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GROUND WATER QUALITY IN ADJOINING AREAS OF RIVER YAMUNA AT DELHI

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PREFACE

Ground water forms the major source of water supply for drinking purposes in most part of the country. For proper utilization of water for various purposes, understanding of geo-chemical controls and study of the extent of ground water contamination are of prime importance. The quality of ground water is particularly important to humans when the water is used for drinking water supply.

The National Capital Territory (NCT) of Delhi is one, which is facing severe problems in management of ground water quality and quantity. The quality of ground water within Delhi varies from place to place along with the depth of water table. It also varies with seasonal changes and is primarily governed by the extent and composition of dissolved solids present in it. The surface water bodies also play a significant role in ground water flow system. The hydraulic gradient imparts significant role in lateral and vertical migration of contaminants in ground water aquifers. Keeping in view these points the Environmental Hydrology Division has taken up the study entitled 'Ground Water Quality in Adjoining Areas of River Yamuna at Delhi' with the objective to see the suitability of ground water for drinking and irrigation purposes and to examine the likely impact of Yamuna river water quality on ground water.

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CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

The ground water quality of adjoining areas of river Yamuna in Delhi has been assessed to see the suitability of ground water for irrigation and domestic applications. Thirty eight ground water samples from shallow and deep wells were collected each during pre-monsoon and post-monsoon seasons in the month of June and November 2000 respectively. Various physico-chemical, trace elements and bacteriological parameters have been determined. The data was analyzed with reference to BIS and WHO standards, ionic relationships were studied, hydrochemical facies were determined and water types identified. The study has clearly indicated higher concentration of total dissolved solids, electrical conductivity, nitrate, sulphate and sodium. The presence of total coliforms indicates bacterial contamination in ground water. The presence of heavy metals in ground water though recorded in many samples but these were not significantly higher. The water quality standards have been violated for TDS, nitrate, sulphate and sodium at few places.

An attempt has also been made to classify the ground water on the basis of different classification schemes, viz., Stiff, Piper trilinear and U.S. Salinity Laboratory classifications. As per the Stiff classification majority of the samples fall under sodium bicarbonate type followed by sodium sulphate and sodium chloride type. In the Piper trilinear and modified diagram, majority of the samples falls in Na-K-Cl-SO_4 followed by Na-K-HCO_3 and Ca-Mg-Cl-SO_4 hydrochemical facies. According to U.S. Salinity Laboratory classification of irrigation water, more than 50% samples fall under water type C3-S1 (high salinity and low SAR) such water cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected. About 30% samples fall under water type C3-S2 (high salinity and medium SAR) such water will induce an appreciable sodium hazard in fine textured soils having good cation exchange capacity, especially under low leaching conditions.

The qualitative analysis of data depicted higher concentration of various physico-chemical and bacteriological parameters in the western side of river Yamuna even in deep aquifers. However, due to paucity of hydro-chemical, geological and water level data no specific inferences could be drawn regarding the probable impact of river water quality on ground water. Further studies are being planned to investigate the impact of Yamuna river water quality on ground water system.

1.0 INTRODUCTION

Water is an essential and vital component for our life support system. In tropical regions ground water plays an important role with context to fluctuating and increasing contamination of surface water resources. Ground water has unique features, which render it particularly suitable for public water supply. It has excellent natural quality, usually free from pathogens, colour and turbidity and can be consumed directly without treatment. Ground water is widely distributed and can be frequently developed incrementally at points near the water demand, thus avoiding the need for large-scale storage, treatment and distribution system. It is particularly important as it accounts for about 88% safe drinking water in rural areas, where population is widely dispersed and the infrastructure needed for treatment and transportation of surface water does not exist. Ground water plays an important role in agriculture, for both watering of crops and for irrigation of dry season crops. It is estimated that about 45% of irrigation water requirement is met from ground water sources. Industrial demands for ground water are also high, as many of the qualities which make ground water a preferred source of potable water (low TDS, low turbidity, absence of pathogens) are also important in use of ground water in various industries.

Unfortunately, the availability of ground water is not unlimited nor it is protected from deterioration. In most of the instances, the extraction of excessive quantities of ground water has resulted in drying up of wells, damaged ecosystems, land subsidence, salt-water intrusion and depletion of the resource. Ground water quality is being increasingly threatened by agricultural, urban and industrial wastes. It has been estimated that once pollution has entered the subsurface environment, it may remain concealed for many years, becoming dispersed over wide areas of ground water aquifer and rendering ground water supplies unsuitable for consumption and other uses. The rate of depletion of ground water levels and deterioration of ground water quality is of immediate concern in major cities and towns of the country. The National Capital Territory (NCT) of Delhi is one, which is facing severe problems in management of ground water quality and quantity (CGWB and CPCB, 2000).

The intensive use of natural resources and the large production of wastes in modern society often pose a threat to ground water quality and have already resulted in many incidents of ground water contamination. Degradation of ground water quality due to various constituents has received considerable attention during recent years. Pollutants are being added to the ground water system through human activities and natural processes. Solid waste from industrial units is being dumped near the factories, which is subjected to reaction with percolating rain water and reaches the ground water level. The percolating water picks up a large amount of dissolved constituents and reaches the aquifer system and contaminates the ground water.

The quality of ground water depends on a large number of individual hydrological, physical, chemical and biological factors. Generally higher proportion of dissolved constituents are found in ground water than in surface water because of greater interaction of ground water with various materials in geologic strata. The water used for drinking purpose should be free from any toxic elements, living and nonliving organism and excessive amount of minerals that may be hazardous to health. Some of the heavy metals are extremely essential to humans, for example, cobalt, copper, etc., but large quantities of them may cause physiological disorders (Trivedy and Goel, 1986).

The adverse effects on ground water quality are the result of man's activity at ground surface, unintentionally by agricultural and industry, unexpectedly by sub-surface disposal of sewage and industrial waste water and solid waste dumps, illegally by small workshops and unfortunately by the abstraction of ground water itself. As a result the quality of ground water in many instances has steadily deteriorated with severe consequences for the use of water for several purposes, especially for drinking water.

Handa (1994) has briefly described the status of ground water contamination in India. The physico-chemical characteristics of waste effluents being released to the environment by various industries depend upon several factors, the most important being the type of industry and the in-house treatment of waste effluents.

The contamination of ground water by heavy metals has assumed great significance during recent years due to their toxicity and accumulative behaviour. These elements, contrary to most pollutants, are not biodegradable and undergo a global eco-biological cycle in which natural waters are the main pathways. The determination of the concentration levels of heavy metals in these waters, as well as the elucidation of the chemical forms in which they appear is a prime target in environmental research today. The sources of metal pollution in the aquatics environment and their health hazards have been discussed in earlier reports (Jain, 1993; Jain et al., 1998).

Chowdhary et al. (1994) reported the status of toxic elements in ground water of Greater Varanasi. It is reported that the tube well water in the region is generally free from toxic heavy metals, viz., cadmium, copper, lead and iron and their contents are far below the safe prescribed limits. However, all the dug wells contained appreciable amount of these elements indicating their pollution from surface and sub-surface sources. Several other reports are also available on water quality studies in Varanasi, which point out the presence of heavy metals in ground water (Chowdhary, 1990; Gupta et al., 1991 a-c). Presence of toxic elements in ground water were also reported earlier by Handa (1983) and Hasan et al. (1986). Srivastava et al. (1991) reported chromium contamination in the carpet belt of Eastern Uttar Pradesh including Varanasi district. Degradation of ground water quality due to heavy metals has also been reported in Faridabad district, Haryana (Khurshid et al., 1997). It was further reported that samples collected from shallow aquifers show higher concentration of heavy metals than those from deeper aquifers.

The problems of ground water quality are more acute in the areas, which are densely populated, thickly industrialized and have shallow ground water table. Ground water is mostly polluted from the effluents discharged by industries on land, seepage from the sewage line and sewage tanks, application of fertilizers, pesticides and insecticides on agricultural land, etc. Therefore, the monitoring of ground water quality is very essential because it is the most important source of water supply for drinking purposes.

The National Capital Territory (NCT) of Delhi is one, which is facing severe problems in management of ground water quality and quantity. The quality of ground water within Delhi varies from place to place along with the depth of water table. It also varies with seasonal changes and is primarily governed by the extent and composition of dissolved solids present in it. The kind and concentration of dissolved salts depends on their sources and nature of sub-surface environment. A collaborative study has been carried out by Central Ground Water Board and Central Pollution Control Board to assess the ground water quality and suitability for various purposes particularly drinking and irrigation purposes including pollution aspects within NCT–Delhi (CGWB and CPCB, 2000). Ground water samples were collected through extensive field surveys covering entire NCT–Delhi area representing various geo-hydrological and land use conditions. The ground water sampling locations represented hand pumps, dug wells and tube wells located in urban and rural areas including thickly populated, commercial, industrial, residential colonies and agricultural areas so as to obtain a comprehensive lateral and vertical representations.

Delhi generates about 2600 MLD of sewage against installed capacity of 1270 MLD of sewage treatment. The balance untreated sewage alongwith significant quantity of partially treated sewage is discharged into Yamuna river every day. The river receives sewage and industrial wastes through twenty two drains, which join river Yamuna between Wazirabad and Okhla. Thus Delhi is the largest contributor of pollution to river Yamuna receiving almost 80% of pollution load through these drains. The surface water bodies play a significant role in ground water flow system. The hydraulic gradient imparts significant role in lateral and vertical migration of contaminants in ground water aquifers. Therefore, the present study has been carried out with the objectives to examine the suitability of ground water for drinking and irrigation purposes and to examine the probable impact of Yamuna river water quality on ground water.

In order to achieve the objectives of the study, ground water samples from the adjoining areas of river Yamuna at Delhi have been collected during pre- and post-monsoon seasons in the month of June and November 2000 and analysed for various physico-chemical constituents, trace elements and bacteriological parameters. The data has been analysed with reference to BIS and WHO standards to examine the suitability of ground water for drinking and irrigation purposes. An attempt has also be made to classify the ground water on the basis of different classification schemes, viz., Stiff diagram, Piper trilinear diagram and U.S. Salinity Laboratory classification.

2.0 STUDY AREA

The NCT of Delhi occupies an area of 1483 km^2 covering six administrative blocks, namely, Alipur, Kanjhawala, Najafgarh, Mehrauli, city and Shahdara (Fig. 1). Delhi generates about 2600 MLD of sewage against installed capacity of 1270 MLD of sewage treatment. The balance untreated sewage alongwith significant quantity of partially treated sewage is discharged into river Yamuna every day. The river receives sewage and industrial wastes through twenty two drains, which join river Yamuna between Wazirabad and Okhla (Fig. 2). Thus Delhi is the largest contributor of pollution to river Yamuna receiving almost 80% of pollution load through these drains.

2.1 Water Requirement

The water requirement of NCT of Delhi constitutes mainly for the drinking water supply of its growing population. The water supply resources in Delhi are continuously under severe pressure due to ever increasing population and industrial activities. The metropolitan city became a major centre of commerce, industry and education after independence. The growth of government departments and office complexes has contributed to the city growth. Civic amenities have not kept pace with increasing urbanisation. The unabated immigration of population has compounded the problems, resulting in flouting of land use regulations and restriction and deterioration of green cover.

2.2 Water Resources and Water Treatment Capacity

The estimated water availability from surface water sources viz. Yamuna, Ganga and Bhakra system is 1150.2 MCM. The Yamuna river contributes a substantial part of this. Of the total 724 MCM water available in Yamuna river, (NCT Delhi share) the flood water is about 580 MCM, of which 50% is not being utilized but flows out of Delhi.

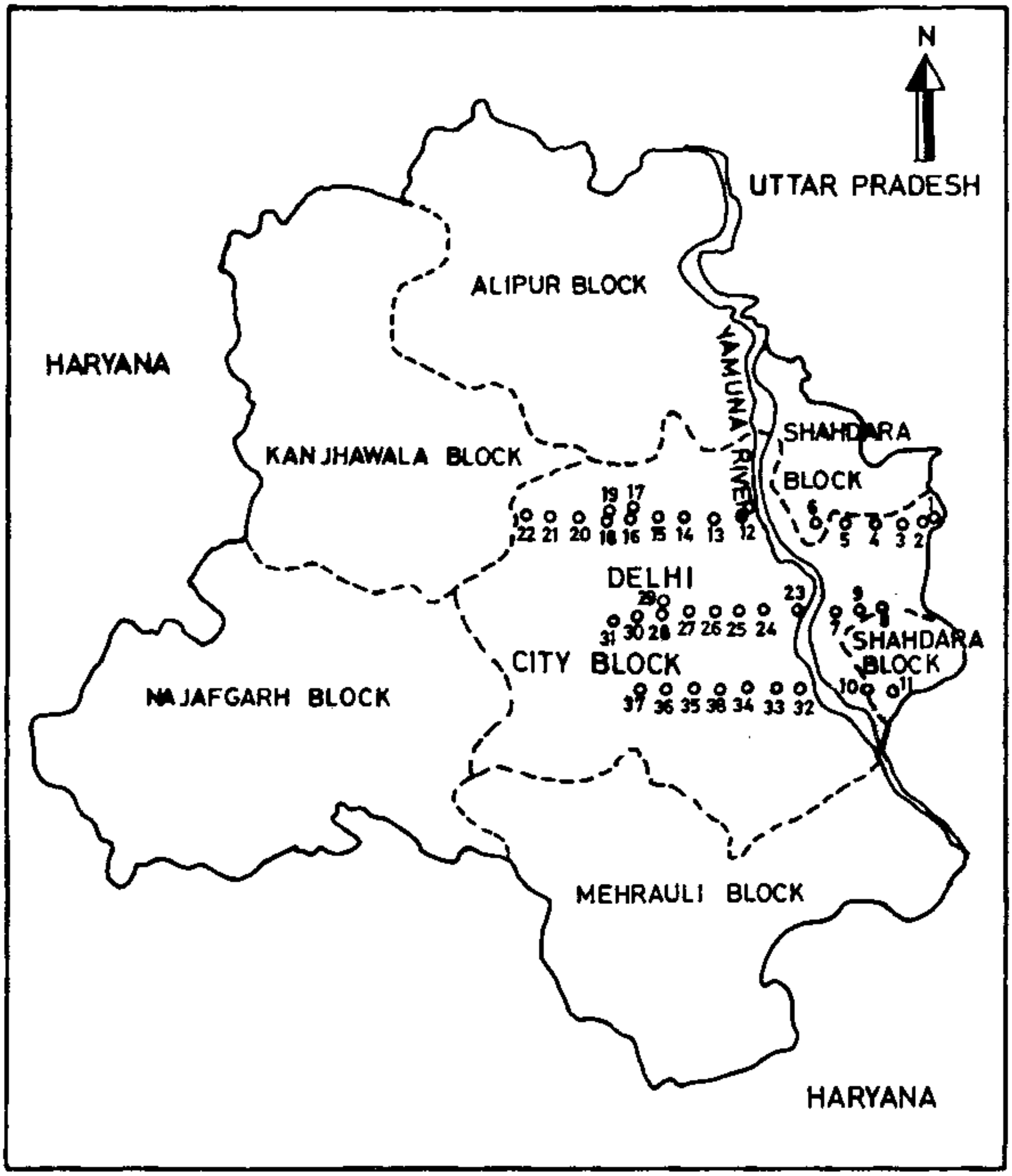

FIG.1: NCT DELHI SHOWING LOCATION OF SAMPLING SITES

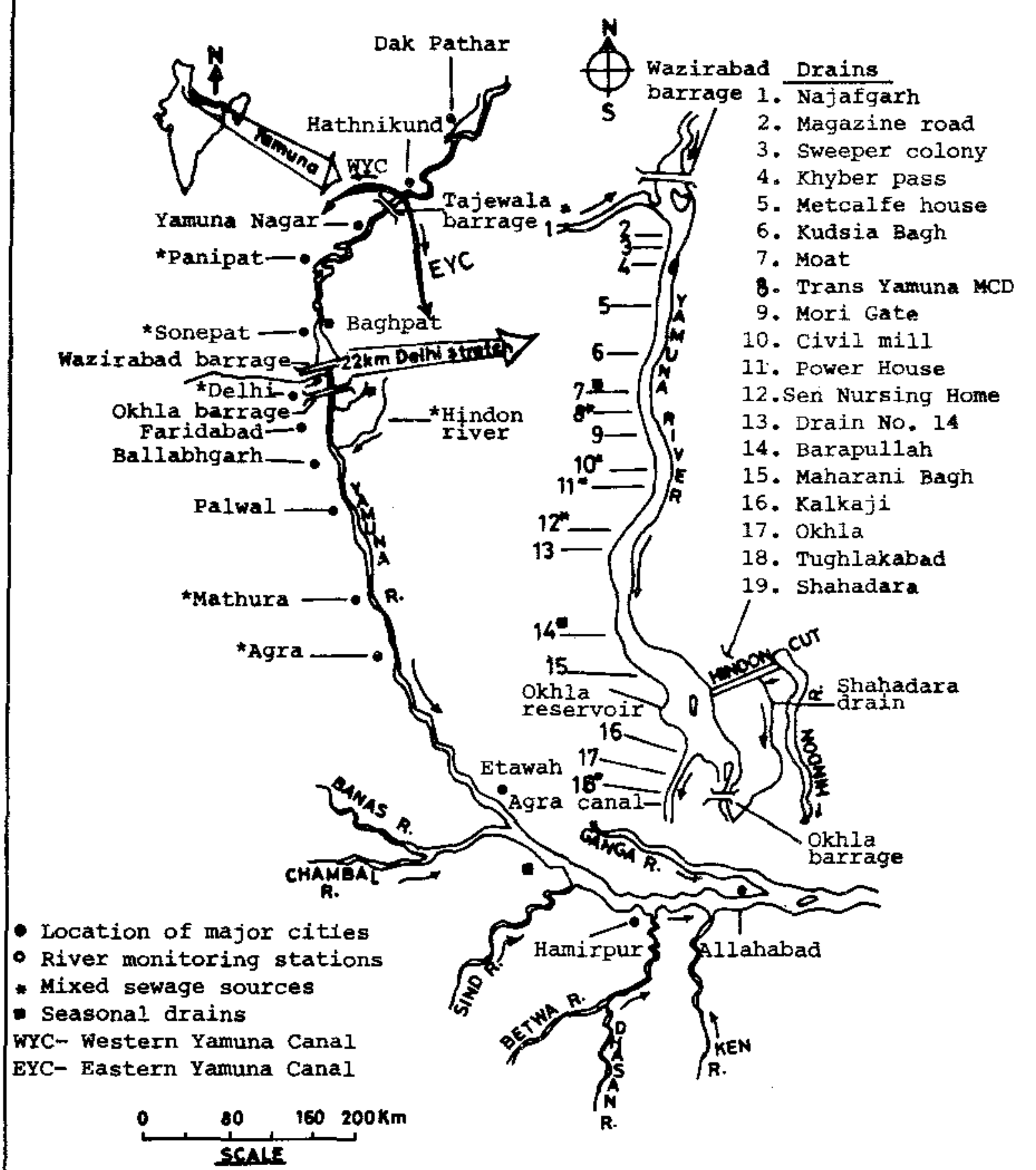

FIG. 2 THE RIVER YAMUNA SHOWING LOCATION OF MAJOR CITIES AND DIFFERENT DRAINS JOINING THE RIVER YAMUNA IN DELHI

The total ground water available in the territory is 291.54 MCM/year. Presently ground water is used for irrigation, drinking and industrial purposes. The surface area irrigated by ground water is about 47.5 hactares, while the quantity of ground water withdrawn for other uses is difficult to assess. A substantial quantity of ground water is being withdrawn by private houses, hotels, hospitals, etc. besides the officially estimated withdrawal of ground water. The contribution from ground water reservoir is quite substantial. A rough estimate indicate that about 142 MCM withdrawal of ground water is for drinking and industrial uses, while about 110 MCM for irrigation purposes.

At present the gross per capita availability of filtered water is about 200 lpcd (44 gpcd), which works out to be about 150 lpcd (33 gpcd) taking into account the conveyance losses. The existing installed capacity of water treatment plants and availability of water from various sources is presented in Table 1 (CGWB and CPCB, 2000).

2.3 Population and Water Supply Status

The population pressure on Delhi metropolitan city is ever growing. As per 1991 census, the population of Delhi was 94.2 lakhs, which is projected to reach 141 lakhs in the year 2001 (Fig. 3). Besides, a floating population of 3 to 4 lakhs per day is recurring feature at Delhi. According to recent survey, more than 50% of Delhi's population lives in about 1304 unauthorised colonies, 1080 Jhuggi Jhonpari clusters, 44 resettlement colonies and 209 rural villages. The total number of vehicles have increased phenomenally in order to meet the transportation demand of population from 2.35 lakhs in 1975 to 26.29 lakh in 1996 and is expected to touch a figure of 60 lakhs in 2011. The master plan 2001 for Delhi suggests the water consumption norm of 364 litres per capita/day (lpcd) as detailed in Table 2.

The requirement of raw water in Delhi would be about 400 litres/capita/day (lpcd) considering the transmission losses in bringing raw water from distant sources. The total estimated water in 2001 would be to the extent of 4.48 MCM/day considering the massive populations increase (Fig. 4).

Table 1. Water resources and water treatment capacity

S.No.	Water Treatment Plant	Installed Capacity	Raw Water Source
1.	Chandrawal I&II	0.410 MCM/day (90 MGD)	River Yamuna
2.	Wazirabad I, II, III	0.546 MCM/day (120 MGD)	River Yamuna
3.	Haiderpur	0.682 MCM/day (150 MGD)	Bhakra Storage
4.	Bhagirathi (Shahdara)	0.455 MCM/day (100 MGD)	Upper Ganga Canal
5.	Ranney Well/Tubewell	0.240 MCM/day (53 MGD)	Ground Water
6.	Okhla	0.060 MCM/day (12 MGD)	Ground Water
	Total	2.393 MCM/day (525 MGD)	

The additional augmentation of water supply during 8th Five year plan are proposed as follows:

S.No.	Water Treatment Plant	Proposed Augmentation
1.	WTP at North Shahdara	0.46 MCM/day (100 MGD)
2.	WTP at South Shahdara	0.18 MCM/day (40 MGD)
3.	WTP at Nangloi	0.18 MCM/day (40 MGD)
4.	WTP at Bawana	0.09 MCM/day (20 MGD)
	Total	0.91 MCM/day (200 MGD)

Source: CGWB and CPCB (2000)

Table 2. Details of water consumption

S.No.	Water Use	Consumption (lpcd)
1.	Domestic	226
2.	Industrial, commercial and community requirement based on 45000 litres per hectare per day	47
3.	Fire protection based on 1% of total demand	04
4.	Garden based on 67 litres par day	35
5.	For floating population and special uses	52
	Total	364

Source: CGWB and CPCB (2000)

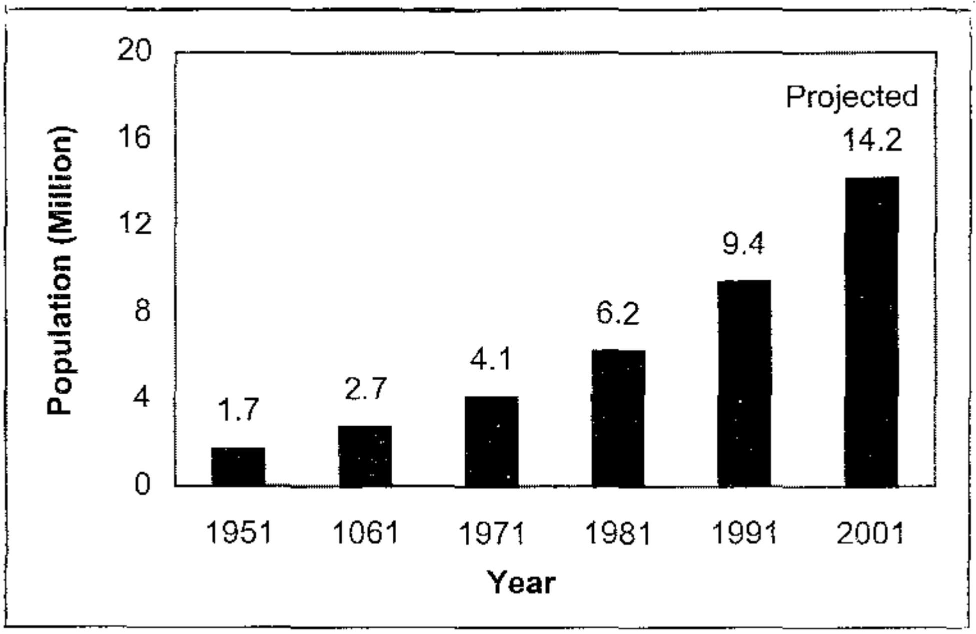

Fig. 3. Population of NCT-Delhi

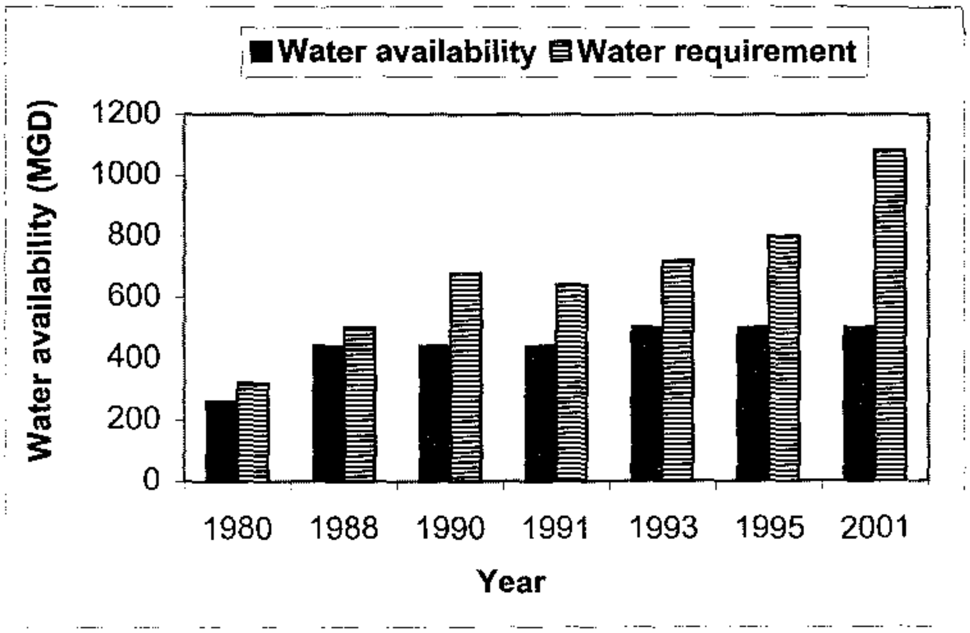

Fig. 4. Projected water requirement of Delhi

2.4 Status of Industries in NCT-Delhi

The small and medium size industries are located in several industrial pockets in the city and these are rapidly expanding. It is estimated that there are approximately 1,25,000 industrial units in Delhi during 1997-98.

Most industries are located in west, south and south-east of the city. Engineering, textile and chemical industries predominate in industrial area, although electronics and electrical goods have gained importance in recent times. There are three coal-based and one gas-based thermal power plants located in Delhi metropolitan area. The location and unit details of the thermal plants are given in Table 3.

The development of industries and industrial growth in Delhi had been streamlined and facilitated by various industrial development authorities of government viz. Department of Industries, Delhi State Industrial Development Corporation (DSIDC) and Delhi Development Authority (DDA). There had been development of twenty eight industrial estates in various parts of Delhi. Most of these industrial estates are located in North-West quadrant of Delhi. There are several other clusters of industrial units being operated in an unorganized manner in non-conforming areas. Industrial estates and type of industries in each of these estates are given in Table 4.

2.5 Waste Water Generation, Collection and Sewage Treatment

Delhi constitutes 2% of the catchment area of Yamuna basin, yet the metropolitan area constitutes substantial pollution load. The municipal wastewater is the main water pollution source in terms of volume. Approximately 1.99MCM/day of wastewater is discharged from municipal sector and 0.32 MCM/day from industrial sector. The installed treatment capacity is 1.27 MCM. The substantial quantity of untreated sewage and partially treated sewage is discharged into the river Yamuna everyday. The Najafgarh drain is estimatedly contributing about 60% of total

Table 3. Description of thermal power station located in NCT-Delhi

S.No.	Thermal Power Station	Location	Capacity	Units	Emission control device
1.	Badarpur Thermal Power Station, Badarpur (NTPC)	South-East near Delhi Haryana Boarder	720 MW	3x100 MW 2x210 MW	Electrostatic Precipitators for particulate emissions
2.	Indraprastha Thermal Power Station (Delhi Vidyut Board)	Central Delhi western bank of river Yamuna on main ring road	283.5 MW	3x62.5 MW 1x60 MW 1x36 MW	Electrostatic Precipitators for particulate emissions
3.	Gas Turbine Power Station (Delhi Vidyut Board)	Central Delhi western bank of river Yamuna on main ring road	180 MW	3x60 MW	-
4.	Rajghat Thermal power Station (Delhi Vidyut Board)	Central Delhi near Rajghat	135 MW	2x67.5 MW	Electrostatic Precipitators for particulate emissions

Source: CGWB and CPCB (2000)

Table 4. Details of industrial estates and broad types of industries in NCT-Delhi

S.No.	Industrial Estates	Types of Industrial Units
LOCATION: NORTH – WEST		
1.	Wazirpur Industrial Area	Textiles, Engineering, Plastics, Soap units, Chemicals, Dyes, Paints, Steel rolling, pickling units
2.	G. T. Karnal Road Industrial Estate	Engineering, Plastics, Chemical units
3.	Lawrence Road Industrial Estate	Engineering, Textile, Plastics, Paint, Steel rolling and other small scale units
4.	SMA Industrial Area	Engineering, Plastics, Chemical units,
5.	SSI Industrial Area	Engineering, Plastics, Chemical units, Hosiery units
6.	Najafgarh Road Industrial Estate	Engineering, Rubber processing, Plastics, Paint, Hosiery, Textile, Chemical plant, Chlorine, Sodium hydroxide, Vegetable oil, Pesticides etc
7.	Motinagar DLF Industrial Estate	Engineering, Steel industry, Chemical units, Vegetable oil, Textile, Plastics, Hosiery etc.
8.	Kirtinagar Industrial Estate	Engineering, Steel industries, Automobiles, Chemical plants, Wood based furniture etc.
9.	Anand Prabhat Industrial Estate	Engineering, Pickling, Automobiles, Electroplating
10.	Flatted Factories Complex, Jhandewalan	Small Scale Industries, Electronics units
11.	Mangolpuri Industrial Estate	Engineering, Textiles, Plastics, Automobile and other small scale industries
12.	Rajasthan Udhyog Nagar	Engineering, Textiles, Hosiery, Plastics and Automobiles etc.
13.	Narela Industreal Area (DSIDC)	Engineering, Textiles, Plastics etc.
14.	Jhilmill Industrial Estate	Engineering, Plastics, Chemical unit, Pickling unit, Rubber & Plastic industry
15.	Shahdara Industrial Estate	Engineering, Wire unit, Rolling mill, Battery manufacture, Tyre and rubber industry, Chemicals Pickling unit
16.	Patparganj Industrial Area	Under establishment
LOCATION: WEST		
17.	Mayapuri Industrial Area	Engineering, Plastics, Tyre and rubber industry, Small scale units
18.	Naraina Industrial Estate	Medium industries about 500 Nos. mostly Engineering
19.	Udhyog Nagar Industrial Estate	Engineering, Plastics and other Small Scale units
20.	Tilak Nagar Industrial Estate	Engineering, Plastics etc.
21.	Nangloi Industrial Area (DSIDC)	Plastics, Engineering, Textiles, Wire units and Hosiery units etc.

LOCATION: SOUTH – EAST		
22.	Okhla Industrial Estate	Textile, Engineering, Plastics, Electronics, Wooden furniture, Sanitary fittings, Soap and Detergents, Wire units, Small scale chemical units, Hosiery, Cloths stitching, Dyeing and Printing units
23.	Flatted Factory Complex Okhla	Electronics, Electrical assembly units
24.	Friends Colony Industrial Area	Textiles, Engineering, Electronics and other small scale units
25.	Mohan Co-operative Industrial Area	Engineering, Plastics, Hosiery and other small scale units
LOCATION: OTHER AREAS		
26.	Badli Industrial Area	Textiles, Electronics, Engineering, Plastics, Soap and detergents, Wire units, Small scale chemical units, Hosiery cloths stitches, Dying and printing units
27.	Pipalthala Industrial Area	Textiles, Plastics, Rolling mills
28.	G.T.Karnal Road Area	Engineering, Electronics, Plastics, wire units, Hosiery and other small scale units

Source: CGWB and CPCB (2000)

wastewater and 45% of the total BOD load into river Yamuna. The municipal wastewater has increased from 0.96 MCM during 1977 to 1.99 MCM during 1997. The capacity for treatment has been enhanced from 0.45 MCM in 1977 to 1.27 MCM during 1997.

2.6 Sanitary Land Fills in NCT-Delhi

The approximate solid waste generation in Delhi is around 6000MT/day. The solid waste disposal in Delhi is not thoroughly systematic and the solid waste is dumped at low-lying areas. The solid waste from house holds and industries is dumped near the roads, parks or in municipal dalaos, from where it ultimately reaches to sanitary land fill areas dispersed in various parts of NCT – Delhi. The continuous generation of solid waste has depleted several landfills area and the land is retrieved for various purposes. There are four major categories of landfills in Delhi.

- Landfills depleted and retrieved land is used for various purposes
- Active landfills with life less than 5 years
- Active landfills with life more than 5 years
- Proposed/identified landfill areas

These four categories of landfills have been depicted in Fig. 5. The major active landfills are located at Ghazipur, Hastsal, Balsava and behind Tulakabad fort, which receive municipal refuse.

2.7 Land Use

Land utilisation in NCT of Delhi has changed drastically over the years. The agricultural land use is repeatedly modified and more and more areas are shifted from cultivation and being utilized for other uses (Table 5). On the basis of land use patters, the area can be demarcated into 6 categories (Fig. 6): non-agricultural use (39%), barren land (13%), forest (1%), fallow land (8%), net sown area (31%), uncultivated land (8%).

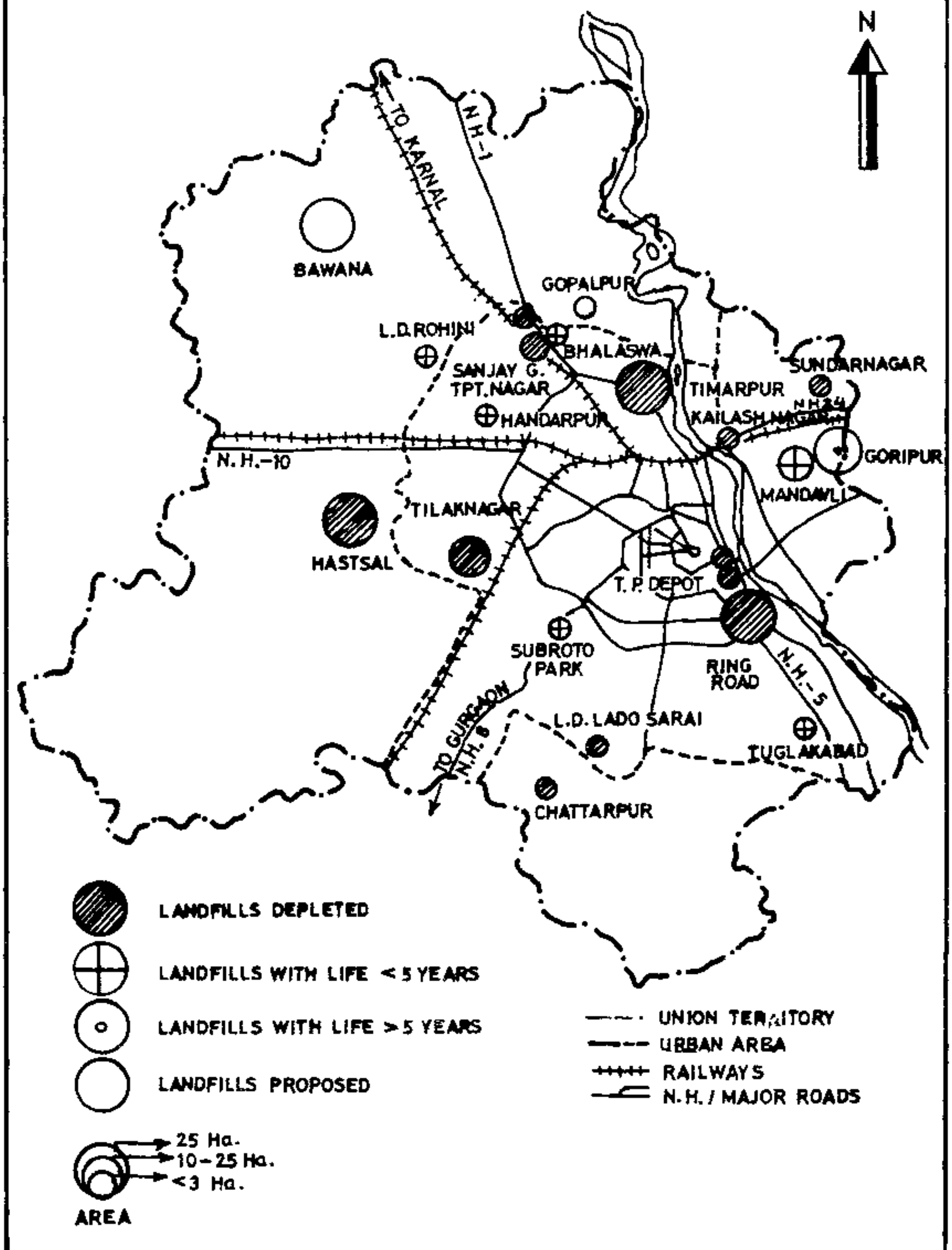

FIG.5: SANITARY LANDFILLS IN DELHI

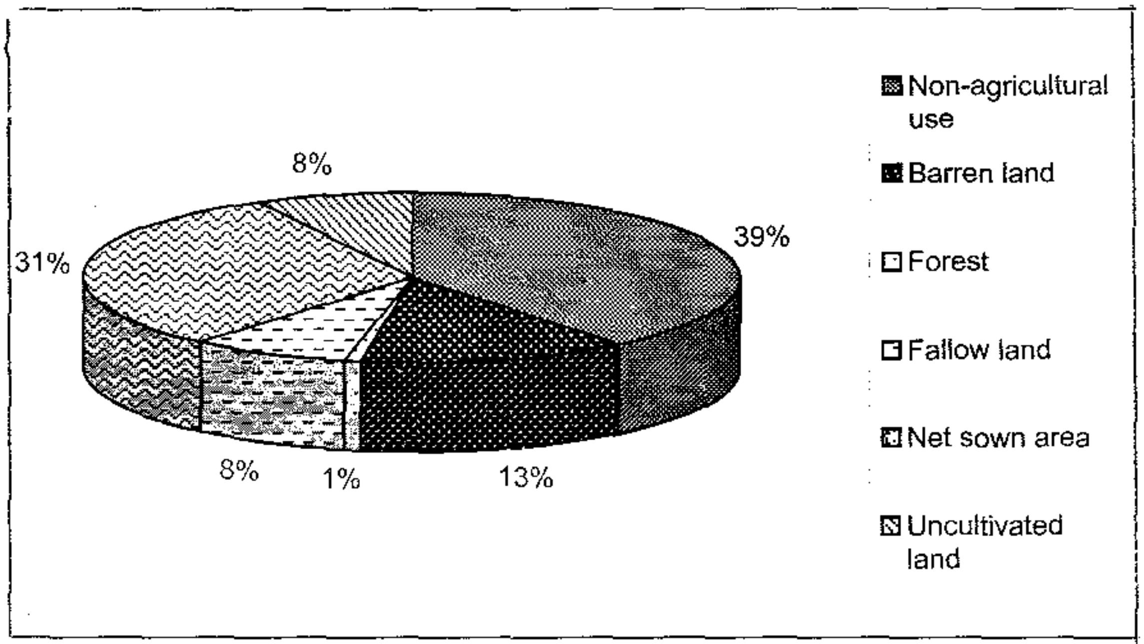

Fig. 6. Land use classification in NCT-Delhi

Table 5. Land utilisation in NCT-Delhi

S.No.	Land Utilisation	Area (Sq. km.)
1.	Total geographical area	1475.00
2.	Forest	11.81
3.	Area not available for cultivation	772.79
	a. Land put to non-agricultural use	577.91
	b. Barren uncultivable land	194.88
4.	Other uncultivated land area excluding fallow land	113.87
	a. Permanent pasture and other grazing land	0.63
	b. Land under miscellaneous tree crops and grooves not included in net areas sown	11.43
	c. Cultivable waste land	101.81
5.	Fallow land	115.50
6.	Net areas sown	460.91

Source: CGWB and CPCB (2000)

2.8 Cimate

The climate of Delhi is mainly influenced by its inland position and the prevalence of air of the continental type during the major part of the year. Extreme dryness with an intensely hot summer and cold winter are the characteristics of the climate. Only during the monsoon months air of oceanic origin penetrate to this area and causes increased humidity, cloudiness and precipitation. The year can broadly be divided into four seasons. The cold season starts in late November and extends to about the beginning of the March. This is followed by the hot season, which lasts till about the end of June when the monsoon arrives over the area. The monsoon continues to the last week of September.

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

The cold season starts towards the latter half of November. January is the coldest month with the mean daily maximum temperature at 21.3°C and the mean daily minimum 7.3°C. From about the middle of March, temperatures begin to rise fairly rapidly. May and June are the hottest months and the maximum temperatures may sometimes reach 46 or 47°C. The air over Delhi is dry during the greater part of the year. Humidity is high in the monsoon months.

2.9 Geology

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

- Alluvial plain on eastern and western sides of the ridge
- Yamuna river flood plain deposites
- Isolated and nearly closed Chattarpur 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 bed rock have different nature of either side of the quartzitic bed rock have different characteristics on either side of the ridge. The Yamuna flood plain contains distinct river 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 Fig. 7. The general stratigraphic sequence of the rock formations in NCT-Delhi is presented in Table 6.

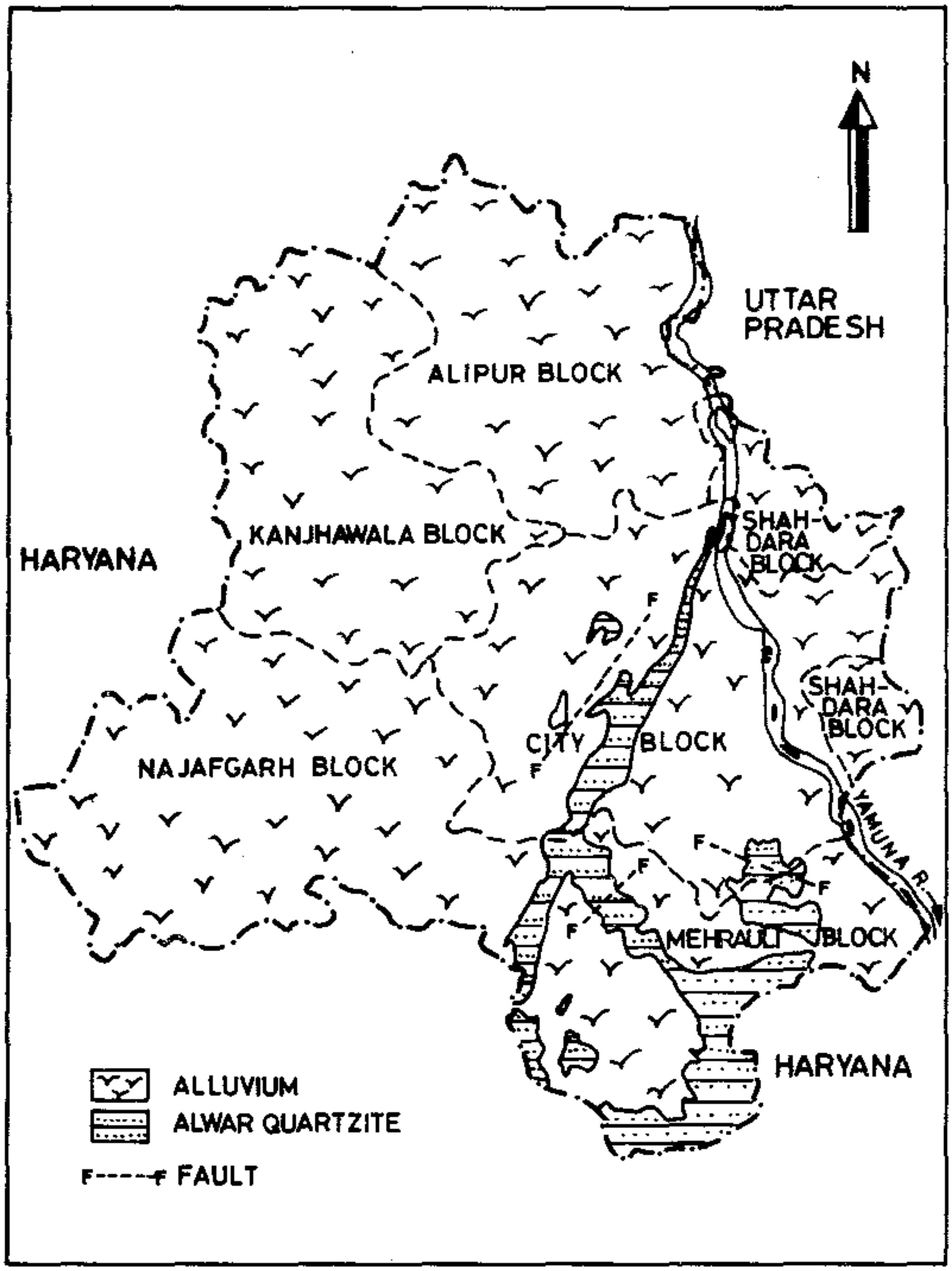

FIG. 7: GEOLOGY OF NCT DELHI

Table 6. 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

Source: CGWB and CPCB (2000)

3.0 EXPERIMENTAL METHODOLOGY

3.1 Sampling and Preservation

The ground water samples were collected in polyethylene bottles during pre-monsoon (June 2000) and post-monsoon (November 2000) seasons from open wells, hand pumps and tube wells/Bore wells at various depths so as to obtain a good areal representation and preserved by adding an appropriate reagent (APHA, 1985; Jain and Bhatia, 1987). The water samples for trace element analysis were collected in acid leached polyethylene bottles and preserved by adding ultra pure nitric acid (5 mL/lit.) Samples for bacteriological analysis were collected in sterilized high density polypropylene bottles. All the samples were stored in sampling kits maintained at 4°C and brought to the laboratory for detailed chemical and bacteriological analysis. The details of sampling locations are given in Table 7. The source and depth wise distribution of sampling locations are given in Table 8.

3.2 Chemicals and Reagents

All chemicals used in the study were of analytical reagent grade (Merck/BDH/HiMedia). Standard solutions of metal ions were procured from Merck, Germany. De-ionized water was used throughout the study. All glassware and other containers used for trace element analysis were thoroughly cleaned by soaking in detergent followed by soaking in 10% nitric acid for 48 h and finally rinsed with de-ionized water several times prior to use. All glassware and reagents used for bacteriological analysis were thoroughly cleaned and sterilized before use.

3.3 Chemical Analysis

The physico-chemical analysis was performed following standard methods (APHA, 1985; Jain and Bhatia, 1987). The brief details of analytical methods and equipment used in the study

Table 7. Description of ground water sampling locations

Sample No.	Label	Location	Type of well (Depth in ft.)
1.	1	Bhagwanpur Khera	HP (25)
2.	2	Loni Road	BW (20)
3.	3	Kabul Nagar	OW (35)
4.	4	Naveen Shahdara	HP (20)
5.	5.	Seelampur	HP (30)
6.	6	Shastri Park	HP (25)
7.	7	Lakshmi Nagar	HP (100)
8.	8	Prit Vihar	TW (40)
9.	9	Shankar Vihar	HP (200)
10.	A	Pratap Nagar	TW (100)
11.	B	Himmatpuri	HP (80)
12.	C	Civil Lines	TW (250)
13.	D	Rajpur road	OW (25)
14.	E	Malka Gunj	HP (20)
15.	F	Tripolia	BW (100)
16.	G	Gulabi Bagh	BW (40)
17.	H	Gulabi Bagh	BW (160)
18.	I	Shastri Nagar	BW (100)
19.	J	Shastri Nagar	BW (60)
20.	K	Lekhu Nagar	HP (40)
21.	L	Ram Pura	HP (40)
22.	M	Punjabi Bagh West	HP (40)
23.	N	Rajghat	BW (50)
24.	P	JLN Marg	HP (60)
25.	Q	GB Pant Hospital	BW (20)
26.	R	Panchkuin Marg	TW (450)
27.	S	Panchkuin Marg	HP (60)
28.	T	Rajendra Nagar	BW (100)
29.	U	Rajendra Nagar	BW (300)
30.	V	Shankar Road	OW (20)
31.	W	IARI, Pusa	TW (120)
32.	X	Zoological Park	HP (60)
33.	Y	Golf Course	BW (80)
34.	Z	Rabindra Nagar	TW (150)
35.	a	Teen Murti Chowk	HP (60)
36.	b	Malcha Marg	BW (100)
37.	c	Sardar Patel Road.	TW (150)
38.	d	Janpath	BW (250)

HP – Hand Pump; OW – Open Well; BW – Bore Well; TW – Tube Well.

Table 8. Source and depth wise distribution of sampling sites

Source structure	Depth range			Total number
	< 20 m	20-40 m	40 m	
Hand Pumps	1,4,5,6,14,20,21, 22,24,27,32,35	7,11	9	15
Tube Wells	8	10,31	12,26,34,37	7
Bore Well	2,16,19,23,25	15,18,28,33,36	17,29,38	13
Open Wells	3,13,30	-	-	3
Total	21	9	8	38

are given in Table 9. Ionic balance was determined, the error in the ionic balance for all samples was <10%.

3.4 Metal Ion Analysis

Metal ion concentrations were determined by flame atomic absorption spectrometry using Perkin-Elmer Atomic Absorption Spectrometer (Model 3110) using air-acetylene flame. Operational conditions were adjusted in accordance with the manufacturer's guidelines to yield optimal determination. Quantification of metals was based upon calibration curves of standard solutions of respective metals. These calibration curves were determined several times during the period of analysis. The detection limits for copper, iron, manganese, cobalt, nickel, chromium, lead, cadmium and zinc are 0.001, 0.003, 0.001, 0.006, 0.004, 0.002, 0.01, 0.0005 and 0.0008 mg/L respectively.

3.5 Bacteriological Analysis

MPN coliforms were determined by multiple tube fermentation technique using MacConkey broth. The collected water samples were inoculated into three sets of tubes each containing 10 ml MacConkey broth and 10, 1 and 0.1 ml each of water samples. All the tubes were incubated at 37°C for 24 to 48 hours. After incubation all the tubes were observed for acid and gas production. The production of acid and gas indicates the presence of coliforms and thus test is positive.

Total counts were determined by plate count method using nutrient agar. The collected water samples were inoculated into three petri dishes each containing 20 ml nutrient agar and 1, 0.1 and 0.01 ml each of water samples. All the petri dishes were incubated at 37°C for 24 to 48 hours. After incubation bacterial colonies were counted using electronic colony counter.

Table 9. Analytical methods and equipment used in the study

S.No.	Parameter	Method	Equipment
1.	pH	Electrometric	pH Meter
2.	Conductivity	Electrometric	Conductivity Meter
3.	TDS	Electrometric	Conductivity/TDS Meter
4.	Alkalinity	Titration by H_2SO_4	-
5.	Hardness	Titration by EDTA	-
6.	Chloride	Titration by $AgNO_3$	-
7.	Sulphate	Turbidimetric	Turbidity Meter
8.	Nitrate	Ultraviolet screening	UV-VIS Spectrophotometer
9.	Phosphate	Molybdophosphoric acid	UV-VIS Spectrophotometer
10.	Fluoride	SPADNS	UV-VIS Spectrophotometer
11.	Sodium	Flame emission	Flame Photometer
12.	Potassium	Flame emission	Flame Photometer
13.	Calcium	Titration by EDTA	-
14.	Magnesium	Titration by EDTA	-
15.	Silica	Heteropoly blue method	UV-VIS Spectrophotometer
16.	Copper	Atomic spectrometry	Atomic Absorption Spectrometer
17.	Iron		
18.	Manganese		
19.	Cobalt		
20.	Nickel		
21.	Chromium		
22.	Lead		
23.	Cadmium		
24	Zinc		
25.	MPN Coliform	Multiple tube fermentation technique	Bacteriological Incubator
26.	Total count	Plate count	Colony Counter

4.0 RESULTS AND DISCUSSION

The National Capital Territory of Delhi has peculiar feature of infiltration of surface water to ground water from river Yamuna and from various drains in addition to customary recharge from rainfall. Ground water recharge also occurs through stagnant water pools in low lying areas, where surface runoff water gets collected. The quartzite ridge, which is the prolongation of Aravalli mountain range, forms the principal watershed in south, south-east, south-west part of Delhi. Because of it, the eastern surface runoff and drainage join river Yamuna, while the runoff from western part of Delhi into Najafgarh drain.

The ever increasing discharge of domestic and industrial wastes into improperly lined sewage drains in Delhi lead to high risk of contamination of ground water. The excessive ground water uplift also has adverse impact on water quality in ground water aquifers of limited thickness.

The hydro-chemical data for the two sets of samples collected from the adjoining area of river Yamuna in Delhi during pre-monsoon and post-monsoon seasons are presented in Table 10 and 11 respectively alongwith Indian standards for drinking water. Distribution of different water quality constituents with depth and season wise.are given in Tables 12-21.

4.1 Water Quality Evaluation for Drinking Purpose

The pH values in the ground water of adjoining areas of river Yamuna are mostly confined within the range 6.7 to 8.3 during pre-monsoon season and 6.6 to 8.2 during post-monsoon season with most of the samples pointing towards alkaline range in both the seasons. The pH values of all the samples are within the limits prescribed by BIS (1991) and WHO (1996) for various uses of water including drinking and other domestic supplies.

The measurement of electrical conductivity is directly related to the concentration of ionized substance in water and may also be related to problems of excessive hardness and/or other mineral contamination. The conductivity values in the ground water samples of adjoining areas of

Table 10. Hydro-chemical data of ground water samples of Delhi (June 2000)

Parameter	Min	Max	Mean	Desirable limit*
pH	6.7	8.3	7.1	6.5-8.5
Conductivity, µS/cm	628	3540	1463	-
TDS, mg/L	402	2266	936	500
Alkalinity, mg/L	116	380	201	200
Hardness, mg/L	116	841	235	300
Chloride	17	400	86	250
Sulphate, mg/L	43	690	180	200
Nitrate, mg/L	1.0	286	78	45
Phosphate, mg/L	0.07	0.28	0.16	-
Fluoride, mg/L	0.33	1.31	0.80	1.0
Sodium, mg/L	55	340	160	-
Potassium, mg/L	4.2	121	26	-
Calcium, mg/L	25	240	59	75
Magnesium, mg/L	9.0	64	21	30
Silica, mg/L	16	75	35	-
MPN Coliform, per 100 ml	nil	2400	-	10
Total count, per ml	10	1850	-	30-300
Copper, mg/L	0.006	0.178	0.023	0.05
Iron, mg/L	0.390	5.740	1.960	0.3
Manganese, mg/L	0.009	0.944	0.162	0.1
Cobalt, mg/L	0.005	0.034	0.016	-
Nickel, mg/L	0.005	0.043	0.028	-
Chromium, mg/L	0.006	0.033	0.013	0.05
Lead, mg/L	0.010	0.064	0.033	0.05
Cadmium, mg/L	0.003	0.010	0.006	0.01
Zinc, mg/L	0.021	1.110	0.320	5.0

* IS-10500-1991

Table 11. Hydro-chemical data of ground water samples of Delhi (November 2000)

Parameter	Min	Max	Mean	Desirable limit*
pH	6.6	8.2	7.1	6.5-8.5
Conductivity, μS/cm	620	3250	1373	-
TDS, mg/L	397	2080	879	500
Alkalinity, mg/L	106	310	194	200
Hardness, mg/L	114	792	225	300
Chloride, mg/L	17	390	86	250
Sulphate, mg/L	48	680	177	200
Nitrate, mg/L	ND	287	68	45
Phosphate, mg/L	0.03	0.21	0.08	-
Fluoride, mg/L	ND	0.76	0.41	1.0
Sodium, mg/L	51	322	157	-
Potassium, mg/L	2.2	103	20	-
Calcium, mg/L	21	227	59	75
Magnesium, mg/L	7.0	56	19	30
Silica, mg/L	13	85	29	-
MPN Coliform, per 100 ml	nil	150	-	10
Total count, per ml	12	540	-	30-300
Copper, mg/L	0.003	0.085	0.012	0.05
Iron, mg/L	0.128	5.842	1.216	0.3
Manganese, mg/L	0.008	0.837	0.183	0.1
Cobalt, mg/L	0.000	0.037	0.011	-
Nickel, mg/L	0.009	0.113	0.028	-
Chromium, mg/L	0.003	0.078	0.011	0.05
Lead, mg/L	0.012	0.098	0.037	0.05
Cadmium, mg/L	0.005	0.021	0.011	0.01
Zinc, mg/L	0.012	0.732	0.190	5.0

* IS-10500-1991

Table 12. TDS distribution in ground water of study area

S. No.	TDS range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	< 500	< 20	21	3,5,13,21	7.9	13.2
		20-40	28	28		
		> 40	29	-		
2.	500-2000	< 20	1,2,3,4,5,6,8,13,14, 16,19,20,22,23,24, 25,27,30,32,35	1,2,4,6,8,14,16,19, 20,22,23,24,25,27, 30,32,35	89.5	84.2
		20-40	7,10,11,15,18,31,36	7,10,11,15,18,31,36		
		> 40	9,12,17,26,34,37,38	9,12,17,26,29,34,37, 38		
3.	> 2000	< 20	-	-	2.6	2.6
		20-40	33	33		
		> 40	-	-		
Total number of samples			38	38	100	100

Table 13. Alkalinity distribution in ground water of study area

S. No.	Alkalinity range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	< 200	< 20	3,4,13,14,16,19,20, 21,23,25,27,30,32, 35	3,4,5,6,13,14,16,19, 21,23,25,27,32	60.5	57.9
		20-40	7,11,15,18,28,33	7,10,11,15,18,28,33		
		> 40	29,34,38	29,38		
2.	200-600	< 20	1,2,5,6,8,22,24	1,2,8,20,22,24,30,35	39.5	42.1
		20-40	10,31,36	31,36		
		> 40	9,12,17,26,37	9,12,17,26,34,37		
3.	> 600	< 20	-	-	nil	nil
		20-40	-	-		
		> 40	-	-		
Total number of samples			38	38	100	100

Table 14. Hardness distribution in ground water of study area

S. No.	Hardness range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	< 300	< 20	3,4,5,6,8,13,14,19, 20,21,22,23,24,25, 27,30,32,35	1,3,4,5,6,8,13,14,19, 20,21,22,23,24,25, 27,30,32,35	81.6	86.9
		20-40	7,10,15,18,28,36	7,10,11,15,18,28,36		
		> 40	9,12,26,29,34,37,38	9,12,26,29,34,37,38		
2.	300-600	< 20	1,2,16	2,16	15.8	10.5
		20-40	11,31	31		
		> 40	17	17		
3.	> 600	< 20	-	-	2.6	2.6
		20-40	33	33		
		> 40	-	-		
Total number of samples			38	38	100	100

Table 15. Calcium distribution in ground water of study area

S. No.	Calcium range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	< 75	< 20	3,4,5,6,8,13,14,19,20, 21,22,23,24,25,27,32, 35	1,3,4,5,6,8,13,14,20, 21,22,23,24,25,27, 30,32,35	76.3	81.6
		20-40	7,10,15,18,28,36	7,10,11,15,18,28,36		
		> 40	9,12,26,29,37,38	9,12,26,29,37,38		
2.	75-200	< 20	1,2,16,30	2,16,19	21.1	15.8
		20-40	11,31	31		
		> 40	17,34	17,34		
3.	> 200	< 20	-	-	2.6	2.6
		20-40	33	33		
		> 40	-	-		
Total number of samples			38	38	100	100

Table 16. Magnesium distribution in ground water of study area

S. No.	Magnesium range, mg/L	Depth Range, M	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	< 30	< 20	3,4,5,6,13,14,19,20, 21,22,23,24,25,27, 30,35	1,2,3,4,5,6,8,13,14, 19,20,21,22,23,24, 25,27,30,32,35	78.9	94.7
		20-40	7,10,11,15,18,28,36	7,10,11,15,18,28, 31,36		
		> 40	9,12,26,29,34,37,38	9,12,17,26,29,34, 37,38		
2.	30-75	< 20	1,2,8,16,32	16	21.1	5.3
		20-40	31,33	33		
		> 40	17	-		
3.	> 75	< 20	-	-	nil	nil
		20-40	-	-		
		> 40	-	-		
Total number of samples			38	38	38	38

Table 17. Chloride distribution in ground water of study area

S. No.	Chloride range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	< 250	< 20	1,2,3,4,5,6,8,13,14,16, 19,20,21,22,23,24,25, 27,30,32,35	1,2,3,4,5,6,8,13,14, 16,19,20,21,22,23,24, 25,27,30,32,35	97.4	97.4
		20-40	7,10,11,15,18,28,31, 36,	7,10,11,15,18,28,31, 36,		
		> 40	9,12,17,26,29,34,37, 38	9,12,17,26,29,34,37, 38		
2.	250-1000	< 20	-		2.6	2.6
		20-40	33	33		
		> 40	-			
3.	> 1000	< 20	-		nil	nil
		20-40	-			
		> 40	-			
Total number of samples			38	38	100	100

Table 18. Nitrate distribution in ground water of study area

S. No.	Nitrate range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	< 45	< 20	3,5,6,8,13,20,21,25, 30,35	3,4,6,8,13,20,21,25, 20,35	52.6	52.6
		20-40	7,10,11,18,28,31	7,10,11,18,28,31		
		> 40	9,29,34,38	9,29,34,38		
2.	45-100	< 20	2,14,23,24,27,32,	4,14,19,22,23,24,27, 32	23.7	29.0
		20-40	33,36	33,36		
		> 40	37	37		
3.	> 100	< 20	1,4,16,19,22	1,2,16	23.7	18.4
		20-40	15	15		
		> 40	12,17,26	12,17,26		
Total number of samples			38	38	100	100

Table 19. Sulphate distribution in ground water of study area

S. No.	Sulphate range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	< 200	< 20	3,4,5,6,13,14,19,20, 21,22,27,30,32,35	1,3,4,5,6,13,14,19, 20,21,22,24,27,30, 32,35	63.1	68.4
		20-40	7,15,18,28,31	7,15,18,28,31,36		
		> 40	9,17,29,37,38	17,29,37,38		
2.	200-400	< 20	1,2,8,16,23,24,25	2,8,16,23,25	31.6	26.3
		20-40	10,36	10		
		> 40	12,26,34	9,12,26,34		
3.	> 400	< 20	-	-	5.3	5.3
		20-40	11,33	11,33		
		> 40	-	-		
Total number of samples			38	38	100	100

Table 20. Fluoride distribution in ground water of study area

S. No.	Fluoride range, mg/L	Depth range, m	Sample numbers		Areal distribution, %	
			Pre-monsoon	Post-monsoon	Pre-monsoon	Post-monsoon
1.	< 1.0	< 20	2,3,4,5,6,8,19,20, 21,22,23,24,25,27, 30,32,35	1,2,3,4,5,6,8,13,14, 16,19,20,21,22,23, 24,25,27,30,32,35	73.7	100.0
		20-40	7,11,18,28,33	7,10,11,15,18,28, 31,33,36		
		> 40	9,12,17,29,37,38	9,12,17,26,29,34, 37,38		
2.	1.0-1.5	< 20	1,13,14,16	-	26.3	nil
		20-40	10,15,31,36	-		
		> 40	26,34	-		
3.	> 1.5	< 20	-	-	nil	nil
		20-40	-	-		
		> 40	-	-		
Total number of samples			38	38	100	100

Table 21. Bacteriological contamination in ground water of study area

Range, MPN Coliform, per 100 ml	Pre-monsoon		Post-monsoon	
	No. of samples	%	No. of samples	%
Nil	9	23.68	6	15.79
< 10	4	10.53	13	34.21
10-20	1	2.63	3	7.89
21-30	5	13.16	1	2.63
31-40	-	-	-	-
41-50	4	10.53	2	5.26
51-100	3	7.89	9	23.69
> 100	12	31.58	4	10.53

river Yamuna vary from 628 to 3540 µS/cm during pre-monsoon season and 620 to 3250 µS/cm during post-monsoon season with more than 70% samples having conductivity value above 1000 µS/cm during both pre- and post-monsoon seasons. The maximum conductivity value of 3540 and 3250 µS/cm was observed at Golf Course during pre- and post-monsoon season respectively. Higher values of conductivity in the nearby areas of river Yamuna indicate high mineralization of the ground water.

In natural waters, dissolved solids consists mainly of inorganic salts such as carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron etc. and small amount of organic matter and dissolved gases. In the present study the values of total dissolved solids (TDS) in the ground water varies from 402 to 2266 mg/L during pre-monsoon season and 397 to 2080 mg/L during post-monsoon season. Only about 10% of the samples analysed were found within the desirable limit of 500 mg/L. More than 80% of the samples were found above the desirable limit of 500 mg/L. Almost similar trend was observed during the post-monsoon season. Water containing more than 500 mg/L of TDS is not considered desirable for drinking water supplies, though more highly mineralized water is also used where better water is not available. For this reason, 500 mg/L as the desirable limit and 2000 mg/L as the maximum permissible limit has been suggested for drinking water (BIS, 1991). Water containing TDS more than 500 mg/L causes gastrointestinal irritation (BIS, 1991). One sample of Golf Course (BW, 80') even crosses the maximum permissible limit of 2000 mg/L.

The presence of carbonates, bicarbonates and hydroxides are the main cause of alkalinity in natural waters. Bicarbonates represent the major form since they are formed in considerable amount from the action of carbonates upon the basic materials in the soil. The alkalinity value in the ground water varies from 116 to 380 mg/L during pre-monsoon season and 106 to 310 mg/L during post-monsoon season. About 60% sample of the study area falls within the desirable limit of 200 mg/L and about 40% sample crosses the desirable limit but are within the maximum permissible limit of 600 mg/L. No sample of the study area crosses the maximum permissible limit of 600 mg/L. The high alkalinity values in the study area may be attributed to the action of carbonates upon the basic materials in the soil. Such water gives unpleasant taste.

Calcium and magnesium along with their carbonates, sulphates and chlorides make the water hard. Samples have both temporary and permanent hardness. A limit of 300 mg/L has been recommended for potable water (BIS, 1991). The total hardness values in the study area ranges from 116 to 871 mg/L during pre-monsoon season and 114 to 792 mg/L during post-monsoon season. More than 80% of the samples were found well within the desirable limits for domestic applications during both pre- and post-monsoon seasons. However, one sample of Golf Course even crosses the maximum permissible limit of 600 mg/L during both the seasons.

The desirable limit for calcium and magnesium for drinking water are 75 and 30 mg/L respectively (BIS, 1991). In ground water of the study area, the values of calcium and magnesium range from 25 to 240 and 9 to 64 mg/L respectively during pre-monsoon season. Slight lower values of calcium and magnesium were observed during the post-monsoon season. In ground water, the calcium content generally exceeds the magnesium content in accordance with their relative abundance in rocks. The increase of magnesium is quite proportionate with calcium in both the seasons.

The concentration of sodium in the study area varies from 55 to 340 mg/L during pre-monsoon season and 51 to 322 mg/L during post-monsoon season. The sodium concentrations more than 50 mg/L make the water unsuitable for domestic use. The sodium concentration was found higher at all the sites in the study area. The high sodium values may be attributed to base exchange phenomena. Ground water with high sodium is unsuitable for irrigation due to sodium sensitivity of crops/plants.

The concentration of potassium in ground water varies from 4.2 to 121 mg/L during pre-monsoon season and 2.2 to 103 mg/L during post-monsoon season. Potassium is an essential element for humans, plants and animals and derived in food chain mainly from vegetation and soil. The main sources of potassium in ground water include rain water, weathering of potash silicate minerals, use of potash fertilizers and use of surface water for irrigation. It is more abundant in sedimentary rocks and commonly present in feldspar, mica and other clay minerals. The Bureau of

Indian Standards has not included potassium in drinking water standards. However, the European Economic Community (EEC, 1980) has prescribed guideline level of potassium at 10 mg/L in drinking water. Though potassium is extensively found in some of igneous and sedimentary rocks, its concentration in natural waters is usually quite low. This is due to the fact that potassium minerals offer resistance to weathering and dissolution. Higher potassium content in ground water are indicative of ground water pollution.

The concentration of chloride varies from 17 to 400 mg/L during pre-monsoon season. Almost same trend was observed during the post-monsoon season. The maximum chloride content in ground water was recorded at Golf Course. No sample in the study area crosses the maximum permissible limit of 1000 mg/L. The limits of chloride have been laid down primarily from taste considerations. A limit of 250 mg/L chloride has been recommended as desirable limit for drinking water supplies (BIS, 1991; WHO, 1996). However, no adverse health effects on humans have been reported from intake of waters containing even higher content of chloride.

The concentration of sulphate in the study area varies from 43 to 690 mg/L during pre-monsoon season and 48 to 680 mg/L during post-monsoon season. Most of the samples fall within the permissible limit (400 mg/L) for drinking water supplies. Only 2 samples of Himmat Puri and Golf Course exceed the maximum permissible limit. In ground water, sulphate generally occurs as soluble salts of calcium, magnesium and sodium. The sulphate content of water may change significantly with time during infiltration of rainfall and ground water recharge, which mostly takes place from stagnant water pools, puddles and surface runoff water collected in low lying areas.

Nitrate content in drinking water is considered important for its adverse health effects. The occurrence of high levels of nitrate in ground water is a prominent problem in NCT-Delhi. There has been wide fluctuations in nitrate concentration in ground water of Delhi (CGWB and CPCB, 2000). The nitrate content in the ground water of adjoining areas of river Yamuna varies from 1 to 286 mg/L during pre-monsoon season. Almost same trend was observed during post-monsoon season. Out of the total 38 samples analysed, 20 samples (52.5%) shows nitrate contents less than 45 mg/L, where as in about 20% ground water samples the nitrate content exceeded even the maximum permissible limit of 100 mg/L. The higher level of nitrate at certain locations may be attributed due the surface disposal of domestic sewage and runoff from agricultural fields or infiltration. It has also been observed that the ground water samples collected from hand pumps at various depths have high nitrate content, which may be attributed to well head pollution. Several other workers have also reported higher concentration of nitrate in ground water (Pande et al., 1986; Andamuthu and Subburam, 1994; Lakashamanan and Krishna Rao, 1996).

Nitrate is effective plant nutrient and moderately toxic. A limit of 45 mg/L has been prescribed by WHO (1996) and BIS (1991) for drinking water supplies. Its concentration above 45 mg/L may prove detriment to human health. In higher concentrations, nitrate may produce a disease known as methaemoglobinaemia (blue babies) which generally affects bottle-fed infants. Repeated heavy doses of nitrates on ingestion may also cause carcinogenic diseases.

The fluoride is present in soil strata due to the presence of geological formations like fluorspar, fluorapatite, ampheboles such as hornblinde, trimolite and mica. Weathering of alkali, silicate, igneous and sedimentary rocks specially shales contribute a major portion of fluorides to ground waters. In addition to natural sources, considerable amount of fluorides may be contributed due to man's activities. Fluoride salts are commonly used in steel, aluminium, bricks and tile-industries. The fluoride containing insecticides and herbicides may be contributed through agricultural runoff. Phosphatic fertilizers, which are extensively used, often contain fluorides as impurity and these may increase levels of fluoride in soil. The accumulation of fluoride in soil eventually results in its leaching due to percolating water, thus increase fluoride concentration in ground water. However, in the ground water of the adjoining area of river Yamuna, the fluoride content was within the maximum permissible limit 1.5 mg/L in all the samples during both pre- and post-monsoon seasons.

Silica content in ground water of the study area varies from 16 to 75 mg/L during pre-monsoon season and 13 to 85 mg/L during post-monsoon season. Silica is generally considered insignificant for irrigation.

The coliform group of bacteria is the principal indicator of suitability of water for domestic, industrial or other uses. The density of coliform group is the criteria for the degree of contamination and has been the basis for bacteriological water quality standard. In ideal situation all the samples taken from the distribution system should be free from coliform organisms but in practice, it is not attainable always and therefore, following standard for water has been recommended (BIS, 1991):

- 95% of water samples should not contain any coliform organisms in 100 ml throughout the year.
- No water sample should contain E.Coli in 100 ml water.
- No water sample should contain more than 10 coliform organisms per 100 ml.
- Coliform organisms should not be detected in 100 ml of any two consecutive water samples.

However, from bacteriological considerations, the objectives should be to reduce the coliform count to less than 10 per 100 ml and more importantly the absence of faecal coliform should be ensured.

The presence of coliforms in water is an indicator of contamination by human or from animal excrement. The presence of faecal colifirms in ground water indicates a potential public health problem, because faecal matter are sources of pathogenic bacteria and viruses. The ground water contamination from faecal coliform bacteria is generally caused by percolation from contamination sources (domestic sewage and septic tank) into the aquifers and also because of poor sanitation. Shallow wells are particularly susceptible for such contamination. The bacteriological contamination of ground water in Delhi is mostly attributable to indiscriminate dumping of waste and garbage without observing any precautions and scientific disposal practices (CGWB and CPCB, 2000). In Delhi most of the hand pumps withdraw ground water from upper strata, which is most susceptible to contamination from polluted surface water.

The ground water samples collected from the adjoining area of river Yamuna in Delhi has significantly high total coliform. The bacteriological analysis indicates the presence of MPN coliform in more than 75% samples during both pre- and post-monsoon season (Table 21). The presence of coliforms was mostly reported from hand pumps. More than 30% samples have MPN coliforms > 100 per 100 ml during pre-monsoon season. Inadequate maintenance of hand pumps, improper sanitation and unhygienic conditions around the structure may be responsible for bacterial contamination. The indiscriminate land disposal of domestic waste on surface, improper disposal of solid waste, leaching of waste water from landfill areas, further aggravate the chances of bacterial contamination.

Most of the trace metals are of immediate concern because of their toxicity and non-biodegradable nature. The cadmium, chromium and lead are highly toxic to humans even in low concentrations. The heavy metals in ground water except iron, which is present in appreciable concentration in ground water have been below the prescribed maximum permissible limits in most of the samples. The concentration of iron varies from 0.39 to 5.74 mg/L during pre-monsoon season and 0.128 to 5.842 mg/L during post-monsoon season. The concentration range of copper and zinc were found well below the maximum permissible limits. The presence of heavy metals and their concentration ranges are presented in Table 10 and 11.

The study has clearly indicated higher concentration of total dissolved solids, electrical conductivity, nitrate, sulphate and sodium. The presence of total coliforms indicates bacterial contamination, which may be attributed due to improper sanitation. Due to improper sanitation, samples are likely to be contaminated. Aquifer may be free from coliform. The presence of heavy metals in ground water though recorded in many samples but these were not significantly higher. The water quality standards have been violated for TDS, nitrate, sulphate and sodium at few places.

4.2 Water Quality Evaluation for Irrigation Purpose

Irrigation water quality refers to its suitability for agricultural use. The concentration and composition of dissolved constituents in water determine its quality for irrigation use. Quality of water is an important consideration in any appraisal of salinity or alkali conditions in an irrigated area. Good quality water has the potential to cause maximum yield under good soil and water management practices. The most important characteristics of water which determine suitability of ground water for irrigation purpose are as follows:

1) Salinity
2) Relative proportion of sodium to other cations
3) Residual Sodium Carbonate
4) Boron

The safe limits of electrical conductivity for crops of different degrees of salt tolerances under varying soil textures and drainage conditions are given in Table 22. 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 (SAR) and Residual Sodium Carbonate (RSC) are given in Table 23.

4.2.1 Salinity

Salinity is broadly related to total dissolved solids (TDS) and electrical conductivity (EC). High concentration of TDS and electrical conductivity in irrigation water may increase the soil salinity, which affect the salt intake of the plant. The salts present in the water, besides affecting the growth of the plants directly, also affect the soil structure, permeability and aeration, which indirectly affect the plant growth. Soil water passes into the plant through the root zone due to osmotic pressure. As the dissolved solid content of the soil water in the root zone increases, it is difficult for the plant to overcome the osmotic pressure and the plants root membrane are able to assimilate water and nutrients. Thus, the dissolved solids content of the residual water in the root zone also has to be maintained within limits by proper leaching. These effects are visible in plants by stunted growth, low yield, discoloration and even leaf burns at margin or top.

Table 22. Safe limits of electrical conductivity for irrigation water

S.No.	Nature of soil	Crop growth	Upper permissible safe limit of EC in water, μS/cm
1.	Deep black soil and alluvial soils having clay content more than 30% soils that are fairly to moderately well drained	Semi-tolerant	1500
		Tolerant	2000
2.	Having textured soils having clay contents of 20-30% soils that are well drained internally and have good surface drainage system	Semi-tolerant	2000
		Tolerant	4000
3.	Medium textured soils having clay 10-20% internally very well drained and having good surface drainage system	Semi-tolerant	4000
		Tolerant	6000
4.	Light textured soils having clay less than 10% soil that have excellent internally and surface drainage system	Semi-tolerant	6000
		Tolerant	8000

Source: CGWB and CPCB (2000).

Table 23. Guidelines for evaluation of irrigation water quality

Water class	Sodium (Na) %	Electrical conductivity, µS/cm	SAR	RSC
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

4.2.2 Relative Proportion of Sodium to other Cations

A high salt concentration in water leads to formation of a saline soil and high sodium leads to development of an alkali soil. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of Sodium Adsorption Ratio (SAR). If the proportion of sodium is high, the alkali hazard is high; and conversely, if calcium and magnesium predominate, the hazard is less. There is a significant relationship between SAR values of irrigation water and the extent to which sodium is absorbed by the soil. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil structure owing to dispersion of the clay particles. A simple method of evaluating the danger of high-sodium water is the sodium-adsorption ratio, SAR (Richards, 1954):

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

The sodium percentage is calculated as:

$$Na\% = \frac{Na^{+} + K^{+}}{Ca^{2+} + Mg^{2+} + Na^{+} + K^{+}} \times 100$$

Where all ionic concentrations are expressed in milliequivalent per liter.

The values of SAR and sodium percentage of the ground water samples collected from the adjoining area of river Yamuna are given in Table 24. Calculation of SAR for given water provides a useful index of the sodium hazard of that water for soils and crops. A low SAR (2 to 10) indicates little danger from sodium; medium hazards are between 7 and 18, high hazards between 11 and 26, and very high hazards above that. The lower the ionic strength of the solution, the greater the sodium hazards for a given SAR (Richards, 1954).

The values of SAR in the ground water of the study area ranged from 1.70 to 12.06 during pre-monsoon season and 1.65 to 11.24 during post-monsoon season. As evident from the SAR values, the ground water of the study area falls under the category of low sodium hazard except two samples (Civil Lines and Sardar Patel Road), which reveals that ground water of the study area

Table 24. Values of Sodium Adsorption Ratio (SAR), Sodium Percentage (Na%) and Residual Sodium Carbonate (RSC)

S.No.	Sample Location	Type	June 2000			November 2000		
			SAR	Na%	RSC	SAR	Na%	RSC
1.	Bhagwanpur Khera	HP (25)	4.93	65.1	0.24	5.35	69.8	1.52
2.	Loni Road	BW (20)	3.81	56.4	0.27	4.10	58.4	-0.31
3.	Kabul Nagar	OW (35)	2.99	55.6	-0.04	2.35	54.1	0.18
4.	Naveen Shahdara	HP (20)	2.74	51.9	-0.30	2.39	49.2	-0.43
5.	Seelampur	HP (30)	1.70	41.7	0.11	1.65	41.0	0.17
6.	Shastri Park	HP (25)	3.20	67.9	1.44	2.87	66.9	1.38
7.	Lakshmi Nagar	HP (100)	2.79	55.1	0.58	2.89	54.8	0.41
8.	Prit Vihar	TW (40)	4.84	64.1	1.76	4.86	65.7	1.75
9.	Shankar Vihar	HP (200)	5.49	71.2	1.31	5.93	72.7	1.92
10.	Pratap Nagar	TW (100)	5.88	71.7	1.05	6.31	74.1	0.98
11.	Himmatpuri	HP (80)	7.40	68.3	-2.75	7.00	68.6	-2.22
12.	Civil Lines	TW (250)	12.06	83.7	1.30	11.24	82.9	1.24
13.	Rajpur road	OW (25)	2.26	48.7	0.39	2.30	50.7	0.57
14.	Malka Gunj	HP (20)	3.01	59.6	0.22	4.83	69.0	0.31
15.	Tripolia	BW (100)	6.15	67.4	-1.74	6.05	67.1	-1.86
16.	Gulabi Bagh	BW (40)	3.31	44.9	-6.02	3.99	48.9	-6.01
17.	Gulabi Bagh	BW (160)	1.94	30.4	-6.71	2.33	34.5	-5.46
18.	Shastri Nagar	BW (100)	3.58	64.0	0.40	3.37	61.0	-0.10
19.	Shastri Nagar	BW (60)	2.48	47.4	-2.31	2.64	47.7	-1.79
20.	Lekhu Nagar	HP (40)	2.99	59.0	0.82	2.64	50.3	0.00
21.	Ram Pura	HP (40)	2.39	52.2	0.60	2.48	52.4	0.53
22.	Punjabi Bagh West	HP (40)	4.31	59.0	-0.69	4.94	60.4	-1.46
23.	Rajghat	BW (50)	4.42	61.2	-1.07	4.25	60.8	-1.22
24.	JLN Marg	HP (60)	8.61	82.0	2.04	8.15	81.8	2.12
25.	GB Pant Hospital	BW (20)	4.28	65.9	-0.08	4.11	64.3	-0.23
26.	Panchkuin Marg	TW (450)	8.00	74.3	0.75	6.74	68.4	-0.91
27.	Panchkuin Marg	HP (60)	4.15	62.7	0.08	3.81	58.9	-0.43
28.	Rajendra Nagar	BW (100)	2.22	54.8	0.01	2.05	49.1	-0.59
29.	Rajendra Nagar	BW (300)	2.13	49.4	-0.32	2.47	48.9	-1.16
30.	Shankar Road	OW (20)	2.70	49.9	-1.66	4.32	60.5	-0.05
31.	IARI, Pusa	TW (120)	5.44	61.1	-1.89	5.28	59.7	-1.63
32.	Zoological Park	HP (60)	3.49	54.5	-1.34	3.25	57.1	-0.62
33.	Golf Course	BW (80)	4.33	44.3	-12.9	4.32	45.2	-12.06
34.	Rabindra Nagar	TW (150)	5.84	65.1	-1.54	5.89	65.0	-1.27
35.	Teen Murti Chowk	HP (60)	7.23	74.1	0.52	6.98	72.5	0.82
36.	Malcha Marg	BW (100)	9.23	75.3	0.34	9.16	76.0	0.58
37.	Sardar Patel Road	TW (150)	10.71	79.6	1.59	10.99	81.3	1.75
38.	Janpath	BW (250)	5.63	67.6	-0.39	5.94	70.2	-0.16

is free from any sodium hazard. The sodium percentage in the study area was found to vary from 30.4 to 83.7 during pre-monsoon season and 34.5 to 82.9 during post-monsoon season. More than 50% samples in the study area exceed the recommended value of 60% during both pre- and post-monsoon season.

4.2.3 Residual Sodium Carbonate

In addition to total dissolved solids, the relative abundance of sodium with respect to alkaline earths and boron, and the quantity of bicarbonate and carbonate in excess of alkaline earths also influence the suitability of water for irrigation purposes. This excess is denoted by Residual Sodium Carbonate (RSC) and is determined by the following formula:

$$RSC = (HCO_3^- + CO_3^{--}) - (Ca^{++} + Mg^{++})$$

Where all ionic concentrations are expressed in epm. Ground water containing high concentration of carbonate and bicarbonate ions tend to precipitate calcium and magnesium as carbonate. As a result, the relative proportion of sodium increases and gets fixed in the soil thereby decreasing the soil permeability. If the RSC exceeds 2.5 epm, the water is generally unsuitable for irrigation. Excessive RSC causes the soil structure to deteriorate, as it restricts the water and air movement through soil. If the value is between 1.25 and 2.5, the water is of marginal quality, while values less than 1.25 epm indicate that the water is safe for irrigation. During the present study, the RSC values have been observed mostly negative. The RSC values (Table 24) clearly indicate that the ground water of the study area is not having residual sodium carbonate hazard.

4.2.4 Boron

Boron is essential to the normal growth of all plants, but the concentration required is very small and if exceeded may cause injury. Plant species vary both in boron requirement and in tolerance to excess boron, so that concentrations necessary for the growth of plants having high boron requirement may be toxic for plants sensitive to boron. Though boron is an essential nutrient for plant growth, generally it becomes toxic beyond 2 ppm in irrigation water for most of the field crops. It does not affect the physical and chemical properties of the soil, but at high concentrations it affects the metabolic activities of the plant.

4.3 Classification of Ground Water

Different accepted and widely used graphical methods such as Stiff diagram, Piper trilinear diagram and U.S. Salinity Laboratory classification have been used in the present study to classify the ground water of the study area. Stiff classification (Stiff, 1951) is used to classify the type of water based on dominant cations and anions. Piper trilinear diagram (Piper, 1944) is used to express similarity and dissimilarity in the chemistry of water based on major cations and anions. U.S. Salinity Laboratory classification (Wilcox, 1955) is used to study the suitability of ground water for irrigation purposes. In classification of irrigation waters, it is assumed that the water will be used under average conditions with respect to soil texture, infiltration rate, drainage, quantity of water used, climate and salt tolerance of crop. The results of all the aforesaid classifications are discussed in the following pages and compiled in Table 25.

4.3.1 Stiff Classification

The Stiff graphical method plots four major cations (Ca, Mg, Na+K, Fe) on the left side and four major anions (HCO_3, SO_4, Cl, NO_3) on the right side. The original Stiff plot connects the points on the diagram and produces a pattern which, when compared to another analysis, is useful in making comparisons of waters. In modified Stiff diagram the length of each line defines the concentration of a particular cation and anion. Concentrations on the diagram are expressed in milliequivalents (meq) per liter. Since iron and nitrate are normally present in insignificant concentrations, most natural waters can be represented as solutions of three major cations (calcium, magnesium sodium with or without potassium) and three major anions (bicarbonate plus carbonate, sulphate, chloride with or without nitrate).

Table 25. Summarized results of water classification

Classification/Type	Sample numbers	
	June 2000	November 2000
Stiff Classification		
Sodium bicarbonate	1-9,13,14,18,20-22,24, 27-29,32.	1-9,13,14,17-22,24, 27-30,32,35
Calcium bicarbonate	17	-
Sodium chloride	19,31,35,36-38	31,36-38.
Sodium sulphate	10-12,16,23,25,26,30, 33,34	10-12,16,23,25,26, 33,34
Sodium nitrate	15	15
Piper Trilinear Classification		
Na-K-HCO_3	1-4,6-8,14,20,21	1-3,6,7,13,20,21
Ca-Mg-HCO_3	5,13	4,5
Ca-Mg-Cl-SO4	16,17,19,29,30,33	16,17,19,28,29,33
Na-K-Cl-SO4	9-12,15,18,22-28, 31,32,34,35,36-38	8-12,14,15,18,22-27, 30-32,34,35,36-38
Modified Piper Trilinear Diagram		
Na-K-HCO_3	1-4,6-8,14,20,21	1-3,6,7,13,20,21
Ca-Mg-HCO_3	5,13	4,5
Ca-Mg-Cl-SO4	16,17,19,29,30,33	16,17,19,28,29,33
Na-K-Cl-SO4	9-12,15,18,22-28, 31,32,34,35,36-38	8-12,14,15,18,22-27, 30-32,34,35,36-38
U.S. Salinity Laboratory Classification		
C2-S1	21,28,29	3,21,28
C3-S1	2-7,13-20,22,23,25, 27,30,32	2,4-8,13,14,16-20,23, 25,27,29,30,32
C3-S2	1,8-11,24,26,31,34, 35,38	1,9-11,15,22,24,26,31, 34,35,36,38
C3-S3	12,36,37	12,37
C4-S2	33	33

The chemical analysis data of all the samples collected from the adjoining area of river Yamuna in Delhi have been studied using Stiff classification and the results of the same have been summarized in Table 25. It is evident from the results that during pre-monsoon season 20 samples of the study area were found to be of sodium bicarbonate type, 10 samples sodium sulphate type, six samples of sodium chloride type and one sample each of calcium bicarbonate and sodium nitrate type. Nearly similar trend was observed during post-monsoon season.

4.3.2 Piper Trilinear Classification

Piper (1944) has developed a form of trilinear diagram, which is an effective tool in segregating analysis data with respect to sources of the dissolved constituents in ground water, modifications in the character of water as it passes through an area and related geochemical problems. The diagram is useful in presenting graphically a group of analysis on the same plot.

The diagram combine three distinct fields by plotting two triangular fields at the lower left and lower right respectively and an intervening diamond-shaped field. All three fields have scales reading in 100 parts. In the triangular fields at the lower left, the percentage reacting values of the three cation groups (Ca, Mg, Na+K) are plotted as a single point according to conventional trilinear coordinates. The three anion groups (HCO_3, SO_4, Cl) are plotted likewise in the triangular field at the lower right. Thus, two points on the diagram, one in each of the two triangular fields, indicate the relative concentrations of the several dissolved constituents of a ground water. The central diamond-shaped field is used to show the overall chemical character of the ground water by a third single point plotting, which is at the intersection of rays projected from the plotting of cations and anions. The position of this plotting indicates the relative composition of a ground water in terms of cation-anion pairs that correspond to the four vertices of the field. The three areas of plotting show the essential chemical character of ground water according to the relative concentrations of its constituents.

The chemical analysis data of all the samples collected from the study area have been plotted on trilinear diagram for both the surveys (Fig. 8 and 9) and results have been summarized in Table 25. The cation and anion plots in the diagram reveal that majority of the samples falls in sodium bicarbonate type during pre- and post-monsoon season.

The Piper trilinear diagram combines three areas of plotting, two triangular areas (cations and anions) and an intervening diamond-shaped area (combined field). Using this diagram water can be classified into different hydrochemical facies. It is evident from the results that during pre-monsoon season majority of the samples fall in Na-K-Cl-SO_4 followed by Na-K-HCO_3 and Ca-Mg-Cl-SO_4 hydrochemical facies. Almost similar trend was observed during post-monsoon season.

4.3.3 Modified Piper Trilinear Diagram (Chadha, 1999)

The diagram is a somewhat modified version of the piper trilinear diagram. In the piper diagram the milliequivalent percentages of the major cations and anions are plotted in two base triangles and the type of water is determined on the basis of position of the data in the respective cationic and anionic triangular fields. The plotting from triangular fields are projected further into the central diamond field, which represents the overall character of the water. Piper diagram allow comparisons to be made among numerous analyses, but this type of diagram has a drawback, as all trilinear diagram do, in that it does not portray actual ion concentration. The distribution of ions within the main field is unsystematic in hydrochemical process terms, so the diagram lacks certain logic. This method is not very convenient when plotting a large volume of data. Nevertheless, this shortcoming does not lessen the usefulness of the Piper diagram in the representation of some geochemical processes.

In contrast, in the modified diagram, the difference in milliequivalent percentage between alkaline earths (calcium plus magnesium) and alkali metals (sodium plus potassium), expressed as percentage reacting values, is plotted on the X axis and the difference in milliequivalent percentage between weak acidic anions (carbonate plus bicarbonate) and strong acidic anions (chloride plus sulphate) is plotted on the Y axis. The resulting field of study is a square or rectangle depending upon the size of the scales chosen for X and Y co-ordinates. The milliequivalent

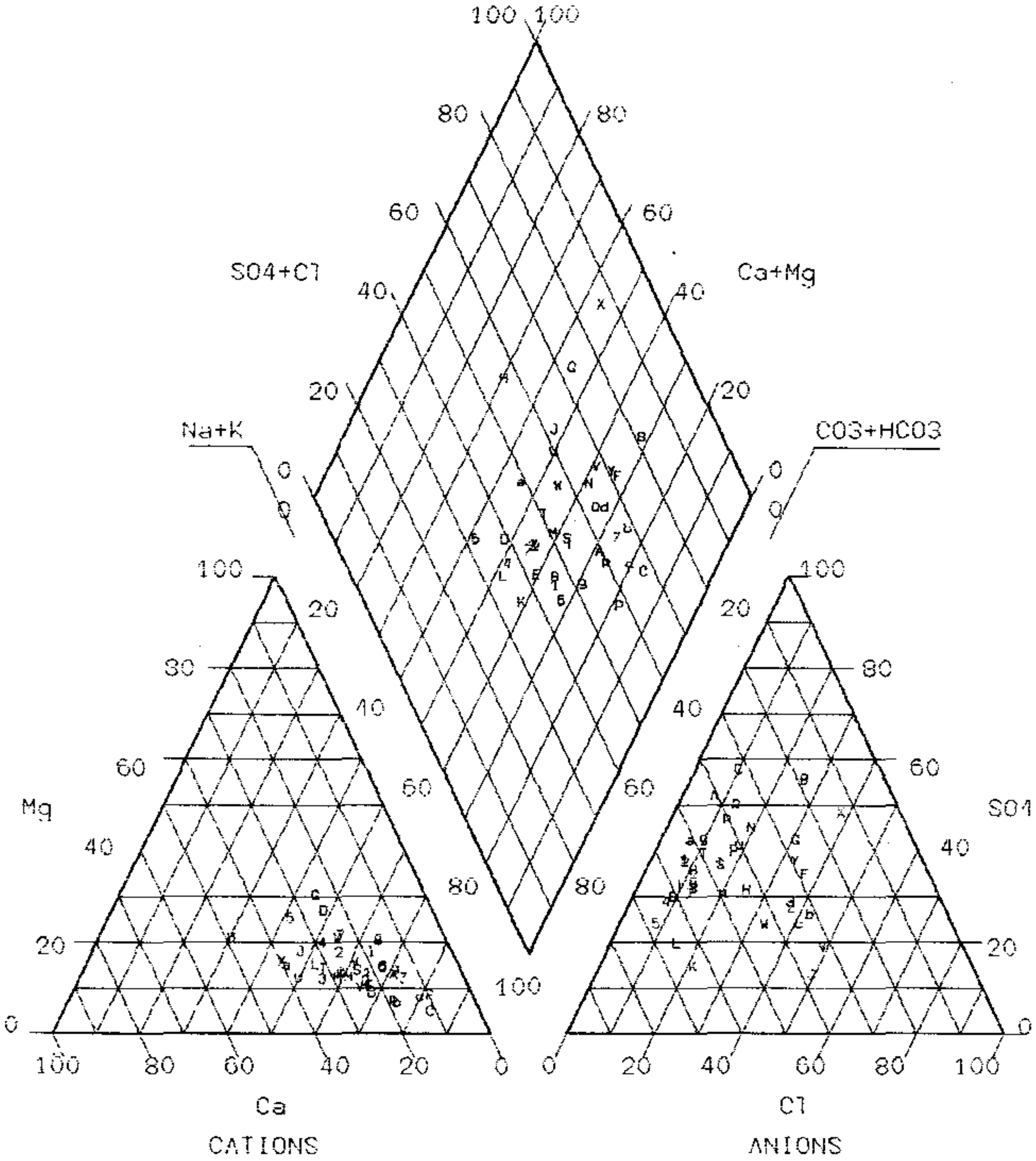

Fig. 8. Piper trilinear diagram showing chemical character of ground water (June 2000)

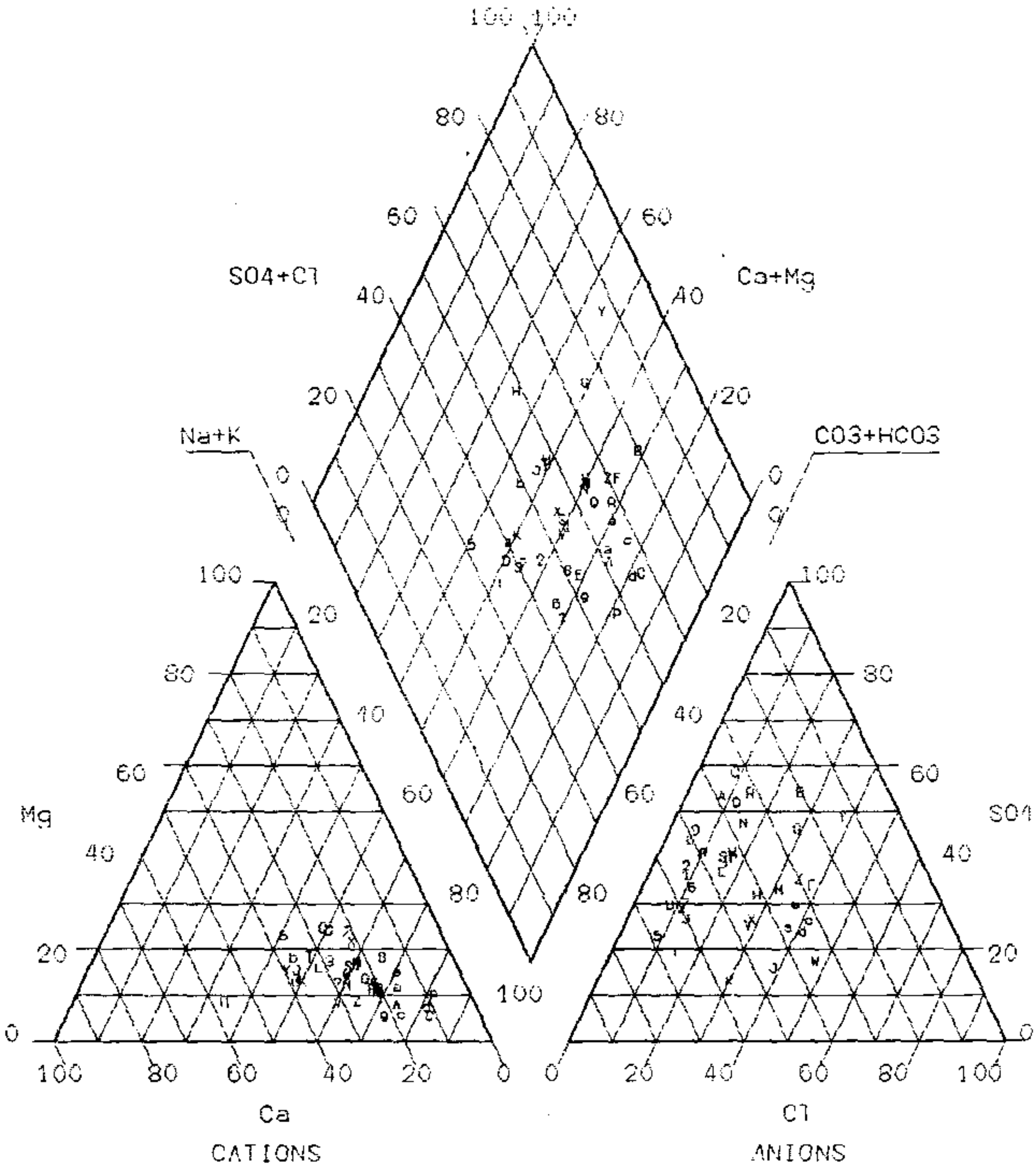

Fig. 9. Piper trilinear diagram showing chemical character of ground water (November 2000)

percentage differences between alkaline earth and alkali metals and between weak acidic anions and strong acidic anions would plot in one of the four possible sub-fields of the diagram. The main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

The square or rectangular field describes the overall character of the water. The diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be used to study various hydrochemical processes, such as base cation exchange, cement pollution, mixing of natural waters, sulphate reduction, saline water (end product water) and other related hydrochemical problems. In order to define the primary character of water, the rectangular field is divided into eight sub-fields, each of which represents a water type, as follows:

1. Alkaline earth exceeds alkali metals.
2. Alkali metals exceed alkaline earth.
3. Weak acidic anions exceed strong acidic anions.
4. Strong acidic anions exceed weak acidic anions.
5. Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions respectively. such water has temporary hardness. The position of data points in the diagram represent Ca^{2+} -Mg^{2+}-HCO_3^- type, Ca^{2+} -Mg^{2+}- dominant HCO_3^- type, or HCO_3^- - dominant Ca^{2+} -Mg^{2+}- type waters.
6. Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use. The position of data points in the diagram represents Ca^{2+} -Mg^{2+}-Cl^- type, Ca^{2+} -Mg^{2+}- dominant Cl^- - type or Cl^- - dominant Ca^{2+} -Mg^{2+}- type waters.
7. Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses. The position of data points in the diagram represent Na^+-Cl^-- type, Na_2SO_4- type, Na^+-dominant Cl^--type, or Cl^--dominant Na^+-type waters.
8. Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate in irrigation use and cause foaming problems. The positions of data points in the diagram represent Na^+- HCO_3^--type, Na^+-dominant HCO_3^- -type, or HCO_3^--dominant Na^+-type waters.

The chemical analysis data of all the samples collected from the adjoining area of river Yamuna in Delhi have been plotted on modified diagram (Fig. 10 and 11) as proposed by Chadha (1999) and results have been summarized in Table 25. It is evident that during pre-monsoon season most of the samples falls in Group 7 (Na-K-Cl-SO4) followed by Group 8 (Na – K – HCO3 type) and Group 6 (Ca-Mg-Cl-SO_4). Almost similar trend was observed during post-monsoon season. The modified diagram has all the advantages of the diamond-shaped field of the Piper trilinear diagram and can be conveniently used to study various hydrochemical processes. Another main advantage of this diagram is that it can be made simply on most spreadsheet software packages.

4.3.4 U. S. Salinity Laboratory Classification

Sodium concentration is an important criterion in irrigation-water classification because sodium reacts with the soil to create sodium hazards by replacing other cations. The extent of this replacement is estimated by Sodium Adsorption Ratio (SAR). A diagram for use in studying the suitability of ground water for irrigation purposes is based on the sodium adsorption ratio (SAR) and electrical conductivity of water expressed in μS/cm.

The chemical analysis data of ground water samples colected from the adjoining area of river Yamuna in Delhi has been processed as per U.S. Salinity Laboratory classification for the two sets of data (Fig. 12 and 13) and the results have been summarized in Table 25. It is evident from the results that during pre-monsoon season, only 3 samples (7.8%) fall under water type C2-S1 (medium salinity and low SAR) such water can be used if a moderate amount of leaching occurs and plants with moderate salt tolerance can be grown in most cases without special practices for salinity control. More than 50% samples fall under water type C3-S1 (high salinity and low SAR) such water cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected. About 30% samples fall under water type C3-S2 (high salinity and medium SAR) such water cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected. The water will also present an

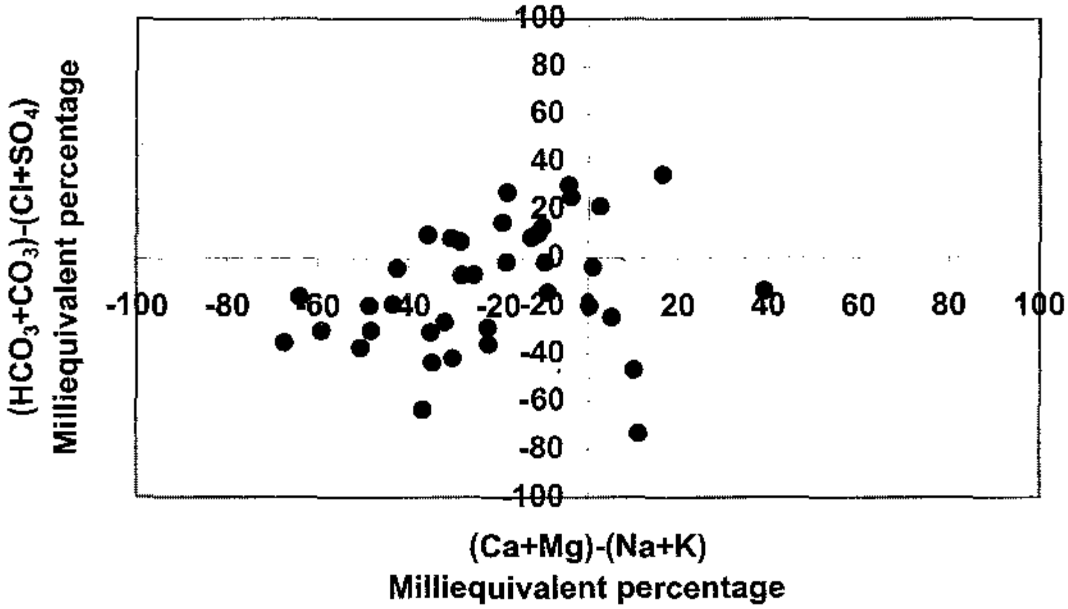

Fig. 10. Modified Piper trilinear diagram (June 2000)

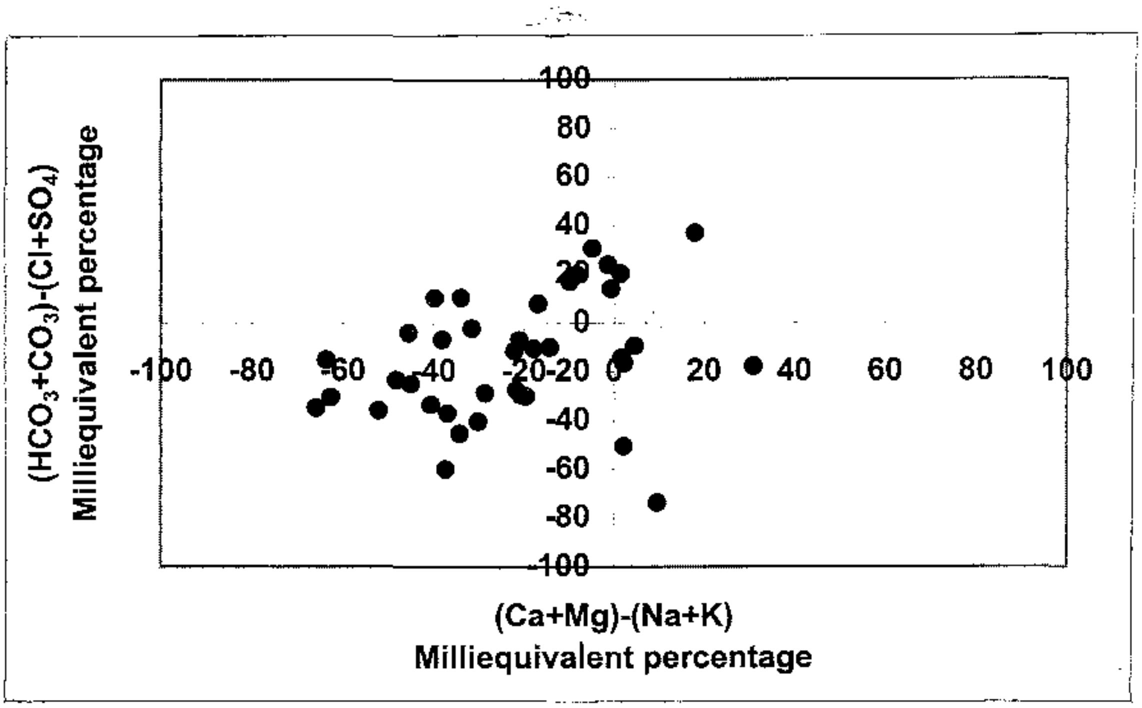

Fig. 11. Modified Piper trilinear diagram (November 2000)

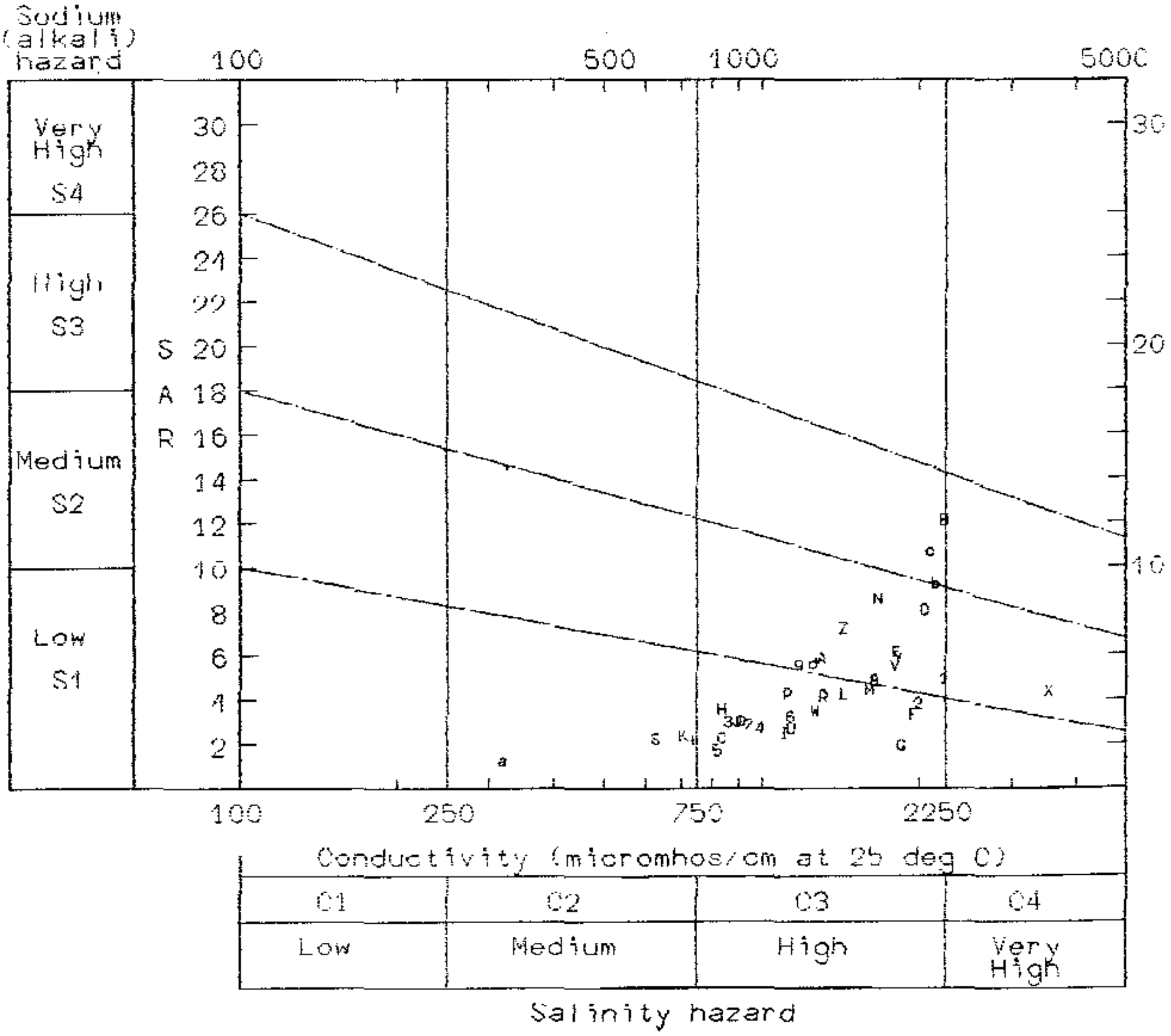

Fig. 12. U.S. Salinity Laboratory Classification (June 2000)

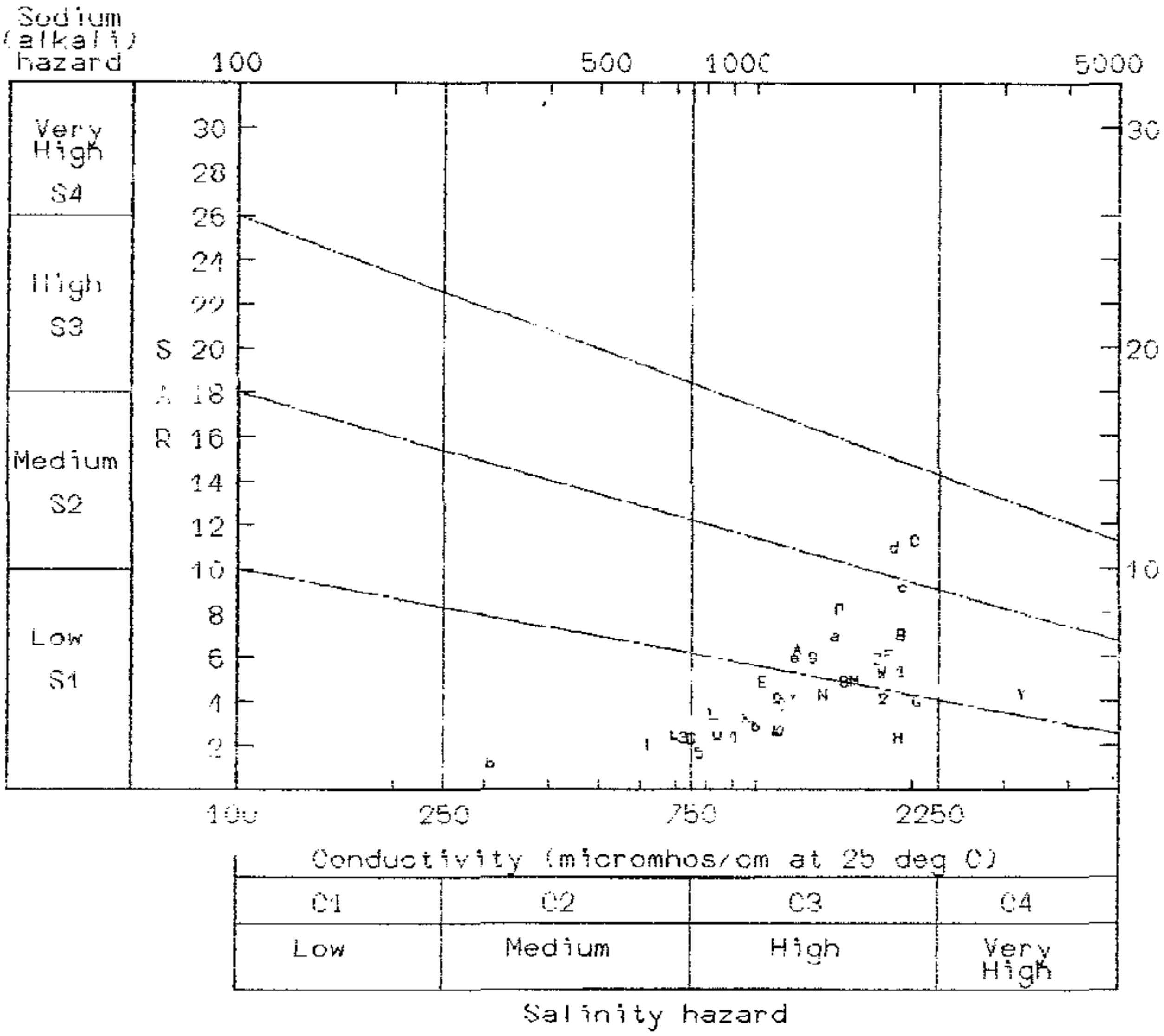

Fig. 13. U.S. Salinity Laboratory Classification (November 2000)

appreciable sodium hazard in fine textured soils having good cation exchange capacity, especially under low leaching conditions. Three samples (7.8%) fall under water type C3-S3 (high salinity and high SAR) such water cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected. The water will also produce harmful levels of exchangeable sodium in most soils and will require special soil management, good drainage, high leaching and organic matter additions. One sample fall under water type C4-S2 (very high salinity and medium SAR) such water is not suitable for irrigation. High salinity is harmful for the plant growth and changes the soil structure, permeability and aeration, which in turn affect the plant growth and yield considerably. Almost similar trend was observed during post-monsoon season.

4.4 Impact of River Water Quality on Ground Water

The river Yamuna enters Delhi near village Bhakhtawarpur in the north-east and leaves Delhi near village Jaitpur in south-east after traversing a distance of about 22 km. The river flows from north to south along the city and divides it into smaller eastern part (Trans - Yamuna) and bigger western part (cis-Yamuna). River occupies flood plain area of about 97 km^2 within NCT-Delhi. The Yamuna river water is extremely used for domestic water supply in upstream stretch, while down stream stretch water is used for industrial cooling, irrigation, washing and bathing at certain locations.

The surface water bodies play an important role in ground water flow system. The infiltration of surface water to ground water usually occurs in recharge geographical area while base flow from ground water to surface water bodies may occur in discharge geographical area. In discharge area the hydraulic head increases with depth and net saturated flow is upward toward water table but in recharge area the water table lies at considerable depth beneath thick unsaturated zone. The relationship of surface water to ground water and its recharge/discharge characteristics may change seasonally or once a longer time span. In deep ground water aquifers the movement of water from recharge to discharge area may take place several years, but in shallow aquifers, recharge and discharge may be much closer and even adjacent to each other. The hydraulic gradient imparts significant role in lateral and vertical migration of contaminants in ground water aquifers.

The impact of Yamuna river water quality on ground water flow system has been studied qualitatively (CGWB and CPCB, 2000). It is apparent that the impact of Yamuna river water quality on ground water is limited and confined to down stream stretches. The ground water samples collected in downstream of Yamuna river (Delhi stretch) has not depicted any significant alteration/modification of value quaiity in terms of organic contamination as well as bacteriological contamination, though the river water have impaired quality in respect of these characteristics. It indicates that either this area lies in discharge zone from ground water to surface water or the contamination transport is extremely slow due to impermeability of substratum.

The impact of Yamuna river water quality on ground water in vicinity of Okhla barrage has been more apparent. The physico-chemical and bacteriological characteristics of ground water samples collected within 1 km stretch of western side of Yamuna river depicted elevated concentration of various physico-chemical characteristics and higher bacteriological contamination, even in deep aquifers (CGWB and CPCB, 2000).

The impact of Yamuna river water quality on ground water will further aggravate with time span, as the transport of contaminant is very slow and complicated process. The improvement in Yamuna river water quality may reverses the process of further deterioration of ground water.

During the present study, 38 ground water samples were collected within 10 km vicinity of eastern and western banks of river Yamuna to ascertain the role of river water impact on ground water. The qualitative analysis of data depicted higher concentration of various physico-chemical and bacteriological parameters in the western side of river Yamuna even in deep aquifers. However, due to paucity of hydro-chemical, geological and water level data no specific inferences could be drawn regarding the probable impact of river water quality on ground water. Further studies are being planned to investigate in detail the impact of Yamuna river water quality on ground water system.

5.0 CONCLUSIONS

The suitability of ground water of adjoining area of river Yamuna in Delhi has been examined as per BIS and WHO standards. The quality of the ground water varies from place to place with the depth of water table. Only about 10% of the total samples analysed were found within the desirable limit of 500 mg/L and more than 80% of the samples were found above the desirable limit but within the maximum permissible limit of 2000 mg/L. From the hardness point of view, more than 80% of the samples were found well within the desirable limits for domestic applications during both pre- and post-monsoon seasons. More than 50% samples show nitrate contents less than 45 mg/L, where as in about 20% ground water samples the nitrate content exceeded even the maximum permissible limit of 100 mg/L. The higher level of nitrate at certain locations may be attributed due to the surface disposal of domestic sewage and runoff from agricultural fields.

The grouping of samples according to their hydrochemical facies clearly indicate that majority of the samples fall in Na-K-Cl-SO_4 followed by Na-K-HCO_3 and Ca-Mg-Cl-SO_4 hydrochemical facies. The U.S. Salinity Laboratory classification for irrigation water indicates that more than 50% samples fall under water type C3-S1 (high salinity and low SAR) such water cannot be used on soils with restricted drainage. Even with adequate drainage special management for salinity control may be required and plants with good tolerance should be selected. About 30% samples fall under water type C3-S2 (high salinity and medium SAR) such water will also induce an appreciable sodium hazard in fine textured soils having good cation exchange capacity, especially under low leaching conditions.

The qualitative analysis of data depicted higher concentration of various physico-chemical and bacteriological parameters in the western side of river Yamuna even in deep aquifers. However, due to paucity of hydro-chemical, geological and water level data no specific inferences could be drawn regarding the impact of river water quality on ground water. More detailed studies including contaminant transport modelling studies are needed to better understand the impact of Yamuna river water quality on ground water aquifer system.

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