive skew indicates an asymmetrical tail extending towards higher values while a negative skew is a pointer towards an asymmetric tail extending towards lower values.

Statistical analysis of the data show that the total cations (tz+) and total anions (tz-) are coupled by the relation tz- = 0.9171 tz+ + 5.7084 with correlation coefficient, R = 0.99 in 209 rainwater samples in Delhi. Thus, the observed total cations (tz+) and total anions (tz-) balance attests to the good quality of our data.

The correlation between (Ca^{2+} + NH_4^+) and (NO_3^- + SO_4^{2-}) ions for 209 rainwater samples in Delhi showed a correlation coefficient , R = 0.98. This indicates that Ca^{2+} and NH_4^{2+} ions are instrumental in neutralization of acidic ions NO_3^- and SO_4^{2-}.

The correlation between E.C. and T.D.S. for 209 rainwater samples in Delhi gave a correlation coefficient of R = 0.96 which shows that there is a good correlation between E.C. and T.D.S. and points to the good quality of data.

The pH of rainwater at Delhi changed between 4.88 and 7.38. The minimum pH was recorded at Paharganj while the maximum pH was recorded at Mukherjee Nagar. The lowest volume weighted mean was at (6.05) and highest was at Rohini (6.45). From the data it is apparent that Shahdara was the most polluted area since the mean pH value is 6.06. This value is higher than the lowest mean pH of 6.03 that was found by Balachandran and Khillare (2001) in Okhla. The increase in vehicular traffic combined with industrial output of pollutants is the main reason for low pH observed at Shahdara.

During the monsoon period of 2005, the average pH of rainwater was 6.24. The number of acidic events in J.N.U, A.I.I.M.S., Badarpur, Okhla, Laxmi Nagar, Shahdara,Phahrganj,Mukherjee Nagar,Rajinder Nagar were 1,2, 3, 2, 1, 5, 3, 1, 4, out of 19 samples from each location, and accounted for 5, 11, 16, 11, 5, 26, 16, 5 and 21 percent acidic events while such events were not observed at all at Dwarka and Rohini. The acidic events at the nine sites except Dwarka and Rohini can be related to the specific activity of most of these areas, which are predominantly commercial cum industrial sites with heavy vehicular traffic. When compared with the report of Kapoor et al. (1972) and Subramanian and Saxena (1980), the values are less alkaline. The present study also agrees with those of Khemani et al (1989 a, b) Varma (1989 a,b) and Ravichandran and Padmanabhamurthy (1994), Balachandran and Khillare (1995), wherein they all inferred that the pH of rainwater in Delhi showed a decreasing trend.

SO_4^{2-} and NO_3^- are conventional acidic ions in precipitation. The relative contribution by these ions to the acidity of rainwater is variable.Until recently SO_4^{2-} was known to make up approximately 70% of the acidity, the remaining 30% being accounted for by HNO_3 (NRC, 1983, Amaguchi, et. al. 1991). However, the contribution of H_2SO_4 to the acidity of the precipitation has decreased recently and that of HNO_3 has increased owing to reductions in SO_2 emissions and less stringent controls on NO_x emission, particularly, in the U.S. and Europe (Byron et.al. 1991, Khwaja and Hussain 1990) and in India at Delhi (Vinish Kathuria, 2004). The average ratio of NO_3^- /SO_4^{2-} in the rain at Delhi was 1.39 which indicates that the contribution of HNO_3 to the acidity of precipitation is more than 50%. This is particularly due to reduction in SO_2 emission in Delhi as a result of CNG implementation. The concentration of NO_2 in ambient air of Delhi has increased by 1.36 times since the year 2000 as a result the contribution of HNO_3 in acidity which was less than 50% in 1995 (Balachandran and Khillare; 2001) has now became more than 50% and the acidity is now no longer influenced more by SO_4^{2-}. This trend was observed at AIIMS, Badarpur, Okhla, Laxmi Nagar, Shahdara, Paharganj, Rohini and Dwarka. The NO_3^-/SO_4^{2-} was less than 1.0 at J.N.U. and Mukherjee Nagar

Ratios of (NH_4^+ + Ca^{2+}) to (NO_3^- + SO_4^{2-}) were also calculated in order to know if acidic components like NO_3^- and SO_4^{2-} were neutralized basically by NH_4^+ and Ca^{2+} as studied by Khemani and co-workers (1994). If the ratio is greater than one, it indicates NH_4^+ and Ca^{2+} have neutralized SO_4^{2-} and NO_3^-. The ratio of (NH_4^{3+} + Ca^{2+})/ (NO_3^-+SO_4^{2-}) in the present study varied between 2.13 to 0.72 for the whole Delhi and the average value was greater than 1.0 at J.N.U., Badarpur, Laxmi Nagar, Mukherjee Nagar,Paharganj, Rohini, and Dwarka. At AIIMS,Okhla,Shahdara, and Rajinder Nagar the ratio was below 1.0 indicating that NO_3^- and SO_4^{2-} were not neutralized by NH_4^+ and Ca^{2+} alone, but possibly by other cations as well.

When anion to cation ratios were calculated, the values were always below 1.0 which shows that there is a deficit in anionic concentrations like weak organic acids, fluoride and phosphate which contribute to electroneutrality. Srivastava (1993) has reported increased weak organic acids which contributes to electroneutrality in rain at Agra, and Al-Momani et al. (1995), deduced up to 35% of organic anions accounts for electroneutrality in anion to cation ratio.

SOURCES OF IONS

Binary correlation between measured ions has been computed in order to obtain additional information the sources of ions in the Delhi precipitation. The correlation matrices are given in table 5.2 (a) to (K). Na^+ and Cl^- ions are not so strongly correlated due to the fact that though Na^+ and Cl^- have their common marine source, yet, Cl^- ion has mean industrial emission and also from other pollutive sources.Na^+ K^+, Ca^{2+} and Mg^{2+} have high correlation coefficients between one another implying that they might have originated from the same source i.e. the soil. Significant correlation of NH_4^+ with NO_3^- and SO_4^{2-} implies that it may have occurred in the form of $NH_4 (NO_3)$ and $(NH_4)_2 SO_4$. Actually NO_3^- and SO_4^{2-} are formed due to the conversion of the oxides of nitrogen and explain from their gaseous form of particulate form. In the process of this conversion they combine with the available reactive cations. It is understood that they find their way to better reactivity with NH_3 than the other cations and thus they seem to occur in the form of ammonium sulphate and ammonium nitrate. Also, when $(NH_4)_2 SO_4$ and $NH_4 NO_3$ fertilizers are applied to soil, some may be converted to NH_3 which eventually escapes to the atmosphere and participates in the neutralization of rain acidity. Further, some of the applied fertilizers may become airborne by mind action to form $(NH_4)_2 SO_4$ and $(NH_4) NO_3$ aerosols which can be incorporated in rain droplets. This second mechanism introduces not only NH_4^+ to rains but also SO_4^{2-} and NO_3 ions. It is further noted that except HCO_3^- all the chemical species show highly significant relationship with the total ion indicating that all the samples have nearly similar chemical composition.

From the figures showing the variation of difference chemical constituents with days at various locations in Delhi it is clear that Ca^{2+}, Na^+, Cl^-, SO_4^{2-}, NH_4^+, NO_3^-, Mg^{2+} and K^+ concentrations decreased with progress of rainy season. However, pH showed an increasing trend at most locations. From the historical perspective of acid rain studies the most well known rainwater acidification mechanism is SO_2 and NO_x emitted into the atmosphere being oxidized to H_2SO_4 and HNO_3 through both gas and aqueous phase processes. HCl also play a role in contributing to rainwater acidity. In addition, weak acids such as H_2CO_3 from dissolved atmospheric CO_2 in rainwater and organic acids (formic acids, acetic acid, etc) contribute to rainwater acidity (Brimblecombe, 1996, Khwaja and Hussain, 1990; Lijenstrand and Morgan, 1978; Seinfeld 1986; Saylor et al.1992; Sclesinger, 1991; Warneck, 1988). There are two sources of bicarbonate (HCO_3^-) ions in rainwater.One is the atmospheric CO_2 that dissolves in rainwater to form bicarbonate ion(HCO_3^-) as well as H^+ ion. The other is the atmospheric aerosol particles of calcite ($CaCO_3$) reacting as strong bases with H^+ ion to give HCO_3^-. Since CO_3^{2-} concentration is very low, generally it is neglected (Losno et al. 1991; Warneck, 1988). In this work anions NO_3^-, SO_4^{2-}, Cl^- and HCO_3^- are proposed as acid factors.

On the other hand, alkaline compounds containing Na^+, K^+, Ca^{2+} and Mg^{2+} can neutralize strong and weak acids in rainwater. The major fraction of alkali source is aerosols particles originated from the soil (Samara et. al., 1992, Saylor et al. 1992; Schlesinger, 1991; Tuncel and Ungor, 1996). Atmospheric ammonia derived from a variety of source (Ap Simon et al. 1987). In addition, a few amines will serve to neutralize acids (Brimblecombe, 1996; Lijestrand and Morgan, 1978; Schliesinger, 1991; Suzuki et al.; 1997). In this work, cations Na^+, NH_4^+,K^+,Ca^{2+} and Mg^{2+} are suggested as alkali factors. H^+ ion concentration in rainwater is the result of interaction of acid and alkali. The acids containing acid factors act as donors of H^+ ion. and the alkalis containing alkali factors act as acceptors of H^+.

In Delhi the first occurrence of acid rain was reported by Khemani et al. (1989a) near Indraprastha power station and later by Ravichandran and Padmanabhamurthy (1994). The chemical composition of Delhi rainwater was compared with that of other cities of the world (Table 5.6).

Table 5.6: Mean concentration (μeq/l) of major inorganic ions in rainwater at selected sites worldwide alongwith pH (in pH units).

Component	Present study	Delhi(India)[a]	Tirupati(India)b	Beijing(N.China)c	Athens(Greece)d	West.Med.(France)e	East.Med.(Turkey)
pH	6.24	6.25	6.78	6.7	-	5.39	5.17
Cl	56.27	43.2	33.91	59	94.2	357	390
NO3	168.74	109.02	40.84	81	23.6	28	70
SO4	131.43	131.31	127.96	337.5	100	42.2	113
Na	56.64	44.04	33.08	77.4	67.7	261.2	450
K	27.59	20.17	33.89	38.2	14.5	8.5	12.1
Ca	217.64	180.64	150.66	759	137	32.7	140
Mg	77.39	44.39	50.51	-	30	35.5	94
NH4	81.29	82.2	20.37	224.4	21.9	24.7	50

[a] Balachandran and Khillare (2001)

[b] Chandra Mouli et al. (2004)

[c] Zaho et al. (1988)

[d] Dikaijos et al. (1990)

[e] Losno et al. (1990)

[f] Al-Momani et al.(1995).

The data compared with that of other areas reveal that concentrations of NO_3^- is higher than those reported for other sites. The pH values reported in the present study is lower than that reported in Northern China, where alkaline dust particle concentrations are higher, similar to India. The concentration of SO_4^{2-} ions follows a stagnant trend compared to 1995 (Balachandran and Khillare; 2001). This might be due to the CNG implementation in Delhi.

Major industries are situated in the east/south-east (E/SE) region of Delhi. During the monsoon season Delhi experiences winds from E/SE direction (Padmanabhamurthy and Ravichandran, 1991).The pollution emitted from these industries are transported and scavenged over Delhi during the monsoon As shown in table 1.9, there are 4.87 million vehicles in Delhi, which is the main cause of air pollution contributing to more than 72% share in air pollution in Delhi. At the sites like Paharganj the acidity is due to the very heavy vehicular traffic. In the initial phase (July-August) of the monsoon rainfall, soil derived dust are in high enough concentrations to neutralize the acidity of the atmosphere. In the later phase of the monsoon i.e. September, the continuous emission of pollutants by industries and vehicular traffic build up such a concentration that total neutralization is not possible leading to acidity of precipitation. But there are deviations from this behaviour of pH at some locations such as Shahdara, Okhla, Badarpur, Paharganj, and Rajinder Nagar .At these locations considerable acidity has been observed in the initial showers which is primarily because of lack of complete neutralization of acidic ions. Rainfall intensity is another factor modifying the pH. When the rainfall is heavy more wash out and rain out occurs, thus affecting pH.

CONCLUSION

CONCLUSIONS:

The average pH of all the eleven sites was 6.24 which is taken as alkaline for rainwater. Out of the 209 samples of rainwater colleted, 22 times pH was found to be below 5.67 which is about 11% of the collected samples. The average ratio of NO_3^- / SO_4^{2-} was 1.39 which indicates that SO_4^{2-} was no longer the predominant ion and acidity is more dominantly caused by NO_3^- The NH_4^+ + Ca^{2+} and NO_3^- + SO_4^{2-} correlation coefficient was 0.96 which indicates that NH_4 and Ca^{2+} play an important role in neutralization of acidic ions in rainwater. For almost all the locations the concentrations of chemical species Cl^-, NO^-_3, SO_4^{2-}, Na^+, NH_4^+, K^+, Ca^{2+} and Mg^{2+} decreased with days as monsoon progressed from July to September. It is evident from the results that NO_3^- concentrations are higher. This also corresponds well with NO_x concentration in the ambient air quality data of Delhi which has shown an increase of 1.36 times between the years 2000 and 2005. i.e. after the CNG implementation in Delhi. This may be due to the fact that the number of CNG vehicles were more in 2005 than in 2000.Moreover, CNG has a higher flash point of 540°C than diesel which has a flash point of 232-282^{0}C. At such high temperatures, more nitrogen from the air compresses and reacts with oxygen in the combustion chamber of CNG driven vehicle in comparison to petrol driven vehicles and thus produces more NO_2. At the same time there are other reasons also for increase in NO_3^- concentration in rainwater and NO_x in air and we can't put the blame only on CNG which can only be one of the reason. Evidently, there are many sources of nitrogen dioxide. The capital's 4.87 million strong fleet of vehicles which is ever increasing can't be underestimated. The annual 5 percent increase in the number of vehicles on Delhi roads is another major reason. These are some of the issues which need to be further investigated and can be apart of any future research in rainwater chemistry.

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APPENDIX

Table1. Concentration of major ions at J.N.U. (all values are in **ppm**, except pH, E.C. and ,TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
1	6/7/2005	6.40	158.00	94.26	15.01	2.18	26.98	24.30	12.25	1.75	2.41	2.61	0.77
2	11/7/2005	6.98	115.20	68.10	3.58	5.43	16.85	21.70	8.07	1.52	2.18	2.74	2.03
3	12/7/2005	6.34	91.80	52.29	2.60	3.24	15.24	16.46	9.03	0.65	0.21	0.42	1.44
4	13/7/2005	6.85	97.00	55.58	4.50	3.37	15.37	17.20	5.09	1.41	3.44	2.68	1.53
5	29/7/2005	6.33	98.23	58.88	2.86	2.55	18.75	17.76	7.23	1.36	1.27	2.44	0.66
6	4/8/2005	7.16	91.60	50.34	0.85	2.88	17.86	15.38	5.91	1.28	1.95	1.09	1.14
7	5/8/2005	7.01	84.50	49.26	5.63	2.90	13.83	13.01	7.06	0.68	1.53	1.40	1.22
8	6/8/2005	6.93	88.25	50.26	3.70	1.56	14.69	16.86	5.72	0.83	3.38	1.85	0.67
9	16/8/2005	6.57	96.45	56.31	5.80	2.73	19.22	14.18	7.78	0.76	2.33	0.85	1.67
10	19/8/2005	6.32	90.52	53.10	5.80	2.51	20.56	11.84	7.65	0.92	1.53	1.12	1.17
11	21/8/2005	6.70	69.00	37.34	0.85	1.62	11.10	12.29	5.05	0.53	1.17	1.01	0.73
12	9/9/2005	6.01	73.20	42.83	6.42	3.83	10.21	10.44	4.58	0.92	1.42	1.58	1.43
13	12/9/2005	6.31	42.00	26.83	2.68	1.54	9.44	5.16	4.05	0.36	1.04	0.41	0.16
14	13/9/2005	5.92	40.16	23.44	4.48	1.02	5.78	6.16	3.01	0.77	0.23	0.54	0.46
15	14/9/2005	6.26	34.26	19.20	1.98	1.78	5.26	3.88	2.56	0.48	0.48	0.50	0.28
16	15/9/2005	6.47	39.00	20.97	2.72	0.90	6.55	5.18	3.05	0.41	0.55	0.28	0.33
17	16/9/2005	5.51	39.80	23.87	5.52	1.07	3.58	7.58	2.11	0.74	0.67	1.52	0.37
18	23/9/2005	6.18	25.25	15.16	3.00	1.14	4.03	2.34	2.18	0.54	0.25	0.37	0.31
19	24/9/2005	6.20	27.58	16.94	2.21	1.62	3.90	4.86	1.70	1.13	0.27	0.32	0.73

Table 2.Concentration of major ions at A.I.I.M.S. (all values are in **ppm**,except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
1	6/7/2005	6.02	145.20	84.80	7.20	5.70	23.71	23.84	8.67	3.68	3.52	3.33	2.16
2	11/7/2005	5.25	138.80	76.43	10.64	3.59	23.47	20.32	8.09	3.35	2.62	2.36	0.99
3	12/7/2005	6.15	106.20	63.81	6.29	2.90	19.59	18.04	7.05	3.14	1.72	1.86	1.22
4	13/7/2005	6.23	110.00	67.48	10.50	2.98	16.80	17.84	6.66	3.39	1.97	1.94	4.40
5	29/7/2005	6.02	108.00	62.55	6.80	2.52	21.77	14.61	5.85	2.31	2.43	2.34	1.92
6	4/8/2005	5.88	98.80	57.79	5.08	2.41	17.16	18.10	5.96	2.34	1.96	1.75	1.03
7	5/8/2005	5.85	88.60	51.20	7.60	1.78	14.54	12.86	5.03	2.21	1.82	1.54	1.82
8	6/8/2005	6.10	88.82	45.98	8.23	2.17	11.14	10.97	5.24	2.32	1.09	1.43	1.40
9	16/8/2005	5.98	56.00	33.32	2.20	1.37	10.08	10.52	3.72	1.37	1.32	1.23	0.52
10	19/8/2005	6.39	62.02	38.98	4.93	1.56	13.06	9.12	3.91	1.82	1.09	0.97	1.52
11	21/8/2005	6.89	60.25	36.76	5.36	1.29	9.78	10.26	3.70	1.63	0.93	1.57	1.24
12	9/9/2005	5.93	60.10	35.57	8.17	1.40	9.14	7.38	3.50	1.45	0.83	1.67	1.03
13	12/9/2005	6.37	42.00	23.88	1.90	1.50	8.50	4.50	1.75	1.39	0.64	1.08	0.63
14	13/9/2005	5.65	34.00	19.43	1.56	1.38	4.93	6.00	1.49	0.87	0.48	1.15	0.57
15	14/9/2005	6.34	35.60	18.77	1.50	1.81	3.68	5.76	1.42	1.78	0.15	0.95	0.73
16	15/9/2005	6.75	27.85	13.62	0.85	0.76	5.11	2.83	1.29	0.87	0.21	0.34	0.36
17	16/9/2005	6.06	30.60	15.90	2.35	0.40	3.84	4.33	0.91	0.82	0.48	0.62	1.17
18	23/9/2005	6.17	39.60	19.15	0.91	0.60	6.16	5.89	2.57	0.34	0.23	0.25	1.22
19	24/9/2005	6.12	17.50	8.89	0.45	0.60	3.02	1.80	0.23	0.81	0.18	0.57	0.22

Table 3. Concentration of major ions at Badarpur (all values are in **ppm**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
1	6/7/2005	4.93	152.20	80.48	11.97	5.33	30.34	7.10	10.11	2.24	4.08	2.23	3.08
2	11/7/2005	5.20	128.00	72.01	10.67	3.24	34.16	4.10	9.71	1.91	3.37	1.69	1.16
3	12/7/2005	6.00	85.60	45.20	6.50	3.26	18.13	3.08	6.00	1.23	1.91	1.87	1.22
4	13/7/2005	6.72	90.20	47.79	8.90	2.87	17.17	3.79	5.31	1.21	3.10	2.00	2.43
5	29/7/2005	5.99	103.00	54.36	7.20	4.13	21.44	4.98	6.17	1.53	3.20	1.79	1.93
6	4/8/2005	5.81	88.00	47.57	5.60	3.26	20.18	4.13	7.11	1.22	1.97	1.54	1.56
7	5/8/2005	5.95	73.20	39.49	1.20	2.02	19.92	3.32	5.06	0.95	1.45	1.73	0.85
8	6/8/2005	6.77	71.80	41.69	4.90	3.23	16.92	3.90	5.86	0.95	1.82	1.18	1.94
9	16/8/2005	6.81	69.20	40.87	5.60	1.40	17.66	3.62	5.97	0.80	1.72	1.86	1.24
10	19/8/2005	6.90	68.40	37.50	6.26	4.20	10.48	3.61	5.17	1.04	1.42	1.50	1.81
11	21/8/2005	6.81	69.80	35.30	5.50	3.33	11.14	3.19	4.53	0.74	1.45	1.90	1.52
12	9/9/2005	6.11	59.60	29.57	8.63	1.26	8.77	1.83	4.63	0.53	1.36	1.00	0.55
13	12/9/2005	6.39	39.60	22.65	1.80	1.70	9.86	1.52	3.07	0.32	1.61	0.41	0.36
14	13/9/2005	5.78	38.00	23.97	5.75	1.08	9.00	1.30	2.95	0.59	0.90	0.98	0.42
15	14/9/2005	6.08	34.80	17.08	4.20	1.09	4.01	1.47	3.07	0.21	0.38	0.54	1.10
16	15/9/2005	6.82	28.80	15.01	1.50	0.55	7.14	1.10	2.43	0.29	0.57	0.31	0.12
17	16/9/2005	5.31	29.96	17.96	2.55	0.90	7.22	2.04	3.05	0.41	0.92	0.29	0.37
18	23/9/2005	5.73	28.50	16.99	0.35	1.17	7.35	1.94	2.42	0.27	0.55	0.37	1.56
19	24/9/2005	5.80	25.20	14.87	0.79	1.86	5.45	1.62	2.53	0.28	0.43	0.64	0.77

Table 4. Concentration of major ions at Okhla (all values are in **ppm**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
1	6/7/2005	5.70	182.30	93.05	11.90	5.41	27.00	21.46	12.00	1.94	2.89	2.18	2.28
2	11/7/2005	4.90	123.50	69.95	8.79	4.03	18.21	20.42	8.26	1.46	2.30	1.95	1.94
3	12/7/2005	5.98	98.90	55.35	6.60	4.03	15.22	13.14	6.26	1.05	2.47	1.93	1.66
4	13/7/2005	5.83	97.50	56.70	8.50	2.17	10.64	20.88	5.85	1.22	1.54	2.22	2.70
5	29/7/2005	5.83	97.91	48.07	5.94	2.88	17.34	9.18	5.02	1.31	1.41	1.85	1.14
6	4/8/2005	5.34	101.36	53.52	7.50	3.03	11.64	15.48	5.22	1.27	1.46	2.05	1.88
7	5/8/2005	6.15	85.69	47.07	4.97	2.66	14.54	12.60	4.51	0.80	2.02	1.31	1.66
8	6/8/2005	6.89	67.25	40.60	5.10	2.40	13.73	8.28	4.26	0.77	1.12	1.84	1.11
9	16/8/2005	5.81	71.23	41.10	4.80	1.06	12.50	11.70	4.05	0.88	1.43	1.08	1.60
10	19/8/2005	6.80	66.11	35.49	4.30	2.40	9.89	8.28	3.91	0.69	1.12	0.83	1.07
11	21/8/2005	6.88	72.65	38.30	5.77	2.18	9.85	10.80	4.68	0.62	1.52	0.48	1.40
12	9/9/2005	6.15	62.56	33.49	3.51	1.84	9.78	8.76	2.50	0.75	1.55	1.27	1.54
13	12/9/2005	5.95	40.82	22.47	2.33	2.20	6.54	4.54	1.58	0.95	0.39	1.05	0.90
14	13/9/2005	6.08	38.45	22.65	2.30	1.50	8.50	4.52	1.94	0.90	0.78	0.59	0.63
15	14/9/2005	6.56	41.20	21.84	2.30	1.74	8.13	3.98	1.86	0.77	1.11	0.94	0.71
16	15/9/2005	6.58	45.94	23.54	2.08	1.84	7.89	5.64	1.97	0.64	1.29	0.71	0.48
17	16/9/2005	5.93	28.00	15.63	2.25	0.84	4.46	3.76	1.30	0.60	0.69	0.39	0.34
18	23/9/2005	6.05	27.60	14.08	0.30	0.46	3.53	5.58	1.13	0.56	0.25	0.41	0.85
19	24/9/2005	6.09	18.30	11.82	1.47	0.37	3.72	3.24	0.62	0.59	0.32	0.52	0.46

Table 5.Concentration of major ions at Laxmi Nagar (all values are in **ppm**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
1	6/7/2005	6.26	185.23	101.93	7.40	5.66	37.11	20.16	8.71	2.66	3.76	3.90	2.58
2	11/7/2005	6.92	129.23	74.45	15.20	5.52	14.16	17.64	7.91	2.21	3.38	2.32	1.11
3	12/7/2005	6.62	91.23	47.97	2.50	3.91	14.53	12.78	5.05	1.40	2.02	1.77	2.01
4	13/7/2005	6.87	95.65	48.08	4.45	1.62	12.08	16.56	4.45	1.27	2.42	2.07	2.17
5	29/7/2005	4.98	87.23	46.69	6.79	2.02	12.24	14.64	4.12	1.85	1.62	1.73	0.69
6	4/8/2005	5.91	89.98	47.26	7.80	2.19	11.16	14.04	4.26	1.28	2.04	1.87	1.64
7	5/8/2005	6.18	79.66	44.23	5.05	1.87	13.86	12.42	3.86	1.22	1.94	1.40	1.60
8	6/8/2005	6.13	75.43	43.66	6.80	3.26	11.46	10.61	4.60	1.41	1.37	1.73	1.42
9	16/8/2005	6.13	67.60	38.49	4.33	1.72	10.54	11.78	5.12	0.92	0.79	1.56	0.73
10	19/8/2005	6.73	70.36	39.56	5.18	1.29	11.14	10.98	3.64	0.87	1.09	1.90	1.48
11	21/8/2005	6.85	11.50	5.95	0.25	0.24	1.36	2.03	0.68	0.14	0.16	0.04	0.05
12	9/9/2005	5.80	65.66	38.51	3.90	3.28	10.25	10.26	4.91	1.20	0.64	1.34	0.73
13	12/9/2005	5.75	60.23	32.32	3.60	1.64	10.43	6.70	3.12	0.79	0.51	1.32	1.22
14	13/9/2005	6.18	46.00	27.41	3.58	1.92	8.00	5.74	3.16	0.50	0.38	1.41	0.73
15	14/9/2005	6.81	36.66	18.78	2.96	0.96	5.63	2.88	3.28	0.60	0.46	0.66	0.36
16	15/9/2005	6.83	40.22	22.82	2.36	1.80	7.03	5.40	2.50	0.35	0.66	1.02	0.70
17	16/9/2005	6.05	15.36	9.72	1.39	0.42	2.28	2.50	1.53	0.13	0.10	0.19	0.17
18	23/9/2005	5.85	28.50	15.73	1.60	0.77	4.73	4.08	1.78	0.27	0.33	0.67	0.48
19	24/9/2005	6.00	24.80	12.84	1.20	0.43	3.02	4.50	1.35	0.16	0.15	0.85	0.67

Table 6. Concentration of major ions at Shahadara (all values are in **ppm**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
1	6/7/2005	4.95	164.60	79.46	7.60	3.93	31.44	18.88	8.26	1.92	3.66	2.88	0.89
2	11/7/2005	5.35	105.60	64.38	4.37	4.14	19.74	17.84	6.27	1.34	2.67	2.11	1.90
3	12/7/2005	6.98	91.60	49.88	5.28	3.66	13.18	12.06	5.07	1.26	1.86	1.96	1.54
4	13/7/2005	6.02	101.21	53.18	3.60	2.86	18.02	14.46	5.00	1.44	1.43	1.96	2.41
5	29/7/2005	5.63	77.20	42.78	3.50	2.94	14.93	9.34	5.11	1.04	1.23	1.55	1.14
6	4/8/2005	6.02	68.00	44.09	1.10	2.55	15.65	12.62	5.64	0.94	1.12	1.38	1.11
7	5/8/2005	5.32	79.60	47.58	2.50	1.11	17.34	15.38	5.58	0.63	1.41	1.55	1.10
8	6/8/2005	6.56	69.20	43.42	5.69	1.38	16.66	8.82	4.41	1.24	0.96	1.04	1.24
9	16/8/2005	6.15	65.00	39.27	0.68	1.26	16.74	10.47	4.83	0.65	0.93	1.23	0.47
10	19/8/2005	6.88	60.25	37.38	4.15	1.48	10.52	10.65	3.64	1.12	1.19	1.27	1.38
11	21/8/2005	6.16	63.20	35.17	2.70	1.46	10.42	10.70	3.85	0.77	1.45	1.31	0.51
12	9/9/2005	5.83	50.20	29.96	2.95	1.81	11.07	5.76	3.82	0.52	0.56	0.63	0.84
13	12/9/2005	6.15	52.10	30.95	0.65	1.61	12.40	8.76	4.04	0.59	0.76	0.86	0.68
14	13/9/2005	6.25	56.82	32.89	2.20	1.47	11.30	9.56	3.63	0.63	0.66	1.71	1.24
15	14/9/2005	6.67	35.80	19.91	0.75	1.02	5.97	6.78	1.71	0.53	0.59	1.13	0.43
16	15/9/2005	5.06	45.20	26.07	0.85	0.52	7.64	9.30	1.78	0.52	0.86	1.05	1.55
17	16/9/2005	6.18	35.60	17.05	1.20	0.25	5.08	4.45	0.86	0.52	0.52	0.70	0.46
18	23/9/2005	6.35	20.20	12.49	0.58	0.60	3.40	4.28	0.90	0.36	0.58	0.57	0.22
19	24/9/2005	6.56	19.60	11.33	0.50	0.72	4.56	2.16	0.57	0.23	0.53	0.73	0.32

Table 7. Concentration of major ions at Paharganj (all values are in **ppm,** except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
1	6/7/2005	4.88	150.60	85.08	5.84	2.88	30.08	24.36	10.30	2.24	3.32	2.33	0.73
2	11/7/2005	5.78	129.82	69.22	7.60	2.11	26.98	14.10	9.51	1.30	1.93	1.81	0.88
3	12/7/2005	5.77	81.00	45.53	3.65	3.26	10.55	10.62	5.06	0.69	1.02	1.27	1.42
4	13/7/2005	6.11	99.55	59.69	7.40	2.49	21.38	13.86	5.89	1.29	1.91	2.48	2.00
5	29/7/2005	6.21	73.40	43.16	2.30	2.55	14.62	12.31	3.92	1.10	1.63	1.76	0.98
6	4/8/2005	5.60	72.00	41.46	1.20	2.32	13.94	12.34	3.72	1.17	1.73	2.13	0.92
7	5/8/2005	5.58	80.60	48.15	3.90	2.43	18.80	10.97	5.13	0.78	1.16	1.61	2.37
8	6/8/2005	7.08	75.00	44.03	4.90	2.20	16.14	8.88	5.83	0.75	1.11	1.34	0.89
9	16/8/2005	6.88	74.20	41.14	4.02	1.66	13.08	11.60	4.90	0.69	1.02	1.48	0.70
10	19/8/2005	6.71	68.00	37.83	3.62	1.72	10.54	11.78	4.25	0.65	0.97	1.56	0.73
11	21/8/2005	6.96	61.20	35.94	6.99	0.99	10.12	7.96	3.70	0.84	1.24	1.21	0.88
12	9/9/2005	6.37	56.20	34.43	3.60	0.40	12.14	8.46	3.24	0.96	1.43	0.98	1.21
13	12/9/2005	5.93	29.00	13.81	0.26	0.60	4.36	3.66	1.64	0.39	0.58	0.11	0.22
14	13/9/2005	6.45	24.00	13.13	2.89	0.38	3.34	2.50	1.64	0.37	0.55	0.33	0.13
15	14/9/2005	6.71	26.20	14.12	0.27	0.60	3.49	5.52	1.31	0.39	0.58	0.73	0.22
16	15/9/2005	5.87	30.20	18.09	1.69	0.77	5.40	5.38	1.70	0.53	0.78	0.63	0.22
17	16/9/2005	5.87	36.20	20.83	2.35	1.46	6.39	4.84	1.72	1.08	1.60	0.63	0.16
18	23/9/2005	6.05	17.60	8.82	2.64	0.60	1.27	1.34	1.11	0.23	0.34	0.19	0.12
19	24/9/2005	5.81	15.10	7.87	0.95	0.66	1.62	1.98	0.83	0.14	0.21	0.42	0.05

Table 8.Concentration of major ions at Mukherjee Nagar(all values are in **ppm**, except pH, E.C.and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
1	6/7/2005	6.40	160.80	85.01	7.60	3.49	34.27	17.84	9.70	1.30	4.46	2.42	0.93
2	11/7/2005	6.60	120.56	65.88	4.86	2.90	27.82	13.38	5.71	1.37	4.29	1.72	0.83
3	12/7/2005	6.80	136.60	77.56	7.50	5.59	26.09	18.90	6.16	2.35	4.65	1.96	2.37
4	13/7/2005	6.05	148.00	83.54	13.50	2.68	32.30	17.10	5.09	2.32	5.15	2.13	2.26
5	29/7/2005	7.38	103.20	60.14	6.61	2.19	20.05	15.61	5.06	1.45	3.71	1.96	1.50
6	4/8/2005	6.57	105.00	64.56	5.83	2.01	25.50	13.50	7.63	1.28	1.65	1.54	1.63
7	5/8/2005	5.82	91.20	48.75	5.22	2.79	14.58	13.60	5.16	2.25	1.01	0.59	1.54
8	6/8/2005	6.98	75.20	44.70	8.60	1.47	10.54	11.78	5.31	0.92	1.33	2.02	0.73
9	16/8/2005	6.83	72.40	43.70	5.15	2.11	13.54	11.00	4.70	1.37	1.16	1.81	0.87
10	19/8/2005	5.65	68.00	40.58	3.65	2.24	13.26	10.74	4.26	1.11	1.47	1.04	0.82
11	21/8/2005	7.13	63.22	39.68	3.53	0.70	14.97	10.62	4.97	0.99	1.37	0.81	0.72
12	9/9/2005	6.27	60.16	36.46	3.53	2.34	14.21	7.02	4.76	0.61	1.29	0.82	0.89
13	12/9/2005	6.79	44.00	28.77	4.05	0.84	8.12	6.86	3.02	0.60	1.28	0.66	0.34
14	13/9/2005	5.81	40.84	24.04	2.71	0.78	6.34	7.92	2.98	0.54	0.79	0.72	0.28
15	14/9/2005	5.81	33.60	22.51	3.24	0.66	6.42	5.65	2.33	0.42	0.89	0.65	0.25
16	15/9/2005	5.87	31.12	21.44	2.78	0.62	5.65	5.84	2.23	0.14	1.43	0.49	0.25
17	16/9/2005	6.18	31.66	22.82	1.96	0.90	8.94	5.28	3.45	0.20	0.87	0.29	0.33
18	23/9/2005	6.36	28.60	17.22	0.84	0.72	5.90	4.92	2.77	0.16	0.48	0.11	0.32
19	24/9/2005	6.06	21.60	12.86	1.57	0.54	2.86	4.10	1.97	0.17	0.23	0.19	0.23

Table 9. Concentration of major ions at Rohini (all values are in **ppm**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S	HCO_3^-	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
1	6/7/2005	6.82	187.20	97.76	7.56	6.01	29.43	22.64	10.06	2.22	4.11	3.14	2.58
2	11/7/2005	6.82	147.20	79.02	6.50	6.01	26.76	19.25	6.06	3.45	3.75	2.45	1.80
3	12/7/2005	5.82	106.20	62.95	5.76	2.41	21.96	16.86	5.51	2.03	3.30	2.02	1.10
4	13/7/2005	6.35	116.20	68.37	6.50	3.75	22.44	18.08	6.91	2.14	3.18	1.76	1.63
5	29/7/2005	6.25	96.00	61.61	5.10	3.42	20.40	16.99	6.25	1.90	2.76	1.38	1.41
6	4/8/2005	6.15	92.00	56.14	4.52	2.53	19.81	14.66	5.94	1.12	2.51	2.15	0.90
7	5/8/2005	6.33	78.60	44.34	6.90	3.39	10.80	10.80	4.14	1.11	2.40	1.60	1.21
8	6/8/2005	6.85	80.20	46.67	10.25	2.41	9.77	10.25	3.66	0.95	2.01	3.86	1.51
9	16/8/2005	6.90	67.20	38.11	5.56	1.12	10.98	10.14	3.43	0.65	2.73	0.99	0.51
10	19/8/2005	7.11	70.60	42.69	7.20	1.22	10.92	11.88	3.92	1.05	1.38	1.60	1.51
11	21/8/2005	7.35	56.36	32.69	2.20	1.07	10.30	9.62	4.27	0.53	1.21	1.07	0.41
12	9/9/2005	6.14	68.25	38.05	5.29	1.25	11.19	9.18	4.72	0.75	0.60	1.78	1.29
13	12/9/2005	6.45	60.54	32.25	3.62	1.01	8.30	8.46	3.06	0.63	1.07	1.00	1.10
14	13/9/2005	5.91	55.22	27.58	5.35	0.90	7.02	6.40	3.05	0.54	1.24	0.77	0.32
15	14/9/2005	6.89	52.22	28.13	5.73	0.70	7.17	6.28	3.53	0.38	1.01	0.90	0.43
16	15/9/2005	6.08	11.26	6.58	0.60	0.24	1.36	1.96	1.02	0.03	0.23	0.06	0.08
17	16/9/2005	6.21	35.20	21.03	2.70	0.42	7.51	4.54	2.57	0.10	0.51	0.68	1.00
18	23/9/2005	6.25	36.20	23.19	3.33	0.66	7.51	5.54	3.97	0.29	0.23	0.23	0.43
19	24/9/2005	5.92	37.56	23.86	2.20	0.50	8.93	6.40	2.97	0.28	0.74	0.50	0.84

Table 10. Concentration of major ions at Rajinder Nagar (all values are in **ppm**, except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
1	6/7/2005	5.55	179.20	104.05	8.00	6.01	38.07	19.62	10.37	2.26	3.76	3.37	2.58
2	11/7/2005	5.68	159.60	79.74	7.60	3.51	27.53	18.30	8.31	1.77	3.33	2.50	1.88
3	12/7/2005	6.75	119.80	64.43	6.50	2.16	20.05	19.26	5.80	1.56	3.11	2.24	1.76
4	13/7/2005	6.84	82.36	52.86	1.50	1.73	18.20	17.36	6.02	1.29	1.40	1.97	1.39
5	29/7/2005	5.55	79.20	46.31	8.00	2.46	9.27	13.42	4.97	1.16	1.96	1.64	1.41
6	4/8/2005	6.20	89.80	50.87	1.50	1.73	16.66	15.02	5.72	1.00	1.51	1.63	1.12
7	5/8/2005	6.15	74.40	44.18	7.80	1.35	9.85	13.32	5.04	1.16	1.34	1.48	0.85
8	6/8/2005	6.78	69.60	40.69	7.50	1.75	10.40	10.08	4.26	1.04	1.52	1.26	0.90
9	16/8/2005	6.78	55.40	29.28	2.50	2.16	8.46	7.02	2.96	0.76	1.29	1.28	0.85
10	19/8/2005	6.21	70.50	38.38	5.50	1.84	8.16	12.96	5.14	0.67	1.08	1.16	0.88
11	21/8/2005	6.85	61.00	34.48	2.98	1.58	10.40	10.08	4.06	0.41	0.89	1.49	0.59
12	9/9/2005	6.01	35.80	20.23	2.20	1.08	5.01	5.69	2.02	0.47	0.55	0.75	0.46
13	12/9/2005	6.54	37.23	21.08	1.80	1.46	6.01	5.46	1.62	0.87	0.56	0.86	0.44
14	13/9/2005	6.20	34.50	21.15	3.20	1.11	4.92	6.00	1.83	0.44	0.34	1.56	0.76
15	14/9/2005	6.75	30.80	19.72	1.87	0.41	6.60	5.68	1.99	0.32	0.30	1.14	0.42
16	15/9/2005	6.06	22.00	13.99	1.40	0.60	5.05	2.88	1.48	0.31	0.28	0.59	0.40
17	16/9/2005	5.86	23.00	12.45	0.87	0.72	4.90	2.73	1.28	0.35	0.27	0.49	0.44
18	23/9/2005	5.45	21.20	12.32	0.35	0.67	4.82	2.90	1.49	0.17	0.29	0.46	0.18
19	24/9/2005	6.15	18.60	10.40	0.65	0.41	2.94	3.17	1.12	0.19	0.15	0.40	0.36

Table 11.Concentration of major ions at Dwarka (all values are in **ppm,** except pH, E.C. and TDS).

Sl.No.	Date	pH	E.C.	T.D.S.	HCO_3	Cl^-	SO_4^{2-}	NO_3^-	Ca^{2+}	Mg^{2+}	NH_4^+	Na^+	K^+
1	6/7/2005	6.02	170.50	95.90	10.60	5.84	29.62	21.78	10.80	2.54	3.13	2.36	3.24
2	11/7/2005	6.25	158.00	73.39	6.64	4.11	24.48	19.16	9.02	2.19	2.17	2.08	1.54
3	12/7/2005	6.05	167.20	74.37	5.76	2.88	26.94	19.10	7.91	1.60	2.13	1.62	2.43
4	13/7/2005	6.21	110.23	62.76	5.33	3.26	20.00	16.28	7.63	1.42	1.70	1.95	1.21
5	29/7/2005	6.15	101.20	62.33	5.64	3.26	20.96	17.52	6.71	1.29	1.88	1.95	1.13
6	4/8/2005	6.25	89.80	55.70	9.09	1.62	17.76	12.96	5.02	1.46	2.17	2.08	1.54
7	5/8/2005	6.11	78.70	48.08	6.03	1.09	14.28	13.76	5.00	1.43	1.86	1.54	1.10
8	6/8/2005	7.32	75.60	44.25	5.45	0.92	12.66	12.29	4.34	0.87	2.07	1.11	1.55
9	16/8/2005	7.13	76.20	40.38	4.75	1.23	10.61	11.16	3.93	0.97	1.94	1.28	1.51
10	19/8/2005	7.17	69.20	39.41	7.42	1.98	7.63	10.45	3.26	1.50	1.70	0.95	2.52
11	21/8/2005	6.78	48.60	30.47	5.33	1.14	9.34	5.90	2.46	0.53	1.57	0.96	1.23
12	9/9/2005	5.75	42.40	26.98	2.34	1.38	8.52	6.00	2.49	0.77	1.19	0.69	0.61
13	12/9/2005	6.15	54.56	32.14	1.92	1.35	8.20	10.44	2.25	0.69	2.14	0.74	1.43
14	13/9/2005	6.24	43.60	26.19	0.76	1.48	7.06	8.82	2.48	0.39	1.51	0.47	1.24
15	14/9/2005	6.11	48.00	24.63	2.59	1.24	6.69	6.20	2.27	0.20	1.40	0.58	1.47
16	15/9/2005	6.16	31.22	18.52	2.33	0.48	5.31	4.60	1.84	0.26	1.07	0.43	0.20
17	16/9/2005	5.79	32.25	17.85	1.13	1.26	6.95	3.78	2.03	0.29	0.63	0.30	0.47
18	23/9/2005	6.62	30.20	17.86	1.34	0.43	6.48	4.50	2.35	0.15	0.55	0.39	0.67
19	24/9/2005	6.12	33.80	20.97	1.41	0.37	6.86	6.70	2.52	0.22	0.96	0.31	0.61

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