INDEXING HYDRO-CHEMICAL QUALITY STATUS OF WATER IN DELHI: A GIS CUM STATISTICAL APPROACH

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

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KANIKA BHARADWAJ

(Roll NO. 8842)

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OF

Prof. S.K. SINGH

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING

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UNIVERSITY OF DELHI

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Department of Civil & Environmental Engineering
Delhi College of Engineering,
Delhi-110042

CERTIFICATE

This is to certify that the project entitled **"Indexing Hydrochemical Quality Status of Water in Delhi-A GIS Cum Statistical Approach"**, which is being submitted by **Kanika Bharadwaj,** is a bonafide record of the student's own work carried by her under my guidance and supervision in partial fulfillment of requirement for the award of the Degree of **Master of Engineering in Environmental Engineering, Department of Civil and Environmental Engineering, Delhi College of Engineering, Delhi, University of Delhi.**

The matter embodied in this project has not been submitted for the award of any other degree.

Dr. S. K. Singh
Professor & Head
Department of Civil & Environmental Engineering
University of Delhi

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Abstract

Contamination of drinking water has become a major challenge to environmentalists in rapidly developing countries. As more and more people are exposed to contamination of drinking water, many issues arise that not only involve premeditating the contaminated water, but also preventing similar situations from occurring in future. More effective and integrated water resource management on the regional scale is thus the need of the hour. Any such water resource management strategy must be based on sound, scientific, qualitative and quantitative assessment of the existing resources.

Decision makers in environmental fields face the difficult challenges of anticipating the potential biophysical and socioeconomic impacts of managements and policy interventions over regions that may vary dramatically in terms of climates, soils, topography, land use and other factors. However, a water quality index is one of the most effective ways to communicate information on the quality of water to the concerned citizens and policy makers. The objective of this index is to turn complex water quality data into information that is understandable, useable and by and large comparable.

The purpose of this project is thus to assess by means of a water quality index the variations groundwater and surface water quality in Delhi. Further, use of a decision support system like GIS is made to identify the problematic areas of water quality and to study the dependence of water quality on geology and groundwater levels. Finally the project aims at development of a strategy plan to augment water quality & quantity in the study area.

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Abbreviations & Acronyms

ABS	Alkyl Benzene Sulfonates
BEI	Base Exchange Index
BIS	Bureau of Indian Standards
CCE	Carbon Chloroform Extract
CGWB	Central Ground Water Board
CPCB	Central Pollution Control Board
CWC	Central Water Commission
DJB	Delhi Jal Board
DPCC	Delhi Pollution Control Committees
EC	Electrical Conductivity
EPA	Environmental Protection Agency
GIS	Geographic Information System
mg/l	milligrams per litre
MLD	Million liters per day
NSF	National Sanitary Foundation
RSC	Residual Sodium Carbonate
SAR	Sodium Absorption Ratio
TDS	Total Dissolved Solids
TH	Total Hardness
USGS	United States Geological Survey
WQI	Water Quality Index

CHAPTER I

INTRODUCTION

Water makes the earth the "blue planet", visually unique from all others in the solar system. Approximately 70 percent of the earth's surface is covered with water. Most water on our planet occurs as saline water in the oceans and deep groundwater or is contained in polar ice caps and the permanent ice cover of the high mountain ranges. So, only 30 million Km^3 of fresh water, that is only 2% of all water, plays an active part in the hydrological cycle and in the maintenance of all life on the continents. [1]

As a universal solvent, water possesses extraordinary ability to dissolve a broad range of substances. The salinity of world's oceans is a direct result of water's ability to dissolve rock materials as it flows overland to sea. The Earth's atmosphere contains 0.02 to 4 percent water by volume, depending on the location. In addition to providing sources for precipitation, atmospheric water vapor intercepts some of the UV radiation and intercepts heat loss from the earth and redirects part of it to the Earth. Because of water's high heat capacity, the presence of oceans, lakes and large rivers prevents extreme fluctuations in local temperatures. Even within the human body (75% water by volume) water is critical in maintaining uniform body temperature. Thus water plays a major role in virtually every aspect of human life. Being one of the keys issues of Sustainable Development; it is also the basic element for human survival, an important production factor in our economy, particularly in agriculture, and also the habitat of a wide range of biodiversity.

1.1 Water Woes

Quantity wise the availability of freshwater is well enough to support the world's population, but the major problem with fresh water supply is its timing and location. Precipitation (in the form of rain or snow) is the major source of water for the surface water bodies as well as subsurface bodies. The distribution of water and intensity of rainfall is highly variable in space and time. Besides these natural causes other factors as excessive withdrawal of groundwater have led to the lowering of water table thereby decreasing the freshwater availability.

Water quality is as important as its quantity, because it's the quality that decides the end use of this invaluable resource. As water moves through the hydrologic cycle, its quality changes in response to differences in the environments through which it passes. The changes may be either natural or human influenced; in some cases they can be controlled, in other cases they cannot, but in most instances they can be managed in order to limit adverse water-quality changes. With increasing population, industrialization, unplanned urbanization and changes in land use, pollution load on water bodies has increased tremendously. The chemistry of many rivers today is strongly influenced by inputs of domestic and industrial wastes. This upsets the natural balance existing in the river by destroying the indigenous biota either through the direct effects of toxic materials or due to oxygen depletion resulting from organic decomposition. [2]

Every year, we need 270,100 million tons more water because of 90 million increasing population. But regrettably too few of us understand the physical and chemical properties of water well enough to efficiently solve and nearly universal problems relating to its availability, distribution, contamination and cost. Water problems, of any type, stem largely from lack of knowledge and therefore from the gross mismanagement of this versatile resource. The fast increasing number of large cities particularly in the developing world raises many problems for water resources management. Adequate water supply and drainage management are urgent tasks, and we need new solutions to overcome the problems arising from, e.g., water scarcity, deteriorating water quality, lack of sufficient supply systems, inappropriate handling of waste water, inadequate storm water management, flood risks etc.

Rising worldwide concern for managing the Earth's fragile natural resources in a more sustainable way is evident from the Agenda 21 adopted by more than 178 governments after the United Nations Conference on Environment and Development referred as the 1992 Earth Summit in Rio de Janeiro. The Agenda states that *"Water is needed in all aspects of life. The general objective is to make certain that adequate supplies of water of good quality are maintained for the entire population of this planet,* *while preserving the hydrological, biological and chemical functions of ecosystems, adapting human activities within the capacity limits of nature …The multi-sectoral nature of water resources development in the context of socio economic development must be recognized, as well as the multi-interest utilization of water resources for water supply and sanitation, agriculture, industry, urban development, hydropower generation, inland fisheries, transportation, recreation, low and flat lands management and other activities".*

The Ministerial Declaration in Hague on Water Security in the 21st century (2000) also emphasized on the management of urban water systems and recognizes the need of *"Search for better integration of land-use and water management within overall environmental management …"* and recommends … *"The adoption of integrated water cycle management in urban areas. Integrated water and waste water management should include conservative water and waste water management through the integration of storm water, ground water and surface water use …. And finally must remain subservient to the goal of sustainability and social equity".* [i]

1.2 Emerging fresh water crisis in India

The National Water Policy (1987) states that "water is a prime natural resource, *a basic human need and a precious national asset" a*nd gives primacy to drinking water for both humans and animals over its other uses. [ii] Fresh water is increasingly taking centre stage on the economic and political agenda, as is evident from the rising number of disputes between states and even at community levels. The freshwater crisis is due to the lack of access to safe water supply to millions of people as a result of inadequate water management and environmental degradation. The fresh water crisis is not the result of natural factors, but has been caused by human actions. During the early 1980s, India developed indigenous capabilities for water well drilling in hard rock areas which provide drinking water for millions of people. But at the same time, the number of energized wells drilled for irrigation of cash crops rapidly increased, encouraged by easy credit and subsidized diesel and electricity. India's rapidly rising population and changing lifestyles also increases the need for fresh water. Intense competition among competing users-agriculture, industry and domestic sector - is driving the ground water table deeper and deeper. The root causes of the crisis are as follows:

- ❖ Widespread pollution of surface and groundwater is reducing the quality of fresh water resources.
- ❖ Communities not being in control of their water resources. Water is used as a political tool, controlled and cornered by the rich, who do not pay the price for this scarce resource. The poverty of incomes, capabilities and opportunities of many is compounded by 'water poverty'.
- ❖ The system of 'water rights' under common law in India which gives the ownership of groundwater to the landowner, despite the fact that ground water is a shared resource from common pool aquifers.
- ❖ Uncontrolled use of the bore well technology which has allowed the extraction of ground water, primarily for irrigation, to grow at phenomenal rates, often exceeding recharge.
- ❖ The lack of adequate attention to water conservation, efficiency in water use, water reuse, ground water recharge and eco-system sustainability.

1.3 The crisis in Delhi

Delhi, the capital of India, too faces a similar crisis; the water supply resources here are continuously under severe pressure due to ever increasing population and industrial activities. The National Capital Region Planning Board projects that in next few years nearly 40% people of Delhi will have difficulty accessing water. The water requirement for the city is 900 MGD (million gallons per day) and the projected demand in 2001 was 1100 MGD. As against this the claimed supply from Delhi Jal Board official sources is 600 MGD leading to a projected demand supply gap of 500 MGD. Proposed upstream reservoirs by Delhi Jal Board (the water supply agency in Delhi) to augment water supplies for Delhi may not even come up while the population will be almost doubled by the year 2021.

Two decades of industrialization have turned the Yamuna into a sewer and toxic drain-an extension of the city's sewerage system. Share of river Yamuna water for Delhi is fully utilized and river bed is almost dry several months in year except monsoon. Delhi's ever growing water demands have already led to major diversions of water from other regions. Delhi already gets 455 MLD from the Ganga and with the recent functioning of Sonia Vihar plant the total amount of water diverted from Ganga alone amplified to 1090 MLD. Further diversion of 3000 million cubic meters per second from the Ganga is built into the Sharda and Yamuna river link. In-situ resource 'groundwater aquifers'-the only buffer stock, are being exploited to meet the piped water demand supply gap resulting rapid depletion of water table over 8-10 m over last few years and wells drying up. [3]

1.4 Objectives of study

With already stressed out surface water resources and an unabated extraction from groundwater aquifers, the rate of depletion of ground water levels and deterioration of ground water quality has become a major point of concern in Delhi. The present study attempts to evaluate the quality of water in Delhi, especially groundwater, with particular reference to drinking and irrigation purposes. The study will provide necessary input database for ground water management of the region. The objectives of this study may be summarized as

- *Spatial analysis of variations in Delhi groundwater quality*
- *Temporal analysis of Yamuna river water quality*
- *Augmenting the development of a strategy plan to supplement water quality & quantity*

CHAPTER II

LITERATURE REVIEW

2.1 General

Rivers are the most important freshwater resource for man. Social, economic and political development has, in the past, been largely related to the availability and distribution of fresh waters contained in riverine systems. Rivers and streams are an important component of the natural environment, and need to be protected from all sources of pollution because man's own survival depends on their sustainable use. Major river water uses are as source of drinking water supply, irrigation of agricultural lands, industrial and municipal water supplies, industrial and municipal waste disposal, navigation, fishing, boating and body-contact recreation, aesthetic value etc.

Groundwater or Subsurface water is the largest source of fresh water on the planet excluding the polar icecaps and glaciers. It constitutes of water present in the unsaturated zone (vadose zone) known as soil moisture and the water present below the water table i.e. in the saturated zone known as groundwater. At present nearly one fifth of all water used in the world is obtained from groundwater resources. Agriculture is the greatest user of water accounting for about 80% of all consumption. The present irrigated area in India is 60 million hectares of which 40% is from groundwater. [4]

2.2 Characteristics of water

Each freshwater body has an individual pattern of physical and chemical characteristics which are determined largely by the climatic, geomorphological and geochemical conditions prevailing in the drainage basin and the underlying aquifer. The chemical quality of the aquatic environment varies according to local geology, the climate, the distance from the ocean and the amount of soil cover, etc. Summary characteristics, such as total dissolved solids, conductivity and redox potential; provide a general classification of water bodies of a similar nature. Mineral content, determined by the total dissolved solids present, is an essential feature of the quality of any water body resulting from the balance between dissolution and precipitation. Oxygen content is another vital feature of any water body because it greatly influences the solubility of metals and is essential for all forms of biological life.

The development of biota (flora and fauna) in surface water is governed by a variety of environmental conditions which determine the selection of species as well as the physiological performance of individual organisms. The degradation of organic substances and the associated bacterial production can be a long-term process which can be important in groundwater and deep lake water which are not directly exposed to sunlight. In contrast to the chemical quality of water bodies, which can be measured by suitable analytical methods, the description of the biological quality of a water body is a combination of qualitative and quantitative characterization.

2.2.1 Major Constituents of Groundwater

All groundwater contains salts in solution; the quantity and type of mineral matter dissolved depend on the chemical composition and physical structure of the rocks as well as the hydrogen-ion concentration (pH) and the redox potential (Eh) of the water. Carbon dioxide in solution, derived from the atmosphere and from organic processes in the soil, assists the solvent action of water as it moves underground. Ordinarily, higher concentrations of dissolved constituents are found in groundwater than in surface water because of the greater exposure to soluble materials in geologic strata. Soluble salts in groundwater originate primarily from solution of rock materials. Bicarbonate, usually the primary anion in groundwater is derived from carbon dioxide released by organic decomposition in the soil. Salinity varies with specific surface area of aquifer materials, solubility of minerals, and contact time; values tend to be highest where movement of groundwater is least; hence it generally increases with depth. A common geochemical sequence in groundwater includes bicarbonate waters near ground surface varying to chloride waters in the deepest portions of formations.

Sedimentary rocks are more soluble than igneous rocks. Because of their high solubility, combined with their great abundance in the earth's crust, they furnish a major portion of the soluble constituents to groundwater. Sodium and calcium are commonly added cations; bicarbonate and sulfate are corresponding anions. Chloride occurs to only a limited extent under normal conditions; important sources of chloride, however, are from sewage, connate water, and intruded seawater. Occasionally nitrate is an important natural constituent otherwise its high concentrations indicate sources of past or present pollution. For most groundwater, 95% of the ions are represented by the eight major ionic species:

- ***Cations:*** Sodium, Potassium, Calcium and Magnesium
- ***Anions:*** Chloride, Sulphate, Bicarbonate & Carbonate and Nitrate

2.3 Water quality and pollution

The natural quality of water depends upon the physical environment and the origin and movement of water. Water quality may be defined as the *description of temporal and spatial variations due to factors internal and external to the water body.* While water pollution may be defined *as introduction by man, directly or indirectly, of substances or energy which results in deleterious effects* such as harm to living resources, hazards to human health, hindrance to aquatic activities including fishing, impairment of water quality with respect to its use in agricultural, industrial and often economic activities, and reduction of amenities. [5]

2.3.1 Water Quality Requirements

Inherently water is multiple use resource. With the advent of industrialization and increasing populations, the ranges of requirements for water have increased, together with greater demands for higher quality of water. The main uses of water are public water supply, outdoor bathing & recreation, fisheries & wildlife propagation, irrigation & other agricultural uses, cooling in power plants, navigation and disposal of wastes. Most of these uses are often conflicting. In order for any water body to function adequately in satisfying any one of the above-mentioned uses, it must have corresponding degree of purity. In terms of quality, drinking water needs highest level of purity, whereas disposal of wastes can be done in any quality of water. Therefore, maintenance of quality of water is as important as the quantity.

2.3.2 Sources of Pollution

Water can receive contaminated infiltration from a variety of sources. A wide range of natural and human influences affect its quality. In contrast to surface water pollution, groundwater pollution is difficult to detect moreover it is not only difficult to control but it persists for decades. Some of the more common artificial polluting sources caused under human influence are domestic sewage and latrines, municipal solid waste, agricultural wastes and manure, and industrial wastes.

Although degradation of water quality is almost invariably the result of human activities, certain natural phenomena can result in water quality falling below the standard required for particular purposes. Natural events such as torrential rainfall and hurricanes lead to excessive erosion and landslides, which in turn increase the content of suspended material in affected rivers and lakes. Seasonal overturn of the water in some lakes can bring water with little or no dissolved oxygen to the surface. Permanent natural conditions in some areas may make water unfit for drinking or for specific uses, such as irrigation. Common examples of this are the salinization of surface water through evaporation in arid and semi-arid regions and the high salt content of some groundwater under certain geological conditions. Many groundwaters are naturally high in carbonates (hardness), thus necessitating their treatment before use for certain industrial applications. Groundwater in certain regions contain specific ions (such as fluoride) and toxic elements (such as arsenic and selenium) in quantities that are harmful to health while others contain elements that cause other types of problems (such as the staining of sanitary fixtures by iron and manganese). The potential causes for groundwater pollution are depicted in Figure 2.1.

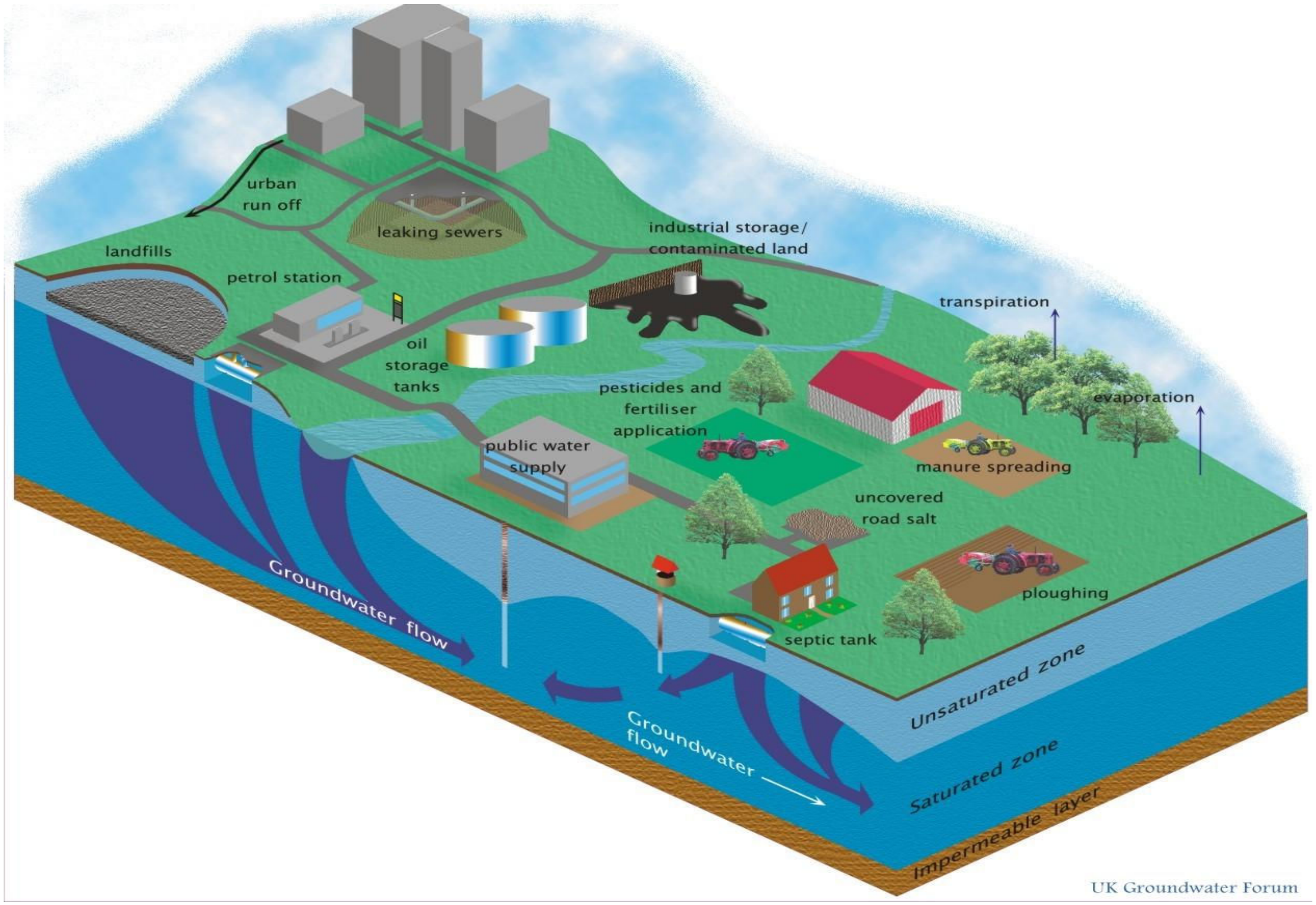


Figure 2.1 Sources of Groundwater Contamination

2.4 Water Quality Criteria

The term water quality criteria may be defined as the *"specific requirement on which a decision or judgment to support a particular use will be based"*. The criteria for various uses are developed from experimental data, and our current knowledge of the health, ecological and economic effects of water quality. Criteria are not a set of static values but get updated as more information and knowledge is gathered.

Water quality objective can be defined as an aim or goal with regard to the water quality which is to be achieved. It is not as rigid and authoritative as a standard, and does not have the enforcement element of requirements. The term standard applies to *any definite principle or measure established by an authority by limiting concentration of constituents in water* which ensure the safe use of water and safeguard the environment. Being established by an authority makes a standard somewhat rigid or quasi-legal. [22]

2.4.1 Constitutional and legal provisions

The concept of environmental protection and improvement was articulated long before environmental degradation was recognized as a serious problem. India has had environmental legislation dealing with water pollution since the Indian Penal Code in 1860 to deal with only public springs and reservoirs used for drinking water purpose.[ii] The Indian constitution adopted in 1950 specially enjoins environmental protection as a fundamental duty.

The Government of India has articulated three policy statements namely, "Policy Statement for abatement of pollution, 1992", "National Conservation Strategy and the Policy Statement on Environment & Development, 1992" as well as the "National Water Policy of 2002". The Policy Statement for Abatement of Pollution has made provisions for the so-called 'reactive' approach alone. It proposed a comprehensive approach *"to integrate environmental and economic aspects in development planning, preventive aspects for pollution abatement and promotion of technological inputs to reduce industrial pollutants, and through reliance upon public cooperation in securing the clean environment".* However during last decade, a number of issues and new challenges have emerged in environment sector, which demands the revision of the national policy document, and it is being reviewed at present.

India has also witnessed passage of a variety of environmental laws on prevention of pollution in water as well as a host of environmental regulations which included The Water (Prevention & Control of Pollution) Act, 1974 Water Cess Act, 1977, Environment (Protection) Act, 1986 etc.The Government policy to protect the Environment while undertaking any developmental activity has made it mandatory to introduce the environmental aspects into planning and development process. The Government of India through notification in 1994 made it mandatory to take environmental clearance for certain categories of industries and projects under EPA, 1986.

The water quality management is performed under the provision of Water Act, 1974 and theobjective is to maintain and restore the *wholesomeness* of national aquatic resources by prevention and control of pollution. It is ambitious and economically unviable to restore the water quality of natural water bodies to pristine quality. Therefore the water quality of these water bodies could be maintained on the basis of the highest or best use to which the water is put to. In view of this, the CPCB has developed a concept of 'designated best use' (DBU) for classifying the water bodies as given in Table 2.1.

2.4.2 Drinking Water Quality Criteria

In view of the direct consumption of water by human beings, the domestic water supply is considered to be the most critical use of water. With the objective to safeguard water from degradation and to establish a basis for improvement in water quality, standards/guidelines/regulations have been laid down by various national and international organizations such as Bureau of Indian Standards (BIS), World Health Organization (WHO), European Economic Community (EEC), Environment Protection Authority (EPA), Indian Council of Medical Research (ICMR) etc. The national water quality standards describe essential and desirable characteristics required to be evaluated to assess suitability of water for drinking purposes. The Bureau of Indian Standards (BIS) has recommended different limits of parameters for the classification of water for drinking which are summarized in Table 2.2 and the probable effects of some important parameters are given in Table 2.3.

Table 2.1 Designated Best Use Classification of Surface water

Designated best use	**Quality Class**	**Primary Water Quality Criteria**
Drinking water source without conventional treatment but with chlorination	A	Total coliform organisms (MPN*/100 ml) shall be 50 or less pH between 6.5 and 8.5 Dissolved Oxygen 6 mg/l or more, and Biochemical Oxygen Demand 2 mg/l or less
Outdoor bathing (organized)	B	Total coliform organisms(MPN/100 ml) shall be 500 or less pH between 6.5 and 8.5 Dissolved Oxygen 5 mg/l or more, and Biochemical Oxygen Demand 3 mg/l or less
Drinking water source with conventional treatment	C	Total coliform organisms(MPN/100 ml) shall be 5000 or less pH between 6 and 9 Dissolved Oxygen 4 mg/l or more, and Biochemical Oxygen Demand 3 mg/l or less
Propagation of wildlife and fisheries	D	pH between 6.5 and 8.5 Dissolved Oxygen 4 mg/l or more, and Free ammonia (as N) 1.2 mg/l or less
Irrigation, industrial cooling, and controlled disposal	E	pH between 6.0 and 8.5 Electrical conductivity less than 2250 micro mhos/cm, Sodium Aborption Ratio less than 26, and Boron less than 2 mg/l.

2.4.3 Irrigation Water Quality Criteria

Water quality plays a significant role in irrigated agriculture. The effect of total solids in irrigation water on crop growth is extremely important. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solids of the soil water in the root zone increase, it becomes difficult for the plant to overcome the osmotic pressure and the plant roots membranes are able to assimilate water and nutrients. Thus the dissolved solids level in residual water in the root zone need to be maintained within limits by proper leaching. These effects are visible in plants as stunted growth, low yield, discoloration, and even leaf burns at margins or top. The Bureau of Indian Standards (BIS) has recommended different limits of parameters for the classification of water for irrigation which are summarized in Table 2.4.

Table 2.2 Drinking water characteristics (IS: 10500:1991)

S. No.	Parameters	Desirable limits mg/l	Permissible limits mg/l
Essential Characteristics			
1.	Colour Hazen unit	5	25
2.	Odour	Unobjectionable	-
3.	Taste	Agreeable	-
4.	Turbidity (NTU)	5	10
5.	pH	6.5 - 8.5	No relaxation
6.	Total Hardness, $CaCO_3$	300	600
7.	Iron (Fe)	0.3	1.0
8.	Chloride (Cl)	250	1000
9.	Residual Free Chlorine	0.2	-
10.	Fluoride (F)	1.0	1.5
Desirable Characteristics			
11.	Dissolved Solids	500	2000
12.	Calcium (Ca)	75	200
13.	Magnesium (Mg)	30	100
14.	Copper (Cu)	0.05	1.5
15.	Manganese (Mn)	0.1	0.3
16.	Sulphate (SO_4)	200	400
17.	Nitrate (NO_3)	45	100
18.	Phenolic Compounds	0.001	0.002
19.	Mercury (Hg)	0.001	No relaxation
20.	Cadmium (Cd)	0.01	No relaxation
21.	Selenium (Se)	0.01	No relaxation
22.	Arsenic (As)	0.05	No relaxation
23.	Cyanide (CN)	0.05	No relaxation
24.	Lead (Pb)	0.05	No relaxation
25.	Zinc (Zn)	5.0	15
26.	Hexavalent Chromium	0.05	no relaxation
27.	Alkalinity	200	600
28.	Aluminium (Al)	0.03	0.2
29.	Boron (B)	1.0	5.0
30.	Pesticides	Absent	0.001

Table 2.3 Effects of some prominent water quality parameters

Parameter	Probable effects
Colour, Odour & Taste	Makes water aesthetically undesirable
Turbidity	High Turbidity indicates contamination
Pathogens	Cause water borne diseases like Coliform jaundice, typhoid, cholera etc. Produce infections involving skin mucous membrane of eyes, ears and throat.
pH	Indicative of acidic/alkaline water, affects taste, corrosivity and the water supply system
Hardness	Affects water supply system (scaling), excessive soap consumption and calcification of arteries. It may cause urinary concretions, diseases of kidney or bladder and stomach disorder although there is no conclusive evidence.
TDS	Palatability decreases and may cause gastro-intestinal irritation in humans. May have laxative effect particularly upon transits and corrosion, may damage water system.
Fluoride	Reduces dental carries, very high concentration may cause crippling skeletal fluorosis
Nitrate	Causes infant methaemoglobinaemia (Blue baby) at very high concentrations, causes gastric cancer and affects adversely the central nervous system and the cardiovascular system.
Iron	Gives bitter sweet astringent taste, causes staining of laundry and porcelain. It is essential for nutrition but in traces.
Chloride	May be fatal to people suffering from diseases of heart or kidney. Taste, indigestion, corrosion and palatability are some of its bad effects.
Magnesium	Its salts are cathartic and diuretic. High concentrations may have a laxative effect particularly on new users. Magnesium deficiency is associated with structural and functional changes. It is essential as an activator for many enzyme systems.
Sulphate	Causes gastro intestinal irritation along with Mg or Na, can have a cathartic effect on users, concentration more than 750 mg/l may have laxative effect along with magnesium.
Alkalinity	Imparts distinctly unpleasant taste, may be deleterious to human beings in presence of high pH, hardness and TDS

Table 2.4 Effects of water quality parameters of irrigation water (IS: 10500, 1991)

Parameters	**Prescribed limits**		**Probable effects**
	Desirable	**Prescribed**	
Salinity/ EC in µmhos/cm at 25^0 C	Sensitive crops <1500 Semi tolerant 1500-3000 Tolerant crop >3000		Plant growth is retarded with stunted fruits, leaves and stem in high salinity
Sodicity/ SAR	<10 10-18 18-26 >26	Excellent Good Medium Bad	Causes deflocculation of soil, restricting free movement of water.
RSC meq/l	<1.25 1.25-2.5 >2.5	Excellent Good Bad	Result in increase of sodium causing adverse effects.
Sodium %	No guideline		Increase total salinity, has adverse effect on sodium sensitive species such.
Chloride mg/l	No guideline		May have direct toxic effects along with sodium.
Nitrate mg/l	No guideline		Excess may delay maturity and seed growth in some plants.
Boron mg/l	Sensitive crops<1.0 Semi tolerant crops - 1.0-2.0 Tolerant crops 2.0-4.0 Unsatisfactory for most crops >4.0		An essential plant nutrient at low concentration but high concentration is toxic to plants.
Copper mg/l	0.20	5.00	Essential for plants as a micro nutrient. Deficiency may cause crop damages, chlorosis also leading to dieback of plant.
Zinc mg/l	2.00	10.00	High concentration produces toxic effects.
Chromium mg/l	0.10	1.00	Toxic to plants. Very high concentration may reduce growth.
Cadmium mg/l	0.01	0.5	Reduces plant growth, bio accumulates in plants, cause adverse effects on human consumption, reduces yields.
Iron mg/l	5.0	20.0	Excess iron contributes to soil acidification.
Nickel mg/l	0.20	2.0	Cause stunted growth of plant in the concentration 0.5 mg/l. toxic to barley, beans, oats, when more than 2.0 mg/l.

2.4.3.1 Sodium

The clay minerals in soil adsorb divalent cations, like calcium and magnesium ions from irrigation water. Whenever the exchange sites in clay are filled by divalent cations, the soil texture is conducive for plant growth. Sodium reacts with soil to reduce its permeability. If the irrigation water is sodium dominant, the clay lattice is filled with sodium ions due to ion exchange. Such soils become impermeable and sticky and as such, the cultivation becomes difficult. However, the cation exchange process is reversible and can be controlled either by adjusting the composition of water or by adjusting the composition of soil or by soil amendment by application of gypsum, which releases cations to occupy exchange position. The tendency of water to replace absorbed calcium and magnesium with sodium can be expresses as Sodium Adsorption Ratio (SAR), where all ion concentrations are in milli-equivalents/ liters.

$$SAR = \sqrt{\frac{Na^{+}}{\frac{Ca^{2+} + Mg^{2+}}{2}}} \tag{2.1}$$

When water having high bicarbonates and low calcium and magnesium is used for irrigation, precipitation of calcium and magnesium as carbonate takes place, changing the residual water to high sodium water with sodium bicarbonate in solution. It is termed as Residual Sodium Carbonate (RSC), which is expressed as

$$RSC(meq/l) = (CO_3 + HCO_3) - (Ca + Mg) \tag{2.2}$$

The quality of water is commonly expressed by classes of relative suitability for irrigation with reference to salinity levels. The recommended classification with respect to electrical conductivity, sodium content, sodium absorption ratio, and residual sodium carbonate etc., under customary irrigation conditions is as shown in Table 2.5 and Table 2.6.

Table 2.5 Guidelines for evaluation of quality of irrigation water (Central Groundwater Board)

Water class	**Sodium (Na) %**	**Electrical conductivity (µmhos/cm) at 25^0 C**	**Alkalinity hazards**	
			SAR	**RSC (meq/l)**
Excellent	<20	<250	<10	<1.25
Good	20-40	250-750	10-18	1.25-2.0
Medium	40-60	750-2250	18-26	2.0-2.5
Bad	60-80	2250-4000	>26	2.5-3.0
Very bad	>80	>4000	>26	>3.0

Table 2.6 Irrigation water quality classification limits (Agriculture Department)

Quality of water	**Electrical conductivity (µmhos/cm) at 25^0 C**	**pH**	**% Na**	**Cl (meq/l)**	**SAR**	**RSC (meq/l)**
Excellent	Up to 500	6.5-7.5	30	2.5	1	1.0
Good	500-1500	7.5-8.0	30-60	2.5-5.0	1-2	1-1.25
Fair	1500-3000	8.0-8.5	60-75	5.0-7.5	2-4	1.25-2
Poor	3000-5000	8.5-9.0	75-80	7.5-10	4-8	2-2.5
Very Poor	5000-6000	9.0-10.0	80-90	10-12.5	8-15	2.5-3
Unsuitable	>6000	>10	>90	>12.5	>15	>3

2.5 Major Water Quality Issues in India

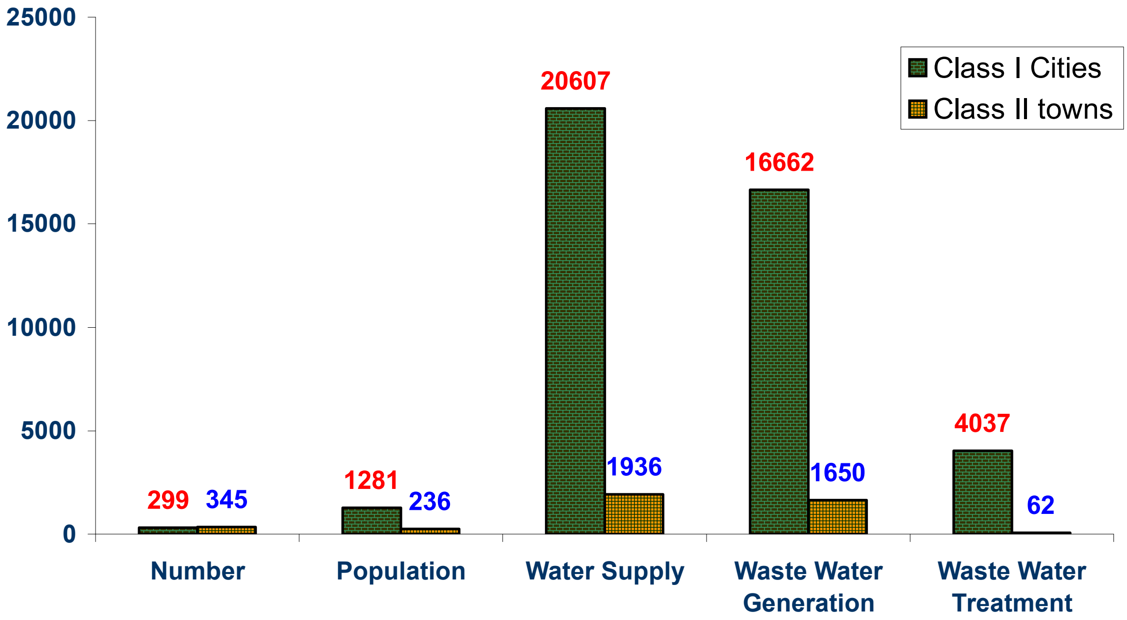
The major water quality issues in Indian context can be summarized as follows:

2.5.1 Water Scarcity

Due to the over-exploitation of water resources, there is shrinkage of many water bodies for considerable period in a year. These are not being replenished due to uneven distribution of rainfall and ever increasing demand for water from various sectors. An optimal flow is therefore required to be maintained to comply with the water quality standards laid down under the Water Act, 1974 and the Environment Protection Act, 1986.

2.5.2 Water Quality Threats

The decline in quantity and deterioration of water quality are directly attributable to the increasing demands of water by various sectors of water uses and indiscriminate disposal of wastes from different sources including urban settlements, industries and agricultural activities. According to latest information (CPCB, 2003) about 22,900 million liters per day (MLD) of domestic wastewater generated from class I cities and class II towns, treatment capacity is availably only for 5,900 MLD (fig 2.2) Industrial sector generates about 13,468 MLD of wastewater, out of which only 8,000 MLD receives treatment . The data indicates a big gap in wastewater generation and treatment. With the increasing urbanization and industrial growth in this country, the gap is expected to be gradually widened. This will obviously deteriorate water quality of the national water bodies including ground/lake water, further. The issue is thus gaining serious concern.



(Source: CPCB, 2003)

Figure 2.2 Comparision of Water Supply & Wastewater Generation from Class-I cities & Class-II towns of India (1996)

2.5.3 Surface Water Quality

Contamination of water is certainly one of the key issues, as it can prevent water from being used for its intended purpose (Expert Report, 2002). Contamination can enter the water bodies through one or more of the following ways:

- Point Sources: Transfer of pollutants from municipal, industrial liquid waste disposal sites and from municipal and household hazardous waste and refuse disposal sites.
- Non-point Sources: Wash off and soil erosion from agricultural lands carrying materials applied during agricultural use, mainly fertilizers, herbicides and pesticides. Run off from urban streets, commercial activities, industrial sites and storage areas.
- Change in the hydraulic regime of a water system due to excessive water abstraction, construction of developmental works etc.

In India, fecal contamination is still the primary water quality issue for both surface and ground waters. Although this applies to the rural as well as urban areas, the situation is probably more critical in fast-growing cities. Fecal contamination is a source of pathogenic organisms responsible for water borne diseases. It affects the health of the users as well as ecological health of the river.

Depletion of oxygen in natural water bodies due to discharge of high organic loads from domestic sector as well as agro based industries deteriorates the health of the water body. Due to such sudden oxygen depletion, survival of aquatic life becomes endangered, which is of concern.

Presence of organic pollutants (mostly organochloro compounds and some persistent toxic substances in water bodies) is also becoming an important water quality issue because of their carcinogenic character. They enter water bodies through point sources, non-point sources as well as through long-range atmospheric transportation. The process of bio-accumulation and bio- magnification of these organic pollutants in fresh water eco-systems is of great importance.

Uncontrolled discharge of industrial wastewaters often causes heavy metal pollution in its inorganic and organic forms. Leachates from landfill sites and mining waste dumps are other contributors of metal pollution. Increased mineral salts in rivers may arise from discharge from industrial/mining wastewaters, irrigation and surface run-off from arid and semi-arid regions.

Water quality has ecological impact in a number of ways. It is assumed that at least ten times dilution with fresh water should be available in a stream where the effluent is going to be discharged. However, reduced flow followed by increased waste load has rendered many rivers almost ecologically dead. Thus, special attention is required in water resource planning under these circumstances.

2.5.4 Groundwater Quality

A vast majority of groundwater quality problems are caused by contamination, over-exploitation, or the combination of two. Most groundwater quality problems are difficult to detect and hard to resolve. The solutions are usually very expensive, time consuming and not always effective. An alarming picture of ground water deterioration is emerging in many parts of the country. Groundwater contamination due to arsenic and intrusion of leachate from landfill sites are some of the glaring example of this in the country.

2.6 Geochemical studies

2.6.1 Surface water

In this context the study done by Reeder et. al. (1972)[6] investigating the factors controlling the inorganic composition of surface water in the Mackenzie River drainage basin, Canada, showed the effect of different rock types on water composition. Also the chemistry of Mattole River in Northern California was studied by Kennedy (1971) [7] and by Kennedy and Malcolm (1977) [8], the emphasis in these studies was interpretation of variation in water composition with time and discharge. The major ion chemistry of the Amazon River basin has been studied in details to know the influence of geology and weathering conditions on dissolved load by Stallard and Edmond (1983) [9]. Gibbs (1970) [10] discussed the mechanism controlling the world water chemistry and cites the three main mechanisms influencing the composition of dissolved solids of world water as; atmospheric precipitation, rock weathering and evaporation crystallization process.

Geochemical studies of Surface water in India were initiated by Raymahashay (1970) [11] followed by Handa (1972) [12] for the Ganges river. Individual river basins have also been investigated thoroughly from the geochemical aspects, viz. Godavari (Bikshamaiah & Subramanian, 1980[13]; Biksham 1985[14]), Cauvery (Subramanian et. al., 1985[15]), Krishna (Ramesh & Subramanian, 1988[16]), Mahanadi (Chakrapani & Subramanian, 1990[17]) and Ganges-Brahmaputra (Abbas & Subramanian, 1984[18]).

2.6.2 Groundwater

Initial studies in groundwater mainly related with the effect of lithology on the water composition. Hydrogeochemical evaluation and related studies were done in detail by Back and Hanshaw (1965) [23], Collin (1975) [24], Kimmel & Braids (1980) [25] worked on the hydrochemistry of quartz sand aquifer on Long Island, New York. Freeze & Cherry (1979) [26] investigated the change in the composition of groundwater as it moves through aquifer due to addition of constituents.

Shanyengana et. al. (2003) [27] investigated the major ion chemistry and groundwater salinization in ephemeral flood plains in some arid regions of Namibia. Mayer (1999) [28] investigated the spatial and temporal variation of groundwater chemistry of in Petty Johns cave, North-west Georgia, U.S.A, describing that important processes controlling the groundwater chemistry of Karst region are evolution via carbonate dissolution along subsurface flow paths, mixing and seasonal variation in the overlaying soil. Eckhardt & Stackelberg (1995) [29] and Bruce & McMohan (1996) [30] found landuse to be correlated with groundwater quality in Suburban Long Island, New York and Denver respectively. The hydro-geochemical interpretation of the data obtained and their graphical interpretation were put forth by Piper (1944) [31]. Later modifications to piper diagram were done by Durov (1948) [32], Handa (1975) [33]. The representation of chemical analysis data using various standard diagrams was also developed by Collin (1975) [24].

The chemical concentration of various ions in absolute and relative values is used in the interpretation of chemical evolution of groundwater and for observed salinity. Meng & Maynard (2001) **[34]** investigated chemical data from Botucatu Sandstone aquifer in the Sao Paulo state, part of the Parana Basin, Brazil, by using geochemical methods and two statistical analyses: cluster analysis and factor analysis. The characteristic chemicals, changing from the recharge areas to the center of the basin, are: SiO_2—(HCO_3^- and Ca^{2+})—(Na^+, CO_3^{2-} and SO_4^{2-}). The distribution of chemicals is interpreted as controlled by different water-rock interaction processes in the different regions. In the recharge area, dissolution of alkali-feldspar minerals in the sandstone is the main reaction observed; in the mid section of the basin calcite dissolution results in high calcium and bicarbonate concentrations; in the center of the basin, leakage from underlying layers becomes the governing factor. Elkrail et. al. (2003) **[35]** undertook the Hydrochemical evaluation of groundwater in Khartoum state, Sudan and concluded that ion concentrations in the study area appreciably tend to increase with increasing distance from the surface water systems. Also high concentrations of hydro chemical constituents and the occurrence of calcite ($CaCO_3$) and evaporite in upper aquifer indicated towards a long history of evaporation and increasing leachates.

In India groundwater research is mainly focused towards analyzing groundwater for determining its suitability for various uses such as irrigation purpose, water supply for public use and industrial uses. Jacks (1973) investigated the effect of crop farming on groundwater quality of Coimbatore district of Southern India. Groundwater in the area is used for irrigation purpose so it is often subject to intense evapotranspiration (600-1300 mm per harvest). High salinities were caused by the evapotranspiration together with the hydrological factor. High amount of dissolved solids were reflected from the high electrical conductivity values (200-8700 µmho/cm). Singh & Sekhon (1976) [36] investigated the nitrate pollution of groundwater from nitrogen fertilizer and animal waste in Punjab, India and found that the nitrate concentration decreases with the depth of water table.

Tamta (1999) [37] studied the occurrence and origin of groundwater salinity in Bhatinda district, Punjab. The results indicate high value of electrical conductivity (330-8830 µmho/cm) and also states that the groundwater salinity is due to simple dissolution of minerals in the aquifer, low ground water flow, mixing of groundwater and infiltration of evaporated irrigation water along with fertilizers NO_3 and K to groundwater system. Som & Bhattacharya (1992) [38] investigated the groundwater geochemistry of recent weathering at Panchpatimali Bauxite bearing plateau, Korapur District, Orissa. The study indicates that groundwater are feebly acidic with positive oxidation potential which transforms Fe^{2+} - Fe^{3+}, Kaolinite is the major weathering product with marginal development of gibbsite. Relative mobility of Al is nil, Fe is low and Mg, Ca and Na is high which are important for the development of Aluminum Silicate and Iron oxide/hydroxide.

Pawar (1993) [39] investigated the geochemistry of carbonate precipitation from groundwater in the basaltic aquifer and found that most groundwater is saturated with respect of calcite and dolomite. The molar Ca/Mg values are less than unity in most samples but Na/Ca values are much higher than unity in majority of the samples. The higher Na/Ca value supports the evidence for the precipitation of calcite particularly in the monsoon season. Pawar & Nikumbh (1999) [40]studied the trace elements in the Behedi basin, Nasik district and found that trace metals Fe, Mn, Cu and Zn have entered into the aquifer due to rain fed recharge. They attributed the spatial variation to Lithological and anthropogenic sources, such as application of fertilizers and pesticides. Mehrotra & Mehrotra (1999) [41] studied the pollution of groundwater by Manganese in Hindon-Yamuna Doab district, Gaziabad. The study indicates Mn concentration varies from 0.094 to 1.35 mg/l which is a relatively higher range. Anthropogenic activities coupled with natural hydrogeochemical environment in the area are responsible for the high Mn concentration in the area.

Nigam (1999) [42] investigated the hydro- geochemistry of fluoride in groundwater of Agra district (U.P). The study shows that the concentration of fluoride ranges from 0.09-7 mg/l and fluoride shows a good correlation with bicarbonate ion. The high concentration of fluoride in the study area is attributed to rock water interaction i.e. reaction between groundwater and easily weathered fluoride bearing minerals like fluorite, fluor apatite etc. Mahadevan & Krishnaswamy (1984) [43] studied the impacts of different surface and subsurface sources of pollution on the quality of groundwater in Madhurai, India. They considered the effect of the type, number and the proximity of the visible surface sources of pollution on the extent and degree of pollution in the neighboring water sources.

Singh et. al. (2003) [44] studied the different physico-chemical parameters of river Gumani and groundwater of the river basin at Islampur, Jharkhand and found the water to be good for irrigation purposes. C.M. Laluraj et. al. (2005) [45] studied the groundwater chemistry of shallow aquifers in the Coastal Zones of Cochin and found that the shallow aquifers were deteriorated characterized by high amount of sodium and chloride (>200 mg/l) indicating the influence of saline water incursion. Also the presence of *E. coli* in all dug wells during the study indicated potentially dangerous fecal contaminations, requiring immediate attention. Prasanna Kumar and Nagaraju (2000) [46] studied the groundwater quality of Pandavapura town, (Mandya district, Karnataka) and prepared 16 different thematic maps directly useful for various consumer demands - TDS, EC, SAR, Corrosivity Ratio, etc. Mahadeswara et. al. [47] (2000) studied the Geological Control on Ground Water Quality in Yelandur Taluk (Karnataka) using a simple computer programme HYCH in BASIC language for determining several important quality parameters and ratios related to water quality.

Singh and Kumar [48] analyzed groundwater quality of Karimnagar district and studied its suitability for domestic and agricultural purposes. Nagaraju et. al. (2005) [49] studied the Hydrogeochemistry of water of Mangampeta Barite Mining Area, Cuddapah Basin (Andhra Pradesh) and found a striking difference in the sulphate content of mine water samples, (ranging from 211 to 589 mg/l, due to the presence of barites) and virgin area water samples (1-20 mg/l) sulphate content. The bicarbonates (262 to 1100mg/l) and alkalinity (198 to 953 mg/l) were also found to be very high and were attributed to the presence of tuff and dolomitic rocks in the virgin area. Garg et. al. (2003) [50] analyzed groundwater quality of Hisar city, Haryana and studied its suitability for domestic purposes. The results indicated that groundwater in the study area is heavily loaded with inorganics and may pose serious health hazards if used as such without treatment.

An evaluation of various graphical and multivariate statistical methods for classification of water chemistry data was done by Guler et. al (2002)[51] and the results showed that principal component analysis is useful for data reduction and to assess the similarities in the data. They concluded that a combination of graphical and statistical techniques provides a consistent and objective means to classify large number of samples.

2.7 Geographic Information Systems

Information is derived through the processes of collecting, collating, structuring, and analyzing factual data. Geographical information is a term which is used to encompass many forms of information derived from many different data sources: *Geographical Information is information which can be related to specific locations on the Earth. It covers an enormous range, including the distribution of natural resources, descriptions of infrastructure, patterns of land use and the health, wealth, employment, housing and voting habits of people.* [60]

A geographic information system (GIS) is a computer-based tool for mapping and analyzing spatial data. GIS technology integrates common database operations such as query and statistical analysis with the unique visualization and geographic analysis benefits offered by maps. These abilities distinguish GIS from other information systems and make it valuable to a wide range of public and private enterprises for explaining events, predicting outcomes, and planning strategies. GIS is considered to be one of the most important new technologies, with the potential to revolutionize many aspects of society through increased ability to make decisions and solve problems. [iii]

Geographical information systems (GIS) are now as widely used as many other desktop information handling and processing tools, such as database management systems and spreadsheets. The fundamental technology requirements of spatial data-based applications are now well understood and addressed by the majority of GIS vendors and researchers. Professionals in every field are increasingly aware of the advantages of thinking and working geographically. [60] A geographic information system (GIS) is a computer-based information system that is designed to work with data referenced by spatial or geographic coordinates. Therefore, a GIS is both a database system, with specific capabilities for spatially referenced data, as well as a set of operations for working with these data. [61] GIS is an acronym for:

- Geographic: This term is used because GIS tend to deal primarily with ‘geographic’ or ‘spatial’ or ‘graphical’ features. These objects can be referenced or related to a specific location in space. The objects may be physical, cultural or economic in nature. Features on a map for instance are pictorial representations of spatial objects in the real world. Symbols, colors and line styles are used to represent the different spatial features on the two-dimensional map. Computer technology has been able to assist in this mapping process through the development of automated cartography (map making) and computer aided design (CAD). Computer programs can now accomplish in minutes and hours tasks, which previously took days or weeks for cartographers and draughtsman to complete.
- Information: This represents the large volumes of data, which are usually handled within a GIS. Every graphical object has their particular set of data, which cannot be represented in full details in the map. So all these data have to be associated with corresponding spatial object so that the map can become intelligent. When these data are associated with respective graphical feature these data get turned to information that is now by click of a mouse on any object its corresponding data get highlighted. All information is data but all data are not information.
- Systems: This term is used to represent the systems approach taken by GIS, whereby complex environments are broken down into their component parts for ease of understanding and handling but are considered to form an

integrated whole. Computer technology has aided and even necessitated this approach so that most information systems are now computer based.

Therefore, Geographic Information System (GIS) is a computer based information system used to digitally represent and analyze the geographic features present on the Earth' surface and the events (non-spatial attributes linked to the geography under study) that taking place on it.

2.7.1 Components of GIS

A working Geographic Information System seamlessly integrates five key components: hardware, software, data, people, and methods as shown in Figure 2.3.

- **Hardware:** A GIS relies on a computer for storage and processing of data. The size of the computing system will depend on the type and nature of the GIS. A small scale GIS will only need a small personal computer to run on, while a large enterprise wide system with larger computers and a host of client machines to support multiple users.
- **Software:** At a core of any GIS system lies the GIS software itself providing the functionality to store, manage, link, query and analyze geographic data. In addition to the core GIS software various other software components can be added to provide access to additional sources of data and forms of functionality.

Figure 2.3 Components of Geographic Information System

- **Data:** Data for a GIS comes in two forms geographic or spatial data, and attribute or aspatial data. Spatial data are data that contain an explicit geographic location in the form of a set of coordinates. Attribute data are descriptive sets of data that contain various information relevant to a particular location, e.g. depth, height, sales figures, etc. and can be linked to a particular location by means of an identifier, e.g. address, pin code, etc. Sources of spatial data include paper maps, charts, and drawings scanned or digitized into the system. Digital files imported from CAD or other graphics systems. Coordinate data recorded using a GPS receiver and data captured from satellite imagery or aerial photography.
- **Methods:** GIS systems are designed and developed to aid the data management and decision support processes of an organization. The operation of any organization is based on a set of practices and business logic unique to that organization. While some organizations may use a GIS on an ad-hoc basis with each user formulating their own standards of work and methods of analysis others define their business logic into the GIS to streamline certain aspects of their operations. So the methodology applied is another factor for success of any GIS project.
- **People:** The system users - those who will use the GIS to solve spatial problems - are most often people who are well trained in GIS, perhaps in a specific application of GIS.[iv]

2.7.2 Data Storage

Geographical data is most often separated into two components: spatial data and attribute data. Spatial data is used in the visualization and manipulation of real world objects in a computer model, e.g. roads, buildings, crime locations. Typically, spatial data is presented as features on a digital map. Attribute data (textual, numeric, photographic, etc.) describes these real-world objects, e.g. name, cost, size, and an image of what the object looks like. These two components often are stored in different data structures, in separate databases.

GIS stores information about the world in a collection of thematic layers that can be linked together by geography (Figure 2.4). This simple but extremely powerful and versatile concept has proven invaluable for solving many real-world problems from modeling global atmospheric circulation, to predicting rural land use, and monitoring changes in rainforest ecosystems. This can be conceptualized as overlaid maps as shown in figure. As shown in figure each theme contains geographical features with similar qualities and characteristics, e.g. one layer may contain only roads, another water features (rivers, lakes, etc.), land use zones, health data, soil type, rainfall, etc.

2.7.3 Data Models

All graphical features on the earth can be represented by only three identities that are line, point and polygon. The layers of data are stored in the GIS using one of two distinctly different data models, known as raster and vector (Figure 2.5).

In raster model, a feature is defined as a set of cells on a grid. All of the cells on the grid are of the same shape and size and each one is identified by a coordinate location and a value which acts as its identifier, features are represented by a cells or groups of cells that share the same identifier. The raster model is particularly useful for working with continuous forms of features such as soil types, vegetation etc.

In vector, a feature is represented as a collection of begin and end points used to define a set of points, lines or polygons which describe the shape and size of the feature. The vector model is particularly useful for representing highly discrete data types such as roads, buildings, boundaries and the like. Vector GIS can store corresponding information of complex objects more efficiently. [iv]

2.7.4 Applications of GIS

It is often said that better information leads to better decisions, however in order to get that information you need to be able to ask the right questions, and in order to ask the right questions you need the right set of tools.[iv] The use and analysis of geographical information are not new requirements of the modern technological age. Mankind has made use of geographical information throughout history. Military strategists, navigators, farmers and cartographers of the earliest civilizations are known to have collected and used geographical data.

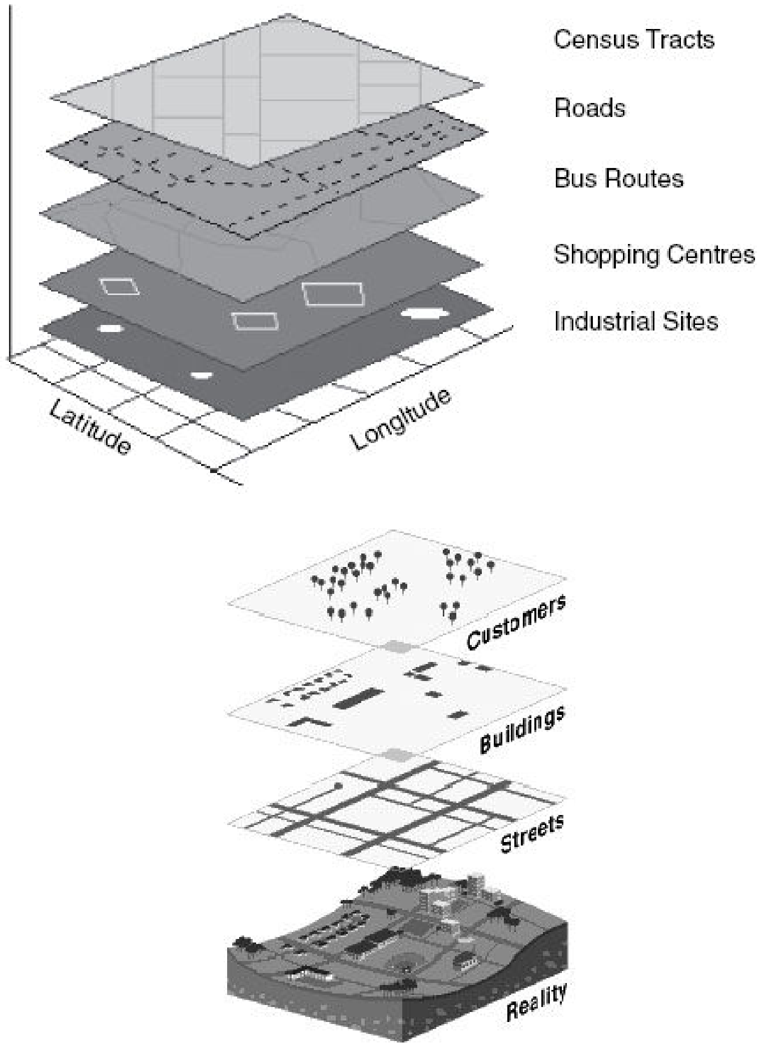
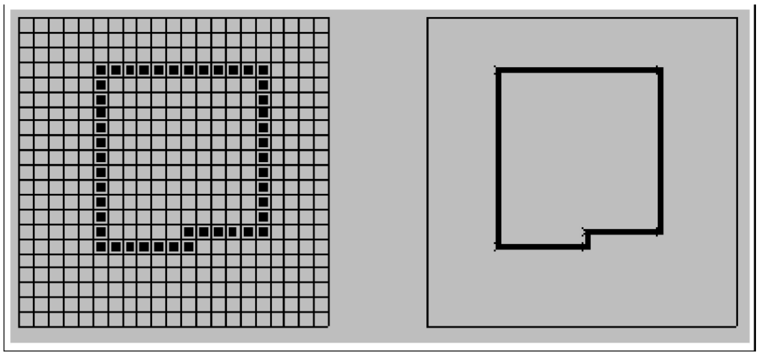


Figure 2.4 GIS themes or layers [60]



Area feature – raster and vector forms

Figure 2.5 Data Models in GIS

The rapid development of the industrial world, together with a greater use and understanding of the Earth's natural resources, has greatly increased the need for geographical information and its management. The variety of uses for geographical information is extensive viz. planning and management of public services, defense and security systems, land use and resource management, environmental monitoring, epidemiology, utility network management, transport network management, property development and investment, marketing and business location, civil engineering, mineral exploitation, vehicle navigation and tracking, mobile phone location-based services (LBS), teaching and education etc. [60]

2.7.5 Applications of GIS in Environmental Engineering

The major functional elements of Geoinformatics are Capturing, Organization, Classification, Qualification, Analysis, Management, Display and dissemination of spatial information for specific needs of the user community. Some of the application areas where Geoinformatics can be used are Forestry, Agriculture, Geology and Geomorphology, Terrain investigation and evaluation, Environmental studies and Impact assessment, Groundwater investigation, targeting, mapping and management, Surface water mapping and inventory, Transportation Engineering and Planning, Disaster Management and mitigation, Land use planning and land suitability, Soil mapping, Oceanography and Coastal zone management. [62]

2.8 Previous work in the study area

In the study area Delhi, experiments carried out by Kakkar (1985) [52] showed that salinity is in patches, which cannot be caused by airborne salts. Using selected chemical data Datta et. al. (1996) [53] found that the local recharge is associated with low salinity water of Ca-Mg-HCO_3^- type. High saline and brackish groundwater in the northwestern and southwestern parts of the study area has a long history of evaporation and oxidation of sulphur gases in the low lying areas. Erikson (1976) [54] investigated the cause of salinity in Delhi groundwater. He argued that the Delhi area alluvium, which was thoroughly washed about 20,000 years ago during the pluvial period, could have hardly retained any saline deposits to cause high salinity. He observed that dissolution of air-borne salts from the Arabian Sea, which got accumulated since Pleistocene time, has resulted in an increase in salinity of groundwater. Subramanian & Saxena (1983) [55] investigated the hydro-geochemistry of Delhi groundwater. According to their study, groundwater chemistry in the area is controlled by lithology and rainfall. Both carbonate and silicate systems influence the alkaline pH of groundwater and groundwater was not polluted with respect to trace metals.

Lalwani et. al. (2004) [56] studied the arsenic level in ground water of Delhi using hydride generator accessory coupled with atomic absorption spectrophotometer and found the arsenic level in ground water samples was in the range of 0.0170 to 0.100 ppm and they attributed the source of arsenic to natural sediments and percolation of chemicals from landfills as leachate.

Das et. al. (1988) [57] investigated Delhi groundwater by using Deuterium and Oxygen-18 isotope studies. According to this study the major sources of high salinity are high rate of evaporation, recycling of irrigation water and re-dissolution of precipitated minerals by monsoon recharge along with non-flushing of deeper water. This is contrary to the finding of earlier workers who proposed that the high salinity of groundwater is related to marine origin or fallout of airborne salts from the Arabian Sea. Datta & Tyagi (1996) [58] investigated the major ion chemistry of Delhi groundwater and found that groundwater is dominated by carbonate weathering. Large lateral variation in chloride concentration indicates that in some part of area, local recharge to the unconfined aquifer is more dominant than recharge from lateral flow. Maria (2005) [59] presented an economic approach towards urban groundwater in the context of a fast growing metropolis of Delhi and attempted to understand the current role of groundwater in the urban water supply for the city of Delhi, India, and proposes possible scenarios of future evolution.

CHAPTER III

WATER QUALITY INDICES

3.1 General

An "Environmental Index" in its broadest concept is a numerical or descriptive categorization of a large quantity of environmental data or information, with the primary purpose being to simplify such data and information so as to make it useful to decision makers and various publics. [65] The basic purpose of environmental indices is to allow comparisons of states of the environment across time or space. [96] Environmental Indices can be useful in accomplishing one or more of the following objectives:

- To summarize existing environmental data.
- To communicate information on the quality of the affected (baseline) environment.
- To evaluate the vulnerability or susceptibility of an environment category to pollution.
- To focus attention on key environmental factors.
- To serve as a basis for the expression of impact by forecasting the difference between the pertinent index with the project and the same index without the project.

While some environmental indices are fairly complicated from a mathematical perspective, simple comparisons of data have also been found useful. It may be noted that conceptual views related to Environmental Index usage have raised concern over the distortion that can occur in the simplification process implied by aggregating environmental variables into one single value. [64] However, with careful selection of indices and their systematic usage and a comparative interpretation of results, it is considered that the risk of distortion can be minimized. [65]

3.2 Need of a Water Quality Index

Water quality indices aim at giving a single value to the water quality of a source which translates the list of constituents and their concentrations present in a sample into a single value. Water Quality Index may have gained prominence during the last few decades but the concept in its rudimentary form was first introduced more than 150 years ago – in 1848 – in Germany where presence or absence of certain organisms in water was used as indicator of the fitness or otherwise of a water source. Since then various European countries have developed and applied different systems to classify the quality of the waters within their regions. These water classification systems were usually of two types:

- those concerned with the amount of pollution present, and
- those concerned with living communities of macroscopic or microscopic organisms.

Rather than assigning a numerical value to represent water quality, these classification systems categorized water bodies into one of several pollution classes or levels. By contrast, indices that use a numerical scale to represent gradations in water quality levels are a recent phenomenon, beginning with Horton's index in 1965.

Water quality characteristics may be classified in three broad categories: physical, chemical, and biological. Within each category, a number of quality variables may be employed. The suitability of a given water source for an intended use depends on the magnitude of these quality variables. In this context, a variety of subindices have been proposed over the last two decades. These subindices can be classified as absolute subindices, which are independent of the water quality standards, and relative subindices, which depend on the water quality standards. The concept of using indices to represent in a single value the status of several variables is not a novel idea; it has been well–entrenched in economics and commerce.

The formulation and use of indices has been strongly advocated by agencies responsible for water supply and control of water pollution. Once the water quality data has been collected through sampling and analysis, a need arises to translate it into a form that is easily understood. Once the Water Quality Indices are developed and applied, they serve as convenient tools to examine trends, to highlight specific environmental conditions, and to help governmental decision-makers in evaluating the effectiveness of regulatory programme. Water Quality Index, of course, is not the only source of information has an influence on water-related decisions. Many other factors are considered besides indices and the monitoring data on which the indices are based. Indeed nearly all the purposes for which one monitors water quality – assessment, utilization, treatment, resource allocation, public information, R&D and environmental planning – are all served by indices as well. In addition, indices make the transfer and utilization of water quality data enormously easier and lucid. Thus, water quality indices may prove to be beneficial in:-

i) *Resource allocation:* Indices may be applied in water-related decisions to assist managers in allocating funds and determining priorities.

ii) *Ranking of allocations:* Indices may be applied to assist in comparing water quality at different locations or geographical areas.

iii) *Enforcement of standards:* Indices may be applied to specific locations to determine the extent to which legislative standards and existing criteria are being met or exceeded.

iv) *Trend analysis:* Indices may be applied to water quality data at different points in time to determine the changes in the quality (degradation or improvement) which have occurred over the period.

v) *Public information:* Index score being an easy to understand measure of water quality level, indices can be used to keep the public informed of the overall water quality of any source, or of different alternative sources, on a day-to-day basis.

vi) *Scientific research:* The inherent quality of an index – which translates a large quantity of data to a single score, is immensely valuable in scientific research. For example in determining the efficacy of any eco-restoration or water treatment strategy on a water body, the impact of developmental activities on water quality, etc.

3.2 Non Statistical Indices

Non statistical indices are based on parameter selection by methods other than statistical analysis are aimed at determining characteristic of water bodies for general or specific (such as for drinking / irrigation / bathing) use of their water.

3.2.1 Horton's Index

Horton's index may be termed as the first modern water quality index and was developed keeping in mind the following criteria:

i) The number of variables to be handled by the index should be limited to avoid making the index unwieldy.

ii) The variables should be of significance in most areas.

iii) Only such variables, for which reliable data is available, or obtainable, should be included.

The steps involved in the formation of the Horton's index are as follows:

1. Selection of quality characteristics on which the index is based
2. Establishment of a rating scale for each characteristic
3. Weighting of several characteristics

The quality characteristics which are considered significant in the development of a WQI are given in Table 3.1. Specific conductance was intended to serve as an approximate measure of total dissolved solids (TDS), and carbon chloroform extract (CCE) was included to reflect the influence of organic matter. One of the variables, sewage treatment (percentage of population served), was designed to reflect the effectiveness of abatement activities on the premise that chemical and biological measures of quality are of little significance until substantial progress has been made in eliminating discharges of raw sewage. The index weight ranged from 1 to 4 as shown in Table 3.2.

Table 3.1 Quality Characteristics for Horton's WQI

Sewage Treatment (% population served)	Rating	pH	Rating	Specific Conductance (µ moles)	Rating
95-100	100	6-8	100	0-750	100
80-95	80	5-6; 8-9	80	750-1500	80
70-80	60	4-5; 9-10	40	1500-2500	40
60-70	40	<4; >10	0	>2500	0
50-60	20				
<50	0				

DO (% saturation)	Rating	Coliforms (MPN/100ml)	Rating	CCE (1×10^2 mg/l)	Rating
>70	100	<1000	100	0-100	100
50-70	80	1000-5000	80	100-200	80
30-50	60	5000-10000	60	200-300	60
10-30	30	10000-20000	30	300-400	30
<10	0	>20000	0	>400	0

Alkalinity	Rating	Chloride	Rating
20-100	100	0-100	100
5-20; 100-200	80	100-175	80
0-5; >200	40	175-250	40
Acid	0	>250	0

Table 3.2 Rating Scale for Horton's WQI

Quality Characteristics	Weighting	Quality Characteristics	Weighting
Sewage Treatment	4	DO	4
pH	4	Coliforms	2
Alkalinity	1	Chloride	1
CCE	1	Specific Conductance	1

Notably Horton's index did not include any toxic chemicals. The index score is obtained with a linear sum aggregation function. The function consists of the weighted sum of the sub-indices divided by the sum of the weights and multiplied by two coefficients M_1 and M_2, which reflect temperature and obvious pollution, respectively.

$$QI = \frac{\sum_{i=1}^{n} w_i I_i}{\sum_{i=1}^{n} w_i} M_1 M_2 \qquad (3.1)$$

where QI = water quality index, I = rating, w = weight,

M_1 = temperature value ($1/2$ or 1 depending on whether there is temperature pollution or not respectively)

M_2 = Obvious pollution value ($1/2$ or 1 depending on whether there is obvious pollution or not respectively)

Horton's index is easy to compute, even though the coefficients M_1 and M_2 require some tailoring to fit individual situations. The index structure, its weights, and rating scale are highly subjective as they are based on the judgment of the author and a few of his associates. Horton's pioneering effort has been followed up by several workers who have striven to develop less and less subjective but more and more sensitive and useful Water quality indices.

3.2.2 Prati's implicit index of pollution

This index was developed by Prati et al (1971) [66] on the basis of water quality standards. The concentration values of all the pollutants were transformed into levels of pollution expressed in new units through mathematical expressions. These mathematical expressions were constructed in such a way that the new units were proportional to the polluting effect relative to other factors. In this way even if a pollutant is to be present in smaller concentrations than other pollutants, it still will exert a large impact on the index score if its polluting effect is greater. In the first step, water quality was classified based on all the parameters based on water quality standards (Table 3.3). In the second step, one pollutant was taken as reference and its actual value was considered directly as reference index. In the third step, mathematical expressions were formed to transform each of the values of the other pollutants into indices. This transformation took into account the polluting capacity of the parameters related to selected reference parameter. In the construction of these functions, the analytical properties of various curves were used to ensure that the resulting transformation would be applicable not only to small values of pollutant concentrations but also to those exceeding the heavily polluted class. The index was computed as the arithmetic mean of the 13 subindices:

$$I = \frac{1}{13}\sum_{i=1}^{13} I_i \qquad (3.2)$$

The index ranges form 0 to 14 (and above) and was applied by Prati *et al* to data on surface waters in Ferrana, Italy.

Table 3.3 Classification of water quality for the development of Prati's index

Parameter	Excellent	Acceptable	Slightly Polluted	Polluted	Heavily Polluted
pH	6.5-8.0	6.0-8.4	5.0-9.0	3.9-10.1	<3.9 - >10.1
DO (% sat)	88-112	75-125	50-150	20-200	<20 - >200
BOD_5 (ppm)	1.5	3.0	6.0	12.0	>12
COD (ppm)	10	20	40	80	>80
Suspended Solids (ppm)	20	40	100	278	>278
NH_3 (ppm)	0.1	0.3	0.9	2.7	>2.7
NO_3 (ppm)	4	12	36	108	>108
Cl (ppm)	50	150	300	620	>620
Iron (ppm)	0.1	0.3	0.9	2.7	>2.7
Manganese (ppm)	0.05	0.17	0.5	1	>1
ABS (ppm)	0.09	1	3.5	8.5	>8.5
CCE (ppm)	1	2	4	8	>8

3.2.3 Brown's water quality index

Brown et al. (1970)[67] developed a water quality index similar in structure to Horton's index but with much greater rigor in selecting parameters, developing a common scale, and assigning weights for which elaborate Delphic exercises were performed. This effort was supported by the National Sanitation Foundation (NSF). For this reason Brown's index is also referred as National Sanitary Foundation Water Quality Index. A panel of 142 persons with expertise in water quality management was formed for the study. The panelists were asked to consider 35 parameters for possible inclusion in the index. The panelists were free to add to the list any parameter of their choice. Each parameter was to be assigned one of the following choices: 'do not include', 'undecided', or 'include'. They panelists were asked to rank the parameters marked as 'include' according to their significance as contributor to the overall quality. The rating was done on a scale of 1 (highest) to 5 (lowest). The responses of the panel were brought to the knowledge of every member of the panel and the members were allowed to review their individual judgment in the light of the full panel's response.

Finally the panelists were asked to select not more than 15 parameters which they considered to be the most important. The complete list of parameters arranged in decreasing order of significance as determined by average rating of the panel was presented to each member. Continuing in this fashion, a list of eleven parameters was finalized (Table 3.4). The panelists were asked to assign values for the variation in the level of water quality produced by different concentrations of the parameters selected as above. The concentration-value relationship of each parameter was obtained in the form of graphs. These graphs were produced by the panelists to denote curves which, in their judgment, best represented the variation in level of water quality produced by possible measurements of each respective parameter. The judgment of all the respondents was averaged to produce a set of curves (Figure 3.1 (a) and (b)), one for each parameter.

Table 3.4 Significant parameters chosen by Delphi approach (NSF index)

Parameter	Rank of Importance	Parameter	Rank of Importance
Dissolved oxygen	1	pH	7
Biochemical oxygen demand	2	Temperature	8
Turbidity	3	Fecal Coliforms	9
Total solids	4	Pesticides	10
Nitrate	5	Toxic elements	11
Phosphate	6		

For pesticides and toxic elements it was proposed that, if the total contents of detected pesticides or toxic elements (of all types) exceed 0.1 mg/1, the water quality index be automatically registered zero. The panelists were asked to compare relative overall water quality using a scale of 1 (highest) to 5 (lowest) for the finally selected parameters. Arithmetic mean was calculated for the ratings of experts. To convert the rating into weights, a temporary weight of 1.0 was assigned to the parameter which received the highest significance rating. All other temporary weights were obtained by dividing each individual mean rating by the highest rating. Each temporary weight was then divided by the sum of all the temporary weights to arrive at the final weight. Table 3.5 gives the mean rating, temporary weights and final weights of the selected parameters. The index is given by

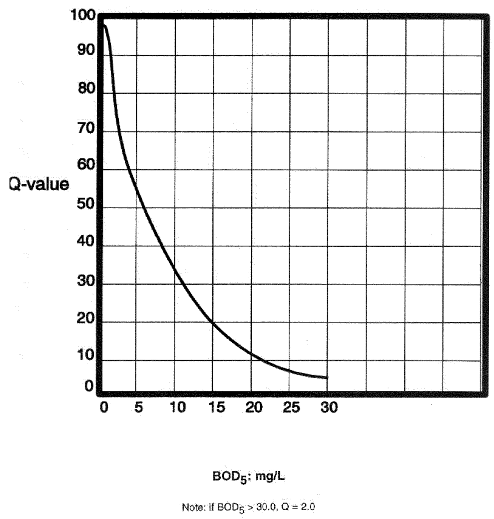
$$NSFWQI = \sum_{i=1}^{n} w_i q_i \tag{3.3}$$

where q_i=the quality of the i^{th} parameter (a number between 0 and 100 read from the appropriate subindex graph), and w_i = the weight of the i^{th} parameter

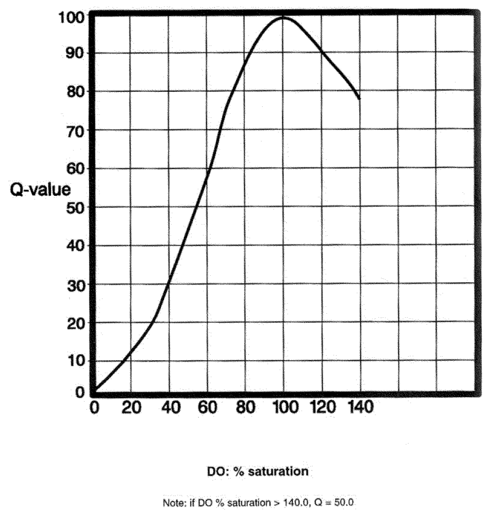
Table 3.5 Significance ratings and weights of parameters (NSF WQI)

Parameters	Mean of all significance ratings returned by respondents	Temporary weights	Final weights
Dissolved oxygen	1.4	1	0.17
Fecal Coliform density	1.5	0.9	0.16
pH	2.1	0.7	0.11
BOD (5-day)	2.3	0.6	0.11
Nitrates	2.4	0.6	0.10
Phosphates	2.4	0.5	0.10
Temperature	2.4	0.6	0.10
Turbidity	2.9	0.5	0.08
Total solids	3.2	0.4	0.07
		Total	1.00

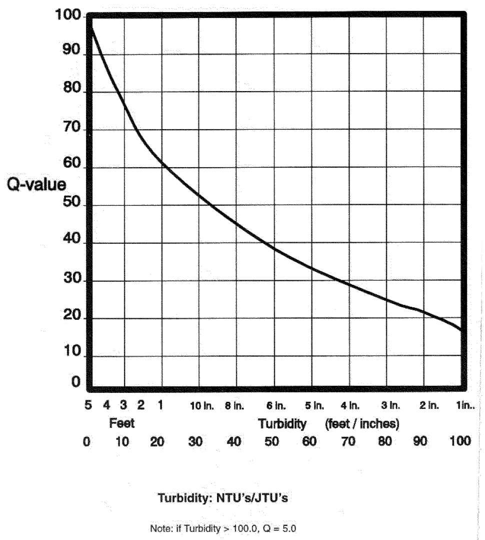
The NSF is a 100 point index can be divided into several ranges corresponding to the general descriptive terms shown in the Table 3.6. When test results from fewer than all nine measurements are available, the relative weights for each factor are preserved and the total scaled so that the range remains 0 to 100. Brown's index represents general water quality. It does not recognize and incorporate specific water functions like drinking water supply, agriculture, industry, etc. Related to this difficulty was an apparent tendency for some respondents to be heavily influenced in their judgment of parameter suitability for inclusion in a WQI by factors such as data availability and existing analytical methodologies for measuring the various parameters.



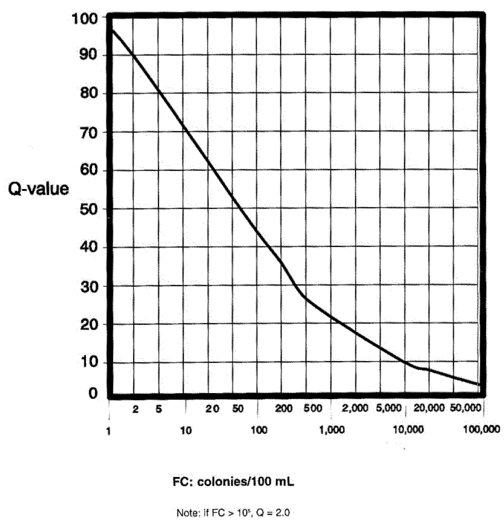
(a) BOD



(b) DO

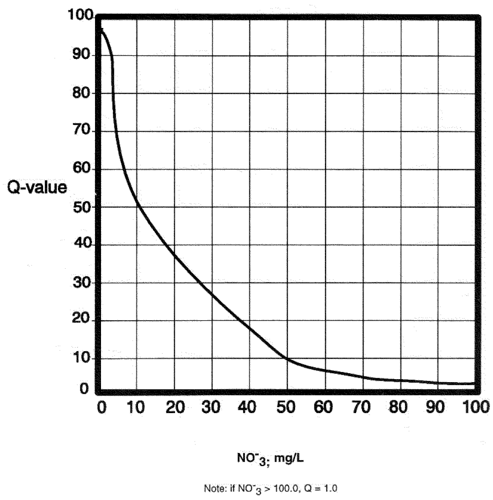


(c) Turbidity

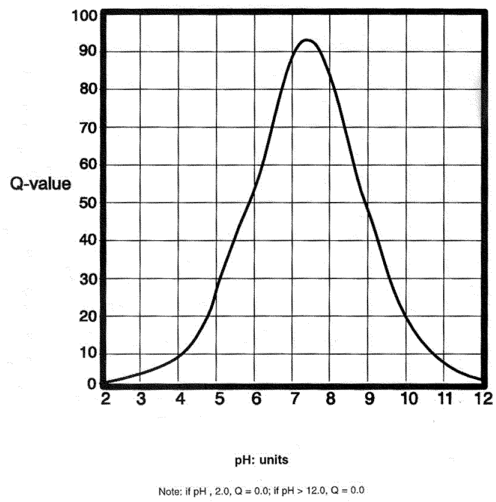


(d) Fecal Coliform

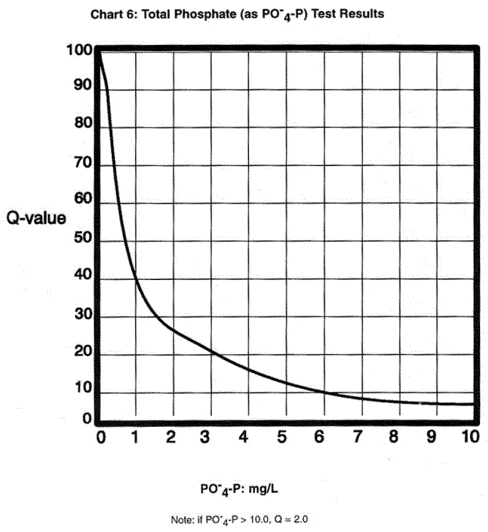
Figure 3.1(a) Subindex functions for NSF WQI



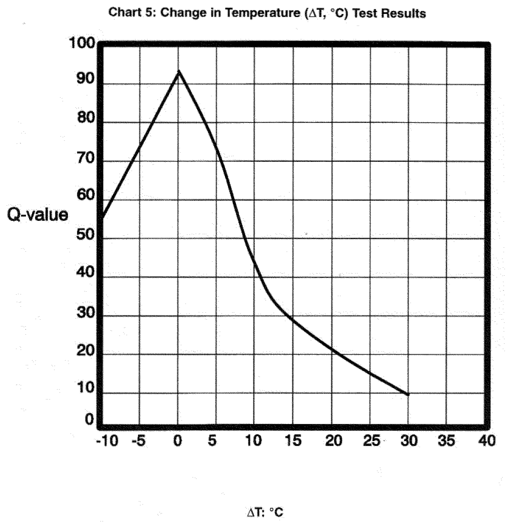
(e) Nitrate



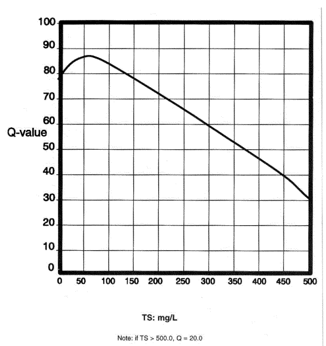
(f) pH



(g) Total Phosphate



(h) Temperature



(i)Total Suspended Solids

Figure 3.1(b) Subindex functions for NSF WQI

Table 3.6 Classification of surface water based on NSF WQI Values

Range	Quality
90-100	Excellent
70-90	Good
50-70	Medium
25-50	Bad
0-25	Very bad

3.2.4 Dinius' water quality index

Dinius' water quality index (1972)[68] broke new ground in the sense that through it an attempt was made to design a rudimentary social accounting system which would measure the costs and impact of pollution control efforts. In this sense, Dinius' Water Quality Index is a forerunner of the 'planning' or 'decision-making' indices. Eleven parameters were selected. Like Horton's index and the NSF WQI, it had decreasing scale, with values expressed as a percentage of perfect water quality which corresponds to 100%. Like Prati's index, the sub-indices in Dinius' index were developed from a review of the published scientific literature.

Dinius examined the water quality described by various authorities to different levels of pollutant variables, and from this information she generated 11 sub-index equations. The index was calculated as the weighted sum of the subindices, like Horton's index and the additive version of the NSF WQI.

$$I = \frac{1}{21}\sum_{i=1}^{11} w_i I_i \tag{3.4}$$

The weights ranged from 0.5 to 5 on a basic scale of importance. On this scale, 1,2,3,4 and 5 denote, respectively, very little, little average, great, and very great importance. The sum of the weights was 21, which is the denominator in the index equation. The index was applied by Dininus on an illustrative basis to data on several streams in Alabama, USA.

3.2.5 Walski and Parker's index

This index (Walski and Parker, 1974) [69] is based on empirical information on the suitability of water for a particular use, and was developed specifically for the recreational water (such as used for swimming and fishing). The authors introduced four general categories of variables:

i) those which affect aquatic life (e.g., DO, pH, and temperature)

ii) those which affect health (e.g., Coliforms)

iii) those which affect taste and odor (e.g., threshold odor number); and

iv) those which affect the appearance of the water (e.g., turbidity, grease and color).

In the second step, the sensitivity functions were determined to assign each parameter a value between one and zero, representing ideal conditions and completely unacceptable conditions respectively. The nature of the sensitivity function was determined by the impact of a change in the value of the parameter on water quality. For substances that are inversely related to water quality a negative exponential curve was thought to best represent the sensitivity function. The authors determined values for the parameters which would be considered perfect, good, poor and intolerable; and assigned to each of these values the numbers 1, 0.9, 0.1 and 0.01 respectively. With these sets of values, the sensitivity functions could be found easily. For example, to determine a sensitivity function for temperature, a listing of lethal temperatures was consulted. As the maintenance of aquatic life is difficult at low as well as high temperatures, it was felt that the sensitivity function for temperature should consist of an inverted parabola (Figure 3.2) described as follows:

$$F(T) = \frac{a^2 - (T-a)^2}{a^2} \tag{3.5}$$

where a = ideal temperature f (a) = 1

A total of 12 different pollutant variables were used in the index. The subindices consist of nonlinear and segmented nonlinear explicit functions. Except for the two unimodel variables, pH and temperature, all subindices are represented by negative exponential equations. The pH was represented by parabolic equation as was temperature (Figure 3.2). Two subindices were used for temperature; one for actual temperature and another for departure from equilibrium temperature. To aggregate the subindices, a geometric mean was employed over an arithmetic mean to avoid the problem of eclipsing. Their aggregation function is as follows:

$$I = \sum_{i=1}^{n} I_i^{w} \quad ^{1/12} \tag{3.6}$$

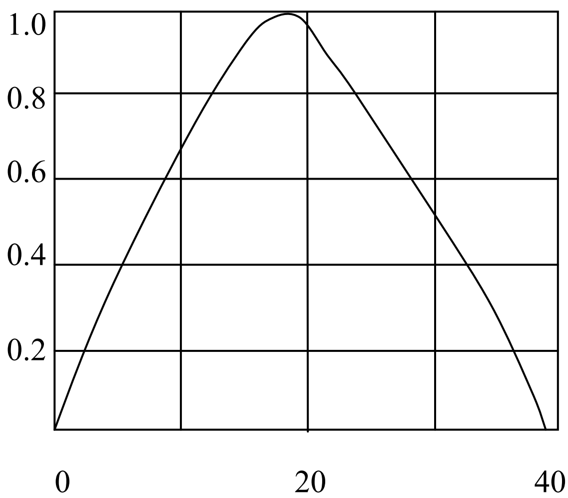


Figure 3.2 Inverted parabola as the sub-index function for temperature (Welski – Parker index.)

3.2.6 Stoner's Index

This index, aimed for use in public water supply and irrigation, employed a single aggregation function which selects from two sets of recommended limits and subindex equations. Although Stoner [70] applied the index to just two water uses, it could be adapted to additional water uses as well. Two types of water quality parameters are used in the Stoner's index, *Type I* - Parameters normally considered toxic (for example, lead, Chlordane, radium–226) and *Type II* - Parameters which affect health or aesthetic characteristics (for example, chlorides, sulphur, color, taste and odor).

The type I pollutant variables were treated in a dichotomous manner, giving subindex step functions. Each type I subindex is assigned the value of zero if the concentration is less than or equal to the recommended limit and the value 100 if the recommended limit is exceeded. The *type II* pollutant variables are represented, by explicit mathematical functions. A total of 26 *type I* pollutant variables were used in the public water supply version of the index, and 5 type I variables in the irrigation version (Tables3.10 & 3.11). The overall index was computed by combining the unweighed type I subindices with the weighted type II subindices:

$$I = \sum_{i=1}^{n} I_i + \sum_{j=1}^{m} w_j I_j \tag{3.7}$$

where I_i = subindex for the i^{th} *type I* pollutant variable

W_j = weight for the j^{th} *type II* pollutant variable

I_j = subindex for the j^{th} *type II* pollutant variable.

3.2.7 Smith's index

This index was developed in 1987 and was designed for four water uses – contact as well as non-contact. It is a hybrid of the two common index types and is based on expert opinion as well as water quality standards. The index addresses four types of water uses viz. General, Regular public bathing, Water supply and Fish spawning. The selection of parameters for each water class, developing sub indices, and assigning weightings were all done using Delphi. Besides the usual Delphic steps, additional rounds of questionnaire were employed to arrive at greater convergence of opinion. The panel members were allowed to phone the coordinator to seek clarifications. This was a departure from the Standard Delphic procedure wherein direct contact and discussions among panel members is discouraged with the view that such discussions may lead to some members unduly influencing some others. However in the procedure adopted by Smith, it was considered prudent to let the experts interact and thrash out points of doubt. To obtain the sub index values the panel members were provided with the following:

1. Expected values of parameters likely to be encountered.
2. Mutually agreed set of descriptors for the range of sub index values as given in Table 3.7.
3. Numerical standards for all the parameters for all the classes and the sub index value for the standard. Mostly, 60 was taken as the fixed sub index value which corresponds to the lowest value in the 'suitable for use' category.

Table 3.7 Suitability range for Smith's index

Range	Suitability
0 – 20	Totally unsuitable
20 – 40	Inadequate for use
40 – 60	Marginally suitable
60 – 80	Suitable for use
80 – 100	Eminently suitable for use

4. Blank graph formats with X axis representing the expected range of parameter value, and Y axis representing the sub index values ranging from 0 to 100.

The panel members were asked to indicate graphically what the likely sub index value would be at different values of the parameter. It was stipulated that the graph should pass through the fixed reference point corresponding to the standard value of the parameter. For example, for bathing water the pH must not fall below 6.5 or rise above 9. Therefore two fixed points would occur in the graph: (6.5, 60) and (9, 60) as illustrated in Figure 3.3. The curves drawn by the panel members were then averaged to produce the final graphs. New curves were returned to panel members for comment and approval. From the water quality data sub index values were obtained for all the parameters for all the water classes from graphs. The minimum operator technique was used to obtain the final index score:

$$I_{\min} = \sum \min(I_{sub1}, \mathrm{I}_{\mathrm{sub2}}, ...I_{subn}) \quad (3.8)$$

Where I_{min} equals the lowest sub index value

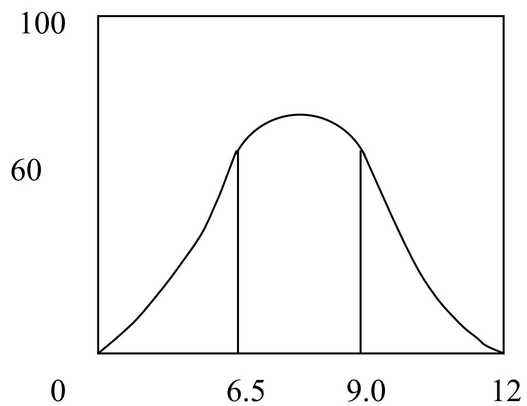


Figure 3.3 Sub-index functions for pH in Smith's index

3.3 Statistical Indices

The point of contrast for statistical indices from non statistical ones is that the parameters of importance and the extent of their importance are determined on the basis of analysis of water quality and related data by statistical techniques such as factor analysis and principal component analysis. This approach has the advantage that there are fewer subjective assumptions than in the traditional indices; however, the indices based on statistical analysis are more complex and more difficult to apply.

Of the statistical techniques on which some of the statistical indices are based, the ones focusing on correlation explore associations among variables to determine the importance of each as a determinant of water quality. Shoji *et al* (1966) applied factor analysis to the Yodo river system in Japan for interrelationships among 20 pollutant variables. By comparing the correlation of each variable with every other variable and selecting combinations with the highest correlations, they identified three major factors that affect the river water quality: pollution, temperature and rainfall.

In an attempt to examine the very basis of the concept of indices, Landwehr (1976)[71] observed, "regardless of its construct, an index is a random variable in as much as the water quality constituents upon which it depends are themselves random variables". He derived and compared the statistical properties of the most widely used functional structures of indices. Joung et al. (1978) [72] used factor analysis to develop water quality indices by examining water quality data from Carson Valley, Nevada. Ten pollutant variables were considered. By manipulating the matrix of correlation coefficients, the authors were able to identify linear combinations of the variables which best explain the variance but which have low correlations with each other. The approach retains the most important information in the raw data while eliminating redundant variables. The authors used the approach to identify the most significant variables and index weights for two water quality indices containing five variables each: the Index of Partial Nutrients and the Index of Total Nutrients. These indices were then applied to the Snake and the Colorado River basins in Nevada, USA. Of the two, the Index of Total Nutrients (with the variables DO, BOD_5, total phosphates, temperature and conductivity) was selected, and its performance was compared with that of the Brown's NSFWQI (Brown et al 1970) [67] using water quality data from 20 locations in the United States.

In another effort at correlation, Coughlin et al. (1972) studied the relationship between the Brown's NSFWQI and the uses of a stream made by the nearby residents. They used principal component analysis to examine the relationships among individual NSFWQI variables and such factors as distance of residence from the stream, land values, and tendency for residents to walk along the stream or to wade in it or fish in it. They reported that water pollution was correlated with wading, fishing, picnicking, bird watching, walking and other activities.

A general methodology for fuzzy clustering analysis was developed and illustrated with a case study of water quality evaluation for Dianshan Lake, Shanghai, China. According to Kung et al (1992) [73], fuzzy clustering analysis may be used when a composite classification of water quality incorporates multiple parameters. In such cases, according to the authors, the technique may be used as a complement or an alternative to comprehensive assessment. In fuzzy clustering analysis, the classification is detailed by a fuzzy relation. After a fuzzy similarity matrix is established and the fuzzy relation stabilized, a dynamic clustering chart can be developed. Given a suitable threshold, the appropriate classification is worked out.

3.4 Indian water quality indices

Water quality indices have been used in India but not as extensively as the tool deserves. Except for the first reported Indian WQI (Bhargava 1985) [74], other indices have been mostly weighted sum indices apparently inspired by Brown's Water Quality Index. The portability of the water of two ponds used by the villagers of Muzaffarpur district, Bihar, was assessed by Sinha (1995) [75]. The study used an index similar to Brown's WQI. Ten parameters (pH, hardness, DO, chloride, Na, K, Zn, Fe, turbidity and Coliform) contributed to the sub-indices forming the WQI. Seasonal fluctuations of water quality of Hanuman Taal, Jabalpur was studied on the basis of a WQI formed with 9 parameters (Turbidity, Conductivity, Dissolved Oxygen, pH, Sodium, Potassium, Zinc, Iron, Chloride, and Hardness) by Dhamija and Jain (1995) [76]. A study on the Water Quality Index of some Indian rivers was also conducted by Ram Karan Singh and H. Anand[77] using modifies Delphi approach and they found the index to be 24.6162 on a scale of 100, which showed that the water was fit for drinking but only after conventional water treatment.

3.4.1 Bhargava's Index

Bhargava's index developed in 1985 is one of the first reported indices by an Indian author, and addresses the issue of drinking water supply. To develop the index, Bhargava (1985) [74] identified 4 groups of parameters. Each group contained sets of one type of parameters. The first group included the concentrations of Coliform organisms to represent the bacterial quality of drinking water. The second group included toxicants, heavy metals, etc, some or all of which have a cumulative toxic effect on the consumer. The third group included parameters that cause physical effects, such as odor, color, and turbidity. The fourth group included the inorganic and organic nontoxic substances such as chloride, sulfate, foaming agents, iron, manganese, zinc, copper, total dissolved solids (TDS) etc. The variables, with their maximum allowable contaminant level, C_{MCL} (as per the US Environmental Protection Agency), and the subindices which include the effects of concentrations of different parameters and their weightings, are given in Table 3.8.

Table 3.8 Subindex functions of Bhargava's drinking water supply index

Variables	**Subindex Function**	**C_{MCL}**
Group I Coliform organisms, e.g., Coliform bacteria	$f_1 = e^{[-16(c-1)]}$	Coliform bacteria / 100 ml
Group II Heavy metals, other toxicants, etc., e.g., Cr, Pb Ag etc.	$f_1 = e^{[-4(c-1)]}$	0.05 mg / l each
Group III Physical variables, e.g., turbidity, color.	$f_1 = e^{[-2(c-1)]}$	1 TU, 15 Color units
Group IV Organic & Inorganic non toxic substances, e.g., chlorides, sulphates, TDS.	$f_1 = e^{[-2(c-1)]}$	250 mg/L each 500 mg/L

The subindices were aggregated as follows:

$$WQI = \sum_{i=1}^{n} f_i^{\frac{1}{12}} \qquad (3.9)$$

where, f_i = subindex for i^{th} variable varied from 0–2.

n = number of variables considered

The index was applied to the raw water quality data at the upstream and downstream of river Yamuna at Delhi. The author suggested that the public drinking water supplies should have a WQI larger than 90.

3.4.2 The River Ganga Index

This index was developed by Ved Prakash et al. in 1990 to evaluate the water quality profile of river Ganga in its entire stretch and to identify the reaches where the gap between the desired and the existing water quality is significant enough to warrant urgent pollution control measures. The index had the weighted multiplication form as follows:

$$WQI = \sum_{i=1}^{p} w_i I_i \qquad (3.10)$$

where I_i = sub index for i^{th} water quality parameter

w_i = weight associated with i^{th} water quality parameter and

P = number of water quality parameters

This index was based on the index of Brown *et al* or National Sanitation Foundation WQI with slight modifications in terms of weightings to confirm to the water quality criteria for different categories of uses as set by Central Water Pollution Board, India. A list of parameters was selected through Delphi. Sub-Index values were obtained by using sub index equations as shown in Table 3.9. To assign weightings, significance ratings were given to all the selected parameters. A temporary weight of 1 was assigned to the parameter which received highest significance rating. All other temporary weights were obtained by dividing each individual mean rating with the highest. Each temporary weight was then divided by the sum of all weights to arrive at the final weights. These weights were modified to suit the water quality criteria for different categories of uses. The classification of water for the final index values is given in Table 3.10.

Table 3.9 Sub-index equations of the index reported by Ved Prakash et al

Parameter	Range applicable	Equation	Correlation
DO	0–40% saturation	IDO = 0.18+0.66 (% sat)	0.99
	40–100% saturation	IDO = -13.5+1.17 (% sat)	0.99
	100–140% saturation	IDO = 263.34-0.62 (% sat)	–0.99
BOD (mg/l)	0–10	IDO = 96.67–7.00 x (BO)	–0.99
	10–30	IBOD = 38.9–1.23 x (BOD)	–0.95
pH	2–5	IpH = 16.1+7.35 x (pH)	0.925
	5–7.3	IpH = 142.67+33.5 x (pH)	0.99
	7.3–10	IpH = 316.96–29.85 x (pH)	–0.98
	10–12	IpH = 96.17–8.00 x (pH)	–0.93
Fecal Coliform	$1–10^3$	Icoli = 97.2–26.80 x (Icoli)	–0.99
	$10^3–10^5$	Icoli = 42.33–7.75 x (Icoli)	–0.98
	10^5	Icoli = 2	

Table 3.10 Water class as per index score (River Ganga Index)

WQI	Description	Class
63 – 100	Good to excellent	A
50 – 63	Medium to good	B
38 – 50	Bad	C
38	Bad to very bad	D,E

CHAPTER IV

DESCRIPTION OF STUDY AREA

The National Capital Territory of Delhi extends from 28° 25’ north to 28° 53’ north latitude and 76° 50’ east to 77° 22’ east longitude. It is bounded in the east by the state of Uttar Pradesh and on the remaining sides surrounded by the state of Haryana. The Yamuna River and the terminal part of the Aravali hill ranges are the two main geographical features of the city. Delhi is at the dividing line between two major river plains of the country, the Ganga-Yamuna plain in the east and the Satluj-Ravi plain in the north. The National Capital 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 m 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. [v]

Physically the National capital 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 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 North-eastern direction. It encircles the city on the West and North -western directions. Leaving aside the Yamuna flood plain *(Khadar)* and the *Ridge*, the entire area of the NCT of Delhi is categorized as *Bangar* or the plain whose land is mostly fertile. A major proportion of the area of NCT of Delhi is plain, prominently areas like Delhi, New Delhi and Delhi Cantonment.

4.1 Demography

The rapid population growth along with a high rate of urbanization and also industrialization has transformed the character of Delhi to a multifunctional metropolis with significant shift towards industry, commerce and services. During the 70’s and 80’s Delhi, the national capital, saw an unprecedented growth in population, vehicles and industries, which caused a serious ecological imbalance and environmental degradation. The problem got further aggravated by increasing migration from neighboring states as shown in Figure 4.1.

The total area of NCT of Delhi is 1483 sq. Km with an urban segment of 685.34 sq Km in the year 1991. The core of Delhi's growth problems lie in its rapid industrialization and its ability to offer opportunities for employment. As per the 2001 census, an essentially administrative center with a population of 1.45 million in 1951 had become a huge urban metropolis with a population of 13.78 million in 2001. At the end of the 10th Five year plan the population of Delhi is expected to reach 17.5 million (Figure 4.2). Urban population in Delhi grew at 51.53% from 1991-2001 as compared to 46.89% during 1981-1991.

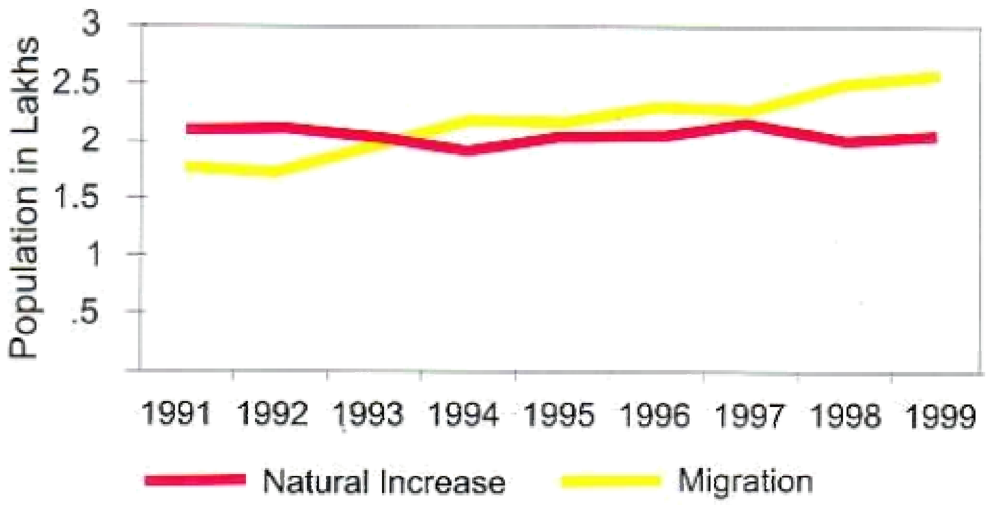


Figure 4.1 Population Growths through Natural Increase & Migration

The trend in the growth of rural population showed only a marginal increase of 1.69% during 1991-2001. Besides a floating population of 3-4 lakhs/day is a recurring feature in Delhi. According to a recent survey, more than 50% of Delhi's population lives in about 1304 unauthorized colonies. 1030 J.J. (Jhuggi Jhonpari) clusters, 44 resettlement colonies & 209 rural villages. The density of the population also increased to 9294 persons/sq. Km (the highest in the country) in the year 2001 against 6352 persons/sq. Km in 1991. [78]

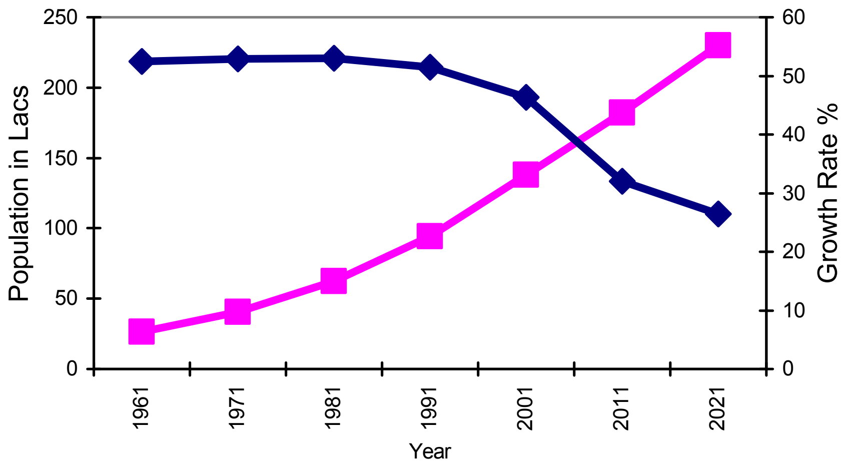


Figure 4.2 Population & Growth Rate trend in Delhi

4.2 Hydro-Geology

The ground water availability in the National Capital Territory-Delhi is controlled by the hydro-geological, characterized by occurrence of alluvial formations and quartzitic hard rocks. The hydro-geological set up and the groundwater occurrence is further influenced by the following distinct physiographic units:

- Alluvial Plain on eastern and western sides of the ridge
- Yamuna River flood plain Deposits
- Isolated and nearly closed Chatarpur alluvial basin
- 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 Km. The alluvial formations overlying the quartzite bedrock have different nature on either side of the ridge. The Yamuna flood plain contains distinctive deposits. The nearly closed Chattarpur alluvial basin covers an area of about 48 Km^2, is occupied by alluvium derived from the adjacent quartzite ridge. The geological units are depicted in Figure 4.5. The general stratigraphic sequence of the rock formations in National Capital Territory - Delhi is presented in Table 4.1.

4.2.1 Alluvial Deposits

The alluvial deposits of quaternary age are mainly composed of unconsolidated clay, silt, and sand with varying proportions of gravel and kankar. The alluvial formation is further divided into:

i) *Newer alluvium:* It belongs to recent age and refers to the sediments deposited in the flood plains of Yamuna River and also along water courses of major streams flowing from the hills. These sediments range in texture from clay/silt mixed with tiny mica flakes to medium/coarse sand and gravel. Newer alluvium, in general, is characterized by absence of permanent vegetation (due to periodic flooding) and lack of kankar.

Table 4.1 General stratigraphic sequence in NCT- Delhi

Quaternary	Newer Alluvium	Unconsolidated, inter-bedded lenses of sand, silt, gravel and clay in narrow flood plains of Yamuna river.
	Older Alluvium	Unconsolidated inter bedded, inter-fingering deposits of sand, clay and kankar, Moderately sorted. Thickness variable, at places more than 300 meters.
Pre-Cambrian	Alwar Quartzites	Well stratified, thick bedded, brown to buff colour, hard and compact, intruded locally by pegmatite and quartz veins inter-bedded with mica schists.

ii) *Older alluvium:* It consists of the sediments deposited as a result of past cycles of sedimentation of Plisestocene age and occurs extensively in the alluvial plains within territory of Delhi. This is comprised of inter bedded, lenticular and inter fingering deposits of clay, silt and sand ranging in size from very fine to very coarse with occasional gravels. The kankar or secondary carbonates of lime occur with clay/silt deposits and sometimes as hard/compact pans. Older alluvium is predominantly clayey in nature in major parts of territory except near closed alluvial basin of Chattarpur, where the alluvial formation is derived from the weathered quatzites rocks.

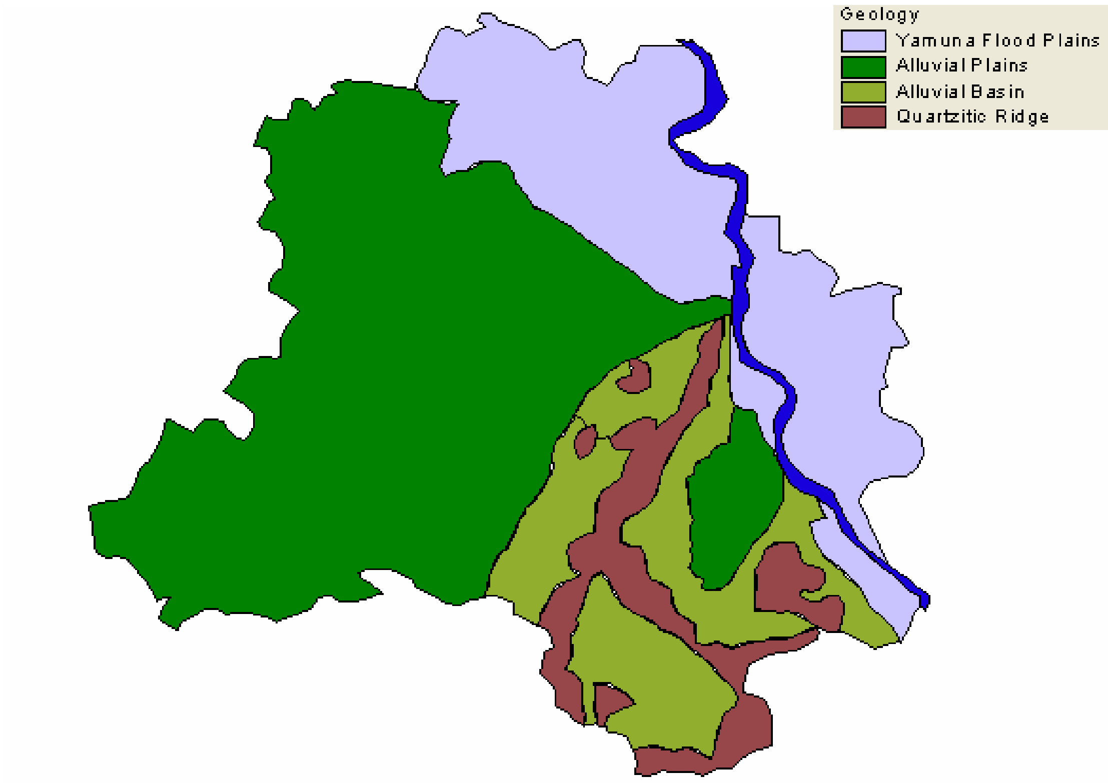


Figure 4.3 Various geological units of Delhi

4.2.2 Hard Rock Formation

The Alwar quartzites of Delhi system exposed in the area belong to pre-Cambrian age. The quartzites are pinkish to grey in colour, hard, compact, highly jointed/fractured and weathered. These occur with interbeds of mica-schists and are intruded locally by pegmatites and quartz veins. The strike of these rocks varies from north east-south west to north east- south southwest with steep dips towards south-east and east except for some local variations due to folding. The prominent joint sets are strike joints, bedding joints and dip joints. Quartzites are ferruginous and gritty types on weathering and subsequent disintegration give rise to coarse sand (Badarpur sands).

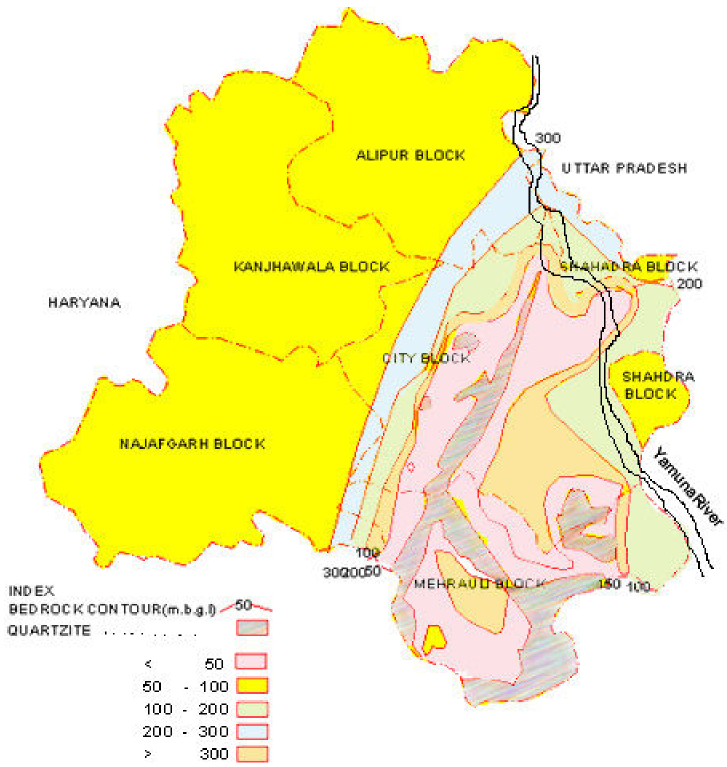


Figure 4.4 Depth to hard rock

4.2.3 Sub-surface Configuration

The exploratory drilling undertaken in different parts of NCT – Delhi has shown that the nature of bedrock topography is rendered uneven due to existence of sub surface ridges. Thickness of alluvium overlying the quartzites increases away from the outcrops. The thickness of alluvium is 300 m or more in most parts of Najafgarh, Kanjhawala and Alipur blocks, while in the south eastern parts of Alipur block, it varies from 100 m to 300 m. In the eastern parts of Najafgarh block, the thickness range is from 50 m to 300 m. In the city block, west of the ridge, the alluvium thickness increases away from the ridge to 300 m or more. East of the ridge, in the areas up to river Yamuna, the alluvium thickness is comparatively less to about 165 m. east of river Yamuna covering parts of city and Shahadra blocks, the thickness ranges between 48 to 240 m. In the Chattarpur basin of Mehrauli block, the alluvial thickness varies from a few meters near the periphery to 115 m around Satbari bund.

4.3 Climate and Rainfall

Delhi has sub-tropical climate with extremely hot summers and moderately cold winters. Its climate is influenced by the Himalayas in the north and the Thar

Desert in the west. The summer season 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 temperatures 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 years maintained by the Meteorological Department.

The rainfall within NCT – Delhi is currently being recorded at 13 stations viz. Chandrwal, New Delhi (Safdarjang), Delhi University, New Delhi (Palam), Okhla, Mehrauli, Delhi Sadar, Nangloi, Shahadra, Najafgarh, Badli, Alipur and Narela. The rainfall increases from south west to North West, about 81% of the annual rainfall is received during three monsoon months of July, August and September. On an average, rains of 2.5 mm or more falls on 27 days in a year. Of these, 19 days are covered under monsoon months; two to three days in June while rest in other seasons. The normal annual rainfall in the National Capital Territory – Delhi is 611.8 mm.

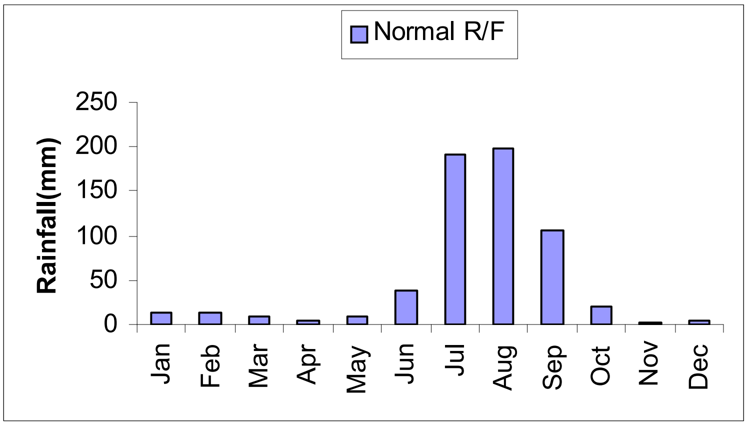


Fig. 4.5 Normal Rainfall in National Capital Territory-Delhi

4.4 Water Supply and Drainage

The Yamuna River flowing in a southerly direction in the eastern part of the Union Territory of Delhi is the only perennial river in the study area. It controls the drainage network of Delhi. Eastern and Western Yamuna canals and Agra canal are the three major canals which originate from the Yamuna River with Bawana, Rajpur and Lampur distributaries. Auchandi, Budhanpur, Sultanpur Mundka, Mongolpur, Nahari, Dhansa and Surkhpur are some of important minors. The Agra canal originates from Okhla, about 12 km. South of Delhi and flows towards Haryana. The

Western Yamuna Canal flowing from North to South supports the Drinking water requirements of the citizens of Delhi. The *Bangar* area of Delhi has a major drain named Najafgarh drain which almost divides the main territory of Delhi in Northern and Southern parts. Almost 86% of Delhi's total water supply comes from surface water sources like Yamuna, Ganga & Bhakra system and is estimated to be 1150.2 MCM (million cubic meters). About 60% of this quantity is contributed by the Yamuna River (724 MCM, NCT Delhi share), out of which flood water accounts for about 580 MCM, almost half of which still remains unutilized in Delhi.

The total groundwater availability in the territory is of the order of 291.54 MCM/year. The surface area irrigated by groundwater in the area is about 47.5 Hectares, while the quantity of groundwater withdrawal for other uses is quite substantial but difficult to access. A rough estimate indicates that about 142 MCM withdrawal of groundwater is for drinking and industrial uses, while about 110 MCM is for irrigation purposes.

As per the "Economic Agenda for Delhi – a proposed Blueprint", prepared by the Confederation of Indian Industry in association with the Rajiv Gandhi Foundation, using the DJB norms on water supply, there will be a huge supply gap by the year 2011. The demand is expected to be 1600 million gallons a day (MGD) versus a proposed treatment capacity of 990 MGD. Owing to this situation of escalating population without a commensurate increase in the availability of raw water, the ground water in Delhi has been over exploited. This has disturbed the hydrological balance leading to decline in the productivity of wells, increasing pumping costs and more energy requirement. Other aspects of concern are poor quality of water supply and inefficient services and inequities in water supply levels. Almost 46 % of the population still does not have access to piped carriage systems. In addition there is the issue of unequal supply – 29 liters per capita per day (lpcd) of water supply in some areas, compared to 509 lpcd in cantonment area. The current demand supply gap is shown in Figure 4.6.

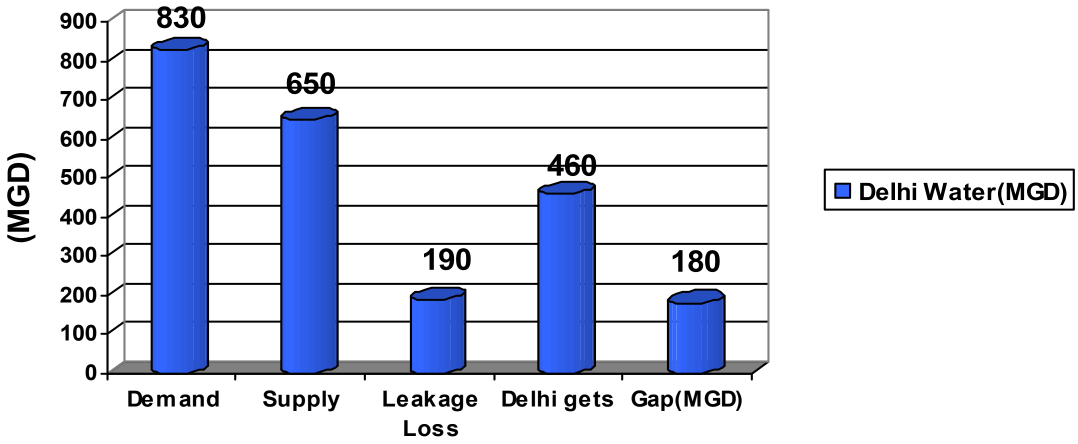


Figure 4.6 The demand-supply gap of water resources in Delhi

There is a disparity in the cost of production and operations of water supply and water tariffs being charged. Currently only 35 % of the cost of proper operation, maintenance and upkeep of the water supply and sewerage system are collected through water tariffs. The revenue collected is hardly able to meet the cost of electricity bill and other requirement of chemicals like chlorine etc. The cost recovery is only 60 % of the production cost of water while the rest is Non- Revenue water.

4.5 Ground Water Situation

The NCT of Delhi, despite its limited areal extent has diversified geological and topographic setup giving rise to divergent ground water situations in different parts. The prevalent rock formations are widely varied in composition and structure ranging in age from pre-Cambrian to recent which control occurrence and movement of ground water. The variations of land forms like ridge areas traversing across the territory, the alluvial plain of western Delhi, closed Chattarpur basins and flood plains of river Yamuna are quite significant to control the occurrence and movement of ground water.

The relatively high relief areas of the Delhi ridge with steeper topographic slopes and characteristic quartzitic formation offer high runoff and less scope for rain water infiltration. The inherent lack of homogeneity and low permeability of these hard rock formations, further create a complex situation for occurrence and movement of ground water. This in turn makes the ground water development site specific which needs to be decided through scientific surveys and exploration. The ground water occurs in weathered and fractured/jointed parts of these rocks. The shallow aquifers mainly consist of weathered residue, whereas the joints and fractures constitute deeper aquifers.

The alluvial tract occupying large parts constitute the potential ground water reservoir in the territory. The characteristics and potential of ground water reservoir, ground water movement and occurrence show a distinct variation even in the alluvial aquifers due to their manner of deposition. The aquifers in western alluvial plains of the territory are distinct from the aquifer of Chattarpur basin and those occurring in Yamuna flood plains. The hydrological parameters and the potential of these aquifers are varied. The variation of quality of ground water in space, as well as depth adds another dimension to the complex ground water situation in the territory. The presence of saline water aquifers at shallow depths varying from 20 m to 50 m below ground level in many parts presents a typical ground water scenario. The ground water occurs under phreatic confined conditions in the shallow aquifer zone whereas semi confined to confined conditions of ground water is quite common in deep aquifers. In the Yamuna flood plains and the Chattarpur basin, the shallow fresh water aquifers available within depth range of 40-50 m, behave as a single unconfined aquifer system.

The ground water resource and irrigation potential for NCT Delhi is presented in Table 4.2 which indicates that most of the blocks have been over developed. The excessive withdrawal of ground water is mainly in the blocks of City, Najafgarh, Kanjhawala and Alipur. There is, however possibility of some development of ground water resources for domestic uses in Alipur, Shahadra and City blocks.

4.5.1 Water Level Trends

The regular and periodic monitoring of ground water levels, through more than 100 hydrograph network stations, comprising of open dug wells & piezometers located throughout the NCT - Delhi have indicated the changes in water levels consequent to continuous ground water abstraction and urbanization. During 1983 – 1995, water levels have declined all over Delhi excepting a small area in northeast (Figure 4.9).Though in most parts of Delhi, the water table decline has been less than 4m; significantly greater declines (4m to more than 8m) have been recorded in areas in central Najafgarh block, both sides of the ridges in southern city block and in the Chattarpur basin of Mehrauli block.

Table 4.2 Ground water resources & irrigation potential

Blocks	Area (km^2)	Population (in lakhs)	Total replenishable resource (MCM)	Net draft (MCM)	Withdrawal for domestic use (MCM)	Total Ground Water withdrawal (MCM)	Balance for various uses (MCM)
Alipur	220.83	2.97	60.90	30.00	6.70	36.70	24.00
Kanjhawala	221.45	4.08	44.92	34.00	4.05	38.05	6.87
Najafgarh	302.43	4.94	27.24	32.00	8.19	40.19	NIL
Mehrauli	166.99	2.34	18.75	18.00	10.25	28.25	NIL
City	531.69	76.02	122.50	0.00	110.50	110.50	12.00
Shahadra	39.61	3.86	17.92	4.00	2.90	6.90	10.02
Total	**1483***	**94.21**	**292.23**	**118.00**	**142.59**	**260.59**	**52.89**

*The total area includes the area occupied by Yamuna river bed also.

It is also estimated that unless the depleted water table in Mehrauli is maintained or replenished, it will experience desertification within the next ten years. The reasons for the decline in ground water levels are:

1. Rapid pace of urbanisation, leading to reduction in recharge of aquifers.
2. Increasing demand in agriculture and industrial sectors as well as domestic needs for the ever growing population.
3. A change in cropping patters in order to raise cash crops in certain areas.
4. Stress laid on ground water extraction during drought periods when all other sources shrink.
5. Unplanned withdrawal from subsoil aquifer.

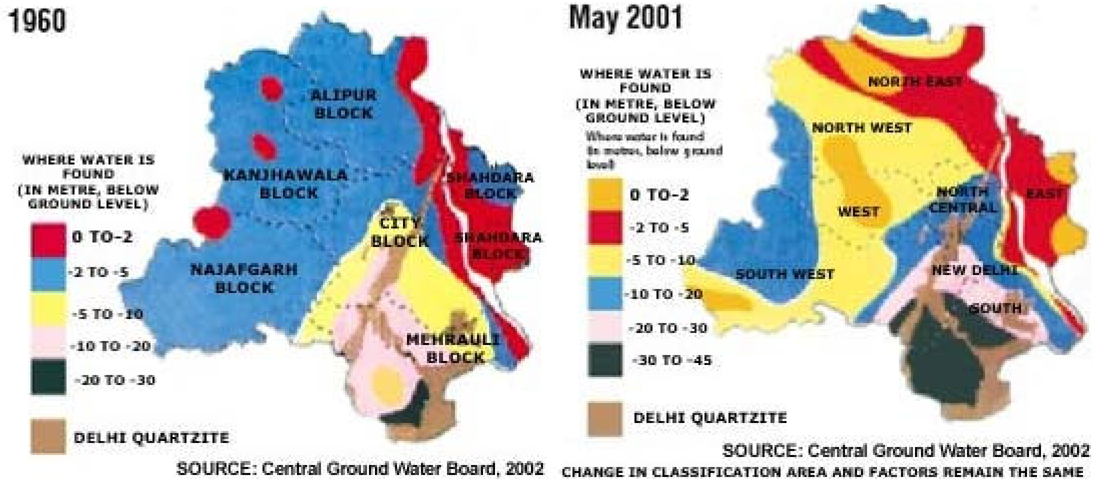


Figure 4.7 Groundwater table fluctuations in Delhi

4.6 River Yamuna

Once the lifeline which spawned the many civilizations and cities that grew in the area of the present NCT of Delhi, the River Yamuna today suffers from inadequate flow and quantum of water and an extremely high degree of pollution. The length of the river in the NCT of Delhi is 48 km from Palla in the North to Okhla in the South, with a total river bed/flood plane area of around 97 km^2 which is about 7 percent of the total area of Delhi. A little over 50 percent of the river lies north of Wazirabad and the rest, around 22 km to its South, in the urban area of Delhi. Apart from being the main sources of water supply for Delhi, it is one of the major sources of ground water recharge. However, over the years, rapid urbanization, encroachments on the river banks, over exploitation of natural resources/water, and serious deficiencies and backlog in sanitation and waste water management services, have resulted in the dwindling of water flow in the river and extremely high levels of pollution in the form of BOD and Coliforms, etc. As against the stipulated 3mg/1, the designated water quality for bathing purposes, the water quality data for 2003-04 suggests that the BOD values range from 1-3 mg/1 at Palla, 5.56 mg/1 at Nizamuddin and nearly 7 at Okhla. Similarly, at all locations, except Palla, the total Coliform levels are many times higher than the minimum tolerable standards for drinking and bathing purposes.

The dry weather flow in the river Yamuna along Delhi is nearly zero. This has resulted in almost total depletion of the self cleansing capacity of the river at Wazirabad. The low self-purification capacity of the river Yamuna is due to want of minimum flow in the river and discharge of heavy municipal and industrial pollution load emanating from Delhi. Even though Delhi constitutes only 2% of the total catchment of the Yamuna basin, yet the area contributes about 80% of the pollution load. The major source of the pollution in the river, to the extent of about 80%, is the discharge of treated and untreated waste water through the 19 major drains (Annexure IV) which flow into the river. The CPCB data shows that six of these drains viz. the Najafgarh and the Supplementary Drain, the Shahadra Drain, the Drain near Sarita Vihar, the Maharani Bagh Drain, the Barapulla drain and the Sen Nursing Home Drain contribute almost 90 percent of the flow and 80 percent BOD load levels respectively. [vi] An index map of the river Yamuna with the five sampling locations under the Yamuna Action Plan (namely Hathnikund, Kalanaur, Sonepat, Palla and Nizamuddin Bridge) is shown in Appendix II.

CHAPTER V

METHODOLOGY

5.1 Methodology of Sampling and Analysis

The ground water quality monitoring studies were undertaken during February to March, 1998 by Central Pollution Control Board, Delhi, through extensive field survey covering entire Delhi area, comprising all the six blocks viz. Alipur, Kanjhawala, Najafgarh, Mehrauli, City and Shahadra (Figure 5.1). The ground water sampling locations have been depicted in Figure 5.2 and their latitude & longitude are given in Annexure I.

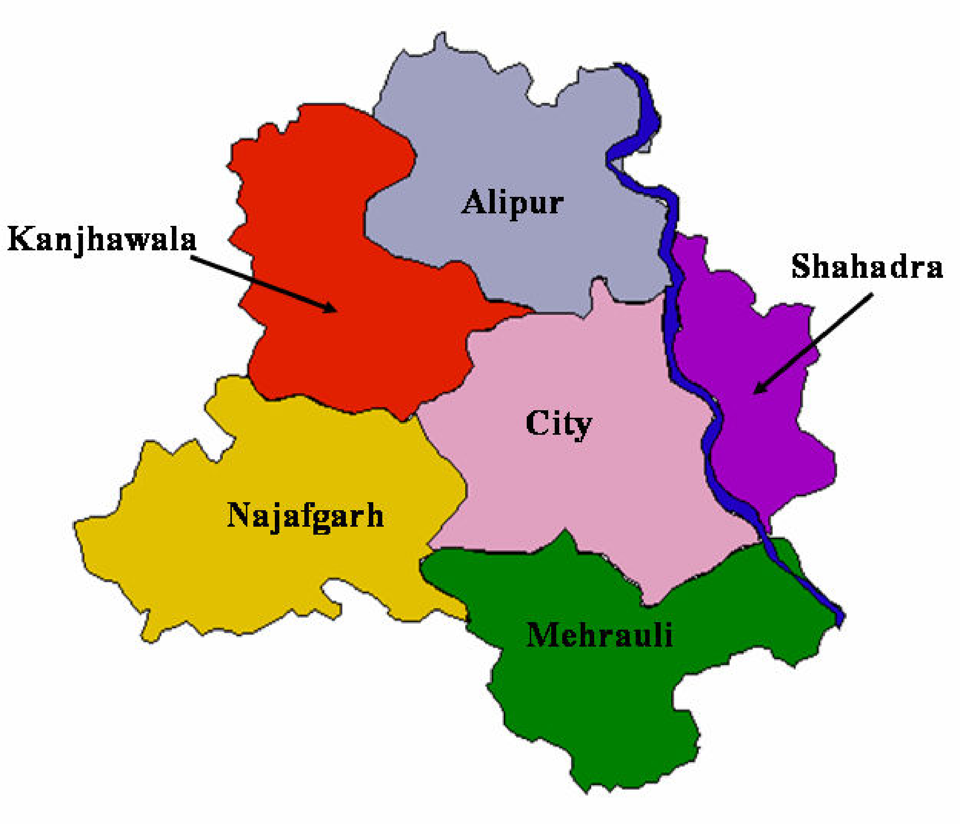
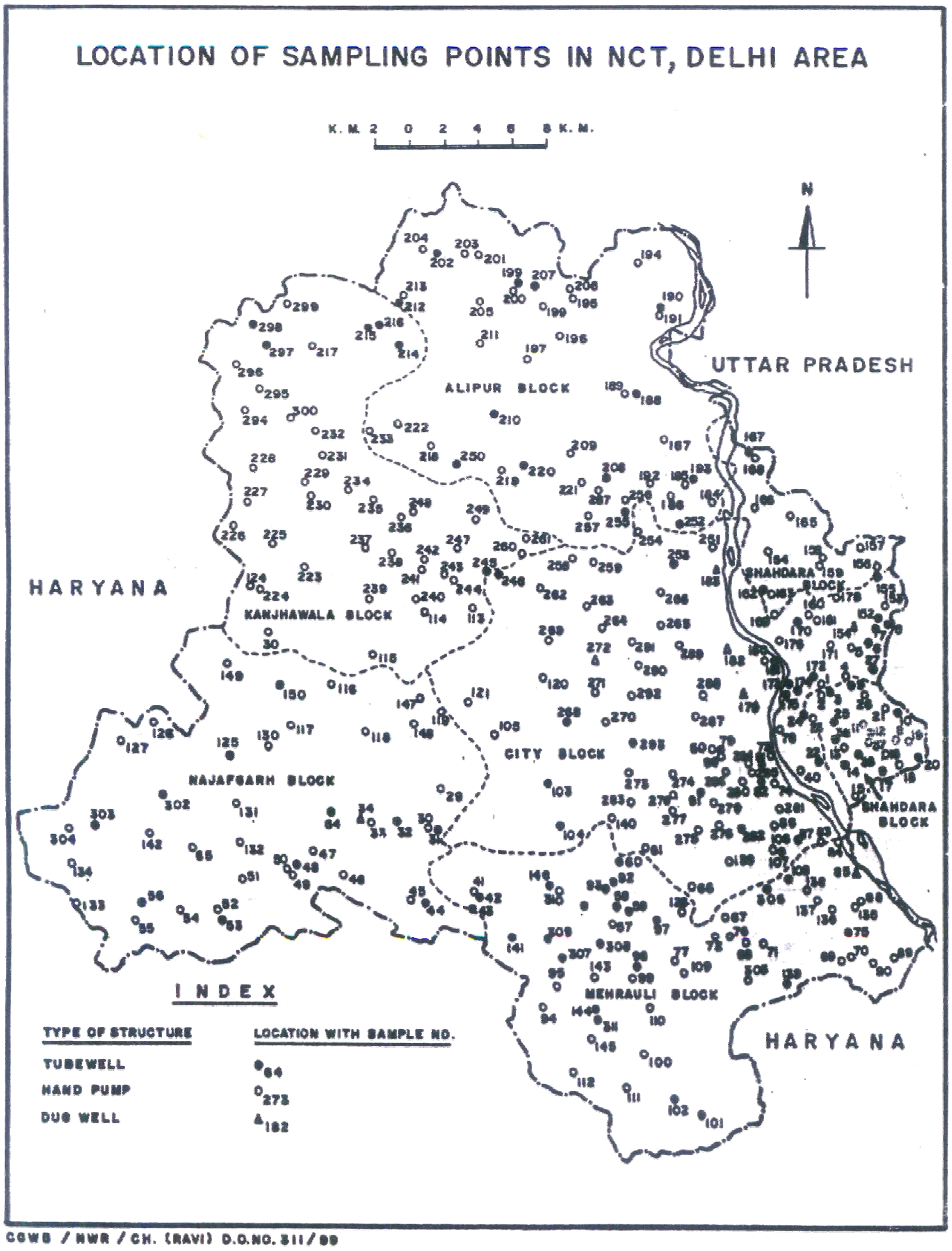


Figure 5.1 Various Administrative blocks in Delhi



CGWB / NWR / CH. (RAVI) D.O.NO. 311/99

Figure 5.2 Location of sampling points in NCT, Delhi

As the water systems are heterogeneous to varying degrees in space and time, the water samples were collected at various sites dispersed in all the blocks and from various abstraction sources (from which water use for human consumption) such as hand pumps, dug wells, tube wells (Shallow and deep) at various depths (Table 5.1 & 5.2), covering urban and rural areas including extensively populated area, commercial, industrial, agricultural and residential colonies as to obtain a good areal representation. The ground water samples were also collected from water structures available in and around petrol pumps, where ground water use is considerably high.

The ground water sampling was intensive covering all the abstraction sources/wells with known or reported water quality problems (Table 5.3). The water sampling for all 303 samples has been undertaken according to standardised procedures being followed by Central Pollution Control Board, Delhi as adopted from APHA (1995) [79].

Table 5.1 Source-wise distribution of sampling sites

Source structure	**Depth Range**			**Total number**
	< 20 m	**20 - 40 m**	**> 40 m**	
Hand pumps	135	52	19	206
Tube wells	13	25	42	80
Dug wells	5	1	-	6
Piezometers	-	1	1	2
Dug Cum bore well	1	4	-	5
Rainey well	-	3	1	4
Total	**154**	**86**	**63**	**303**

Table 5.2 Block-wise and depth wise numbers of ground water samples

Depth range (m)	**Blocks**					
	Alipur	**Kanjhawala**	**Najafgarh**	**Mehrauli**	**Shahadra**	**City**
< 20	27	37	10	Nil	34	46
20 - 40	10	5	26	11	12	22
> 40	2	2	7	29	10	13
Total	**39**	**44**	**43**	**40**	**56**	**81**

Table 5.3 Land use of Ground Water samples collection sites in NCT -Delhi

Land use	**Block-wise number of samples**						**Total**
	Alipur	**Kanjhawala**	**Najafgarh**	**Mehrauli**	**City**	**Shahadra**	
Inhabited	26	26	26	28	53	37	196
Commercial	-	11	2	5	10	3	31
Horticulture	2	1	1	3	7	4	18
Land fill	1	-	-	-	2	2	5
Agriculture	7	3	12	1	4	7	34
Brick kilns factory	1	1	-	1	-	-	3
Service station	-	1	1	-	1	2	5
Forest area	-	-	-	2	-	-	2
Dairy farm	2	-	1	-	1	-	4
Industrial area	-	1	-	-	3	1	5
Total	**39**	**44**	**43**	**40**	**81**	**56**	**303**

The Physico-chemical water quality data for groundwater at various sampling points in the study area is shown in Annexure V.

5.2 Statistical Analysis

Frequent monitoring of water quality is indeed an expensive and time-consuming assignment due to various technical and practical problems. Spatial and seasonal fluctuations, variations in trend and interrelationships between various parameters are needed to be studied during planning stage of any monitoring program. Recently, it has been well established by number of researchers that correlation analysis of water quality parameters are useful in the predications of parameters and thus could be employed as an analytical tool for rapid monitoring of water quality status. In the present study an attempt is made to find out the relations between various physico-chemical parameters and also to estimate regression equations. Statistical analysis, Correlation-Regression analysis was done using *Microsoft Excel ® 2002*.

5.2.1 Correlation

Karl Pearson Correlation coefficient is a bivariate measure of association (strength) of the relationship between two variables. It varies from 0 (random relationship) to 1 (perfect linear relationship) or -1 (perfect negative linear relationship). It is usually reported in terms of its square (r^2), interpreted as percent of variance explained. The Correlation Matrix report generates a correlation matrix for a specified number of sample parameters that are common to all active samples.

5.2.2 Regression

The correlation is high if it can be "summarized" by a straight line (sloped upwards or downwards). This line is called the regression line or least squares line, because it is determined such that the sum of the *squared* distances of all the data points from the line is the lowest possible. A linear regression routine calculates the regression coefficient (r), and the slope and intercept of the regression line. This allows you to quickly determine the similarities or differences between your water samples. The regression of the variable 'X' on the variable 'Y' is given by the linear regression equation; $Y = aX + b$; where 'Y' is called the dependent variables and 'X' is called the independent variables; 'a' and 'b' are constants.

Reddy and Raju (1990) clearly demonstrated that the regression model predictability is very near to the actual measured when compared with the other method of determining total dissolved solids. This approach used in the study can be used in ground water quality studies where TDS data are desired. In the present study the linear regression equation for some highly correlated parameters are also found out.

5.2.3 Factor Analysis

Factor analysis aims to explain observed relation between numerous variables in terms of simpler relations. It is also a way to classify manifestation of variables (Cattel, 1965) [80]. Although developed as a tool in the social sciences, R-mode factor analysis has proven highly effective in studies of groundwater quality (e.g. Love and Hallbauer, 1998[82]; Olmez et al., 1994[83]; Reghunath et al., 2002[84]; Subbarao et al., 1995[85]). The technique examines the relationships between variables (such as chemical parameters in groundwater), which are shown by a number of cases (such as sampling points). [81]

The Microsoft Excel add-on package *StatistiXL® software (Version 1.4)* was used to perform R-mode factor analysis. The factor loadings were calculated using the Varimax rotation method. Before computation, the testing data were standardized in order to avoid misclassifications arising from different orders of magnitude of tested variables [86] (Figure 5.3 & Figure 5.4). Therefore the data were mean (average) centered and scaled by the standard deviation using Eqn. 5.1.

$$\frac{x_i - \bar{x}}{s} \tag{5.1}$$

where $\bar{x}$ = mean of the data, s = standard deviation of the dataset and x_i = i^{th} value of the variable x which is to be standardized.

5.3 Geochemical Plots

A robust classification scheme for partitioning water chemistry samples into homogeneous groups is an important tool for the characterization of hydrologic systems. Conventional studies of ground water have placed a heavy emphasis on the variations in the chemical characteristics of ground water in time and space (Kennedy et al., 1999). Therefore, many researchers have performed multiple ground water sampling and subsequent chemical analyses. The main tools for the interpretation of chemical analysis results are graphical methods (usually based on Stiff and Piper diagrams) combined with basic statistics (e.g., average, frequency, correlation) (Montgomery et al., 1987; Hem, 1989 [19]; Frapporti et al., 1993). Based on the chemical evolution pattern of natural ground water by water-rock interactions, the major chemical components have been used to characterize the water types. Graphical methods, however easy to understand and use, make use of a limited number of parameters, usually a subset of the available data, unlike the statistical methods that can utilize all the available parameters.

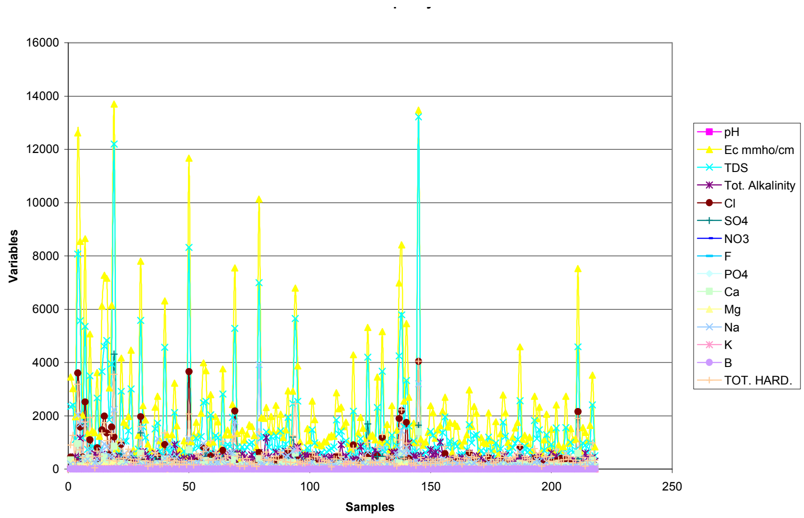


Figure 5.3 Plot of the water quality variables

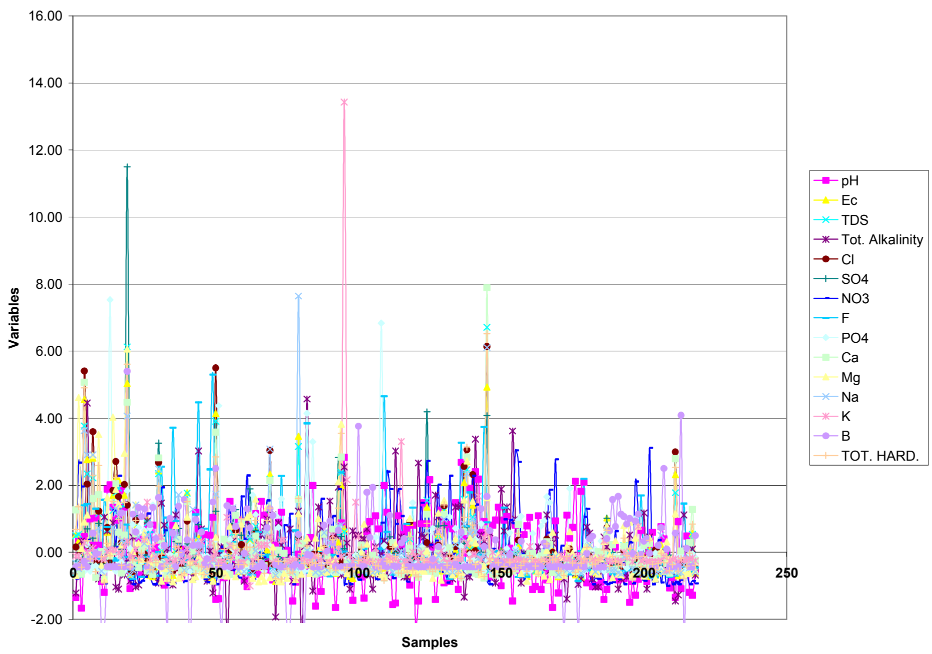


Figure 5.4 Plot of the standardized water quality variables

5.3.1 Stiff Diagram

The Stiff plot belongs to the group of pattern plots (Hem 1989 [19]). It is constructed by plotting the milliequivalents per liter of three or more anions and three or more cations. Stiff plots can be used to evaluate the change in water quality at a single location over a period of time, or they can be used to evaluate the change in water quality as the water passes through different geologic formations or different subsurface conditions. Cations (positively charged ions) are plotted on the left side of the diagram, with anions (negatively charged ions) plotted on the right. The length of the diagram vertices is proportional to ionic content. The Stiff diagram is usually plotted without the labeled axis and is useful making visual comparison of waters with different characteristics. The patterns tend to maintain its shape upon concentration or dilution, thus visually allowing us to trace the flow paths on maps (Stiff 1951) [87]. *AquaChem® software (Version 3.6)* was used to plot the Stiff diagrams for different blocks.

5.3.2 Radial Plots

The Radial plot is used to compare multiple parameter values for a single sample and to compare the ratios of these values for many different samples. Radial plots can be used to evaluate the change in water quality at a single location over a period of time, or they can be used to evaluate the change in water quality as the water passes through different geologic formations or different subsurface conditions. *AquaChem® software (Version 3.6)* was used to plot the Radial diagrams for different blocks.

5.3.3 Scholler Plot

Schoeller (1962) [88] developed semi-logarithmic plots to represent major ion analyses in milliequivalents per liter and to demonstrate different hydrochemical water types on the same plot. It shows the total concentration of major ions in log-scale. The number of analyses that can be illustrated at one time is limited because of the lines. The plot has the advantage that, unlike trilinear plots, actual parameter concentrations are displayed. *AquaChem® software (Version 3.6)* was used to plot the Scholler diagram for different blocks.

5.3.4 Ternary Diagram

Ternary plot is used to determine the relationship between the concentrations of three different parameters in multiple samples. Like the Piper and Durov plots, the Ternary plot displays relative concentrations of each parameter with respect to the sum of the concentrations of each parameter. Each vertex of the Ternary plot represents a relative concentration of 100% for the parameter at the respective vertex, while the base represents a relative concentration of 0% for the parameter plotted at the opposite vertex. In our case anions were taken to be a mixture of SO_4, Cl and HCO_3, while cations were represented by Ca, Mg and Na. These ions were selected because they are often used in geochemical analysis (Hem, 1989 [19]) and comprise most of the major inorganic ions in atmospheric precipitation (Berner & Berner, 1987), rock weathering (Hutchinson, 1957) and evaporation and crystallization (Hutchinson, 1957). *AquaChem® software (Version 3.6)* was used to plot the Ternary diagram for different blocks.

5.3.5 Durov Plot

The trilinear Durov plot is based on the percentage of major ion milliequivalents. The Cations and Anions values are plotted on two separate triangular plots and the data points are projected onto a square grid at the base of each triangle. The Durov plot is an alternative to the Piper plot which is described later in this chapter. Since the data points are projected along the base of the triangle, which lies perpendicular to the third axis in each triangle, information about the concentration of the vertex element (the third element) is lost in the square grid. Changing the orientation of parameters in both triangles may improve your ability to detect distinct groups. *AquaChem® software (Version 3.6)* was used to plot the Durov plot for different blocks.

5.3.6 Piper Diagram

The concept of hydrochemical facies can be used to denote the diagnostic chemical processes occurring between the mineral within the lithological framework and in the groundwater. The flow pattern based on the geology of the area controls the type of facies and its distribution. The difference in hydrochemical facies in the same group of formation may be caused by characteristics of groundwater flow and the dilution effect of local recharge.

The Piper diagram (Piper 1944 [31]) is the most widely used graphical form and it is quite similar to the diagram proposed by Hill (1940, 1942). It is considered to be a traditional method of classification in the study of hydrochemistry (Ophori and Tóth, 1989; Hem, 1992). It can easily be shown that the analysis of any mixture of waters will plot in a straight line (Hem, 1992). The diagram displays the relative concentrations of the major cations and anions on two separate trilinear plots, together with a central diamond plot where the points from the two trilinear plots are projected. The central diamond-shaped field (quadrilateral field) is used to show overall chemical character of the water (Hill 1940; Piper 1944 [31]). Back (1961) [89] and Back and Hanshaw (1965) [90] defined subdivisions of the diamond field, which represent water-type categories that form the basis for one common classification scheme for natural waters. The Piper plot is useful for showing multiple samples and trends in major ions. The mixing of water from different sources or evolution pathways can also be illustrated by this diagram (Freeze and Cherry 1979 [26]). Symbol sizes can be scaled to TDS on the diamond-shaped field to add even more information (Domenico and Schwartz 1997 [91]).

The Piper diagram not only shows graphically the nature of a given water sample, but also dictates the relationship to other samples. For example, by classifying samples on the Piper diagram, we can identify geologic units with chemically similar water, and define the evolution in water chemistry along the flow path. However, the method has limited usage because of the selection of available parameters (Ca, Mg, Na, K, HCO_3, Cl and SO_4) and an arbitrary choice of classification limits (Frapporti et al., 1993). In order to draw Piper diagram of groundwater for different blocks *Triplot Software* run online from Rhyme site was used.

5.3.7 Contour Diagram

Contour diagrams of various water quality parameter concentrations were drawn by using *Golden Surfer® (Version 8.0)* software. First the base map was georeferenced using *PCI Geomatica ® software*, after georeferencing concentration contours were drawn in Surfer by using Latitude & Longitude values of sampling points.

5.4 Groundwater Quality Index

Pure analytical data may not always convey the significance of poor water quality or the possible impact of elevated chemical concentration. So for this it is necessary to use special tools to communicate relevant information in a manner that will prompt suitable interventions. In this case information can be summarized and presented in the form of water quality indices.

In the formation of water quality index, the importance of various water quality parameters depends on the intended use of water. In the present case study we calculate the index with reference to the suitability of water for human consumption. For formulation of the index ten parameters viz. pH, TDS, Total Hardness, Calcium, Magnesium, Chloride, Sulphate, Nitrate, Fluoride and Total alkalinity have been selected as shown in the first column of Table 5.4. The index is based on the Drinking water standards (IS 10500, 1991), in principle; more harmful pollutants have smaller value in magnitude in the standard for drinking water. So the unit weight w_i for the i^{th} parameter P_i is assumed to be inversely proportional to its recommended standard s_i (where i=1,2,…n and n= number of parameters considered). Thus

$$w_i = \frac{k}{s_i} = \frac{1}{s_i} \tag{5.2}$$

where the constant of proportionality k has been assumed to be unity for the sake of simplicity. The unit weights w_i of the parameters in consideration are shown in Table 5.4, where pH has been assigned the same weight as Chloride or Sulphate. [92]

The quality rating for the i^{th} parameter P_i is given for all the other parameters except pH, by:

$$q_i = 100\left(\frac{v_i}{s_i}\right) \tag{5.3}$$

where v_i is the observed value of the i^{th} parameter and

s_i is its recommended standard for drinking water

Table 5.4 Water quality parameters, their standards and unit weights

Parameter (P_i)	**Standard (s_i)**	**Unit weight (w_i)**
pH	7 - 8.5	0.005
TDS	500	0.002
Total Hardness	300	0.003
Calcium	75	0.013
Magnesium	30	0.033
Chloride	250	0.004
Sulphate	200	0.005
Nitrate	45	0.022
Fluoride	1.5	0.667
Total Alkalinity	200	0.005
		$\sum w_i = 0.760$

For pH, the quality rating q_{pH} can be calculated from the relation

$$q_{pH} = 100\left(\frac{(v_i \sim 7.0)}{1.5}\right) \tag{5.4}$$

where v_i is the observed value of pH

Finally the water quality index (WQI) can be calculated by taking the weighed arithmetic mean of the quality ratings q_i as follows:

$$WQI = \left[\frac{\sum_{i=1}^{n}(q_i \times w_i)}{\sum_{i=1}^{n} w_i}\right] \tag{5.5}$$

where WQI is the water quality index,

q_i. is the quality rating of the i^{th} parameter, and

w_i is the unit weight of the i^{th} parameter

Actual formulation is explained using a sample calculation as shown in Table 5.5, where the quality rating is calculated by making use of either Eqn. 5.3 or Eqn. 5.4 based on the standard value and unit weight given in Table 5.4. The numerical value of water quality index implies that the water under consideration is fit for human consumption if its WQI < 100, and unfit if WQI> 100. Moreover, the larger the value of WQI, the more polluted the water concerned. A classification scheme worked out for indicating the quality of water to evaluate its fitness for drinking purpose as shown in Table 5.6. *Microsoft Excel ® 2002 and MATLAB® (Version 7.0)* were both employed to find the groundwater quality index of the various sampling points. The code for water quality index calculation in MATLAB® (Version 7.0) is given in Appendix II.

Table 5.5 Sample calculation of GWQI for Delhi

Parameter	Modal Value (v_i)	Quality Rating (q_i)	Subindex (q_i w_i)
pH	7.74	49.33	0.247
TDS	590	118	0.236
Total Hardness	400	133.33	0.399
Calcium	127	169.33	2.201
Magnesium	20	66.67	2.2
Chloride	92	36.8	0.147
Sulphate	112	56	0.28
Nitrate	4	8.89	0.1956
Fluoride	0.31	20.67	13.787
Total Alkalinity	337	168.5	0.84
WQI= $\left[\frac{\sum(q_i \cdot w_i)}{\sum w_i}\right] = \frac{20.5326}{0.76}$ **= 27.02**			

For simplicity in understanding, the water quality index is further classified into five classes as given in Table 5.6. In the above case water quality may be termed as "Excellent".

Table 5.6 Classification of groundwater based on WQI values

WQI Range	Quality Rating
<50	Excellent
50-75	Good
75-100	Moderate
100-150	Marginal
>150	Bad

5.4.1 Other Water Quality Indicators

Percent Sodium (% Na): The value of percent sodium was calculated to classify the water for irrigation purpose, where all concentrations are expresses in milli-equivalents per liter.

$$\%Na = \frac{Na}{Ca + Mg + Na + K} \times 100 \tag{5.6}$$

Sodium Absorption Ratio (SAR): The tendency of water to replace absorbed calcium and magnesium with sodium can be expressed by Sodium Absorption Ratio, where all concentration of ions is expressed in milli-equivalents per liter.

$$SAR = \frac{Na^{+}}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (5.7)$$

Base Exchange Index: Base Exchange index (BEI) values were calculated to demarcate the recharge and discharge area. All concentrations are expressed as milli-equivalents per liter. If BEI is negative then the area is recharge area else it is discharge area.

$$BEI = \frac{(Cl - Na)}{Cl} \quad (5.8)$$

Chloride-Bicarbonate ratio: This ratio was calculated to find instances of salt water intrusion.

$$CBR = \frac{Cl}{(CO_3 + HCO_3)} \quad (5.9)$$

Total Dissolved Solids: In the present study the classification of water based on TDS is done as proposed by Davis & De Wiest (1967) [20] as follows:

Water Classification	TDS
Fresh water	0-1000 mg/l
Brackish water	1000-10,000 mg/l
Saline water	10,000-100,000 mg/l
Brines	>100,000 mg/l

Total Hardness: For the purpose of classifying water according to its hardness the following classification scheme is used:

Water Classification	Hardness (as $CaCO_3$)
Soft water	0-75 mg/l
Moderate water	75-150 mg/l
Hard water	150-300 mg/l
Very Hard water	>300 mg/l

5.5 Surface water quality Index

In order to calculate the water quality of Yamuna River, U.S. National Sanitary Foundation index has been put to use. It is based on the Delphi approach and summarizes results from a total of nine different measurements. The variables considered are pH, Dissolved Oxygen, Turbidity, Fecal Coliforms, Biochemical Oxygen Demand, Total Phosphates, Nitrates and Total Suspended Solids. In the present case the calculations of the NSF water quality index for Yamuna River have been done using averaged curves for the nine parameters (as shown in earlier chapter) given in literature and verification of the calculated values has been done by a Java applet developed by Wilkes University Center for Environmental Quality GeoEnvironmental Sciences and Engineering Department.

Based on the observed values of the various physico-chemical water quality parameters in the Yamuna River, at five stations (namely Hathnikund, Kalanaur, Sonepat, Palla and Nizamuddin Bridge) for four years (1995-1998), the quality index is worked out using weighed sum method a sample calculation of which is shown in Table 5.7., further classification of water quality is done based on Table 3.7. In this case the water quality may be classified as "Excellent".

Table 5.7 Sample calculation of NSF index for Yamuna

Parameters	**Weight (w_i)**	**Value**	**Quality Index(q_i)**
DO	0.17	7.6	99
FC/100 ML	0.16	0	100
pH	0.11	7.87	88
BOD	0.11	1	95
Temperature Change	0.10	0	93
PO4	0.10	0.05	98
NO3	0.10	0	97
Turbidity	0.08	1	96
TDS	0.07	124	81
NSF Water Quality Index	$= \sum(q_i \cdot w_i) = \mathbf{94.85}$		

5.6 Water quality Mapping

An attempt is made to assess the relation between the various groundwater quality characteristics and the geology and water level trends in Delhi. Two type of databases: spatial and attribute, are created by using GIS software package, *ArcView GIS® (Version 3.1)*. The spatial data consists of all the necessary thematic maps which are converted into digital format compatible with *ArcView GIS®*. The attribute data consists of groundwater quality of the area under study. The sampling point map and the other indicative maps (for administrative blocks, geology and water levels) were first georeferenced using *PCI Geomatica Software* and then digitized using *ArcView GIS® (Version 3.1)*. Attribute data was fed manually in accordance with the sampling point ID and location. The attribute data consists of Sample ID, latitude, longitude, location, block name, pH, TDS, NO_3, F, hardness, Calcium, Magnesium, Chloride, Sulphate and total alkalinity, water quality index, RSC, SAR, USSL class, and landuse data.

Broadly GIS was used in this case (i) to identify and detect the problematic areas of water quality, (ii) to study the impact of geology, and (iii) to study the correlation between the groundwater level and water quality index. The interface used in the GIS map development is shown in Figure 5.5. The various layers/themes developed are shown on the left side of the figure, which include sampling point locations, block boundaries, Yamuna river, Geology, water table level and groundwater vulnerable area.

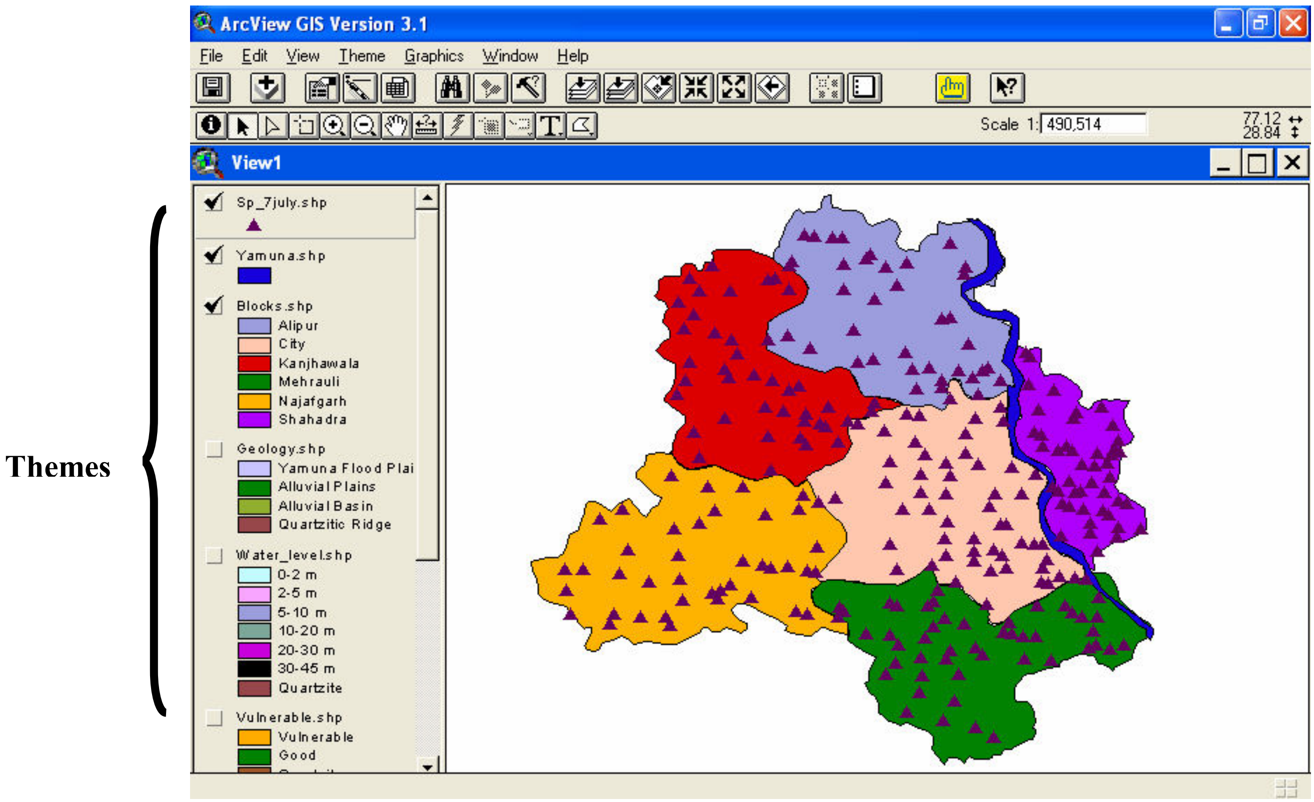


Figure 5.5 Interface used in GIS map development

CHAPTER VI

RESULTS & DISCUSSION

6.1 Water Chemistry

The chemical composition observed in natural water is the result of a variety of chemical reactions and physico-chemical processes acting in concert. An attempt is made to classify the water quality based on drinking water quality (IS 10500, 1991) (Table 6.1) and irrigation water quality standards.

Table 6.1 Comparison of Groundwater quality with IS 10500, 1991 Drinking water standards

Parameter (mg/l)	IS 10500, 1991 Drinking water Standard	Range	Mean	Median	Standard Deviation
pH	7 - 8.5	6.9 - 8.61	7.65	7.65	0.31
TDS	500	165 - 8540	1378.06	975	1177.62
T. Alk.	300	95 - 1333	465.80	432	174.58
Cl	200	0 - 4461	365.99	183	493.94
SO4	200	5 - 2325	213.75	135	261.23
NO3	45	0.01 - 1589	72.41	31	141.98
F	1.5	0.08 - 12.52	1.52	0.81	1.82
Ca	75	0 - 619	106.00	88	77.54
Mg	30	3.40 - 567	68.08	45	72.59
T H.	300	47 - 3583	544.44	430	457.06

About 45.5% ground water samples, have been found unsuitable for drinking based on overall impact of physico-chemical characteristics .The block-wise sequence of overall deterioration of ground water quality has been observed as Kanjhawala block > Najafgarh block > City block > Alipur block > Mehrauli block > Shahadra block.

The determination of irrigation water quality is mainly based on the combined effect of Conductivity (EC), Sodium (% Na) and Sodium Absorption Ratio (SAR) and the classification of water is based on the Irrigation water classification given by

Agriculture Department and Central Ground Water Board (refer Table 2.8 & Table 2.9)

Table 6.2 Comparison of Groundwater quality with various irrigation standards

Block	EC	% Na	SAR	Water Class	
				Agriculture Dept	CGWB
Alipur	2407.740	48.40	5.256	Poor	Bad
City	1630.220	45.30	4.815	Poor	Medium
Kanjhawala	3405.667	52.73	9.773	Very Poor	Bad
Mehrauli	1165.575	42.98	3.376	Fair	Medium
Najafgarh	2931.302	55.76	7.504	Poor	Bad
Shahadra	1471.304	39.39	3.540	Fair	Medium

As detailed in Table 6.2, irrigation water quality is found to be poorest in Kanjhawala block according to classification given by Agriculture department, while both Mehrauli and Shahadra blocks are consistently maintaining a fair quality of water for irrigation in both classifications. The ranges of other important water quality parameters for the study area are given in Table 6.3.

Table 6.3 Ranges of other water quality parameters

Parameter (mg/l)	Range	Mean	Median	Standard Deviation
EC (µmho/cm)	225 - 13200	2073.26	1528	1643.73
PO4	0 - 7.06	0.13	0.08	0.44
Na	6 - 2500	284.88	200	307.12
K	0.40 - 1100	19.04	6.30	70.07
B	0 - 3.55	0.25	0.12	0.43
SiO2	6 - 49	23.55	23	8.61

6.1.1 Water quality based on TDS & Hardness

The chemical quality of groundwater is often conveniently described for domestic and industrial use in terms of its salinity and its hardness. Salinity refers to the concentration of total dissolved solids present in the water, and hardness is generally the measure of Calcium and Magnesium content. The quality based on the total dissolved solids and hardness is mentioned in Table 6.4.

Table 6.4 Water Classification based on Hardness & TDS

Classification	Hardness			TDS	
	Soft to Moderate	Hard	Very Hard	Fresh water	Brackish water
	<150	150-300	>300	0-1000 mg/l	1000-10000 mg/l
	% of samples			% of samples	
Alipur	0.00	12.82	87.18	38.46	61.54
City	8.64	18.52	72.84	60.49	39.51
Kanjhawala	7.14	4.76	88.10	11.90	88.10
Mehrauli	5.00	52.50	42.50	50.00	50.00
Najafgarh	4.65	16.28	79.07	32.56	67.44
Shahadra	3.57	21.43	75.00	62.50	37.50
Total	5.32	20.6	74.09	45.85	54.15

As it is evident from the above table, the water of Delhi mostly falls in the very hard and brackish category. Kanjhawala block is the worst affected by the twin problems of Hardness and Salinity (TDS) closely followed by Alipur and Najafgarh blocks. While water quality is found satisfactory in terms of salinity for Shahadra, City and Mehrauli blocks, water quality in terms of hardness is fair only for Mehrauli.

6.1.2 Saline water Intrusion

Salt water may invade fresh water aquifers to create point or non point sources of pollution. In coastal aquifers seawater is the pollutant; in inland aquifers any of several sources of saline water may be responsible. Chloride is the dominant anion of seawater and normally occurs in only small amounts in ground water. On the other hand, bicarbonate is usually the most abundant anion in ground water and occurs in only minor amounts in seawater. In order to avoid mistaken diagnoses of seawater intrusion as evidenced by temporary increases of total dissolved salts, Revelle[93] recommended the chloride-bicarbonate ratio as a criterion to evaluate intrusion, although pollutants other than seawater can also change the chloride-bicarbonate ratio. If chloride-bicarbonate ratio is up to 0.5 then water is “good ground water”; up to 2.8 then water is “contaminated ground water” and around 200 the water is “sea water”.

Table 6.5 Block wise range of chloride-bicarbonate ratio

Block	**Chloride-Bicarbonate ratio Range meq/l**	**Good Groundwater (% of total samples)**	**Block**	**Chloride-Bicarbonate ratio Range meq/l**	**Good Groundwater (% of total samples)**
Alipur	0.09 – 40.8	23.08%	Mehrauli	0 – 1.87	65%
City	0.014 – 8.97	45.67%	Najafgarh	0.047-19.97	23.26%
Kanjhawala	0.147 – 11.01	14.29%	Shahadra	0.076-6.79	53.57%
			Total	**0 – 40.8**	**39.20 %**

Kanjhawala, Alipur and Najafgarh blocks again seems to be a critical blocks with maximum percentage of polluted groundwater, the water quality in general is inferior in nature here due to the presence of saline water aquifer at shallow depth. The aquifer contamination in Najafgarh may also be attributed to the Najafgarh drain intrusion into groundwater.

6.1.3 Classification on the basis of Base Exchange Index

Base Exchange index values were calculated to demarcate the recharge and discharge area. All concentrations are expressed as milli-equivalents per liter. If BEI is negative then the area is recharge area else it is discharge area. It is observed from the table 6.6 that the maximum discharge area is of Kanjhawala block, Najafgarh block and some parts of Alipur & Shahadra block. It has also been observed that water quality from recharge to discharge area is deteriorating.

Table 6.6 Classification of groundwater aquifer on the basis of Base Exchange

	Alipur		**City**		**Kanjhawala**		**Mehrauli**		**Najafgarh**		**Shahadra**	
Samples	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Recharge	28	71.79	63	77.78	26	61.9	33	82.5	30	69.77	45	80.36
Discharge	11	28.21	18	22.22	16	38.1	7	17.5	13	30.23	11	19.64

6.2 Karl Pearson Correlation & Regression Analyses

In order to observe the relationship among the various analyzed physico-chemical parameters Karl-Pearson correlation analysis was performed and the resultant correlation matrix is presented in Table 6.7.

Table 6.7 Correlation matrix of Delhi-groundwater

	pH	EC	TDS	TA	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	B	TH
pH	1														
EC	-0.151	1													
TDS	-0.154	**0.987**	1												
TA	-0.074	0.204	0.213	1											
Cl	-0.133	**0.955**	**0.930**	0.026	1										
SO4	-0.122	**0.771**	**0.811**	0.149	0.628	1									
NO3	-0.151	0.465	0.499	0.150	0.336	0.368	1								
F	0.309	0.289	0.304	0.352	0.220	0.283	0.152	1							
PO4	-0.068	-0.025	-0.023	0.016	-0.030	-0.030	0.015	-0.048	1						
Ca	-0.387	0.638	0.606	-0.155	0.664	0.422	0.383	-0.140	0	1					
Mg	-0.219	**0.815**	**0.797**	0.050	**0.794**	0.588	0.566	0.137	-0.032	0.692	1				
Na	-0.006	**0.889**	**0.907**	0.313	**0.840**	**0.736**	0.314	0.425	-0.037	0.311	0.552	1			
K	-0.091	0.201	0.226	0.311	0.084	0.227	0.182	0.084	0.077	0.035	0.116	0.11	1		
B	0.086	0.447	0.467	0.309	0.346	0.519	0.086	0.449	-0.009	0.003	0.179	0.519	0.44	1	
TH	-0.311	**0.820**	**0.797**	-0.028	**0.815**	0.592	0.533	0.040	-0.021	**0.873**	**0.950**	0.515	0.09	0.14	1

Highly significant and positive correlation has been observed between many physico-chemical parameters. A linear regression routine calculates the regression coefficient (r), and the slope and intercept of the regression line. This allows one to quickly determine the similarities or differences between the water samples. Based on the correlation analysis attempt has been made to develop the linear regression equations for different physico-chemical parameters whose correlations were strong (r > 0.7). The results so obtained are presented in Table 6.3. The R^2 values indicate the percentage of data adhering to the computed regression equation.

6.3 Factor Analysis

Factor analysis aims to explain observed relation between numerous variables in terms of simpler relations. It is also a way of classifying manifestation of variables (Cattel, 1965 [80]). For the water chemistry data of Delhi region factor analysis was performed after standardization of water quality variables. Figure 6.1 shows the plot of the physico-chemical variable values for the study area while Figure 6.2 shows the plot of the standardized physico-chemical parameter values.

Table 6.8 Regression analysis for water samples

Independent (x)	Dependent (y)	Correlation coefficient r	R^2	Regression Equation y =ax+b
EC	TDS	0.987	0.9748	y = 0.7073x - 88.43
EC	Cl	0.955	0.9116	y = 0.2869x - 228.86
EC	SO_4	0.771	0.595	y = 0.1226x - 40.405
EC	Mg	0.815	0.6635	y = 0.036x - 6.5005
EC	Na	0.889	0.7899	y = 0.1661x - 59.391
EC	Total Hardness	0.820	0.6718	y = 0.2279x + 71.91
TDS	Cl	0.930	0.8652	y = 0.3901x - 171.65
TDS	SO_4	0.811	0.6579	y = 0.1799x - 34.198
TDS	Mg	0.797	0.6345	y = 0.0491x + 0.4144
TDS	Na	0.907	0.8224	y = 0.2365x - 41.025
TDS	Total Hardness	0.797	0.6356	y = 0.3094x + 118.03
Cl	Mg	0.794	0.6309	y = 0.1167x + 25.356
Cl	Na	0.840	0.7052	y = 0.5221x + 93.784
Cl	Total Hardness	0.815	0.6643	y = 0.7542x + 268.42
SO_4	Na	0.736	0.5424	y = 0.8658x + 99.814
Total Hardness	Ca	0.873	0.7617	y = 0.1481x + 25.386
Total Hardness	Mg	0.950	0.9019	y = 0.1508x - 14.039

Table 6.9 Factor Analysis of groundwater chemistry for Delhi

Varimax Rotated Factor Loadings				
Variable	**Factor 1**	**Factor 2**	**Factor 3**	**Factor 4**
pH	-0.004	0.079	-0.063	0.841
EC µmho/cm	0.864	-0.465	-0.033	0.075
TDS	0.848	-0.501	-0.010	0.064
Tot. Alkalinity	-0.016	-0.408	0.350	0.545
Cl	0.858	-0.362	-0.175	-0.024
SO4	0.609	-0.559	0.012	-0.017
NO3	0.600	0.019	0.374	0.154
F	0.048	-0.544	-0.119	0.560
PO4	0.009	0.114	0.578	-0.007
Ca	0.854	0.160	0.038	-0.170
Mg	0.924	-0.080	0.059	0.061
Na	0.609	-0.666	-0.173	0.147
K	0.028	-0.450	0.702	-0.054
B	0.091	-0.854	0.132	0.053
TOT. HARD.	0.972	-0.009	0.047	-0.034
Explained Variance (Eigen values)				
Eigen Value	6.821	2.224	1.178	1.028
% Total variance	45.470	14.823	7.856	6.856
Cumulative %	45.470	60.294	68.149	75.006

Table 6.10 Results of Factor Analysis of groundwater chemistry for Delhi

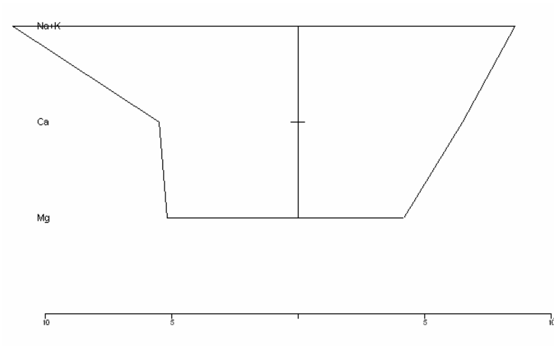
Factor	Eigen value	% Total variance	Variables
Factor 1	6.821	45.470 %	EC, TDS, Cl^-, Total Hardness, Ca^{2+}, Mg^{2+} , Na^+, NO_3^- and SO_4
Factor 2	2.224	14.823 %	B
Factor 3	1.178	7.856 %	K^+ and PO_4^-
Factor 4	1.028	6.856 %	pH, F^- and Total Alkalinity

The factor analysis generated four significant factors (those with Eigen values of 1 or greater). These factors, rotated factor loadings, Eigen values and proportion of variance explained are presented in Tables 6.9. The factors given in Table 6.10 explain 75.006% of the variance in the dataset.

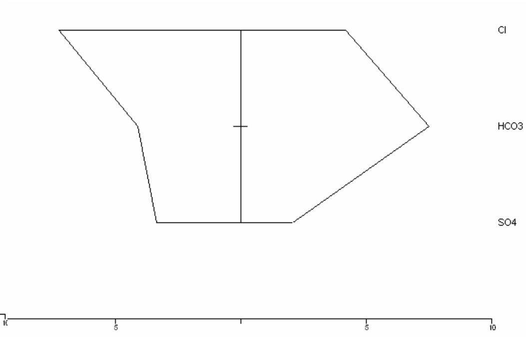
While some part of the first factor (Na, Ca, Mg and Total Hardness) may be attributed to weathering processes in the area. Some other variables (EC, TDS, Cl and SO_4) of the same factor are attributed to precipitation and deposition of dust while NO_3^- is attributed to anthropogenic discharge. Factor 2 (B) may be attributed to anthropogenic causes alone like agricultural runoff. Factor 3 (variable K^+ and PO_4^-) may also be attributed to anthropogenic sources. Factor 4 is solely attributed to the geochemical processes occurring in the area coupled with natural weathering actions

6.4 Graphical Techniques

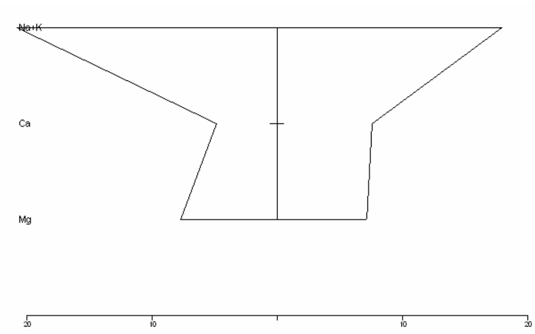
A robust classification scheme for partitioning water chemistry samples into homogeneous groups is an important tool for the characterization of hydrologic systems. Graphical methods, however easy to understand and use, make use of a limited number of parameters, usually a subset of the available data, unlike the statistical methods that can utilize all the available parameters. A number of graphical techniques were applied to analyze the groundwater chemistry in the study area.



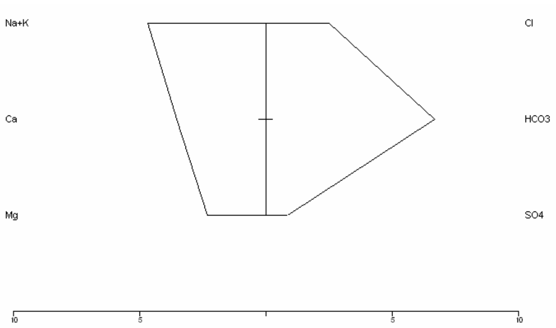
(a) Alipur



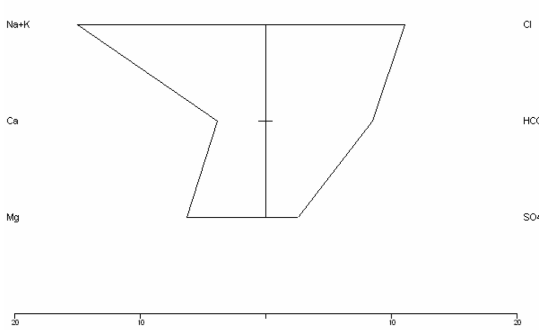
(b) City



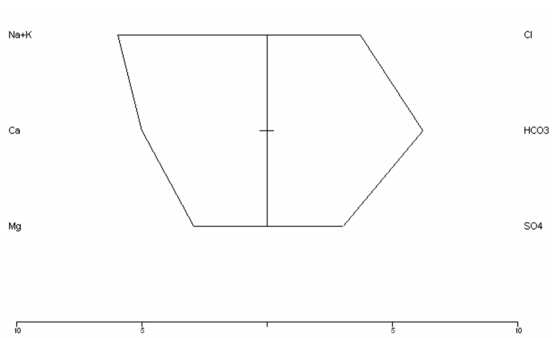
(c) Kanjhawala



(d) Mehrauli

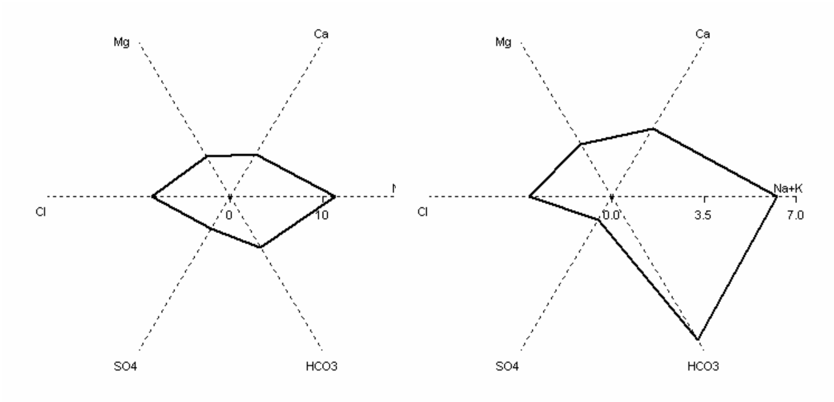


(e) Najafgarh

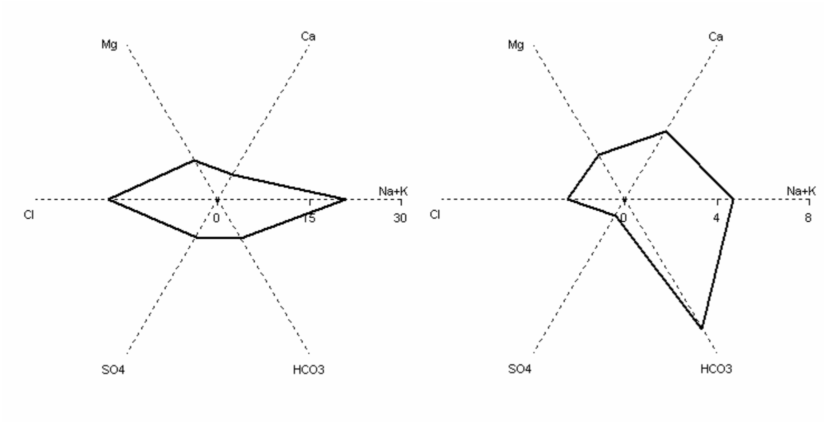


(f) Shahadra

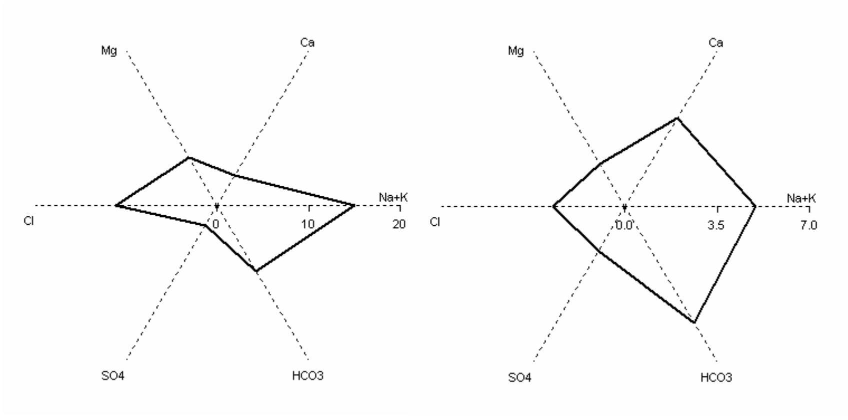
Figure 6.1 Stiff Diagrams for various blocks in the study area



(a) Alipur (b) City



(c) Kanjhawala (d) Mehrauli



(e) Najafgarh (f) Shahadra

Figure 6.2 Radial Plots for various blocks in the study area

Firstly on carefully observing the Stiff Diagram for various blocks we note that all the blocks show quite different water characteristics as indicated by the different shapes of the diagram as seen in Figure 6.1. Radial plots of the groundwater characteristics of various blocks are shown in Figure 6.2 which indicates that the water in City and Mehrauli blocks is quite similar in nature.

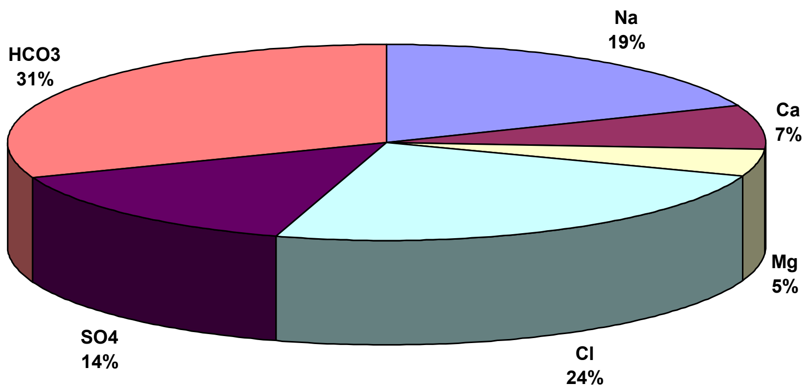


Figure 6.3 Pie Diagram for the study area

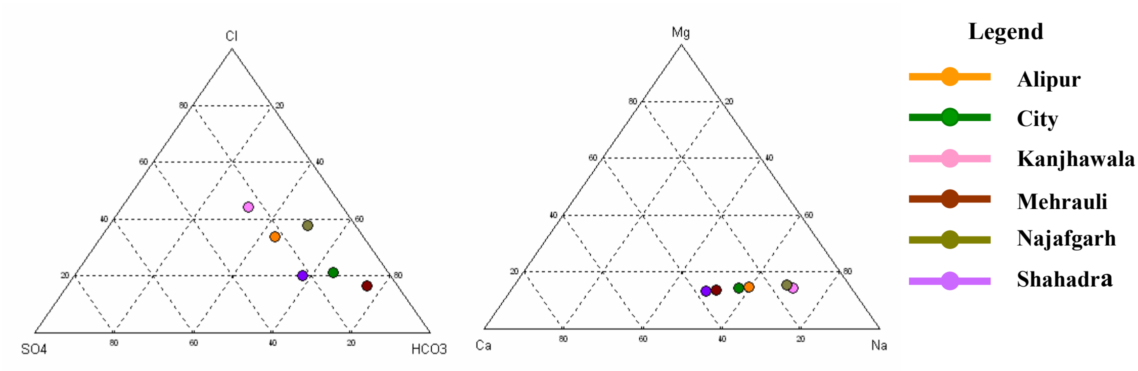


Figure 6.4 Ternary Plot for the study area

Pie diagram of the groundwater chemistry of the study area present the major ion composition in percent milliequivalents per liter as shown in Figure 6.3. As seen from these figures, the Radial, Pie and Stiff methods produce a single diagram for each sample. Clearly, it is not practical to produce and manually sort numerous separate figures (e.g., Stiff diagrams), one for each sample, in order to sort and classify large data sets. The choice of similarity would be based on the evaluation of the analyst, which is highly subjective. Therefore, using purely graphical methods to group the samples is not efficient and can produce biased results. However, these methods are useful for presentation of maps showing hydrochemical facies, and softwares are also available (e.g., RockWorks®, AquaChem®) to automatically and rapidly prepare such maps.

Ternary diagrams were generated (Figure 6.4) using data of groundwater samples of Delhi area, which plot the relative proportion of the three components of some mixture, in this case major anions or cations are plotted. Anions were a mixture of SO_4, Cl and HCO_3, while cations were represented by Ca, Mg and (Na+K). In the following figures Group 1-6 represent the six blocks namely Alipur, City, Kanjhawala, Mehrauli, Najafgarh and Shahadra. As the data is averaged over the block due to restrictions in the software, it may be erroneous to draw conclusions regarding the type of rock weathering.

The Scholler semi-logarithmic diagram (Scholler 1955, 1962 [88]; Figure 6.5) allows the major ions of many samples to be represented on a single graph, in which samples with similar patterns can be easily discriminated. Approximately Similar patterns are observed between water in Kanjhawala, Mehrauli and Shahadra water. Durov's plot an alternative to the Piper plot is also drawn for the study area as shown in Figure 6.6.

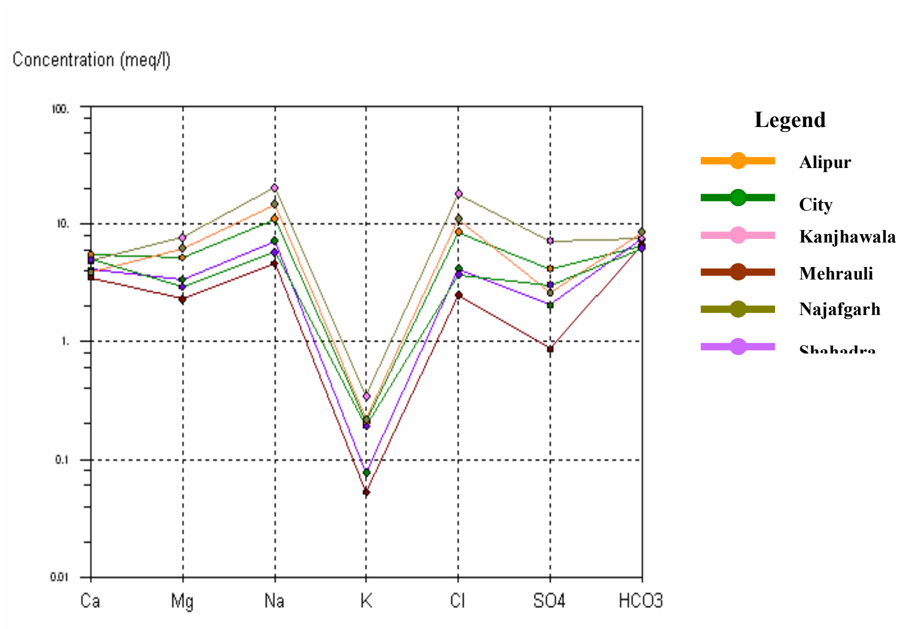


Figure 6.5 Scholler semi-logarithmic diagram for the study area

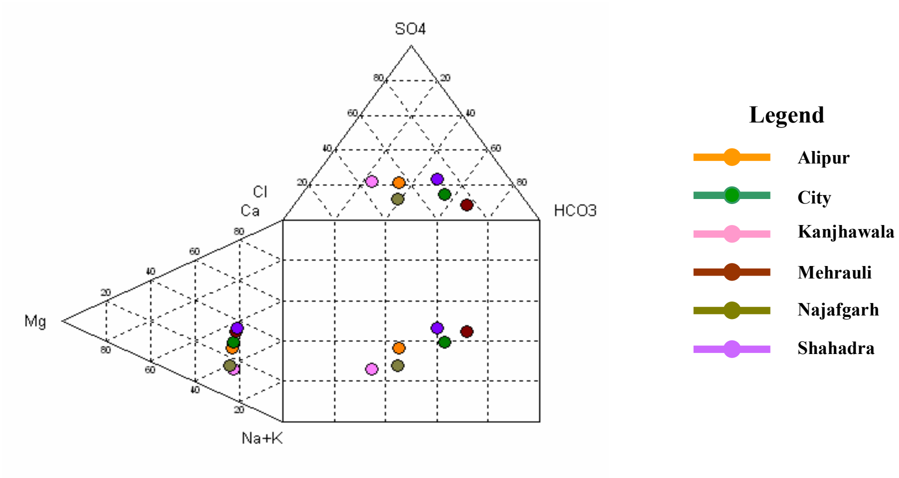


Figure 6.6 Durov's Plot for the study area

6.4.1 Contour Diagram

Contour diagrams of various water quality parameter concentrations were drawn by making use of a georeferenced base map of the sampling points hence the water chemistry data and the latitude-longitude of the sampling point were used to draw contours in the study area using *Golden Surfer® (Version 8.0)* software as shown in Figure 6.7 – Figure 6.11.

6.4.1.1 Chloride

Sand, composed of feldspar, quartz, gypsum, hornblende, calcite and salt particles, on interaction with rainwater dissolve the same producing chloride ion (Waldia, 1978) [108]. The other major sources of Chloride are air-borne dry deposition of particles and anthropogenic sources such as domestic waste water, industrial discharge especially from paper and pulp and leather industry. As it is evident from Figure 6.7, Chloride concentrations were found higher especially in the northern and western part of the study area which is the area covered with sand dunes formed due to the weathering of the ridge material. Previous studies also reported Chloride level high in the same region (P.K. Jha, 2004 [94]). In these regions rainwater may react with the evaporated material to increase Cl, HCO_3 and Na in the topsoil (Subramanian & Saxena, 1983 [55]).

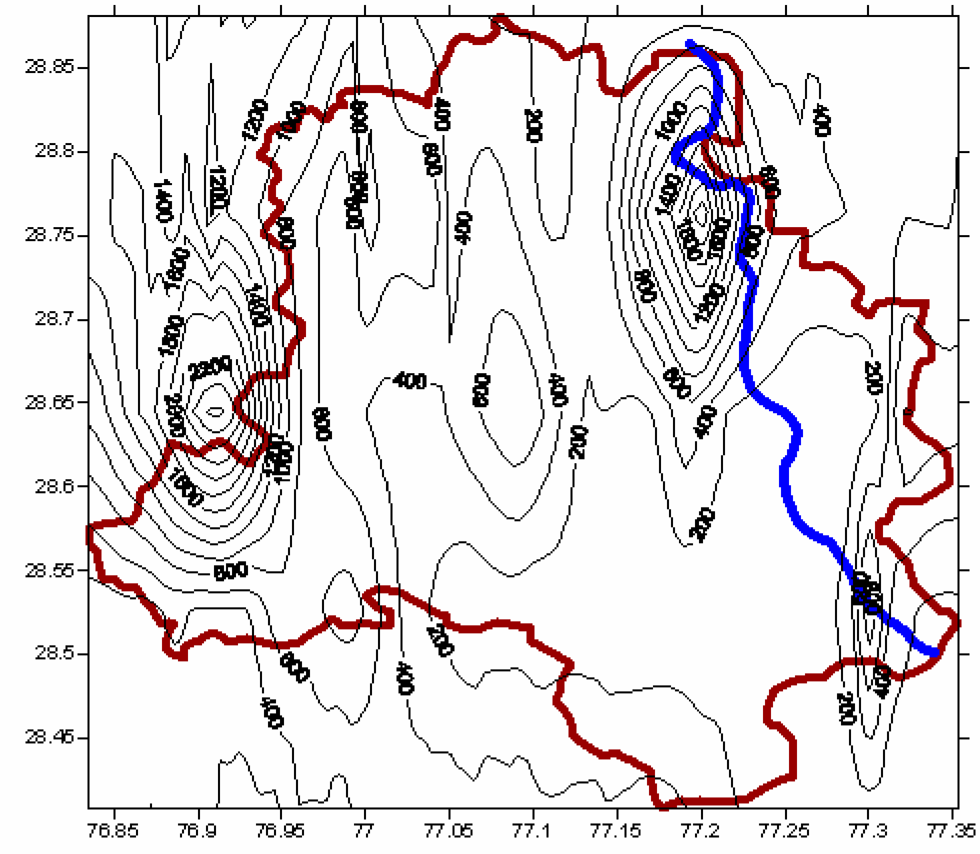


Figure 6.7 Contour diagram of Chloride in Delhi Groundwater

6.4.1.2 Fluoride

Fluoride is present in the soil strata due to natural processes in geological formations in the form of fluorspar, fluorapatite, amphiboles such as hornblende, trimolite and mica. Weathering of alkali, silicates, igneous and sedimentary rocks especially shale contributes major portion of fluorides in natural water (Neely, 1979 [95]). In addition to natural sources, considerable amount of fluorides may be contributed due to anthropogenic activities. Fluoride salts are commonly used in steel, aluminum, bricks and tiles industries. Fluoride containing insecticides, herbicides and also phosphatic fertilizers (containing fluoride as an impurity) may contribute through agricultural runoff.

The accumulation of fluoride in soil eventually results in its leaching due to percolating water pressure, thereby increasing its concentration. A high concentration in drinking water increases dental carries and may cause crippling skeletal fluorosis.

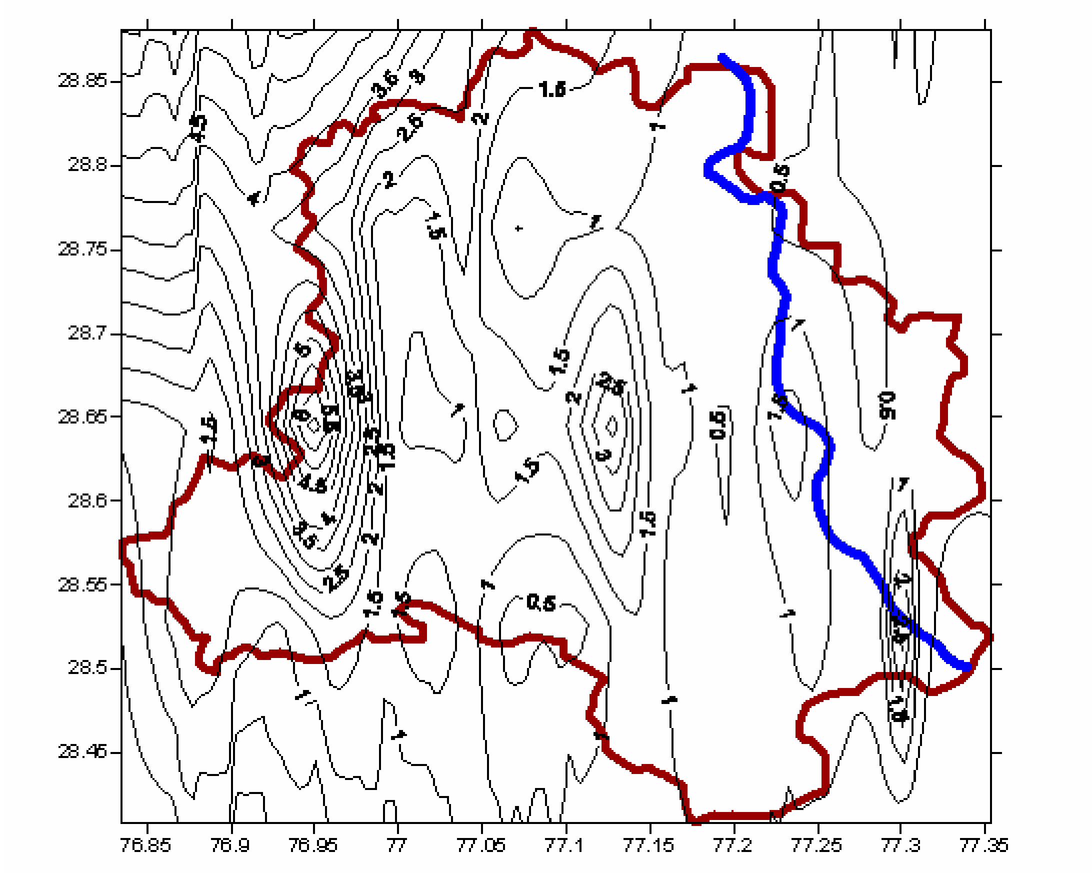


Figure 6.8 Contour diagram of Fluoride in Delhi Groundwater

As evident from Figure 6.8 fluoride concentrations in large number of water samples is higher than the permissible level which may be attributed to the presence of Fluoride bearing minerals in the study area aquifers. Comparatively high fluoride concentrations are observed in the western and central part of the study area. Another reason for such high concentrations especially in the western part of the study area is due to brick kilns which use fluoride salts for manufacturing bricks and agro-chemicals containing fluoride salts. The fluoride concentration in groundwater has been found to be within limits for most parts of NCT-Delhi however it exceeded limits for 27.4% of the total number of samples. Western and central parts of Najafgarh and north and south-east parts of Kanjhawala have been identified as areas having high fluoride concentration in ground water.

6.4.1.3 Nitrate

Nitrogen is known to be an important plant nutrient, thus it is used often as a fertilizer and is found in high concentrations in agricultural runoff. The major sources of nitrates are geological deposits, atmospheric precipitation, landfills, industrial wastes, sewage, animal wastes and agricultural sources. Out of the total samples analyzed, 18.8% of the samples exceeded even the permissible limit (100 mg/L). High levels of nitrate accelerate eutrophication of surface waters and when present in drinking water cause methaemoglobinaemia (Blue baby syndrome), gastric cancer and adversely affects the central nervous system and cardiovascular system. Nitrates consumed over a long period of time may result in formation of nitroso-amino compounds which may be carcinogenic.

Higher values of nitrate in Southern part of the study area may be attributed to leachates from agricultural fields such as Chattarpur area containing high amount of nitrates; leachates from landfill such as Bawana may be the reason of higher values in the western part of the study area. It can be seen that Kanjhawala, Najafgarh, and City Blocks are the most affected by nitrate pollution. Najafgarh drain in Delhi receives untreated domestic and industrial wastewater through various industrial outlets, which may be directly linked to the presence of high amount of nitrates in the groundwater of the area. There are a number of small dairies and farms in and around Delhi. These do not have provisions for disposal of cattle waste; as a result it keeps on accumulating and contributes to the nitrate increase in ground water. The nitrate pollution in Delhi may be attributed to, percolation of waste from unlined drains carrying sewage; untreated discharge of waste water into river Yamuna; land fills; waste water stagnation at JJ clusters, unsanitary conditions; and agricultural sources.

6.4.1.3 Dissolved Solids & Hardness

Natural waters never occur in the form of pure water, the composition of solids present, mainly depends upon the nature of the bed rocks and the soil developed from it. Total Dissolved Solids and Hardness are found to be very high in the study area (figure 6.10 & 6.11). The salt content of the bodies of water often increases by the developmental activities in the catchment area. The drainage of irrigation water also leaches out significant quantities of salts from the soil that finally return to the river as high salinity groundwater or can contaminate the groundwater. Much of the concern regarding hardness is for the problems in the domestic and industrial use rather than for its health effects. Hard water is unsuitable for textile, food and beer industry, it also produces heat retarding scales on equipments.

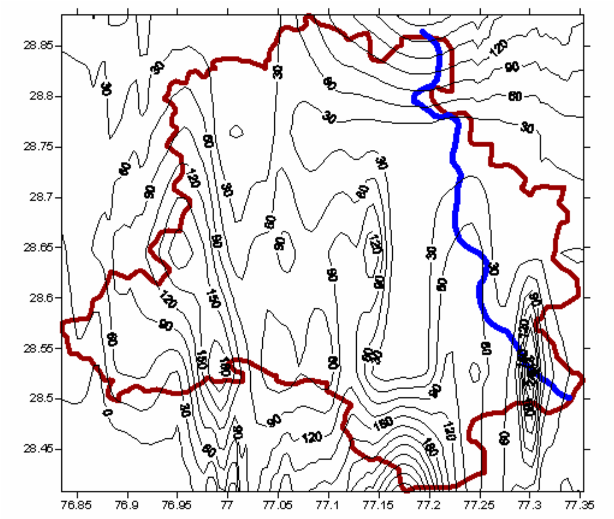


Figure 6.9 Contour diagram of Nitrate in Delhi Groundwater

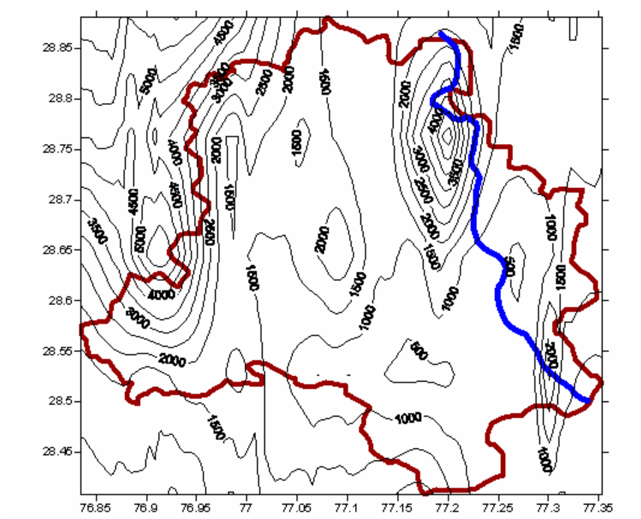


Figure 6.10 Contour diagram of TDS in Delhi Groundwater

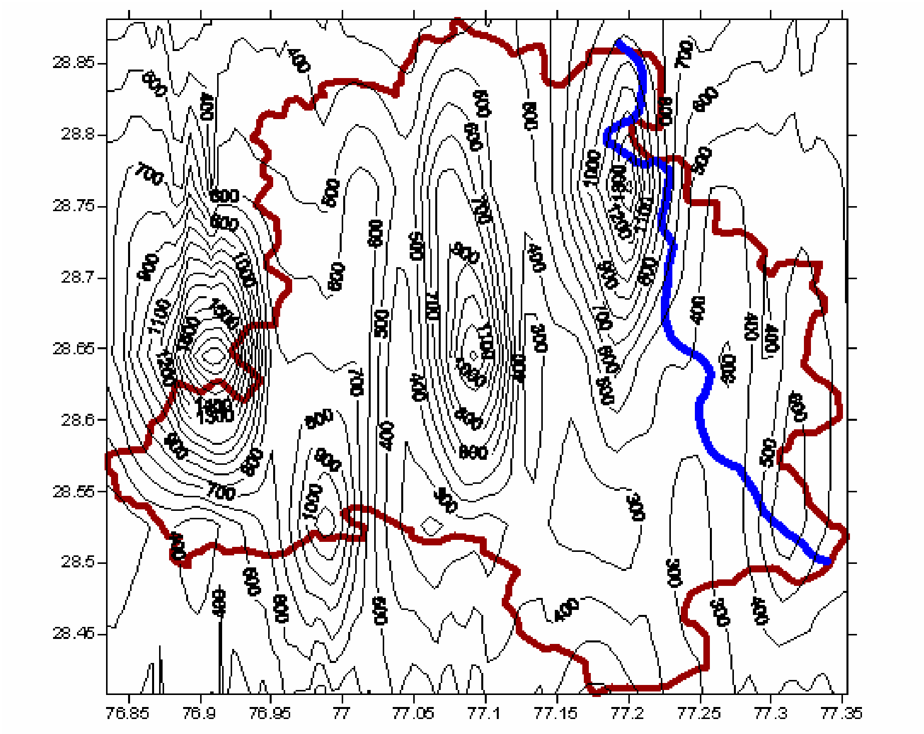


Figure 6.11 Contour diagram of Hardness in Delhi Groundwater

6.4.2 Piper Trilinear Classification

Piper classification (1944) [31] is an effective tool in segregating analysis data with respect to sources of the dissolved constituents in groundwater, modification in the character of water as it passes through an area, and related geochemical problems. For the piper trilinear diagram, groundwater is treated substantially as though it contained three cations constituents (Mg, Na+K, Ca) and three anion constituents (Cl, SO_4 and HCO_3). The diagram is useful in presenting graphically a group of analysis on the same plot. The three trilinear plotting will show the essential chemical character of groundwater according to the relative concentration of its constituents. Using this diagram water can be classified into four different hydro chemical facies. The Piper trilinear diagram for the six sets of blocks is shown in Figure 6.12 - Figure 6.17 and the results are summarized in the subsequent text.

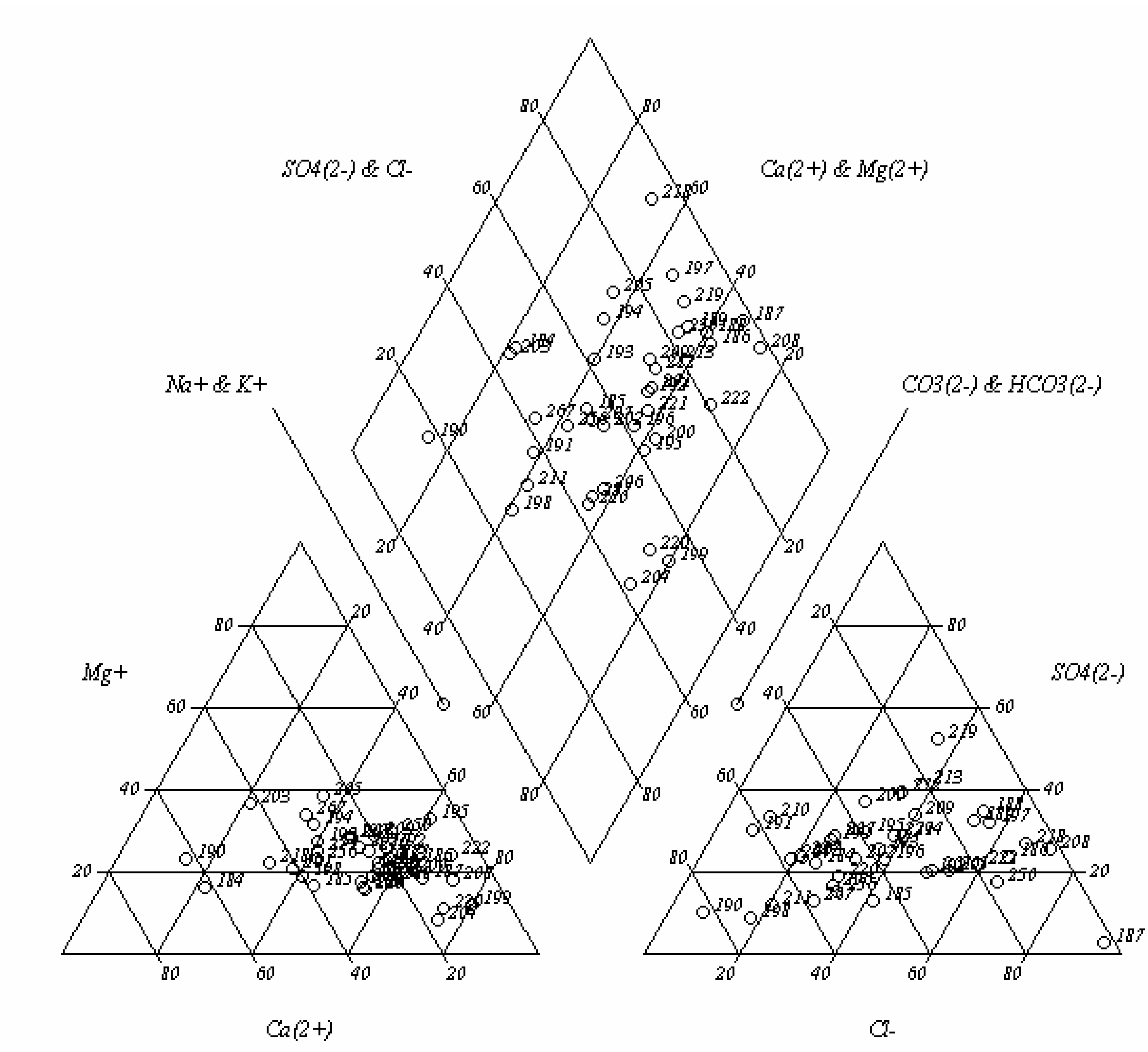


Figure 6.12 Trilinear plot for Alipur Block

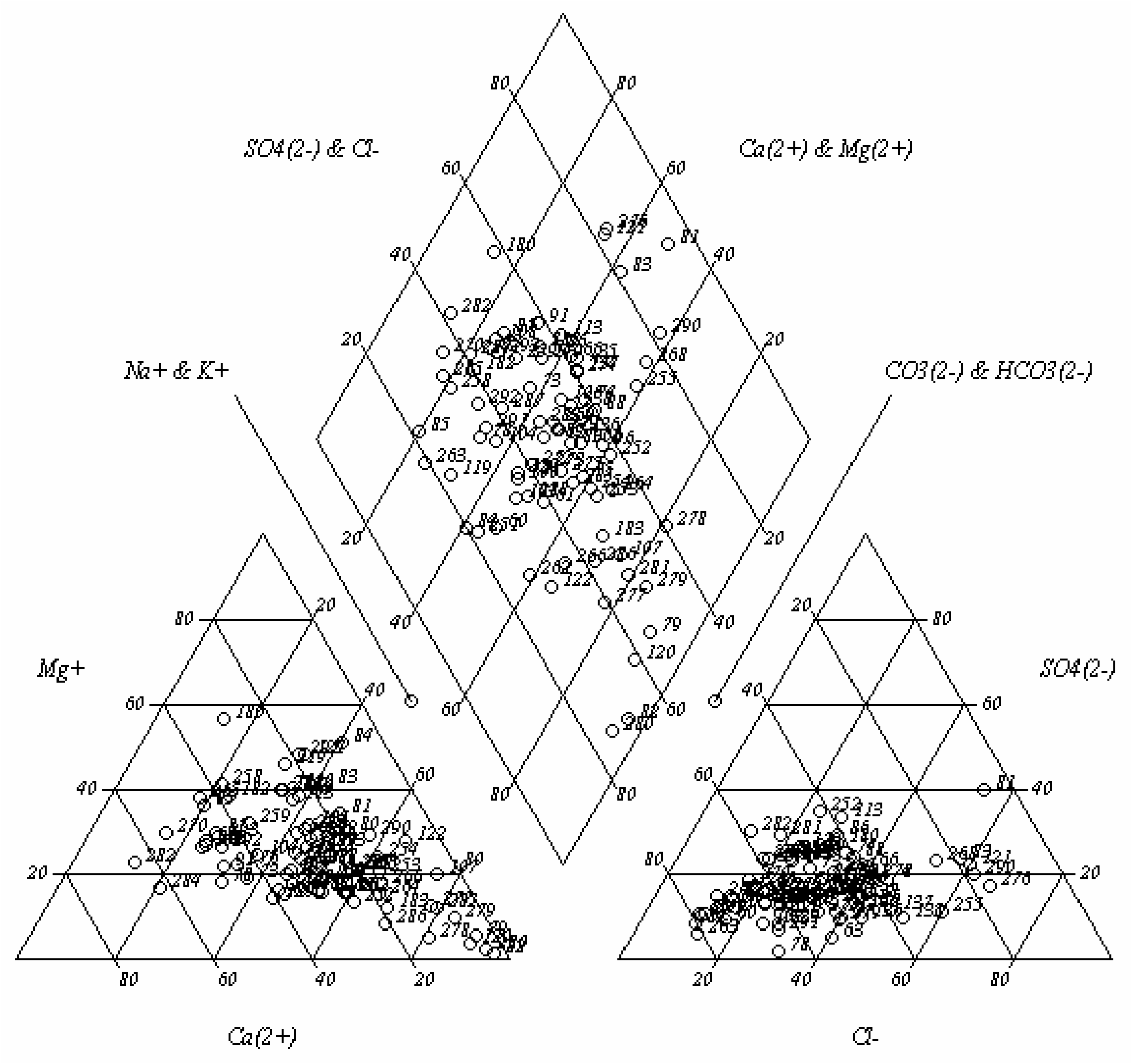


Figure 6.13 Trilinear plot for City Block

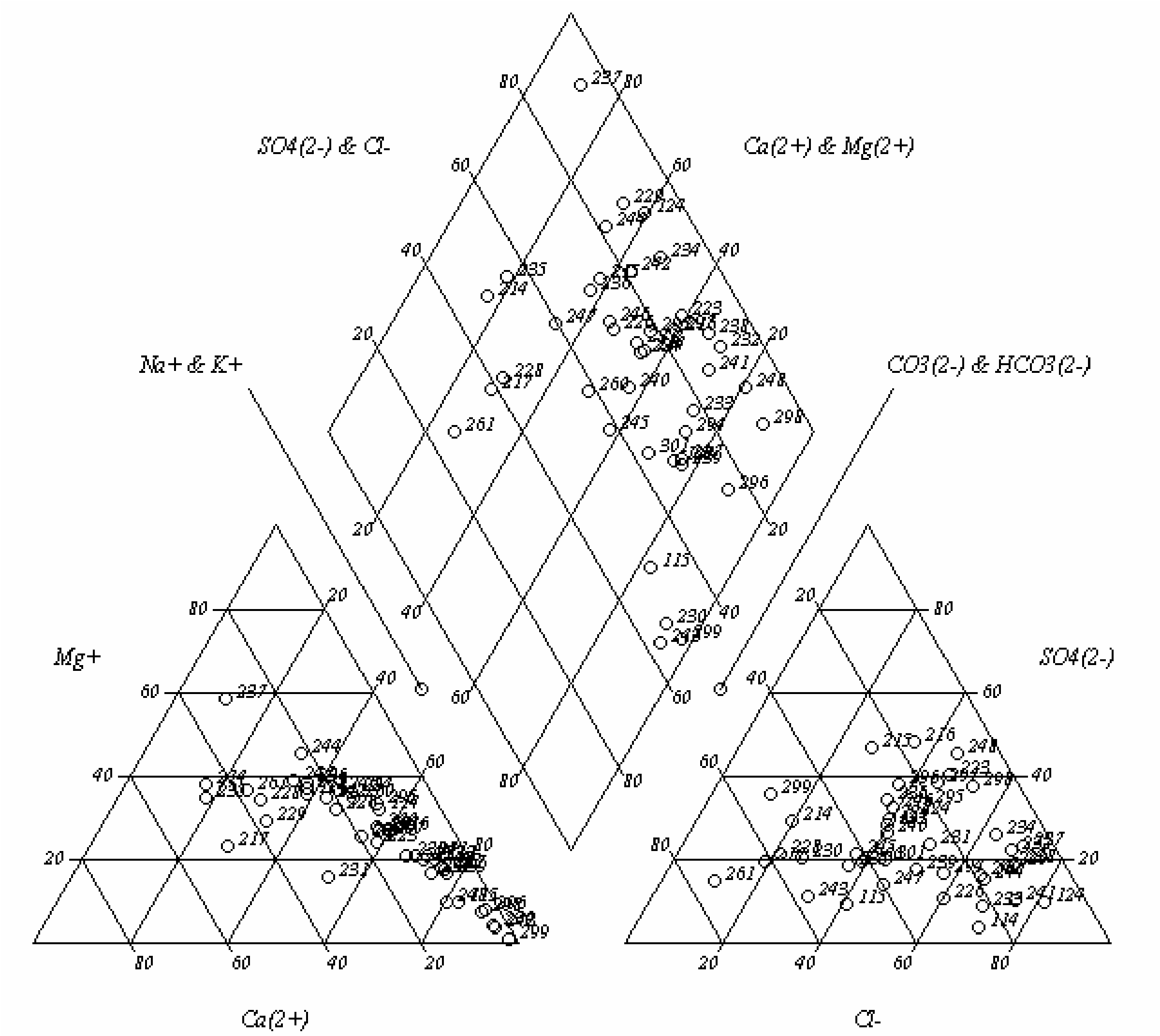


Figure 6.14 Trilinear plot for Kanjhawala Block

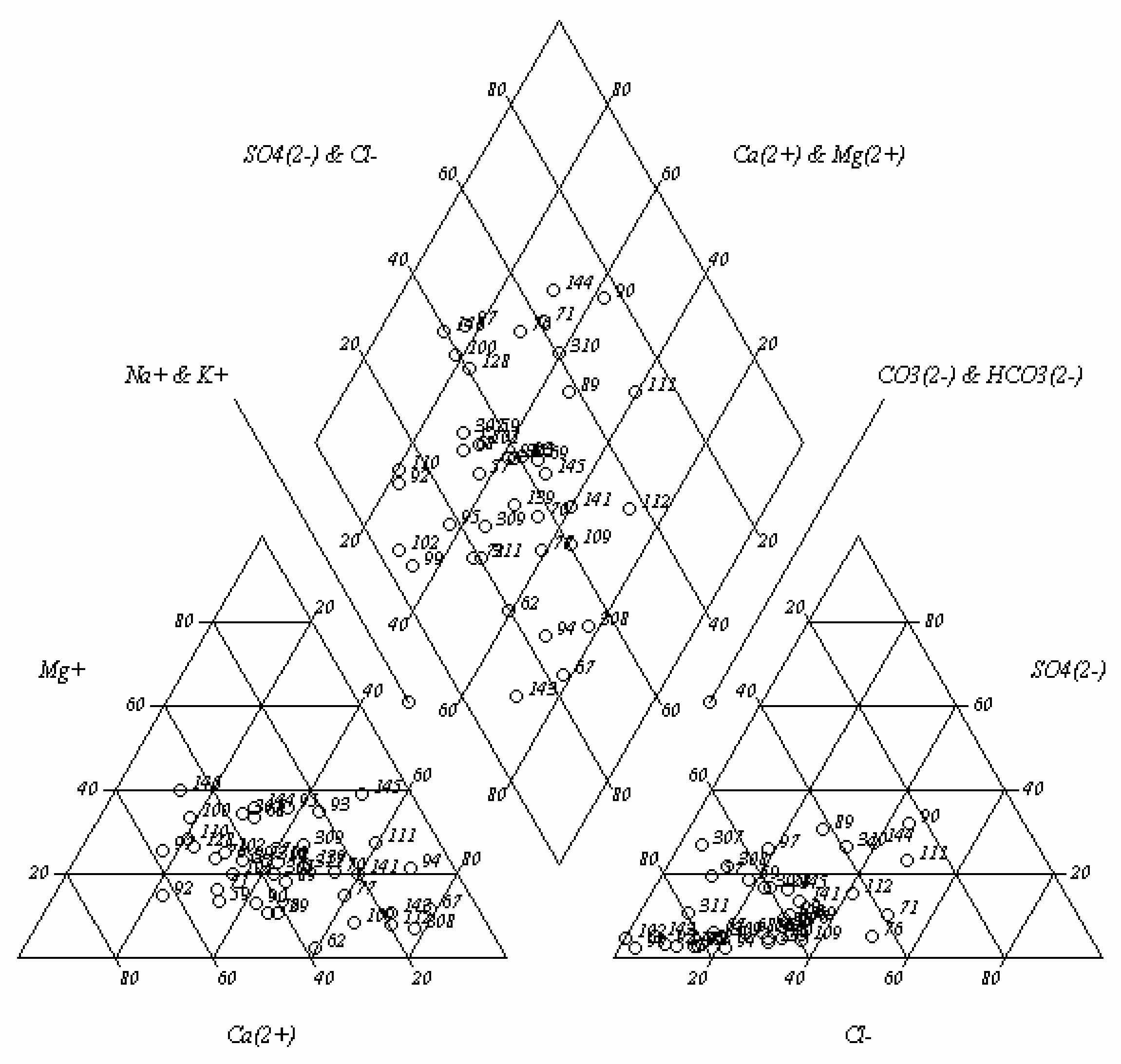


Figure 6.15 Trilinear plot for Mehrauli Block

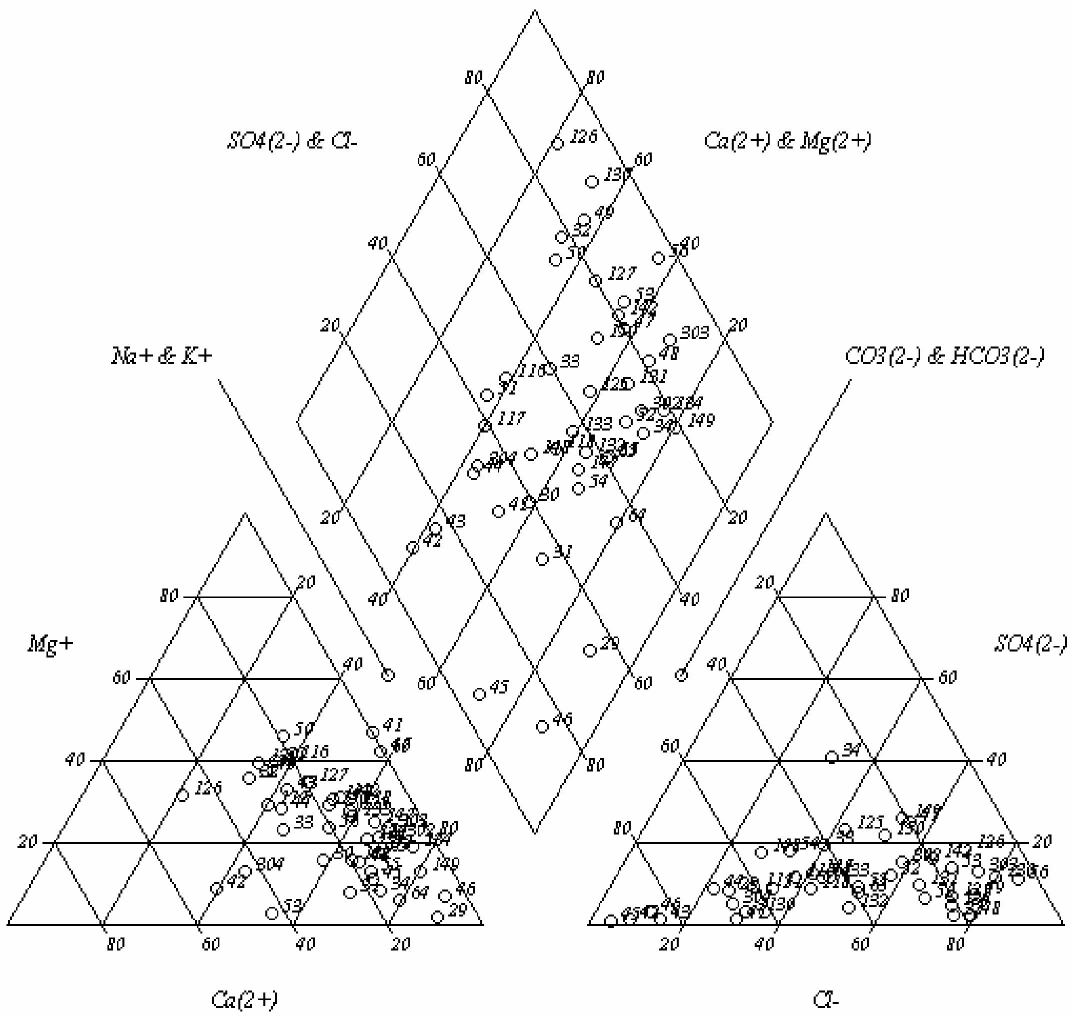


Figure 6.16 Trilinear plot for Najafgarh Block

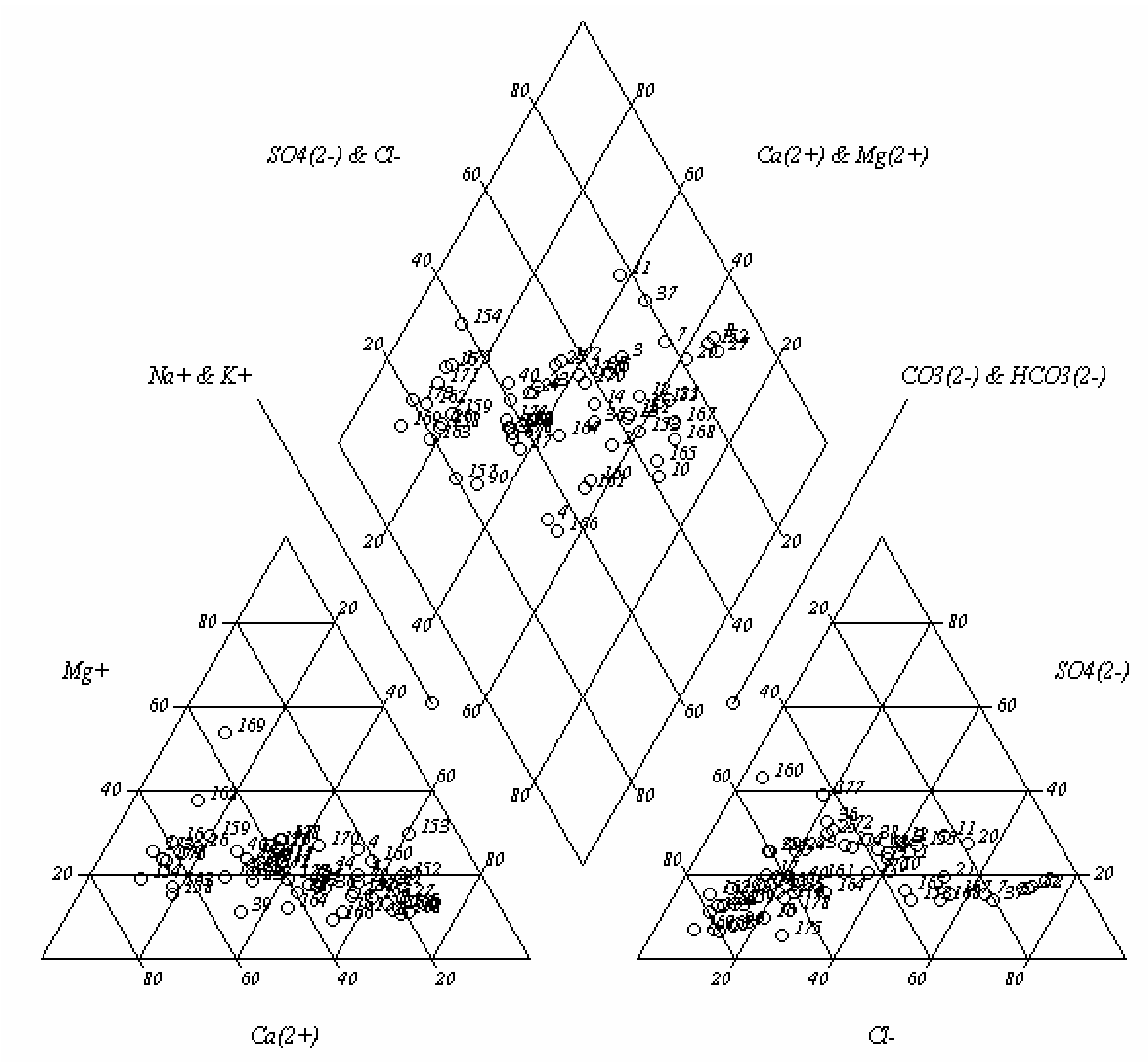


Figure 6.17 Trilinear plot for Shahadra Block

The plot of chemical analysis data(figure 6.12) of ground water from Alipur block indicates that the water is predominantly of mixed facies such as Na-Ca-HCO_3-Cl, Na-Mg-HCO_3-Cl, Ca-Mg-HCO_3-SO_4, Na-Ca-Cl- HCO_3, Na-Mg-HCO_3-SO_4, Na-SO_4-HCO_3, Na-HCO_3-Cl, Ca-Na-HCO_3, Na-SO_4-Cl indicating dissolution of calcium and magnesium type minerals at a few places. Eventually, when exchange reactions are completed ground water is of Na-Cl or Na-HCO_3 types.

In city block (figure 6.13) mixed type hydrochemical facies are dominant. Mixed characteristics comprising Na-Ca-HCO_3, Ca-Na-HCO_3, Ca-Mg-HCO_3, Mg-Na-HCO_3, Na-Ca-HCO_3-Cl, Ca-Mg-HCO_3-Cl and Na-Mg-Cl-SO_4 exist due to Base Exchange reaction or presence of saline water body.

Ground water in Kanjhawala block (figure 6.14) is mostly of mixed type with different chemical composition at shallow and deeper depths. At deeper depths, the water is of mixed type but with predominance of Na-cations. In some parts of this block, the ground water is of mixed type with composition like Na-Mg-HCO_3, Na-Ca-SO_4-HCO_3, Mg-Ca-Cl- HCO_3 type. The predominance of mixed character of various compositions in this area is due to the effect of soil amendments by chemicals and mixing of ground water with different salt contents.

In Mehrauli block (figure 6.15), the hydrochemical facies of ground water is mostly of mixed type such as Na-Ca-HCO_3, Na-Mg-HCO_3, Ca-Na-HCO_3 and Ca-Mg-HCO_3 and the facies are of Na-HCO_3 type, where exchange reactions are completed.

The hydrochemical facies in Najafgarh (figure 6.16) at all depths are generally of Na-CI type particularly in south-west part. The ground water is of high salinity, and primarily alkaline. At Samlkha road, Bijwasan, Banauli, Palamgaon and PapanKalan Nawada majra area, the ground water is of Na-HCO3 type indicating extension effect of Base Exchange reactions in this area. In north-west, north-east and central part of the block, the hydrochemical facies of ground water are of mixed type i.e. Na-Ca-CIHCO3 Na-Ca-Mg-HCO3, Ca-Mg-HCO3-CI, Mg-Na-HCO3, Na-ca-Mg-HCO3, Na-Mg-CI, Na-SO4-CI, Mg-Na-CI, NaHCO3-CI and Na-CI-HCO3. These facies are characterized by medium to high saline ground water.

The hydrochemical characteristics of shallow ground water in north east and south east parts of Shahadra (figure 6.17) are generally calcium bicarbonate type. The ground water facies are of NaCl type along with the eastern border. The remaining parts of Shahadra block depict increase in mineralization and mixed type of ground water having Na-Ca-Cl-HCO_3, Ca-Na-Cl-SO_4, Na-Ca-HCO_3, Na-Mg-HCO_3-Cl, Na-Cl-HCO_3 and Ca-Na-HCO_3 type facies. The predominance of Na cations, indicate that apart from common source of NaCl, there may be some additional sources of sodium, calcium and bicarbonates.

6.5 Groundwater Quality Index

In the formation of water quality index, the importance of various water quality parameters depends on the intended use of water. In the present case study we calculate the index with reference to the suitability of water for human consumption. The numerical value of water quality index implies that the water under consideration is fit for human consumption if its WQI < 100, and unfit if WQI> 100. Moreover, the larger the value of WQI, the more polluted the water concerned. The block wise average values for water quality index are given in Table 6.11 and Figure 6.18.

Table 6.11 Water Quality Index for groundwater of Delhi

Block	Water Quality Index	Block	Water Quality Index
Alipur	58.94	**Mehrauli**	47
City	81.85	**Najafgarh**	133.32
Kanjhawala	173.28	**Shahadra**	44.14
Average		**89.755**	

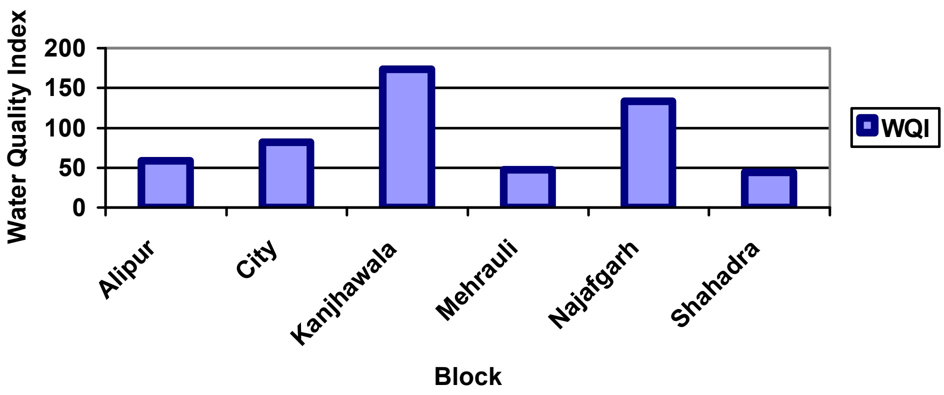


Figure 6.18 Water Quality Index trend for Delhi

A close study of Table 6.11 and Figure 6.18 reveals some interesting and important information about the quality of the groundwater in Delhi. The overall quality of the groundwater of Delhi is reflected in the average value of WQI, which is found to be 89.755. Thus it may be concluded that the water quality is precariously close to the unsafe limit. On observing block wise it is seen that the groundwater quality is good in Shahadra, and Mehrauli blocks while it is pretty fair in Alipur Block. It is precarious in the City block, while it becomes unsafe for human consumption in Najafgarh Block with the worst quality being in the Kanjhawala Block. The overall distribution is shown in Figure 6.19 in the form of a contour diagram.

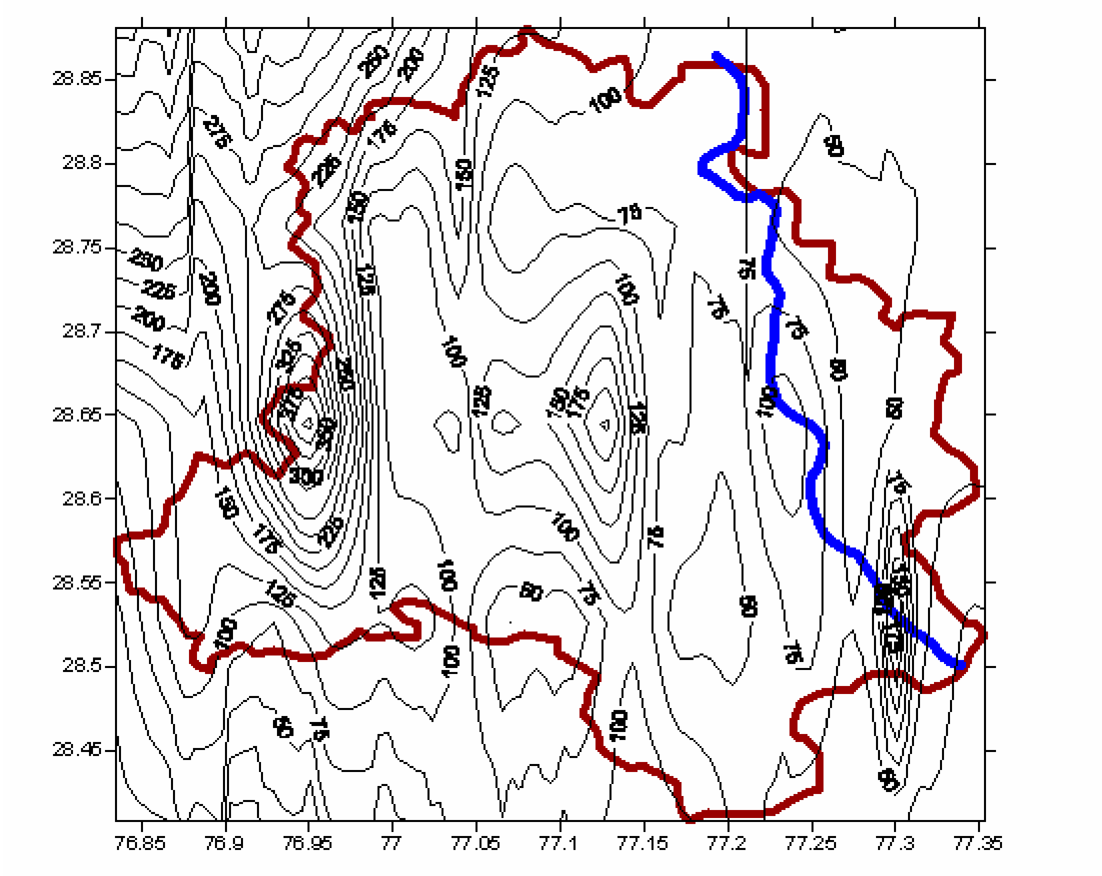


Figure 6.19 Contour diagram of Water Quality Index for Delhi Groundwater

The high values of water quality index in Najafgarh may be attributed to the presence of Najafgarh drain and also on agricultural runoff in the area which has a strong bearing on the groundwater. In Mehrauli the groundwater table is quite low thus there are less chances of intrusion of pollutants from land thus the groundwater there is in a good state. Contrarily in Shahadra block the high water table leads to more dilution of pollutants, if any, thus the subsequent groundwater quality is quite good. In Kanjhawala the reason for the worst quality of water may be that the area is dominated by saline water aquifer while the fresh water is of limited depth only. Also the recharge in this area is comparatively less thereby decreasing chances of natural dilution. In Alipur the occurrence of fresh water in alluvium formation is up to a depth of 30m to 60m thereby giving good quality of water.

A Graphic User Interface module was also developed in Visual Basic® (Version 6.0) for interactive and easy Water quality index calculations, the screen shot of which is given in figure 6.20.

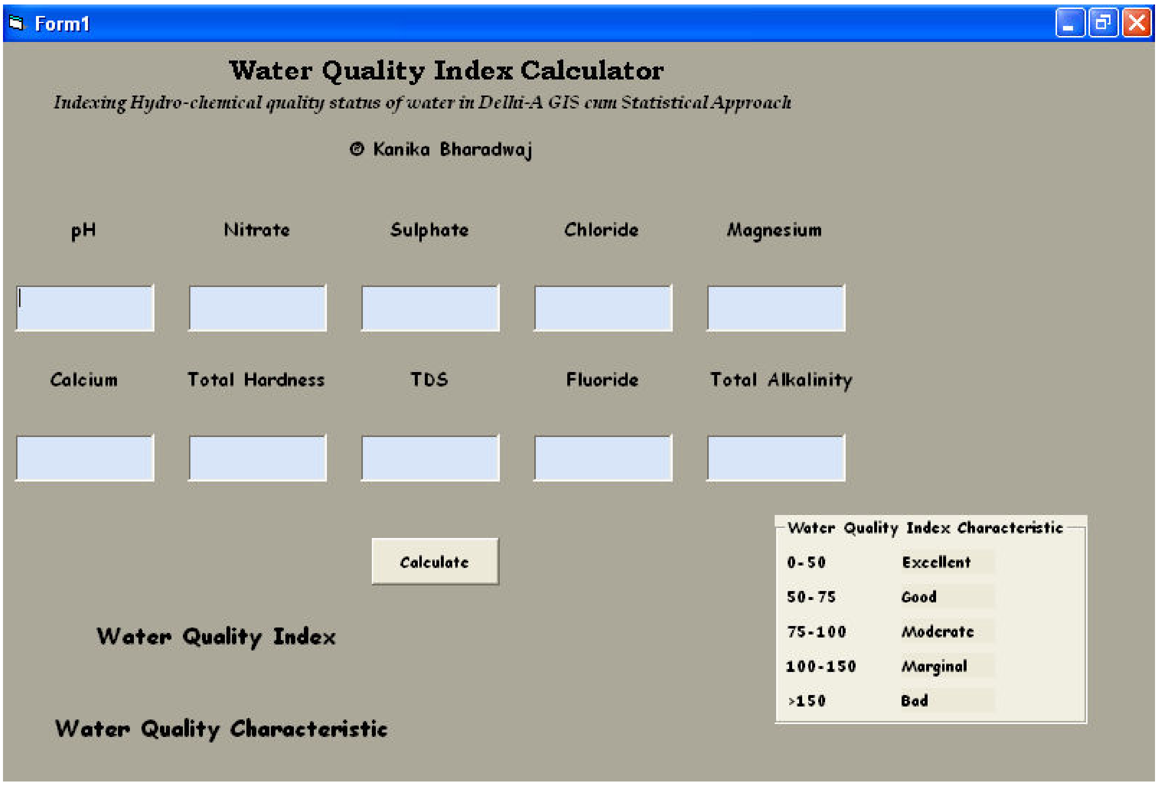


Figure 6.20 Water Quality Index calculator

6.6 Surface water quality index

In order to calculate the water quality of Yamuna River flowing through Delhi, U.S. National Sanitary Foundation index has been put to use. It is based on the Delphi approach and summarizes results from a total of nine different measurements when complete. The stations considered for index measurement are Hathnikund, Kalanaur, Sonepat, Palla and Nizamuddin Bridge while the variables considered for calculation are pH, Dissolved Oxygen, Turbidity, Fecal Coliforms, Biochemical Oxygen Demand, Total Phosphates, Nitrates and Total Suspended Solids. The results are summarized in Table 6.7 and the water quality index trend is shown in Figure 6.21.

Table 6.7 Average NSF Water Quality Index for Yamuna (1995-1998)

Station	NSF WQI	NSF Category
Hathnikund	78.30	Good
Kalanaur	64.71	Medium
Sonepat	65.92	Medium
Palla	73.45	Good
Nizamuddin Bridge	47.01	Bad

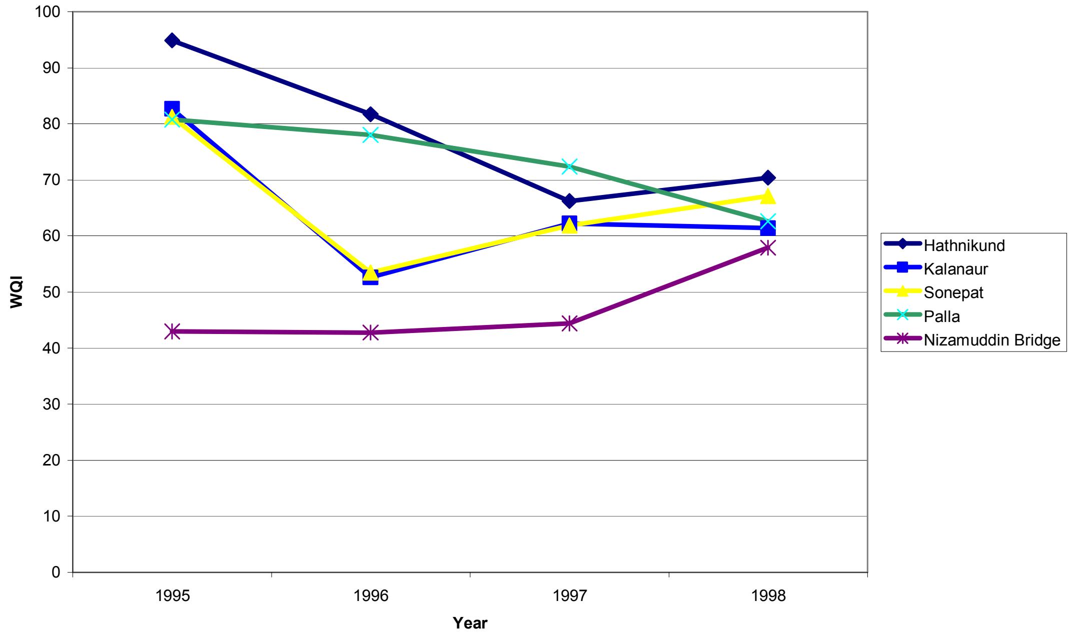


Figure 6.21 NSF Water Quality Index trend for Yamuna

As it is evident from the Figure 6.21 the water quality for Nizamuddin Bridge station is the worst, which is quite obvious as quality here is affected by the discharge of heavy municipal and industrial pollution load emanating from Delhi. Even though Delhi constitutes only 2% of the total catchment of the Yamuna basin, yet the area contributes about 80% of the pollution load. The major source of the pollution in the river, to the extent of about 80%, is the discharge of treated and untreated waste water through the 19 major drains (Annexure III) which flow into the river.

6.7 GIS mapping

In order to investigate whether water quality variables and/or water quality index has any correlation with the geology in the study area and also the groundwater levels, Geographic Information System was put to use. For this purpose four thematic maps containing various spatial information like administrative boundaries, geology and water table levels were prepared. They contained various attribute data including the location, groundwater quality characteristics etc. of the sampling point in question. The digitized map for sampling point locations is shown in Figure 6.21. On querying the GIS regarding the areal distribution of various water quality parameters the results as shown in Figure 6.22 – Figure 6.26 are obtained. The areal distribution of WQI > 150 is shown in Figure 6.27.

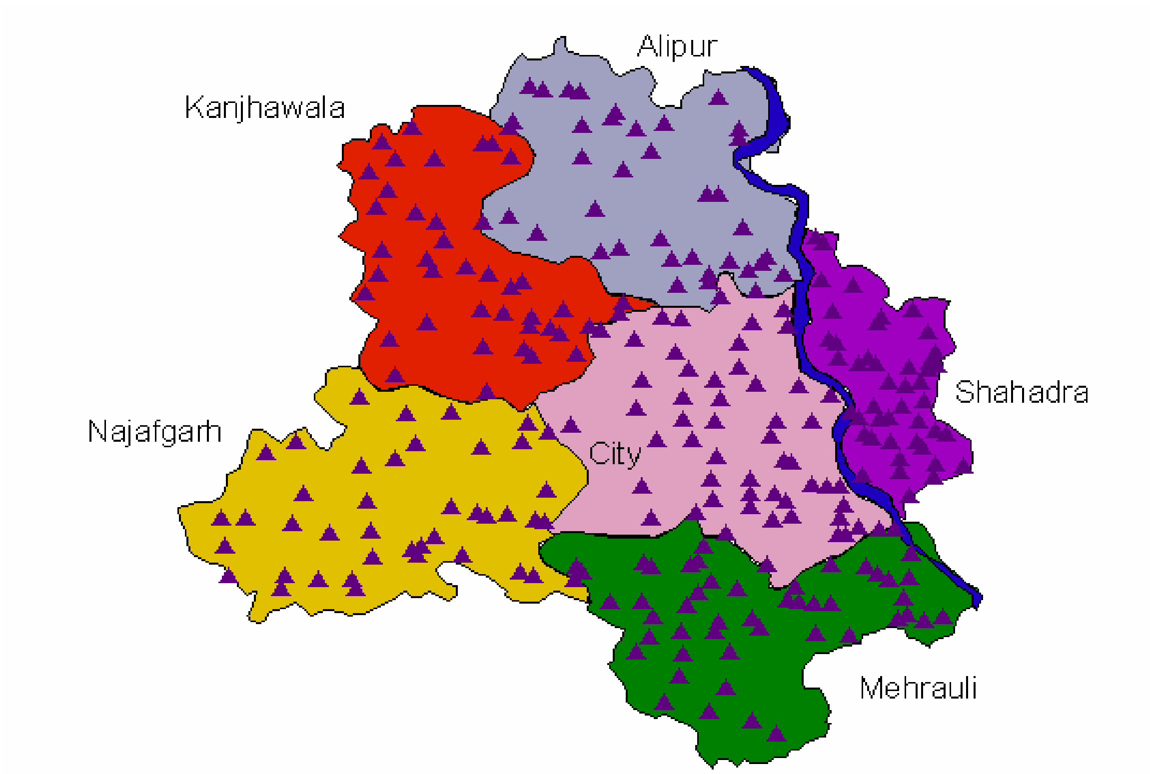


Figure 6.22 Digitized map of Sampling point locations

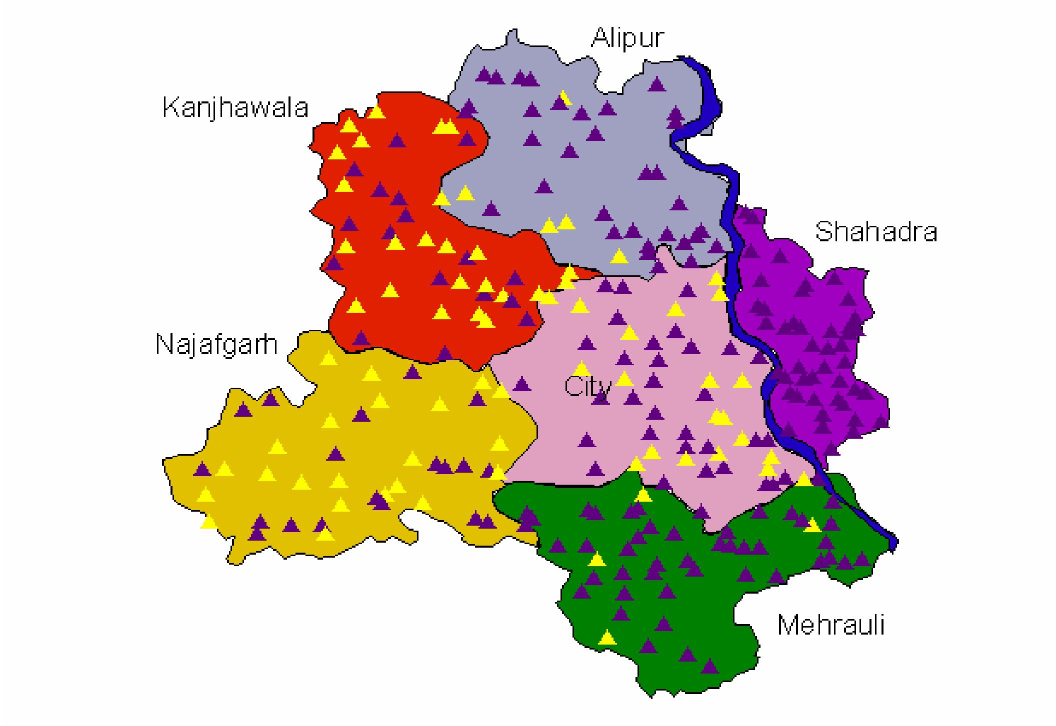


Figure 6.23 Sampling point locations with F>1.5mg/l

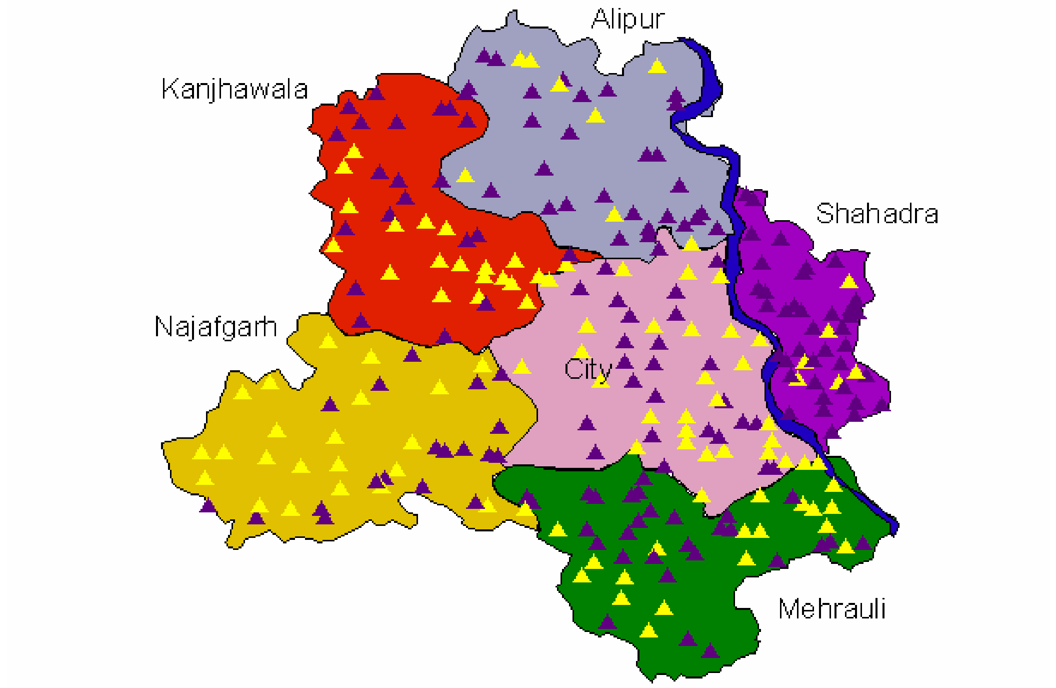


Figure 6.24 Sampling point locations with NO_3 > 45 mg/l

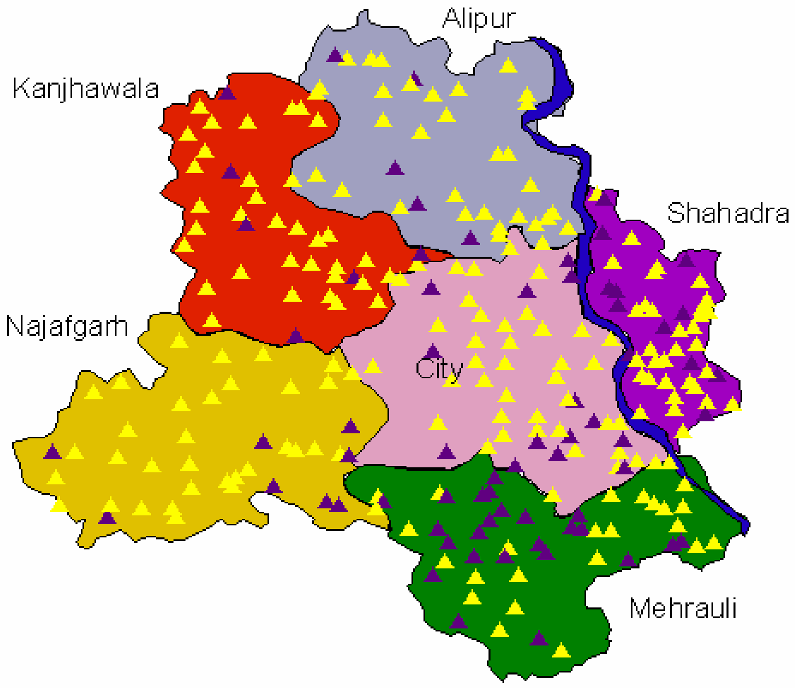


Figure 6.25 Sampling point locations with Hardness > 300 mg/l

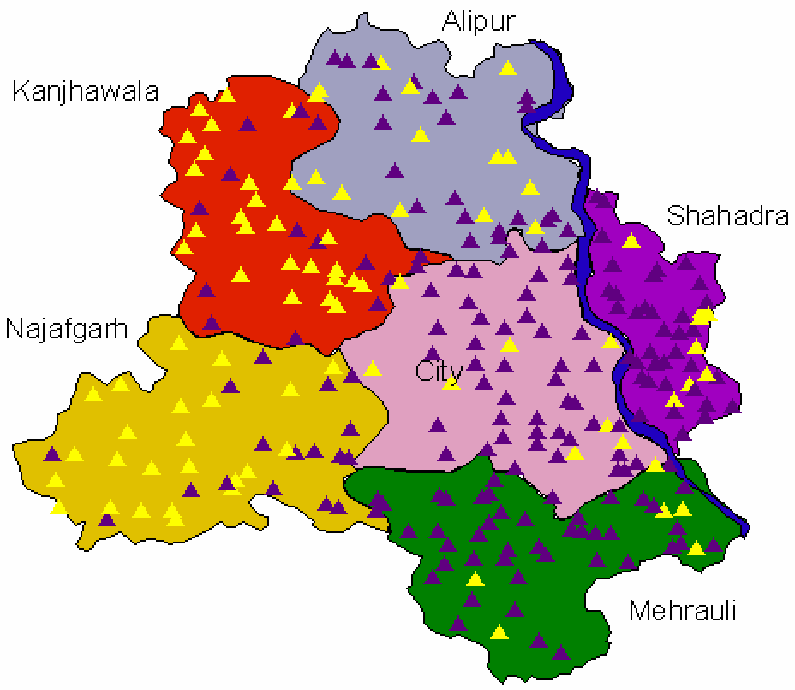


Figure 6.26 Sampling point locations with TDS> 1500 mg/l

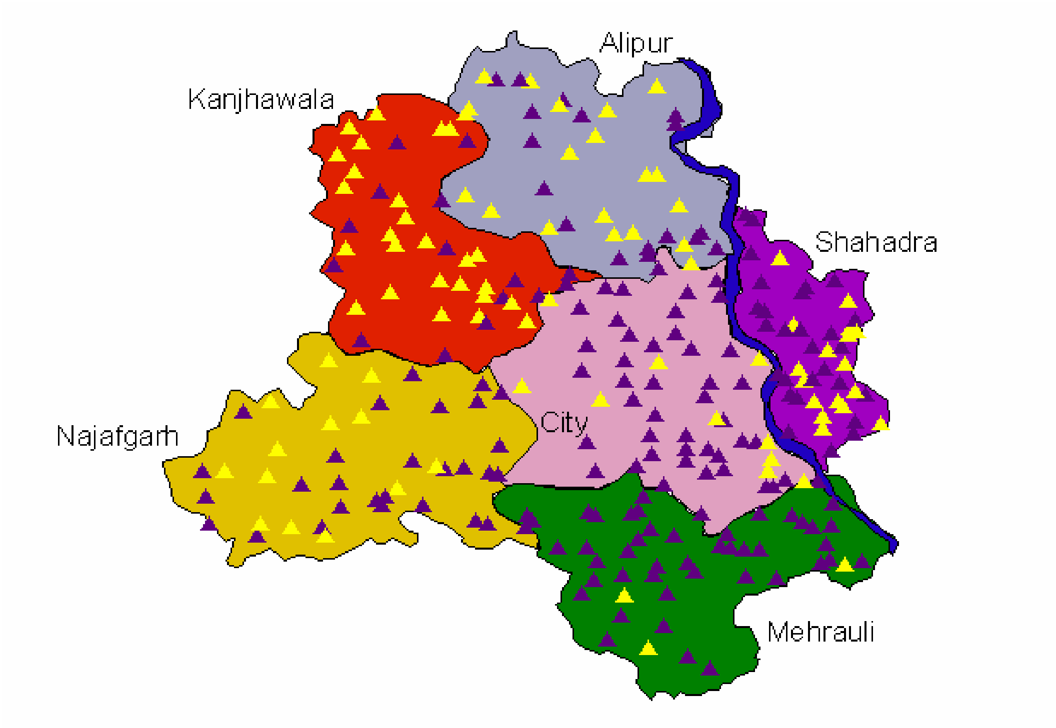


Figure 6.27 Sampling point locations with Sulphate> 200 mg/l

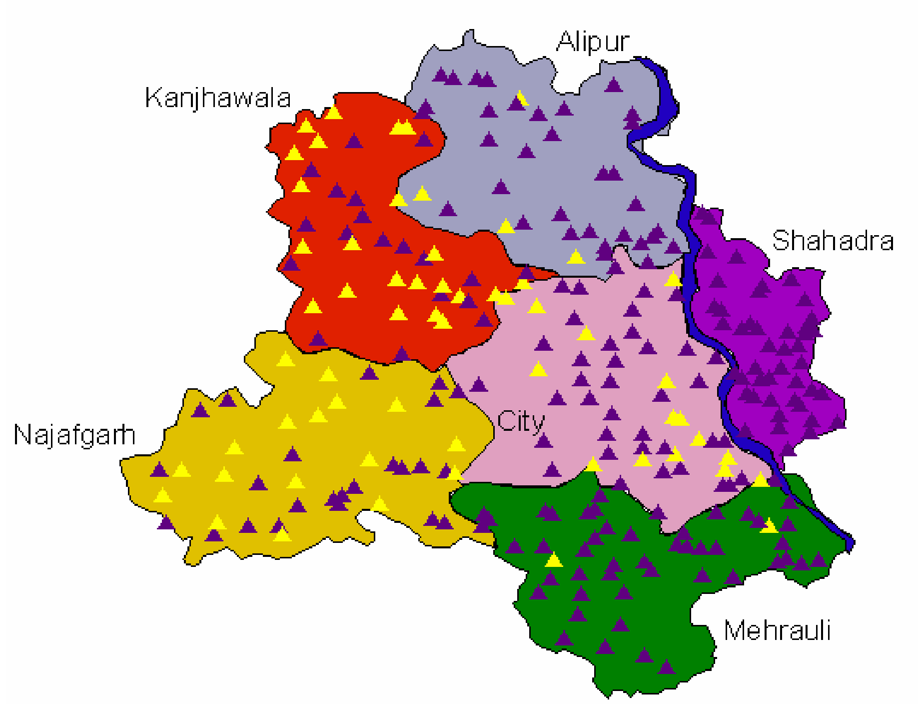


Figure 6.28 Sampling point locations with WQI >150

Validation of the groundwater quality index developed may be done using a groundwater vulnerability map developed by CGWB, as it is evident from Figure 6.28, the sampling points with WQI >150 mostly fall in the vulnerable category of the vulnerability map.

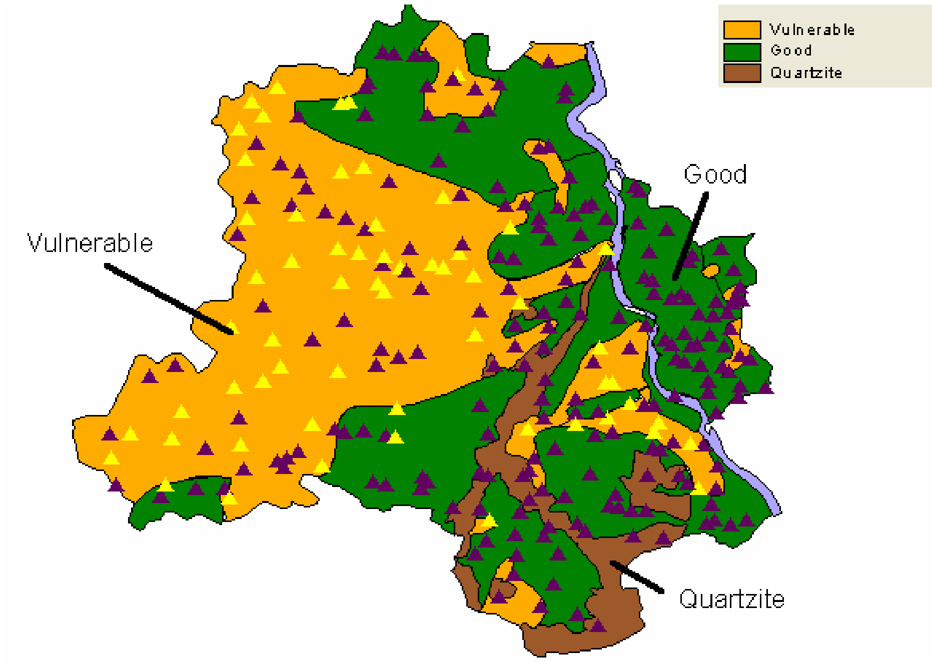


Figure 6.29 Validation of results with CGWB Vulnerability map

In order to make the dissemination of information regarding water quality to the general public easier a webpage (figure 6.29) was also made to interactively display water quality related data at the click of a mouse at different locations around Delhi.

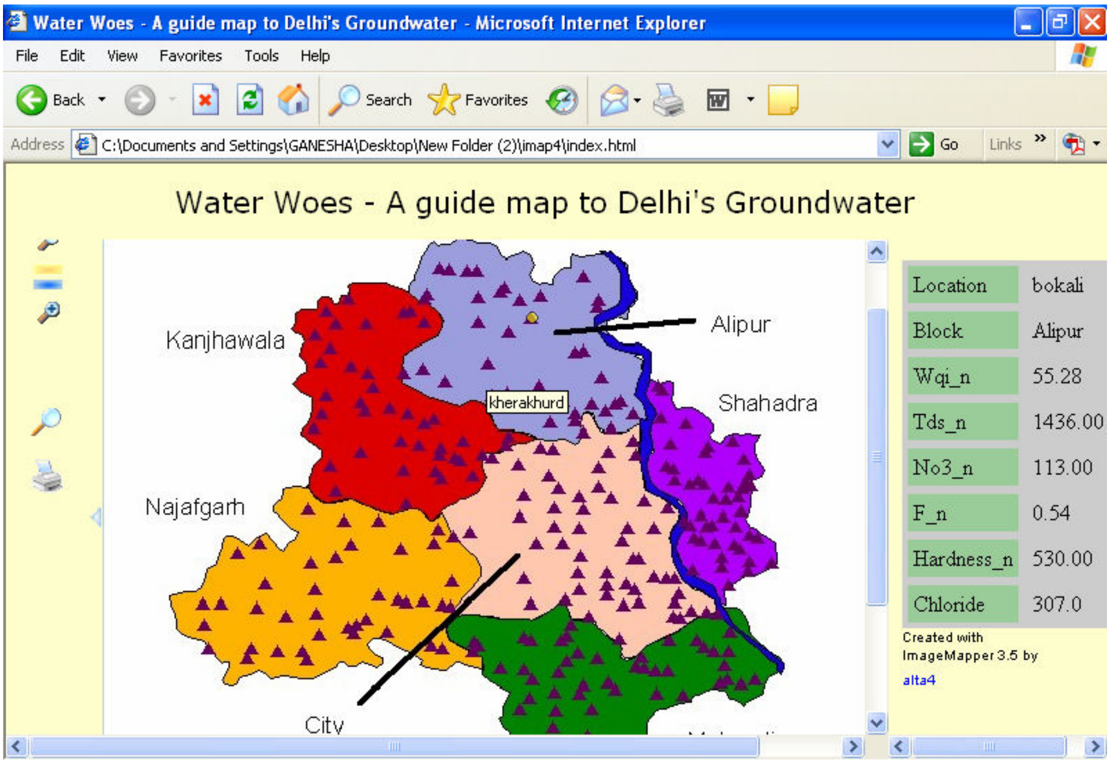


Figure 6.29 Interactive webpage to display water quality information

6.7.1 Correlation of water quality with geology

In our case study comparatively high fluoride concentrations are observed in the western and central part of the study area. On observing the thematic map (figure 6.30) of geology with that of excessive fluoride concentrations (>1.5) it is seen that an abundance of fluoride is present in the Alluvial Plains in the study area thus natural weathering processes may be one of the causes for the fluorides. The major sources of Chloride contain both natural and anthropogenic ones. In our case chloride concentrations were found higher especially in the northern and western part of the study area one of the main causes of which is that the north-western area of Delhi is covered with sand dunes formed due to the weathering of the ridge material (Figure 6.31).

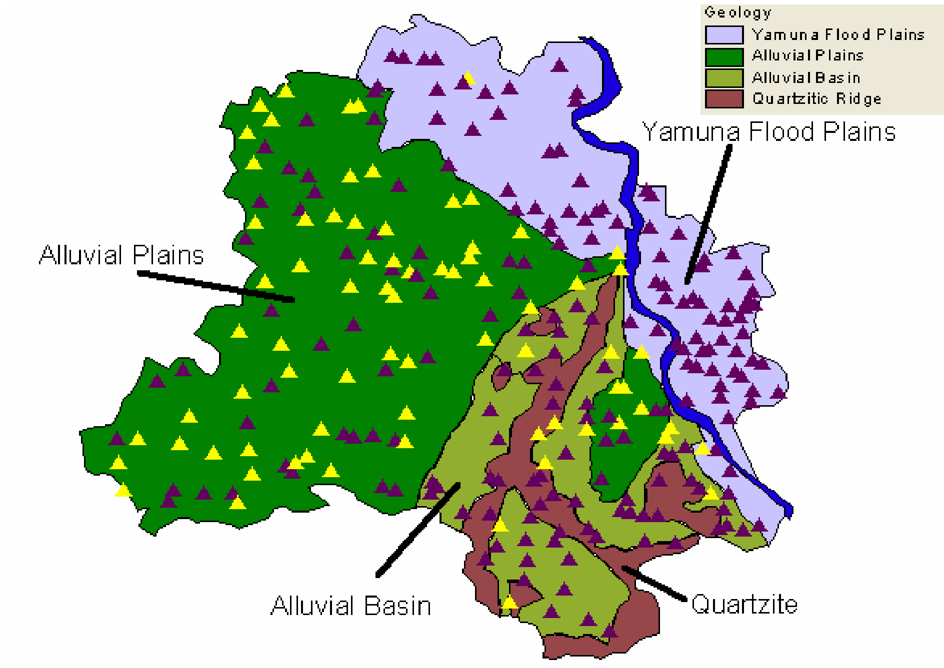


Figure 6.30 Correlation of Geology with Fluoride> 1.5 mg/l

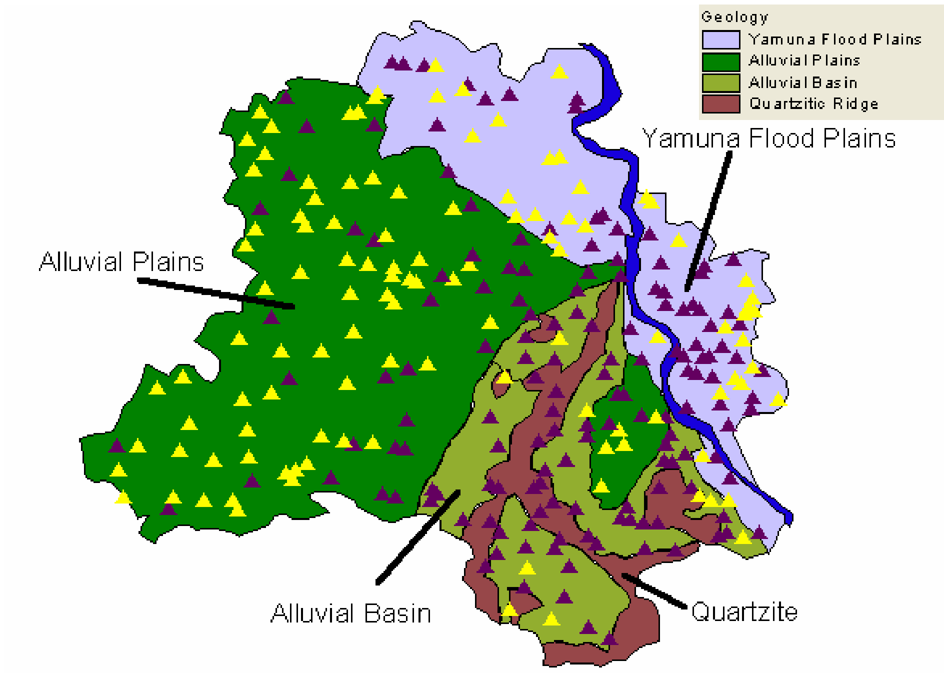


Figure 6.31 Correlation of Geology with Chloride > 250 mg/l

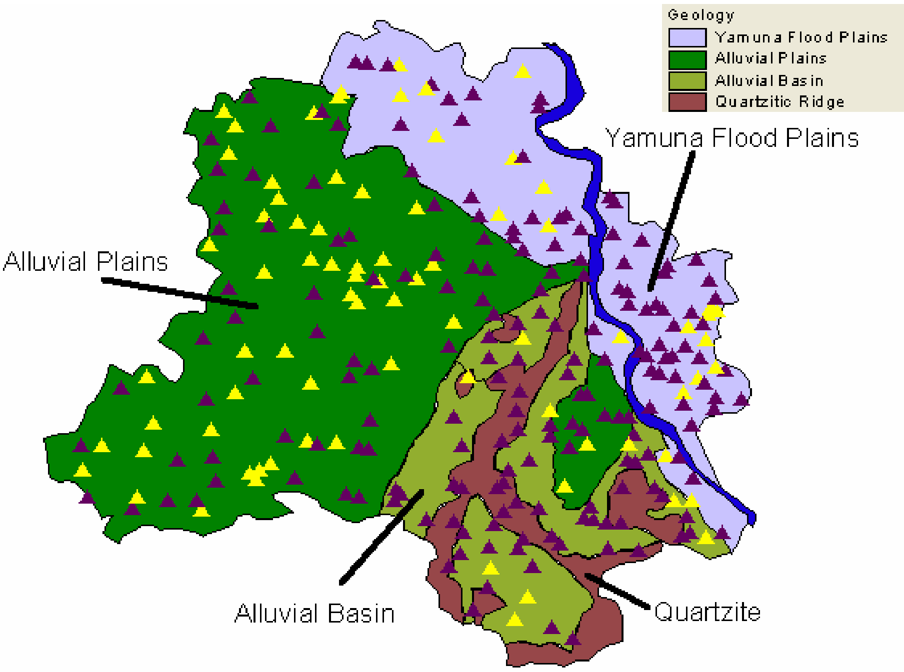


Figure 6.32 Correlation of Geology with Hardness >600 mg/l

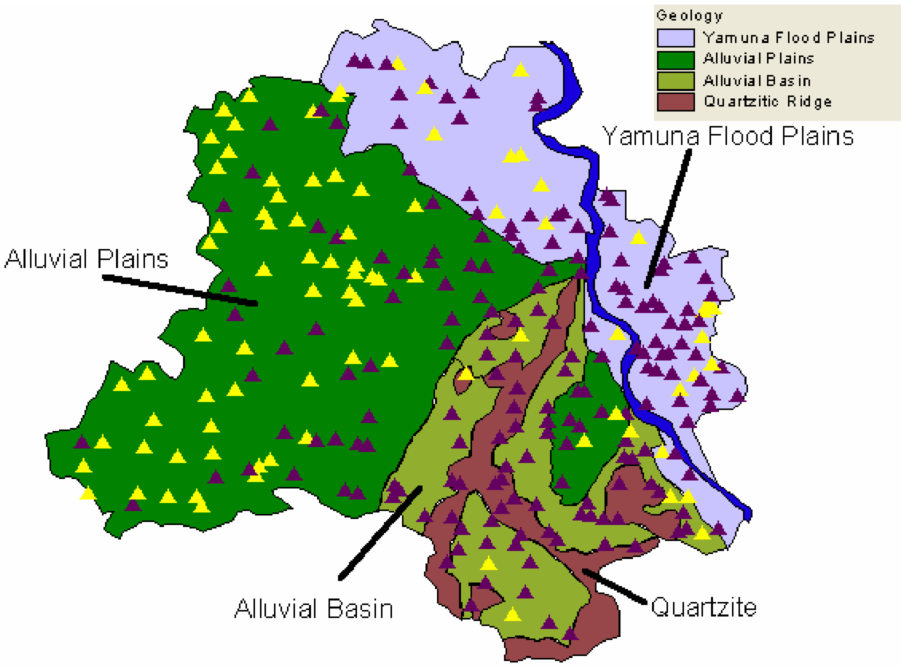


Figure 6.33 Correlation of Geology with TDS > 1500 mg/l

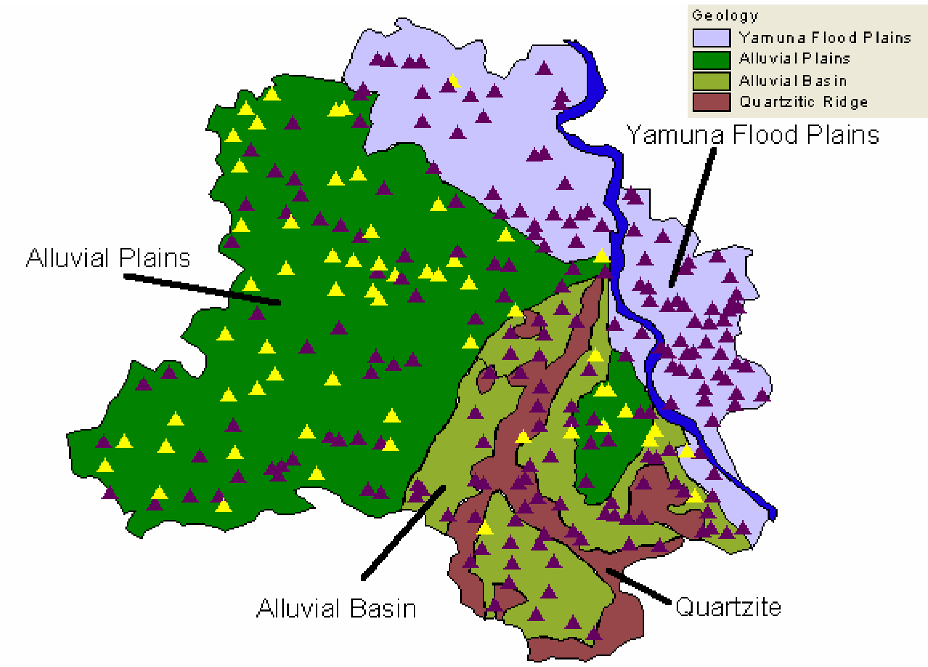


Figure 6.34 Correlation of Geology with WQI >150

As it is evident from figure 6.32 and figure 6.33 high values of hardness and Total dissolved solids are basically distributed in the alluvial plain region of the study area, although some aberrations are also found to exist in the Yamuna flood plain area on the eastern side of the study area. Even the sampling locations with water quality index in the "Bad" category seem to be located in the same area as it is evident from figure 6.34.

6.6.2 Correlation of water quality with groundwater table

As it is evident from figure 6.35 the sampling locations with fluoride levels in excess of 1.5 mg/l seem to be concentrated in the region with groundwater levels greater than 5 m, a similar interpretation may be drawn for the case of water quality index values greater than 150, as evident from figure 6.36.

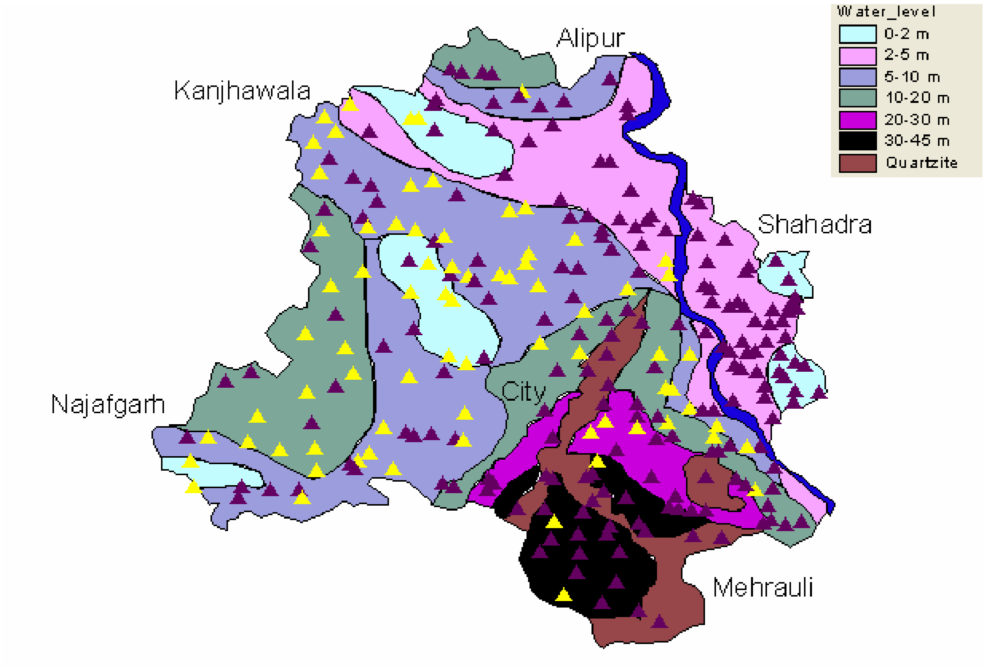


Figure 6.35 Correlation of water table depth with Fluoride>1.5 mg/l

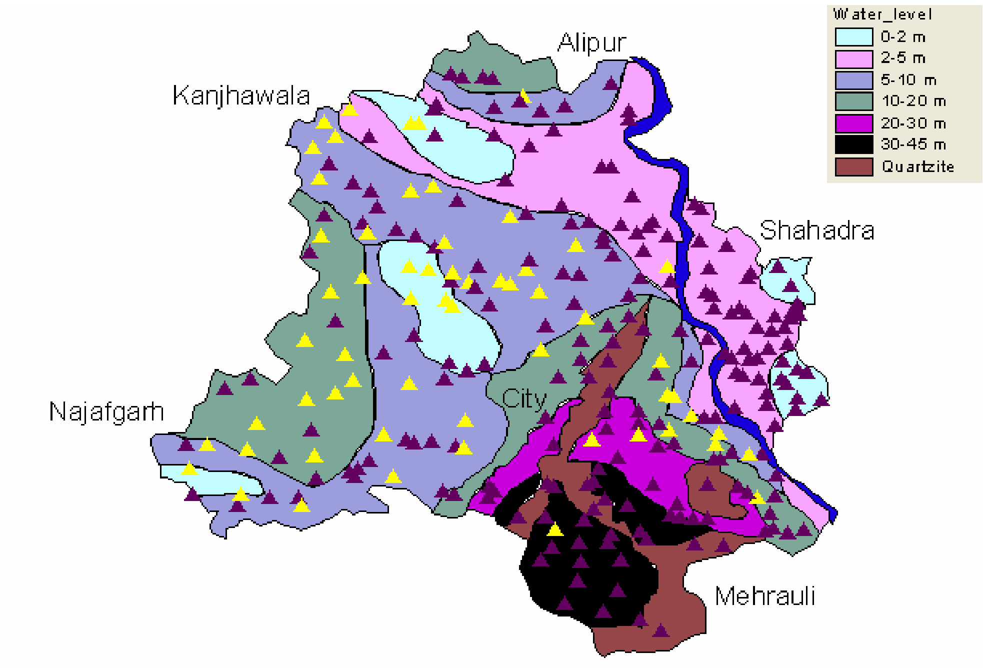


Figure 6.36 Correlation of water table depth with WQI>150

CHAPTER VII

CONCLUSIONS

- The ground water in Delhi has been observed to be mainly of mixed type. However, NaCl or $NaHCO_3$ type of ground water with predominance of Sodium cations has been observed in Najafgarh, Kanjhawla and Alipur block.
- The ground water quality in Delhi has indicated higher concentration of Total Dissolved Solids, Electrical Conductivity, Nitrate, Sulphate, and Fluoride as compared to drinking water standards and violation of water quality standards have been observed at many places.
- Strong correlations have been found between many water quality variables like, EC-TDS, EC-Cl, EC-SO_4, TH-Ca, TH-Mg etc.
- About 45.5% ground water samples out of the total samples have been found unsuitable for drinking purposes based on overall impact of physico-chemical characteristics. Irrigation water quality is found to be poorest in Kanjhawala block while both Mehrauli and Shahadra blocks have a fair quality of water for irrigation.
- Almost 55% of the samples are found to be Brackish with salinity in observed in the blockwise order of Kanjhawla> Najafgarh> Alipur> City> Mehrauli> Shahdara, while 75% of the total samples were characterized as Very hard .
- With respect to chloride-bicarbonate ratio (an indicator of saline water intrusion), only 39.2% of the total samples are found to fall in the Good category while the rest are polluted due to natural and anthropogenic causes.
- With regards to base exchange index, the maximum discharge area is in Kanjhawala block, Najafgarh block and some parts of Alipur & Shahadra block. It has also been observed that water quality from recharge to discharge area is deteriorating.
- The overall quality of the groundwater of Delhi reflected by WQI is found to be precariously close to the unsafe limit. The blockwise sequence of overall

deterioration of ground water quality has been observed as Kanjhawla> Najafgarh> City> Alipur> Mehrauli> Shahdara.

- Chloride concentrations too are found higher especially in the northern and western part of the study area, one of the main natural sources of which may be that the said area is covered with sand dunes formed due to the weathering of the ridge material.
- An abundance of samples violating drinking water standards of fluoride is present in the Alluvial Plains of the study area thus natural weathering processes may be one of the causes for the fluorides. They also seem to be concentrated in the region with groundwater levels greater than 5 m bgl, thus attributing this to comparatively less dilution offered by the water table may not be entirely incorrect. A similar interpretation may be drawn for the case of water quality index values greater than 150 which too show a strong correlation with areas having water table more than 5 m bgl.
- With regards to Yamuna water quality the water quality index for Nizamuddin Bridge station is the worst, which is quite obvious as quality here is affected by the discharge of heavy municipal and industrial pollution load emanating from Delhi.

CHAPTER VIII

RECOMMENDATIONS

- A comprehensive information system about the groundwater resource base must be developed soon on the national and regional levels.
- Mass awareness programs need to be launched for promoting economized use of water. The following measures need to be popularized for economizing water use:
  - (i) Use of water efficient cultural practices
  - (ii) Prevention of idle running of taps, Recycling and Reuse of domestic and industrial waste water
  - (iii)Adoption of suitable cropping pattern; soil moisture conservation by mulching; use of proper frequency, timing and depth of irrigation; introduction of rational irrigation practices must be taken up to discourage wastage of water.
- The Government must initiate the establishment of groundwater protected areas for key aquifers and also look into the possibility of setting of separate groundwater & surface water quality standards reflecting our national priorities. Extraction control must be done by setting legal limits on pumping or by developing awareness for efficient use of groundwater.
- Revival of traditional water harvesting concepts must be done for initiating surplus monsoon flows to recharge the underground aquifers. Public participation needs to be ensured while promoting extensive use of rainwater harvesting techinques by providing fringe benefits like tax deductions. Advantages and benefits of rainwater harvesting are numerous (Krishna, 2003) [109] both for the general public and the policy makers:
  - i) The water is free; the only cost is for collection and use. The end use of harvested water is located close to the source, eliminating the need for complex and costly distribution systems. Rainwater provides a water

source when groundwater is unacceptable or unavailable, or it can augment limited groundwater supplies.

ii) The zero hardness of rainwater helps prevent scale on appliances, extending their use; rainwater eliminates the need for a water softener and the salts added during the softening process.

iii) It helps utilities not only reduces the summer demand peak and delay expansion of existing water treatment plants but it also reduces consumers' utility bills.

iv) It reduces flow to storm water drains and also reduces non-point source pollution. Thereby lessening the impact of erosion and decreasing the load on storm sewers. Decreasing storm water volume also helps keep potential storm water pollutants, such as pesticides, fertilizers, and petroleum products, out of rivers and groundwater.

- ❖ Groundwater pollution control must be done first by identifying sources and the extent of pollution and by strict enforcement of remedial measures. Legal restrictions must be enforced on subsurface disposal of solid as well as liquid waste and landuse regulation must be done by the local authorities by restricting use of chemical fertilizer and pesticides, and housing density.
- ❖ We must promote the use of saline/ brackish water for irrigation of salt tolerant crops. In urban areas saline water should be used after blending with fresh water for uses other than drinking. Urban drainage water quality should also be analyzed and possible treatments and use areas such as irrigation and other "productive use" use such as brick making should be explored.
- ❖ For removal of naturally occurring fluoride from drinking water, the public needs to be made aware regarding handy domestic techniques like the Nalgonda Technique etc. which can be can be used equally well for domestic as well as community water supply schemes.
- ❖ Suitable areas close to the point of meeting wastewater drains emanating from Delhi with the Yamuna should be identified for development of wetlands for

their treatment prior to discharge into the Yamuna. Shukla et al. (1999)[110] suggested the conversion of the Yamuna flood plain into a wetland and then allowing the Najafgarh drain to cross the Yamuna River rather than joining it at the existing point for treatment in the developed wetland. The treated water from the wetland could then be allowed to seep back into the Yamuna River which would help maintain its natural flow and encourage religious and recreational activities in it. According to them valuable vegetations can also be grown in the area and the foliage can be used as fodder. They suggested exploring the possibilities of raising sugarcane, cashew nuts, and rice crops with the only deterrence being the use of the produce from the wetland for domestic consumption in case the waste water contains excessive amounts of trace/toxic metals.

- ❖ Lastly the public themselves need to be aware of the rising concerns regarding environment and water quality issues and should actively participate at tandem with the policy making authority for better management of our limited natural resources.

FUTURE SCOPE OF WORK

- Due to lack of data, spatial variations in water quality were only studied as part of this project; the work may be extended to study of temporal variations in water quality in the study area.
- In context of hydro-geochemical studies future emphasis should be laid on ground water-surface water interactions in order to estimate the anthropogenic/geological inputs to the ground water quality.
- Development of a suitable water quality index with due weightage to the critical heavy metals (maybe area specific), pesticides etc. may also be taken up as a future endeavor.
- One of the purposes of this project was to study the spatial correlations of water quality parameters and water quality index with geology and water table depths, similar correlations may also be found in regards to landuse of an area and water quality.
- Effects of saline water aquifers, waste water drains and Yamuna River on groundwater quality may also be studied on a spatial and temporal scale.
- Similar mapping techniques may also be applied to study the prominent factors affecting the water quality of Yamuna River.

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Annexure I
Various sampling points and their respective longitudes and latitudes

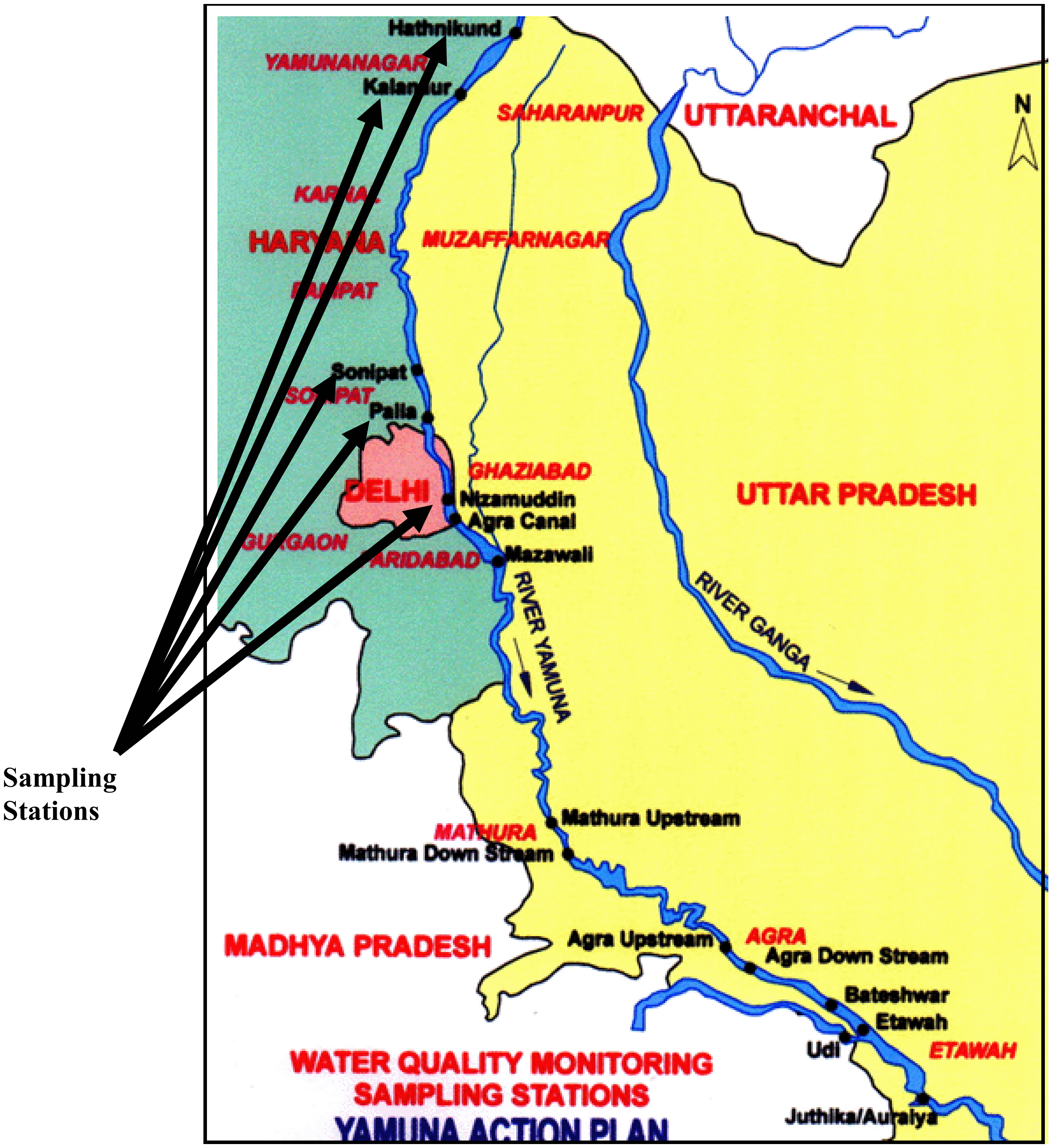
ID	Location	Block	Latitude	Longitude	ID	Location	Block	Latitude	Longitude
189	Ibrahimpur 2	Alipur	28.78	77.18	257	Shalimar Village	Alipur	28.72	77.16
190	Tigipur 1	Alipur	28.82	77.20	251	Timarpur	City	28.70	77.23
191	Tigipur 2	Alipur	28.81	77.20	252	Nirankari Colony	City	28.72	77.21
194	Palla	Alipur	28.84	77.19	253	Malkapur	City	28.70	77.21
195	Hamidpur	Alipur	28.82	77.15	254	Kewal Park	City	28.71	77.19
196	Bokali	Alipur	28.81	77.14	255	Adarsh Nagar	City	28.72	77.18
197	Alipurgarhi	Alipur	28.79	77.12	258	Pitampura Yp Blo	City	28.70	77.15
198	Khempur	Alipur	28.82	77.13	259	Wazirpur Indl. A	City	28.70	77.16
199	Tikrikhurd 1	Alipur	28.83	77.12	262	Maharani Bagh	City	28.68	77.13
200	Tikrikhurd 2	Alipur	28.83	77.12	263	Narang Colony	City	28.68	77.16
201	Mamurpur	Alipur	28.84	77.10	264	Zakhira	City	28.66	77.17
202	Bankner	Alipur	28.85	77.07	265	Pratapnagar	City	28.67	77.20
203	Narela	Alipur	28.85	77.09	266	Rana Pratap Naga	City	28.68	77.20
204	Lampur	Alipur	28.85	77.06	183	Majnu Ka Tilla	City	28.69	77.23
205	Bhorgarh	Alipur	28.82	77.10	182	Old Delhi Rly. S	City	28.65	77.24
210	Kherakhurd	Alipur	28.77	77.11	119	Vikaspuri	City	28.62	77.08
211	Halambi Kalan	Alipur	28.80	77.10	121	Nangli Jamb	City	28.63	77.09
212	Ghoga Village 1	Alipur	28.82	77.05	103	Age Office Cant.	City	28.59	77.14
213	Ghoga Village 2	Alipur	28.83	77.05	104	Cant. Area APS C	City	28.57	77.14
184	Wazirabad	Alipur	28.73	77.23	120	Rajauri Garden	City	28.64	77.13
185	Jagtarpur 1	Alipur	28.73	77.21	269	Sudarshanpuri	City	28.66	77.14
186	Jaroda	Alipur	28.73	77.20	270	Todapur	City	28.62	77.17
187	Burari	Alipur	28.76	77.20	271	Inderpuri	City	28.63	77.16
188	Ibrahimpur 1	Alipur	28.78	77.19	272	West Patel Nagar	City	28.65	77.16
192	Shivkunj Colony	Alipur	28.73	77.19	273	Bapudham Complex	City	28.59	77.18
193	Jagatpur 2	Alipur	0.00	77.22	268	Naraina	City	28.62	77.15
219	Shahbad Dairy	Alipur	28.74	77.11	287	Election Commiss	City	28.62	77.22
220	Shahbad Daulatpu	Alipur	28.74	77.12	288	Panchkula Road	City	28.63	77.22
221	Samaypur Badli	Alipur	28.76	77.05	289	Bara Hindu Rao	City	28.66	77.21
222	Puthkhurd Villag	Alipur	28.76	77.05	290	Kishan Ganj	City	28.65	77.19
208	Bhalsawa Dairy	Alipur	28.74	77.17	291	Than Singh Nagar	City	28.66	77.18
209	Burekhan Drgan	Alipur	28.75	77.15	292	New Rajiv Nagar	City	28.63	77.18
218	Barwala Village	Alipur	28.75	77.07	293	Budha Park	City	28.61	77.18
233	Sultanpur Dabas	Alipur	28.76	77.04	60	Munirka Dda Flat	City	28.55	77.18
256	Jahangirpuri	Alipur	28.73	77.18	61	Rk Puram	City	28.56	77.19

ID	Location	Block	Latitude	Longitude	ID	Location	Block	Latitude	Longitude
66	Begampur	City	28.54	77.22	294	Punjabkhor	Kanjhawala	28.77	76.97
75	Pwd Nursery	City	28.52	77.31	295	Jatkhor	Kanjhawala	28.78	76.97
135	Sarita Vihar 1	City	28.53	77.31	296	Kutubgarh	Kanjhawala	28.79	76.96
306	Kalkaji Extn.	City	28.54	77.26	297	Mungesmpur 1	Kanjhawala	28.80	76.98
137	Okhla Indl.1	City	28.53	77.29	298	Mungeshpur	Kanjhawala	28.81	76.97
138	Okhla Indl.Phas2	City	28.54	77.28	299	Avchandi	Kanjhawala	28.82	76.99
140	Vasant Enclave	City	28.57	77.17	300	Majradabasbudamp	Kanjhawala	28.77	76.99
283	Moti Bagh Colony	City	28.58	77.18	223	Gherva	Kanjhawala	28.69	77.00
274	Sanjay Camp Chan	City	28.59	77.21	224	Tikrikalan	Kanjhawala	28.68	76.97
275	Kidwai Nagar	City	28.58	77.21	226	Nizampur	Kanjhawala	28.71	76.96
276	Kotla Mubarakpur	City	28.57	77.23	227	Garhirindhala	Kanjhawala	28.73	76.97
277	Laxmibai Nagar	City	28.58	77.21	228	Jaunti	Kanjhawala	28.74	76.97
278	Safdarjang Airpo	City	28.57	77.22	229	Ladpur	Kanjhawala	28.74	77.00
279	Pragti Vihar	City	28.58	77.23	230	Kanjhawala	Kanjhawala	28.73	77.00
84	Okhla	City	28.56	77.30	231	Chandpur Kalan	Kanjhawala	28.75	77.01
85	Abdul Fazal Encl	City	28.55	77.31	232	Chandpur	Kanjhawala	28.76	77.00
106	Okhlardekail 1	City	28.56	77.26	234	Kerala	Kanjhawala	28.73	77.02
107	Okhlard Ekail 2	City	28.56	77.27	235	Mohammadpur Majra	Kanjhawala	28.73	77.04
79	India Gate 1	City	28.61	77.23	236	Ramvihar Block A	Kanjhawala	28.72	77.05
80	India Gate 2	City	28.61	77.23	237	Bhageyvihar	Kanjhawala	28.70	77.03
91	Lodhi Garden	City	28.59	77.22	238	Agarnar Morre Pr	Kanjhawala	28.70	77.05
280	Nizamuddin	City	28.55	77.25	239	Mundka More	Kanjhawala	28.68	77.04
83	Jammila	City	28.56	77.29	240	Nangloi Veena	Kanjhawala	28.68	77.06
86	Ashram Chowk	City	28.57	77.26	241	Kirari 1	Kanjhawala	28.69	77.07
87	New Friends Colony	City	28.56	77.28	242	Kirari 2	Kanjhawala	28.70	77.07
281	Jeevan Vihar	City	28.58	77.27	243	Sultanpuri	Kanjhawala	28.69	77.08
74	Kilokiri	City	28.59	77.26	244	Mangolpuri	Kanjhawala	28.60	77.08
179	Parsh Dharamshal	City	28.63	77.25	245	Mangolpur Khurd	Kanjhawala	28.69	77.10
180	Shanti Vampustro	City	28.65	77.26	246	Mangolpur Kalan	Kanjhawala	28.69	77.11
214	Bawana Village 1	Kanjhawala	28.80	77.05	247	Krishna Vihar	Kanjhawala	28.70	77.08
215	Bawana Village 2	Kanjhawala	28.81	77.03	248	Rajiv Nagar Phas	Kanjhawala	28.72	77.06
216	Bawana Village 3	Kanjhawala	28.81	77.04	30	Papankala 1	Najafgarh	28.66	76.98
217	Nangal Thakuran	Kanjhawala	28.80	77.00	113	Indira Enclave	Kanjhawala	28.67	77.09
260	Naharpuri Rohini	Kanjhawala	28.70	77.12	114	Mangloi	Kanjhawala	28.67	77.07
261	Rohini Sector 11	Kanjhawala	28.71	77.12	115	Rauhola	Kanjhawala	28.65	77.04

ID	Location	Block	Latitude	Longitude	ID	Location	Block	Latitude	Longitude
100	Fatehpurberi	Mehrauli	28.46	77.19	44	Bijwasal 1	Najafgarh	28.53	77.07
101	Indira Nagar Col	Mehrauli	28.43	77.22	45	Bijwasal 2	Najafgarh	28.53	77.06
102	Compound Of Sh.	Mehrauli	28.44	77.21	52	Shikarpur 1	Najafgarh	28.59	77.26
111	Deragaon	Mehrauli	28.44	77.18	116	Baprola	Najafgarh	28.64	77.01
112	Andheri More	Mehrauli	28.45	77.15	117	Ugarsan Park	Najafgarh	28.62	76.99
144	Vill. Gadaipur	Mehrauli	28.48	77.16	118	Kakrola	Najafgarh	28.61	77.03
145	Vill. Junapur	Mehrauli	28.47	77.16	125	Mitron	Najafgarh	28.60	76.96
110	Satbari	Mehrauli	28.48	77.19	130	Donbosco Najafga	Najafgarh	28.61	76.98
94	Aya Nagar	Mehrauli	28.48	77.13	149	Jharoda Kalan	Najafgarh	28.65	76.95
95	Chitroni	Mehrauli	28.49	77.14	150	Village Dichaan	Najafgarh	28.64	76.98
307	North Chitorni	Mehrauli	28.51	77.14	47	Chchawala	Najafgarh	28.56	77.00
308	Kishangarh 1	Mehrauli	28.51	77.17	48	Kanganhari 1	Najafgarh	28.55	76.99
309	Kishangarh 2	Mehrauli	28.51	77.14	49	Kanganhari 2	Najafgarh	28.54	76.99
141	Rajokari Rd.	Mehrauli	28.51	77.12	50	Kanganhari 3	Najafgarh	28.55	76.99
143	Sultanpur	Mehrauli	28.50	77.16	51	Daulatapur	Najafgarh	28.54	76.96
97	Kutub Booster Pu	Mehrauli	28.52	77.20	52	Shikarpur 1	Najafgarh	28.53	76.95
98	Chattarpur	Mehrauli	28.50	77.19	53	Shikarpur 2	Najafgarh	28.52	76.95
99	Block A Chattarp	Mehrauli	28.47	77.21	54	Gumanhera	Najafgarh	28.53	76.93
57	Vasant Kunj	Mehrauli	28.52	77.17	55	Raota	Najafgarh	28.52	76.90
59	Nuclear Sci. Cen	Mehrauli	28.53	77.18	46	Bamnauli	Najafgarh	28.55	77.02
92	JNU Based Camp C	Mehrauli	28.54	77.17	56	Jhiljhuli	Najafgarh	28.62	76.91
93	Paschimabad JNU	Mehrauli	28.54	77.17	126	Kair	Najafgarh	28.62	76.91
146	Mahipal	Mehrauli	28.54	77.14	127	Mundela Khurd	Najafgarh	28.61	76.90
310	Rangpuri Mohau	Mehrauli	28.54	77.14	131	Kharkhari Nahar	Najafgarh	28.58	76.96
77	Nebsari	Mehrauli	28.50	77.21	132	Pindwala Kalan	Najafgarh	28.56	76.96
109	Indira Enclave N	Mehrauli	28.50	77.21	133	Dhansa 1	Najafgarh	28.53	76.87
72	Kanpur Jj Colony	Mehrauli	28.52	77.23	134	Dhansa 2	Najafgarh	28.55	76.87
305	Krishna Market	Mehrauli	28.49	77.25	142	Ujhwa Vill.	Najafgarh	28.57	76.91
67	Virat Road	Mehrauli	28.52	77.24	302	Vill. Jafarpur K	Najafgarh	28.58	76.92
70	Badarpur	Mehrauli	28.49	77.24	303	Vill. Gazipur	Najafgarh	28.57	76.88
71	Hamdard Nagar	Mehrauli	28.49	77.27	304	Vill. Isapur	Najafgarh	28.57	76.87
139	Wild Life Sanctu	Mehrauli	28.48	77.27	65	Kharkhera Round	Najafgarh	28.56	76.94
134	Dhansa 2	Najafgarh	28.53	77.30	64	Goclakhurd	Najafgarh	28.58	77.01
69	Tuglakabad Rly.	Mehrauli	28.50	77.30	29	Palam Gaon Extn.	Najafgarh	28.59	77.08
70	Badarpur	Mehrauli	28.50	77.31	30	Papankala 1	Najafgarh	28.57	77.07
68	Satya Narain Man	Mehrauli	28.51	77.25	31	Papankala 2	Najafgarh	28.57	77.07
89	Harinagar Extn.	Mehrauli	28.50	77.33	32	Ambahari Dwarka	Najafgarh	28.57	77.05
90	Molarband	Mehrauli	28.50	77.32	33	Gola Dairy Villa	Najafgarh	28.57	77.04

ID	Location	Block	Latitude	Longitude	ID	Location	Block	Latitude	Longitude
42	Airport India Au	Najafgarh	28.53	77.10	23	Shakurpur 1	Shahadra	28.62	77.29
43	Samlakha Village	Najafgarh	28.53	777.09	24	Shakurpur 2	Shahadra	28.62	77.28
34	Gola Dairy	Najafgarh	28.57	77.03	25	Mandoli	Shahadra	28.62	77.30
41	Samlakha Road	Najafgarh	28.54	77.09	26	Hasanpur	Shahadra	28.63	77.31
147	Hasthal	Najafgarh	28.63	77.06	27	Anand Vihar Isbt	Shahadra	28.65	77.32
148	Nawada Majra	Najafgarh	28.62	77.06	173	Kishankunj 1	Shahadra	28.64	77.27
165	Karawal Nagar	Shahadra	28.72	77.27	174	Kishanganj 2	Shahadra	28.63	77.28
166	Sonia Vihar	Shahadra	28.72	77.25	40	Rozapur	Shahadra	28.60	77.28
167	Subeypur 1	Shahadra	28.75	77.25	2	Laxmi Nagar 1	Shahadra	28.63	77.29
168	Subeypur 2	Shahadra	28.75	77.25	3	Laxmi Nagar 2	Shahadra	28.63	77.30
152	Vivek Vihar Rly.	Shahadra	28.67	77.32	4	Gaganvihar	Shahadra	28.64	77.30
153	Dilshad Garden	Shahadra	28.68	77.33	5	CBD Complex	Shahadra	28.65	77.31
154	GT Road Shahadra	Shahadra	28.67	77.31	6	Jhilmil Colony	Shahadra	28.66	77.32
155	Nand Nagri Gali	Shahadra	28.69	77.32	7	Vivek Vihar	Shahadra	28.66	77.32
157	Saboli Gali No.	Shahadra	28.70	77.31	8	Vivek Vihar 1	Shahadra	28.67	77.33
158	Gokulpuri 1 Sanj	Shahadra	28.70	77.29	10	Ghazipur	Shahadra	28.62	77.33
159	Gokulpuri 2	Shahadra	28.70	77.29	11	East Vinode Viha	Shahadra	28.62	77.31
160	Shahadra Kanti N	Shahadra	28.67	77.28	12	Khitchripur	Shahadra	28.61	77.32
161	Kanti Nagar 2	Shahadra	28.67	77.29	13	Mayurvihar I 1	Shahadra	28.61	77.30
162	Usmanpur 1	Shahadra	28.68	77.26	14	Mayurvihar I 2	Shahadra	28.60	77.30
163	Usmanpur 2	Shahadra	28.68	77.26	15	Chilla Saroda	Shahadra	28.58	77.31
164	Rajiv Vihar	Shahadra	28.70	77.26	16	Dallupura 1	Shahadra	28.60	77.33
169	Shanti Park	Shahadra	28.67	77.26	17	Dallupura 2	Shahadra	28.60	77.33
170	Seelampur	Shahadra	28.67	77.28	172	Geeta Colony	Shahadra	28.64	77.29
171	Krishan Nagar	Shahadra	28.66	77.30	21	Ghazipur 2	Shahadra	28.63	77.00
20	Mayur Vihar 3	Shahadra	28.60	77.35					

Annexure II
Sampling Stations for Surface water quality monitoring
(Yamuna Action Plan)



Annexure III
MATLAB Code for WQI Calculation

```
d=load ('C:\data alipur.txt');
WQIalipur = zeros (1, 39);
for i=1:39
        if (d(i,1)>7.0)
    qph=100*((d(i,1)-7.0)/(200*1.5));
        else
    qph=100*(7.0-(d(i,1))/(200*1.5));
        end
  qf=100*(d(i,2)/(1.5*1.5));
  qcl=100*(d(i,3)/(200*200));
  qNO3=100*(d(i,4)/(45*45));
  qSO4=100*(d(i,5)/(200*200));
  qtds=100*(d(i,6)/(500*500));
  qCa=100*(d(i,7)/(75*75));
  qMg=100*(d(i,8)/(30*30));
  qTH=100*(d(i,9)/(200*200));
  qAlk=100*(d(i,10)/(600*600));
  WQIalipur(i)=(qph+qf+qcl+qNO3+qSO4+qtds+qCa+qMg+qTH+qAlk)/0.759;
end

d2=load ('C:\data city.txt');
WQIcity = zeros (1, 81);
for i=1:81
        if (d2(i,1)>7.0)
    qph=100*((d2(i,1)-7.0)/(200*1.5));
        else
    qph=100*(7.0-(d2(i,1))/(200*1.5));
        end
  qf=100*(d2(i,2)/(1.5*1.5));
  qcl=100*(d2(i,3)/(200*200));
  qNO3=100*(d2(i,4)/(45*45));
  qSO4=100*(d2(i,5)/(200*200));
  qtds=100*(d2(i,6)/(500*500));
  qCa=100*(d2(i,7)/(75*75));
  qMg=100*(d2(i,8)/(30*30));
  qTH=100*(d2(i,9)/(200*200));
  qAlk=100*(d2(i,10)/(600*600));
  WQIcity(i)=(qph+qf+qcl+qNO3+qSO4+qtds+qCa+qMg+qTH+qAlk)/0.759;
end
```

```
d3=load ('C:\data kanjhawala.txt');
WQIkanj= zeros (1, 42);
for i=1:42
        if (d3(i,1)>7.0)
    qph=100*((d3(i,1)-7.0)/(200*1.5));
        else
    qph=100*(7.0-(d3(i,1))/(200*1.5));
        end
  qf=100*(d3(i,2)/(1.5*1.5));
  qcl=100*(d3(i,3)/(200*200));
  qNO3=100*(d3(i,4)/(45*45));
  qSO4=100*(d3(i,5)/(200*200));
  qtds=100*(d3(i,6)/(500*500));
  qCa=100*(d3(i,7)/(75*75));
  qMg=100*(d3(i,8)/(30*30));
  qTH=100*(d3(i,9)/(200*200));
  qAlk=100*(d3(i,10)/(600*600));
  WQIkanj(i)=(qph+qf+qcl+qNO3+qSO4+qtds+qCa+qMg+qTH+qAlk)/0.759;
end

d4=load ('C:\data mehrauli.txt');
WQImeh= zeros (1, 39);
for i=1:39
        if (d4(i,1)>7.0)
    qph=100*((d4(i,1)-7.0)/(200*1.5));
        else
    qph=100*(7.0-(d4(i,1))/(200*1.5));
        end
  qf=100*(d4(i,2)/(1.5*1.5));
  qcl=100*(d4(i,3)/(200*200));
  qNO3=100*(d4(i,4)/(45*45));
  qSO4=100*(d4(i,5)/(200*200));
  qtds=100*(d4(i,6)/(500*500));
  qCa=100*(d4(i,7)/(75*75));
  qMg=100*(d4(i,8)/(30*30));
  qTH=100*(d4(i,9)/(200*200));
  qAlk=100*(d4(i,10)/(600*600));
  WQImeh(i)=(qph+qf+qcl+qNO3+qSO4+qtds+qCa+qMg+qTH+qAlk)/0.759;
end
```

```
d5=load ('C:\data najafgarh.txt');
WQInaj= zeros (1, 43);
for i=1:43
        if (d5(i,1) >7.0)
    qph=100*((d5(i,1)-7.0)/(200*1.5));
        else
    qph=100*(7.0-(d5(i,1))/(200*1.5));
        end
  qf=100*(d5(i,2)/(1.5*1.5));
  qcl=100*(d5(i,3)/(200*200));
  qNO3=100*(d5(i,4)/(45*45));
  qSO4=100*(d5(i,5)/(200*200));
  qtds=100*(d5(i,6)/(500*500));
  qCa=100*(d5(i,7)/(75*75));
  qMg=100*(d5(i,8)/(30*30));
  qTH=100*(d5(i,9)/(200*200));
  qAlk=100*(d5(i,10)/(600*600));
  WQInaj(i)=(qph+qf+qcl+qNO3+qSO4+qtds+qCa+qMg+qTH+qAlk)/0.759;
end

d6=load ('C:\data shahadra.txt');
WQIsh= zeros (1, 55);
for i=1:55
        if (d6(i,1)>7.0)
    qph=100*((d6(i,1)-7.0)/(200*1.5));
        else
    qph=100*(7.0-(d6(i,1))/(200*1.5));
        end
  qf=100*(d6(i,2)/(1.5*1.5));
  qcl=100*(d6(i,3)/(200*200));
  qNO3=100*(d6(i,4)/(45*45));
  qSO4=100*(d6(i,5)/(200*200));
  qtds=100*(d6(i,6)/(500*500));
  qCa=100*(d6(i,7)/(75*75));
  qMg=100*(d6(i,8)/(30*30));
  qTH=100*(d6(i,9)/(200*200));
  qAlk=100*(d6(i,10)/(600*600));
  WQIsh(i)=(qph+qf+qcl+qNO3+qSO4+qtds+qCa+qMg+qTH+qAlk)/0.759;
end
```

Annexure IV

List of the 19 drains out falling into River Yamuna:

1. Najafgarh drain

2. Magazine Road drain

3. Sweeper Colony drain

4. Khyber Pass drain

5. Metcalfe drain

6. Kudsia Bagh drain

7. Moat drain

8. Trans Yamuna MCD drain

9. Mori Gate drain

10. Civil Mill Drain

11. Power House drain

12. Sen Nursing Home drain

13. Drain No. 14

14. Barapullah Drain

15. Maharani Bagh drain

16. Kalkaji drain

17. Okhla drain

18. Tughlakabad drain

19. Shahadara drain

Annexure V

CENTRAL GROUND WATER BOARD, NWR, CHANDIGARH
(BLOCK WISE RESULTS OF CHEMICAL ANALYSIS OF WATER SAMPLES FOR NCT DELHI)

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC	FC	RSC	SAR	USSL Classi fication	LAND USE
							concentration in mg/l															No./100ml		in meq/l			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
BLOCK ALIPUR																											
1.	Wazirabad	184	HP	10.0	7.74	900	590	Nil	337	92	112	4	0.31	0.05	127	20	48	6.6	12	0.15	400	4.0	NIL	-2.48	1.04	C3S1	Inh.
2.	Jagtarpur-1	185	STW	13.0	7.54	1250	795	Nil	388	205	88	3.8	0.50	0.05	110	29	140	6.7	15	0.15	396	NIL	NIL	-1.55	3.06	C3S1	Ag.
3.	Jaroda	186	HP	12.0	7.78	3230	2280	Nil	271	861	425	4.2	0.37	0.05	112	99	520	8.9	11	0.20	689	14.0	NIL	-9.32	8.62	C4S2	D.F
4.	Burari	187	HP	9.0	7.80	7850	5875	Nil	110	2610	1110	13	0.92	0.03	302	227	1525	15	16	0.45	1689	46.0	NIL	-31.96	8.07	>C4	Inh.
5.	Ibrahimpur-1	188	STW	13.0	7.92	2540	1743	Nil	199	552	480	3.62	0.40	0.06	124	63	390	8.7	22	0.12	570	NIL	NIL	-8.14	7.12	C4S2	Inh.
6.	Ibrahimpur-2	189	HP	10.0	7.52	3000	2048	Nil	301	636	530	7.9	0.62	0.05	196	68	430	8.3	20	0.19	771	NIL	NIL	-10.46	6.74	C4S2	Inh.
7.	Tigipur-1	190	STW	12.0	7.65	792	457	Nil	397	21	38	15	0.23	0.05	108	24	25	5.6	22	Nil	370	NIL	NIL	-0.89	0.57	C3S1	Ag.
8.	Tigipur-2	191	HP	6.0	7.88	884	603	Nil	391	28	148	3.7	0.32	0.05	88	27	90	5.5	17	0.06	330	NIL	NIL	-0.19	2.15	C3S1	Inh.
9.	Shivkunj Colony	192	HP	8.0	7.91	1970	1231	Nil	397	370	200	10	0.23	0.15	84	68	270	8.8	21	0.12	490	NIL	NIL	-3.29	5.30	C3S2	Inh.
10.	Jagatpur-II	193	HP	8.0	7.76	965	649	Nil	256	143	135	10	0.13	0.07	72	36	96	6.8	22	0.06	330	NIL	NIL	-2.40	2.30	C3S1	Ag.
11.	Palla	194	HP	15.0	7.43	2870	2036	Nil	564	423	405	277	0.37	0.05	212	129	270	24	14	0.25	1061	NIL	NIL	-11.96	3.61	C4S1	Inh.
12.	Hamidpur	195	HP	20.0	8.40	1489	917	25	308	168	215	32	0.23	0.04	20	63	210	20	10	0.19	310	NIL	NIL	-0.32	5.18	C3S1	Inh.
13.	Bokali	196	HP	12.0	7.96	2240	1436	Nil	519	307	250	113	0.54	0.06	112	61	310	4.1	19	0.06	530	-	-	-2.09	5.86	C3S2	D.F.
14.	Alipurgarhi	197	HP	16.0	7.83	3730	2292	Nil	276	779	600	2.8	0.62	0.06	204	134	410	9.2	14	0.69	1061	NIL	NIL	-16.68	5.48	C4S2	Ag.
15.	Khempur	198	HP	12.0	8.00	1461	831	Nil	641	91	60	30	0.6	0.06	120	34	120	34	21	0.06	440	2.0	NIL	1.70	2.49	C3S1	Inh.
16.	Tikrikhurd-1	199	TW	28.0	8.39	1553	907	32	366	136	200	5.2	3.2	0.06	24	22	275	3.4	23	0.25	150	NIL	NIL	4.04	9.77	C3S2	Inh.
17.	Tikrikhurd-2	200	HP	20.0	7.56	3180	1981	Nil	666	311	555	84	1.0	0.10	116	78	460	8.1	34	0.31	610	NIL	NIL	-1.28	8.10	C4S2	Inh.
18.	Mamurpur	201	HP	8.0	7.33	3360	2231	Nil	564	559	310	236	0.46	3.18	160	97	330	210	43	0.31	801	46.0	NIL	-6.76	5.07	C4S2	Inh.
19.	Bankner	202	TW	40.0	7.76	1620	1001	Nil	455	196	186	22	0.96	0.11	84	54	190	8.5	32	0.19	430	10.0	NIL	-1.14	3.98	C3S1	Inh
20.	Narela	203	HP	33.0	7.92	949	681	Nil	340	77	115	79	1.48	0.08	96	51	51	8.2	32	0.06	450	NIL	NIL	-3.43	1.05	C3S1	Inh.
21.	Lampur	204	HP	27.0	8.22	1691	1095	Nil	635	122	201	11	1	0.12	64	19	320	5.6	34	0.06	240	NIL	NIL	5.60	8.98	C3S2	Inh.
22.	Bhorgarh	205	HP	17.0	7.74	2340	1054	Nil	320	389	200	16	0.41	0.07	108	97	125	78	42	0.31	671	NIL	NIL	-8.15	2.10	C4S1	Inh.
23.	Hamidpur	206	HP	15.0	7.72	1960	1130	Nil	628	220	157	9.8	0.70	0.09	96	44	250	17	21	0.19	420	NIL	NIL	1.89	5.30	C3S2	Ag.
24.	Tikrikhurd	207	STW	21.0	7.34	1525	760	Nil	481	156	236	6.0	0.75	0.07	88	61	185	6.8	22	Nil	470	NIL	NIL	-1.52	3.71	C3S1	Ag.

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC No./100ml	FC No./100ml	RSC in meq/l	SAR	USSL Classi fication	LAND USE
							concentration in mg/l																				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
25.	Bhalsawa Dairy	208	STW	50.0	7.14	7900	5502	Nil	115	2367	1140	18	0.96	0.04	160	202	1500	54	21	0.81	1231	18.0	NIL	-22.71	18.60	>C4	L.F
26.	Burekhan Dargan	209	HP	28.0	7.96	1920	1252	Nil	346	304	346	4.4	1.18	0.07	84	73	245	6.8	15	0.25	510	6.0	NIL	-4.53	4.74	C3S2	Inh.
27.	Kherakhurd	210	STW	50.0	7.58	1029	715	Nil	410	42	188	26	0.46	0.08	72	24	160	4.4	35	0.19	280	NIL	NIL	1.12	4.16	C3S1	Hor.
28.	Halambi Kalan	211	HP	20.0	7.49	1151	667	Nil	461	84	64	5.3	1.09	0.09	76	34	51	93	28	0.06	330	22.0	NIL	0.96	1.22	C3S1	Inh.
29.	Ghoga Village-1	212	STW	24.0	7.37	2420	1755	Nil	461	349	545	0.71	0.63	0.1	168	63	360	5.4	33	0.25	681	NIL	NIL	-6.04	6.02	C4S2	Ag.
30.	Ghoga Village-2	213	HP	17.0	7.54	3040	2207	Nil	474	489	720	0.06	0.79	0.08	152	102	475	6	25	0.31	801	32.0	NIL	-8.23	7.32	C4S2	B.K.F
31.	Shahabad Daulatpur	220	STW	20.0	8.52	1145	691	32	282	127	105	1.80	2.14	0.08	34	16	200	4.1	29	0.25	150	NIL	NIL	2.67	7.10	C3S2	Hor.
32.	Samaypur Badli	221	HP	13.0	8.13	2080	1433	Nil	461	307	315	60	1.29	0.19	92	66	275	53	33	0.25	500	30.0	NIL	-2.44	5.37	C3S2	Inh.
33.	Puthkhurd Village	222	HP	13.0	7.31	6030	5147	Nil	794	1419	710	266	3.48	0.11	136	326	1650	213	26	0.88	1681	NIL	NIL	-20.58	8.39	>C4	Inh.
34.	Pehladpur	250	HP	17.0	7.84	3410	2052	Nil	372	827	298	14	5.42	0.03	118	131	450	7.3	15	0.75	836	28.0	NIL	-10.61	6.77	C4S2	Inh.
35.	Bhalswa Village	267	HP	8.0	7.45	1315	865	Nil	549	162	97	14	0.46	0.12	97	63	115	10	32	0.01	502	2.0	NIL	-1.04	2.23	C3S1	Inh.
36.	Barwala Village	218	HP	12.0	7.37	2800	2062	Nil	141	817	450	9	0.36	0.08	317	95	255	6.3	32	0.25	1181	22.0	NIL	-21.29	3.23		Inh.
37.	Shahabad Dairy	219	HP	10.0	7.75	3690	2476	Nil	295	496	1000	8.9	3.03	0.08	188	124	480	4.5	24	1.19	981	NIL	NIL	-14.77	6.77	C4S4	Inh.
38.	Jahangirpuri	256	HP	8.0	7.34	1625	1072	-	577	212	135	36	.57	.07	134	54	183	4	25	0.18	555	NIL	NIL	-1.65	3.38		Inh.
39.	Shalimar Village	257	HP	15.0	7.32	998	714	-	397	87	138	20	3.69	.07	62	28	153	7.6	17	0.12	270	6.0	NIL	1.11	4.05		Inh.

BLOCK KANJHAWALA (KN)

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC No./100ml	FC No./100ml	RSC in meq/l	SAR	USSL Classi fication	LAND USE
40.	Bawana Village-1	214	DW	3.60	7.69	1121	781	Nil	436	98	196	2.20	0.84	0.09	124	63	51	2.6	26	0.06	570	14.0	NIL	-4.26	0.92	C3S1	Ag.
41.	Bawana Village-II	215	STW	10.0	7.46	2650	1746	Nil	461	286	660	2.6	3.18	0.08	148	131	250	6.7	28	0.31	911	4.0	NIL	-10.64	3.60	C4S1	Ag.
42.	Bawana Village-III	216	TW	70.0	8.46	2020	1348	25	167	276	510	0.01	2.51	0.06	60	75	310	5.4	22	0.19	460	-	-	-5.63	6.29	C3S2	Inh.
43.	Nangal Thakuran	217	HP	12.0	7.55	900	602	Nil	384	70	96	9.6	0.08	0.09	100	29	56	19	31	0.06	370	NIL	NIL	-1.1	1.27	C3S1	Inh.
44.	Rauhola	115	HP	10.0	8.00	2200	1370	Nil	702	337	105	38	0.81	0.07	36	28	450	1.6	15	Nil	205	28.0	NIL	-7.40	13.07	C3S4	Inh.
45.	Gherva	223	HP	15.0	7.65	4030	2700	Nil	346	707	825	76	2.21	0.06	152	129	590	21	25	0.50	911	42.0	NIL	-12.53	8.62	C4S3	Inh.
46.	Tikrikalan	224	HP	17.0	8.19	1918	1259	Nil	333	323	305	14	5.47	0.07	84	66	260	13	22	0.44	480	NIL	NIL	-4.14	5.16	C3S1	Inh.
47.	Sauda	225	HP	20.0	8.29	3420	2229	Nil	961	467	440	1.1	0.74	0.08	44	46	720	13	17	2.19	300	NIL	NIL	9.75	18.02	C4S4	Inh.

Sr No | Location | Sample No | Source of Sample | Depth in mtr. | pH | Ec in micro- | TDS | CO3 | HCO3 | Cl | SO4 | NO3 | F | PO4 | Ca | Mg | Na | K | SiO2 | B | Total Hardness | TC No./100ml | FC | RSC in meq/l | SAR | USSL Classi | LAND USE

						mhos/Cm at 25oC	concentration in mg/l														as CaCO3					fication	
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
48.	Nizampur	226	HP	17.0	7.60	3400	2211	Nil	666	803	190	106	0.87	0.10	168	151	395	35	29	0.56	1041	6.0	NIL	-9.88	5.33	C4S2	Inh.
49.	Garhirindhala	227	HP	23.0	8.16	3530	2534	Nil	794	597	610	16	2.59	0.11	56	90	730	10	25	1.0	510	NIL	NIL	2.82	14.08	C4S4	Inh.
50.	Jaunti	228	HP	13.0	7.81	962	653	Nil	327	70	95	79	0.34	0.10	76	44	40	54	31	Nil	370	NIL	NIL	-2.04	0.90	C3S1	Inh.
51.	Ladpur	229	HP	9.0	7.40	4640	3116	Nil	391	1346	488	31	0.51	0.08	409	195	410	19	22	0.44	1821	NIL	NIL	-29.99	4.17	C4S2	Inh.
52.	Kanjawala	230	HP	13.0	8.17	2900	1969	Nil	981	280	296	140	10	0.16	20	17	690	3.8	22	2.50	120	6.0	NIL	13.67	27.39	C4S4	S.S
53.	Chandpur Kalan	231	HP	15.0	7.19	3940	2444	Nil	647	747	465	14	0.59	0.13	261	80	480	48	25	Nil	981	8.0	NIL	-8.99	6.67	C4S2	Inh.
54.	Chandpur	232	HP	13.0	8.01	3943	2658	Nil	256	1093	485	1.9	1.48	0.08	84	109	715	15	26	1.06	661	NIL	NIL	-9.00	12.10	C4S4	BKF
55.	Sultanpur Dabas	233	HP	17.0	8.29	3250	1970	Tr	461	840	143	2.4	2.6	0.09	52	83	565	23	28	1.55	470	30.0	NIL	-1.84	11.34	C4S3	Hor.
56.	Kerala	234	HP	11.0	7.97	4520	3063	Nil	340	1173	650	55	1.53	0.08	172	233	570	13	25	1.31	1391	20.0	NIL	-22.23	6.65	C4S3	Inh.
57.	Mohmmadpur Majri	235	HP	13.0	7.45	1760	1050	Nil	410	197	134	161	1.92	0.10	168	75	72	6.6	29	0.13	731	40.0	NIL	-7.88	1.16	C3S1	Inh.
58.	Ramavihar Block-A	236	HP	13.0	8.28	1051	741	TR	218	160	204	16	0.40	0.09	60	58	103	4.5	26	Nil	390	282	20.6	-4.23	2.27	C3S1	Inh.
59.	Bhageyvihar	237	HP	12.0	7.22	7170	4421	Nil	308	1973	875	115	1.22	0.12	501	567	178	27	30	0.69	3583	NIL	NIL	-66.56	1.29	>C4	Inh.
60.	Agarnagar Morre Prem Nagar-4	238	HP	10.0	7.86	4780	3100	Nil	308	1290	470	80	2.43	0.12	132	134	800	5.9	32	1.10	881	NIL	NIL	-12.56	11.73	C4S4	Inh.
61.	Mundka More	239	HP	13.0	7.81	4350	2390	Nil	859	823	382	119	2.29	0.08	60	97	780	92	35	0.12	550	26.0	NIL	3.07	14.47	C4S4	Inh.
62.	Nangloi Veena Enclave	240	HP	13.0	7.90	3090	2214	Nil	666	486	428	190	10.2	0.05	116	125	480	14	31	1.12	806	2.0	NIL	-5.18	7.36	C4S2	Com.
63.	Kirari-1	241	HP	13.0	7.73	5620	3428	Nil	545	1675	313	82	0.92	0.05	106	165	1040	17	30	0.37	946	38.0	NIL	-9.97	14.72	>C4	Com.
64.	Kirari-2	242	HP	23.0	7.59	4560	3054	Nil	564	1153	388	184	4.21	0.07	241	227	530	8.1	37	0.50	1536	NIL	NIL	-21.46	5.88	C4S2	Ind.
65.	Sultanpuri	243	HP	13.0	7.89	3060	2082	Nil	1070	354	164	208	4.9	0.07	20	15	750	5	26	1.12	110	NIL	NIL	15.34	31.10	C4S4	Com.
66.	Mangolpuri	244	HP	13.0	7.35	3630	2070	Nil	417	869	276	180	0.41	0.05	180	226	305	4.7	30	0.12	1381	14.0	NIL	-20.77	3.57	C4S2	Com.
67.	Mangolpur Khurd	245	STW	15.0	7.98	1875	1250	Nil	487	250	196	114	6.1	0.05	64	68	255	35	18	0.12	440	4.0	NIL	-0.82	5.29	C3S2	Inh.
68.	Mangolpur Kalan	246	STW	15.0	7.75	2920	2080	Nil	425	334	376	652	4.06	0.06	136	161	285	148	14	0.12	1001	4.0	NIL	-11.39	3.92	C4S2	Com.
69.	Krishna Vihar	247	HP	13.0	7.65	1825	1250	Nil	461	309	124	141	1.39	0.03	116	102	112	94	21	0.25	711	20.0	NIL	-6.64	1.83	C3S1	Com.
70.	Rajiv Nagar Phase-II	248	HP	13.0	7.97	4350	2640	Nil	225	676	905	39	4.78	0.11	84	49	765	24	16	1.85	410	NIL	NIL	-4.52	16.44	C4S4	Com.
71.	Rithala	249	HP	13.0	7.92	1175	585	Nil	525	59	152	21	5.10	0.03	28	19	225	59	17	nil	150	26.0	NIL	5.61	7.99	C3S2	Com.

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC No./100ml	FC	RSC in meq/l	SAR	USSL Classi fication	LAND USE
							concentration in mg/l																				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
72.	Punjabkhor Delhi-8	294	HP	13.0	7.46	3590	2390	Nil	630	797	310	96	3.48	0.13	78	83	680	8.2	14	1.69	535	42.0	8.0	-0.38	12.78	C4S4	Inh.
73.	Jatkhor	295	HP	13.0	7.05	4960	3515	--	688	832	840	390	0.75	0.18	140	232	700	14	22	ND	1303	19.0	NIL	-14.76	8.44	C4S3	Inh.
74.	Kutubgarh	296	HP	13.0	7.68	5390	4105	nil	996	882	1220	28	5.26	0.12	41	62	1350	3.5	13	2.35	358	2.0	NIL	9.16	31.04	>C4	Com.
75.	Mungesmpur-I	297	DTW	60.0	7.72	3060	2600	Nil	439	698	810	6.3	4.07	0.12	127	136	580	6.8	14	0.44	875	-	-	-10.38	8.53	C4S3	Inh.
76.	Mungeshpur	298	DTW	33.0	7.77	9920	7940	Nil	740	2420	2325	1.3	6.43	0.11	95	109	2500	8.8	12	2.65	1056	10.0	NIL	-8.99	33.47	>C4	Inh.
77.	Avchandi	299	HP	10.0	7.50	3920	3075	Nil	1333	182	715	45	3.73	0.31	15	4.6	330	1100	8	3.55	56	NIL	NIL	20.72	19.19	C4S4	Ag.
78.	Mundka village	123	HP	13.0	7.85	3570	2410	Nil	785	566	540	32	2.8	0.06	58	89	690	17	16	0.44	510	14.0	NIL	-2.67	13.29	C4S4	Com.
79.	Tikrikalan Indl.Area	124	HP	35.0	7.56	3810	2420	Nil	231	1260	206	8.5	1.18	0.38	224	187	375	21	21	0.12	1331	NIL	NIL	-22.82	4.47	C4S2	Com.
80.	Mangloi	114	HP	10.0	7.64	3930	2280	Nil	631	1039	78	29	3.8	0.09	106	162	520	19	14	Nil	916	2.0	NIL	-7.96	7.48	C4S2	Inh.
81.	Vill.Neelwa	301	HP	16.0	7.93	2320	1458	Nil	596	413	258	117	5.08	0.06	64	74	460	6.3	30	0.25	465	NIL	NIL	0.47	9.27		Inh.
82.	Naharpuri Rohini	260	HP	10.0	7.83	1994	1338	-	532	292	195	108	7.46	.08	78	100	260	8.2	24	0.56	606	10.0	NIL	-3.38	4.60		Inh.
83.	Rohini Sector 11	261	HP	8.0	7.89	609	410	-	327	28	52	6.60	2.40	.03	56	33	41	5.3	24	0.12	275	2.0	NIL	-0.14	1.07		Inh.
BLOCK NAJAFGARH																											
84.	Mundela Khurd	127	HP	16.0	8.42	2890	1606	57	225	713	89	83	1.48	0.11	110	118	288	11	23	0.12	485	-	-	-9.63	4.55	C4S2	Inh.
85.	Palam Gaon Extn. Dr	29	HP	40.0	7.99	1321	830	Nil	573	129	56	26	3.3	0.07	25	3.6	300	2.1	17	Nil	79	NIL	NIL	7.82	10.90	C3S3	Inh.
86.	PapankalA-1	30	HP	12.0	7.30	1467	900	Nil	611	207	26	17	1.14	0.09	86	32	222	0.9	18	0.06	348	42.0	NIL	3.06	5.18	C3S1	Ag.
87.	Papankala-2	31	STW	20.0	7.81	1149	720	Nil	495	140	20	15	5.17	0.04	61	12	198	2.3	13	0.06	201	-	-	4.10	6.07	C3S2	Inh.
88.	Ambahari Dawarka Project	32	STW	60.0	7.27	2520	1450	Nil	361	718	30	2.0	1.09	0.09	169	117	195	15	25	0.18	902	12.0	NIL	-12.12	2.82	C4S1	Inh.
89.	Gola Dairy Village	33	HP	16.0	7.31	1509	916	Nil	393	225	150	2.7	0.59	0.08	100	46	172	5.5	17	Nil	441	22.0	NIL	-2.68	3.56	C3S1	Inh.
90.	Gola Dairy	34	HP	20.0	7.19	3760	2840	Nil	805	504	900	1.0	0.93	0.05	165	46	790	9.7	28	0.20	603	-	-	1.14	14.01	C4S4	DF
91.	Samalkha Road	41	HP	30.0	7.59	1448	950	Nil	695	180	10	10	1.24	0.08	Nil	93	200	0.8	15	0.06	382	22.0	NIL	3.75	4.45	C3S1	Inh.
92.	Airport India Authority	42	DTW	50.0	7.41	656	400	Nil	425	22	5	9	0.33	7.06	76	7.8	66	2.2	13	Nil	221	-	-	2.55	1.93	C2S1	Ag.

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC	FC	RSC in meq/l	SAR	USSL Classi fication	LAND USE
							concentration in mg/l															No./100ml					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
93.	Samalkha Vill.	43	BH	40.0	7.34	1038	714	Nil	573	58	8.5	52	1.11	0.05	61	49	118	0.9	15	0.10	353	-	-	2.33	2.73	C3S1	S.S
94.	Bijwasal-1	44	TW	100.0	8.16	630	445	Nil	264	49	27	60	0.21	0.14	41	25	71	2.5	37	Nil	205	-	-	0.23	2.16	C2S1	Hor.
95.	Bijwasal-2	45	HP	40.0	7.55	1029	622	Nil	624	17	5	23	0.51	0.04	39	15	182	1.8	16	Nil	162	NIL	NIL	7.00	6.23	C3S2	Inh.
96.	Bamnauli	46	HP	20.0	7.65	1743	1122	Nil	1101	87	32	11	3.65	0.10	19	17	420	2.5	29	0.30	117	38.0	NIL	5.72	16.93	C3S4	Inh.
97.	Chchawala	47	HP	a1.0	7.31	3110	2100	Nil	406	658	400	130	1.8	0.04	1.82	136	345	6.5	32	0.28	1040	86.0	2.0	-16.13	4.66	C4S2	Inh.
98.	Kanganhari-1	48	TW	35.0	7.22	4040	2600	Nil	515	1269	48	14	1.90	0.06	167	83	680	18	38	0.30	760	-	-	-6.75	10.73	C4S3	Ag.
99.	Kanganhari-2	49	DCB	26.0	7.28	4210	2660	Nil	380	1133	146	300	1.01	0.13	242	204	360	20	35	0.12	1442	-	-	-20.59	4.13	C4S2	Ag.
100.	Kanganhari-3	50	HP	30.0	7.63	2220	1286	Nil	354	538	68	40	0.91	0.04	88	128	175	15	31	0.18	746	4.0	NIL	-9.10	2.79	C3S1	Inh.
101.	Daulatpur	51	HP	60.0	7.61	1289	787	Nil	457	160	55	70	2.05	0.05	69	70	118	8.2	17	0.08	461	NIL	NIL	1.72	2.39	C3S1	Inh.
102.	Shikarpur-1	52	HP	35.0	7.55	2310	1515	Nil	476	522	145	22	1.06	0.08	65	61	420	14	26	0.29	414	22.0	NIL	-0.48	8.98	C4S2	Inh.
103.	Shikarpur-2	53	TW	60.0	7.94	4050	2250	Nil	450	1079	296	38	2.55	0.03	381	14	540	16	40	0.16	1010	-	-	-12.81	7.39	C4S3	Ag.
104.	Gumanhera	54	HP	12.0	8.04	2430	1640	Nil	824	326	240	59	0.81	0.07	65	76	445	8.6	20	0.06	476	94.0	26.0	3.99	8.77	C4S2	Inh.
105.	Raota	55	HP	20.0	7.80	1205	690	Nil	283	222	52	3.7	0.95	0.05	43	20	200	1.2	13	Nil	191	62.0	NIL	0.82	6.30	C3S2	Ag.
106.	Jhiljhuli	56	TW	20.0	7.04	13200	8540	Nil	384	4461	775	86	1.20	0.08	619	433	1925	22	34	Nil	3325	-	-	-60.74	14.36	>C4	Ag.
107.	Goclakhurd	64	DCB	26.0	7.96	1995	1314	Nil	593	330	122	48	7.25	0.07	67	16	410	5.5	19	Nil	231	NIL	NIL	5.10	11.62	C3S3	Ag.
108.	Kharkhera round	65	HP	20.0	7.38	2780	1812	Nil	740	577	120	56	1.6	0.07	83	67	500	6.9	30	Nil	480	NIL	NIL	2.53	9.81	C4S3	Inh.
109.	Baprola	116	HP	10.0	7.55	2140	1320	Nil	702	306	125	40	0.97	Nil	100	118	162	90	16	0.06	736	38.0	NIL	-3.20	2.59	C3S1	Inh.
110.	Ugarsan park	117	HP	20.0	8.06	1094	648	Nil	399	115	48	41	2.4	0.05	72	42	106	4.8	18	Nil	355	6.0	NIL	-0.50	2.45	C3S1	Inh.
111.	Kakrola	118	HP	10.0	7.67	3470	2200	Nil	1068	542	150	379	3.05	0.06	108	147	540	22	21	0.31	876	74.0	NIL	0.01	7.94	C4S2	Com.
112.	Mitron	125	TW	a5.0	8.03	2590	1527	Nil	545	386	284	35	5.47	0.14	74	89	340	15	26	0.44	550	2.0	NIL	-2.07	6.31	C4S2	Ag.
113.	Kair	126	HP	25.0	7.69	5150	3512	Nil	391	1396	496	264	0.59	0.16	585	233	274	38	30	0.12	2422	42.0	NIL	-41.99	2.42	>C4	Inh.
114.	Donbosco Najafgarh	130	HP	40.0	7.24	6470	4154	Nil	308	1673	323	688	0.87	0.15	397	343	530	22	23	0.31	2402	8.0	NIL	42.96	4.71	>C4	Inh.
115.	Kharkhari Nahar	131	HP	25.0	7.63	3950	2432	Nil	602	883	182	203	0.63	0.17	116	105	610	7.3	24	0.44	721	4.0	NIL	-4.53	9.89	C4S3	Inh.
116.	Pindwala Kalan	132	HP	50.0	8.19	2390	1579	Nil	500	357	37	361	2.21	0.12	96	46	285	125	20	0.62	430	6.0	NIL	-0.41	5.98	C4S2	Inh.
117.	Dhansa-1	133	HP	13.0	8.06	2000	1692	Nil	596	360	126	1.96	1.99	0.10	64	71	300	1.0	18	0.19	450	2.0	NIL	0.77	6.15	C3S2	Ag.
118.	Dhansa-2	134	HP	20.0	8.14	5270	3316	Nil	641	1303	113	377	3.84	0.10	60	129	970	24	16	0.94	681	6.0	NIL	-3.10	16.18	>C4	Inh.

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO_3	HCO_3	Cl	SO_4	NO_3	F	PO_4	Ca	Mg	Na	K	SiO_2	B	Total Hardness as $CaCO_3$	TC	FC	RSC	SAR	USSL Classi fication	LAND USE
							concentration in mg/l															No./100ml		in meq/l			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
119.	Ujhwa Vill.	142	HP	50.0	7.79	4210	2962	Nil	481	931	320	508	2.14	0.06	140	182	595	22	22	1.06	1101	NIL	NIL	-14.02	7.15	C4S2	Inh.
120.	Jharoda Kalan	149	HP	28.0	7.45	4200	3397	Nil	666	966	648	208	7.3	0.07	76	88	1020	22	29	0.94	550	6.0	NIL	-0.08	18.92	C4S4	Inh.
121.	Village Dichaan	150	BH	33.0	7.76	2790	1816	Nil	519	584	338	178	3.69	0.05	126	124	420	11	31	0.06	826	14.0	NIL	-7.99	6.36	C4S2	Inh.
122.	Vill.Jafarpur Kalan	302	BH	20.0	8.23	3830	2465	Nil	756	980	344	96	6.9	0.06	78	128	800	12	21	0.37	721	6.0	NIL	-2.01	12.96	C4S4	Inh.
123.	Vill.Gazipur	303	T/W	20.0	7.84	7640	5397	Nil	654	2432	560	389	11	0.04	156	282	1525	18	24	1.81	1551	NIL	NIL	-20.29	16.84	>C4	Ag.
124.	Vill.Isapur	304	HP	16.0	7.79	908	458	Nil	346	83	20	106	0.5	0.06	90	16	102	1.8	41	0.06	290	16.0	NIL	-0.13	2.61	C3S3	Ag.
125.	Hasthal	147	HP	16.0	7.45	2470	1760	Nil	775	393	165	171	1.85	0.08	64	92	450	6.4	36	0.37	540	NIL	NIL	1.91	8.42		Inh.
126.	Nawada Majra	148	HP	10.0	7.82	1475	740	Nil	596	174	149	26	0.75	0.06	60	68	220	5.3	38	0.12	430	22.0	NIL	1.17	4.61		Com.
BLOCK MEHRAULI																											
127.	Vasantkunj	57	HP	70.0	7.52	725	482	Nil	348	30	75	26	0.33	0.07	63	24	69	1.0	17	Nil	255	8.0	NIL	0.60	1.88	C2S1	Inh.
128.	Nuclear Sci. Centre-2	59	DTW	60.0	7.50	535	377	Nil	234	39	54	9.2	0.67	0.12	65	10	48	2	32	0.05	205	NIL	NIL	-0.25	1.46	C2S1	Hor.
129.	Masoodpur	62	DTW	70.0	7.88	1055	710	Nil	600	71	19	21	0.59	0.13	93	3.4	165	2.5	34	0.25	247	2.0	NIL	4.91	4.57	C3S1	Inh.
130.	Virat Road	67	HP	40.0	8.06	1251	810	Nil	657	87	40	37	0.81	0.07	29	20	260	1.1	18	Nil	157	NIL	NIL	7.62	8.92	C3S2	Com.
131.	Satya Narain Mandir	68	HP	40.0	8.09	869	550	Nil	354	69	24	75	0.49	0.07	69	40	70	2.1	31	0.06	338	22.0	NIL	-2.96	1.65	C3S1	Inh.
132.	Tuglakabad Rly.Stn.	69	HP	40.0	7.91	913	566	Nil	328	118	40	9	0.51	0.07	83	13	107	4.0	20	Nil	260	20.0	NIL	0.19	2.85	C3S1	Inh.
133.	Badarpur	70	HP	40.0	7.87	1058	626	Nil	412	122	25	41	1.10	0.07	59	29	145	3.0	28	Nil	265	38.0	NIL	1.46	3.83	C3S1	Com.
134.	Hamdard Nagar	71	HP	30.0	8.04	1355	846	Nil	296	226	60	95	0.53	0.05	149	29	106	5.7	24	0.06	490	16.0	NIL	-4.95	2.08	C3S1	Inh.
135.	Kanpur JJ Colony	72	HP	60.0	8.06	700	490	Nil	367	42	10	29	0.51	0.06	65	9.6	78	1.6	20	0.25	201	4.0	NIL	1.99	2.36	C2S1	Com.
136.	Dakhanpur	76	HP	40.0	7.41	1349	800	Nil	367	240	32	59	0.39	0.08	134	40	91	2.4	23	0.06	500	44.0	NIL	-3.90	1.75	C3S1	Inh.
137.	Nebsari	77	HP	55.0	7.97	1150	710	Nil	483	125	26	35	1.05	0.10	66	23	172	2.3	19	Nil	260	NIL	NIL	2.71	4.59	C3S1	Inh.
138.	Harinagar Extn.	89	HP	20.0	7.37	1345	783	Nil	333	126	190	33	0.40	0.20	96	29	137	4.8	29	1.45	360	6.0	NIL	-1.74	3.14	C3S1	Inh.
139.	Molarband	90	TW	60.0	7.10	2930	1749	Nil	410	447	440	57	0.61	0.16	264	46	280	9.5	30	0.16	851	42.0	NIL	-22.71	4.17	C4S2	Inh.
140.	JNU based Camp CGWB	92	PZ	118	7.61	587	358	Nil	354	21	10	4.2	0.98	0.07	84	12	33	1	24	Nil	260	38.0	NIL	0.60	0.88	C2S1	Inh.
141.	Paschimabad JNU Campus	93	TW	60.0	7.48	1024	560	Nil	367	111	50	37	1.12	0.06	64	65	155	0.9	20	0.06	220	NIL	NIL	1.61	4.49	C3S1	Inh.

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC	FC	RSC	SAR	USSL Classi fication	LAND USE
							concentration in mg/l															No./100ml		in meq/l			
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
142.	Aya Nagar	94	HP	50.0	8.02	1326	806	Nil	605	101	15	70	0.88	0.09	26	38	235	1.6	22	Nil	220	4.0	NIL	5.52	6.81	C3S2	Inh.
143.	Chitroni	95	HP	36.0	7.87	907	510	Nil	483	52	12	52	0.39	0.07	58	46	90	1.7	17	Nil	335	NIL	NIL	1.21	2.14	C3S1	Inh.
144.	Kutub Booster Pump	97	DTW	83.0	8.20	320	205	Nil	117	23	43	4.2	0.44	0.03	41	11	12	2.7	9	Nil	149	-	-	-1.06	0.42	C2S1	Inh.
145.	Chattarpur	98	DTW	50.0	7.27	1526	950	Nil	593	170	55	74	0.70	0.12	120	47	160	2.8	19	Nil	495	-	-	-0.19	3.13	C3S1	Inh.
146.	Block A Chattarpur	99	HP	60.0	7.62	750	490	Nil	513	9.9	9	10	0.31	0.13	75	25	69	2.30	30	0.05	289	6.0	NIL	2.63	1.77	C2S1	Inh.
147.	Fatehpurberi	100	HP	50.0	7.30	1448	900	Nil	579	167	70	60	0.37	0.11	158	66	68	2.7	17	0.06	666	NIL	NIL	3.81	1.15	C3S1	Com.
148.	Indira Nagar Colony	101	TW	76.0	7.72	923	540	Nil	361	87	25	41	0.46	0.11	90	24	76	1.4	17	Nil	325	-	-	-0.59	1.84	C3S1	Inh.
149.	Compound of Sh Muni Ram	102	TW	83.0	7.81	496	306	Nil	315	10	12	4.9	0.35	0.07	50	17	37	1.9	35	.19	195	20.0	NIL	1.27	1.15	C2S1	Inh.
150.	Indira Enclave New Colony	109	HP	56.0	7.71	1026	636	Nil	393	139	22	13	0.81	0.09	58	11	157	1.6	36	Nil	190	NIL	NIL	2.64	4.96	C3S1	Inh.
151.	Satbari	110	TW	100	7.70	783	442	Nil	406	31	10	18	0.63	0.09	80	27	36	1.4	39	.06	310	34.0	2.0	0.45	0.89	C3S1	Inh.
152.	Deragaon	111	HP	50.0	7.51	4130	3210	Nil	695	688	450	690	0.90	0.09	134	167	690	4.7	43	0.06	1021	6.0	NIL	-9.00	9.40	C4S3	Inh.
153.	Andheri More	112	HP	50.0	7.71	1858	1200	Nil	502	274	140	40	1.65	0.14	76	19	320	2.0	26	Nil	270	NIL	NIL	2.83	8.47	C3S2	Inh.
154.	Wild life Sanctuary	139	HP	115	7.16	577	364	Nil	243	63	10	1.1	0.23	0.17	36	16	64	3.4	49	0.06	155	6.0	NIL	0.89	2.23	C2S1	F.A.
155.	Rajokari Rd	141	BH	53.0	7.62	1542	1183	Nil	494	163	93	262	0.46	0.14	76	45	255	1.3	40	0.90	375	10.0	NIL	0.59	5.73	C3S1	Hor.
156.	Sultanpur	143	HP	50.0	8.01	877	569	Nil	525	20	24	19.8	0.54	0.13	36	13	160	2.4	31	0.31	145	36.0	NIL	5.71	5.78	C3S2	Inh.
157.	Vill.Gadaipur	144	BH	90.0	7.50	2910	2272	Nil	487	334	312	743	0.50	0.07	237	153	245	4.3	27	0.06	1221	NIL	NIL	-16.42	3.05	C4S1	Com.
158.	Vill.Junapur	145	HP	50.0	7.64	1562	810	Nil	570	160	130	124	1.12	0.09	43	101	250	2.9	24	Nil	360	22.0	NIL	2.15	5.73	C3S2	Ag.
159.	Mahipal	146	TW	35.0	7.68	764	328	Nil	308	94	32	31	0.28	0.07	80	41	26	0.6	24	.06	370	NIL	NIL	-2.36	0.59	C3S1	Inh.
160.	Krishna Market	305	HP	70.0	7.65	1002	724	Nil	423	90	91	67	0.94	0.03	90	29	114	5.4	26	0.12	345	-	-	0.03	2.67	C3S1	Inh.
161.	North Chitorni	307	TW	30.0	7.71	640	546	Nil	423	17	130	18	3.53	0.09	58	33	52	0.9	24	Nil	280	NIL	NIL	-1.67	1.35	C2S1	F.A.
162.	Kishangarh-1	308	TW	162	7.55	1312	723	Nil	705	76	185	31	1.01	0.09	58	16	335	1.20	29	0.31	210	NIL	NIL	7.35	10.05	C3S2	Hor.
163.	Kishangarh-2	309	TW	70.0	8.07	605	512	Nil	397	59	22	20	1.1	0.06	50	29	90	1.1	41	0.12	245	64.0	4.0	1.61	2.50	C2S1	B.K.F
164.	Rangpuri Mohau	310	HP	25.0	7.97	834	591	Nil	218	111	116	39	0.65	0.08	72	27	8 6	1.4	30	Nil	290	NIL	NIL	-2.23	2.20	C3S1	Inh.
165.	Vill. Godaipur	311	DTW	150	7.65	830	598	Nil	493	35	52	41	0.41	0.08	62	26	108	2.2	28	0.12	260	-	-	2.89	2.91	C3S1	Inh.
166.	Havsrani	128	TW	46.0	7.94	859	640	Nil	346	80	76	69	0.13	0.17	110	35	56	1.5	39	0.06	420	42.0	NIL	-2.73	1.19		Inh.

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC No./100ml	FC	RSC in meq/l	SAR	USSL Classi fication	LAND USE
							concentration in mg/l																				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
BLOCK CITY																											
167.	Palam colony	63	HP	40.0	7.80	1319	820	Nil	418	181	31	105	0.23	0.08	135	48	79	1.6	32	0.06	534	NIL	NIL	-3.82	1.47		Inh.
168.	Munirka DDA Flats	60	DTW	80.0	7.45	880	580	Nil	425	56	42	34	2.20	0.11	75	18	105	1.5	32	0.10	261	NIL	NIL	-2.25	2.83	C3S1	Inh.
169.	RK Puram	61	HP	70.0	7.99	1136	680	Nil	406	97	68	42	1.27	0.06	75	23	148	0.9	23	Nil	280	NIL	NIL	1.06	3.86	C3S1	Inh.
170.	Begampur	66	DTW	110.0	7.77	2150	1400	Nil	457	271	200	240	0.81	0.07	133	85	225	2.4	20	0.19	682	36.0	NIL	-6.13	3.75	C3S1	Com.
171.	Sant Nagar	73	HP	15.0	7.79	1199	790	Nil	419	135	140	6.6	4.4	0.06	122	32	110	15	18	0.06	435	NIL	NIL	-1.84	2.27	C3S1	L.F.
172.	Kilokiri	74	HP	20.0	7.74	1818	1216	Nil	477	226	230	75	0.37	0.24	144	41	232	12	11	0.13	530	NIL	NIL	-2.79	4.30	C3S1	L.F
173.	PWD Nursery	75	TW	50.0	7.84	1716	1070	Nil	535	238	92	71	1.22	0.09	96	36	250	3.5	19	0.13	390	-	-	0.96	5.50	C3S1	Hor.
174.	Shakarpur	78	HP	10.0	7.52	750	505	Nil	308	85	7	56	0.44	0.25	82	18	55	13	34	0.30	279	NIL	NIL	-0.54	1.43	C2S1	Ag.
175.	India Gate-1	79	PZ	35.0	8.25	1190	795	Nil	410	88	144	22	12.52	0.11	11	9	280	1.4	23	0.20	65	-	-	-5.42	15.11	C3S3	Hor.
176.	India Gate-2	80	HP	13.0	7.80	1910	1315	Nil	622	197	245	121	2.54	0.14	84	86	265	28	17	Nil	563	102.0	NIL	-1.05	4.86	C3S1	Hor.
177.	Delhi Zoo	81	TW	50.0	7.04	10600	8460	Nil	395	2060	2060	1589	2.97	0.12	451	541	1300	235	26	0.30	3351	NIL	NIL	-60.48	9.77	>C4S3	Inh.
178.	Nizamudin	82	STW	15.0	8.25	1940	1360	Nil	945	120	160	36	4.83	0.21	13	3.4	520	1	28	0.10	47	6.0	NIL	14.55	33.17	C4S4	Hor.
179.	Jammila	83	HP	12.0	7.75	3830	2800	Nil	513	917	515	194	2.46	0.20	164	242	470	1.5	38	Nil	1406	42.0	NIL	-19.69	5.46	C4S2	Inh.
180.	Okhla	84	HP	10.0	7.46	1198	768	Nil	721	59	60	3.9	1.02	.06	24	88	67	112	15	Nil	420	22.0	NIL	3.42	1.41	C3S1	Inh.
181.	Abdul Fazal Enclave	85	HP	10.0	7.37	914	570	Nil	515	42	55	2.3	0.39	0.05	98	49	43	13	12	Nil	445	NIL	NIL	0.46	0.88	C3S1	Inh
182.	Ashram Chawk	86	HP	25.0	7.26	1923	1270	Nil	521	222	290	74	2.30	0.09	106	106	196	1.3	20	.06	700	2.0	NIL	-5.46	3.22	C3S1	Inh.
183.	New Friends colony	87	TW	25.0	7.62	1110	635	Nil	322	120	98	102	1.29	0.11	108	43	70	1.7	32	Nil	447	NIL	NIL	-3.65	1.44	C3S1	Inh.
184.	Madanpur Khandar	88	HP	8.0	7.77	1790	1220	Nil	498	254	235	42	0.49	0.09	125	40	230	27	19	0.40	475	22.0	NIL	-1.33	4.59	C3S1	D.F.
185.	Lodhi garden	91	TW	40.0	7.22	1381	880	Nil	386	226	122	20	0.12	0.08	146	41	110	1.6	23	0.06	535	770	2.0	-4.37	2.04	C3S1	Hor.
186.	UPSC	96	HP	36.0	7.77	2040	1280	Nil	541	326	130	74	1.75	0.08	114	43	300	5.3	20	Nil	460	NIL	NIL	-0.34	6.08	C3S2	Inh.
187.	Age office Cant.Area	103	TW	60-100	8.04	1020	670	Nil	469	102	45	29	0.74	0.10	82	25	125	3	24	Nil	307	2.0	NIL	1.54	3.10	C3S1	Inh.
188.	Cant.Area APS Colony	104	TW	60-100	8.20	630	404	Nil	265	56	43	17	0.50	0.06	58	22	61	3	10	0.10	233	NIL	NIL	-0.21	1.74	C2S1	Inh.
189.	Okhla Road East of Kailash-1	106	HP	30.0	7.62	1334	800	Nil	386	208	80	6.2	0.68	0.07	110	28	147	1.9	28	Nil	390	NIL	NIL	-1.47	3.24	C3S1	Inh.

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC No./100ml	FC	RSC in meq/l	SAR	USSL Classi fication	LAND USE
							concentration in mg/l																				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
190.	Okhla Road East of Kailash-2	107	DTW	40.0	8.61	970	630	32	245	115	75	36	0.98	0.06	10	24	172	1.0	33	Nil	125	24.0	NIL	2.52	6.69	C3S2	Inh.
191.	Kalka Mandir	108	D/W	36.0	8.06	1399	820	Nil	444	163	104	41	0.92	0.38	150	49	85	2.1	14	0.50	575	142.0	22.0	-4.22	1.54	C2S1	Hor.
192.	Indira Enclave	113	HP	13.0	7.75	2020	1314	Nil	522	226	356	68	0.95	0.11	120	109	200	5.1	15	Nil	751	30.0	NIL	-6.45	4.32	C3S1	Inh.
193.	Vikaspuri	119	HP	15.0	8.05	911	530	Nil	450	42	50	29	1.85	.09	46	56	69	7.1	12	Nil	345	NIL	NIL	0.48	1.62	C3S1	Com.
194.	Rajauri Garden	120	HP	13.0	7.64	1549	990	Nil	587	153	80	74	4.25	0.05	20	7.3	340	1.9	14	0.19	80	4.0	NIL	8.00	16.53	C3S4	Com.
195.	Nangli Jamb	121	HP	13.0	7.71	5080	3200	Nil	599	1185	600	78	1.35	0.06	206	339	440	27	14	.06	1912	22.0	2.0	-28.39	6.38	>C4S2	Com.
196.	Meera Bagh	122	HP	15.0	7.99	976	600	Nil	438	59	70	22	2.05	0.05	16	38	165	2.8	13	Nil	195	-	-	3.27	5.14	C3S1	Inh.
197.	Greater Kailash	129	HP	20.0	7.68	1212	725	Nil	461	120	48	35	0.51	0.18	104	22	130	0.8	34	0.12	350	34.0	NIL	0.56	3.02	C3S1	Inh.
198.	Sarita Vihar-1	135	HP	20.0	7.82	2810	1785	Nil	673	547	139	149	0.74	0.13	156	119	307	4.2	26	0.12	881	-	-	-6.57	4.50	C4S2	Ag.
199.	Sarita Vihar-2	136	HP	35.0	7.34	2190	1284	Nil	635	353	108	23	1.11	0.15	128	54	271	3.5	25	0.12	540	NIL	NIL	-0.40	5.07	C3S2	Inh.
200.	Okhla Indl. Phase-I(1)	137	HP	63.0	7.39	1883	1105	Nil	410	300	97	110	0.90	0.13	132	45	187	7.0	21	0.06	515	2.0	NIL	-3.58	3.58	C3S1	Ind.
201.	Okhla Indl. Phase-I(2)	138	HP	65.0	7.68	1184	741	Nil	346	186	88	10	0.8	0.12	80	36	142	3.8	21	0.19	350	NIL	NIL	-1.33	3.30	C3S1	Ind.
202.	Vasant Enclave	140	HP	36.0	7.66	1528	1018	Nil	410	200	126	133	2.43	0.15	82	84	142	0.5	43	0.25	550	74.0	NIL	-4.28	2.64	C3S1	Inh.
203.	Kalkaji Extn.	306	T/W	70.0	7.62	1232	680	Nil	397	170	121	62	1.2	0.08	88	28	180	1.6	29	0.19	335	8.0	NIL	-0.19	4.28	C3S1	Inh.
204.	Parsh Dharam-shala	179	D/W	6.15	7.90	1305	950	Nil	425	116	176	100	2.03	0.07	80	49	138	49	29	0.35	400	28	2.0	-1.04	3.00	C3S1	Inh.
205.	Shanti Vampustron	180	HP	7.0	7.20	2220	1605	Nil	652	275	335	144	0.62	0.10	112	129	45	26	13	0.40	809	-	-	-5.50	3.75	C3S1	Inh.
206.	Bela State Shantivan	181	T/W	13.0	7.39	1795	1175	Nil	578	282	194	7.9	0.35	0.05	110	102	158	14	19	0.05	694	-	-	-4.38	2.61	C3S1	Ag.
207.	Old Delhi Rly.Stn.	182	DW	4.08	7.64	980	660	Nil	381	92	75	79	1.29	0.11	86	53	61	2.80	17	0.15	433	22.0	NIL	-2.41	1.27	C3S1	Inh.
208.	Majnu Ka Tilla	183	DW	19.0	7.75	1640	1200	Nil	578	145	200	62	2.28	0.24	73	28	205	170	25	0.75	298	46.0	2.0	-3.53	5.17	C3S1	Inh.
209.	Timarpur	251	HP	8.0	7.81	841	497	Nil	378	33	39	34	2.73	0.10	54	26	83	6.4	30	Nil	240	18.0	NIL	1.40	2.33	C3S1	Ag.
210	Nirankari Colony	252	HP	20.0	7.91	1365	900	Nil	372	120	242	86	1.32	0.11	80	26	150	128	31	0.19	305	196	118	-0.01	3.72	C3S1	Inh.
211.	Malkapur	253	HP	18.0	7.75	1758	1075	Nil	532	197	152	47	0.46	0.15	60	46	265	6.0	35	Nil	340	24.0	NIL	1.92	6.25	C3S2	S.S
212.	Kewal Park	254	HP	10.0	7.59	1872	1233	Nil	673	273	154	6.6	0.37	0.11	64	64	305	6.7	23	Nil	425	4.0	NIL	2.53	2.57	C3S1	Inh.

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC	FC	RSC in meq/l	SAR	USSL Classi fication	LAND USE
							concentration in mg/l															No./100ml					
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
213.	Adarsh Nagar	255	HP	10.0	7.65	2380	1385	Nil	423	510	128	6.3	0.60	0.10	100	63	325	15	25	0.31	510	38.0	NIL	-3.27	6.26	C4S2	Inh.
214.	Pitampur YP Block	258	HP	15.0	7.91	750	316	-	352	56	62	3.0	.78	.07	68	45	41	4.3	37	.06	355	NIL	NIL	-1.32	0.94	C2S1	Inh.
215.	Wazirpur Indust.Area	259	HP	33.0	7.45	1335	940	-	442	129	175	92	.71	.05	118	62	110	6	27	0.12	550	4.0	NIL	-3.75	2.04	C3S1	Ind.
216.	Maharani Bagh	262	HP	13.0	8.05	570	365	-	278	28	44	5.7	3.99	0.06	32	12	82	7.3	8	0.26	130	NIL	NIL	1.96	3.13	C2S1	Com.
217.	Narang Colony	263	HP	13.0	7.50	925	610	-	571	53	34	2.7	0.34	0.14	110	37	62	4.5	21	ND	428	4.0	NIL	0.80	1.31	C3S1	Inh.
218.	Zakhira	264	HP	13.0	8.20	1645	1140	-	542	229	190	28	2.63	0.16	71	36	290	1.10	23	0.06	326	24.0	NIL	2.37	6.99	C3S2	Com.
219.	Pratapnagar	265	HP	15.0	7.96	655	435	-	308	49	54	3.8	0.32	0.16	65	34	31	0.4	46	ND	303	NIL	NIL	-1.01	0.78	C2S1	Com.
220.	Ranapratap Nagar	266	HP	13.0	8.10	1250	790	-	578	99	122	27	2.28	0.14	54	33	230	3.4	31	0.09	270	18.0	NIL	4.09	6.09	C3S2	Com.
221.	Naraina	268	TW	33.0	7.15	3510	2635	-	469	593	350	600	0.59	0.15	179	103	540	1.8	28	0.10	870	NIL	NIL	-9.71	7.97	C4S2	Inh.
222.	Sudarshanpuri	269	HP	17.0	7.0	2000	1425	-	630	268	132	202	0.94	0.12	142	66	230	26	41	0.01	623	150	2.0	-2.14	4.01	C3S1	Inh.
223.	Todapur	270	DTW	13.0	7.35	935	635	-	432	67	99	17	0.54	0.14	121	40	39	0.70	34	ND	465	16.0	NIL	-2.22	0.79	C3S2	Inh.
224.	Inderpuri	271	HP	13.0	7.65	1150	730	-	381	180	60	17	1.67	0.14	71	40	145	0.7	22	0.03	340	50.0	NIL	-0.55	3.42	C3S1	Inh.
225.	West Patel Nagar	272	TW	20.0	7.68	1040	685	-	410	99	86	45	0.75	0.17	58	42	126	0.8	24	0.07	316	2.0	NIL	0.40	3.08	C3S1	Inh.
226.	Bapudham Complex	273	HP	33.0	7.40	1465	955	-	542	166	94	75	1.12	0.20	80	52	185	1.0	29	ND	414	NIL	NIL	0.60	3.96	C3S1	Inh.
227.	Sanjay Camp Chankyapuri-I	274	HP	33.0	7.40	2000	1450	-	469	289	180	240	1.09	0.20	157	59	240	1.5	46	0.03	633	NIL	NIL	-4.97	4.15	C3S1	Inh.
228.	Kidwai Nagar	275	HP	23.0	7.50	1525	975	-	527	197	86	58	0.59	0.19	95	40	210	1.9	21	0.01	400	NIL	NIL	0.64	4.56	C3S1	Com.
229.	Kotla Muba-rakpur	276	HP	47.0	7.30	2500	1750	-	234	550	190	328	0.25	0.17	246	75	215	2.7	24	0.01	921	22.0	NIL	-14.57	3.08	C4S1	Inh.
230.	Laxmibai Nagar	277	HP	23.0	7.75	1370	935	-	557	141	94	48	3.65	0.13	33	25	295	0.7	16	0.01	186	4.0	NIL	5.40	9.41	C3S2	Inh.
231.	Safdarjang airport	278	HP	17.0	7.60	2000	1315	-	491	303	184	76	0.91	0.15	62	14	415	1.0	15	0.07	210	4.0	NIL	3.85	12.47	C3S3	Inh.
232.	Pragati Vihar	279	HP	8.0	7.90	1840	1180	-	608	282	86	31	6.43	0.10	26	25	405	1.5	13	0.04	168	2.0	NIL	6.61	13.61	C3S3	Inh.
233.	Nizamuddin	280	HP	13.0	8.08	1370	1000	-	754	81	98	16	5.95	0.15	13	4.5	380	2.5	20	ND	51	2.0	NIL	11.34	23.15	C3S4	Inh.
234.	Jeevan Vihar	281	HP	13.0	7.60	2080	1635	-	732	148	320	232	3.23	0.13	45	38	470	4.2	11	0.03	270	NIL	NIL	6.61	12.46	C3S3	Inh.
235.	Jalsadan	282	DTW	100.0	8.15	225	165	-	95	11	39	3.50	0.41	0.05	37	7.9	7.0	2.0	10	0.02	126	6.0	NIL	0.95	0.27	C1S1	Inh.
236.	Moti Bagh Colony	283	HP	13.0	7.62	1065	735	-	381	134	87	41	2.11	0.17	65	46	122	0.70	43	0.16	354	4.0	NIL	-0.83	4.82	C3S1	Inh.

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC No./100ml	FC	RSC in meq/l	SAR	USSL Classi fication	LAND USE
							concentration in mg/l																				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
237.	Hafeez nagar	284	HP	13.0	7.68	435	320	-	183	31	58	1.5	0.20	0.09	62	10	21	5.10	38	0.07	196	2.0	NIL	-0.91	0.65	C2S1	Inh.
238.	Chiriya Ghat At gate	285	HP	13.0	7.40	1300	975	-	498	120	177	56	0.91	0.15	69	41	180	47	34	0.66	340	8.0	NIL	1.46	4.25	C3S1	Inh.
239.	Pandara Road	286	HP	13.0	7.54	1255	925	-	535	99	170	32	1.0	0.14	65	16	250	1.70	23	0.42	228	NIL	NIL	4.20	7.20	C3S2	Inh.
240.	Election Commission	287	HP	13.0	7.27	1330	920	--	535	148	96	87	0.89	0.17	86	79	126	0.8	30	0.01	540	6.0	NIL	-2.03	2.36	C3S1	Inh.
241.	Panchkuia Road	288	HP	17.0	7.35	1135	850	-	573	120	90	43	2.38	0.15	82	40	165	2.6	35	0.24	368	2.0	NIL	1.05	3.75	C3S1	Inh.
242.	Bara Hindu RAO	289	HP	13.0	7.14	1260	860	--	432	145	95	80	0.54	0.20	78	45	112	58	32	0.11	382	8.0	NIL	-0.55	2.49	C3S1	Inh.
243.	Kishan Ganj	290	HP	13.0	7.55	2930	2080	--	351	705	310	130	0.42	0.16	97	122	450	3.7	26	0.07	745	NIL	NIL	-9.12	7.18	C4S2	Inh.
244.	Than Singh nagar,.	291	HP	10.0	6.90	1480	960	Nil	637	166	55	76	1.09	0.12	65	101	110	37	28	0.01	577	122	NIL	-1.09	1.99	C3S1	Inh.
245.	New Rajiv Nagar,	292	HP	7.0	7.32	970	630	NIL	432	85	85	8.5	0.60	.18	101	36	73	1	25	ND	400	4.0	NIL	-0.92	1.59	C3S1	Com.
246.	Budha park	293	DTW	83.0	6.95	1050	710	NIL	410	106	142	2.4	0.75	0.15	112	43	75	0.8	25	ND	456	NIL	NIL	-2.39	1.53	C3S1	Hor.
247.	Majradabas Budampur	300	HP	12.0	7.70	820	530	Nil	344	71	58	14	0.95	0.10	48	31	58	64	12	0.53	247	NIL	NIL	0.71	1.60	C3S1	Inh.

BLOCK SHAHADRA

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC No./100ml	FC	RSC in meq/l	SAR	USSL Classi fication	LAND USE
248.	Laxmi Nagar-1	2	HP	10.0	7.27	1752	1171	Nil	516	196	245	49	0.77	0.10	115	36	250	6.7	14	0.20	434	46.0	NIL	-0.22	5.22	C3S1	Inh.
249.	Laxmi nagar-2	3	TW	60.0	7.66	1085	702	Nil	227	169	152	1.3	0.71	0.09	86	25	130	6.0	29	0.05	316	-	-	-2.60	3.18	C3S1	Com.
250.	Gaganvihar	4	HP	10.0	7.75	1160	760	Nil	557	78	118	3.4	0.74	0.09	63	45	165	6.1	22	0.72	344	NIL	NIL	2.24	3.87	C3S1	Inh.
251.	CBD complex	5	HP	10.0	7.33	2080	1408	Nil	510	318	280	49	0.58	0.05	158	59	255	16	17	0.15	636	14.0	NIL	-4.35	4.40	C3S1	Ag.
252.	Jhilmil colony	6	HP	10.0	7.60	937	585	Nil	412	68	89	5.6	0.59	0.09	77	36	80	7.6	15	0.10	340	NIL	NIL	-0.04	1.89	C3S1	Inh.
253.	Vivek Vihar	7	BH	16.0	7.33	3020	1965	Nil	435	762	250	1.2	0.68	0.06	177	85	440	6.7	25	0.25	794	4.0	NIL	-8.73	6.80	C4S2	Hor.
254.	Vivek Vihar-1	8	DTW	50.0	7.45	3160	1991	Nil	215	849	270	12	0.48	0.05	158	53	500	9.8	31	0.35	611	16.0	2.0	-8.70	8.80	C4S2	Inh.
255.	Ghazipur	10	DTW	40.0	7.85	1400	890	Nil	351	219	152	0.8	1.01	0.11	56	20	230	5.2	30	0.14	223	-	-	1.30	6.70	C3S2	L.F
256.	East Vinode Vihar	11	HP	10.0	7.41	2250	1534	Nil	308	385	315	180	0.79	0.07	194	70	210	6.5	19	0.05	774	6.0	NIL	-10.38	3.29	C3S1	Inh.
257.	Khitchripur	12	DTW	40.0	7.32	1687	1121	Nil	377	260	250	3.6	0.79	0.06	101	43	245	7.0	22	0.15	427	-	-	-2.36	5.16	C3S2	Inh.
258.	Mayur Vihar Phase-I(1)	13	HP	10.0	7.29	2280	1568	Nil	615	342	330	1.7	0.99	0.03	156	52	350	6.8	21	0.05	602	NIL	NIL	-1.96	6.20	C4S2	Com.
259.	Mayur Vihar Phase-I(2)	14	Ramney Well	50.0	7.35	1473	945	Nil	429	179	206	2.9	0.65	0.06	101	40	170	8.9	22	0.10	417	NIL	NIL	-1.31	3.62	C3S1	Inh.

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC No./100ml	FC	RSC in meq/l	SAR	USSL Classi fication	LAND USE
							concentration in mg/l																				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
260.	Chilla Saroda	15	DTW	40.0	7.30	1178	757	Nil	493	116	103	3.5	0.38	0.05	129	40	93	5.8	20	0.15	485	2.0	NIL	-1.62	1.84	C3S1	Inh.
261.	Dallupura -1	16	HP	10.0	7.36	965	622	Nil	493	75	48	4.0	0.36	0.05	96	27	19	8.3	27	0.55	352	NIL	NIL	1.05	2.08	C3S1	Inh.
262.	Dallupura -2	17	DTW	20.0	7.55	795	518	Nil	348	53	85	2.2	0.51	0.06	74	26	79	4.3	20	0.15	291	6.0	NIL	-0.12	2.02	C3S1	Inh.
263.	Kundli	90	HP	16.0	7.35	780	504	Nil	406	49	32	17	0.28	0.06	80	25	61	15	22	0.05	303	NIL	NIL	0.59	1.52	C3S1	Inh.
264.	Mayur Vihar 3	20	DTW	100.0	7.70	2190	1480	Nil	278	469	320	7.7	0.72	0.10	101	57	350	8.5	26	0.32	485	-	-	-5.11	6.92	C3S2	Hor.
265.	Ghazipur	21	HP	10.0	7.20	3740	2320	Nil	591	667	333	139	0.40	0.05	153	83	450	180	20	0.35	723	NIL	NIL	-4.76	7.28	C4S2	Inh
266.	Yamuna Bed Patparganj	32	STW	20.0	7.50	921	590	Nil	400	77	78	2.7	1.15	0.05	99	26	75	10	21	0.25	354	24.0	NIL	-0.52	1.73	C3S1	Ag.
267.	Shakurpur-1	23	HP	25.0	7.25	1195	813	Nil	406	97	156	60	0.24	0.04	132	31	98	18	18	0.25	456	NIL	NIL	-2.47	1.99	C3S1	Inh.
268.	Shakurpur-2	24	Ramney	40.0	7.35	1065	701	Nil	394	83	144	12	0.31	0.04	107	37	92	7.9	21	0.10	420	-	-	-1.93	1.95	C3S1	Inh.
269.	Mandoli	25	STW	20.0	7.25	1375	937	Nil	464	141	234	5.0	0.35	0.02	126	53	128	7.4	10	Nil	534	4.0	NIL	-3.07	2.41	C3S1	Inh.
270.	Hasanpur	26	HP	10.0	7.46	641	388	Nil	331	29	42	2.3	0.68	0.03	78	23	28	5.2	16	0.06	289	NIL	NIL	-0.35	0.72	C2S1	Inh.
271.	Anand Vihar ISBT	27	TW	70.0	7.91	3810	2400	Nil	283	1031	325	0.02	0.66	0.02	155	72	620	9.3	40	0.18	682	-	-	-8.98	8.84	C4S3	Inh.
272.	Trilokpuri-1	36	TW	50.0	7.55	1170	678	Nil	320	93	180	1.16	0.90	0.10	80	24	132	7.0	22	0.55	300	26.0	NIL	-0.75	3.31	C3S1	Hor.
273.	Kalyanpur	37	HP	40.0	7.30	2530	1408	Nil	307	580	166	1.22	0.70	0.15	184	53	260	9.5	28	0.30	680	NIL	NIL	-8.56	4.33	C4S2	Inh.
274.	Trilokpuri-2	38	HP	12.0	7.32	1630	957	Nil	372	186	216	33	0.48	0.08	132	32	167	4.0	14	0.30	460	4.0	NIL	-3.11	3.38	C3S1	Inh.
275.	Ashok Nagar	39	HP	12.0	7.57	920	508	Nil	333	46	110	3	0.50	0.13	96	12	70	4.7	18	Nil	290	12.0	NIL	-0.34	1.76	C3S1	L.F
276.	Rozapur	40	HP	8.0	7.35	1100	606	Nil	397	93	100	2.8	0.5	0.15	104	34	64	9.5	20	0.6	400	2.0	NIL	-1.50	1.39	C3S1	Ag.
277.	Jhilmil Indust.Area	151	HP	7.62	7.58	1910	1265	Nil	469	289	235	55	0.40	0.03	119	41	270	7.3	14	Nil	465	NIL	NIL	-1.62	5.44	C3S2	Ind.
278.	Vivek Vihar Rly.Station	152	DTW	65.0	7.60	3320	2170	Nil	286	924	300	23	0.75	0.04	123	88	535	10	21	0.25	670	-	-	-8.71	8.99	C4S3	Inh.
279.	Dilshad Garden	153	HP	9.0	7.52	2240	1495	Nil	600	465	175	5.3	0.67	0.03	56	99	380	5.7	10	0.25	549	NIL	NIL	-1.49	7.06	C3S2	S.S
280.	GT Road Shahadra	154	D/W	15.0	7.85	260	165	Nil	103	14	34	2.1	0.23	0.01	41	6.7	6.0	2.5	6.0	0.05	130	-	-	-0.92	0.23	C2S1	Inh.
281.	Nand Nagri Gali No.2	155	DTW	60.0	7.98	1588	1188	Nil	327	281	232	63	1.01	0.08	98	34	265	9.2	42	0.12	385	NIL	NIL	-2.34	5.87	C3S2	Inh.
282.	Saboli Gali No.20	157	HP	27.74	7.40	575	380	Nil	330	32	21	5.5	1.07	0.05	71	16	41	4.3	23	Nil	242	14.0	NIL	0.56	1.14	C2S1	Inh.
283.	Gokulpuri-1 Sanjay Colony	158	HP	12.0	7.35	660	420	Nil	359	28	45	3	0.57	0.02	99	14	26	12	13	Nil	303	NIL	NIL	-0.17	0.65	C2S1	Inh.
284	Gokulpuri-2	159	HP	12.0	7.57	1006	414	NIL	519	56	73	36	0.41	0.0	128	44	55	3.9	19	0.87	500	NIL	NIL	-1.49	1.07	C3S1	Inh.

Sr No	Location	Sample No	Source of Sample	Depth in mtr.	pH	Ec in micro-mhos/Cm at 25oC	TDS	CO3	HCO3	Cl	SO4	NO3	F	PO4	Ca	Mg	Na	K	SiO2	B	Total Hardness as CaCO3	TC No./100ml	FC No./100ml	RSC in meq/l	SAR	USSL Classi fication	LAND USE
							concentration in mg/l																				
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)
285.	Shahdra Kanti Nagar-1	160	HP	15.0	7.45	1970	1110	Nil	542	24	350	5.3	1.06	0.02	93	63	285	6.3	13	0.20	493	NIL	NIL	-0.98	5.58	C3S1	S.S
286.	Kanti Nagar-2	161	HP	12.0	7.40	1415	925	Nil	542	152	146	3.2	0.44	0.03	106	22	200	13	11	0.05	354	NIL	NIL	1.81	4.63	C3S1	Inh.
287.	Usmanpur-1	162	TW	12.0	7.70	590	318	Nil	330	18	52	3.2	0.44	0.65	76	35	19	8	14	0.05	293	NIL	NIL	-0.46	0.48	C2S1	Hor.
288.	Usmanpur-2	163	HP	9.0	7.68	365	235	Nil	205	18	14	1.2	0.28	0.02	56	9	14	7	11	0.05	177	NIL	NIL	-0.17	0.46	C2S1	Inh.
289.	Karawal Nagar	165	HP	7.5	7.32	2580	1695	Nil	674	494	232	4.2	0.37	0.02	123	42	445	11	10	0.05	479	NIL	NIL	1.46	8.85	C4S3	Inh.
290.	Rajiv Vihar	164	HP	7.5	7.15	1510	975	Nil	557	183	130	21	0.32	0.02	149	25	160	22	7	Nil	475	-	-	-0.37	3.20	C3S1	Inh.
291.	Sonia Vihar	166	HP	6.0	7.95	460	298	Nil	205	32	42	0.5	0.69	0.03	37	5.7	64	2.8	9	Nil	117	NIL	NIL	1.03	2.57	C2S1	Inh.
292.	Subeypur-1	167	T/W	12.0	7.68	1710	1065	Nil	322	370	135	1.6	0.40	0.04	80	25	270	9	11	0.05	303	-	-	-0.77	6.75	C3S2	Ag.
293.	Subeypur-2	168	HP	7.5	7.58	1740	1080	Nil	351	363	125	2.2	0.50	0.02	80	24	290	8	12	0.20	298	102	NIL	-0.19	7.32	C3S2	Ag.
294.	Shanti Park	169	HP	7.5	7.45	470	320	Nil	249	14	16	5	0.37	0.03	63	58	18	7	11	Nil	196	NIL	NIL	0.17	0.56	C2S1	Inh.
295.	Seelampur	170	DTW	80.0	7.40	1340	850	Nil	388	197	148	1.20	0.57	0.04	91	50	148	7.2	15	0.05	433	NIL	NIL	-2.29	3.10	C3S1	Com.
296.	Krishan Nagar	171	HP	9.0	7.82	380	255	Nil	205	18	37	1.0	0.68	0.01	58	13	11	4.4	7	Nil	196	NIL	NIL	-0.55	0.34	C2S1	Inh.
297.	Geeta Colony	172	DTW	61.0	7.35	1235	855	Nil	381	123	204	26	0.41	0.04	123	37	100	32	18	0.85	461	NIL	NIL	-2.97	2.03	C3S1	Inh.
298.	Kishankunj-1	173	STW	12.0	7.42	475	310	Nil	271	18	30	5.2	0.57	0.09	76	18	10	6.2	12	Nil	265	6.0	NIL	-0.86	0.26	C2S1	Ag.
299.	Kishanganj-2	174	Renney well-11	24.5	7.30	870	595	Nil	388	83	69	24	0.40	0.05	95	28	70	10	20	0.35	354	34.0	10.0	-0.71	1.62	C3S1	Inh.
300.	Kishanganj-3	175	Renney Well-14	23.0	7.10	800	530	Nil	366	85	23	32	0.57	0.06	86	19	17	8.3	18	0.10	293	14.0	2.0	0.14	1.78	C3S1	Inh.
301.	Loni boarder Check Post	177	STW	13.0	7.68	1105	800	Nil	351	88	250	2.4	0.68	0.04	108	31	123	5.4	17	0.15	396	18.0	NIL	-1.75	2.69	C3S1	Ag.
302.	Gandhi Nagar Hilayat Nagar	176	HP	10.0	7.16	1630	1095	Nil	776	162	140	7.3	0.4	0.03	157	64	133	30	11	0.25	656	NIL	NIL	-0.39	2.26	C3S1	Inh.
303.	Durgapuri Chowk	178	HP	9.0	6.90	1900	1286	Nil	743	174	106	141	0.39	0.06	172	80	150	56	36	0.06	671	NIL	NIL	-1.22	2.52	C3S1	Inh.

ABBREVIATIONS

Inh. - Inhabitent
Com. - Commercial.
Hor - Horticulture.
L.F - Land Fill Area.
Ag. - Agroci;tire.
BKS - Brick Kiln Factory,
S.S - Service Station.
F.A - Forest Area.

H.P. - Hand Pump
S.T.W - Shallow Tube Well.
D.T.W - Dee[Tnbe Well.
DW - Dug Well,
Pz - Piezoemeter.
D.F - Dairy Farm.
Ind. - Industrial Area.