Identification and Spatial Analysis of Groundwater Vulnerability Zones of Murshidabad District (West Bengal)

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Under the Supervision

of

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Certificate

This is to certify that the thesis entitled "**Identification and Spatial Analysis of Groundwater Vulnerability Zones of Murshidabad District (West Bengal)**" is an original research work submitted by Tathagata Ghosh, to the Department of Geography, Faculty of Science, The Maharaja Sayajirao University of Baroda in the fulfillment of the requirements for the award of the degree of Doctor of Philosophy in Geography. The thesis or any part thereof has not been submitted elsewhere for any other degree, diploma or certificate course.

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Tathagata Ghosh

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Abbreviations

ARP	Arsenic Removal Plants
As	Arsenic
BDL	Below Detectable Limit
BGS	British Geological Survey
BIS	Bureau of Indian Standards
CaCO3	Calcium carbonate
Cl^-	Chloride
DEM	Digital Elevation Model
EC	Electrical Conductivity
EDTA	Ethylenediaminetetraacetic acid
ERDAS	Earth Resources Data Analysis System
ETM+	Enhanced Thematic Mapper Plus
Fe	Iron
GB	Gigabyte
GHz	Gigahertz
GIS	Geographic Information System
gm/l	gram/litre
GPS	Global Positioning System
INFLIBNET	Information and Library Network
l/s	Litres per Second
m	metre
Mbgl	Metres Below Ground Level
mg/l	Miligram per litre

mm	Millimetre
MRVSA	Map Removal Variation Sensitivity Analysis
NATMO	National Atlas & Thematic Mapping Organisation
NH	National Highway
NO_2	Nitrite
NO^{-3}	Nitrate
PET	Polyethylene terephthalate
pH	Potential of Hydrogen
PHC	Primary Health Centers
PHED	Public Health Engineering Department
R.F.	Representative Fraction
RAM	Random-access memory
$s/cm^{-1} x\ 10^{-3}$	Siemens/centimeter
SO_4^{-2}	Sulfate
SOES	School of Environmental Studies
SOI	Survey of India
SPSS	Statistical Package for the Social Sciences
sq. km.	Square kilometre
SRTM	Shuttle Radar Topography Mission
TDS	Total dissolved solids
UV/VIS	Ultraviolet/Visible
WHO	World Health Organization

To My Beloved Father & Mother

Mr. Tapas Kumar Ghosh

&

Mrs. Sampa Ghosh

Chapter 1

Introduction

Chapter 1

Introduction

1.1 The Research Problem:

Groundwater is one of the important elements of environment which is indispensable for life. It is used for various purposes like - domestic, agricultural, industrial etc. The versatile use of the element has enhanced its importance but with its continuous harnessing for ages its volume may reach to the threshold level and its quality might get affected (**Smith** et al. 2000, **Harvey** et al. 2006, **Onodera** et al. 2009). This condition of depletion of water quantity and quality may be avoided if the rate of recharge and withdrawal of groundwater is balanced. But the issue is that the two conditions need not necessarily be in equilibrium. With the acceleration in the process of industrialization and urbanization, pressure on the subsurface water has increased through withdrawal, resulting into lowering of water table and deteriorating water quality (**Vizintin** et al. 2009, **Helena** et al. 2000, **Begum** et al. 2009, **Jeong** 2001, **Rao** et al. 1998, **Muszkat** et al. 1993, **Jury** et al. 1987, **Onodera** et al. 2008, **El Khalil** et al. 2008). Groundwater is recharged by the rainfall as well as the surface water like rivers. The rate of recharge depends upon the components like subsurface geology, surface characteristics, slope of the land, aquifer medium, soil condition, precipitation and vegetation cover (**Healy** et al. 2002, **Fitts** 2002, **Harbor** 1994, **Cook** et al. 1989). With the increase in the intensity of the rainfall and decrease in the slope of the land, the water carrying capacity of the aquifer and storage of groundwater increases along with the rise in the water table. Deterioration of groundwater is a result of both natural as well as anthropogenic causes. Pollution due to human interferences can be minimized to a certain extent but controlling natural causes is much more difficult and complex. Industrial effluents, pesticides and insecticides used in agricultural fields are some anthropogenic factors which add to the contamination of groundwater. They find their path to the subsurface groundwater through infiltration (Ando et al. 2001, Chatterjee et al. 1993, Yadav et al. 2002, Pionke et al. 1989, Ritter 1990, Melo et al. 2012, Silva et al. 2012, Shahsavari et al. 2012, Kanmani et al. 2013) and adversely affect the quality of water. Elements like *iron, zinc, manganese, aluminum, nickel, chloride, sulphate, nitrate, nitrite* etc. are naturally mixed in groundwater (Venkatesan et al. 2013, Hasan et al. 2013, Cheng et al. 2013, El Alfy et al. 2013, Umar et al. 2013, Kanmani et al. 2013). These elements have different desirable and permissible limits and deviation from the restrictions affects the quality of water. Imbalances at both the extremes are harmful and drinking this water is injurious to human health (Jimmy et al. 2013, Meier et al. 2013, Migeot et al. 2013, Machdar et al. 2013, Schnug et al. 2013, Alomary 2013). The morbidity of various ailments varies from mild to severe depending upon the level of contamination and duration of exposure to a particular element (Su et al. 2013, Jennings 2013, Andricevic et al. 2012, Peluso et al. 2012, Siirila et al. 2012, Pereira et al. 2012, Fatmi et al. 2013, Ujević Bošnjak et al. 2012). Considering, the safety of sub surface water, World Health Organisation (WHO), has recommended of setting shallow hand-pumps and tube-wells all over the country, even in areas where fresh surface water is available. Underground water, is considered safe and free from certain pollutants but a large variety of elements, minerals and chemicals which are found in the earth's crust, gets dissolved in water and lead to its contamination (Ravenscroft 2009) and affect the water quality. Some of these elements, even when present in trace amount, create serious health issues (National Council of Applied Economic Research 2001). For example – *cadmium*, one of the by-products of *zinc* production is a toxic element and when mixed with water and consumed by human beings creates health issues like toxicity to kidney and demineralization of bones (Bernard 2008). Higher concentration of *fluoride* in drinking water can result into *dental fluorosis* (Fordyce et al. 2007). Exposure to *mercury* is associated with *minamata* disease which leads to muscular weakness, numbness of feet and hand etc. (Järup 2003). *Lead* toxicity can result into interference in the work of heart, kidney, reproductive and nervous system (Järup 2003).

Arsenic is one of such element which is found in the earth crust and is a cause of concern throughout the world (Smedley and Kinniburgh 2002, Ng et al. 2003, Bhattacharya et al. 1997, Mukherjee et al. 2006). Human health is adversely affected even if it is consumed in trace amount for a longer duration. The permissible limit recommended by WHO is 0.01mg/l in developed countries and 0.05 mg/l for *India* and *Bangladesh*. (WHO, 1993, Ravenscroft et al. 2009, Karim et al. 2000).

1.2 Arsenic in the Environment:

The term *'Arsenic'* came from Persian word *'Al-Zarnich'*, modification to its root word '*Zar*' means yellow or gold orpiment (Azcue and Nriagu 1994). It does not have any colour, smell or taste when mixed up with water, hence is not easily traceable (Ravenscroft et al. 2009). The position of *Arsenic* in periodic table is number 33, in the group of 15 (Henke 2009). The most common valence state of arsenic is -3, 0, +3 and +5. From the historic time human used *arsenic* compounds like realgar (As_4S_4), orpiment (As_2S_6) and arsenite (As_2O_3) for wide variety of products like pigments, medicines, alloys, pesticides, glasswares and as a depilatory in leather manufacturing (Penrose et al. 1974, Basu et al. 2013, Kruger et al. 2013, Bergés-Tiznado et al. 2013, Mondal et al. 2013, Ansone et al. 2013). The element is found in rocks, sediments, soils, plants, food grains, pulses and vegetables and also in industrial and mining activities (arsenic bearing wastes, arsenical pesticides), (Simsek 2013, Matthews-Amune et al. 2012, Bian et al. 2012, Pignattelli et al. 2012, Bhattacharya et al. 2010, Williams et al. 2005, Mandal et al. 2002, Liao et al. 2005, Dahal et al. 2008). Hydrothermal fluids are also the major source of *arsenic* concentration. Hydrothermal fluids which have originated from the magmatic water have important source of *arsenic,* mostly As (III) (Pichler et al. 1999). In general, arsenide, arsenisulfide and arsenic-rich sulfide minerals are related to metamorphic and intrusive igneous rocks (Foster 2003). It is found in both organic and inorganic form of As (III) (Trivalent) and As (V) (Pentavalent) among which As (III) tend to be more toxic (Henke 2009).

1.3 World Pattern:

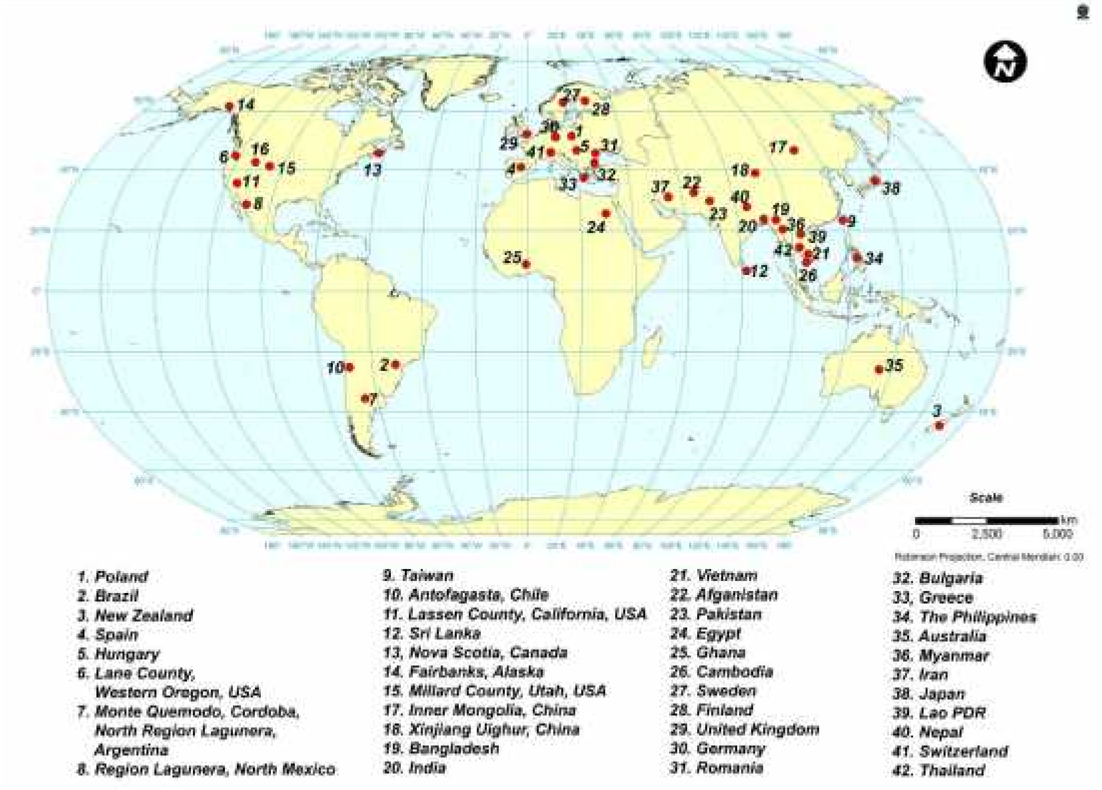


Fig. 1.1: Arsenic Contamination Scenario around the World (after Mukherjee et al. 2006)

Presence of *arsenic* with differential intensity in groundwater can be traced in different parts of the world. In *Asia*, the *Bengal Plain* of *Indian* subcontinent and *Bangladesh* are considered to be the largest contaminated regions (Smith et al. 2000, Karim et al. 2000, Mazumdar et al. 1998, Pal et al. 2007). The problem of groundwater contamination due to *arsenic* is very acute here (Chowdhury et al. 2000, Smith et al. 2000, Mandal et al. 1998, Chakraborti et al. 2002). The presence of *arsenic* in Bengal plains was noticed as early as 1910 but there was not sufficient proof to endorse it (Ravenscroft et al. 2009). The earliest case of *arsenic* induced arsenic poisoning was identified in 1983 by K. C. Saha [Department of Dermatology, School of Tropical medicine, Calcutta (Chakraborti et al. 2002)].

Nine districts viz. *Malda, Murshidabad, Nadia, North 24 Parganas, South 24 Parganas, Barddhaman, Howrah, Hoogly* and parts of *Kolkata* are the affected districts of *West Bengal* (Nickson et al. 2000, Chakraborti et al. 2002, Stuben et al. 2003). Other than *Bengal Plain*, a higher amount of *arsenic* in ground water is also found in parts of *Chattisgarh, Bihar, Uttar-Pradesh, Assam* and *Manipur* (Chakraborti et al. 2003, Chakraborti et al. 2002, Ahamad et al. 2006, Chakraborti et al. 1999, Pandey et al. 1999, Singh, 2004, Chakraborti et al. 2008). *Bangladesh* is considered to be a major *arsenic* contaminated zone in *Asia* (Ravenscroft et al. 2009, Rahman et al. 2003, Das et al. 1995).

Besides, the *Bengal Plain* and *Bangladesh*, stray incidences of groundwater contamination are also observed in different parts of *Asia*. Badruzzaman et al. (1998), BGS & DPHE (2001) estimated that, except for eastern and northern part, whole of

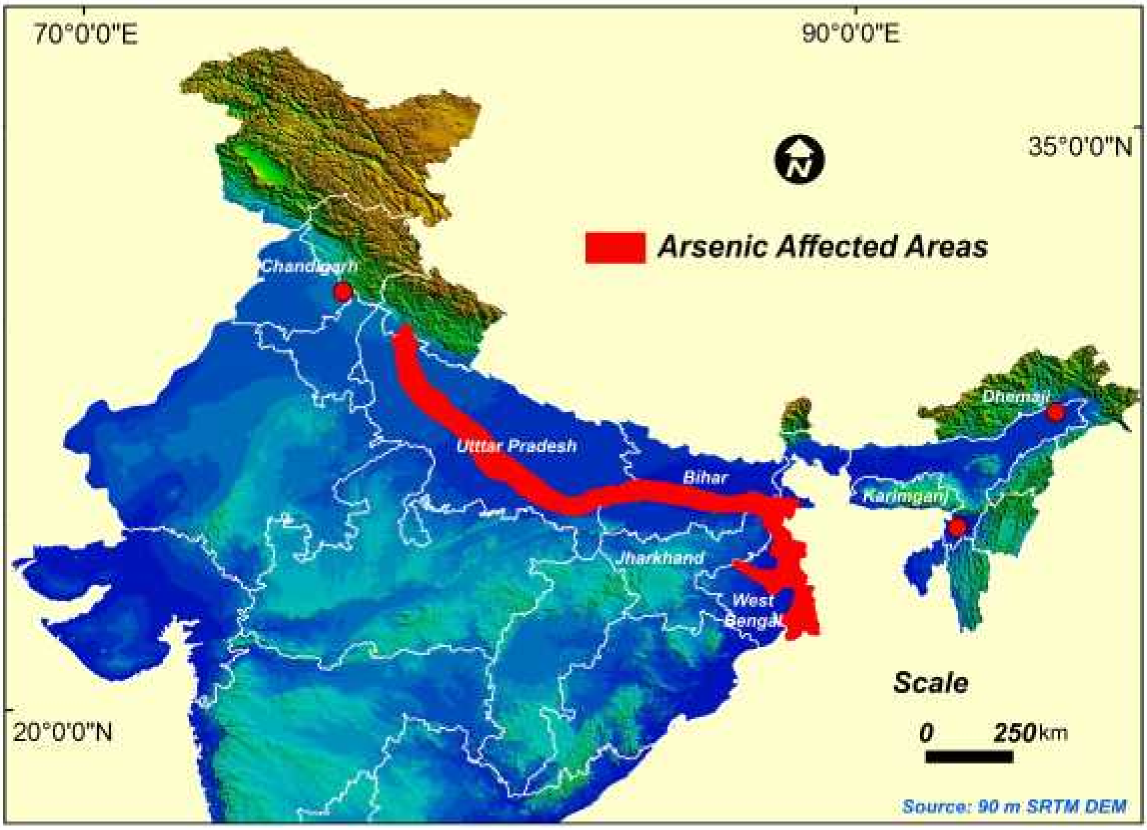


Fig. 1.2: Arsenic affected areas in India (Modified after Report work done by SOES, 2004)

Bangladesh has higher concentration of *arsenic* in groundwater. In the country, different studies has been conducted regarding the spatial distribution of *arsenic* in *Bangladesh* (Van Geen et al. 2003, Yu et al. 2003, Hossain et al. 2005, Frisbie et al. 2002). Chowdhury et al. (2003), Sengupta et al. (2003) and WHO (1993) estimated that, 50 out of 64 districts of *Bangladesh* have *arsenic* level above permissible limit of

50 mg/l. Large number of Recently in *Vietnam*, presence of arsenic is detected around *Hanoi* city, (**Xia** et al. 2004, **Deng** et al. 2009).

It is observed that *arsenic* is found in both shallow and deeper aquifers of *Pakistan* and *Sindh* (**Farooqi** et al. 2009). In several places of *Pakistan* like *Muzaffargarh* District of south-western *Punjab*, central *Pakistan*, *arsenic* concentration is very high (**Nickson** et al. 2005).

In European countries, the problem of *arsenic* in ground water is more or less controlled (**Ravenscroft** et al. 2009) and is found in few isolated pockets having lower concentration. In *Hungary*, above 50 mg/l concentration was traced during 1941-1983 (**Egyedi** and **Pataky** 1978). Higher level of contamination is found in *Greece*, *Bulgaria*, *Slovakia*, *Poland*, *Finland* and *Sweden* (**Ravenscroft** et al. 2009). In *United States*, the major hotspot of *arsenic* contamination is *Yellowstone*, *Oklahoma*, *Montana* and *Tacoma* (**Welch** et al. 1988). In *Argentina*, the underground water in south eastern part is heavily affected by the *arsenic* concentration (upto 300 mg/l) (**Concha** et al. 1998, **Bhattacharya** et al. 2006, **Smedley** et al. 2005).

1.4 Source of Arsenic in Bengal basin:

In terms of *arsenic* concentration and areal coverage, *Bengal basin* is one of the major *arsenic* affected region in the world (**Henke** 2009). Several perceptions related to arsenic mobilisation in groundwater have been postulated and four major types of mechanism have been put forward:

1.4.1 Oxidation of Pyrite:

Mandal et al. (1998), **Mallick** and **Rajagopal** (1996) have postulated that the concentration of *arsenic* in alluvial sediments of *Bengal basin* is mainly due to oxidation of pyrite present in the subsurface lithology, associated with withdrawal of groundwater, depletion of water table and finally aeration of previously anoxic sediments.

1.4.2 Comparative Ion Exchange:

Hypothesis put forward by **Acharyya** et al. (2000) stated that, *arsenic* ions are absorbed into the sediments, displaced into the solution by comparative ion exchange with phosphate which is mainly used in fertilizers. In case of *West Bengal*, the study of

Mukherjee and **Fryar** (2008), shows that there is no trace of *phosphate* in the deeper aquifer.

1.4.3 Reductive Dissolution of Iron (oxy) (hydr)oxides:

According to **Bhattacharya** et al. (1997), **Nickson** et al. (1998, 2000), **McArthur** et al. (2001), the *Bengal Basin* and *Bangladesh*, are associated with low NO^{-3}, SO_4^{-2}, high *iron* and *manganese* indicating towards the reducing condition. Hence, under reducing condition *arsenic* is resultant from Ferric (Iron) oxy-hydroxide.

1.4.4 Reduction and Oxidation:

The main concept of reduction and oxidation is that, at first, *arsenic* is mobilized through reduction of *iron* but local oxidation of pyrite is also possible. According to the study of **Lin** et.al. (2000), crystal structure of clay, plays an important role in oxidation / reduction of *arsenic*. Oxidation of As (III) to As (V) takes place on the clay surface while reduction of As (V) to As (III) is not found. The study also states that, oxidation depends upon the type and age of clay.

Other views about the source of *arsenic* in *West Bengal* are as follows –

1. It is transported by the river *Ganga* and its numerous tributaries from the *Rajmahal trap* which is situated in the western segment of the basin (**Saha** et al. 1991, **Acharyya** et al. 2000).

2. It is conveyed through the north *Bengal* tributaries of *Bhagirathi* and *Padma* Rivers from the eastern *Himalayas* (**Ray** et al. 1999).

3. It is mainly transported through the fluvial sediments from the *Himalayas* (**McArthur** et al. 2004).

1.5 Arsenic and Human Health:

Consumption of *arsenic* affected water for longer period of time gives rise to different health issues which may vary from general to severe. In the initial stage, the symptoms of *arsenic* poisoning are non specific and are general in nature like nausea/vomiting and limb pain. With the increase in exposure over time the health issues became more prominent like *thickening* and *pigmentation* (black and white) of skin. In severe cases the symptoms like *keratosis* and *carcinoma* of skin develop. Sometimes, when the severity of the problem increases, internal organs like kidney and liver also get adversely affected. The last stage is the development of cancer and amputation of body parts. In stray instances, cases of cancer have been observed even at lower age of 23 years (**Ravenscroft** et al. 2009).

1.6 Recent Literature Review:

The problem of *arsenic* has been addressed by different scholars in different ways. **Sengupta** (2003) discussed the concentration of arsenic in the *Ganga-Padma-Meghna-Bramhaputra* plain of *India* and *Bangladesh*. **Chakraborti** (2003) mainly focused on the *arsenic* concentration in the middle *Ganga* plain of *Bihar* and considered it as 'future danger'. **Rahman** (2001) worked on the similar lines but highlighted the *arsenic* concentration in *Bangladesh*. A comparative study was done by **Das** et al. (1995) by taking into account six districts of *West Bengal*. **Kouras** (2007) investigated upon the spatial variation of *arsenic* in the northern *Greece* while **Roychowdhury** (2010) extensively worked on *arsenic* contamination in 107 blocks of *West Bengal*.

A few researches are focused on the dermatological as well as biological sample studies associated with *arsenic* toxicity on human health. *Arsenic* contamination and its effect on human health was studied by **Kapaj** (2006) and **Kwok** et al. (2007), they largely focused upon the *arsenic* poisoning and blood pressure of women in inner *Mongolia* of *China*. **Wilhelm** et al. (2004) executed a comparative study of *arsenic* exposure in fingernails and urinary samples in the coal field near *Slovakia*. **Gault** et al. (2008) worked on the similar pattern taking fingernails and hair as bio markers. **Samanta** et al. (2004) attempted a study in *West Bengal* in respect to *arsenic* contamination and its effect on hair, nail, and skin-scales. Recent update on arsenic contamination and human health issues around the world was reviewed by **Naujokas** et al. (2013) while **Vahter** et al. (2008) worked on the effects of early life exposure to *arsenic* contamination.

Geochemists and geologists largely focused on finding the source, distribution and pathway of *arsenic* in groundwater and soil. **Banning** et al. (2009) undertook a study to identify the natural sources of *arsenic* in the *arsenic* affected *North Rhine-Westphalia, Germany*. **Ravenscroft** et al. (2005) focused upon the distribution of *arsenic* in relation to field characteristics and hydrological setup of *Bengal Basin* and *Bangladesh*. An attempt was made by **Matschullat** (2000) on the basis of extensive literature survey to estimate the *arsenic* concentration in different elements of the earth including atmosphere, biosphere, hydrosphere and lithosphere. **Acharyya** et al. (2005) discussed about the *arsenic* concentration in the quaternary sediments of *Bengal* plain with major emphasis upon the stratigraphy. A similar kind of study was done mainly to identify the influence of morpho-stratigraphy and fluvial geomorphology upon the *arsenic* contaminated *Damodar* fan-delta and west of *Bhagirathi* River (**Acharyya** 2007). **Kanchan** and **Ghosh** (2012) attempted to identify the vulnerability zones of *arsenic* contamination in the *Bengal* alluvial tract by using groundwater samples from eight districts of *West Bengal*. **Bhattacharya** et al. (2009) investigated the geochemistry, *arsenic* concentration and mobilization in the Holocene flood plain of south-central *Bangladesh*. A similar study was done by **Guo** et al. (2008) in a different area (shallow aquifer of Hetao Basin of inner Mongolia). **Aloupi** et al. (2009) studied the influence of geology in *arsenic* concentration in surface and subsurface water in *Greece*. **Nath** et al. (2009) worked on the *arsenic* mobilization in the subsurface water in the sandy aquifer.

A few studies have concentrated upon the spatio-temporal pattern of different parameters in groundwater. Seasonal pattern of *arsenic* concentration and hydrochemistry was studied by **Sultan** et al. (2006) in a small creek area of *Australia* while **Thundiyil** et al. (2007) worked on a wells of *Nevada*. **Cheng** et al. (2005) investigated the temporal stability of *arsenic* concentration in the wells for three years located at *Araihazar (Bangladesh)*. **Ghosh**[2] and **Kanchan** (2011) and **Farooq** et al. (2011) attempted a study on spatio-temporal pattern in *Murshidabad* district (*West Bengal*). **Steinmaus** et al. (2005) executed a similar type of study in *Nevada* while **Munk** et al. (2011) worked on *Alaska* region. Seasonal variation in surface water of *Cooum* river of *Chennai* was studied by **Giridharan** et al. (2008). **Tripathi** et al. (2012) discussed the *arsenic* accumulation in the local plants of *West Bengal*. **Rahman** et al. (2009) focused upon the daily intake of *arsenic* through rice and also incorporated the importance of irrigation in *Bangladesh*. **Sanz** et al. (2007) and **Smith** et al. (2008)

studied the concentration of *arsenic* in the nail, hair and rice straw in the lower *Ganga* plain.

Statistical tools and techniques like principal component, cluster analysis, and discriminate analysis are adopted by the different scholars to observe the complex probable relationship between different elements and parameters. Ghosh[1] and Kanchan (2014) focused on the central alluvial tract of *West Bengal* and employed factor and cluster analysis for identification of groundwater contamination zone. Cloutier et al. (2008) adopted multivariate statistical analysis to investigate the complex evaluation of groundwater geochemical parameters in the sedimentary Basin of north-west *Montréal*. Sources of industrial metals were investigated by Tariq et al. (2008) through statistical analysis in *Punjab* province of *Pakistan*, Similarly spatial and temporal analysis of groundwater level in *Fars* province of South *Iran* was studied by Ahmadi et al. (2007). Water chemistry data was analyzed applying multivariate statistical analysis in southwestern *USA* by Güler et al. (2002) while Panda et al. (2006) focused upon the river water and estuarine water in *Mahanadi* River. Hydrochemical study was conducted by Reghunath et al. (2002) in the surface water of *Karnataka*. Yang et al. (2010) worked on similar line in *Dinachi* lake of *China*. Yidana et al. (2010) employed water quality indexing technique in parts of *Ghana* while Boyacioglu et al. (2008) worked in *Tahtali* Basin.

Deep groundwater analysis was done by Chapagain et al. (2010) in *Kathmandu* valley of Nepal. Liu et al. (2003) employed similar technique in the blackfoot diseased region of *Taiwan* while water quality prediction method was proposed by Mahapatra et al. (2012) in urban area of *Rourkela* in *Sundergarh* district of *Odisha*. Mathes et al. (2006) proposed a method of combining multivariate statistical analysis with geographic information system for determining the water quality. Water quality was analyzed by Shrestha et al. (2007) in *Fiji* Basin of *Japan*. Similar kind of study was conducted by Sundaray (2010) in *Bramhani-Koel* river Basin.

For model building and understanding the behavior of arsenic in groundwater in association with other elements and minerals, Geographical Information System as well as conceptual models are generated. A GIS based DRASTIC model considering depth to water, groundwater recharge, aquifer media, soil types, topography, impact of vadose zone and hydraulic conductivity, was proposed by Babiker et al. (2005). Groundwater travel time and concentration of nitrite in river water in *Japan*, associated with land use change applying GIS was studied by Schilling et al. (2007). Guo et al. (2007) proposed a DRARCH model for identification of groundwater vulnerability zone in Northern *China*. For decision making, a GIS based model coupled with fuzzy logic was proposed by Pathak et al. (2011), Dixon (2005). Oh et al. (2011) and Vernieuwe et al. (2007) worked on the similar pattern with cluster based model of groundwater contamination of groundwater.

Ozdemir (2011) proposed a new model for groundwater modeling by comparing the methods of frequency ratio, weights of evidence and logistic regression in Turkey. Groundwater potential zones of hard terrain of *Mamundiyar* basin, applying GIS and Remote Sensing technique was undertaken by Dar et al. (2010). Bojórquez-Tapia et al. (2009) employed a modified V-DRASTIC model for the identification of groundwater vulnerability zone in *Mexican Central Highlands*.

For tracing the mobilisation of *arsenic*, scientists have undertaken studies associated with microbial activities, organic matters and humic substances. Kar et al. (2011) discussed the role of organic matter and humic substances in binding and mobilizing of *arsenic* in *Gangetic* aquifer. Similarly, the major focus of Dhar et al. (2011) is upon the enhanced *arsenic* concentration due of microbes in the aquifer of *Bangladesh*. Islam et al. (2004) assessed the role of metal reducing bacteria in releasing *arsenic* in the aquifer of *Bengal Plain*. In addition to the microbial activities, a comprehensive review on *arsenic* speciation was done by Bissen et al. (2003). Studies of Nickson et al. 2000, Swartz et al. 2004 suggests that the mechanism of *arsenic* release in *Bangladesh* is associated with the mobilization mechanism and also with local and regional geochemical processes.

Remedies from *arsenic* contamination through ways like purification system, organic interventions and different laboratory experiments were undertaken by different scholars. Sargent-Michaud et al. (2006) in his study proposed a cost effective *arsenic* purification system for the wells. Mondal et al. (2012) worked on a neural based stimulated model for the removal of *arsenic*, *iron* and *manganese* from groundwater. **Halford** et al. (2010) put forward *arsenic* management through well modifications and simulation in *Antilope* valley of *California*. **Sinha** et al. (2011) proposed the probable remedy of *arsenic* through organic investigations in the lower *Ganga* plains. A small scale *arsenic* purification method was suggested in *Pakistan* by **Hashmi** et al. (2011) while **Chen** et al. (2007) suggested the use of iron modified activated carbon for the removal of this element from water.

1.7 Objectives:

The present study envisages to-

1. Study the spatio-temporal variations in the level of *arsenic* in groundwater.
2. Identify the factors responsible for the spatio-temporal variations.
3. Establish the relationship of *arsenic* with other elements.
4. Study the impact of *arsenic* contaminated drinking water on human health.
5. Identify the factors responsible for the incidence of *arcenicosis.*
6. Identify the groundwater vulnerability zones.
7. Identify the zones of safe drinking water.

1.8 Hypotheses:

The hypothesis of the present study are-

1. Level / Concentration of geochemical parameters of groundwater vary in different seasons.

2. A positive relationship exists between the *arsenic* concentration in groundwater and human health.

1.9 Database and Methodology:

Arsenic concentration above the permissible limit prescribed by BIS (0.05mg/l) (Table 1.2) is noted in eight districts of the *West Bengal* viz. *Malda, Murshidabad, Nadia, N-24 Parganas, S-24 Parganas, Barddhaman, Howrah* (**Public Health Engineering Department, Government of India, West Bengal**). For the identification of the study area for the present work, all the districts reported as *arsenic* contaminated were taken into consideration (Table 1.1). Applying random sampling technique seven sampling locations were selected from each of the 7 districts. 49 water samples were collected (Fig. 1.6) in pre-monsoon 2009 and they were chemically analysed.

Table : 1.1 Arsenic Affected Districts of West Bengal:

Concentration of Arsenic	Name of the District
Above 0.05mg/l	Most parts of **Murshidabad***, **Nadia***, **Malda***, **N-24 Parganas***, **S-24 Parganas***, Kolkata and Parts of **Howrah***
0.05 mg/l to 0.03 mg/l	Howrah, Kolkata, parts of Hoogly, Darjeeling, Cooch-Behar, Uttar Dinajpur, Dakshin Dinajpur
Below 0.03 mg/l	Birbhum, Purulia, Puramedinipur, Pachim Medinipur, Banura and parts of Barddhaman

**-Groundwater Samples Collected from these districts.*
Source: *Public Health Engineering Department, Government of India, West Bengal.*

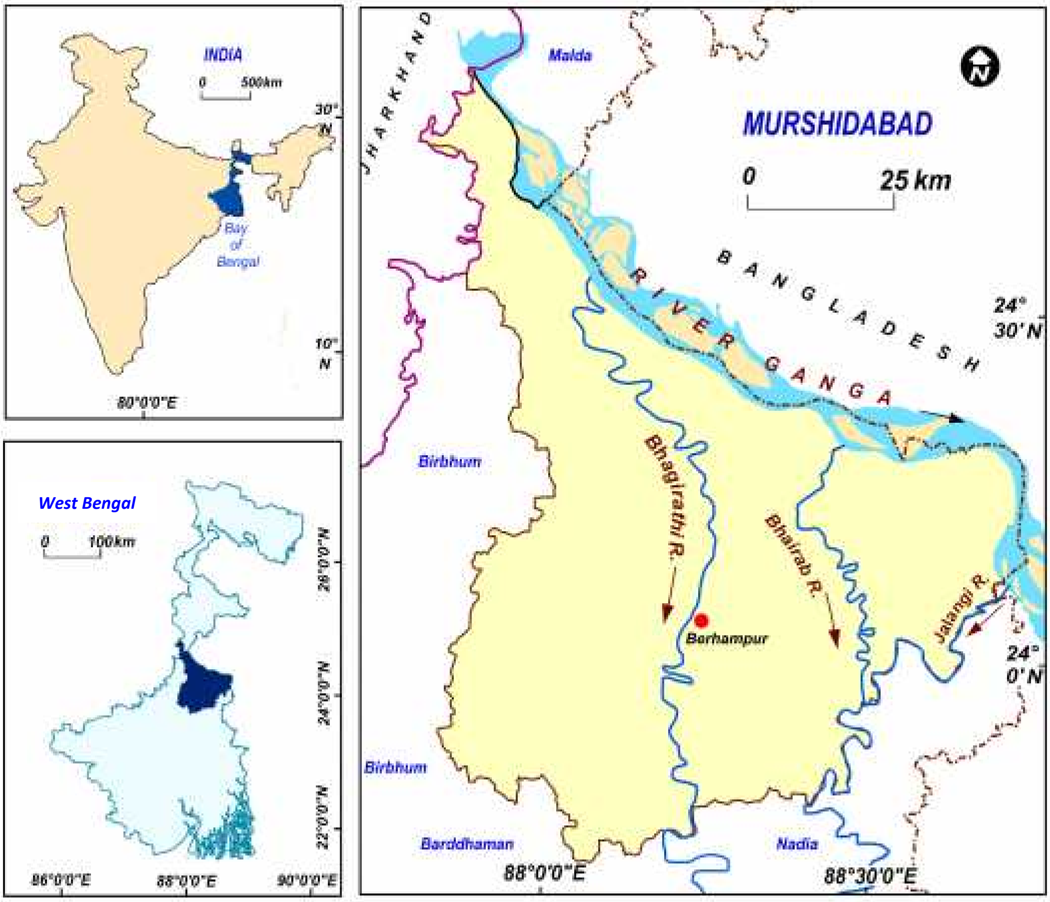


Fig. 1.3: Location Map of Murshidabad District

Maximum average concentration of *arsenic* was noted in *Murshidabad* district, hence, this district was chosen for the in-depth study (Fig. 1.3).

Table 1.2 Permissible Limits of Bureau of Indian Standards (BIS) for selected parameters:

Sl.no	Parameters	Permissible Limit
1	Arsenic	0.05 mg/l
2	pH	6.5-8.5
3	TDS	2000 mg/l
4	EC	N.A.
5	Iron	0.3 mg/l
6	Chloride	1000 mg/l
7	Sulfate	400 mg/l
8	Total Hardness as CaCO3	600 mg/l
9	Nitrite	N.A.

Source: bis.org.in/sf/fad/FAD25(2047)c.pdf

The present study was based on the analysis of 1404 groundwater samples, 312 soil samples and 2500 household schedules. For the understanding of the groundwater condition of the study area, water samples were collected from all 26 blocks for three seasons (pre-monsoon, monsoon and post-monsoon) successively for three years i.e. 2010, 2011 and 2012. Randomly, six sampling locations were selected from each block. Thus *26 X 6 = 156* groundwater samples were collected for one season for one year. Accordingly, for three seasons of a particular year, total number of samples were *156 X 3 = 468*. Finally, for three years, a total of *468 X 3 = 1404* groundwater samples were chemically analysed. In the entire study area, significant quantity of groundwater is consumed from shallower *depth,* that is why, water samples have been collected from the shallower aquifers (09 m to 90 m). Only one sample from each block was collected from the deeper aquifer and it was found that, *arsenic* concentration was below permissible limit in all the samples.

The samples were collected in 500 ml capped PET (Polyethylene terephthalate) bottles and were acidified with hydrochloric acid for retaining *pH* value below 2. The samples were kept in low temperature (4° C) till they were chemically analysed.

Sampling locations were marked by hand held GPS (Garmin e-Trex Vista). Parameters like *pH, Total Dissolved Solids, Electrical Conductivity and Chloride* were determined on the field by calibrated portable pH digital tester (Hanna, Model No. HI-9827), Portable TDS tester (Hanna, Dist 1, Model No. HI 98300), Portable EC tester (Hanna, Dist 4, Model No. HI 98303)

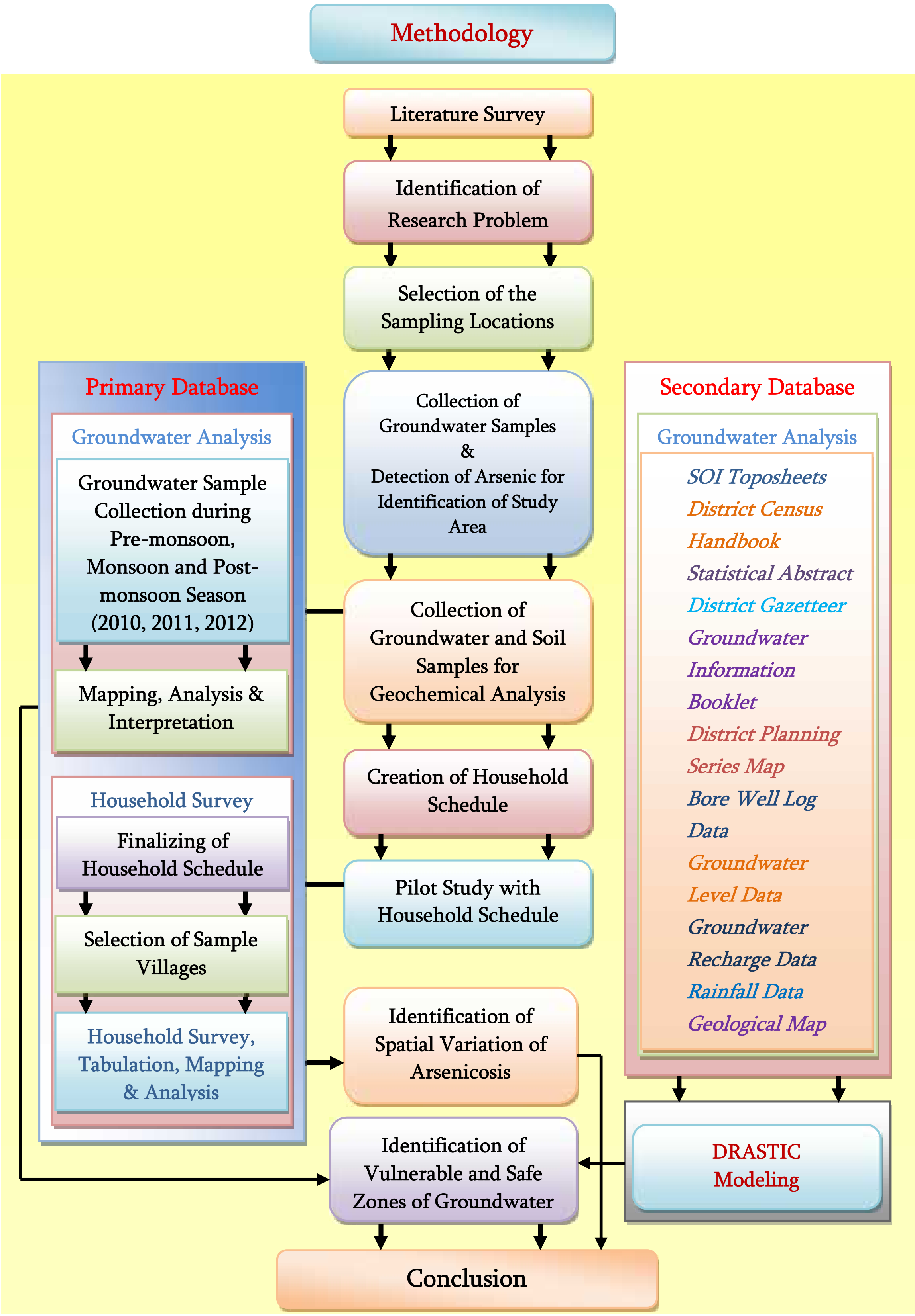


Fig. 1.4: Flow Diagram of Methodology

and *Chloride* Test Kit (HI 3815, mercuric-nitrate titration).Sulfate and Total Hardness as $CaCO_3$ were determined through the standard techniques (HI 38001, Sulfate Low and High Range Test Kit, Hanna and in Environmental Engineering Laboratory, Civil Engineering Department, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda).

Concentration of *Iron* (Fe) and *Nitrite* (NO_2) were determined by using colourimetric technique through Spectrophotometer in the laboratory of Department of Geography, Faculty of Science, The M. S. University of Baroda (Elico Double Beam UV/VIS Spectrophotometer SL 210) (APHA 1989, Mendham et al. 2006) (Fig.1.5f-1.5j). Concentration of *arsenic* was analysed by the professionals in the government recognized water testing laboratory (Southern Health Improvement Samiti, South 24 Parganas, West Bengal). For the cross checking of the results, some of the samples were analysed through colourimetric technique (Basett et al. 1986) in the departmental laboratory by using UV/VIS Spectrophotometric technique. For the identification of major ions of *calcium* and *magnesium,* standard Titration method (APHA 1989) was adopted. The concentration of *sodium* and *potassium* was analysed by the professionals of the government recognized water testing laboratory (Environmental Engineering Laboratory, Civil Engineering Department, Faculty of Technology and Engineering, The Maharaja Sayajirao University of Baroda and Southern Health Improvement Samiti, South 24 Parganas, West Bengal).

To minimize the effect of anthropogenic interventions, soil samples were collected from a depth of 0.30 m (approximately 1feet). For the selection of the soil samples, random sampling technique was applied. Care was taken to cover the whole area and twelve samples from each block were chosen and were collected in 500 gram zipped polyethylene bags with predefined sample location codes. Soils sampling locations were also marked by the hand held GPS (Garmin eTrex Vista).

All the glasswares were of Durasil, Borosil and Borosilicate make and were thoroughly sterilized by Hydrochloric acid, rinsed with distilled water and dried before analysis. Analytical Reagent grade or Lab Reagent grade (Merk, SDFL, Sulab, Loban, National Chemicals) chemicals were used for the entire analysis.

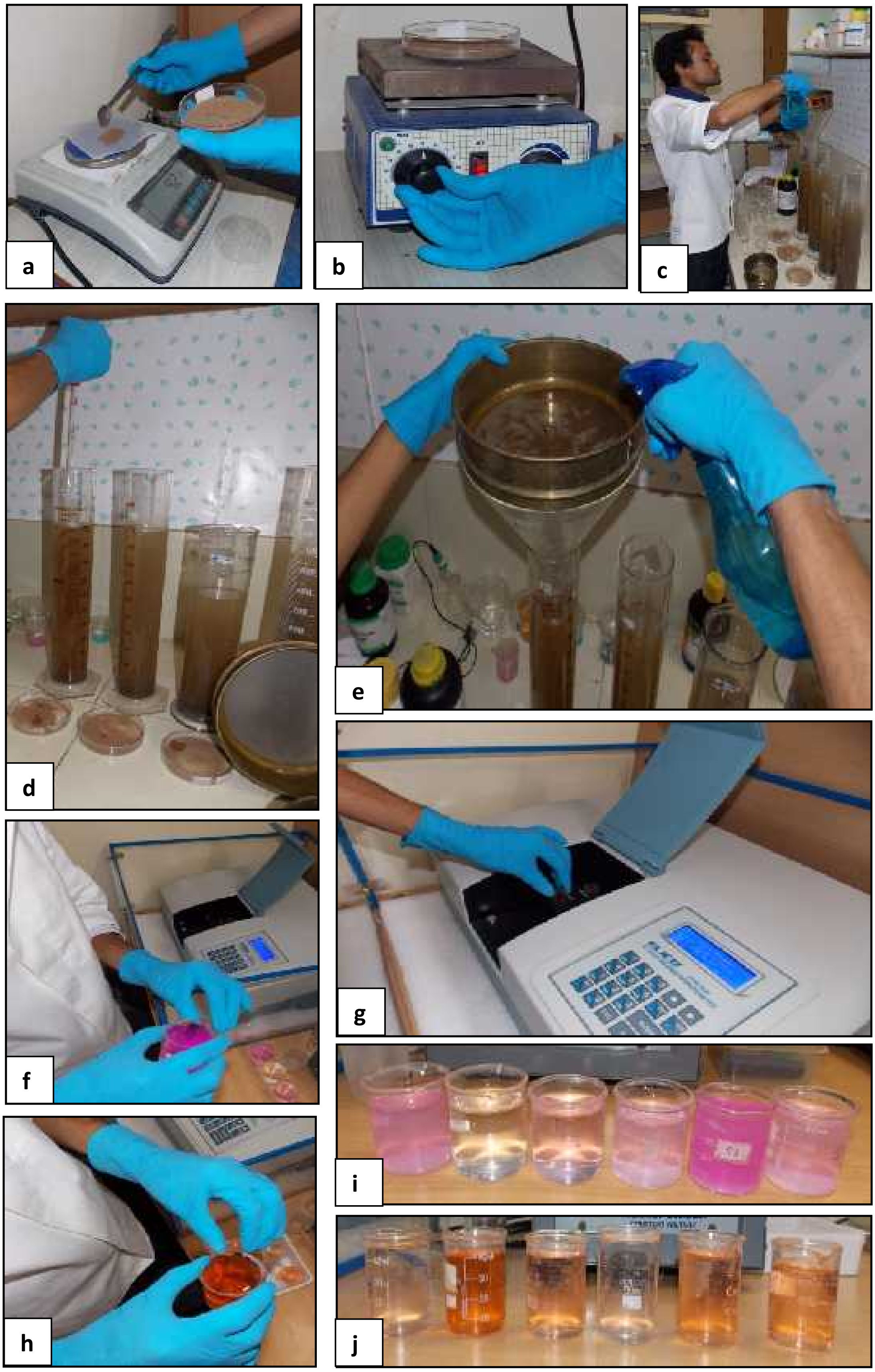


Fig. 1.5a -1.5e Wet Sieving Process
Fig. 1.5f -1.5j Spectrophotometric Determination of Nitrite (Pink Solution) and Iron (Orange Solution)

Standard wet sieving method through pipette was adopted for the analysis of grain size of sediments (**Folk** 1974, **Gracia** 2008) (Fig. 1.5a-1.5e).

Effects of *arsenic* contamination on human health was collected through structured schedules. Multistage stratified random sampling method was applied and 13 blocks were identified and one village from each block was randomly selected. For detailed study, 200 households from each village were randomly selected. Thus, approximately 2500 households were surveyed. For the identification of *arsenic* affected ailments, help of health personnel was taken.

Fig. 1.6 Water Sample Collection and GPS Location Marking

The data was tabulated and for analysis statistical packages like SPSS V.20 (Evaluation Period) and ORIGIN 8.5 (Evaluation Period) were used. Three dimensional Sub-surface lithological modeling was done in Rockworks 15 (Evaluation Period) software. Arc GIS 10® software was used for the preparation of maps. For the tripping of data from the GPS, Mapsource® software was used. ERDAS 8.5® was used for the preparation of Land-use/Land-cover mapping. All the softwares were installed and run on Windows 7 ® operating system with I Core 5 Intel 3 GHz processor with 4 GB RAM and inbuilt graphics card [Intel ®] support .

The present study was based on both primary and secondary data sources as stated below:

1.10 Secondary Data Sources:

Secondary data has been collected from:

Libraries of Smt. Hansa Mehta Library, The M. S. University of Baroda, Gujarat, Indian Institute of Technology Kharagpur (IIT), West Bengal; School of

Environmental Studies (SOES), Jadavpur University, West Bengal and Bharatidasan University , Tiruchirappalli.

Online journals were referred through-

Google Scholar (http://scholar.google.co.in/schhp?hl=en), Science Direct (www.sciencedirect.com), Springer Online (www.springer.com); Oxford Journals (www.oxfordjournals.org); Wiley Online Library (onlinelibrary.wiley.com); Taylor and Francis (www.tandf.co.uk/journals), American Chemical Society Publications (http://pubs.acs.org/), Journals were also accessed from Directories Open Access Journals (www.doaj.org).

All of the above said websites were accessed and articles were downloaded from the portal of The Maharaja Sayajirao University of Baroda through INFLIBNET.

District Census Handbooks, Statistical Abstract of West Bengal were collected from Census of India, Kolkata, Toposheets (Toposheet no. 72 P/16 and 72 P/14 with R.F. 1: 50,000), Geological Maps were collected from Survey of India, Kolkata. Department of Geography, The Maharaja Sayajirao University of Baroda also had few toposheets which were also taken into account (Toposheet No. 72 P/13, 72 P/15, 73 M/13, 73 D/4, 73 D/8, 79 A/1, 79 A/2 and 79 A/5 with R.F. 1 : 63,360). District Planning Series Maps and some of the toposheets were collected from National Atlas and Thematic Mapping Organisation (NATMO) (Toposheet no. 78 D/7 and 78 D/3 with R.F. 1 : 50,000), Kolkata. Bore-well log data was collected from Public Health Engineering Department, Murshidabad (PHED), and also from different Non Government Organisations. Rainfall data for different years was taken from the website of Indian Meteorological Department (http://www.imd.gov.in/section/hydro/distrainfall/webrain/wb/murshidabad.txt).

Groundwater level data for different years, water quality data, Bhujal News - Quarterly Journals, Ground Water Year Books, Ground Water Monitoring Reports, District Ground Water Reports, District Ground Water Profile Brochure of Murshidabad district were downloaded from Central Groundwater Board website (http://cgwb.gov.in/). Satellite images (LANDSAT ETM+) were downloaded from glovis.usgs.gov. Google earth images were also used in different stages of research.

Data related to arsenic affected person in the villages was collected from the Primary Health Centers (PHC's), of Murshidabad. Local Gram Panchayat Samiti provided Village profile and population structure of the villages. News paper cuttings were collected from Anandabazar Patrika.

1.11 Limitations of the Study:

The limitations of the present study are as follows-

1. The study is limited to a particular district of West Bengal.
2. The study incorporates only selected groundwater parameters.

1.12 Structure of the Thesis:

The structure of the thesis is as follows-

Chapter 1: Introduction deals with research problems, global distribution pattern of *arsenic*, objectives of the study, literature review, database, methodology and limitations of the study.

Chapter 2: Murshidabad: Profile of the Study Area focuses upon the location and extent of the district. The physical aspects of the study area associated with physiography of the region, hydrogeological setup, drainage, soil, climate, aquifer and vegetation. The socioeconomic setup focuses upon demographic pattern, agriculture and irrigation, industry, transport and connectivity, water facility and landuse/land cover pattern of the district. The chapter also looks into the issue of *arsenic* in the district.

Chapter 3: Spatio-temporal Pattern of the Geochemical Properties of Groundwater incorporates spatio-temporal pattern of different groundwater parameters in pre-monsoon, monsoon and post-monsoon season, interrelationship among the parameters and characterization of groundwater quality according to the level of contamination.

Chapter 4: Arsenic in Groundwater and Human Health deals with comparative study of *arsenic* contamination in groundwater and its effect on human health in the 13 surveyed villages.

Chapter 5: Identification of Vulnerability and Safe Zones of Groundwater gives a detailed account of groundwater contamination and potential zones by using DRASTIC model. *Arsenic* has been included in the model. Safe and unsafe groundwater zones have also been identified by using the model.

Chapter 6: Inferences and Future Study summarizes the findings of all the chapters and also suggests the study regarding harnessing of safe drinking water.

Resume:

Present chapter constructed the primary structure of research that dealt with research problem, literature review, data base and methodology. The next chapter will looked into the brief characteristics of physical and socio-economic setup of the study area.

Chapter: 2

Murshidabad: A Brief Profile

Chapter: 2

Murshidabad: A Brief Profile

2.1 Location and Geographical extent:

Murshidabad district, geographically extends longitudinally from 88°46′0″ E to 87°46′17″ E and latitudinally between 23°43′30″ N and 24°50′20″ N covering an area of 5,324 sq. km (Fig 2.1) (District Census Hand Book 2001). It occupies the central plain of the state of *West Bengal* and is surrounded by *Malda* in the north, *Barddhaman* in the south, *Nadia* in the south-east and *Birbhum* in the west. The state boundary between *West Bengal* and *Jharkhand* lies in the north-west. In the north-east and east, it shares the international boundary between *India* and *Bangladesh*. *Berhampur* is the district head quarter located in the central part and at the flank of River *Bhagirathi*. The district came into existence long before independence (Banerjee et al. 2003, District Census Hand Book 2001). Currently, it has divided into five sub divisions namely *Kandi*, *Lalbag, Jangipur, Sadar* and *Domkal* and twenty six blocks- *Hariharpara, Berhampur, Domkal, Beldanga-I, Beldanga-II, Nawda, Jalangi, Samsherganj, Suti-I, Suti-II, Sagardighi, Raghunathgunj-I, Raghunathgunj-II, Farakka, Kandi, Burwan, Bharatpur-I, Bharatpur-II, Khargram, Raninagar-I, Raninagar-II, Murshidabad-Jiagunj, Lalgola, Nabagram, Bhagawangola-I* and *Bhagawangola-II* (Fig 2.1). There are seven municipalities (*Dhulian, Jangipur, Jiaguanj, Ajimguaj, Murshidabad, Kandi, Beldanga* and *Baharampur*).

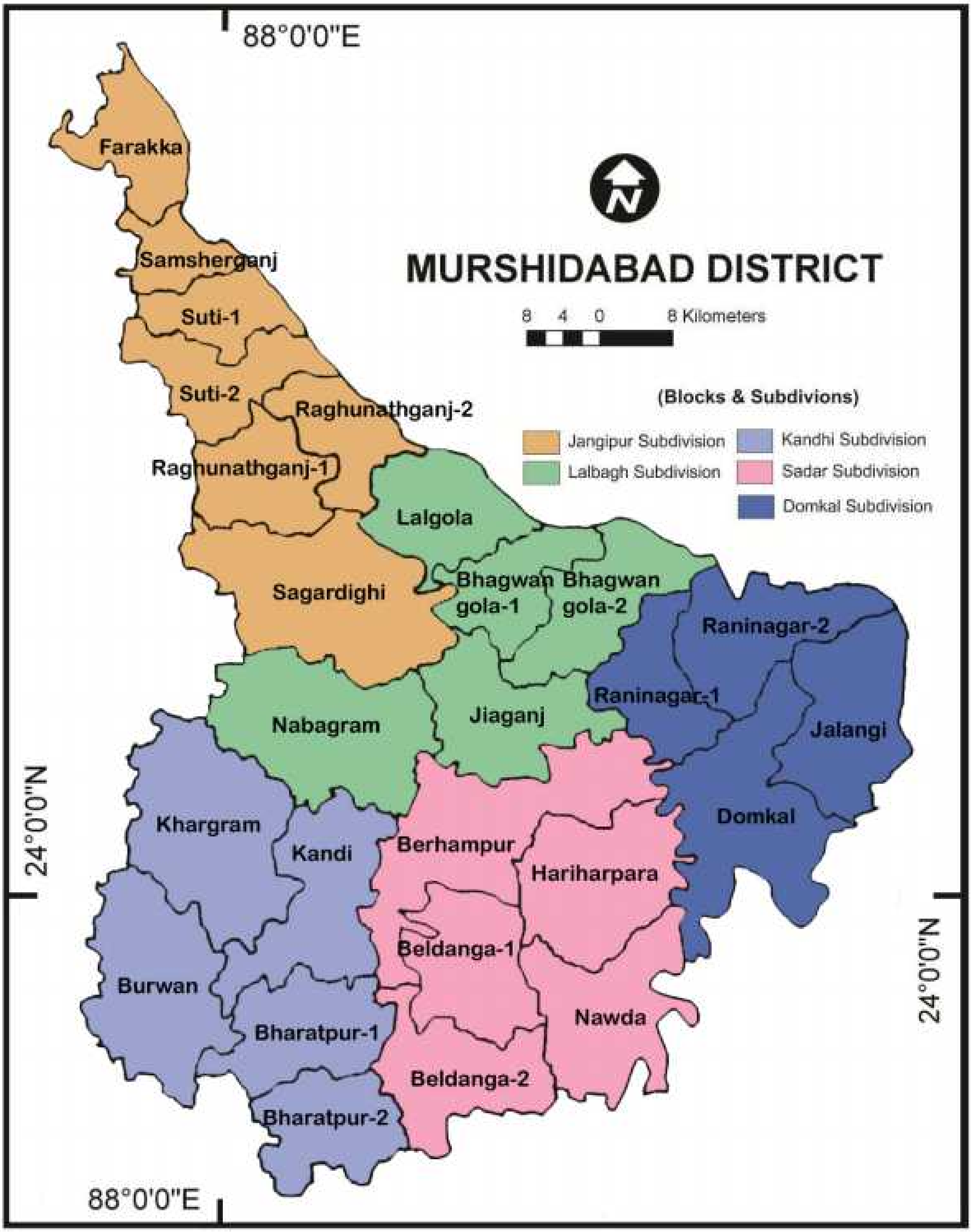


Fig. 2.1: Blocks and Subdivisions map of Murshidabad District (Source: DCBH, 2001)

There are 26 police stations, 26 Panchayet samities, 255 gram panchayets and 2210 villages in whole of the district. From the point of view of tourist's attraction, the district has several important places of historical significance. One of the points of attraction is *Hazarduari*. It is the last palace of *Nawab Bahadur* in *Murshidabad* and is situated on the bank of River *Bhagirathi. Sripur Palace* of *Kasimbazar*, District library at *Kashimbazar*, Textile Technology Institute and *Berhampur* Fort (Fig 2.2) are few other places of attraction. There are numerous temples situated across the district and are of religious, tourist and archeological significance (District Census Hand Book, 2001, Banerjee et al. 2003).

Fig. 2.2: Berhampur Fort (1850)
Artist: W. Purser, Engraver: W. J. Cooke,
Source: http://murshidabad.net/

Long back in 5th century AD, *Gupta's* ruled the northern part of present day *Radh* and *Begri*. In 7th century AD King *Sasanka* had ruled over whole of the *Radh* region. In present time, *Murshidabad* took a significant twist when Murshid Kuli Kha (Fig 2.3) was appointed as the faujdar of the district (*Makshudabad*) and Dewan of *Bengal* by the *King Aurangzeb*. The district derived its name from the name of '*Murshid Kuli*

Fig. 2.3: Nawab Murshidkuli Kha.
Source : http://murshidabad.net/ history/ showimage-img-murshid-quli-khan.jpg

Kha'. The present *Murshidabad* came in to existence in 1787 as part of *Birbhum* district. The final form of the district of *Murshidabad* came into existence through jurisdictional interchanges with *Birbhum* in 1879 and after that there has been changes in the boundaries of the district.

2.2 Physical Setup:

2.2.1 Physiography and Geomorphology:

The entire district is plain with elevation varying between 10-50 m above mean sea level (**District Resource Map**, 2008). Hence, the district is prone to floods during the monsoon season. Topographically, the study area is further classified into five micro regions-

1. ***Nabagram Plain*** - slopes gently towards east with low lying area in the north,

2. ***Mayurakshi-Dwarka Plain*** - is located in the southwestern part of the district and has the characteristics of *Radh* and is associated with *Sub-Vindhyan* region.

3. ***Ganga-Bhagirathi Basin*** - extends in the narrow valley of *Ganga* and *Bhagirathi* and is highly fertile and suitable for cultivation.

4. ***Jalangi-Bhagirathi Interfluve*** - extends between River *Bhagirathi* in the east and *Bhairab* in the west and River *Jalangi* in the south-east.

5. ***Raninagar Plain*** - is associated with '*Begri'* region and has numerous swamps, extends between *Bhairab* and *Jalangi* Rivers in the north-eastern sector (**District Census Handbook**, 2001).

2.2.2 Geological Settings:

The whole district is associated with the unconsolidated sediments of the late Pleistocene to late Holocene time. Quaternary sediments mainly belong to *Rampurhat, Kandi* and *Bhagirathi* formations whereas older formations belong to *Rajmahal trap.*

Western part of River *Bhagirathi* is dominated by *Rampurhat* formations having sandy and silty clay. *Kandi* formation is extensively spread over the district with alternating layering of sand, silt and clay sediments (Fig 2.4) (District Resource Map 2008, Groundwater Information Booklet 2007).

Fig. 2.4: Geological Settings of the Study Area (Source: District Resource Map, Murshidabad, West Bengal, 2008)

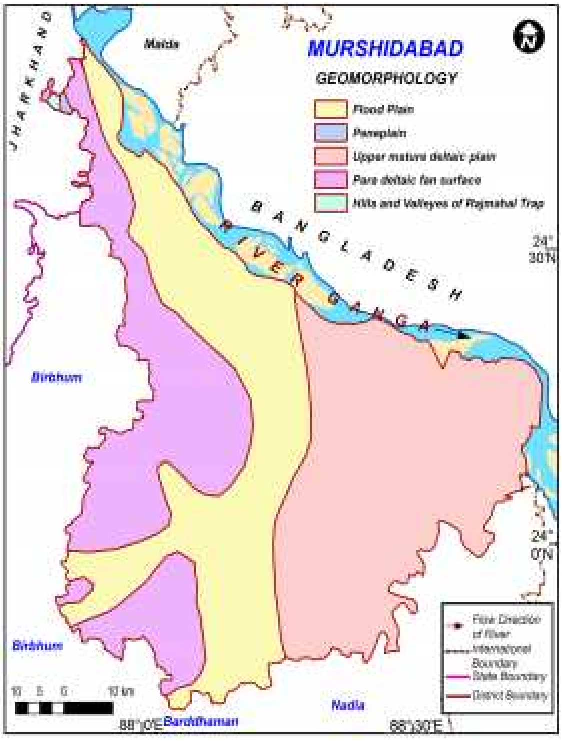


Fig. 2.5: Geomorphic Settings of the Study Area (Source: District Resource Map, Murshidabad, West Bengal, 2008)

The *Bhagirathi* formations, also contain silt and clay and are associated with present day fine grained flood plain regions. A small patch of *Rajmahal trap*, associated with basaltic rock is situated in the north-western part of the district.

2.2.3 Drainage:

The major river of the district is *Ganga* and its distributaries like *Bhagirathi*, *Bhairab* and *Jalangi*. The river flows from north-west to south-east along the northern flank of the district. Large bars and meandering is noticed in the upper reach, whereas, the lower reach is characterized by large meandering pattern with narrowed channel close to eastern part. River *Bhagirathi*, flows in north-south direction in meandered path with numerous ox-bow lakes. The river approximately divides the entire district into two halves.

(**District Resource Map** 2008, **Groundwater Information Booklet** 2007, **District Census Handbook** 2001). River *Bhairab* flows in north-south direction in a meandered path on the east of River *Bhagirathi*. River *Jalangi* flows nearer to *Bangladesh* and meets river *Bhairab.* It follows the path in the south-east and marks the district boundary between *Murshidabad* and *Nadia* (Fig 2.6). In the southwestern segment of the district, a small part of river *Mayurakhi* enters the district from *Birbhum* district of *West Bengal*. All the distributaries carry considerable amount of water only during the monsoon season.

Fig. 2.6: Drainage of the Study Area (Source: District Planning Series Map, Murshidabad, West Bengal, 2002)

There are several other smaller rivers which drain the district. *Bansloi* is an important tributary of *Bhagirathi*. It enters the district from *Birbhum* district of *West Bengal* and after flowing in the eastward direction it meets River *Bhagirathi*. In the south of *Bansloi*, another small tributary of *Bhagirathi* known as *Pagla,* flows in

Fig. 2.7: A Bil near Berhampur

the same direction and meets the river.

Apart from rivers, several smaller ponds and tanks locally known as *'bils'* are found in the eastern part of the district. 129 sq. km of the area in the south-eastern part of the district is swampy. These *'bils'* are mostly used for fish production and for irrigation (Fig. 2.7). Even in the district head quarter of *Murshidabad*, there is a big tank known as '*Sagardighi*' (District Census Handbook, 2001). Some of the important '*bil's* are as follows-

1. ***Hijal bil*** is located in the south-western part of the district. Major parts falls in the block of *Kandi* and some part comes in *Berhampur* also. The average depth of the '*bil*' is not more than 4-5 feet but during rainy season it increases to 20 feet.
2. ***Telkar bil*** is located in the western part of river *Bhagirathi* near to *Khagda* railway station. Recently the '*bil*' is filled up and used for irrigational purpose.
3. ***Basiar-bil*** is located in the block of *Nabagram* with a perimeter of 15 kms and touches >50 villagaes.
4. ***Motijhil bil*** is located in the south-east of *Murshidabad* city. It is an ox-bow lake which is formed due to change in the path of river *Bhagirathi.*
5. ***Gobornala*** is a small channel of river *Bhagirathi* and is located in it's the eastern side the channel is the result of the excess of river water.

Patan, Baloler, Mundmala, Damos, Ahiron, Telkar and *Ahikar* etc. are the other important *'bils'* in the district.

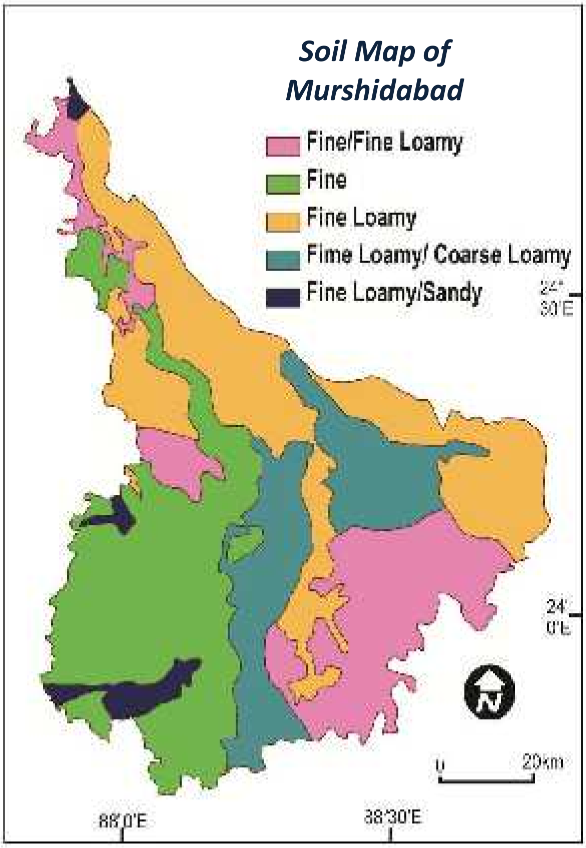


Fig. 2.8: Soil Map of the Study Area (Source: NBBS & LUP Regional Centre, Kolkata, http://agricoop.nic.in/Agriculture%20contingency%20Plan/West%20Bengal/WestBengal%2011-Murshidabad-31.12.2011.pdf)

2.2.4 Soil:

The eastern segment of the district which is on the east of the river *Bhagirathi* is associated with fertile light alluvial soil locally known as '*bagri*' (fine loamy and sandy) while western part of river *Bhagirathi* has lateritic clay and calcareous nodules and continuation of sub-*vindhyan* region, locally known as "*Rarh*" (fine loamy). The characteristics of the soil are light texture, low organic carbon content and slightly acidic in nature. (**NBBS & LUP Regional Centre,** Kolkata, **District Planning Series Map,** Murshidabad, 2002) (Fig. 2.8).

2.3 Climate :

The climate of the district is hot and humid. Rainfall mainly occurs from the southwest monsoon. Average rainfall of the district is about 1400-1700 mm and 74% of it falls between June and September only. Mean monthly temperature varies

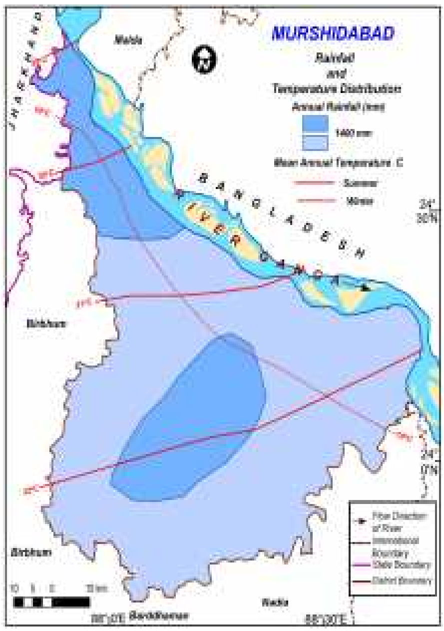


Fig. 2.9: Rainfall and Temperature Distribution of the Study Area (Source: District Planning Series Map, Murshidabad, West Bengal, 2002)

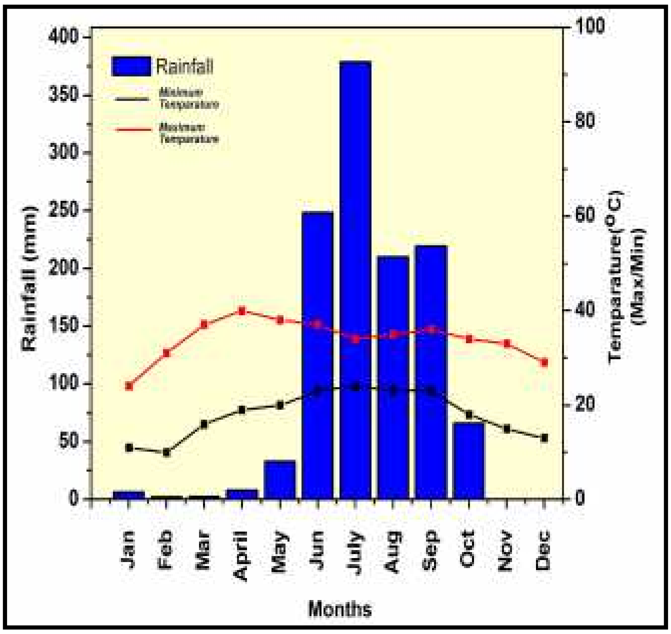


Fig. 2.10: Rainfall and Temperature 2008
Source (Rainfall): http://www.imd.gov.in/ webrain/ wb/murshidabad.txt
Source (Temperature): http://www.wbagrimarketingboard.gov.in/max mintemp/maxmintemp_murshidabad.html

between 17°C to 35°C. May is the hottest month with 46C highest recorded temperature. Thunderstorm, hailstorm and heavy rain associated with dusty gust are commonly observed during early summer season.

This convective type of storm in the evening time is locally known as "*Kal – baisakhi*" (District Census Handbook 2001). December and January are the winter months, January is the coldest month with minimum temperature between 9°C to 11°C and maximum of 25°C (Fig. 2.9 and Fig. 2.10).

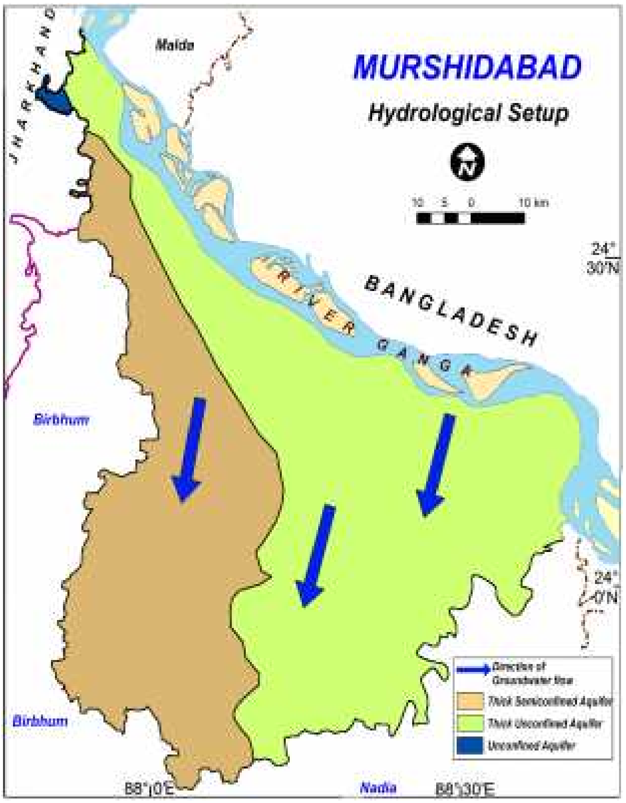


Fig. 2.11: Hydrological Setup of the Study Area (Source: Groundwater Information Booklet, Murshidabad, 2007)

2.4 Aquifer Condition:

Three types of aquifer system are found in the entire district-

i) Eastern segment of river *Bhagirathi* is associated with thick unconfined aquifer. In this aquifer is that no significant impermeable layer between surface and subsurface layers due to which interaction of water from the surface is more frequent and with greater intensity.

ii) The western part the district is associated with thick semi confined aquifer. This aquifer is partly confined by the layers of lower permeability materials. Under confined condition the clay beds are connected with each other and resulted into artesian condition in several places (Groundwater Information Booklet, Murshidabad, 2007).

iii) In the north-western tip of the district a small patch of unconfined aquifer composed of basaltic rock is found (**District Resource Map** 2008, **Groundwater Information Booklet** 2007). In the eastern part of the district groundwater saturation zone is extended upto 150 m due to absence of any major obstacle. Generally, water table is found within 2-5 m below the ground level throughout the district (Fig. 2.11). General subsurface flow of water is towards south and potential of groundwater (>42 yield l/s) (**Groundwater Information Booklet** 2007) is in the east and southern part of the district.

2.5 Vegetation:

Deltaic environmental type of vegetation is dominant and bamboo is found everywhere in the district. *Bot, Aswatha, Sal, Segun, Mahua, Mango, Jackfruit* are usually found. Mangoes are mainly found in the eastern segment of the district. In the blocks of *Berhampur*, *Islampur* and *Beldanga*, *Mulberry* is grown. Other than these, *Plum* and *Babla* are also found extensively. Forest products are mainly used for timber and fuel. According to the census of 2001, whole of the district accounts for just 8 sq. km forest cover which is only 0.15% of the total geographical area (**Banerjee** et al. 2003).

2.6 Socio-Economic Setup:

2.6.1 Demographic Setup:

According to 2011, the district has a total population of 7,103,807 with 51% males and 49% females. Between 2001 to 2011, population of the district grew by 21.07%. Sex ratio in the district is 938 females per thousand males. About 80% of the total population lives in rural areas (**Census** 2011). In terms of child sex ratio it is about 968 girls per 1000 boys. Density of population increased from 1101 in 2001 to 1334 person per sq. km. in 2011. The average literacy rate has increased from 54.35% to 67.53% in the last decade.

2.6.2 Agriculture and Irrigation:

Paddy and jute are the major crop of the district. Wheat, oilseeds, pulses, jute and potato are some of the other important crops (**Murshidabad.net** 2013, **District Census Hand Book**, 2001). In the last few decades, the production of jute has increased to almost twice. Vegetables are grown three times in a year and a fourfold increase has been observed in the last three decades.

The district depends upon irrigation throughout the year, except for the monsoon season.

Fig. 2.12: Agricultural Activities in Murshidabad

2.6.3 Industry:

The district basically relies on agriculture hence no major industries are developed. Silk is one of the important products of the district which holds a significant position in the economy. Mulberry cultivation and silk worm production, peeling of silk and its weaving are developed in the district. Historically, silk of Murshidabad district is

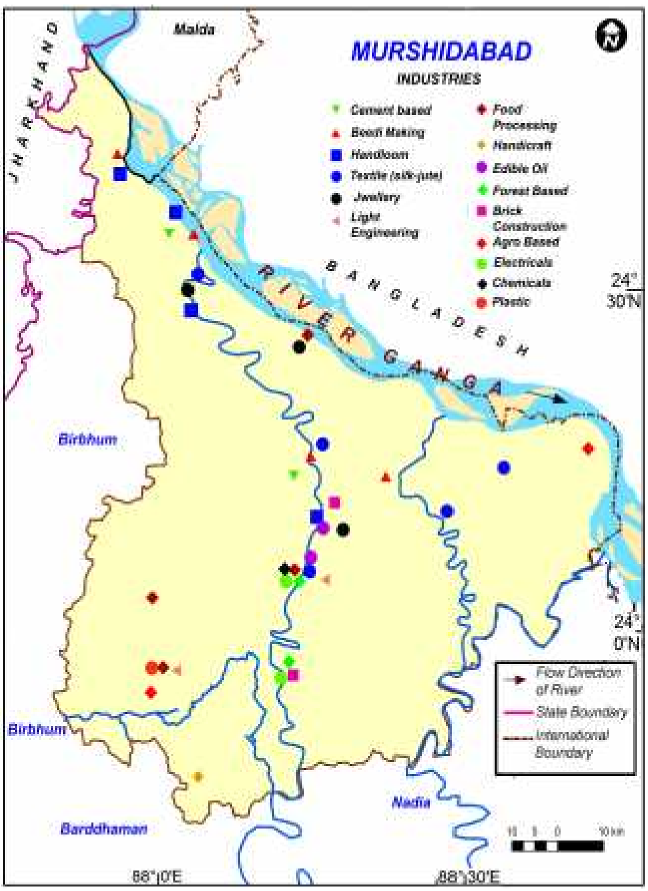


Fig. 2.13: Industries of Murshidabad District (Source: District Industrial Centre, Murshidabad and District Census Handbook, Murshidabad, 2001)

well developed (Mookherjee 1990). Due to the influence of *East India Company* it got a major thrust. But after industrial revolution in *England*, Murshidabad district received a major setback due to the availability of cheaper and more durable machine made textiles (Mookherjee 1990). This adversely affected the production but it continued to be an important source of economy. Small scale industry of ivory craving in *Khagra* and *Jiaganj* is also an important economic activity since the time of Nawab. In *Samshergunj* and *Suti* blocks thousands of families are engaged in *'Beedi'* manufacturing (District Census Handbook 2001) (Fig. 2.13). Other than silk, *Khadi* and *Muslin* industry of the district also holds a very significant position. Among 280 active *Khadi* societies in *West Bengal*, 96 are located in Murshidabad district. Khadi cloth and apparel are even exported. The district is also associated with several small scale home based industries like jute products, ornament making, manufacturing and polishing of brass utensils and ivory products (Banerjee et al. 2003).

Fig. 2.14: Transport Map of Murshidabad District (Source: District Census Handbook, Murshidabad, 2001)

Farakka thermal plant supplies electricity to the whole of the district. Presently, five units of the thermal plant are engaged in commercial electricity generation (District Census Handbook 2001).

2.6.4 Transport and Connectivity:

The district is well connected by national and state highways. National Highway (NH) number 34 passes through the district connecting *Kolkata* in the south and *Siligiri* in the north. After entering the district near *Raginagar*, it passes through *Beldanga*, *Baharmapur* and *Farakka* blocks and enters *Malda* district.

Major state highway in the district is Morgram-Panagrah Super Highway. Till 1905, Ajimgunj-Nalhati was the only rail line in the district. Later, Ranaghat-Bhagawangola rail line was laid. Presently, the longest rail line in district is Badhadoa-Ajimgunj-Katoa line of which 137 km lies in the district (Fig.2.14).

2.6.5 Water Facility:

River *Ganga*, *Bhagirathi* and *Bhairab* are the major source of irrigation. Groundwater is used for of drinking as well as for irrigation. The extraction of groundwater is largely done by hand pumps, shallow tube wells and dug wells (Ravenscroft et al. 2009). There are numerous ponds and tanks in the district but still dependency on the groundwater is notably high due to the shallower groundwater table and high potential. Government has paid attention towards establishment of deep tube wells in the municipal as well as in the rural areas. (Bhattacharya et al. 1997, District Census Handbook 2001).

2.7 Arsenic in Groundwater:

Murshidabad district lies in the central alluvial plain of *West Bengal* and is associated with the problem of natural arsenic contamination of groundwater (Acharyya et al. 2007). Direct consumption of arsenic contaminated water through drinking as well as its use in the agriculture through irrigation is related to serious health issues. (Díaz et al. 2004, Huang et al. 2006, Williams et al. 2006).

2.8 Land Use/Land Cover Pattern of the district:

The entire district is dominated by the agricultural land. An area of 3969.66 sq. km area is associated with agriculture which is about 74.56 % of the entire study area. Agricultural fallow land comprises an area of 31.79 sq. km while agricultural land related to plantation is having an area of 52.21 sq. km which accounts for 0.60 % and 0.98 % respectively. Wetlands/water-bodies/rivers/streams and canals all together encompasses an area 6.25 % of the total area (Fig.2.15). Wetland/reservoir and lakes has the total area of 29.02 sq. km which is 0.55 % of the total area. The deciduous forest is associated with an area of 5.51 sq. km while forest plantation

land is only 1.12 sq. km. The built up area of rural area and urban area is 793.02 sq. km and 93.28 sq. km respectively (14.90 % and 1.75 %). The barren/uncultivable land and wasteland is only about 3 sq. km.

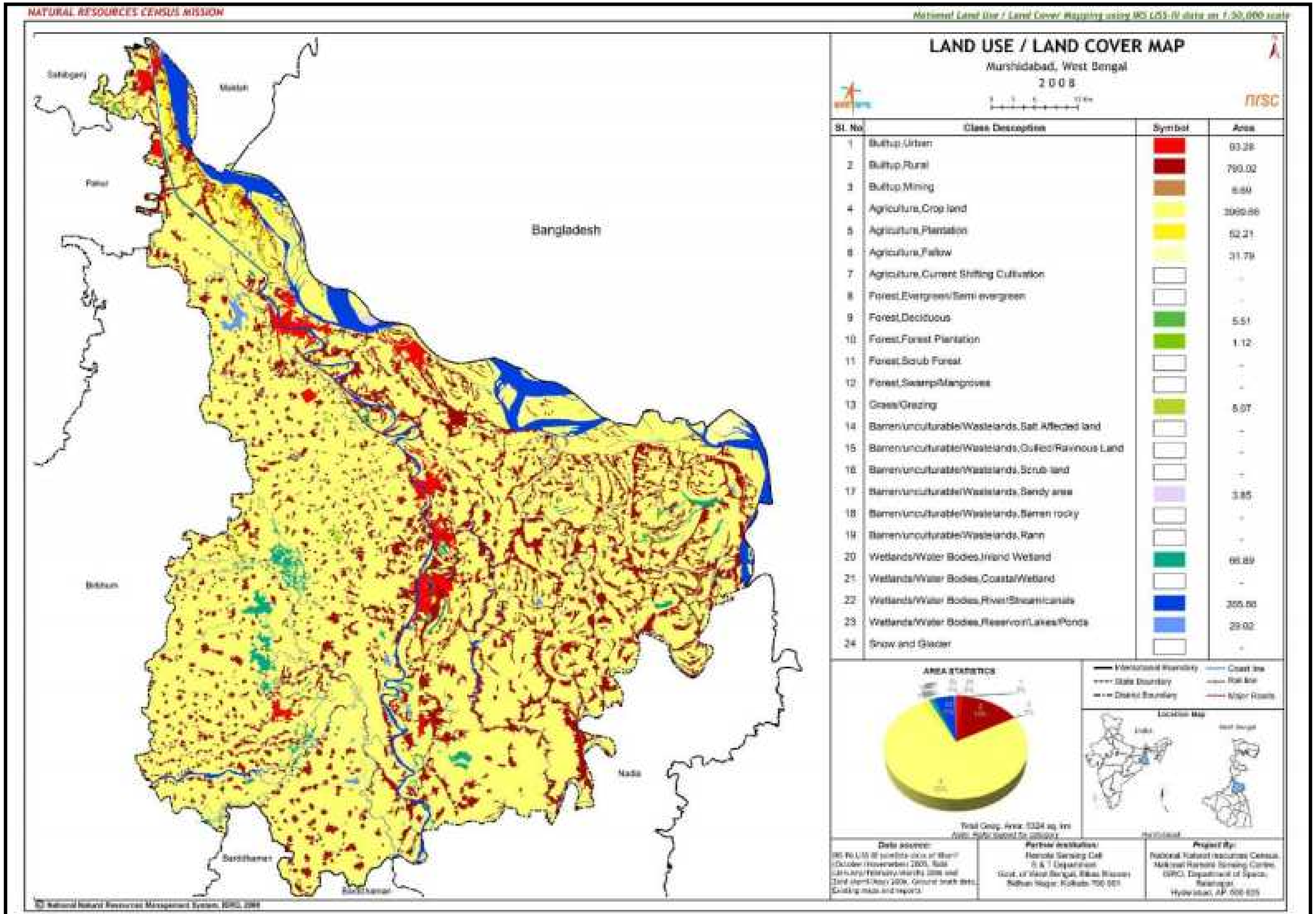


Fig . 2.15: Landuse/Landcover map of Murshidabad District	**Data source:** IRS P6 LISS III satellite data of Kharif (October/November) 2005, Rabi (January/February/March) 2006 and Zaid (April/May) 2006. Ground truth data, Existing maps and reports	**Partner Institution:** Remote Sensing Cell S & T Department Govt. of West Bengal, Bikas Bhavan Bidhan Nagar, Kolkata-700 091	**Project By:** National Natural resources Census, National Remote Sensing Centre, ISRO, Department of Space, Balanagar, Hyderabad, AP, 500 625

Resume:

The present chapter illustrated the physical and socio-economic condition of *Murshidabad* District of *West Bengal*. The district is almost plain and drained by river *Ganga* and its distributaries like *Bhagirathi* and *Bhairab.* The entire district is associated with thick alluvium soil with considerably higher amount of precipitation. Agriculture is the major economic activity along with silk, beedi and agro based industries. The next chapter focused upon the spatio-temporal characteristics of groundwater of the district.

Chapter – 3

Spatio-temporal Pattern of Geochemical Properties of Groundwater

Chapter – 3

Spatio-temporal Pattern of Geochemical Properties of Groundwater

3.1 Geochemical Properties of Groundwater:

Geochemical properties of groundwater play a significant role in determining its uses for different purposes. On one hand, these parameters are individually significant and minor deviation from the norm can create issues related to the quality of water, on the other hand, these parameters are dependent to each other (**Demirel** & **Güler** 2006). Hence, to understand the groundwater processes, it is essential to look into the groundwater parameters individually as well as in association with each other. In the present study, ten groundwater parameters (*arsenic* (As), *pH, total dissolved solids* (TDS), *electrical conductivity* (EC), *iron* (Fe), *chloride* (Cl^-), *sulfate* (SO_4^{-2}), *total hardness as* $CaCO_3$, *nitrite* (NO_2) and *depth*) were taken into consideration. Parameters such as *arsenic* (As) and *nitrite* (NO_2) disturb the water quality of water even if they are present in a trace amount (**Ghosh** and **Kanchan** 2014). *pH* is the power of hydrogen which determines the level of acidity or alkalinity. A significant variation in the level of *pH* can alter the characteristics of the ground water. *Total dissolved solids* (TDS) and *electrical conductivity* (EC) indicates the amount of dissolved solids into the water which determines its usability. Similarly, major ions like *sulfate* (SO_4^{-2}) and *chloride* (Cl^-) also determine the portability. Individually, *Iron* (Fe), does not create any issue regarding the quality of water but excess amount can change its colour and taste (**Haman** & **Bottcher** 1986). In the present work, these parameters were chemically examined, and their results were analysed by using appropriate statistical tools. The groundwater sampling locations are illustrated in Fig. 3.1.

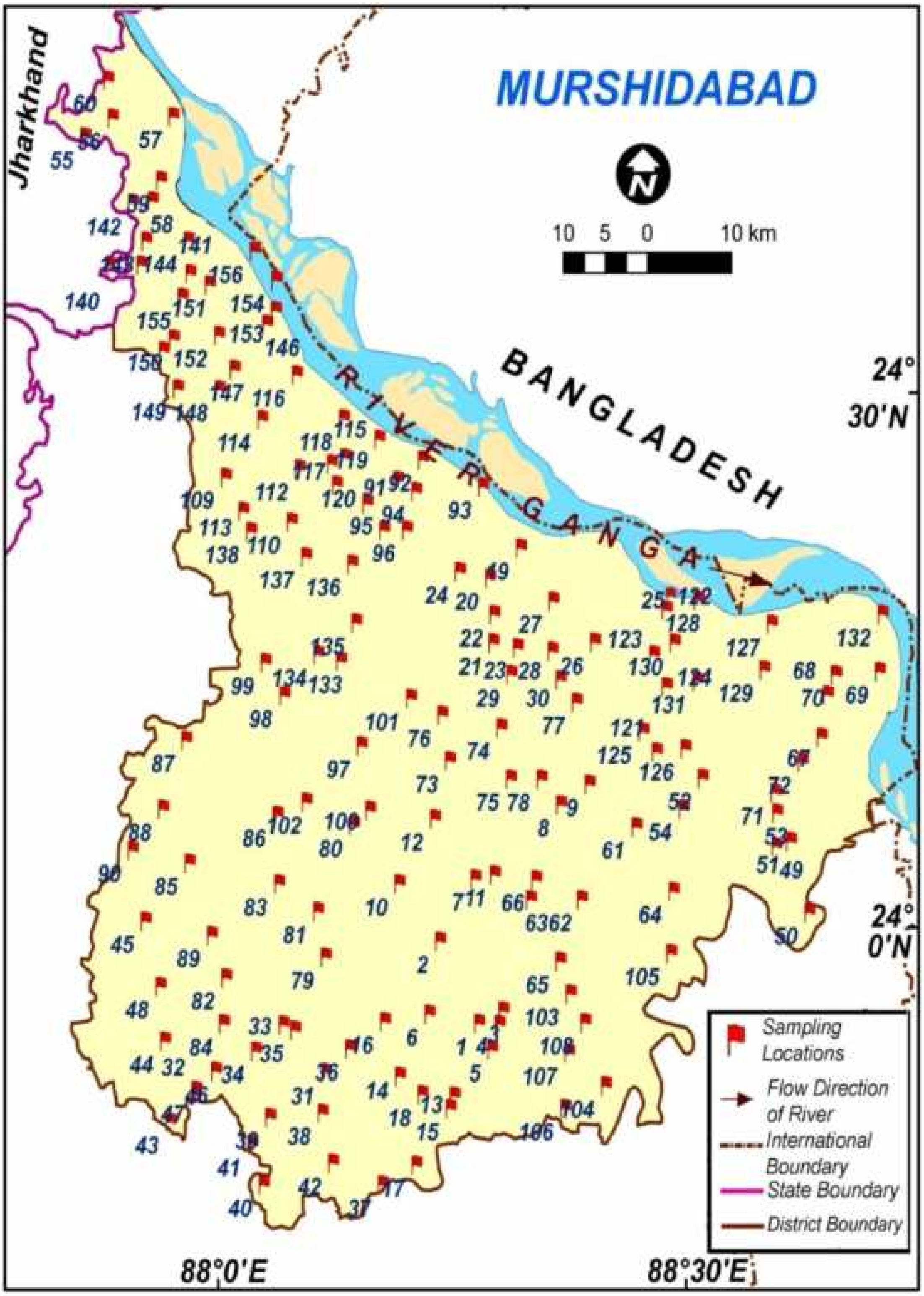


Fig. 3.1: Groundwater Sampling Locations

3.2 General Characteristics of Groundwater:

3.2.1. Pre-monsoon:

During the pre-monsoon season the concentration of *arsenic* ranged between BDL to 0.78 mg/l with an average of 0.06 mg/l (Fig. 3.2) (Table 3.1). A considerably high variation in the level of concentration of *arsenic* in ground water was observed (0.10 mg/l) in the district. Skewness and kurtosis also depicted positive and high values of +5.27 and +29.63 respectively. The value of kurtosis showed high peakedness, justifying the high standard deviation. The maximum concentration of arsenic was observed in the depths of 0-25 mbgl and 50-90 mbgl (Fig. 3.3).

Pre-monsoon Season (Arsenic)

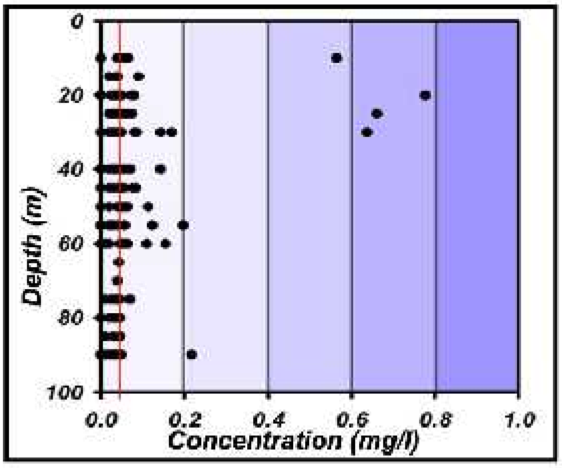


Fig. 3.2 Concentration

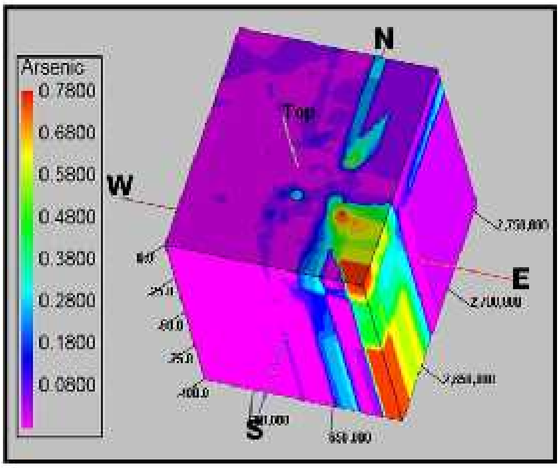


Fig. 3.3 Distribution

The level of *pH* varied between 6.27 and 8.07, ranging between slightly acidic to the alkaline condition (Fig.3.4). The mean of *pH* in groundwater was 7.38 indicating a normal condition and a less deviation of 0.39. Skewness and kurtosis showed low values. Negative value of skewness (-0.57) was observed while kurtosis showed positive value (+0.01). The former is the indication of slightly less availability of higher values while latter indicates flatter distribution of data. The *pH* value between 7 and 7.40 was found extensively from 10 mbgl to 90 mbgl (Fig. 3.5). The concentration of *TDS* varied between a 267.97 mg/l to 1250.57 mg/l (Fig. 3.6).

Pre-monsoon Season (pH)

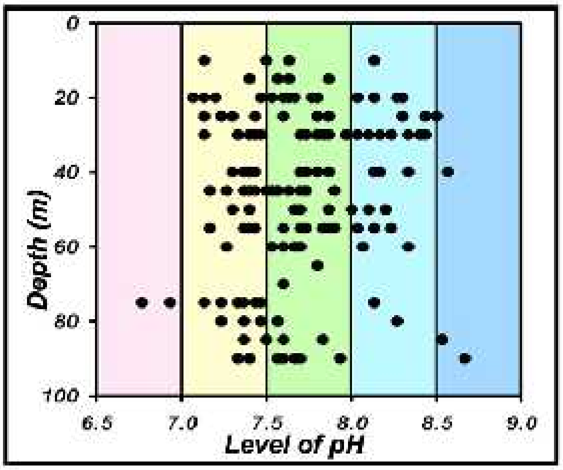


Fig. 3.4 Level of pH

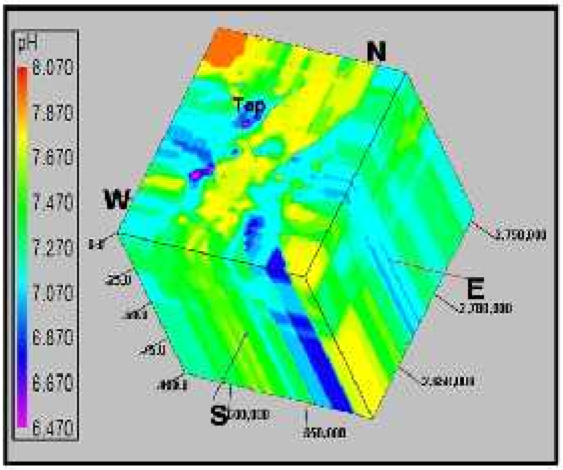


Fig. 3.5 Distribution

Table: 3.1 Descriptive statistics of Groundwater Parameters during Pre-monsoon Season (2010-2012)

Parameters	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Arsenic	156	BDL	0.78	0.06	0.10	5.27	29.63
pH	156	6.27	8.07	7.38	0.39	-0.57	0.01
TDS	156	267.97	1250.57	599.52	154.72	0.66	1.59
EC	156	0.53	2.50	1.19	0.31	0.68	1.69
Iron	156	0.70	82.32	7.78	10.79	3.64	16.70
Chloride	156	15.23	434.13	82.78	50.58	2.29	13.49
Sulfate	156	45.87	1458.87	395.72	339.58	0.89	-0.32
Total Hardness as $CaCO_3$	156	48.03	1242.33	449.66	282.09	0.24	-0.59
NO_2	156	5.59	81.17	29.47	15.66	1.58	1.88

Unit all the parameters is in mg/l except *EC* ($s/cm^{-1} x 10^{-3}$) and *pH*, N=Total number of samples

The mean concentration (599.52 mg/l) as well as standard deviation (154.72 mg/l) were high denoting a wide range of concentration throughout the space. Skewness and kurtosis showed small and positive values of +0.66 and +1.59 respectively. Skewness showed left skewed distribution indicating the concentration on the right side of the mean with extreme values to the left. Kurtosis indicates platy distribution flatter than the normal distribution. Up to the depth of 90 mbgl the concentration of *TDS* ranged between 400 mg/l and 600 mg/l (Fig. 3.7).

Pre-monsoon Season (Total Dissolved Soilids)

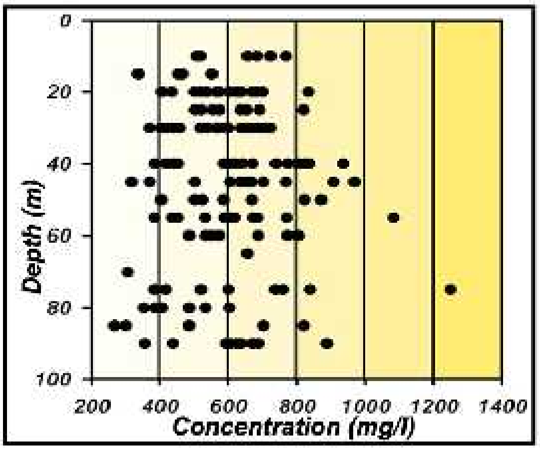


Fig. 3.6 Concentration

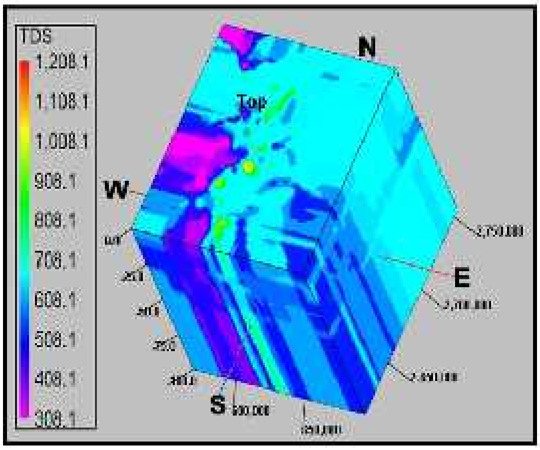


Fig. 3.7 Distribution

Pre-monsoon Season (Electrical Conductivity)

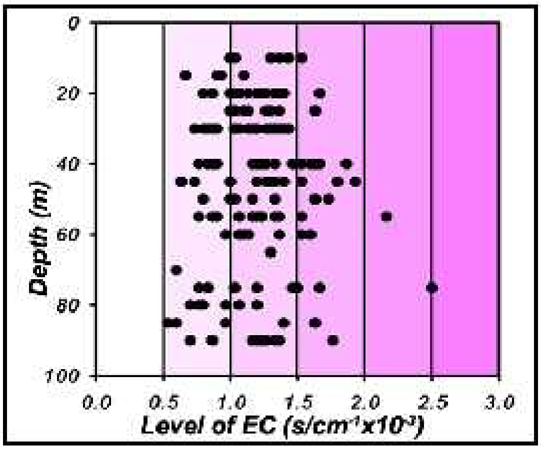


Fig. 3.8 Concentration

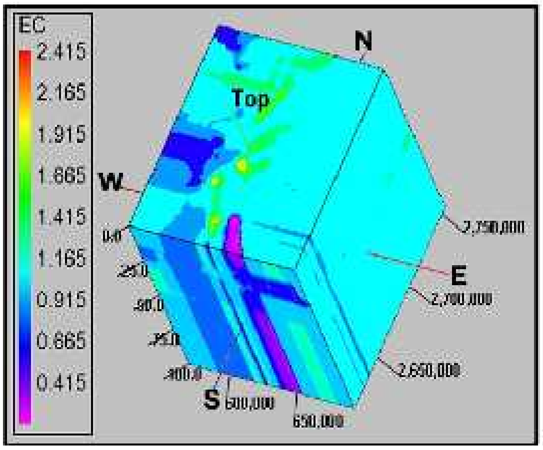


Fig. 3.9 Distribution

The level of *EC* varied from 0.53 s/cm^{-1}x 10^{-3} to 2.50 s/cm^{-1}x 10^{-3} and with mean of 1.19 s/cm^{-1}x 10^{-3} (Fig. 3.8).

The standard deviation also indicated relatively lesser variability (0.31 s/cm^{-1}x 10^{-3}) of *EC* throughout the space. Skewness and kurtosis were associated with very low and positive values of +0.68 and +1.69 respectively. The level of *EC* at the greater depth showed relatively lower values (Fig. 3.9). The concentration of *iron* ranged between 0.70 mg/l and 82.32 mg/l (Fig. 3.10). The mean value was considerably low (7.78 mg/l), indicating a relatively small variation in the level of concentration.

Standard deviation was 10.79 mg/l, while skewness and were positive with considerably high values (+3.64 and +16.70 respectively).

Pre-monsoon Season (Iron)

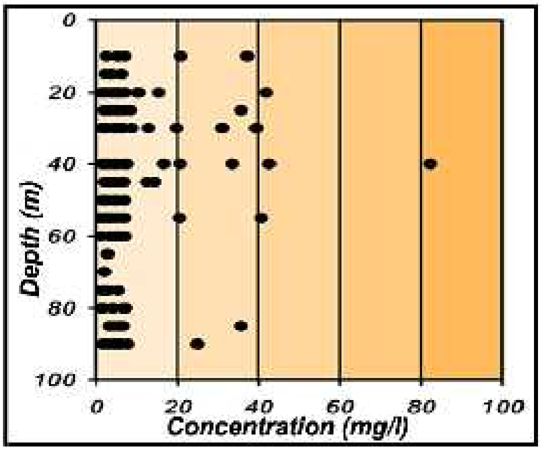


Fig. 3.10 Concentration

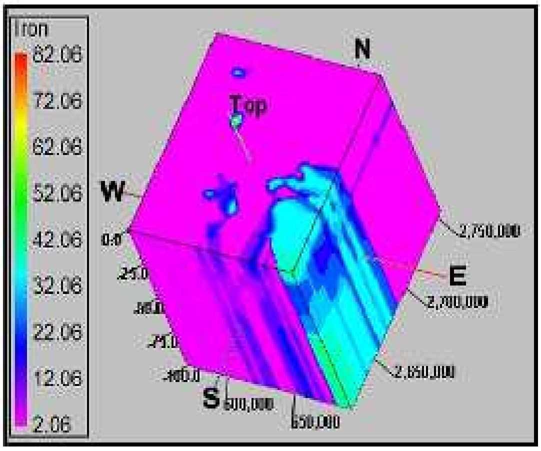


Fig. 3.11 Distribution

Pre-monsoon Season (Chloride)

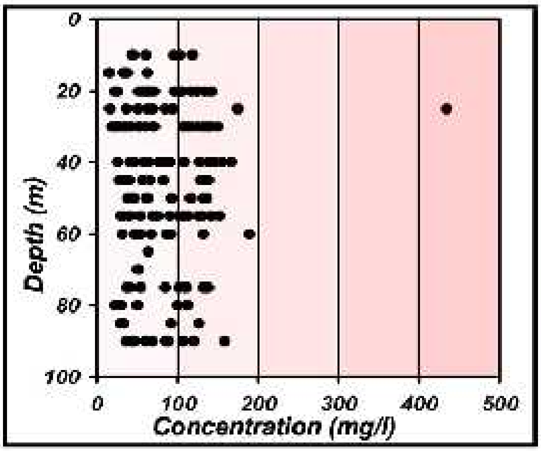


Fig. 3.12 Concentration

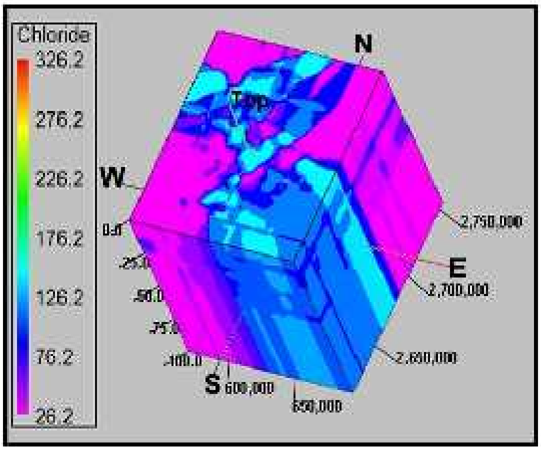


Fig. 3.13 Distribution

Depth wise variation in *iron* showed concentration ranging from 42 mg/l to 22 mg/l up to the depth of 90 mbgl (Fig. 3.11).

The concentration of *chloride* ranged between 15.23 mg/l to 434.13 mg/l. The mean and deviation values were 82.78 mg/l and 50.58 mg/l respectively (Fig. 3.12), indicating a considerably lesser variability. Skewness and kurtosis again were positive with moderate values of +2.29 and +13.49 respectively and was found at the greater depth (Fig. 3.13).

Pre-monsoon Season (Sulfate)

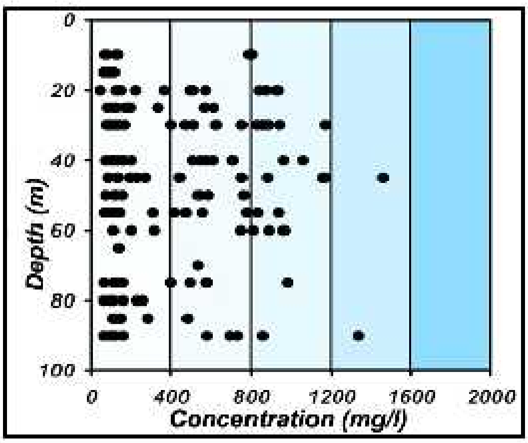


Fig. 3.14 Concentration

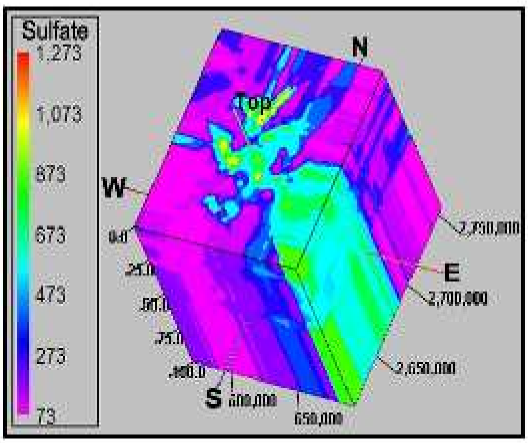


Fig. 3.15 Distribution

The concentration of *sulfate* varied from 45.87 mg/l to 1458.87 mg/l (Fig. 3.14). Both mean (395.72 mg/l) as well as the standard deviation were high (339.58 mg/l). Skewness and kurtosis showed very low values with former, positive (+0.89) while later, negative (-0.32) and it was observed to a considerable level up to 90 mbgl (Fig. 3.15).

Pre-monsoon Season (Total Hardness as $CaCO_3$)

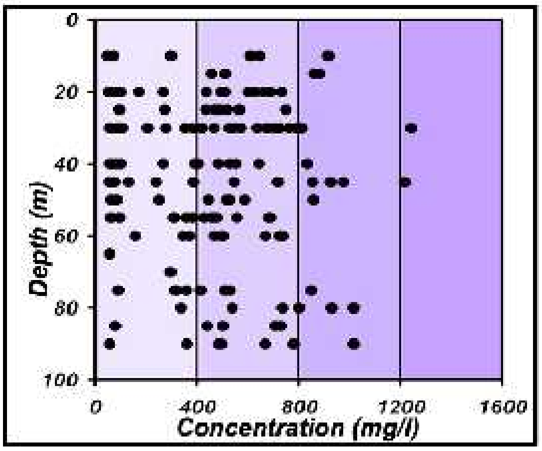


Fig. 3.16 Concentration

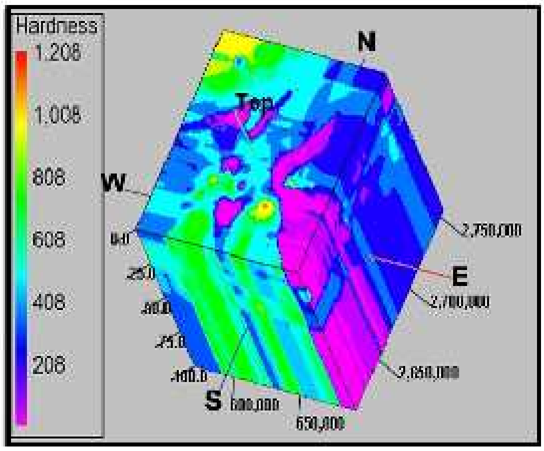


Fig. 3.17 Distribution

The concentration of *total hardness as* $CaCO_3$ had a minimum of 48.03 mg/l and maximum of 1242.33 mg/l (Fig. 3.16). The mean (449.66 mg/l) and standard deviation (282.09 mg/l) were high. Skewness and kurtosis had low values but former was positive (+0.24) while the later negative (-0.59). The concentration of 208 mg/l to 808 mg/l was found in up to 90 mbgl depth (Fig. 3.17).

The concentration of *nitrite* varied from 5.59 mg/l to 81.17 mg/l (Fig. 3.18).

Pre-monsoon Season (Nitrite)

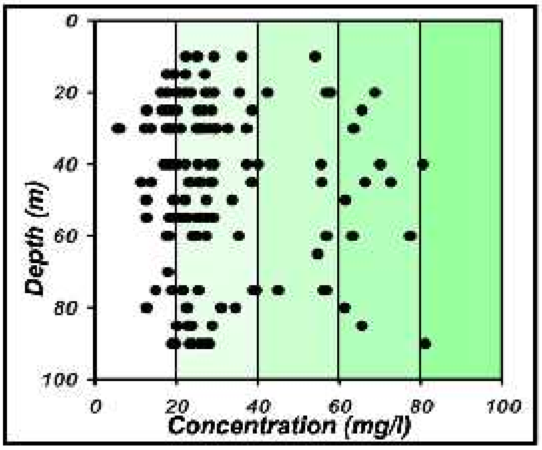


Fig. 3.18 Concentration

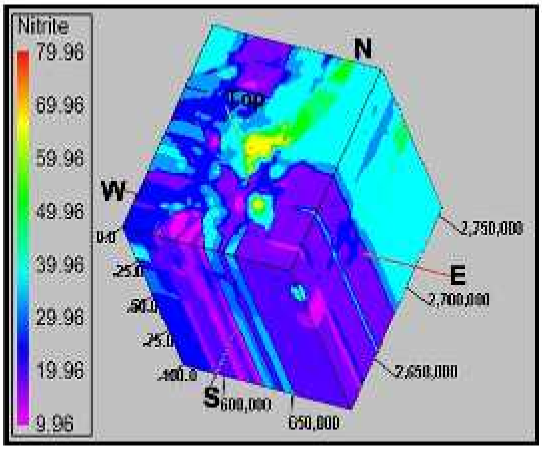


Fig. 3.19 Distribution

The mean concentration was 29.47 mg/l and the deviation from mean was considerably low (15.66mg/l). Skewness and kurtosis showed considerably low positive values at +1.58 and +1.88 respectively. Fig. 3.19 depicted that the concentration of the element is largely restrained at the shallower depth.

3.2.2. Monsoon:

The concentration of *arsenic* during the monsoon season varied between BDL and 0.33mg/l (Fig 3.20) and even found in the depth between 50 mbgl – 90 mbgl (Fig. 3.21). The mean concentration was 0.03 mg/l and the low variability of concentration 0.04 mg/l was observed. Skewness and kurtosis showed very high and positive values of +4.99 and +31.28 respectively. The level of *pH* indicated a wide range from the acidic (6.77) to alkaline condition (8.67) (Fig. 3.22). A slight deviation from the mean value was observed (0.37).

Small values of skewness and kurtosis were observed but former was positive (+0.47) and later negative (-0.15). In the entire region, the level of *pH* in the greater depth ranged between 6 -7 (Fig. 3.23).

Monsoon Season (Arsenic)

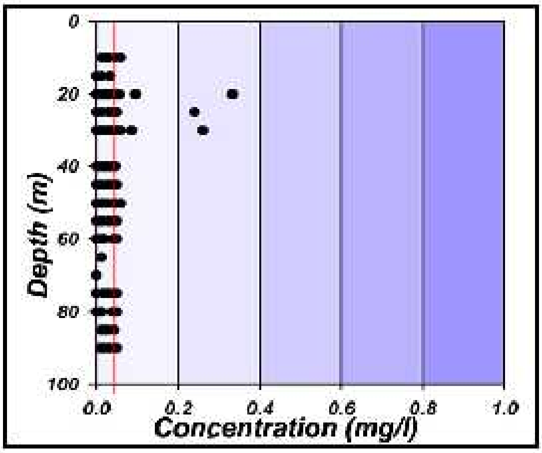


Fig. 3.20 Concentration

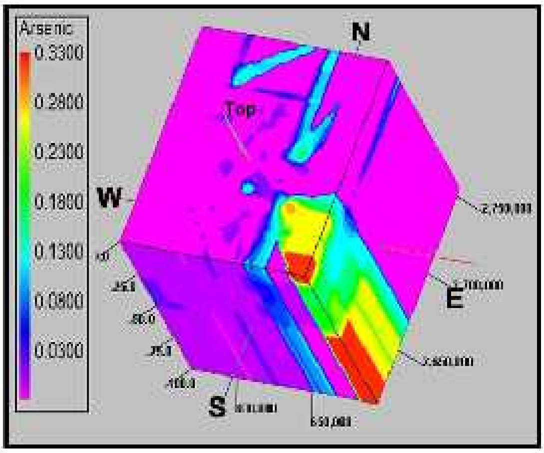


Fig. 3.21 Distribution

Monsoon (pH)

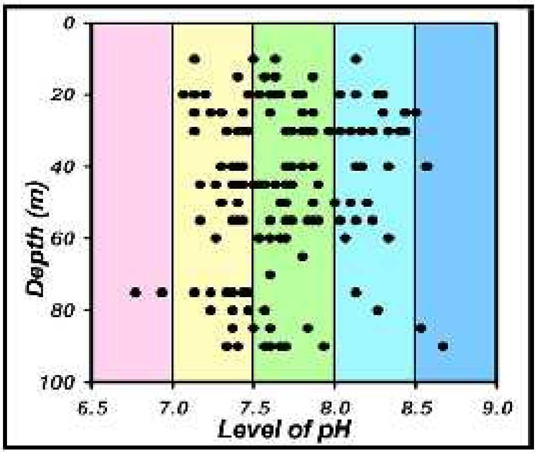


Fig. 3.22 Concentration

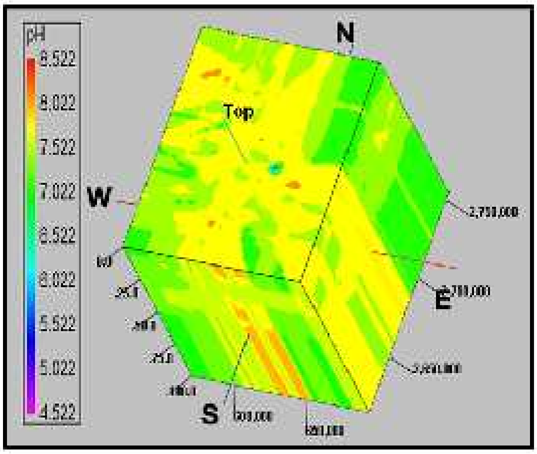


Fig. 3.23 Distribution

The concentration of *TDS* ranged between 183.83 mg/l to 982 mg/l denoting a high range (477.08 mg/l) (Fig. 3.24). The higher deviation from mean (135.68 mg/l) indicated spatial variability (Fig. 3.25). Skewness and kurtosis showed very low and positive values of +0.35 and +0.72 respectively.

Monsoon Season (Total Dissolved Solids)

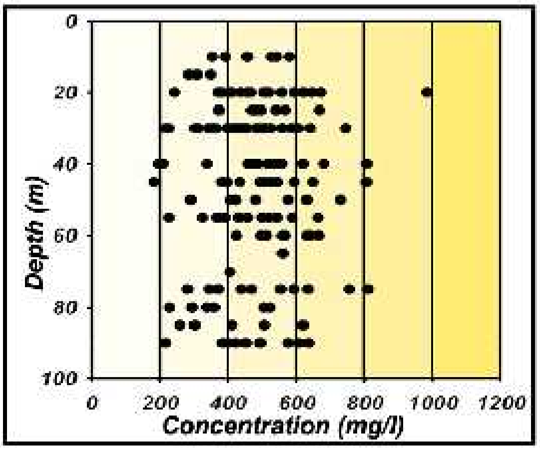


Fig. 3.24 Concentration

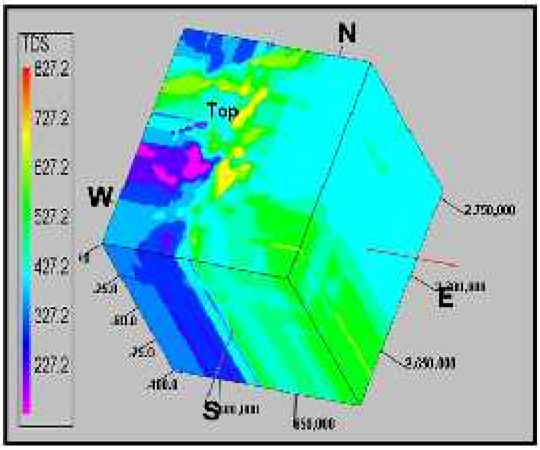


Fig. 3.25 Distribution

Table : 3.2 Descriptive statistics of Groundwater Parameters during Monsoon Season (2010-2012)

Parameters	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Arsenic	156	BDL	0.33	0.03	0.04	4.99	31.28
pH	156	6.77	8.67	7.68	0.37	0.47	-0.15
TDS	156	183.83	982.00	477.08	135.68	0.35	0.72
EC	156	0.36	1.96	0.95	0.27	0.36	0.72
Iron	156	1.00	50.44	7.68	9.21	2.45	6.64
Chloride	156	27.50	284.83	98.32	46.16	0.86	1.12
Sulfate	156	32.27	1297.47	217.69	261.81	2.11	4.07
Total Hardness as $CaCO_3$	156	50.20	1050.43	524.74	254.39	-0.08	-0.78
NO_2	156	7.52	69.50	25.51	12.01	1.69	2.89

Unit of all the parameters is in mg/l except *EC* (s/cm^{-1}x 10^{-3}) and *pH*, N=Total number of samples

The level of *EC* had a minimum of 0.36 s/cm^{-1}x 10^{-3} and maximum of 1.96 s/cm^{-1}x 10^{-3} (Fig. 3.26). The mean was 0.95 s/cm^{-1}x 10^{-3} and deviation from mean was 0.27 s/cm^{-1}x 10^{-3}. Skewness and kurtosis had low positive values of +0.36 and +0.72 respectively. *EC* depicted lower values at greater depth in the entire region (Fig. 3.27) (Table 3.2).

Monsoon Season (Electrical Conductivity)

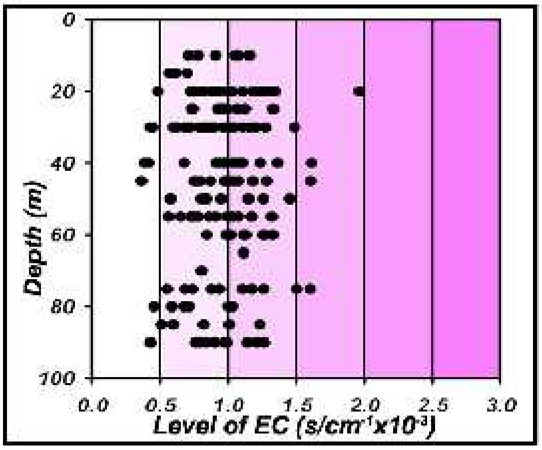


Fig. 3.26 Concentration

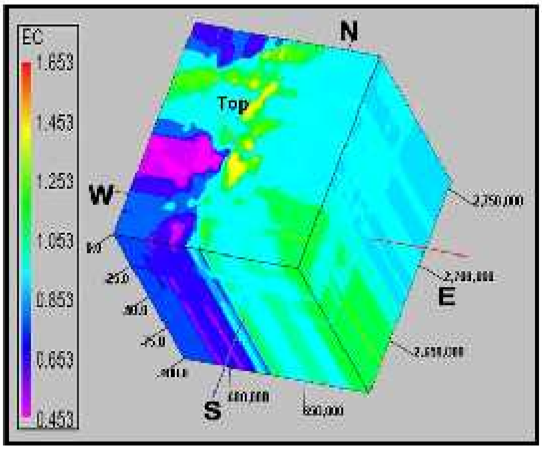


Fig. 3.27 Distribution

Monsoon Season (Iron)

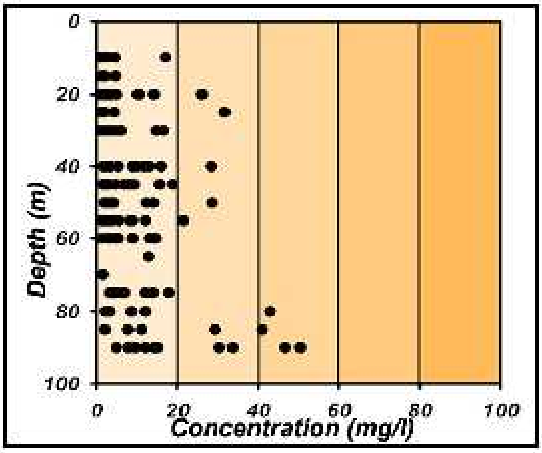


Fig. 3.28 Concentration

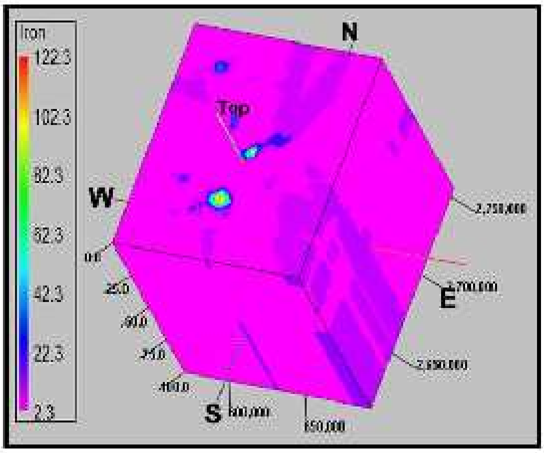
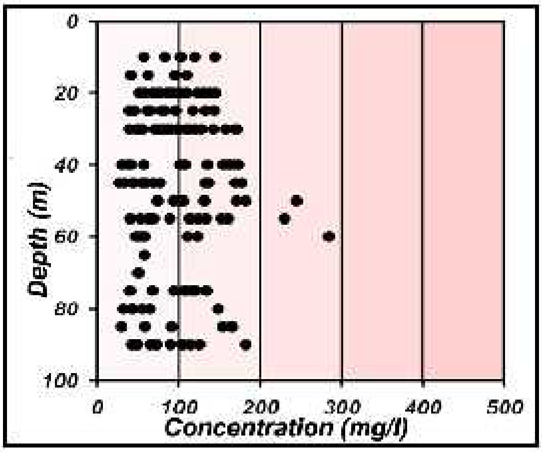


Fig. 3.29 Distribution

The concentration of *iron* varied between 1.00 mg/l to 50.44 mg/l (Fig. 3.28). The mean concentration of *iron* was 7.68 mg/l and depicted a considerably less deviation from mean (9.21 mg/l) throughout the space while it did not show any significant variation at greater depths (Fig. 3.29). Skewness and kurtosis showed moderate and positive value of +2.45 and +6.64 respectively. The concentration of *chloride* varied between 27.50 mg/l and 284.83 mg/l (Fig. 3.30). The mean concentration was 98.32 mg/l while deviation from mean was 46.16 mg/l.

Monsoon Season (Chloride)



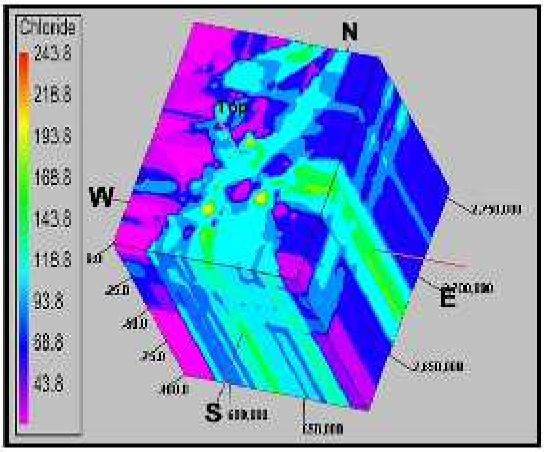
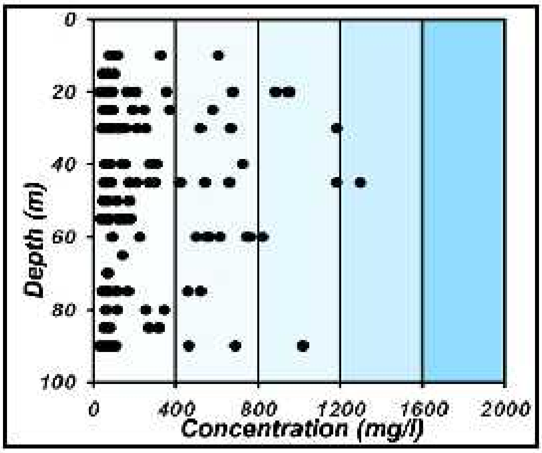


Fig. 3.30 Concentration **Fig. 3.31 Distribution**

Monsoon Season (Sulfate)



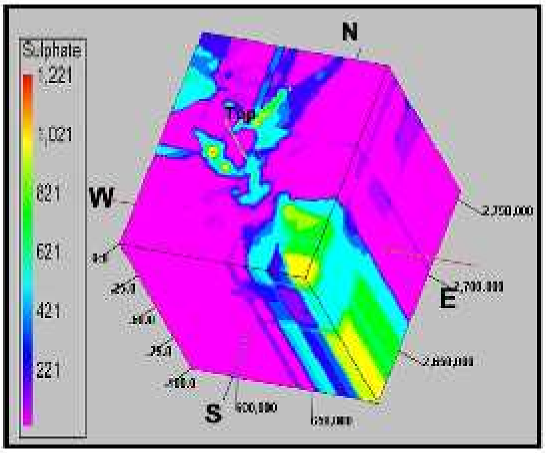
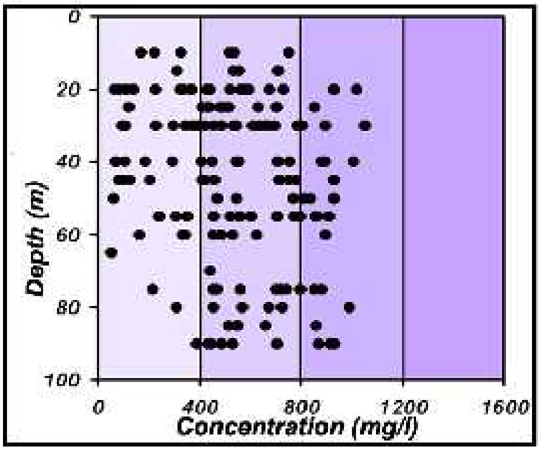


Fig. 3.32 Concentration **Fig. 3.33 Distribution**

Skewness and kurtosis showed low and positive values of +0.86 and +1.12.Considerable variation in concentration in terms of depth was observed (Fig. 3.31).

The concentration of *sulfate* ranged from 32.27 mg/l to 1297.47 mg/l (Fig. 3.32). Although the range of data was very high but mean concentration was 217.69 mg/l indicating lesser variability of the *sulfate*. Standard deviation indicated higher deviation from mean (261.81 mg/l) while skewness and kurtosis showed moderate and

Monsoon Season (Total Hardness as $CaCO_3$)



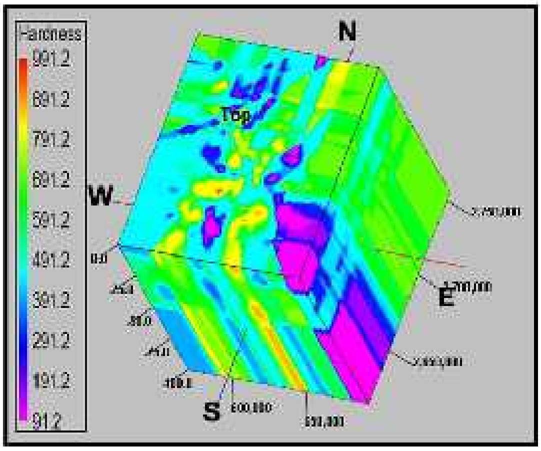
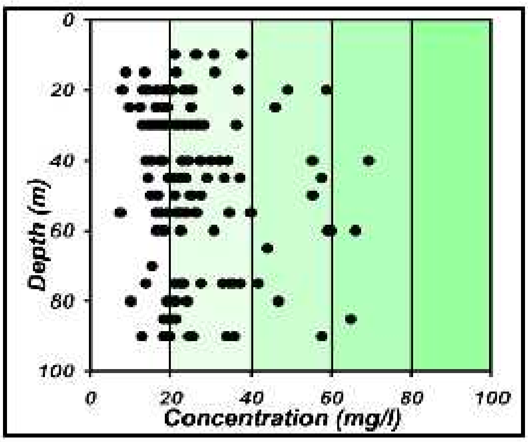


Fig. 3.34 Concentration **Fig. 3.35 Distribution**

positive values (+2.11 and +4.07 respectively). The concentration was found as high as 1000 mg/l at the greater depths (Fig. 3.33).

The concentration of *total hardness as $CaCO_3$* ranged from 50.20 mg/l to 1050.43 mg/l (Fig. 3.34) with considerable variation in depth (Fig. 3.35). The mean concentration was 524.74 mg/l and the deviation from mean was high (254.39 mg/l).

Monsoon Season (Nitrite)



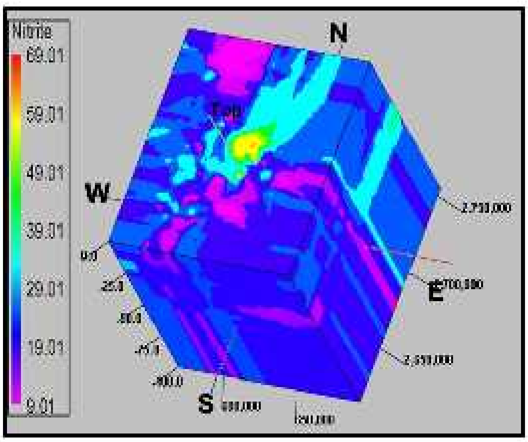


Fig. 3.36 Concentration **Fig. 3.37 Distribution**

Skewness and kurtosis showed negative and low values (-0.08 and -0.78 respectively). The minimum concentration of *nitrite* was 7.52 mg/l and the maximum 69.50 mg/l. The mean dilution was 25.51 mg/l and deviation from mean was just 12.01 mg/l (Fig. 3.36) with less variation in depth (Fig. 3.37). Skewness and kurtosis were low and positive (+1.69 and +2.89 respectively).

3.2.3. Post-monsoon:

The concentration of *arsenic* during post-monsoon season ranged between BDL to 0.81mg/l (Fig. 3.38) with higher concentration up to depth of 90 mbgl (Fig. 3.39). The mean concentration of *arsenic* was 0.06 mg/l which is considerably higher than the

Post-monsoon Season (Arsenic)

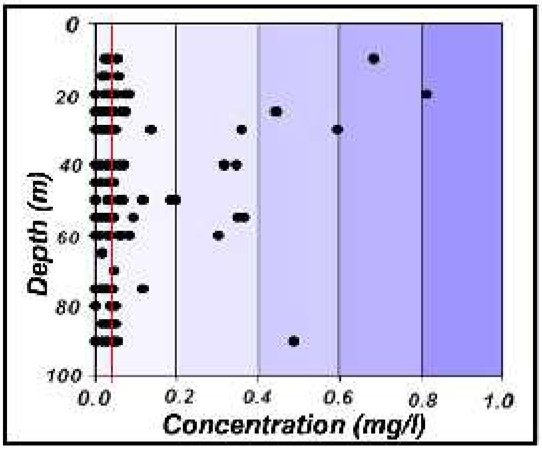


Fig. 3.38 Concentration

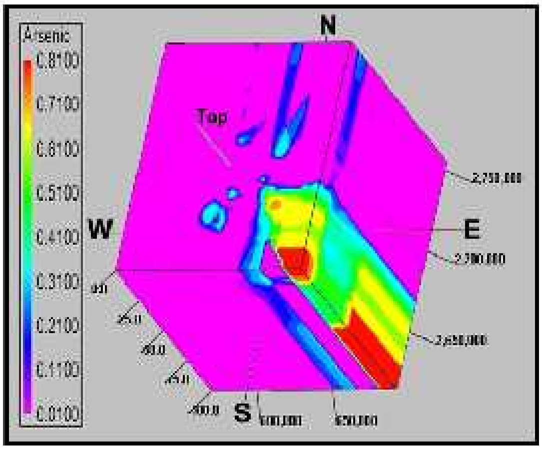


Fig. 3.39 Distribution

permissible limit. The standard deviation was 0.12 mg/l indicating very little variation. Skewness and kurtosis showed high and positive values (+3.85 and +16.24 respectively).

Post-monsoon Season (pH)

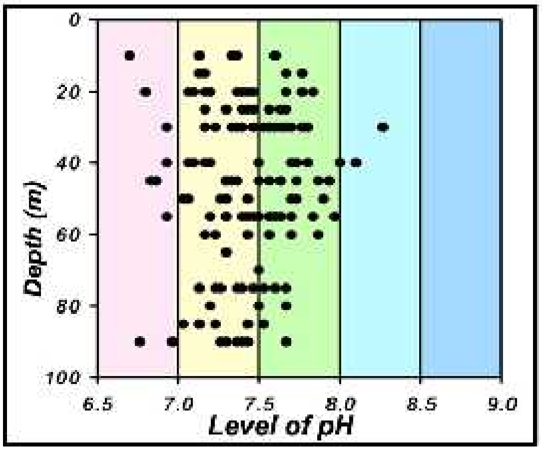


Fig. 3.40 Concentration

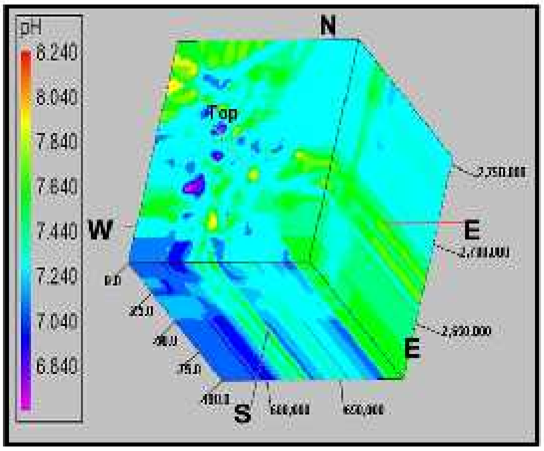


Fig. 3.41 Distribution

The level of *pH* ranged from acidic (6.70) to alkaline (8.27) condition (Fig. 3.40). The mean depicted slightly alkaline condition (7.43) spatially as well as vertically (Fig. 3.41). Not much variation was observed in *pH* values in terms of standard deviation (0.27). Skewness was -0.02, while kurtosis was positive and moderate (+0.28).

Post-monsoon Season (Total Dissolved Solids)

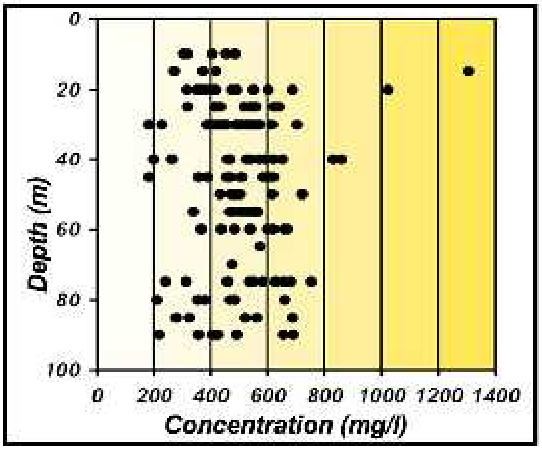


Fig. 3.42 Concentration

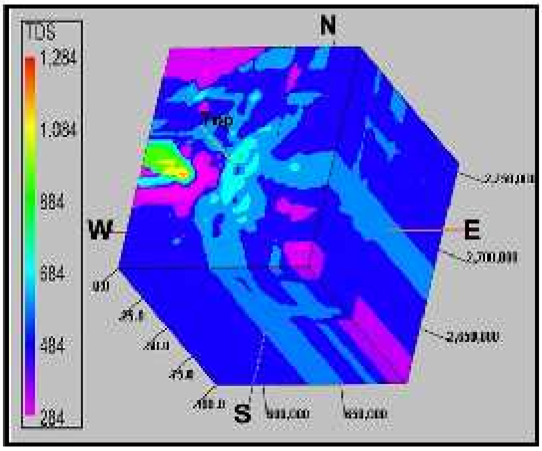


Fig. 3.43 Distribution

The concentration of *TDS* ranged from 183.43 mg/l to 1305.90 mg/l (Fig. 3.42) mainly confined to shallower depth (Fig. 3.43). The mean concentration was 494.51 mg/l

Post-monsoon Season (Electrical Conductivity)

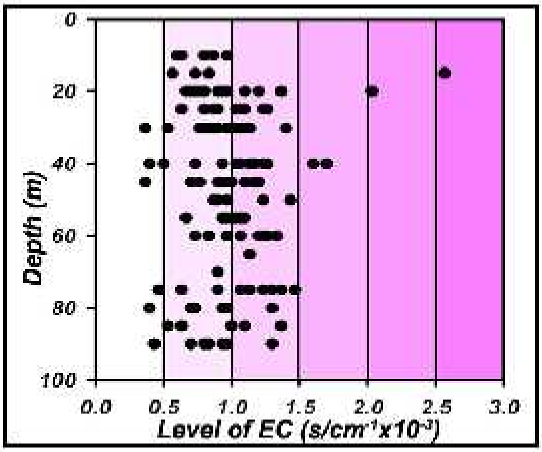


Fig. 3.44 Concentration

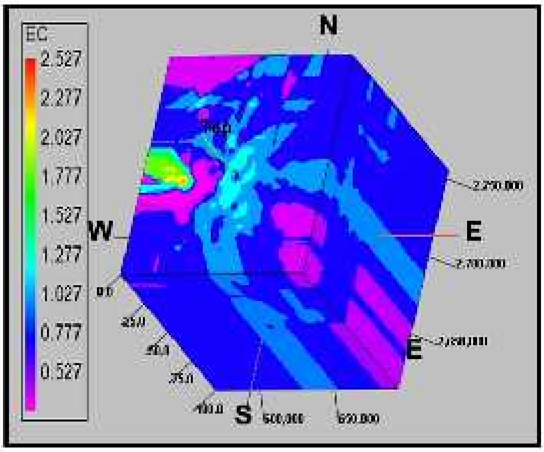


Fig. 3.45 Distribution

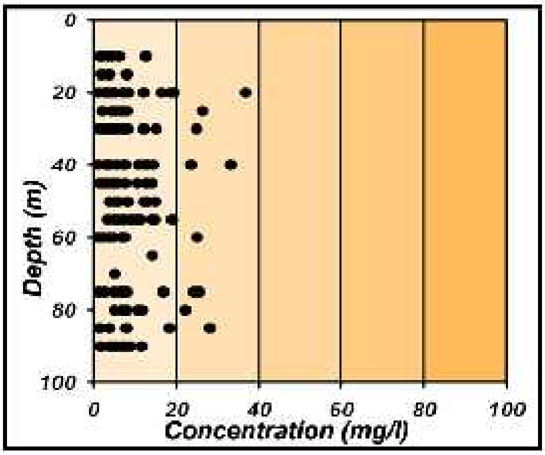
and the deviation from the mean was 145.44 mg/l. Skewness and kurtosis were positive and moderate (+1.30 and +6.39 respectively).

Table : 3. 3 Descriptive statistics of Groundwater Parameters during Post-monsoon Season (2010-2012)

Parameters	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	Kurtosis
Arsenic	156	BDL	0.81	0.06	0.12	3.85	16.24
pH	156	6.70	8.27	7.43	0.27	-0.02	0.28
TDS	156	183.43	1305.90	494.51	145.44	1.30	6.39
EC	156	0.37	2.57	0.97	0.29	1.35	6.46
Iron	156	1.10	36.84	8.21	6.51	1.87	3.92
Chloride	156	12.23	173.80	82.44	40.25	0.34	-1.05
Sulfate	156	50.33	1679.80	445.84	352.79	0.87	-0.22
Total Hardness as $CaCO_3$	156	55.37	970.27	420.22	208.66	0.40	-0.54
NO_2	156	10.21	58.03	25.64	8.61	1.27	2.32

Unit of all the parameters is in mg/l except *EC* ($s/cm^{-1} x\ 10^{-3}$) and *pH*, N=Total number of samples

Post-monsoon Season (Iron)



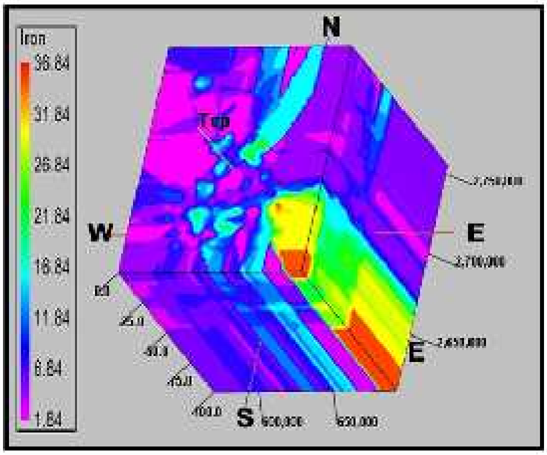


Fig. 3.46 Concentration

Fig. 3.47 Distribution

Post-monsoon Season (Chloride)

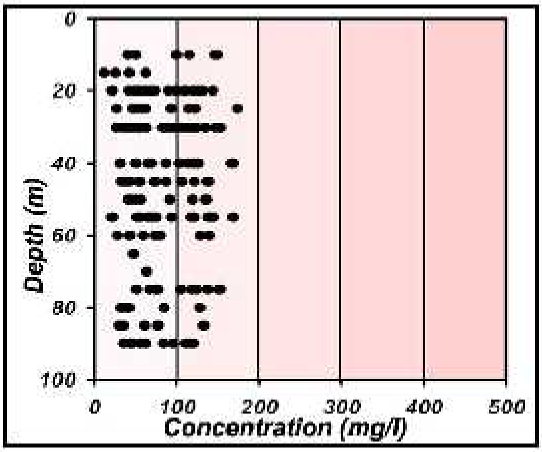


Fig. 3.48 Concentration

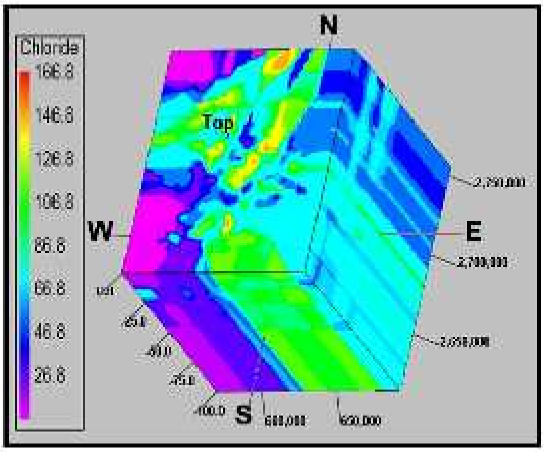


Fig. 3.49 Distribution

The concentration of *iron* ranged from 1.10mg/l to 36.84 mg/l (Fig.3.46) with a low mean of 8.21mg/l and higher concentration in greater depth (90 mbgl) (Fig.3.47). Deviation from the mean was small (6.51 mg/l). Skewness and kurtosis indicated low and positive values of +1.87 and +3.92 respectively.

Post-monsoon Season (Sulfate)

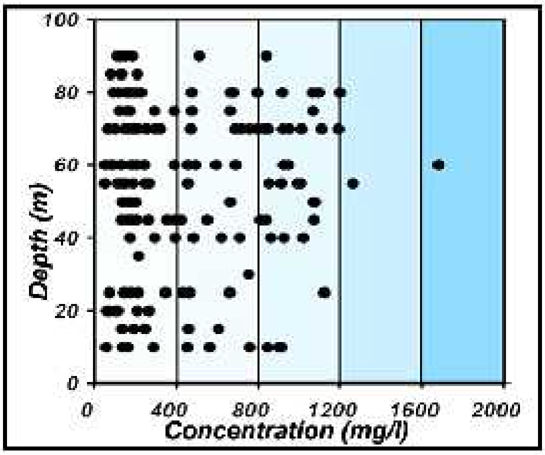


Fig. 3.50 Concentration

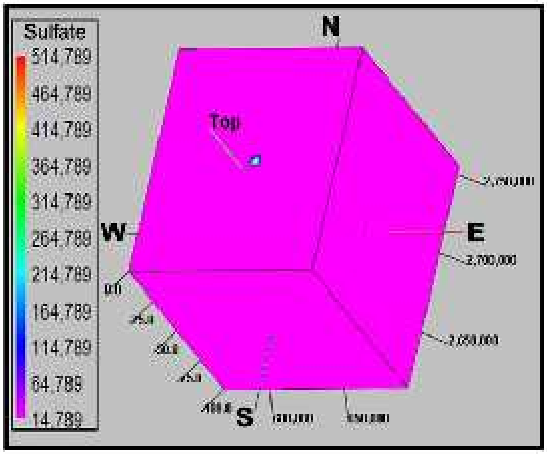


Fig. 3.51 Distribution

The minimum concentration of *chloride* was 12.23 mg/l while the maximum was 173.80 mg/l (Fig. 3.48) with a mean of 82.44 mg/l and moderate concentration considerable depth (90 mbgl) (Fig. 3.49). Standard deviation was 40.25 indicating a moderate deviation from the mean. Skewness (+0.34) and kurtosis (-1.05).

The concentration of *sulfate* varied between 50.33 mg/l to 1679.80 mg/l (Fig. 3.50) with moderate mean of 445.84 mg/l and very less vertical variation (Fig. 3.51). Deviation from the mean was also moderate (352.79 mg/l). Skewness was positive (+0.87) while kurtosis had a negative value of -0.22.

Post-monsoon Season (Total Hardness as $CaCO_3$)

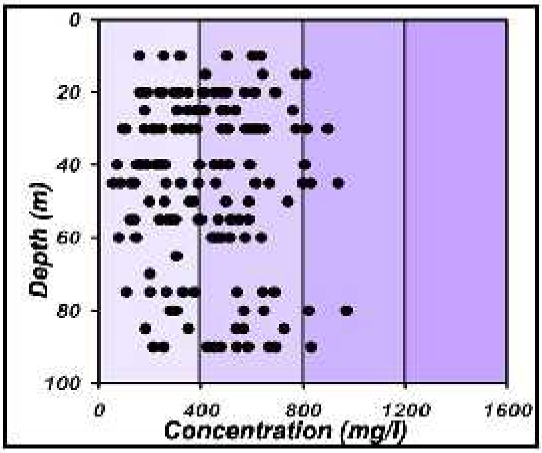


Fig. 3.52 Concentration

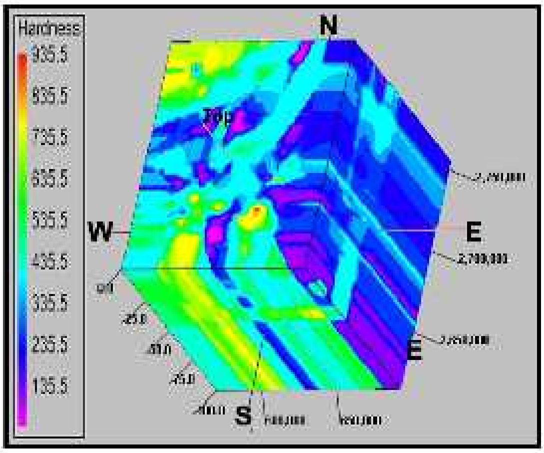


Fig. 3.53 Distribution

The concentration of *total hardness as $CaCO_3$* varied between 55.37mg/l and 970.27mg/l (Fig. 3.52) with considerable higher concentration up to depth of 90 mbgl (Fig. 3.53). The mean concentration was 420.22mg/l and the deviation from the mean was 208.66. Skewness and kurtosis indicated positive low values of +0.40 and -0.54 respectively.

The concentration of *nitrite* ranged from 10.21 mg/l to 58.03 mg/l (Fig. 3.54). The mean concentration was 25.64 mg/l while standard deviation of 8.61, depicting low deviation from the mean. Skewness and kurtosis were positive (+1.27 and +2.32 respectively). Concentration of the parameters can be traced up to the depth of 90 mbgl (Fig. 3.55).

Post-monsoon Season (Nitrite)

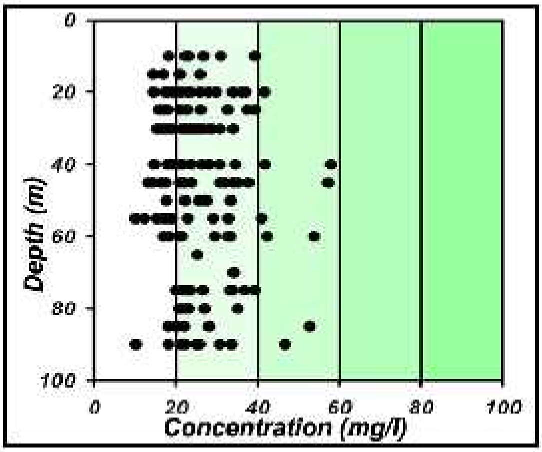


Fig. 3.54 Concentration

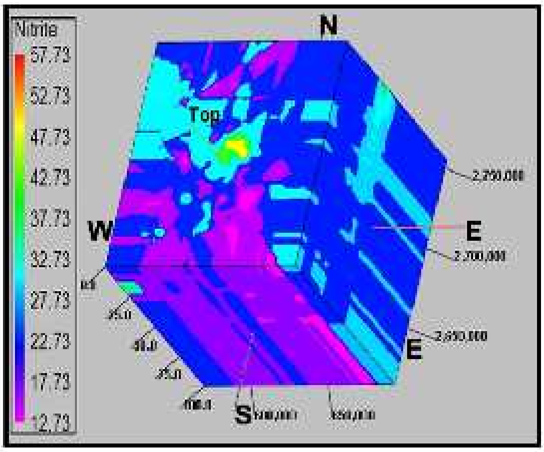


Fig. 3.55 Distribution

3.3 Factor analysis:

With increasing number of variables, the interrelationships among them becomes much more complex. Factor analysis is a type of multivariate statistical analysis which helps in identifying the internal similarity of data set (Davis, 1986, Cloutier, et al. 2008). The main aim of this type of analysis is to reduce the dimensionality of the data set and reproduce set of interrelated variable without losing any information (Farnham et al. 2002). In the present study, factor analysis technique was applied by using "Kaiser Criterion" where eigenvalues more than 1 were retained (Davis, 1986). Decreasing eigenvalues were plotted against the factor number to obtain scree plot. The break in the scree plot signified the number of factor to be taken into considerations. For ensuring maximum variability of the data 'varimax' rotation technique was applied. The factor depicted through the analysis, grouped the larger number of variables into smaller ones, which can be analyzed and interpreted in a much efficient way.

3.3.1. Pre-monsoon season:

Four important factors showed 62.194% of the total variability of the data set (Table 3.4).

Table: 3.4 Total Variance Explained by Factor Analysis during Pre-monsoon Season (2010-2012)

Factors	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.351	23.510	23.510	2.351	23.510	23.510
2	1.677	16.769	40.279	1.677	16.769	40.279
3	1.146	11.461	51.740	1.146	11.461	51.740
4	1.045	10.454	62.194	1.045	10.454	62.194
5	0.928	9.283	71.477			
6	0.840	8.400	79.877			
7	0.787	7.870	87.748			
8	0.650	6.498	94.246			
9	0.575	5.753	99.999			
10	0.000	0.001	100.000			

Extraction Method: Principal Component Analysis.

Table: 3.5 Rotated Component Matrix of Pre-monsoon season (2010-2012)

Parameters	Factors 1	2	3	4
Arsenic	0.064	**-0.684**	0.312	-0.067
Depth	0.000	**0.678**	0.097	-0.095
pH	0.220	-0.169	-0.407	**0.484**
TDS	**0.963**	-0.079	0.000	0.078
EC	**0.964**	-0.079	0.002	0.077
Iron	-0.225	-0.338	0.203	**0.564**
Chloride	0.169	0.187	0.207	**0.784**
Sulfate	0.124	0.094	**0.692**	0.193
Total Hardness as $CaCO_3$	-0.020	0346	**-0.696**	-0.055
NO_2	**0.497**	0.352	0.220	-0.021

Extraction Method: Principal Component Analysis. **Rotation Method:** Varimax with Kaiser Normalization. Rotation converged in 5 iterations. Bold values are significant factor loadings.

Similar pattern was observed through the scree plot where number of factors above the eigenvalues of 1 were four (Fig. 3.56). The first factor depicted 23.510% of the variability of the data set,

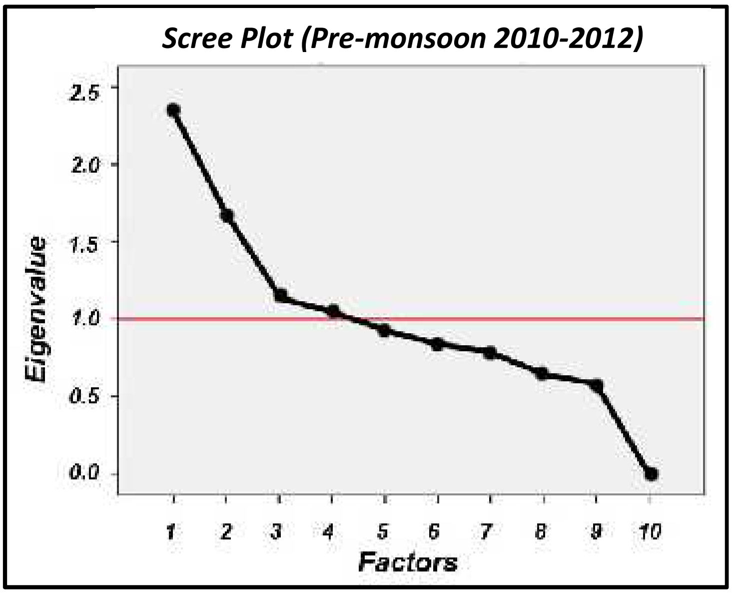


Fig. 3.56: Scree Plot of pre-monsoon season

followed by second factor (16.769%) third 11.461% and fourth 10.454%. Factor 1 was associated with *TDS*, *EC* and *nitrite* parameters with loadings of +0.963, +0.964 and +0.497 respectively (Table 3.5). *Arsenic* and *depth* with loadings of -0.684 and +0.678 respectively were found in Factor 2. The third factor was *sulfate* and *total hardness as* $CaCO_3$ with loadings of +0.692 and -0.696 respectively. The last factor associated *pH*, *iron* and *chloride* had loadings of +0.484, +0.564 and +0.784 respectively.

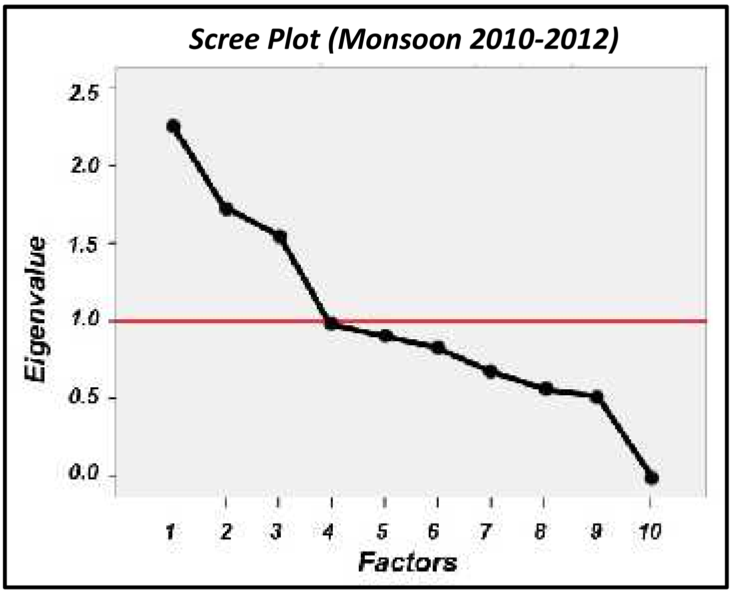


Fig. 3.57: Scree Plot of monsoon season

3.2.2. Monsoon season:

During the monsoon season the data set had a total variability of 65.079%. The first factor represents 22.50% of variability while the other three factors had 17.270%, 15.479% and 9.860% of variability (Table. 3.6) (Fig. 3.57). The first factor with parameters of *TDS* and *EC* had very high loadings of +0.963 and +0.965 respectively.

The second factor is associated with the parameters of *depth, chloride, sulfate* and *total hardness as CaCO₃*. *Depth* and *sulfate* show positive loadings (+0.548 and +0.734 respectively) while *chloride* and *total* hardness *as CaCO₃* had negative loadings (-0.426 and -715 respectively). *Arsenic* and *iron* are the third factors with high positive loadings (+0.794 and +0.840 respectively). The fourth factor showed highest loadings on *pH* (+0.858) and *nitrite* (-0.571).

Table: 3.6 Total Variance Explained by Factor Analysis during Monsoon Season (2010-2012)

Factors	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.250	22.500	22.505	2.250	22.505	22.505
2	1.727	17.270	39.774	1.727	17.270	39.774
3	1.548	15.479	55.254	1.548	15.479	55.254
4	0.986	9.860	65.079	0.986	9.826	65.079
5	0.906	9.060	74.149			
6	0.822	8.229	82.378			
7	0.678	6.784	89.172			
8	0.564	5.641	94.814			
9	0.511	5.170	99.993			
10	0.001	0.007	100.000			

Extraction Method: Principal Component Analysis.

Table: 3.7 Rotated Component Matrix of Monsoon season (2010-2012)

Parameters	Factors			
	1	2	3	4
Arsenic	0.000	-0.186	**0.794**	-0.105
Depth	0.108	**0.548**	-0.140	0.099
pH	0.220	0.107	0.046	**0.858**
TDS	**0.963**	0.040	-0.043	-0.002
EC	**0.965**	0.038	-0.043	0.000
Iron	-0.061	0.027	**0.840**	-0.003
Chloride	0.420	**-0.426**	0.019	0.123
Sulfate	0.125	**0.734**	0.194	-0.215
Total Hardness as $CaCO_3$	0.155	**-0.715**	0.152	-0.105
NO_2	0.335	0.148	0.277	**-0.571**

Extraction Method: Principal Component Analysis. **Rotation Method:** Varimax with Kaiser Normalization. Rotation converged in 5 iterations. Bold values are significant factor loadings.

3.3.3. Post-monsoon season:

Table: 3.8 Total Variance Explained by Factor Analysis during Post-monsoon Season (2010-2012)

Factors	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.273	22.727	22.727	2.273	22.727	22.727
2	1.593	15.934	38.661	1.593	15.934	38.661
3	1.221	12.209	50.870	1.221	12.209	50.870
4	1.113	11.132	62.002	1.113	11.132	62.002
5	0.995	9.948	71.950			
6	0.827	8.272	80.222			
7	0.754	7.536	87.758			
8	0.651	6.514	94.271			
9	0.568	5.681	99.952			
10	0.005	0.048	100.000			

Extraction Method: Principal Component Analysis.

During the post-monsoon season the four factors (Fig. 3.58) had 62.002% of the total variability of the dataset. The first factor had 22.727% of the variability followed by 15.934%, 12.209% and 11.132% (Table. 3.8). During the post monsoon season, factor 1 was associated with the parameters of *TDS* and *EC*, where the factor loadings were high and positive (+0.982 and +0.984 respectively) (Table. 3.9). The second factor included *chloride*,

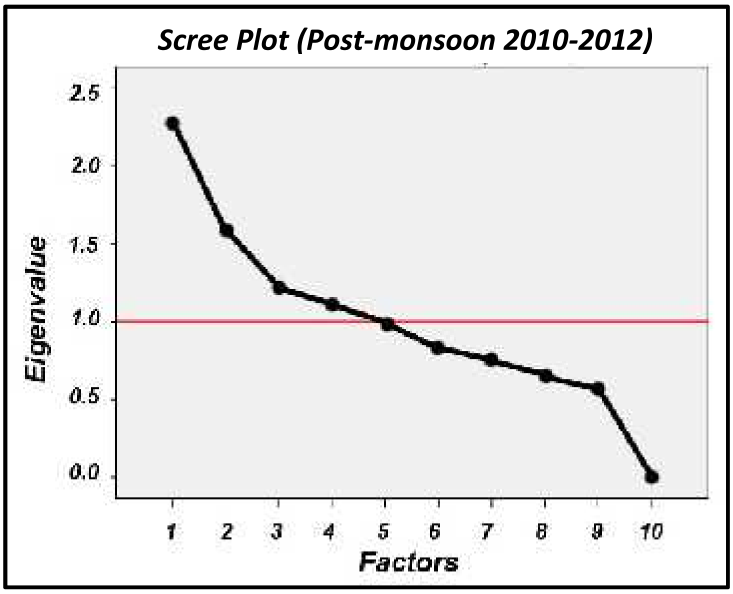


Fig. 3.58: Scree Plot of Post-monsoon season

sulfate and *total hardness as $CaCO_3$* with high loadings of +0.626 and 0.633 and -0.663 respectively. The third factor associated with

Table: 3.9 Rotated Component Matrix of Post-monsoon season (2010-2012)

Parameters	Factors 1	2	3	4
Arsenic	-0.010	-0.326	0.417	**0.425**
Depth	-0.051	0.243	-0.252	**0.599**
pH	0.110	0.127	**-0.703**	0.110
TDS	**0.982**	0.042	0.048	0.023
EC	**0.984**	0.038	0.036	0.024
Iron	0.081	0.064	0.038	**0.817**
Chloride	0.185	**0.626**	0.334	0.027
Sulfate	0.112	**0.633**	-0.040	0.059
Total Hardness as $CaCO_3$	0.195	**-0.663**	0.159	-0.134
NO_2	0.272	0.235	**0.702**	-0.015

Extraction Method: Principal Component Analysis. **Rotation Method:** Varimax with Kaiser Normalization. Rotation converged in 5 iterations. Bold values are significant factor loadings.

pH and *nitrite* had high loadings (-0.703 and +0.702 respectively). The fourth factor composed of three major parameters (*arsenic, depth* and *iron*) with positive loadings of +0.425, +0.599 and +0.817 respectively. Table 3.10 depicted overall distribution of factors in different seasons.

Table: 3. 10 Distribution of Factor Score in Different Seasons

Factors \ Season	Pre-monsoon	Monsoon	Post-monsoon
1	TDS, EC and Nitrite	TDS and EC	TDS and EC
2	Arsenic and Depth	Depth, Chloride, Sulfate and Total Hardness as $CaCO_3$	Chloride, Sulfate and Total Hardness as $CaCO_3$
3	Sulfate and Total Hardness as $CaCO_3$	Arsenic and Iron	pH and Nitrite
4	pH, Iron and Chloride	pH and Nitrite	Arsenic, Depth and Iron

3.4. Inter-factorial Relationship:

Factors extracted from the factor analysis are a group of interrelated variables. It is widely used to understand the importance of each of the factors and their interdependence. Different combinations among the factors are taken into consideration for the analysis of the dynamics in the relationship between the factors.

3.4.1. Pre-monsoon season:

Between factor 1 and 2, a positive relationship was observed between *TDS*, *EC*, *nitrite* and *depth* whereas it was negative with *arsenic*. Between factor 1 and 3 a positive association exists in *TDS, EC, nitrite* and *sulfate* and negative with *total hardness as* $CaCO_3$. Positive association was observed amongst all the parameters of factor 1 and 4. In factor 2 and 3 *total hardness as* $CaCO_3$ has negative connection with *depth* and *sulfate*. The relationship between factor 2 and 4 depict only negative association of *arsenic* with other parameters. The relationship between factor 3 and 4, positive association between *sulfate, pH*, *iron* and *chloride* but negative relationship with *total hardness as* $CaCO_3$.

3.4.2. Monsoon season:

During monsoon season, amongst factor 1 and 2, positive relationship was observed between *TDS and EC* with *depth* and *sulfate* while negative with *chloride* and *total hardness as* $CaCO_3$. The association between factor 1 and 3 was positive in all the parameters viz., *TDS, EC* with *iron* and *arsenic*. Factor 1 and 4 had positive relationship on *TDS* and *EC* with *pH* and it was negative with *nitrite*. The bond between factor 2 and 3 was positive between *depth* and *sulfate* with *arsenic* and *iron* but negative with *chloride* and *total hardness as* $CaCO_3$. Similarly between factor 2 and 4 relationship was positive between *depth* and *sulfate* with *pH* while it was negative relation with *chloride, total hardness as* $CaCO_3$ with *nitrite*. The connection between factor 3 and factor 4 was positive between parameters of *arsenic* and *iron* with *pH* but negative with *nitrite*.

3.4.3. Post-monsoon season:

During the post-monsoon season, inter-factorial relationship between factor 1 and factor 2, depicted positive bond between *TDS* and *EC* with *chloride, sulfate,* while negative with *total hardness as* $CaCO_3$. Between factor 1 and 3, positive relationship existed among the parameters of *TDS* and *EC* with *nitrite* but negative with *pH*. The aassociation between factor 1 and 4 was positive in all the parameters of *TDS* and *EC* with *arsenic, depth* and *iron.* Between factor 2 and 3 positive relations in *chloride* and *sulfate* with *nitrite*, while negative in *total hardness as* $CaCO_3$ and *pH.* The link between factor 2 and 4 was negative with *total hardness as* $CaCO_3$, while it was positive in parameters of *chloride* and *sulfate* with *arsenic, depth* and *iron*. The association between the factor 3 and factor 4 was positive between the parameters of *nitrite* with *arsenic*, *depth* and *iron* but negative on *pH.*

3.5. Dynamics of factor scores:

Factor scores are the composites of the variables that are used to make the latent factor into an observed variable. The variation in the factor score during the seasons is one of the indicator of changes that are taking place in the geo-chemistry of the groundwater. Each factor scores were plotted in different seasons to understand the changing pattern of factors.

3.5.1. Factor score 1:

Factor score 1 distribution graph depicted the distribution of scores of the three seasons. Blocks like *Beldanga-2*, *Bhagwangloa-1*, *Bhagawangola-2* and *Jiagunj* showed very high factor scores (above 1) while *Bharatpur-1, Farakka, Khargram* and *Nabagram* had low factor scores (below -1). The graph depicted that in all the three seasons the pattern of the graph had similarity with each other (Fig. 3.59).

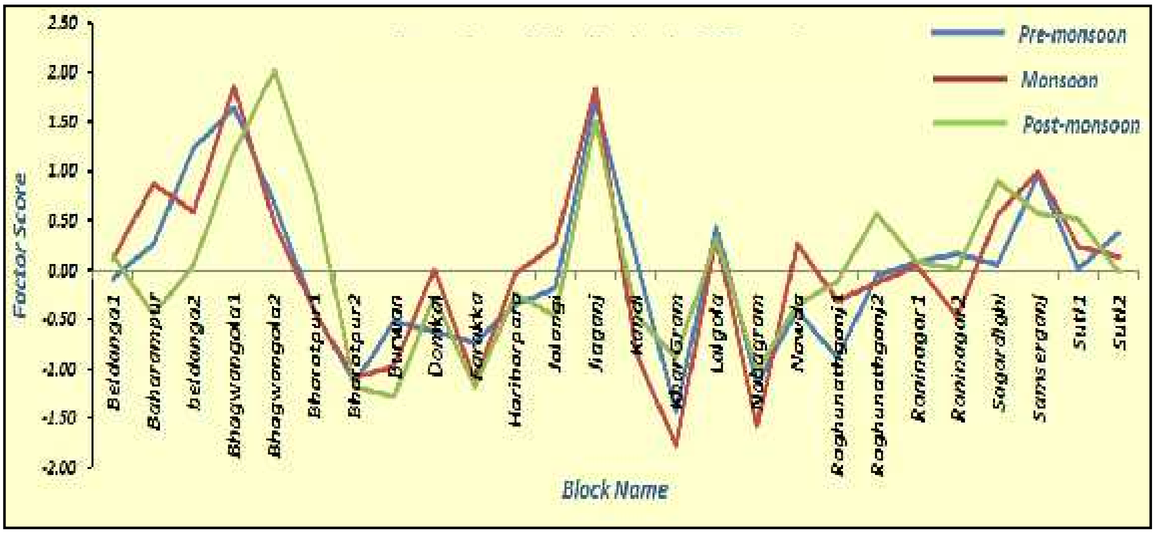


Fig. 3.59: Factor Score 1 Distribution in Different Seasons

3.5.2. Factor score 2:

Factor score 2 distribution graph showed that the blocks of *Beldanga-1*, *Domkal* and *Raghunathganj-2* had very high factor score (above 1) during pre-monsoon season.

During monsoon season all the blocks other than *Domkal* showed low factor scores (Fig. 3.60). During the post-monsoon season a very high peak can be seen in *Beldanga-1* and *Domkal* blocks where the factor score almost touches the score of 2. During post-monsoon season the blocks of *Samshergunj* showed very low factor score (below 1).

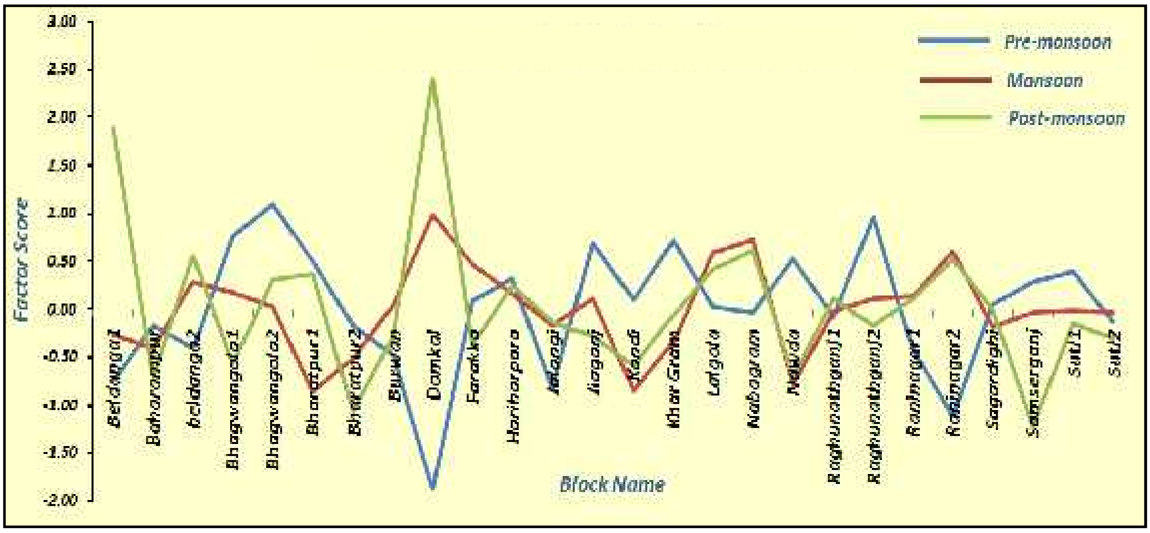


Fig. 3.60: Factor Score 2 Distribution in Different Seasons

3.5.3. Factor score 3:

Factor score 3 distribution graph depicts further variability in the pattern. During pre-monsoon season, very high peak can be observed in the blocks of *Domkal*, *Lalgola* and *Raghunathganj-2* while blocks of *Bhratpur-2*, *Farakka*, *Kandi* and *Samshergunj* showed very low factor score (below 1) (Fig. 3.61). During monsoon season *Bhagawangola-2* and *Raghunathganj-2* showed higher factor scores (above 1) while *Raninagar-2* touched scores of below -1.

During post-monsoon season factor – 3 had very high factor score for the blocks of *Berhampur*, *Jalangi* and *Lalgoal* (above +1). On the other hand, the blocks of *Khargram* and *Samshegunj* had very low factor scores (below-1).

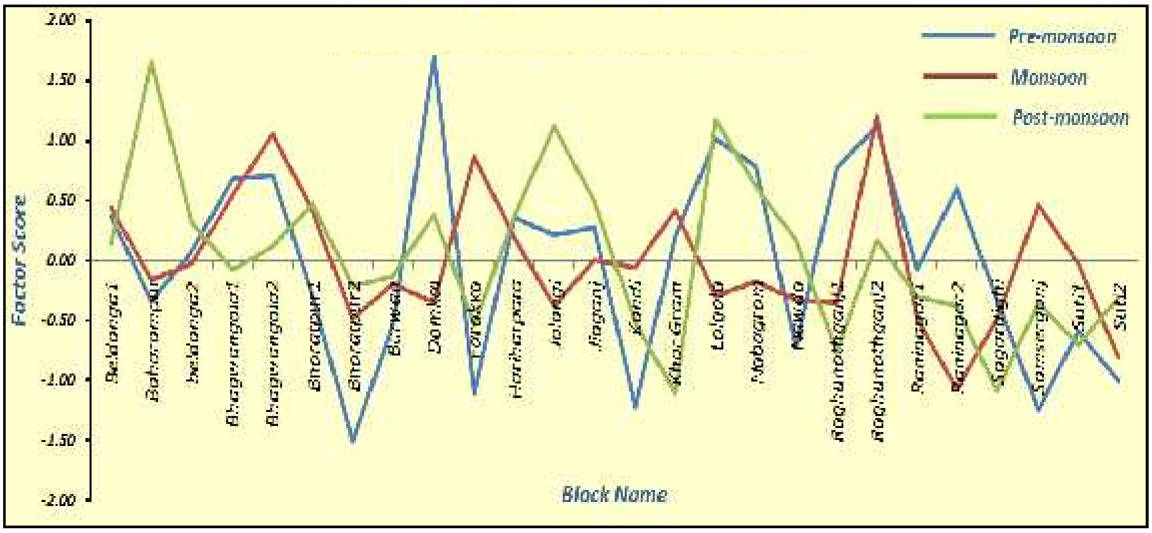


Fig. 3.61: Factor Score 3 Distribution in Different Seasons

3.5.4. Factor score 4:

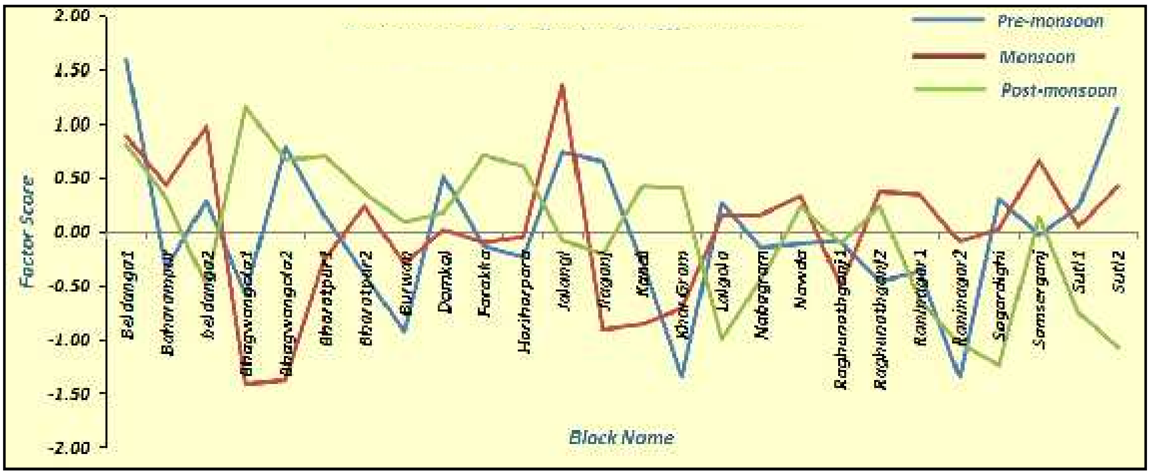


Fig. 3.62: Factor Score 4 Distribution in Different Seasons

During pre-monsoons season, factor score 4, had very high scores in the blocks of *Beldanga-1* (above +1). On the other hand, blocks of *Khragram, Buwan* and *Raninagar-2* showed very low factor score (below -1).

In monsoon season, *Beldanga-1, Beldanga-2* and *Jalangi* factor scores are illustrating very high factor scores (above +1) while *Bhagawangola-1, Bhagawangola*-2 and *Jiagunj* were the blocks which had very low factor scores (below -1) (Fig. 3.62). During post monsoon season *Bhagawangola-1* demonstrated high factor score while blocks of *Lalgola, Sagardighi* and *Suti-2* depicted low factor scores (below-1).

3.6 Cluster Analysis:

Cluster analysis is one of the important methods to combine hydrochemical data on the basis of *Euclidian Distance Method* having similar kind of characteristics (**Daughney** et al. 2012, **Kim** et al. 2009). Hierarchical Cluster Analysis is one of the clustering techniques which is widely used for cluster analysis (**Davis** 1986). Dendrogram is the representation of cluster analysis which showed the linkage of the sampling locations. In the present work, Ward's linkage agglomeration schedule coefficient was used to identify the number of clusters to be retained. Results obtained from the analysis, extracted four clusters. These clusters were further organized in their respective locations and isolines were generated using Inverse Distance Weighting method.

3.6.1. Pre-monsoon season:

Table: 3.11 Cluster Analysis of Pre-monsoon Season (2010-2012)

Cluster	Depth	Arsenic	pH	TDS	EC	Iron	Chloride	Sulfate	Total Hardness as $CaCO_3$	NO_2	Nx
1	47.00	0.08	7.41	654.52	1.30	10.35	101.86	506.84	298.06	31.46	30.00
2	45.68	0.04	7.46	595.53	1.18	6.48	78.91	139.40	746.29	27.26	51.00
3	44.00	0.07	7.38	606.62	1.21	8.04	91.81	880.76	370.35	31.25	39.00
4	45.00	0.05	7.23	554.46	1.10	7.02	63.49	120.91	250.02	28.66	36.00

Unit of all the parameters is in mg/l except *EC* (s/cm^{-1}x 10^{-3}) and *pH*,
Nx = total number of samples in the cluster

3.6.1.1 Cluster 1:

During pre-monsoon season 30 sampling locations were included in the cluster 1. In this cluster, the average *depth* to groundwater was 47 m and *arsenic* concentration was 0.08 mg/l. The average *pH* value depicted alkaline condition with a average value of 7.41. The level of *TDS* demonstrated the highest average concentration of 654.52 mg/l among all the clusters. Similar pattern was also observed in *EC* with average level of 1.30 $s/cm^{-1} x\ 10^{-3}$. The concentration of *iron* showed the highest average value of 10.35 mg/l which was highest among all the clusters. The concentration of *chloride* was as high as 101.86 mg/l. The concentration of *sulfate* showed moderate concentration of 506.84 mg/l and *total hardness as* $CaCO_3$ was as low as 298.06 mg/l. First cluster also had highest *nitrite* concentration 31.46 mg/l (Table 3.11). Most of the blocks located in the eastern and north central segment of the district (*Beldanga-1*, *Beldanga-2*, *Bhagawangola-1*, *Bhagawangola-2*, *Domkal, Hairharpara, Jiagunj, Nabagram, Raghunathganj-2* and *Raninagar-2)* were associated with cluster 1 (Fig. 3.63).

3.6.1.2 Cluster 2:

Cluster 2 is associated with relatively higher number of sampling locations (51). The average *depth* to the groundwater was 45.68 m, which was lower than the cluster 1. The average concentration of *arsenic* in this cluster was 0.04 mg/l which was below permissible limit set by BIS. The *pH* level of groundwater was 7.46 indicating a slight alkaline condition. The average concentration of *TDS* and *EC* were moderate in this cluster with concentration of 595.53 mg/l and 1.18 $s/cm^{-1} x\ 10^{-3}$ respectively(Table 3.11). The concentration of *iron* and *chloride* in the cluster depicted least values of 6.48 mg/l and 78.91 mg/l respectively. *Sulfate* showed relatively low value of 139.40 mg/l while *total hardness* as $CaCO_3$ depicted highest concentration among all the clusters (746.29 mg/l). *Nitrite* also showed the least average concentration among all the clusters (27.26 mg/l). Spatially, it can be observed that, cluster 2 included major segments of *Bharatpur-1*, *Bharatpur-2*, *Farakka*, *Kandi*, *Bhagawangola*, *Suti-1*, *Suti-2 and Samshergunj* located in the northern and southern part of the district (Fig. 3.63).

3.6.1.3 Cluster 3:

This cluster consists of 39 sampling locations where an average *depth* of groundwater was 44 m and the average concentration of *arsenic* was 0.07mg/l indicating higher concentration. The level of *pH* showed slightly alkaline condition

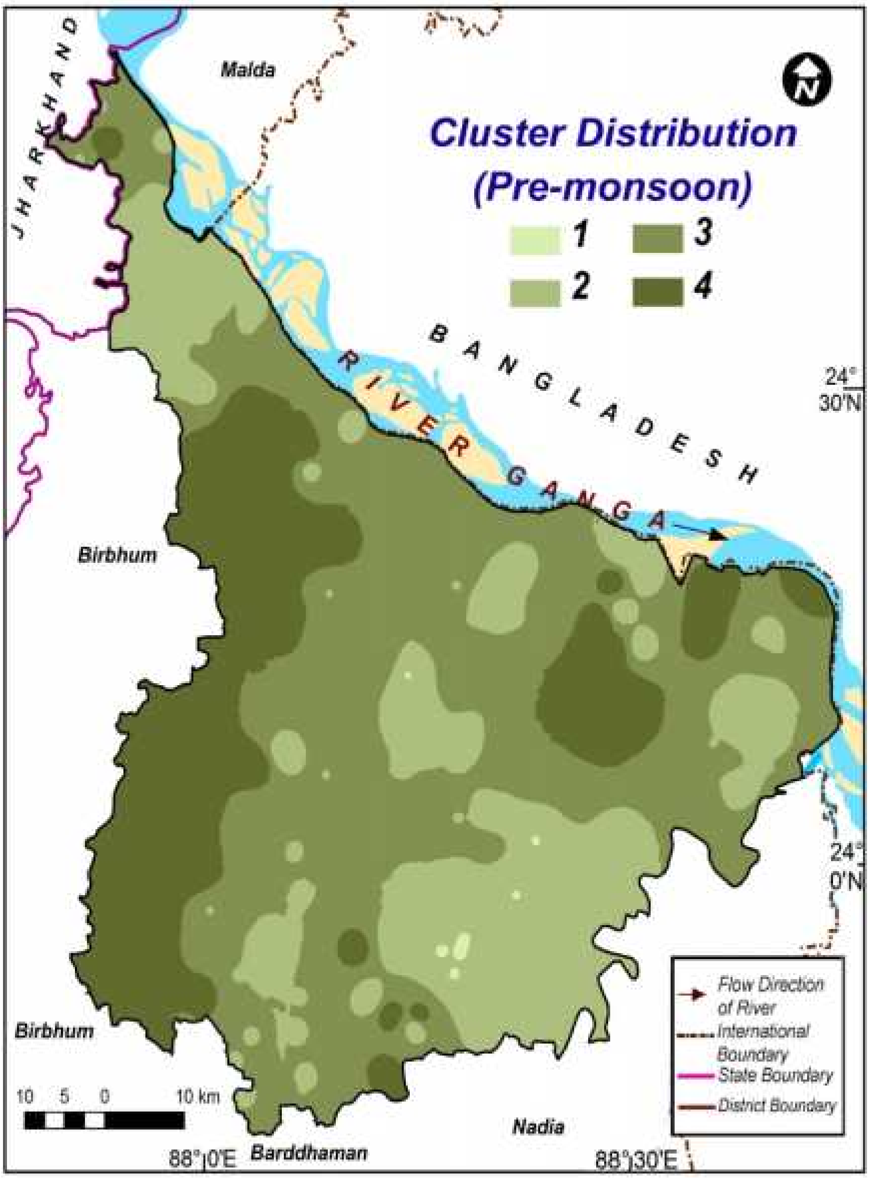


Fig. 3.63: Cluster Distribution during pre-monsoon season

(7.38) while higher concentration was observed in *TDS* and *EC* (606.62 mg/l and 1.21 s/cm^{-1}x 10^{-3} respectively). The average concentration of *iron* (8.04 mg/l) and *chloride* (91.81 mg/l) were considerably high. The concentration of *sulfate* was highest among all the clusters (880.76 mg/l). The concentration of *total hardness* as *CaCO3* and *nitrite* were moderate (370.35 mg/l and 31.25 mg/ l respectively) (Table 3.11). Spatially, it was observed that, this cluster was mostly confined in the north central as well as in the eastern segment of the district includeing blocks of *Behrampur, Bhagawangola-1, Bhagawangola-2, Domkal, Nabagram, Raghunathganj-2* (Fig. 3.63).

3.6.1.4 Cluster 4:

Fourth cluster incorporated 36 sampling locations and the average *depth* of the water was 45 m. The amount of *pH* was 7.23 and *arsenic* concentration was 0.05 mg/l. The concentration of *TDS* and *EC* were moderate (554.46 mg/l and 1.10 s/cm^{-1}x 10^{-3} respectively). The level of *iron, chloride, sulfate* and *total hardness as CaCO3* depicted least concentration (7.02 mg/l, 63.49 mg/l, 120.91mg/l and 250.02 mg/l respectively) (Table 3.11)whereas, concentration of *nitrite* was 28.66 mg/l. This cluster was located in the eastern and northern part of district including blocks of *Burwan, Khargram, Raghunathganj-1, Raninagar-1, Raningar-2* and *Sagardighi* (Fig. 3.63).

3.6.2 Monsoon season:

3.6.2.1 Cluster 1:

During the monsoon season, cluster 1 included 22 sampling locations. The average *depth* of water was 36.59 m. The maximum concentration of *arsenic* in this cluster was 0.11 mg/l. The level of *pH* showed slightly alkaline condition (7.34)

Table: 3.12 Cluster Analysis of Monsoon Season (2010-2012)

Cluster	Depth	Arsenic	pH	TDS	EC	Iron	Chloride	Sulfate	Total Hardness as $CaCO_3$	No_2	Nx
1	36.59	0.11	7.34	675.72	1.34	6.58	81.47	287.41	168.56	30.26	22.00
2	44.32	0.05	7.35	529.54	1.05	9.10	80.22	251.99	448.26	24.47	59.00
3	48.52	0.09	7.40	634.52	1.26	6.29	88.44	824.04	430.05	37.10	27.00
4	49.27	0.03	7.41	630.93	1.25	7.54	83.33	381.11	591.23	30.96	48.00

Unit of all the parameters is in mg/l except *EC* (s/cm^{-1}x 10^{-3}) and *pH*,
Nx = total number of samples in the cluster

(Table.3.12). The concentration of *TDS* was 675.72 mg/l and of was *EC* 1.34 s/cm^{-1}x 10^{-3}. The concentration of *iron* (6.58 mg/l), *chloride* (81.47 mg/l), *sulfate* (287.41 mg/l), *total hardness as* $CaCO_3$ (168.56 mg/l) and *nitrite* (30.26 mg/l) ranged from moderate to low. Spatially, the eastern and north western segment of the district were associated with this cluster that encompassed the blocks of *Beldanga-1, Beldanga-2, Raghunathganj-1, Raninagar-1, Raninagar-2* (Table 3.12) (Fig. 3.64).

3.6.2.2 Cluster 2:

Cluster 2 comprised of 59 sampling locations. In this cluster the average depth was 44.32 m and the average concentration of *arsenic* just touched the permissible limit of *arsenic* in groundwater (0.05 mg/l) (Red vertical line showed permissible limit of arsenic in Fig. 3.2, Fig. 3.20 and Fig. 3.38). The level of *pH* was almost same as cluster 1 with slight alkaline condition of 7.35. The level of *TDS* was 529.54 mg/l and that of *EC* of was 1.05 s/cm^{-1}x 10^{-3}. The concentration of *iron* was highest among all the clusters (9.10 mg/l) (Table 3.12). On the other hand, it was noticed that *chloride* and *sulfate* had least concentration of 80.22 mg/l and 251.99 mg/l respectively. The concentration of *total hardness as* $CaCO_3$ was 448.26 mg/l and that of *nitrite* was 24.47 mg/l. This cluster comprised of *Beldanga-1, Burwan, Farakka, Raninagar-1, Raninagar-2, Suti-1 and Suti-2* blocks which were largely located in the western side of the *Murshidabad* district (Fig. 3.64).

3.6.2.3 Cluster 3:

Cluster 3 incorporated 27 sampling locations. The average *depth* of water in this cluster was 48.52 m while average *arsenic* concentration was 0.09mg/l. The level of *pH* showed slight alkaline condition (7.40). The mean concentration of *TDS was* 634.52 mg/l, *EC* 1.26 s/cm^{-1}x 10^{-3} and of *iron* 6.29 mg/l. *Chloride* and *sulfate* had a maximum concentration among all the clusters (88.44 mg/l and 824.04 mg/l respectively) (Table 3.12). The level of *total hardness as* $CaCO_3$ had a moderate value of 430.05 mg/l while *nitrite* depicted maximum concentration of 37.10 mg/l. Major segments of *Domkal, Hariharpara, Raghunathganj-2* were included in this cluster which largely cover the north central portion of the study area (Fig. 3.64).

3.6.2.4 Cluster 4:

Fourth cluster which had 48 sampling locations had 49.27 m average *depth* of water. The mean *arsenic* concentration was as low as 0.03 mg/l while level of *pH* was highest among all the clusters (7.41). The concentration of *TDS* and *EC* were

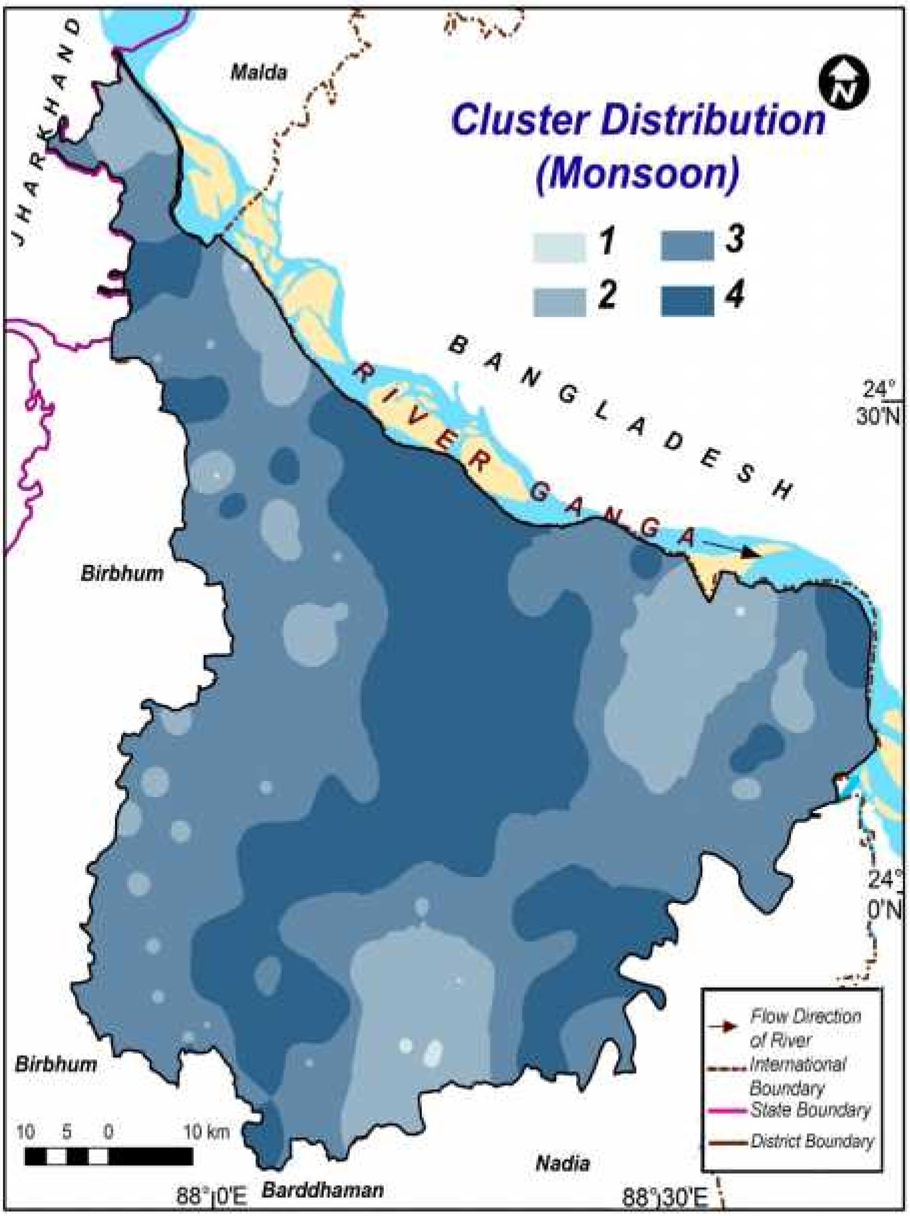


Fig. 3.64: Cluster Distribution during Monsoon Season

moderate (630.93 mg/l and 1.25 s/cm^{-1}x 10^{-3} respectively). The concentration of *iron*, *chloride* and *sulfate* were moderate (7.54 mg/l, 83.33 mg/l and 381.11 mg/l respectively) (Table 3.12). The concentration of *total hardness as* $CaCO_3$ depicted highest value of 591.23 mg/l in all of the clusters while the concentration of *nitrite* showed moderate value of 30.96 mg/l. The blocks of *Beharmapur*, *Bhagawangola-1*, *Bhagawangola-2, Bharatpur- 1, Jiagunj, Raghunathganj-1, Raghunathganj-2* and *Shamsherganj* were associated with this cluster covering the northern and central segments of the district (Fig. 3.64).

3.6.3. Post-Monsoon:

3.6.3.1 Cluster 1:

During post monsoon, the cluster 1 incorporated 54 sampling locations. The average *depth* of groundwater was 46.76 m with higher concentration of *arsenic* (0.08 mg/l). The level of *pH* in cluster 1 was 7.36 which indicated a slight alkaline condition. The concentration of *TDS* and *EC* was as high as 593.45 mg/l and 1.18 $s/cm^{-1} x 10^{-3}$ respectively. The level of *iron* concentration was highest in this cluster (9.11 mg/l). The concentration of *chloride* and *sulfate was* moderate (88.14 mg/l and 208.24mg/l respectively). Average concentration of *total hardness as CaCO3* and *nitrite* was least in this cluster (297.85 mg/l and 27.03 mg/l respectively) (Table 3.13). Spatial distribution of the cluster showed concentration around the eastern as well as in the southern part of the study area. The blocks of *Raninarag-1, Raninagar-2, Beldanga-1, Beldanga-2* and *Raghunathganj-1* were mostly associated with this cluster (Fig. 3.65).

3.6.3.2 Cluster 2:

Cluster 2 is associated with 39 sampling locations. The average *depth* of the groundwater is 44.23 m with low concentration of *arsenic* (0.04 mg/l). The level of *pH* is highest among the clusters with *a* value of 7.43, depicting a slight alkaline condition. The concentration of *TDS* and *EC* was 596.37 mg/l and 1.17 $s/cm^{-1} x 10^{-3}$ respectively (Table 3.13). The concentration of *iron* was least among all the clusters (6.06 mg/l). Similar type of condition was also observed in the case of *chloride* and *sulfate* where concentration was least among all the clusters (63.65 mg/l and 167.05 mg/l respectively). The concentration of *total hardness as* $CaCO_3$ was highest among all the cluster (725.92 mg/l). The concentration of *nitrite* was almost like cluster 1 (28.68 mg/l). The blocks which were incorporated in this cluster are *Bharatpur-1, Bharatpur-2, Farakka, Kandi* and *Shamsherganj* mostly located in the western as well as southern fragment of the study area. Some smaller patches were also seen in the central part (Fig. 3.65).

Table: 3.13 Cluster Analysis of Post-monsoon Season (2010-2012)

Cluster	Depth	Arsenic	pH	TDS	EC	Iron	Chloride	Sulfate	Total Hardness as $CaCO_3$	No2	Nx
1	46.76	0.08	7.36	593.45	1.18	9.11	88.14	208.24	297.85	27.03	54.00
2	44.23	0.04	7.43	596.37	1.17	6.06	63.65	167.05	725.92	28.68	39.00
3	44.00	0.06	7.35	598.90	1.19	7.01	87.62	834.63	335.35	31.98	40.00
4	47.17	0.03	7.37	620.19	1.23	8.92	94.18	460.33	536.42	32.15	23.00

Nx = total number of samples in the cluster

3.6.3.3 Cluster 3:

This cluster was associated with 40 sampling locations with average *depth* of the groundwater being 44 m. The average concentration of *arsenic* in this cluster was just above the permissible limit (0.06 mg/l). The level of *pH* was least among all the clusters showing alkaline condition (7.35). The level of *TDS* and *EC* showed moderate concentration (598 mg/l and 1.19 $s/cm^{-1}x\ 10^{-3}$ respectively) (Table 3.13). The concentration of *iron* too was moderate with the value of 7.01 mg/l, that of *chloride* was 87.62 mg/l which was considerably high. The level of sulfate was 834.63 mg/l which was highest among all the clusters, reversely, in *total hardness as* $CaCO_3$ it was low among the clusters (335.35 mg/l). The concentration of *nitrite* was 31.98 mg/l showing higher concentration. The clusters are mostly located in the blocks of *Lalgola*, *Nabagram*, *Raghunathganj-2* and *Behramapur*. Spatially, concentrated in the north central portion of Murshidabad District (Fig. 3.65).

3.6.3.4 Cluster 4:

Cluster 4 was associated with 23 sampling locations. The average *depth* of the groundwater was 47.17 m while that of *arsenic* was least among all the clusters (0.03 mg/l). The level of *pH* was indicated slight alkaline condition with a value of 7.37.

TDS and *EC* had highest value among all the clusters 620.19 mg/l and 1.23 s/cm^{-1}x 10^{-3} respectively (Table 3.13).

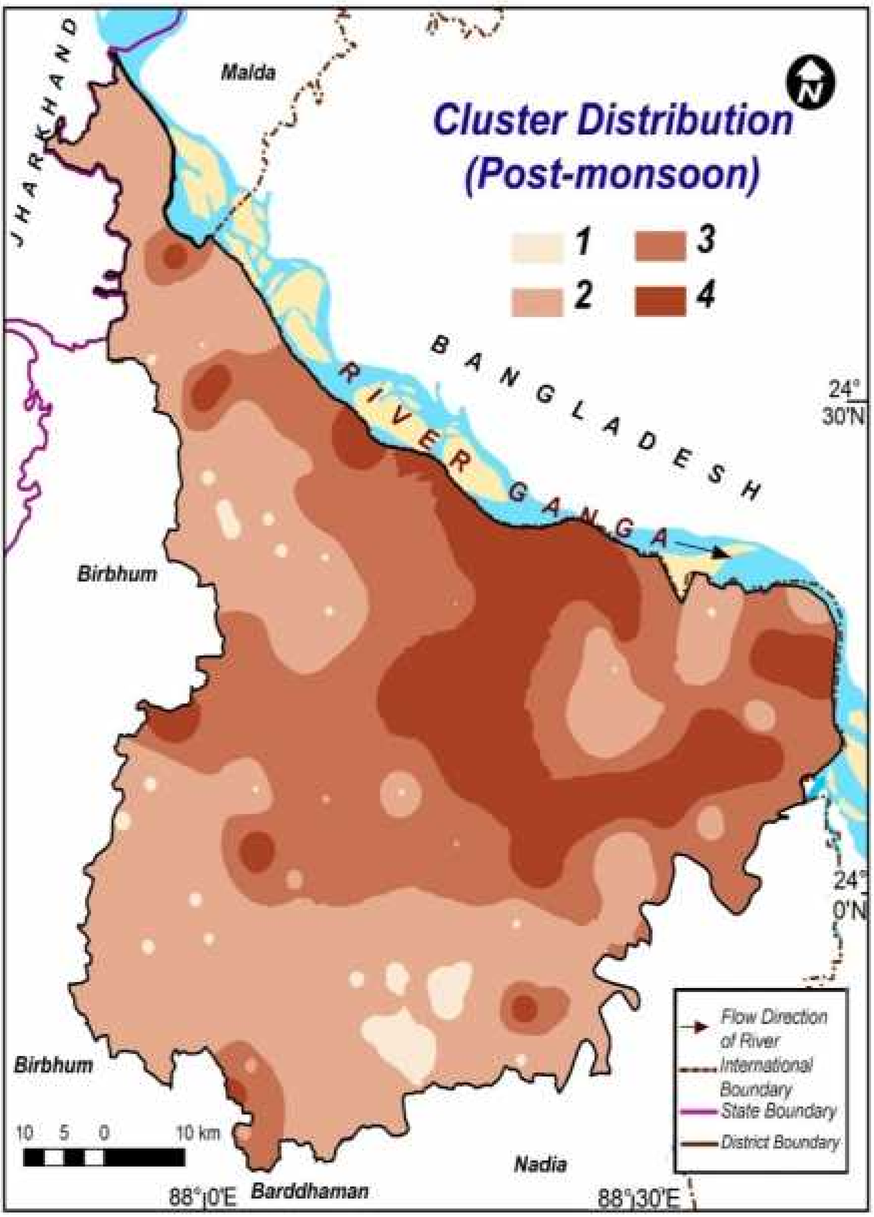


Fig. 3.65: Cluster Distribution during Post-monsoon Season

The *iron* was moderately concentrated (8.92 mg/l) while *chloride* concentration among all the clusters was the highest (94.18 mg/l) (Fig. 3.65). A moderate concentration of *sulfate* was observed in this cluster with a value of 460.33 mg/l. *Total hardness as* $CaCO_3$ showed moderate concentration of 536.42 mg/l while concentration of *nitrite* is highest among all the clusters (32.15 mg/l). The blocks of

Jiagunj and *Bhagawangola-1* were largely associated with these clusters concentrated in the peripheral region of the district.

3.7 Seasonal Variability:

Paired t-test was performed on the parameter in different seasons on 156 samples with 95 % significance level. The results obtained from the analysis indicated the pattern of change in the mean of the parameters in different seasons. To perform the analysis, three pairs had been formed (Table 3.14). Results obtained from the analysis are illustrated for each of the parameters-

Table: 3.14 Pairs of Different Seasons for Seasonal Variability

Parameters	Pre-monsoon & Monsoon	Monsoon & Post-monsoon	Pre-monsoon & Post-monsoon
Arsenic	Pair 1a	Pair 2a	Pair 3a
pH	Pair 1p	Pair 2p	Pair 3p
TDS	Pair 1t	Pair 2t	Pair 3t
EC	Pair 1e	Pair 2e	Pair 4e
Iron	Pair 1i	Pair 2i	Pair 3i
Chloride	Pair 1c	Pair 2c	Pair 3c
Sulfate	Pair 1s	Pair 2s	Pair 3s
Total Hardness as $CaCO_3$	Pair 1th	Pair 2th	Pair 3th
Nitrite	Pair 1n	Pair 2n	Pair 3n

The letters written after the pair numbers are the initial letter(s) of the parameters.

3.7.1 Arsenic:

Correlation value of Pair 1a, Pair 2a and Pair 3a seasons are +0.797, +0.634 and +0.881 respectively (Table 3.15). The t-statistic was higher than the tabulated values indicating a significant variation in *arsenic* concentration in Pair 1a and Pair 2a, where as in Pair 3a the t-statistic was lesser than the tabulated one. In case of Pair 1a

Table: 3.15 Correlation and Paired 't' statistics of different seasons.

Pairs	Seasons Combinations	Correlation	t statistics	df	Sig. (2-tailed)
Pair 1a	pre-monsoon - monsoon	0.797	4.944	155	0.000
Pair 2a	monsoon - post-monsoon	0.634	4.071	155	0.000
Pair 3a	pre-monsoon - post-monsoon	0.881	**0.585**	155	0.560
Pair 1p	pre-monsoon - monsoon	0.216	7.927	155	0.000
Pair 2p	monsoon - post-monsoon	0.316	8.195	155	0.000
Pair 3p	pre-monsoon - Post-monsoon	0.391	**1.679**	155	0.095
Pair 1t	pre-monsoon - monsoon	0.720	13.884	155	0.000
Pair 2t	monsoon - post-monsoon	0.612	**1.753**	155	0.082
Pair 3t	pre-monsoon - post-monsoon	0.452	8.336	155	0.000
Pair 1e	pre-monsoon - monsoon	0.719	13.639	155	0.000
Pair 2e	Monsoon - post-monsoon	0.619	**1.093**	155	0.276
Pair 3e	pre-monsoon - post-monsoon	0.463	8.856	155	0.000
Pair 1i	pre-monsoon - monsoon	0.235	**0.095**	155	0.924
Pair 2i	Monsoon - post-monsoon	0.346	**0.706**	155	0.482
Pair 3i	pre-monsoon - post-monsoon	0.222	**0.474**	155	0.636
Pair 1c	pre-monsoon - monsoon	0.420	3.717	155	0.000
Pair 2c	Monsoon - post-monsoon	0.413	4.214	155	0.000
Pair 3c	pre-monsoon - post-monsoon	0.689	**0.113**	155	0.910
Pair 1s	pre-monsoon - monsoon	0.590	7.912	155	0.000
Pair 2s	Monsoon - post-monsoon	0.410	8.320	155	0.000
Pair 3s	pre-monsoon - post-monsoon	0.853	3.322	155	0.001
Pair 1th	pre-monsoon - monsoon	0.572	3.760	155	0.000
Pair 2th	Monsoon - post-monsoon	0.459	5.352	155	0.000
Pair 3th	Pre-monsoon - post-monsoon	0.859	2.482	155	0.014
Pair 1n	pre-monsoon - monsoon	0.812	5.399	155	0.000
Pair 2n	Monsoon - post-monsoon	0.611	**0.175**	155	0.861
Pair 3n	pre-monsoon - post-monsoon	0.677	4.085	155	0.000

df= degree of freedom, the analysis was done at 95% significance level.
The boldfaced values in the table are lesser than the tabulated t values.

and Pair 2a null hypothesis can be rejected while, in case of Pair 3a null hypothesis can be accepted (Table 3.16). Further, it can be concluded that in pre-monsoon & monsoon and monsoon & post-monsoon, significant change was observed while pre-monsoon and post-monsoon season, no significant change was detected.

3.7.2 pH:

Correlation values of Pair 1p, Pair 2p and Pair 3p were +0.216, +0.316 and +0.391 respectively. In Pair 1p and Pair 2p the t-statistic value was more than the tabulated value (-7.927 and 8.195 respectively) (Table 3.15) indicating a significant change while

Pair 3p showed t-statistic less than the tabulated value (-1.679). It can be inferred from the results that from pre-monsoon & monsoon and monsoon & post-monsoon,

Table: 3.16 Seasonal Variability of Parameters

Parameters	Pre-monsoon & Monsoon		Monsoon & Post-monsoon		Pre-monsoon & Post-monsoon	
	Null Hypothesis	Alternative Hypothesis	Null Hypothesis	Alternative Hypothesis	Null Hypothesis	Alternative Hypothesis
Arsenic		√		√	√	
pH		√		√	√	
TDS		√	√			√
EC		√	√			√
Iron	√		√		√	
Chloride		√		√	√	
Sulfate		√		√		√
Total Hardness as $CaCO_3$		√		√		√
Nitrite		√	√			√

significant change was witnessed. Hence, in Pair 1p and Pair 2p, null hypothesis can be rejected while in case of Pair 3p it can be accepted.

3.7.3 TDS:

In *TDS* the correlation values of the pairs were +0.720, +0.612 and +0.452 respectively. The t-statistic for the pairs was +13.884, -1.753 and +8.336 respectively. The t-statistic was greater than the tabulated t value i.e. 1.975, in Pair 1t and Pair 3t while in Pair 2t, the t-statistic was lesser than the tabulated value. The former indicated a change in the *TDS* concentration while no significant change was observed in Pair 2t. Thus, in case of Pair 1t and Pair 3t, null hypothesis can be rejected while in Pair 2t, null hypothesis was accepted (Table 3.15).

3.7.4 EC:

In *EC* the correlation value of three Pairs were +0.719, +0.619 and +0.463 respectively. The t-statistic of Pair 1e and Pair 2e were +13.639 and -1.093 while for Pair 3e it was +8.836. For the Pair 1e and 3e the table value was greater than the t-statistic indicated a significant change but for the last Pair 2e it is lesser than t-value illustrating no significant change. Thus for 1e and 3e, alternative hypothesis can be accepted while for Pair 2e, null hypothesis was accepted.

3.7.5 Iron:

The correlation of pairs for *iron* were +0.235, +0.346 and +0.222 respectively. The t-statistic of the pairs were +0.095, -0.706and -0.474. In all the cases the values were smaller than the table value which indicated that there was no significant change amongst the seasons, thus, null hypothesis can be accepted.

3.7.6 Chloride:

The correlation of the Pairs 1c, 2c and 3c were +0.420, +0.413 and +0.689 respectively. The t-statistics indicated that value of Pair 1c and Pair 2c is greater than the table value (-3.7171 and 4.214) while the value of Pair 3c was lesser than the table value (0.113). Hence significant change was observed in Pair 1c and Pair 2c, while in Pair 3c no significant change was observed. Thus, null hypothesis can be rejected for Pair 1c and Pair 2c while in Pair 3c null hypothesis was accepted (Table 3.15).

3.6.7 Sulfate:

For Pairs 1s, 2s and 3s the correlation was +0.590, +0.410 and +0.853 respectively. The t-statistic for the three pairs was higher than the table value (7.912, 8.320 and 3.322). Hence, significant changes were observed in all the seasons. Consequently, alternative hypothesis was observed between all the seasons.

3.7.8 Total Hardness as $CaCO_3$:

The correlation value of *Total Hardness as* $CaCO_3$ the three pairs was +0.572, +0.459 and +0.859 respectively. The t-static was -3.760, +5.352and +2.482 which was greater than the table, indicated a significant change in concentration in different seasons thus alternative hypothesis was accepted in all the season.

3.7.9 Nitrite:

The correlation for *nitrite* was +0.812, +0.611 and +0.677 respectively. The value of t-statistic of Pair 1n and 3n was more than the table value, while for the Pair 2n it was less. Thus, for the two pairs (Pair 1n and Pair 3n) a significant change in the concentration was observed and the null hypothesis can be rejected while for the Pair 2n no significant change was observed, hence, alternative hypothesis was accepted (Table 3.15).

3.8 Discussion:

3.8.1 Pre-monsoon:

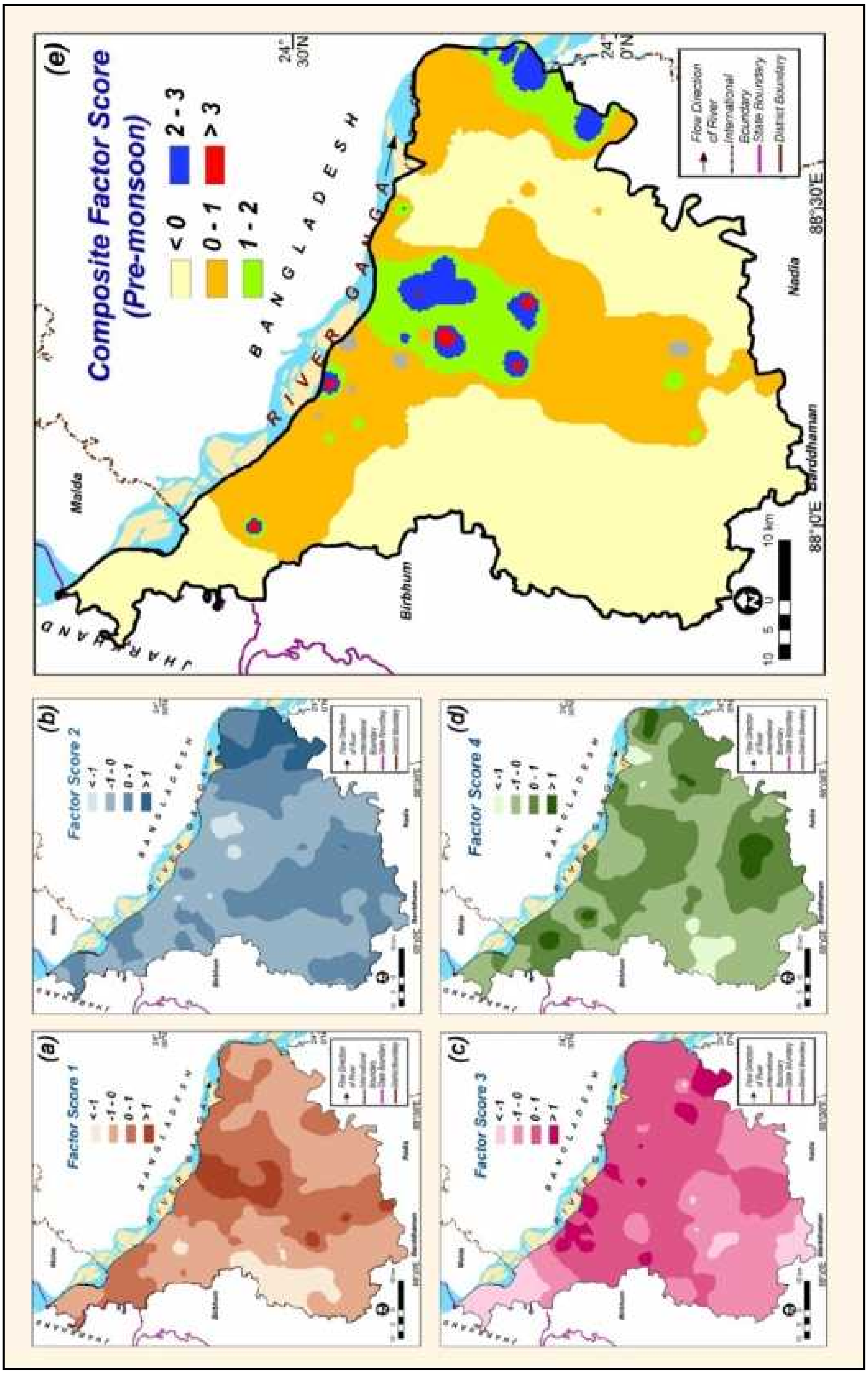


Fig. 3.66: Factor Score Distribution Map during pre-monsoon season

During the pre-monsoon season, factor 1 is associated with the parameters of *TDS*, *EC* and *nitrite*, thus this factor was assigned as 'turbidity factor' (Fig. 3.66a). High turbidity was observed on the northern periphery and also along the narrow trail of the river Bhagirathi. Percolation of river water and mixing with the subsurface groundwater might be one of the governing factors that affects the turbidity (**Ghosh** & **Kanchan**, 2014). This factor decreased gradually on the western as well as on the eastern ends where the number of tributaries and distributaries are less. As per the result, it can be said that these three factors during pre-monsoon season contributed significantly in controlling the overall variability of the groundwater characteristics.

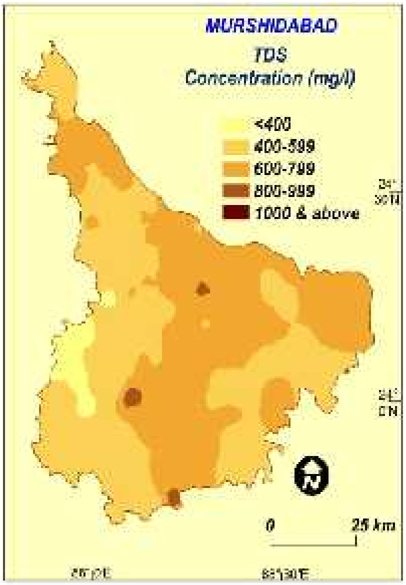


Fig. 3.67: Spatial Distribution of TDS during pre-monsoon season.

Higher average concentration of *TDS, EC* and *nitrite* were associated with cluster 1 (Fig. 3.63). This cluster was largely confined in the eastern and north-central part of *Murshidabad* district.

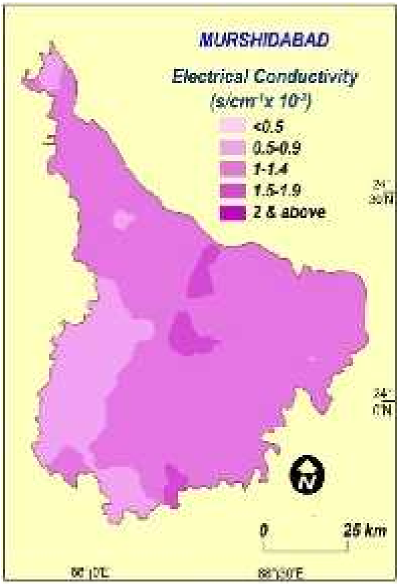


Fig. 3.68: Spatial Distribution of EC during pre-monsoon season.

In cluster 1, the average concentration of *arsenic* was considerably higher (0.08mg/l) and was largely confined in the eastern part. Higher concentration of *TDS* (Fig. 3.67) and *EC* (Fig. 3.68) was located in the central portion and eastern side of the river *Bhagirathi* while *nitrite* concentration (Fig. 3.69) was mostly located in the north central portion of the district.

Factor 2 was associated with *arsenic* and *depth*. Positive loading on the *depth* and negative loading on *arsenic* indicated concentration of *arsenic* in the shallower *depth*.

The easternmost side of the study area depicted very high concentration of *arsenic* at

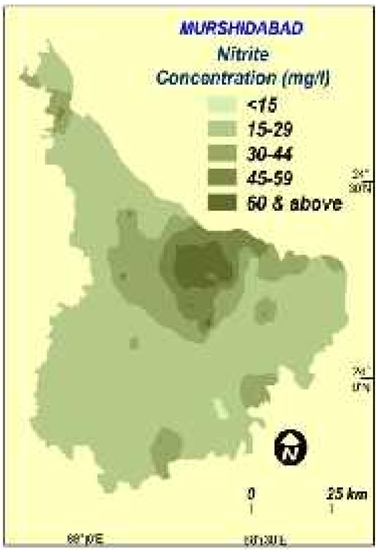


Fig. 3.69: Spatial Distribution of Nitrite during pre-monsoon season.

the shallower *depth* (Fig. 3.66b). The aquifer system in the eastern part of river *Bhagirathi* is thick unconfined and is associated with easy interaction and percolation of surface and subsurface water.

The results obtained from the cluster analysis showed that, cluster 3 is associated with similar kind of characteristics and were mostly situated in the eastern most segment in a confined area having lesser *depth*. In this season, the *arsenic* concentration was 0.06 mg/l which is just above the permissible limit of BIS (Fig. 3.70). The concentration of *arsenic* in eastern most part of the study area of river Bhagirathi during pre-monsoon season was a common characteristic of cluster 1 and 3.

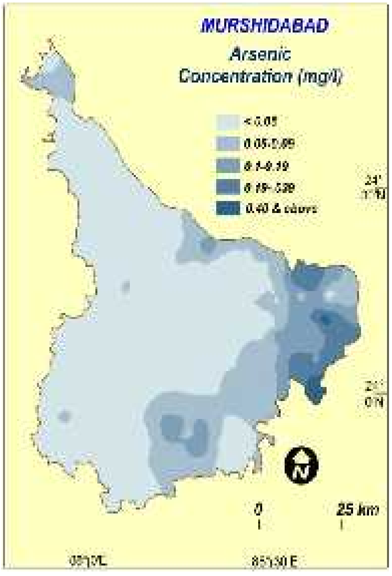


Fig. 3.70: Spatial Distribution of Arsenic during premonsoon season

The results obtained from the inter-factorial relation between factor 1 and 2 depicted that all the parameters had positive characteristics except *arsenic* which illustrated the fact that its concentration was higher at the shallower *depth*. With increasing *depth* concentration lowers down. In case of *TDS, EC* and *nitrite* and it was spread throughout the district.

Factor 3 associated with the parameters of *sulfate* and *total hardness as* $CaCO_3$ showed the concentration of *sulfate* (Fig. 3.71) in the eastern side of the river *Bhagirathi*. No definite pattern was observed for *total hardness as* $CaCO_3$ (Fig. 3.72). This phenomenon might be due to the weathering of calcium bearing rocks in the region and excessive use of lime in the agricultural land and subsequently, mixing with the groundwater (Sawyer and McCarthy 1967, Giridharan et al. 2008). Considerably higher factor scores were observed in central and north central segment while they were lower in the south western segment (Fig. 3. 66c). Results obtained from the cluster analysis showed that, cluster 3 (Fig. 3.63) was associated with considerably higher average of *sulfate* and *total hardness as* $CaCO_3$ while the highest concentration of later was in cluster 2.

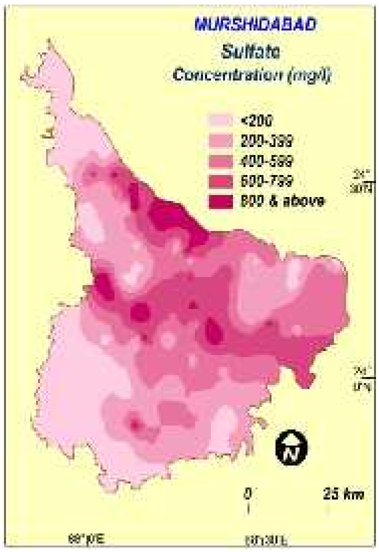


Fig. 3.71: Spatial Distribution of Sulfate during pre-monsoon season.

Inter factorial relation between factors 1 and 3 depicted that the region where *total hardness as* $CaCO_3$ was moderate to lower, the concentration of *TDS* and *EC* and *nitrite* was moderate. Under the same circumstances the concentration of *arsenic* was higher shallower *depth*. Relation between factor 2 and factor 3 had a positive association in all the parameters except *arsenic* and *total hardness as* $CaCO_3$. The factor 3 and cluster 2 both were mostly found in central part of *Murshidabad* district.

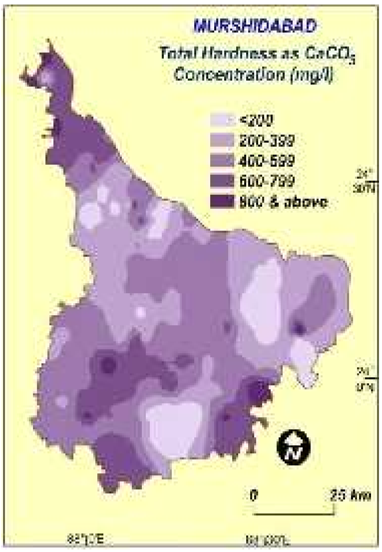


Fig. 3.72: Spatial Distribution of Total Hardness as $CaCO_3$ **during pre-monsoon season.**

pH, *chloride* and *iron* were associated with factor 4 (Fig.3.66d). *pH* is considered to be one of the important parameters which helps in determining the hydro chemical characteristics of groundwater, as the level of *pH* is associated with further chemical reactions (Ghosh[1] & Kanchan 2014).

The level of *pH* in the central part was slightly alkaline while in the other parts of the district it ranged from normal to slightly acidic (Fig. 3.73). The concentration of *chloride* in the entire region was considerably high except in the western side (Fig. 3.74) while *iron* was much higher in the western and north western segment.

The particular condition can be observed in cluster 1 of *chloride* where the concentration of the *iron*, *chloride* and *pH* was high. The inter factorial relationship among the factor 1 and factor 4, factor 2 and factor 4 and factor 3 and factor 4.

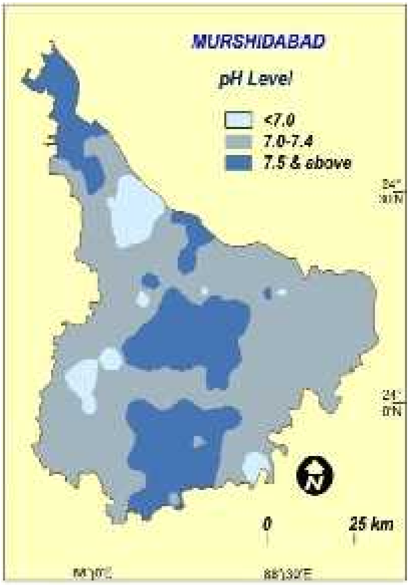


Fig. 3.73: Spatial Distribution of pH during pre-monsoon season.

The composite factor score showed major concentration in the north central and eastern part of the district (Fig.3.66e).

Thus, in the pre-monsoon season higher concentration of *arsenic* with slightly alkaline condition was noted. Similarity in-terms of the spatial distribution of *arsenic* and *iron* can be observed in the eastern end of the *Murshidabad* district indicating a definite relation between the two. The concentration of *nitrite*, *TDS* and *EC* was related with river as their concentration is much higher nearer to it. This also indicated the interaction of surface and subsurface water (Oinam et al. 2011). *Sulfate*, *chloride* and *total hardness as* $CaCO_3$ was extensively found throughout the study area. The results obtained from the factor analysis depicted that factor scores were much higher in the eastern side of the river *Bhagirathi*.

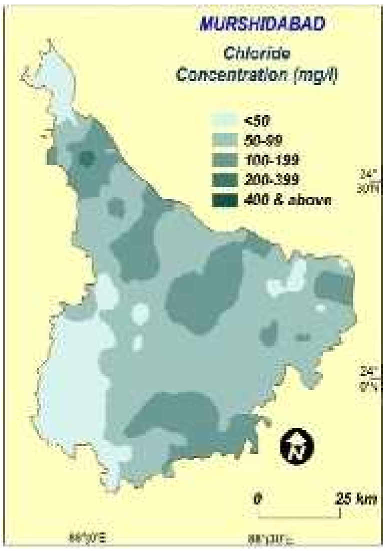


Fig. 3.74: Spatial Distribution of Chloride during pre-monsoon season.

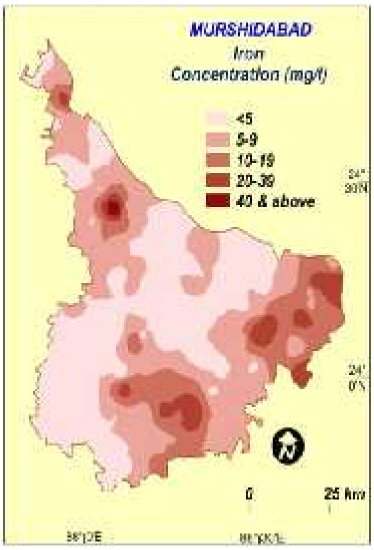


Fig. 3.75: Spatial Distribution of Iron during pre-monsoon season.

3.8.2 Monsoon:

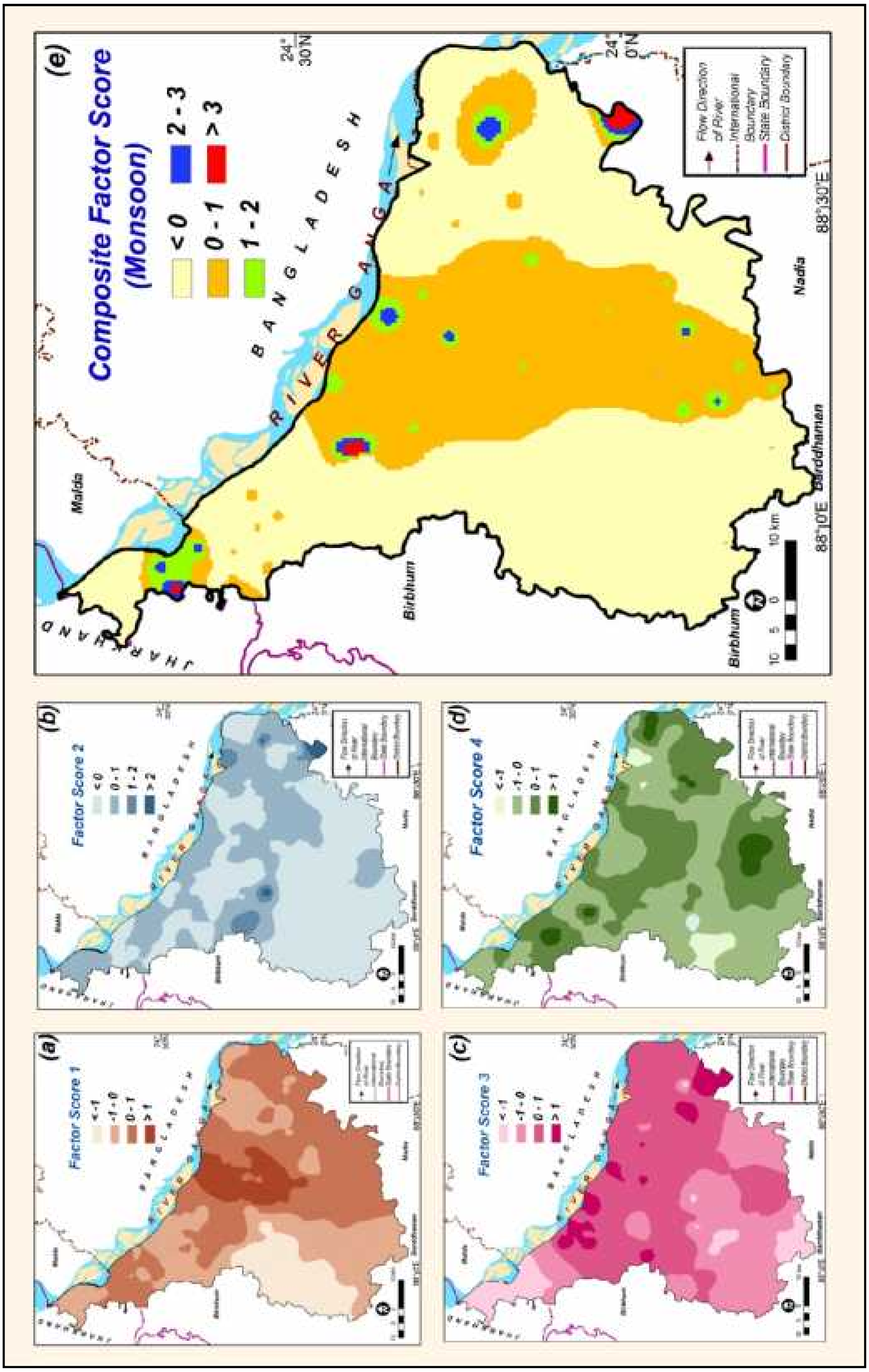


Fig. 3.76: Factor Score Distribution Map during Monsoon Season

During monsoon season, factor 1 is associated with the parameters of *TDS* and *EC* (Fig. 3.76a). In respect to pre-monsoon season, a slight decrease was observed in concentration. In respect to pre-monsoon season, a slight decrease in the concentration of *TDS* and *EC* was observed in the monsoon season. Dilution of subsurface water due to percolation of rain water might be one of the reason behind this condition (Ghosh & Kanchan 2011). The eastern part of the river *Bhagirathi* had a higher level of *TDS* (Fig. 3.77).

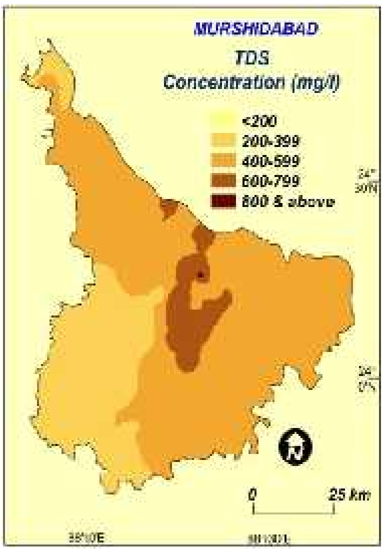


Fig. 3.77: Spatial Distribution of TDS during Monsoon Season.

A narrow trail of higher level of *TDS* and *EC* (Fig. 3.78) can be observed in the central portion of the district which follows the path of the river *Bhagirathi*. The factor score map also confirmed that the entire study area is associated with higher factor score except in its western part (Fig. 3.76a).

The results obtained from the cluster analysis depicted that cluster 1 was associated with the highest concentration of *TDS* and *EC*. This cluster largely covers the eastern and north western part of the district. On the other hand, this cluster was almost absent in the western most segment indicating a relatively lesser concentration of each of the parameters. Least number of locations was found in this cluster but they are distributed in a much wider area indicating a widespread impact of natural phenomenon. Another fact, which might also contribute in the lowering of the concentration of *TDS* and *EC* in this season is the condition of the aquifers.

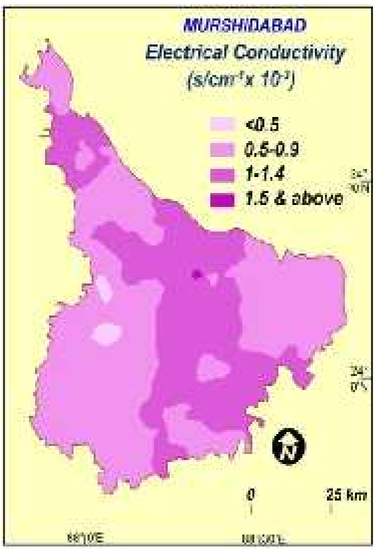


Fig. 3.78: Spatial Distribution of EC during Monsoon Season.

Thick unconfined aquifer is found in the eastern part which is associated with easier interaction of surface and subsurface water and there is no significant intervening layer. This leads to easier and faster percolation of water in the eastern part rather than the western segment which has thick semi confined aquifer having intervening layers that slower down the process of percolation (Groundwater Information Booklet, 2007). *Chloride*, *sulfate*, *total hardness as $CaCO_3$*, and *depth* form the second factor (Fig. 3.76b). The concentration of *chloride* was mostly confined in the central and eastern part of the district (Fig. 3.79). *Total hardness as $CaCO_3$* showed extensive distribution and is mostly confined in the central region (Fig. 3.80). The level of *sulfate* was also high in the entire district. *Total hardness as $CaCO_3$* and *chloride* concentration increased in this season, but the level of *sulfate* decreased slightly. Greater runoff from the agricultural fields, percolation through the soil and mixing with the groundwater might govern this condition.

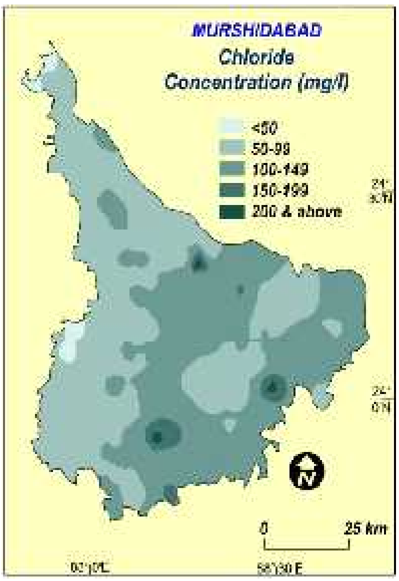


Fig. 3.79: Spatial Distribution of Chloride during Monsoon Season

The factor score are considerably higher in northern peripheral part and lower in central part. Cluster analysis depicts highest concentration of *chloride* and *sulfate* in

cluster 3 which was confined in the central part (Fig. 3.81). In the same cluster, the concentration of *arsenic* was also very high. Both the results (factor and cluster analysis), demarcated the eastern portion as the most contaminated in respect to factor 2. The inter-factorial relationship between factor 1 and 2 explained a negative relationship of *chloride* with all other parameters. Factor 3 is related with *arsenic* and *iron* and its concentration was found higher in the eastern part. No significant change in *iron* concentration was observed between pre-monsoon and monsoon season, indicating predominance of this element

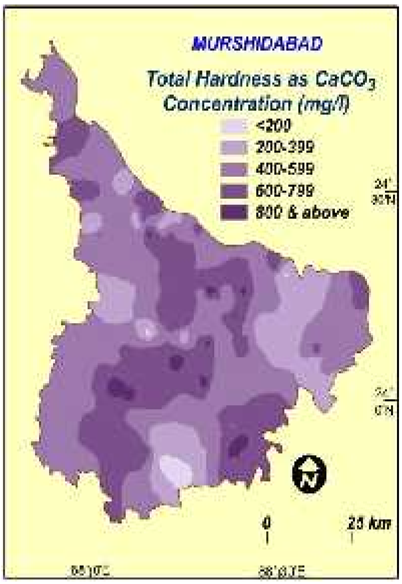


Fig. 3.80: Spatial Distribution of Total Hardness as $CaCO_3$ during Monsoon Season.

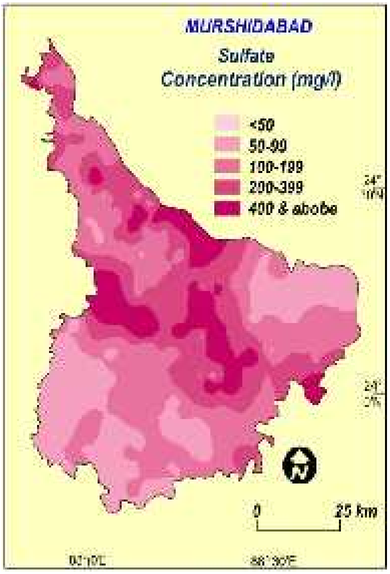


Fig. 3.81: Spatial Distribution of Sulfate during Monsoon Season

in shallower aquifers (Fig. 3.82). Entire region, except western part of the river *Bhagirathi* depicted higher factor score (Fig. 3.76c).

As per cluster analysis, cluster 2 had 59 sampling location and the highest average *iron* concentration was confined in the eastern and western part of river *Bhagirathi* (Fig. 3.64). The average concentration of *arsenic* decreased to a considerable level and was confined in a small patch in the eastern side (Fig. 3.83). This decrease might be due to the dilution of rain water (Ghosh & Kanchan 2011). Even in this season the eastern side showed very high concentration of arsenic.

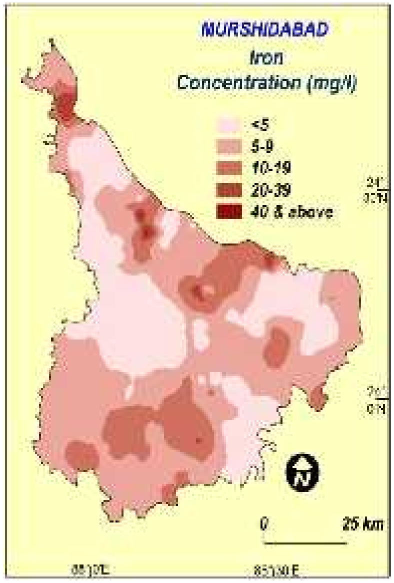


Fig. 3.82: Spatial Distribution of Iron during Monsoon Season

The inter factorial relation between factor 1 and 3 depicted a positive relationship with each other indicating no single factor being dominating and controlling. Inter factorial relation between factor 2 and 3, on the other hand, showed a negative relationship with *total hardness as* $CaCO_3$, *chloride* while positive association of *sulfate* and *depth* with other parameters like *iron* and *arsenic*. Thus, regions with higher *arsenic* and *iron* concentration have lower *total hardness as* $CaCO_3$. On the other hand, cluster 4 depicts least average arsenic concentration but at the same time the *total hardness as* $CaCO_3$ was highest (Fig. 3.76d) (Table. 3.12).

pH and *nitrite* were included in the fourth factor with least variability of the entire data set. In this case, *pH* is associated with positive loading while the *nitrite* is associated with negative loadings (Table. 3.7). *pH* value was slightly higher in the entire district (Fig. 3.84). On the other hand, *nitrite* is concentrated in a very small patch in the north central portion (Fig. 3.85). Other than this, there is no significant concentration of this element which indicates excessive use of nitrogen bearing pesticides and fertilizers in the agricultural ground (Schmoll et al. 2006, Mishima et al. 2010). The factor scores are considerably higher (Table. 3.7) (Fig. 3.76d). The cluster analysis depicted two clusters viz. cluster 1 and 4 where the condition of these two parameters are almost identical (Fig. 3.64) (Table. 3.12).

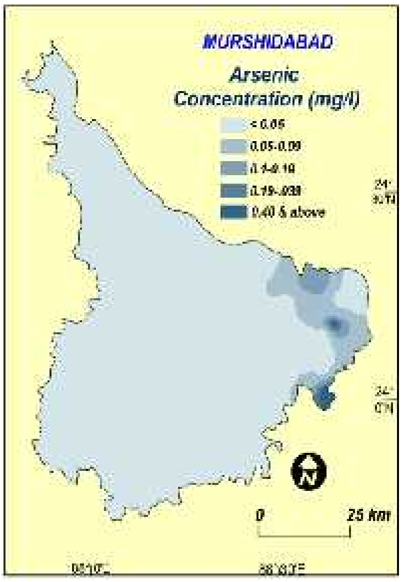


Fig. 3.83: Spatial Distribution of Arsenic during Monsoon Season

These clusters are mostly confined in the eastern side of the river *Bhagirathi* which also coincide with the region of higher factor scores (Fig. 3.64). The inter factorial relationship between factor 1 and 4, factor 2 and 4 and factor 3 and 4 depicted the facts that during this season the parameters of *nitrite*, *chloride* and *total hardness as* $CaCO_3$ had a negative relationship with other parameters like *arsenic*, *sulfate*, *TDS*, *EC* and *pH*. The composite factor score (Fig. 3.76e) depicted the overall characteristics of the factors during monsoon season that showed major concentration along the river *Bhagirathi* in different patches.

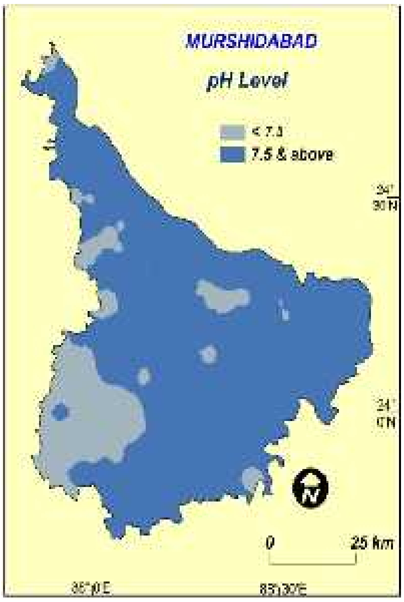


Fig. 3.84: Spatial Distribution of pH during Monsoon Season

Thus between pre-monsoon and monsoon season significant change in concentration was observed in all the parameters except *iron*. Rainfall is one of the important factors that helped in deterring the characteristics of groundwater and changing its nature (Ghosh[1] & Kanchan 2011). During pre-monsoon all the factors aligned in a particular way but during monsoon season their orientation is relatively less oriented (Fig. 3.60 and Fig. 3.62) that showed significant shift of the factor scores.

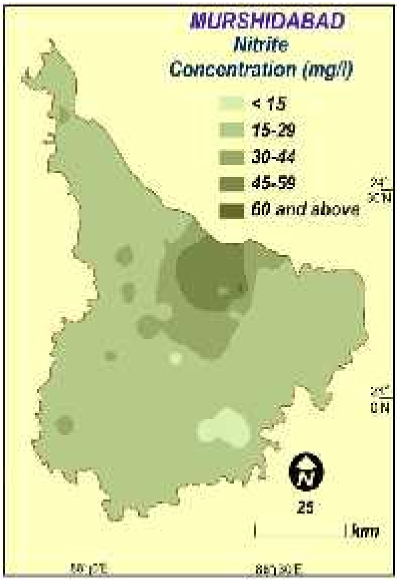


Fig. 3.85: Spatial Distribution of Nitrite during Monsoon Season

3.8.3 Post-monsoon:

During post-monsoon factor 1 is associated with the parameters of *TDS and EC*. This condition can be explained with the fluctuation in the level of groundwater. As the level of groundwater or the volume of water decreases the concentration respectively. The location of higher concentration of *TDS* and *EC* were located nearer to the rivers. The concentration of *TDS* was much higher along the path of the river *Bhagirathi* (Fig. 3.86 and Fig. 3.87).

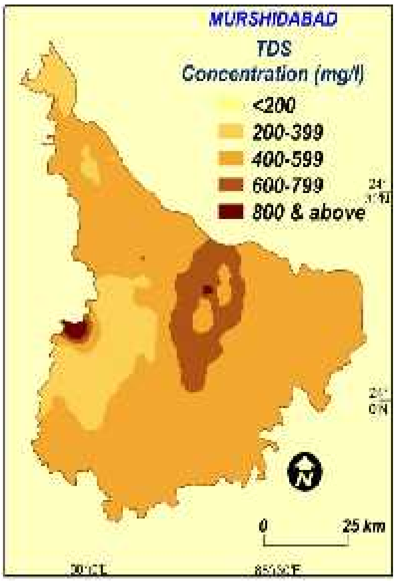


Fig. 3.86: Spatial Distribution of TDS during Post-monsoon Season

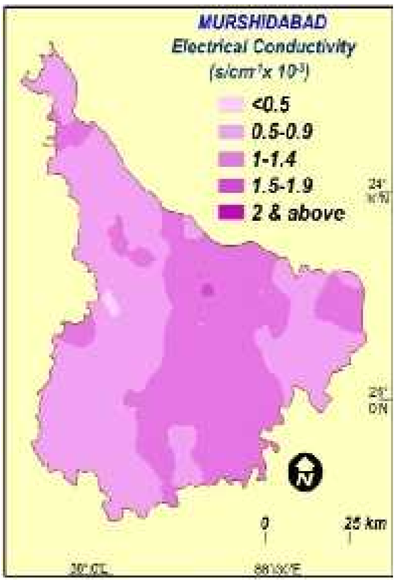


Fig. 3.87: Spatial Distribution of EC during Post-monsoon Season.

Factor 1 depicted that, the central and eastern part of the river *Bhagirathi* is associated with higher factor scores (Fig.3.88a) while in the western segment factor scores are relatively lesser indicating lesser concentration of parameters except a small patch which might be due to some local phenomenon. Factor 2 score were associated with *total hardness as* $CaCO_3$,

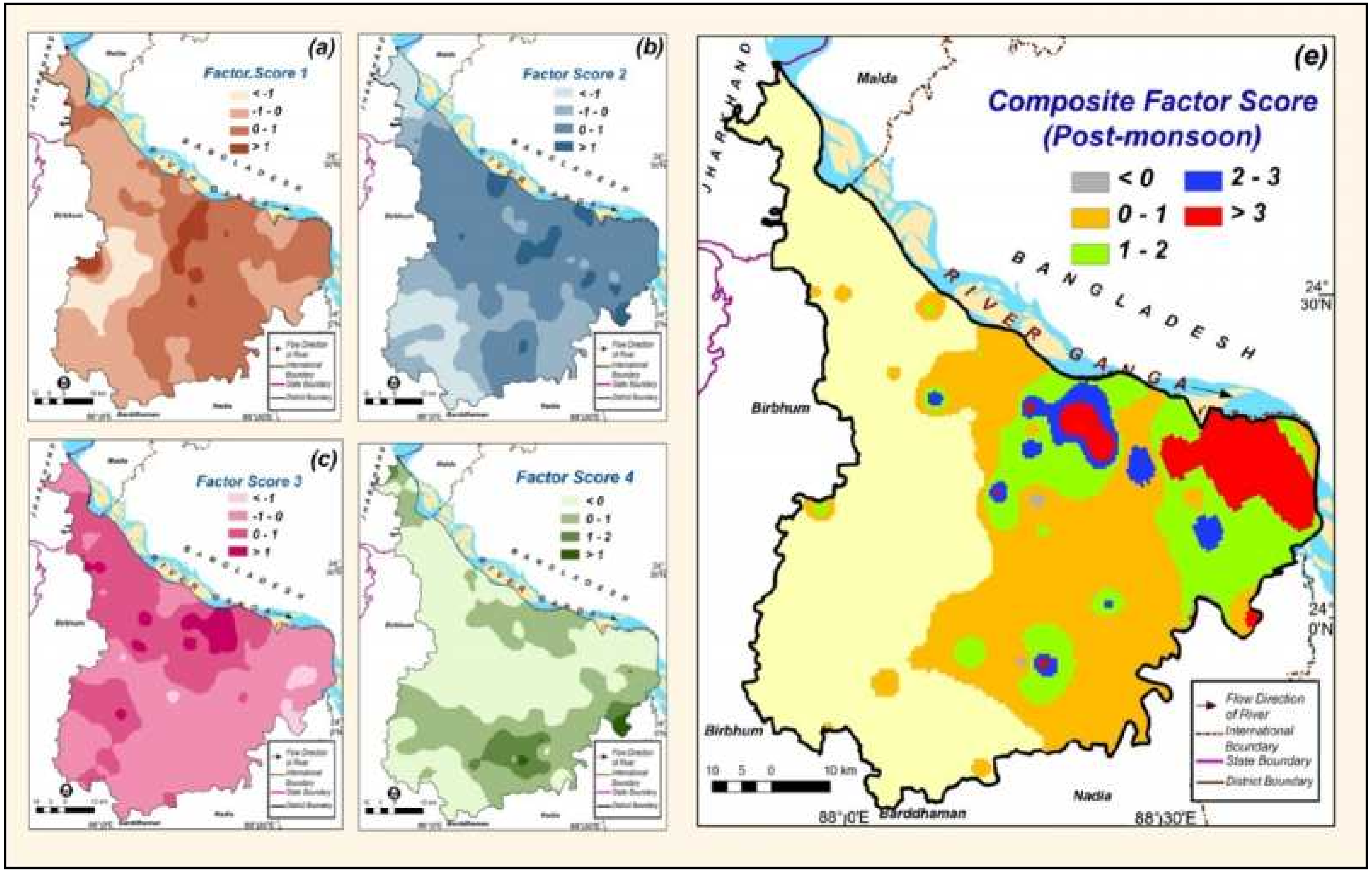


Fig. 3.88: Factor Score Distribution Map during Post-monsoon Season

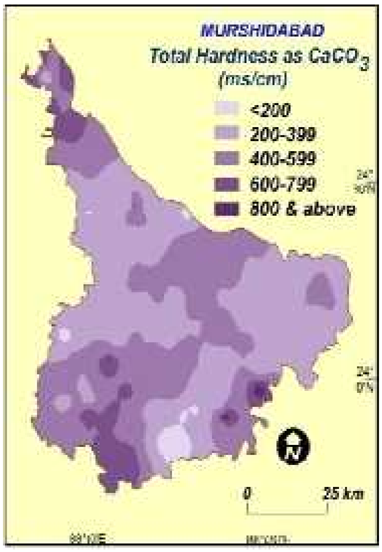


Fig. 3.89: Spatial Distribution of Total Hardness as $CaCO_3$ during post-monsoon season.

chloride and *sulfate.* The factor scores were associated with higher values in the entire region except western part (Fig. 3.88b). The concentration of *total hardness as* $CaCO_3$ was extensively distributed throughout the space and maximum concentration was in the south western and central part which confronted with the rivers (Fig. 3.89). The results obtained from the cluster analysis depicted highest average concentration of *total hardness as* $CaCO_3$ in the second cluster (Table. 3.13). The use of *chloride* based fertilizers in the agricultural field might be one of the major reason behind it (Hudak 1999). Cluster analysis results indicated that cluster 4 is associated with highest *chloride* and *nitrite* concentration.

The particular cluster is located in the entire district except western side of the river *Bhagirathi* (Fig. 3.65). Spatial distribution of *chloride* showed almost even distribution throughout the space with smaller patches in the northern and southern part. The south western part is associated with the least concentration (Fig. 3.90). Both the result from factor distribution map and cluster distribution map are coinciding with each other (Fig. 3.88b). This effect is also observed in the concentration of *sulfate*. As the rainwater percolates it dissolves the minerals of sulfur and mixed up with the groundwater, hence, an increase in the concentration of *sulfate* can be observed in the post monsoon season (O'Day et al. 2004). The entire district showed considerably higher

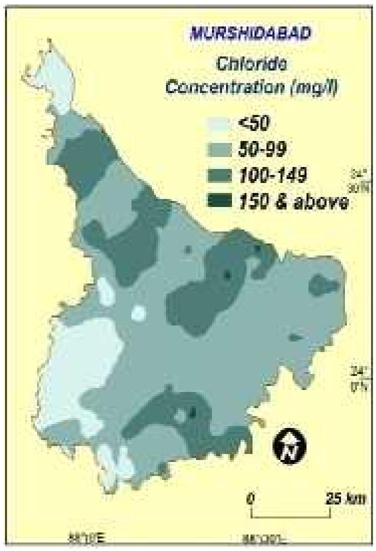


Fig. 3.90: Spatial Distribution of Chloride during post-monsoon season.

concentration of sulfate while central portion was associated with highest concentration (Fig. 3.91).

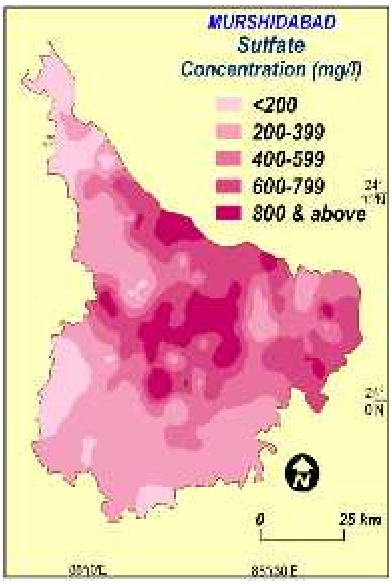


Fig. 3.91: Spatial Distribution of Sulfate during post-monsoon season.

Factor 3 associated with the parameters of *pH* and *nitrite* and the entire district is associated with slightly acidic condition (Fig.3.88c). Patches of acidic condition was observed in southern and eastern portion value ranging between less than 7 to 7.5. The factor scores were higher in the north central and western part and it decreases in the central part of the district. The values of *pH* indicated slightly acidic condition in the southern portion (Fig. 3.92) while concentration of *nitrite* is considerably lower in the north central region (Fig. 3.93).

As the samples belonged to post-monsoon season, the rainwater played an important role in altering the condition of groundwater. As the rainwater itself is slightly acidic in nature and it might help in lowering down the level of *pH* (Rodriguez et al. 2004). The inter factorial relationship between factor 2 and 3 showed a positive relation with all the parameters other than *total hardness as* $CaCO_3$. During post-monsoon, the level of *pH* turns slightly acidic while the concentration of *arsenic* increases.

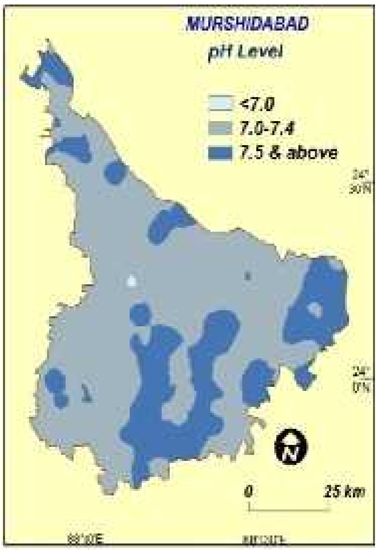


Fig. 3.92: Spatial Distribution of pH during post-monsoon season.

Nitrite, on the other hand, was concentrated in the north central segment where river Bhagirathi distributed from river *Ganga* (Fig. 3.93). The concentration of *nitrite* in a particular region indicates the probable association of anthropogenic sources as they are stable throughout the time period (Canter 1996).

Factor 4 was associated with the parameters of *arsenic*, *iron* and *depth* (Fig. 3.88d)

The concentration of *arsenic* was higher towards the east while in the west of the district the concentration was considerably lower (Fig. 3.94) at the same time *iron* concentration is extensively found throughout the space. During this season the mean concentration was highest (Fig. 3.95). It revealed that the oxidation had taken place and helped in oxidizing the *iron* present in the subsurface (**Akai** et al. 2004).

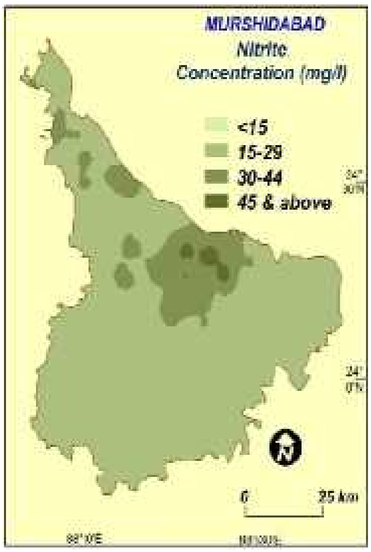


Fig. 3.93: Spatial Distribution of Nitrite during post-monsoon season

The inter-factorial relationship between the factor 1 and 4 showed a positive relationship between *chloride* and *nitrite* with *iron* and *depth* while a negative relation exists with *TDS*. The relation between factor 3 and 4 was positive between all parameters except *TDS*.

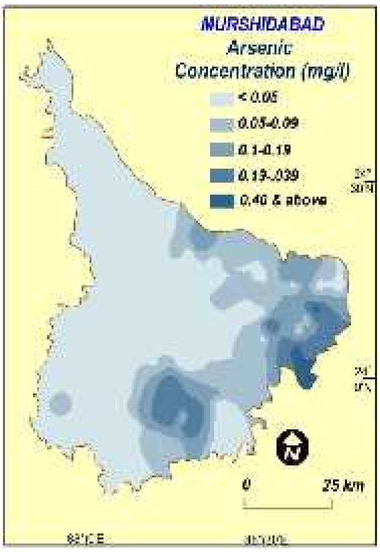


Fig. 3.94: Spatial Distribution of Arsenic during post-monsoon season.

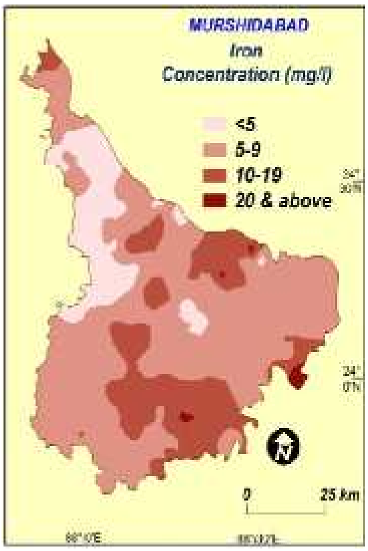


Fig. 3.95: Spatial Distribution of Iron during post-monsoon season

The relation between factor 2 and 4 showed that the concentration of *arsenic* with *iron* and *depth*. The higher concentration of *arsenic* and *iron* was found in the shallower aquifers. At the same time the negative sign of *TDS* and *total hardness as* $CaCO_3$ indicated increasing *depth, arsenic* and *iron* concentration these are generally decreases.

The concentration of *arsenic* from pre-monsoon to monsoon season showed significant change according to the result of paired 't' test.

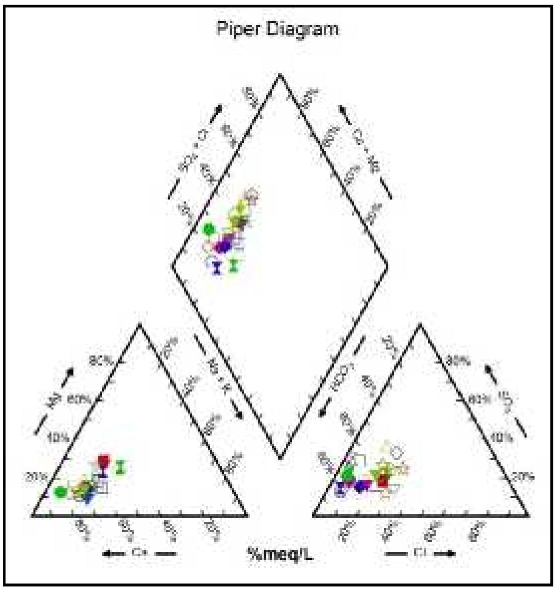


Fig. 3.96: Distribution of Major Ions during pre- monsoon season

The influence of rainfall might be one of major reason behind it which helped in lowering down relative concentration of *arsenic* (Ghosh & Kanchan 2011). On the other hand, concentration manifold increases was observed in post-monsoon in the eastern part of the district indicating that as the level of groundwater decreases due to evaporation and groundwater withdrawal for drinking, irrigation and other purposes (Harvey et al. 2002).

The level of *pH* also showed a considerable change from pre-monsoon to monsoon and monsoon to post-monsoon while no considerable change was observed between

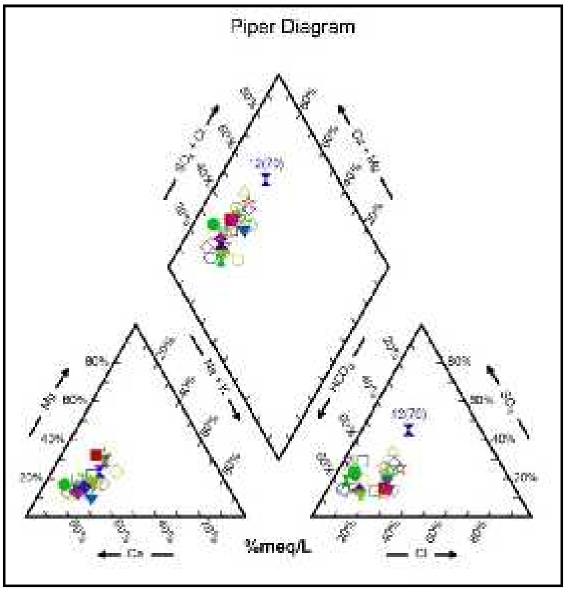


Fig. 3.97: Distribution of Major Ions during monsoon Season

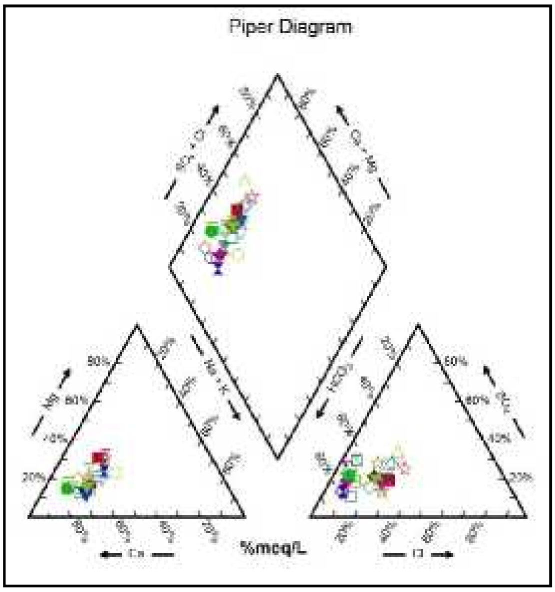


Fig. 3.98: Distribution of Major Ions during post-monsoon season

pre-monsoon to post-monsoon seasons. The distribution of major ions in three seasons do not showed any significant change (Fig 3.96, Fig. 3.97 and Fig 3.98) that indicated relatively stable characteristics of major ionic distribution. In all the seasons the groundwater samples were clustered around the particular segment of the graphs. The level of *pH* in post-monsoon was slightly acidic. The concentration of *TDS* and *EC* depicted a similar pattern. During the monsoon season there is considerable decrease while during post-monsoon, an increase in the concentration was observed indicating the importance of rainfall. The concentration of both the elements was higher in the regions nearer and along the rivers. The concentration of *iron* does not showed any significant change in concentration throughout the year which indicated that there is predominance of *iron* in the groundwater as well as aquifers. The correlation matrix of different seasons did not reflect any significant association which indicated the importance of each parameter as individual (Table. 3.17, Table. 3.18 and Table. 3.19) which also showed the importance of associational analysis rather one to one. Factor scores and cluster analysis also indicate a relatively stable zone of higher concentrations.

The concentration of *arsenic* and *iron* was also high in the shallower aquifer. During pre-monsoon and post-monsoon the concentration was relatively higher where as during monsoon season it decreased. The parameters like *chloride* and *total hardness as* $CaCO_3$ also depicted similar pattern. One of the reasons might be the dilution of *chloride* bearing minerals with rainwater and mixing up with the groundwater. Other than this, the excessive use of *chloride* based fertilizers is another important factor. During the monsoon season the excess amount of fertilizers are diluted with water, percolated and come in contact with the groundwater which can increases its concentration. Soil sampling locations are depicted in the figure 3.98. 12 soil samples from each of the blocks were collected. Sand, silt and clay percentage for each of the blocks were calculated. The results of 12 soil samples were averaged in one for each of the block thus 26 soil sample result was obtain for 26 blocks . The grain size distribution in the entire district also depicted silty-clay type of soil with relatively less availability of sand (Fig. 3.100). It was observed that to improve the productivity of the soil, lime is sprinkled in the agricultural fields during the monsoon and this phenomenon is also responsible for the increases

Table: 3.17 Correlation Matrix (pre-monsoon season)

Parameters	Depth	Arsenic	pH	TDS	EC	Iron	Chloride	Sulfate	Total Hardness	NO_2
Depth	1.000									
Arsenic	-0.175	1.000								
pH	-0.050	0.049	1.000							
TDS	-0.011	0.053	0.164	1.000						
EC	-0.010	0.054	0.162	1.000	1.000					
Iron	-0.121	0.214	-0.008	-0.062	-0.061	1.000				
Chloride	-0.033	-0.030	0.111	0.199	0.198	0.206	1.000			
Sulfate	0.025	0.110	0.034	0.112	0.113	0.070	0.174	1.000		
Total Hardness	0.139	-0.259	0.054	-0.050	-0.050	-0.166	-0.128	-0.283	1.000	
No_2	0.088	-0.029	0.005	0.310	0.310	-0.120	0.159	0.104	0.014	1.0

Table: 3.18 Correlation Matrix (monsoon season)

Parameters	Depth	Arsenic	pH	TDS	EC	Iron	Chloride	Sulfate	Total Hardness	NO_2
Depth	1.000									
Arsenic	-0.176	1.000								
pH	-0.109	0.051	1.000							
TDS	-0.003	0.080	0.150	1.000						
EC	-0.004	0.083	0.154	0.999	1.000					
Iron	0.422	-0.036	-0.083	-0.071	-0.071	1.000				
Chloride	-0.007	-0.066	0.106	0.239	0.247	0.036	1.000			
Sulfate	0.010	0.157	-0.023	0.112	0.110	0.087	-0.206	1.000		
Total Hardness	0.208	-0.213	-0.053	0.093	0.096	0.078	0.175	-0.302	1.000	
NO_2	0.153	0.031	-0.138	0.191	0.193	0.162	0.117	0.220	0.025	1.000

Table: 3.19 Correlation Matrix (post-monsoon season)

Parameters	Depth	Arsenic	pH	TDS	EC	Iron	Chloride	Sulfate	Total Hardness	NO_2
Depth	1.000									
Arsenic	-.087	1.000								
pH	-.075	.078	1.000							
TDS	.024	-.009	.001	1.000						
EC	.018	-.011	.012	.995	1.000					
Iron	.106	.242	.067	.070	.074	1.000				
Chloride	-.022	.031	-.003	.190	.187	.112	1.000			
Sulfate	-.031	.044	.140	.104	.104	.115	.194	1.000		
Total Hardness	.070	-.232	-.083	.076	.081	-.043	-.166	-.211	1.000	
NO_2	.084	-.046	-.239	.263	.255	.045	.259	.100	.061	1.00

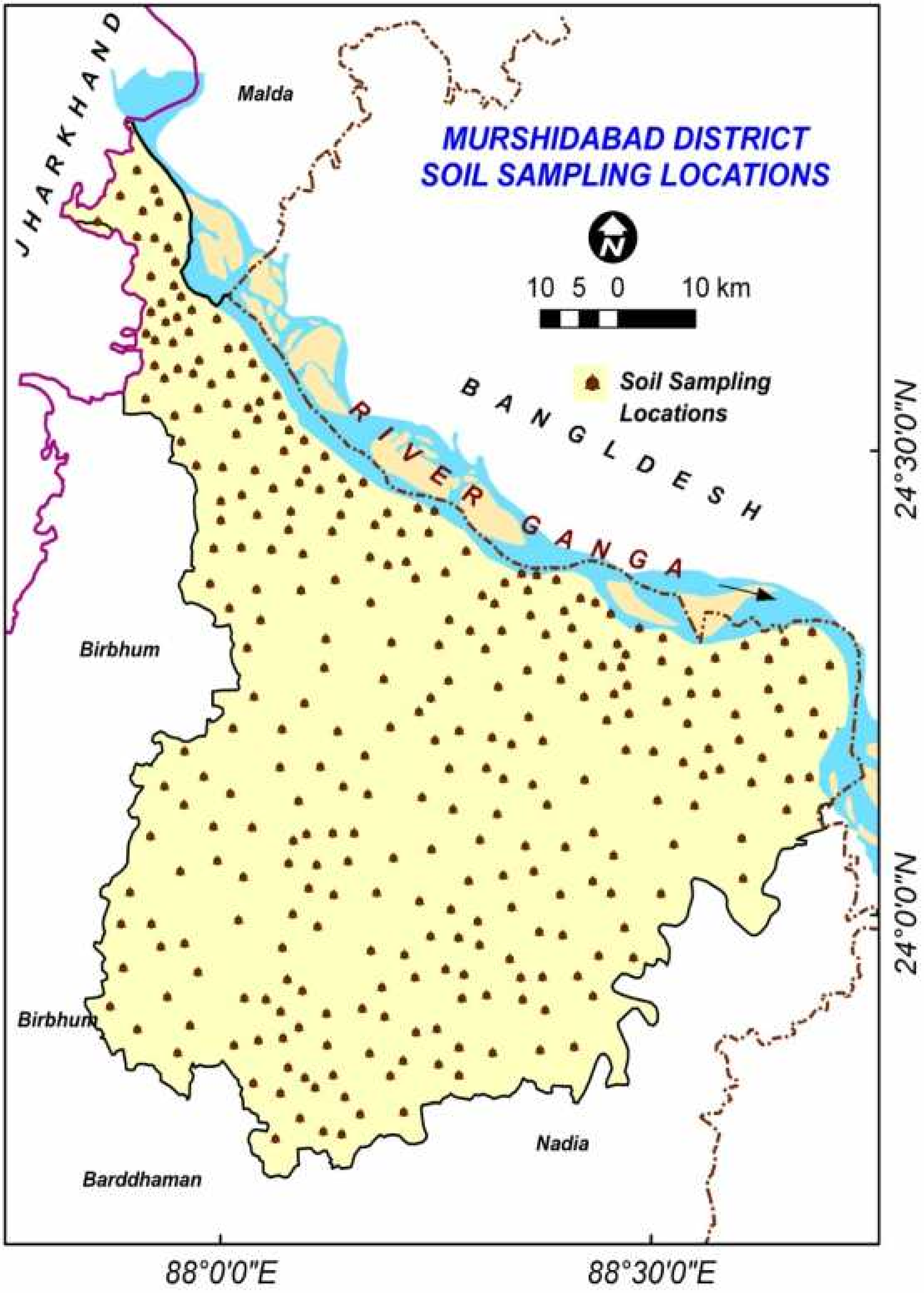


Fig. 3.99: Soil Sampling Locations

in *total hardness as* $CaCO_3$.The concentrations of *total hardness as CaCO3* and *sulfate* were higher during. The dissolution from the minerals such as gypsum and anhydrate were the major sources of *sulfate* in groundwater (Hudak 1999). The concentration of *nitrite* in groundwater was found in the north central part of the district.

The major sources of *nitrite* in groundwater are organic nitrates including anthropogenic local pollution and livestock manure (Kumazawa 2002, Gupta et al. 2008). The concentration of *nitrite* decreases during monsoon but remains stable in the post-monsoon indicating the importance of rainfall in diluting the element. The zones of higher and lower concentration is relatively stable throughout the time period. So concludingly, spatial distribution of different parameters does not showed any significant change.

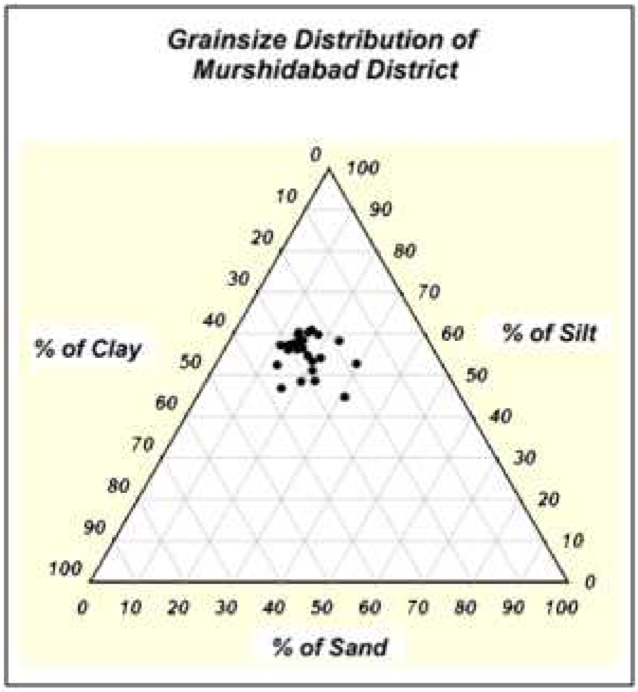


Fig. 3. 100: Grain Size Characteristics

Resume: In this chapter, the geochemical characteristics of groundwater was anlysed with ten parameters. Most of the parameters including arsenic, had higher concentration in eastern segment of the study area. Geochemical parameters showed significant association with different season. Multivariate statistical analysis helped in understanding the relationship among the parameters. The following chapter analyses the association between the arsenic in groundwater and its effects on human health.

Chapter – 4

Effects of Arsenic on Human Health

Chapter – 4

Effects of Arsenic on Human Health

4.1 Arsenic Contamination and Human Health Issues:

Water is an important element that controls different functions of human body, hence, it must be free from all the contaminants. The results from chapter 3 revealed the presence of different elements in the groundwater of *Murshidabad* district. These elements can create health issues ranging from mild to severe, amongst which *arsenic* is considered to be the most problematic. Hence, the present chapter focuses upon the effect of *arsenic* contaminated drinking water on human health. The health condition of the people was analyzed by the household survey.

4.2 General Characteristics of Arsenicosis:

Drinking of *arsenic* contaminated water depicted various symptoms which affects different parts of the body. The occurrence of ailments is associated with differential level of exposure to the *arsenic* concentration in groundwater (**Shannon** and **Strayer** 1989). The symptoms vary from non-specific minor ailments like limb pain, hyperpathia and vomiting/nausea, to severe types like painful *blisters, gangrene* and *carcinoma* of body parts.

Melanosis is the darkening of skin on the palm which slowly extends on the different parts of the body (**Saha** et. al 1999). It is further divided in two categories- *Diffused* and *Spotted Melanosis*. *Diffused melanosis* is the darkening of skin mainly on the palm, trunk and it gradually spreads over entire body while *spotted melanosis* is associated with spot on the hands and legs (**Guha** et. al 2006).

Black and white spots on different parts of the body (chest, back, hands and legs) is known as *Leucomelanosis*. This particular symptom is observed in the body of the patients in the advance stage of *arsenicosis* (Saha 1995). *Spotted* and *diffused keratosis* is another type of symptom that is related to the dry and spotted nodules and thickening of skin that generally appears after 5-10 years of the first sign of *Arsenicosis* (Squibbs et. al 1983). The thickening of skin on palms and soles further converts into cracks which is known as *hyperkeratosis* (Mazumder et. al 1988). Co-morbidity of *melanosis* and *keratosis* is also observed among the patients.

Carcinoma and severe *gangrene* is detected when the *arsenic* contamination in drinking water is high and is consumed for a longer period of time (Ravenscroft 2009).

From the survey it was observed that the effect of *arsenic* contamination was negligible in people below 20 years as the incubation period of *arsenic* poisoning is about 15-20 years.

The first sign of *arsenicosis* is largely observed in the people above 20 years (Saha et. al 1999). Hence, persons below 20 years were excluded from the analysis.

Fig. 4.1: Location of Sample Villages

The health pattern is based on the analysis of household survey conducted in 13 randomly selected villages using structured schedule. All of the surveyed villages except *Mokrampur* of *Beldanga-1* block, come under gram panchayat. *Mokrampur* is a municipal area and has deep underground water supply system, hence, it was taken into consideration. Till recent past, people used to consume water from the shallow hand pumps. In all the surveyed villages, groundwater is the major source of drinking water and shallow hand-pumps are largely used for extracting of groundwater.

Table 4.1. Basic Information of the Surveyed Villages

Sample Code	Block Name	Village Name	Total Population	Total Population Surveyed	Affected Population*
1	Raninagar-2	Katlamari	25798	488	295
2	Domkal	Garaimari	27943	463	189
3	Jalangi	Khayramari	15996	539	171
4	Berhampur	Balia Danga	913	506	153
5	Beldanga-1	Mokrampur	1534	484	79
6	Hariharpara	Dharampur Ramna	1058	427	60
7	Bhagawangola-2	Boalia	1270	389	42
8	Nawda	Patikabari	8840	462	13
9	Raghunatgunj-2	Mithipur	10885	459	9
10	Bhagawangola-1	Mahatpur	908	506	2
11	Burwan	Rahigram	731	382	0
12	Lalgola	Krishnapur	15165	437	0
13	Sagardighi	Binodbati	985	452	0

Source: DCHB 2001, Murshidabad, * Calculated from the Primary Data Collected from Field

4.3 Prevalence Rate and Arsenic Concentration in Groundwater:

The prevalence rate of *arsenicosis* ranged from nil to 60%. It was highest in the *Katlamari* village of *Raninagar-2* block (60.45%) where male and female rate was 36.88% and 23.57% respectively. In this village, the average *arsenic* concentration of groundwater was 0.12mg/l which was many-fold higher than the permissible limit of BIS (Table 1.2). The correlation value between arsenic concentration and prevalence rate was 0.633 (Fig. 4.2). In *Garaimari* village (*Domkal* block), *Khayramari (Jalangi* block) and *Balia Danga* village *(Berhampur* block*)*, the prevalence rates were 40.82%, 31.73% and 30.24% respectively.The male percentage was 55.56%, 61.40% and 72.55% respectively while amongst the females it was 44.44%, 38.60% and 27.45% respectively (Table. 4.2) (Fig. 4.3 and Fig. 4.4). The *arsenic* concentration in the three blocks was higher than the permissible limit except in *Balia Danga* (*Berhampur* block) (0.02mg/l).

Table 4.2. Prevalence Rate and Arsenic Concentration in Groundwater			
Block Name	Village Name	Prevalence Rate (%)	Arsenic Concentration (mg/l)
Raninagar-2	Katlamari	60.45	0.12
Domkal	Garaimari	40.82	0.25
Jalangi	Khayramari	31.73	0.10
Berhampur	Balia Danga	30.24	0.02
Beldanga-1	Mokrampur	16.32	0.16
Hariharpara	Dharampur Ramna	14.05	0.05
Bhagawangola-2	Boalia	10.28	0.04
Nawda	Patikabari	2.81	0.03
Raghunatgunj-2	Mithipur	1.96	0.02
Bhagawangola-1	Mahatpur	0.40	0.06
Burwan	Rahigram	0.00	0.03
Lalgola	Krishnapur	0.00	0.03
Sagardighi	Binodbati	0.00	0.02
Source: Calculated from the Primary Data Collected from Field			

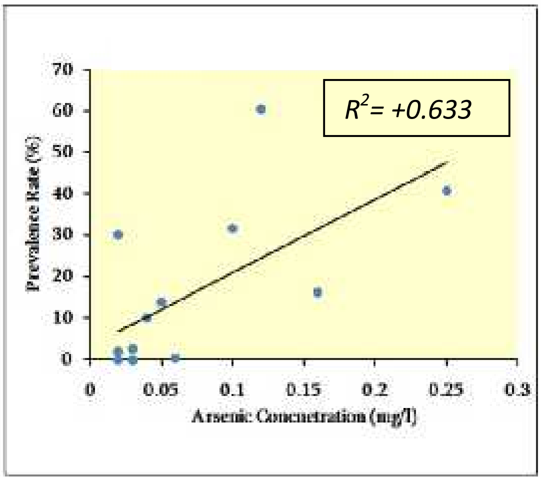


Fig. 4.2: Correlation between Prevalence Prevalence rate and Arsenic concentration concentration.

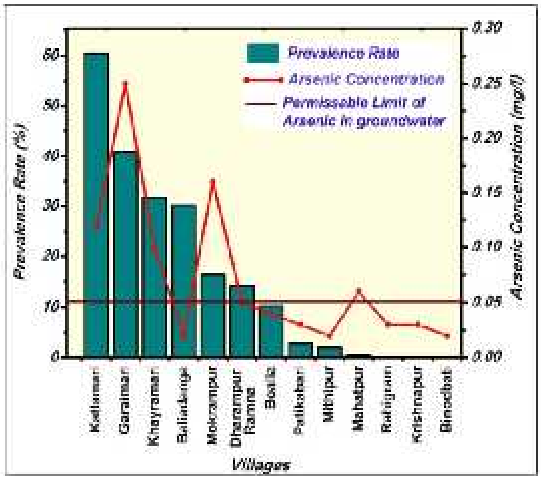


Fig. 4.3: Relationship between rate and Arsenic

The prevalence rate (Fig.4.3) in the *Mokrampur* (*Beldanaga-1* block), *Dharampur Ramna* village (*Hariharpara* block) and *Mahatpur* village of *Bhagawangola-1* block was 16.32%, 14.05% and 10.28% respectively and the concentration of arsenic was 0.16 mg/l, 0.05 mg/l and 0.04 mg/l respectively (Fig.4.2). It was low in *Patikabari* village (*Nawda* block), *Mithipur* village *(Raghunathganj-2* block*)* and *Boalia* village of *Bhagawangola-2* block (2.81%, 1.96% and 0.04% respectively). No person was affected in *Rahigram* village *(Burwan* block*), Krishnapur village (Lalgola)* and *Binodbati* village of *Sagardighi* block.

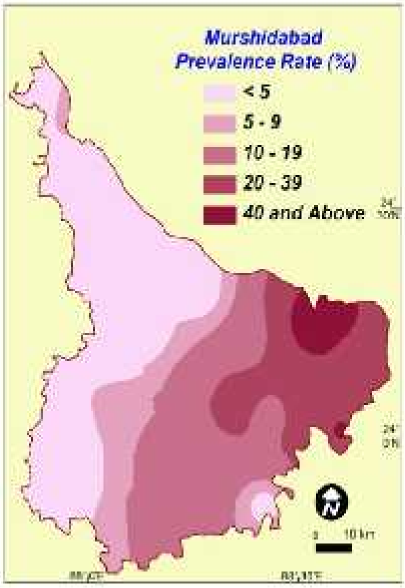


Fig. 4.4: Distribution of Prevalence Rate in Murshidabad District

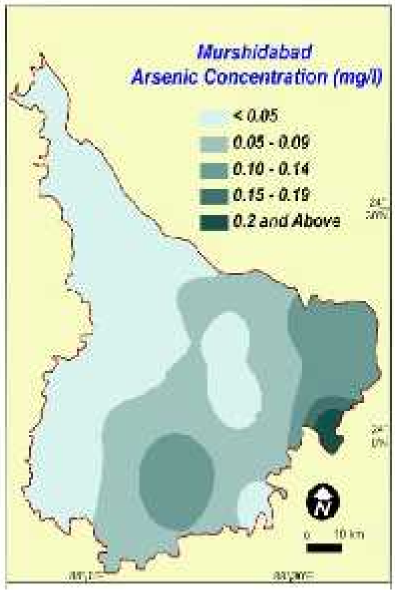


Fig. 4.5: Distribution of Arsenic Concentration in Murshidabad District

It is important to note that the concentration of arsenic in these blocks was below permissible limit. The high prevalence rate was noted in the eastern part (Fig. 4.4) and the concentration of arsenic in groundwater was also high in this part of the district.

4.4 Age and Gender Wise Distribution of Prevalence Rate:

4.4.1 Age Group wise Prevalence Rate:

The prevalence rate in *Katlamari* village of *Raninagar-2* block was 60.45%. An uniform increment was observed from 20-24 years (11.49%) to the age group of +65 years (100%). Similar pattern was observed in males and females (Table 4.3) (Fig.4.6). In all the age groups the prevalence rate was higher amongst male except between 25-34 years where the occurrence was higher in female (46.43% in 25-29 years and 86.27% in 30-34 years respectively).

In *Garaimari* village of *Domkal* block, prevalence rate was 40.82%. A consistent increase in rates from 20-24 years (10.11%) to 35-39 years (57.14%) was observed.

Table 4.3: Age group wise Prevalence Rate
(Katlamari village of Raninagar-2 block)

Age Group	Male	Female	Total
20-24	10.87	12.20	11.49
25-29	58.62	40.00	46.43
30-34	76.92	60.78	67.78
35-39	95.59	67.65	86.27
40-44	95.83	71.43	86.84
45-49	100	80.00	92.86
50-54	90.91	87.50	89.47
55-59	81.82	66.67	76.47
60-64	100	100.00	100
65 & above	0	100.00	100

Source: Computed from data collected through household survey

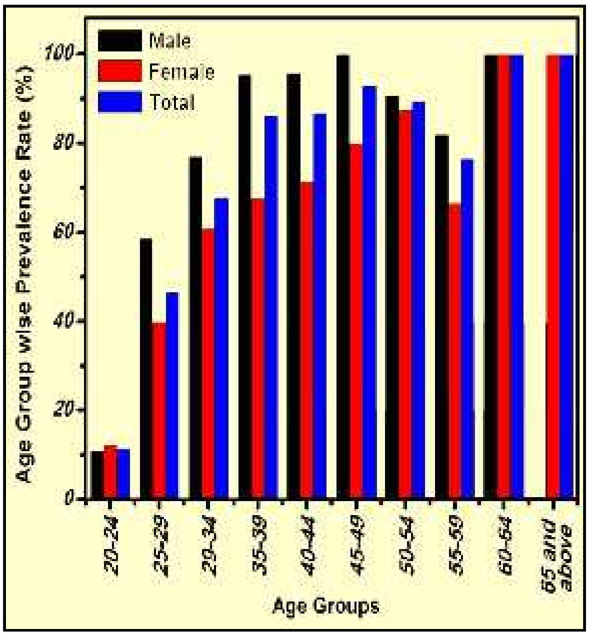


Fig. 4.6: Age group wise prevalence rate in Katlamari village of Raninagar-2 Block

Table 4.4: Age group wise Prevalence Rate
(Garaimari village of Domkal block)

Age Group	Male	Female	Total
20-24	14.89	4.76	10.11
25-29	29.73	32.6	31.33
30-34	52.78	50.00	51.52
35-39	66.67	50.00	57.14
40-44	46.88	66.67	52.27
45-49	69.23	42.11	57.78
50-54	33.33	62.50	45.00
55-59	33.33	33.33	33.33
60-64	0.00	50.00	25.00
65 & above	50.00	33.33	40.00

Source: Computed from data collected through household survey

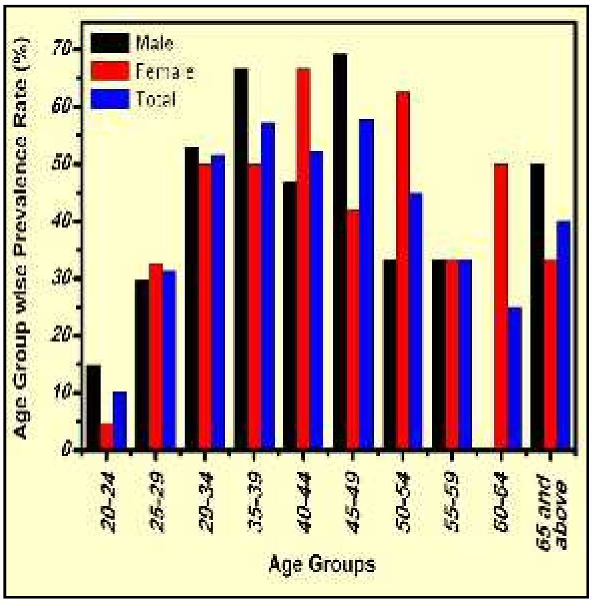


Fig. 4.7: Age group wise prevalence rate in Garaimari village of Domkal Block

Table 4.5: Age group wise Prevalence Rate (Khayramari village of Jalangi block)		
Age Group	Male	Female
20-24	60.00	40.00
25-29	41.18	58.82
30-34	60.61	39.39
35-39	71.43	28.57
40-44	39.29	60.71
45-49	76.92	23.08
50-54	81.82	18.18
55-59	62.50	37.50
60-64	66.67	33.33
65 & above	0.00	0.00

Source: Computed from data collected through household survey

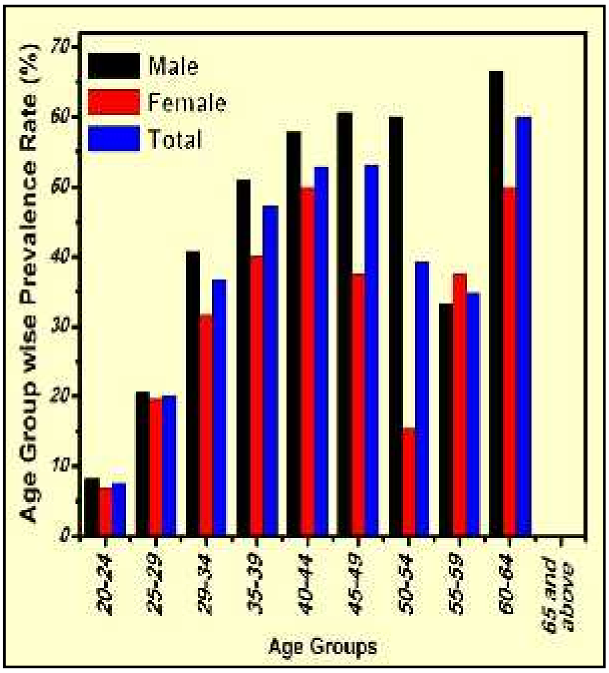


Fig. 4.8: Age group wise prevalence rate in Khayramari village of Jalangi Block

Later, no significant variation up to the age group of 45-49 years (57.78%) was observed. Subsequently, a decline was noticed with just a slight increase in + 65 years. Age group wise male-female share to total surveyed population showed that in 25-29 years (32.61%), 40-44 years (66.67%), 50-54 years (62.50%) and 60-64 years (50%) the males were more affected (Table 4.4) (Fig.4.7).

Khayramari village of *Jalangi* block ranks third in terms of prevalence rate (31.73%). A consistent increase was observed up to the age group of 45-49 years (53.06 %). Thereafter, a decrease was observed in the age group of 50-54 years (39.29%) and 55-59 years (34.78%) (Table 4.5) (Fig.4.8). A steep rise existed in the age group of 60-64 years (60%) but above 65 years, no person was found suffering with *arsenicosis*.

Balia Danga village of *Berhampur* block had almost similar prevalence rate (30.24%). A continuous increase in prevalence rate was observed between 20-24 years, the prevalence rate was 0.82% to 30-35 years (22.13%).

Table 4.6: Age group wise Prevalence Rate (Balia Danga village of Berhampur block)			
Age Group	Male	Female	Total
20-24	1.32	0.00	0.82
25-29	10.53	13.04	11.48
30-34	28.95	10.87	22.13
35-39	28.95	8.70	21.31
40-44	13.16	13.04	13.11
45-49	30.26	21.74	27.05
50-54	11.84	17.39	13.93
55-59	18.42	6.52	13.93
60-64	1.32	0.00	0.82
65 & above	1.32	0.00	0.82

Source: Computed from data collected through household survey

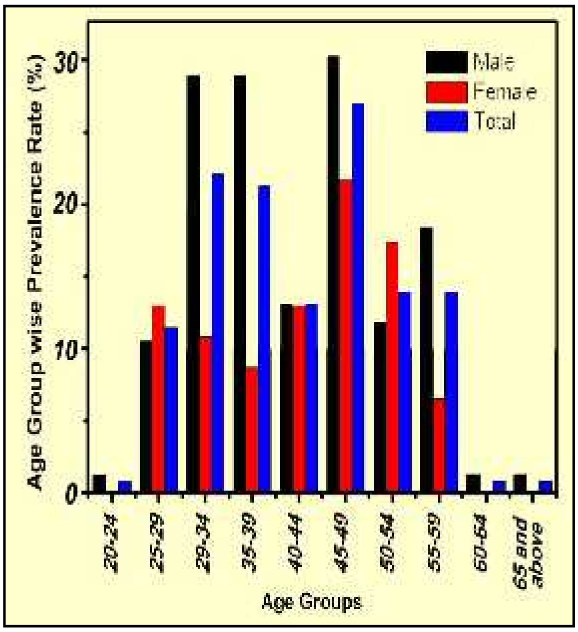


Fig. 4.9: Age group wise prevalence rate in Balia Danga village of Behrampur Block

From 35-39 years (21.31%) to 40-45 years (13.11%) a constant decrease was observed. Subsequently, uniform decrease up to the age group of + 65 years (0.82%) with a spike in the age group of 45-50 years age group was depicted (Table 4.6) (Fig.4.9). A continuous increase in male prevalence rate was observed up to 35-39 years (28.95%). Following this, a continuous decline existed in the prevalence rate with a higher percentage in the age group of 45-49 years. Females had higher prevalence rate in the age groups of 25-29 years (13.04%) and 50-54 years (17.39%).

The mean prevalence rate in *Mokrampur* of *Beldanga-1* block was 16.32%. A considerable rise of affected persons up to the age of 35-39 years was noticed (30.23%). Thereafter, a decrease except in the age group of 55-59 years (27.78%) was observed (Table 4.7) (Fig.4.10). There was a consistent increase of percentage in male population up to the age group of 35-39 years (38.89). Once again a steady decrease in the percentage existed and no person (male/female) + 60 years was found. The highest percentage of female affected persons was between 55-60 years (40%). In general, males were more affected than females. Prevalence rate in *Dharampur Ramna* village of *Hariharpara* block was 14.05%.

Table 4.7: Age group wise Prevalence Rate (Mokrampur of Beldanga 1 block)			
Age Group	Male	Female	Total
20-24	0.00	0.00	0.00
25-29	10.00	3.28	5.94
30-34	28.57	9.09	18.60
35-39	38.89	15.63	30.23
40-44	37.50	15.79	27.91
45-49	29.63	21.05	26.09
50-54	12.50	14.29	13.33
55-59	23.08	40.00	27.78
60-64	0.00	0.00	0.00
65 & above	0.00	0.00	0.00

Source: Computed from data collected through household survey

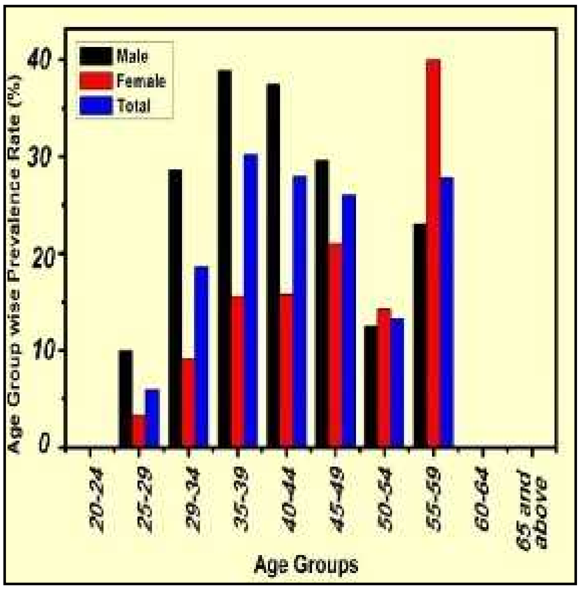


Fig. 4.10: Age group wise prevalence rate in Mokrampur of Beldanga-1 Block

Table 4.8: Age group wise Prevalence Rate (Dharampur Ramna village of Hariharpara block)			
Age Group	Male	Female	Total
20-24	16.67	20.00	19.23
25-29	21.21	12.77	16.25
30-34	29.03	18.92	23.53
35-39	17.07	0.00	12.28
40-44	33.33	0.00	27.59
45-49	0.00	0.00	0
50-54	0.00	0.00	0
55-59	0.00	0.00	0
60-64	33.33	0.00	14.29
65 & above	5.45	5.41	5.43

Source: Computed from data collected through household survey

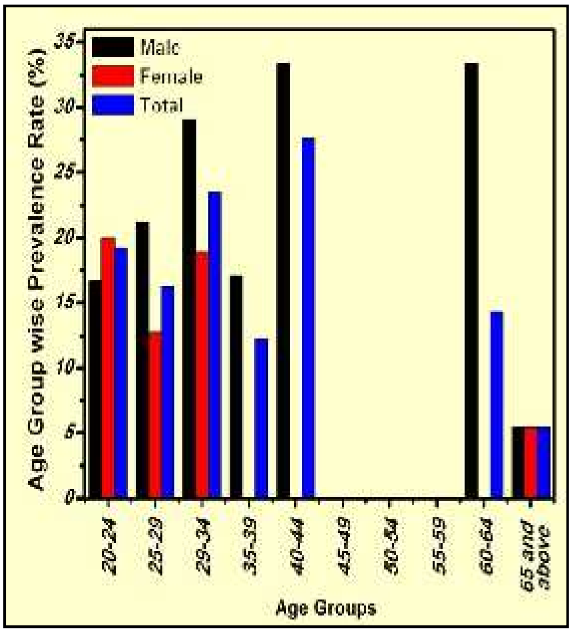


Fig. 4.11: Age group wise prevalence rate in Dharampur Ramna village of Hariharpara Block

A uniform increment was observed from 20-24 years (19.23%) to 40-44 years (27.59%). Thereafter, a sudden fall in the prevalence rate existed [60-65 years (14.29%) and above 65 years (5.43%)]. The similar pattern was noticed in males. The highest prevalence rate, were in 40-44 years and 60-64 years (33.00%). Between 45 and 60 years no case of *arsenicosis* was found. The prevalence rate in females, was 20% in 20-24 years, 12.77% in 25-29 years and 18.92% in 30-34 years (Table 4.8) (Fig.4.11). Above 35 years of females no cases of *arsenicosis* was observed. It was only + 65 years, where 5.41% females showed signs of *arsenicosis*.

In *Boalia* village of *Bhagawangola-2* block the prevalence rate was 10.28%. A continuous increase in prevalence rates was observed up to 45-49 years. After this, no

case of affected person was brought into notice. Between 20-24 years the percentage of affected person was least (Table 4.9) (Fig.4.12) while between 30-34 years it was 18.18% and between 45-49 years, it was considerably high (12.50%). An increment up

Table 4.9: Age group wise Prevalence Rate (Boalia village of Bhagawangola-2 block)

Age Group	Male	Female	Total
20-24	0.00	6.12	4.11
25-29	5.26	7.27	6.45
30-34	25.64	10.53	18.18
35-39	16.33	4.35	12.50
40-44	15.15	0.00	11.90
45-49	15.79	0.00	12.50
50-54	0.00	0.00	0.00
55-59	0.00	0.00	0.00
60-64	0.00	0.00	0.00
65 & above	0.00	0.00	0.00

Source: Computed from data collected through household survey

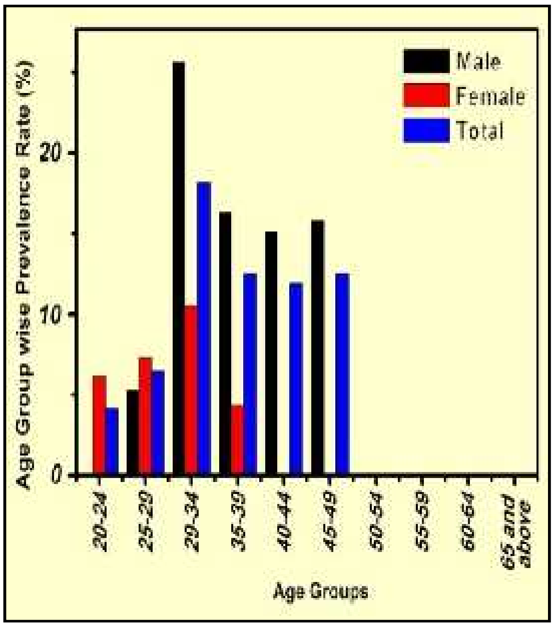


Fig. 4.12: Age group wise prevalence rate in Boalia village of Bhagawangola Block

to 45-49 years was observed in males. Maximum percentage of affected male person was in 45-49 years (15.79%) and no affected person was found above 50 years.

Patikabari village of *Nawda* block with *arsenic* concentration of 0.03 mg/l had a low prevalence rate of 2.81%. The highest rate was observed in the age group of 60-64 years (20%) and above 35 years no case of affected persons were found. The prevalence rate in other age groups varied between 1.61% (25-29 years) to 8.33% (55-59 years).

Table 4.10: Age group wise Prevalence Rate (Patikabari village of Nawda block)

Age Group	Male	Female	Total
20-24	3.33	3.08	3.16
25-29	1.52	1.72	1.61
30-34	4.55	2.04	3.23
35-39	0	0	0
40-44	0	0	0
45-49	0	20	7.14
50-54	12.50	0	6.25
55-59	11.11	0	8.33
60-64	25	0	20
65 & above	0	0	0

Source: Computed from data collected through household survey

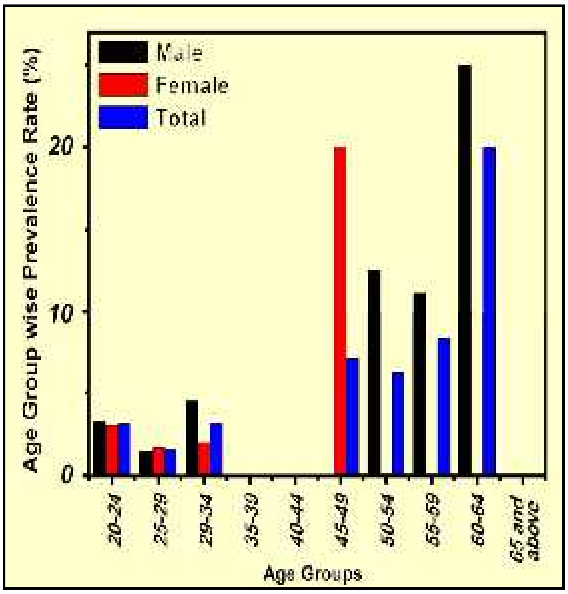


Fig. 4.13: Age group wise prevalence rate in Patikabari village of Nawda Block

Similar pattern was observed among males with highest prevalence rate in the 60-64 years (25%). No male was affected between 35 to 50 years and + 65 years (Table 4.10) (Fig.4.13). Affected females were only found in 20-24, 25-29, 30-34 and 45-49 of age groups with considerably lower prevalence rates of 3.08%, 1.72%, 2.04 and 20% respectively. No case of affected females was found above 50 years.

Mithipur village of *Raghunathganj-2* block had the total prevalence rate of 1.96% with average *arsenic* concentration of 0.02 mg/l. 1/3rd of the persons were affected in the age group of 55-59 years. In rest, it varied between 1.59% (35-39 years) to 11.11% (60-64 years).

No person was found affected in 20-29 years and 50-54 years (Table 4.11) (Fig.4.14). Male prevalence rate varied between 3.03% (35-39 years) to 5.13% (+ 65 years) without any specific pattern. In terms of females, it varied from 6.25% (40-44 years) to 50% (55-59 years).

In *Mahatpur* village of *Bhagawangola-1* block, the prevalence rate was as low as 0.04% with *arsenic* concentration of 0.05 mg/l. In this block only in the age group of 60-64 years few affected males were noticed.

Table 4.11: Age group wise Prevalence Rate (Mithipur village of Raghunathganj-2 block)			
Age Group	Male	Female	Total
20-24	0	0	0
25-29	0	0	0
30-34	4.76	0	2.70
35-39	3.03	0	1.59
40-44	3.33	6.25	4.35
45-49	0	0	0
50-54	0	0	0
55-59	0	50	33.33
60-64	0	14.29	11.11
65 & above	5.13	0	3.57

Source: Computed from data collected through household survey

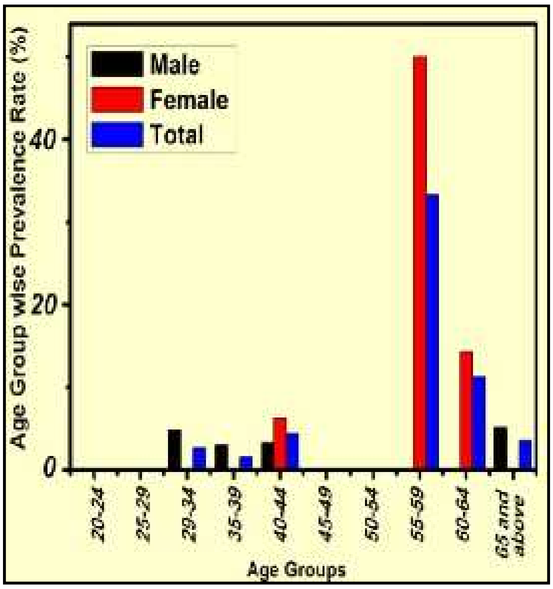


Fig. 4.14: Age group wise prevalence rate in Mithipur village of Raghunathganj-2 Block

In *Rahigram* village of *Burwan* block, *Krishnapur* village of *Lalgola* block and *Binodbati* village of *Sagardighi* block, no case of *arsenic* affected person was found. The *arsenic* content in these blocks were just 0.03 mg/l, 0.03 mg/l and 0.02 mg/l respectively.

4.4.2 Gender wise Percentage of Affected Person:

(Table 4.12) depicted gender wise and age wise percentage of affected persons in *Katlamari* village of *Raninagar-2* (Fig.4.15). In the age groups of 20-24 years and 60-64 years both the genders had similar share (50%). In the age groups of 20-24 years and 60-64 years both the genders had similar share (50%).

The percentage of males were higher in the age groups of 35-39 years (73.68%) to 55-59 years (69.23%). The percentage of females was higher than the males in the age groups of 25-29 years (56.41%) and + 65 years (100%).

No particular pattern was observed in *Garaimari* village of *Domkal* block. Maximum male percentage (77.78) was between 20-24 years (Table 4.13) (Fig.4.16). In all the ages the males were more in number with 25-30 years of age group being only exception where male percentage was 42.31 and female share was 57.69%. 100% females of 60-64 years were affected.

Table 4.12: Age group wise Prevalence Rate (Katlamari village of Raninagar-2 block)		
Age Group	Male	Female
20-24	50.00	50.00
25-29	43.59	56.41
30-34	49.18	50.82
35-39	73.86	26.14
40-44	69.70	30.30
45-49	69.23	30.77
50-54	58.82	41.18
55-59	69.23	30.77
60-64	50.00	50.00
65 & above	0.00	100.00

Source: Computed from data collected through household survey

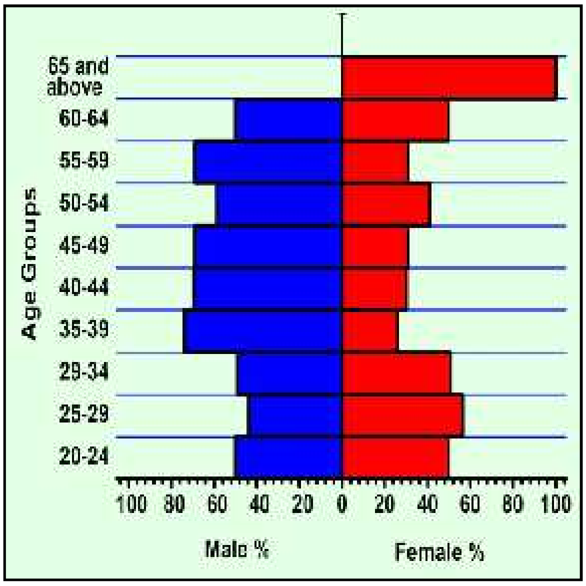


Fig. 4.15: Gender wise prevalence rate in Katlamari village of Raninagar-2 Block

Table 4.13: Age group wise Prevalence Rate (Garaimari village of Domkal block)		
Age Group	Male	Female
20-24	77.78	22.22
25-29	42.31	57.69
30-34	55.88	44.12
35-39	50.00	50.00
40-44	65.22	34.78
45-49	69.23	30.77
50-54	44.44	50.56
55-59	66.67	33.33
60-64	0.00	100.00
65 & above	50.00	50.00

Source: Computed from data collected through household survey

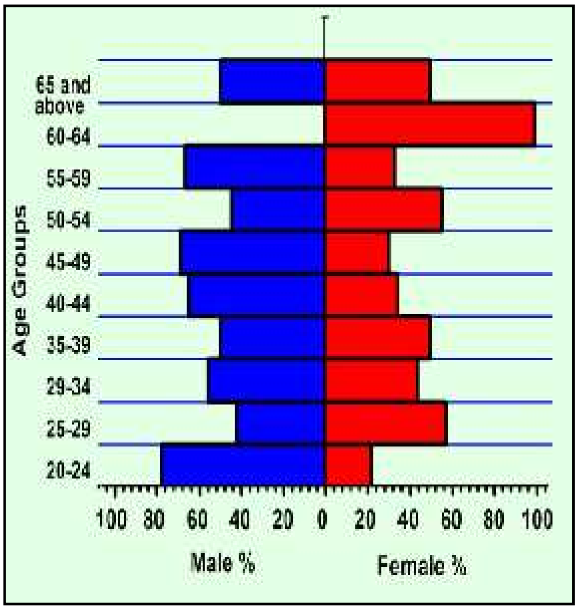


Fig. 4.16: Gender wise prevalence rate in Garaimari village of Domkal Block

In *Khayaramari* village of *Jalangi* block males were more affected than the females. Except for 25-29 and 40-44 years, the percentage of affected males was > 60%. In the age group of 50-54 years, the percentage of affected male was 81.82% while in 40-44 years, it was 39.29% (Table 4.14) (Fig.4.17).

Table 4.14: Age group wise Prevalence Rate (Khayramari village of Jalangi block)

Age Group	Male	Female
20-24	60.00	40.00
25-29	41.18	58.82
30-34	60.61	39.39
35-39	71.43	28.57
40-44	39.29	60.71
45-49	76.92	23.08
50-54	81.82	18.18
55-59	62.50	37.50
60-64	66.67	33.33
65 & above	0.00	0.00

Source: Computed from data collected through household survey

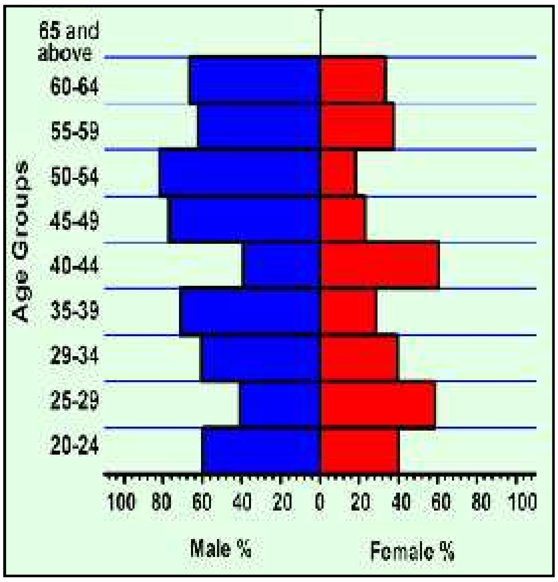


Fig. 4.17: Gender wise prevalence rate in Khayramari village of Jalangi Block

Highest prevalence rate in females was in the age group of 40-44 years (60.71%) while between 50-54 years it was least (18.18%). Rest of the age groups the prevalence rate amongst females was 23.08% (45-49 years) and 58.82% (25-29 years).

Table 4.15: Age group wise Prevalence Rate (Balia Danga village of Berhampur block)

Age Group	Male	Female
20-24	100.00	0.00
25-29	57.14	42.86
30-34	81.48	18.52
35-39	84.62	15.38
40-44	62.50	37.50
45-49	69.70	30.30
50-54	52.94	47.06
55-59	82.35	17.65
60-64	100.00	0.00
65 & above	100.00	0.00

Source: Computed from data collected through household survey

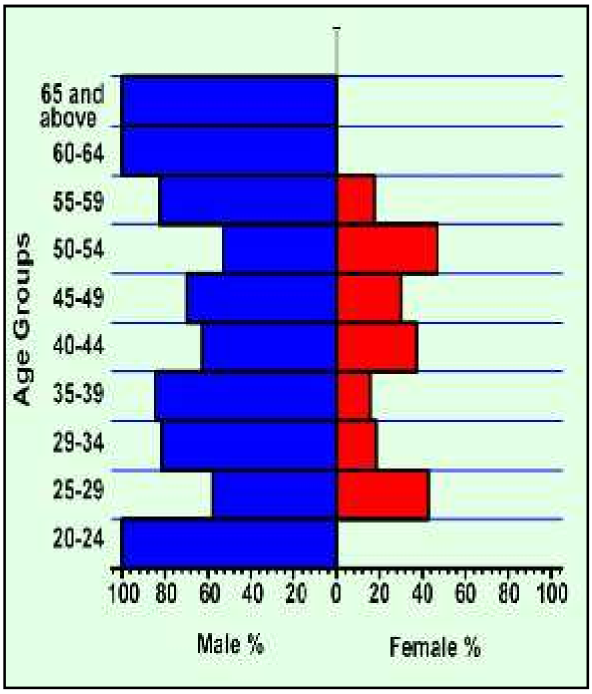


Fig. 4.18: Gender wise prevalence rate in Balia Danga village of Behrampur Block

In *Balia Danga* village of *Beharmapur* block, the highest percentage (47.06) of female population was in the age group of 50-54 years (47.06%). In rest of the age groups, the percentage of affected female population was considerably low.

In all ages, the male share was more than 60%; while, females contributed more in 25-29 years (42.86%) and 40-44 years (37.50%) age groups (Table 4.15) (Fig.4.18).

Table 4.16: Age group wise Prevalence Rate (Mokrampur of Beldanga-1 block)

Age Group	Male	Female
20-24	0.00	0.00
25-29	66.67	33.33
30-34	75.00	25.00
35-39	80.77	19.23
40-44	75.00	25.00
45-49	66.67	33.33
50-54	50.00	50.00
55-59	60.00	40.00
60-64	0.00	0.00
65 & above	0.00	0.00

Source: Computed from data collected through household survey

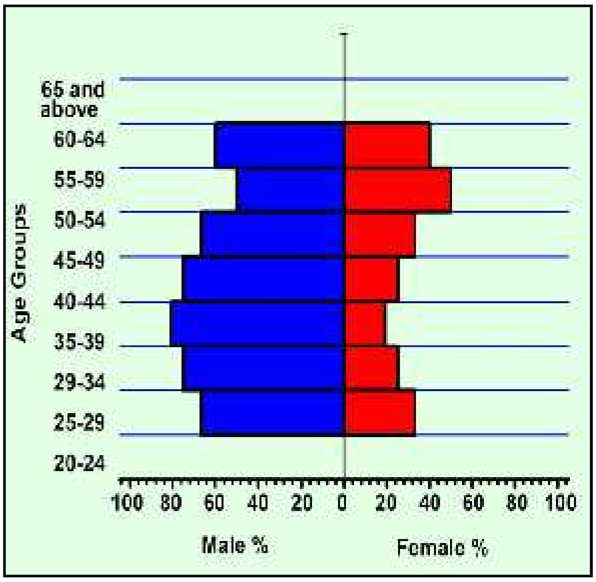


Fig. 4.19: Gender wise prevalence rate in Mokrampur of Beldanga-1 Block

Dharampur Ramna village of *Hariharpara* block had more affected males except for 20-24 years age group where female percentage was much higher (80%). In 35-39 years, 40-44 years and 60-64 years, 100% males were affected (Table 4.17) (Fig.4.20). Female affected persons were only observed between 20-34 years and in the age group of + 65 years.

In *Mokrampur* of *Beldanga-1*, 80.77% of men were affected in the age group of 35-39 years. In rest of the age groups the percentage was more than 50% with 20-24 years and + 60 years as exceptions (Table 4.16) (Fig.4.19). A continuous increment was observed in females up to the 55-59 years (40%). It was only in the age group of 35-39 years a slight decrease in female share was observed.

Table 4.17: Age group wise Prevalence Rate (Dharampur Ramna village of Hariharpara block)		
Age Group	Male	Female
20-24	20.00	80.00
25-29	53.85	46.15
30-34	56.25	43.75
35-39	100.00	0.00
40-44	100.00	0.00
45-49	0.00	0.00
50-54	0.00	0.00
55-59	0.00	0.00
60-64	100.00	0.00
65 & above	60.00	40.00

Source: Computed from data collected through household survey

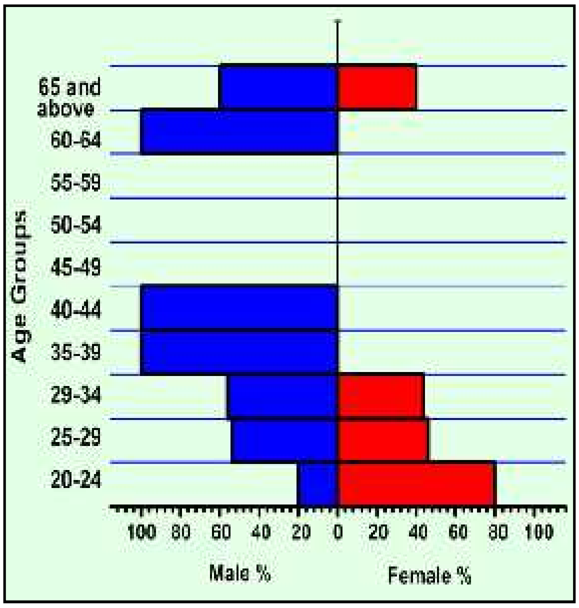


Fig. 4.20: Gender wise prevalence rate in Dharampur Ramna village of Hariharpara Block

Patikabari village of *Nawda* block the age groups of 50-55 years, 55-60 years, and 60-65 years, 100% males were affected while in the age group of 45-50 years,

Table 4.18: Age group wise Prevalence Rate (Patikabari village of Nawda block)		
Age Group	Male	Female
20-24	33.33	66.67
25-29	50.00	50.00
30-34	66.67	33.33
35-39	0.00	0.00
40-44	0.00	0.00
45-49	0.00	100.00
50-54	100.00	0.00
55-59	100.00	0.00
60-64	100.00	0.00
65 & above	0.00	0.00

Source: Computed from data collected through household survey

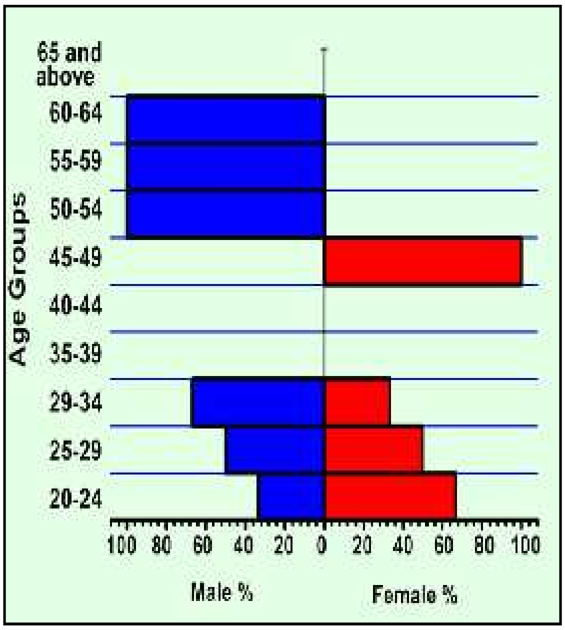


Fig. 4.21: Gender wise prevalence rate in Patikabari village of Hariharpara Block

female share was 100% (Table 4.18) (Fig.4.21). Other than these age groups, age groups of 20-25 years, 25-30 years and 30-35 years showed male percentage of

33.33%, 50% and 66.67% respectively, while in the same age groups the female share were 66.67%, 50% and 33.33% respectively.

In *Mithipur* village of *Raghunathganj-2* block, 100% males were noticed in the age groups of 30-34 years, 35-39 years and + 65 years, while in the age groups of 55-59 years and 60-64 years, 100% females were affected (Table 4.19) (Fig.4.22). In the age group of 40-44 years, both males and females had equal percentage. In the remaining age groups no case of *arsenicosis* was found in both the genders.

Table 4.19: Age group wise Prevalence Rate (Mithipur village of Raghunathganj-2 block)

Age Group	Male	Female
20-24	0.00	0.00
25-29	0.00	0.00
30-34	100.00	0.00
35-39	100.00	0.00
40-44	50.00	50.00
45-49	0.00	0.00
50-54	0.00	0.00
55-59	0.00	100.00
60-64	0.00	100.00
65 & above	100.00	0.00

Source: Computed from data collected through household survey

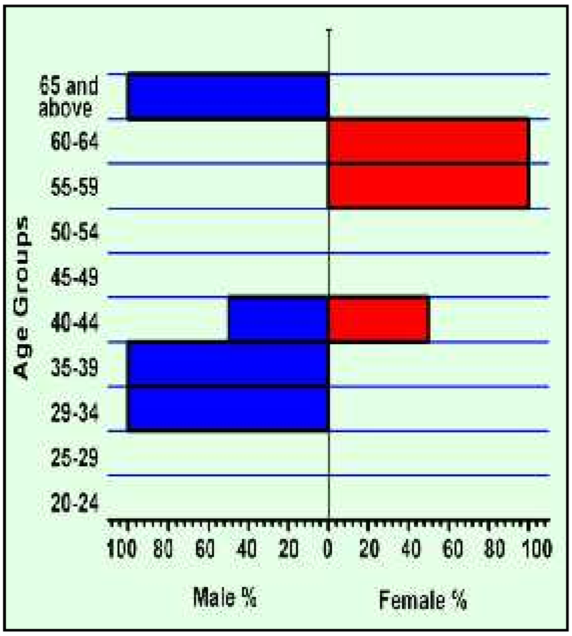


Fig. 4.22: Gender wise prevalence rate in Mithipur village of Raghunathganj-2 Block

4.5 Health Characteristics of the Surveyed Villages:

4.5.1 General Symptoms:

Issues like *limb pain, nausea/vomiting, cough complaint, hyperpathtia, distal parethesias, tremor* and *abnormal sweating* are broadly categorized as non-specific general symptoms. The co-morbidity of these symptoms was 263.47% in *Dharampur Ramna* village of *Hariharpara* block, 223.97%in *Garaimari* village of *Domkal* block (Table 4.20). Other than these two villages, *Raninagar-2* had co-morbidity of 176.64%, *Bhagawangola-2* had 210.80%, *Raghunathguanj-2* had 193.90% and *Lalagola* showed

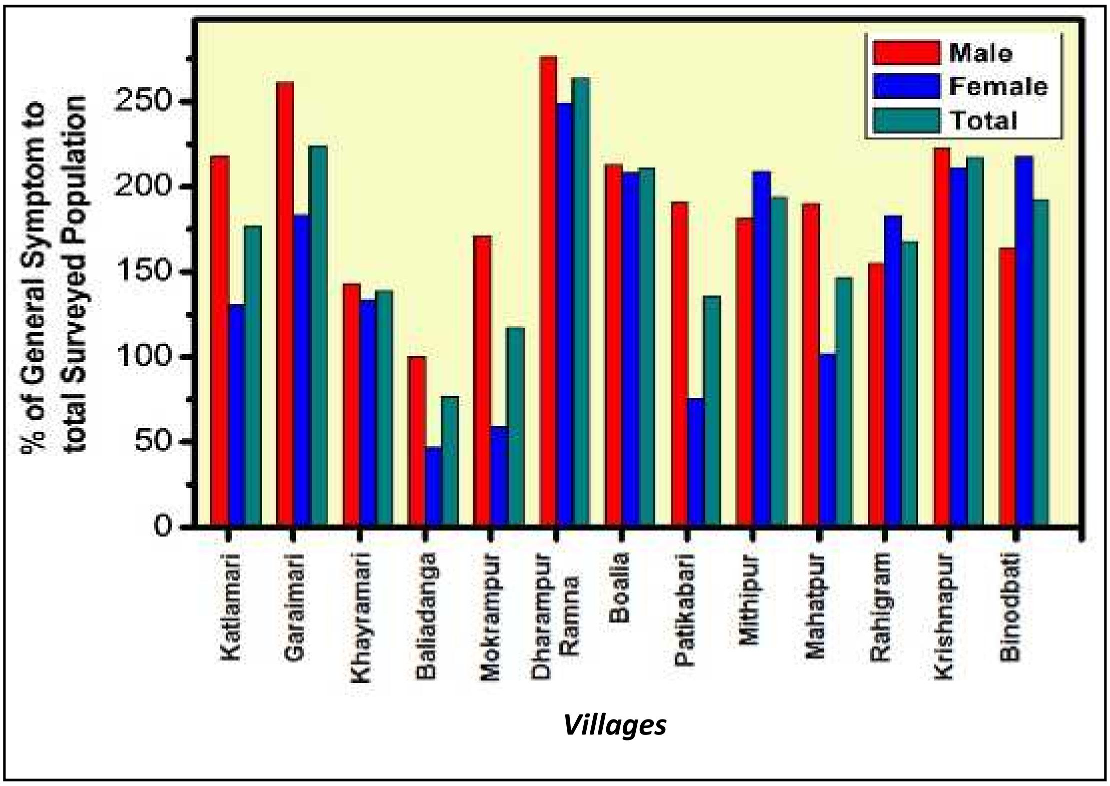


Fig. 4.23: Village wise Percentage of Total General Symptoms

217.39%. In the blocks of *Sagardighi* and *Burwan* the percentage of co-morbidity was 192.48% and 167.80% respectively. The males outnumbered females in terms of sufferings.

In terms of gender wise distribution (Fig.4.24), the share of males and females in *Katlamari* village was 64.97% and 35.03% respectively. In *Garaimari* village it was 60.95% and 39.05% while in *Dharampur Ramna* village, it was 55.73% and 44.27% respectively.

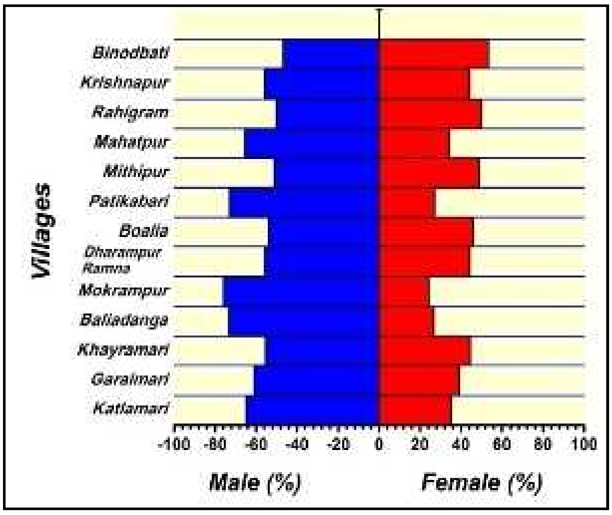


Fig. 4.24: Gender wise % of Persons Having Total General Symptoms

Table 4.20: Percentage of General Symptoms

Sr. No.	Block Name	Village Name	(%) of Total General Symptoms to Surveyed Population			(%) of Total General Symptoms to Affected Population	
			Male	Female	Total	Male	Female
1	Raninagar-2	Katlamari	217.90	130.74	176.64	64.97	35.03
2	Domkal	Garaimari	261.16	183.26	223.97	60.95	39.05
3	Jalangi	Khayramari	142.76	133.73	138.59	55.42	44.58
4	Bearampur	Balia Danga	100.35	46.85	76.88	73.26	26.74
5	Beldanga-1	Mokrampur	171.03	59.05	117.36	75.88	24.12
6	Hariharpara	Dharampur Ramna	276.21	249.00	263.47	55.73	44.27
7	Bhagawangola-2	Boalia	212.98	208.29	210.80	54.02	45.98
8	Nawda	Patikabari	190.79	75.78	135.28	72.96	27.04
9	Raghunathganj-2	Mithipur	181.27	209.13	193.90	51.12	48.88
10	Bhagawangola-1	Mahatpur	190.20	101.99	146.44	65.45	34.55
11	Burwan	Rahigram	155.07	182.86	167.80	50.08	49.92
12	Lalgola	Krishnapur	222.69	211.06	217.39	55.79	44.21
13	Sagardighi	Binodbati	163.71	217.84	192.48	46.67	53.33

Source: Calculated from the Primary Data Collected from Field

4.5.2 Thickening of Skin and Skin Lesions:

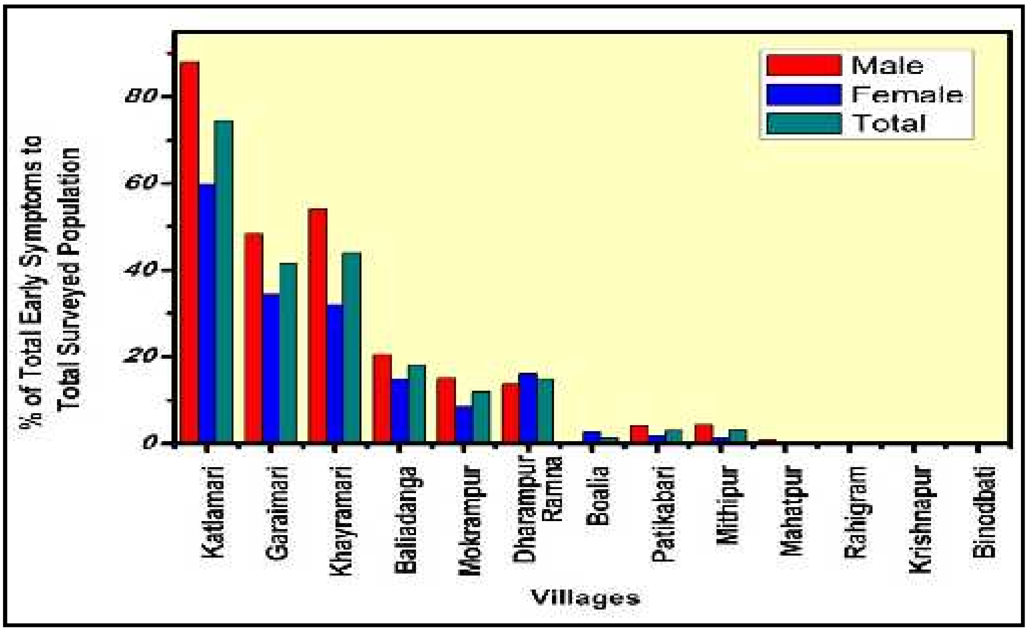


Fig. 4.25: Village wise Total Percentage of Thickening of skin and skin lesions

Co-morbidity of thickening of skin and skin lesions had highest percentage in the *Katlamari* village of *Raninagar-2* block (74.59%).

In the village of *Garaimari (Domkal)* and *Khayramari (Jalangi)* the percentage is 41.68% and 43.97% respectively. In the remaining villages, the co-morbidity to these two symptoms ranged between 17.98% *(Balia Danga* village of *Berhampur)* to 0.40% *(Mahatpur* village of *Bhagawangola-1* block).

In the villages of *Rahigram (Burwan), Krisnapur (Lalgola)* and *Binodbati (Sagardighi)* no cases of these two symptoms were found. In all the villages the percentage of affected male was higher than the females.

Table 4.21: Percentage of Thickening of Skin and Skin Lesions

Sr. No.	Block Name	Village Name	(%) of Total Early symptom to Surveyed Population			(%) of Total Early Symptom to Effected Population	
			Male	Female	Total	Male	Female
1	Raninagar-2	Katlamari	87.94	59.74	74.59	62.09	37.91
2	Domkal	Garaimari	48.35	34.39	41.68	60.62	39.38
3	Jalangi	Khayramari	54.14	32.13	43.97	66.24	33.76
4	Bearampur	Balia Danga	20.42	14.86	17.98	63.74	36.26
5	Beldanga-1	Mokrampur	15.08	8.62	11.98	65.52	34.48
6	Hariharpara	Dharampur Ramna	13.66	16.00	14.75	49.21	50.79
7	Bhagawangola-2	Boalia	0.00	2.76	1.29	0	100
8	Nawda	Patikabari	4.18	1.79	3.03	71.43	28.57
9	Raghunathganj-2	Mithipur	4.38	1.44	3.05	78.57	21.43
10	Bhagawangola-1	Mahatpur	0.78	0	0.40	100	0
11	Burwan	Rahigram	0	0	0	0	0
12	Lalgola	Krishnapur	0	0	0	0	0
13	Sagardighi	Binodbati	0	0	0	0	0

Source: Calculated from the Primary Data Collected from Field

In *Katlamari* village the male share was 87.94% while the females were 59.74%. In the village of *Mahatpur* males were least (0.78%) and no case of affected females was found (Table 4.21) (Fig.4.25).

The number of males were more in all the villages than the females except for the village of *Dharampur Ramna* where they contributed a similar percentages (49.21 and 50.79 respectively). In all the villages affected males were more than 60% while affected females varied between 21.43% *(Raghunathganj-2)* and *Bhagawangola-2* (100%).

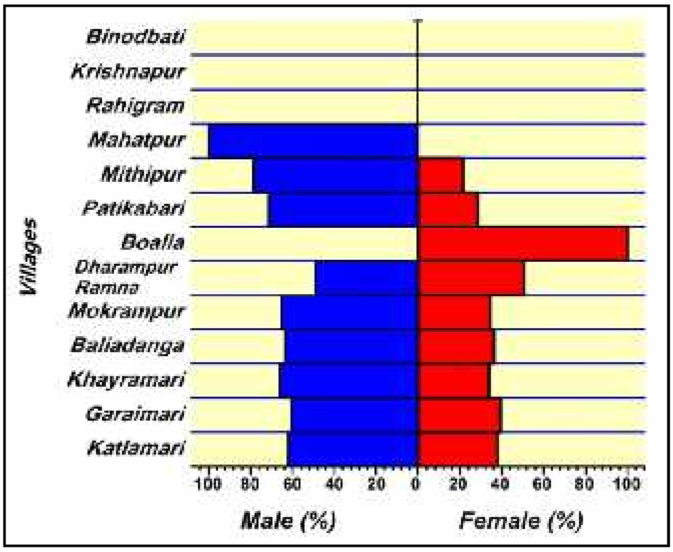


Fig. 4.26: Gender wise % of Persons Having Total Thickening of Skin and Skin Lesions

Garaimari village of *Domkal* block (41.68%), *Katlamari* Village of *Raninagar-2* (74.59%) and *Khayramari* village of *Jalangi* (43.97%) had the highest percentage of thickening of skin. In *Garaimari* and *Khayramari* male dominance in this ailment was noticed (60.62% and 66.24% respectively). The remaining ten villages had considerably less inhabitants with the problem of thickening of skin. In the *Mahatpur* village of *Bhagawangola-1*, *Binodbati* village of *Sagardighi*, *Krishnapur* village of *Lalgola* and *Rahigram* village of *Burwan* none of the people were suffering from this particular symptom.

Skin lesions were largely observed in the *Katlamari* village of *Raninagar-2* (30.94%) and *Khayramari* village of *Jalangi* (17.25%) with higher percentage of males (27.04% and 16.60% respectively) (Fig.4.26). In *Dharmapur Ramna* village (*Hariharpara),Balia danga* village *(Berhampur)* and *Garaimari* village (*Domkal)* the percentage of population associated with the ailment, ranged between 6% to 9% with higher percentage of male population. In the remaining blocks considerably lower percentage of people were affected.

4.5.3 Pigmentation:

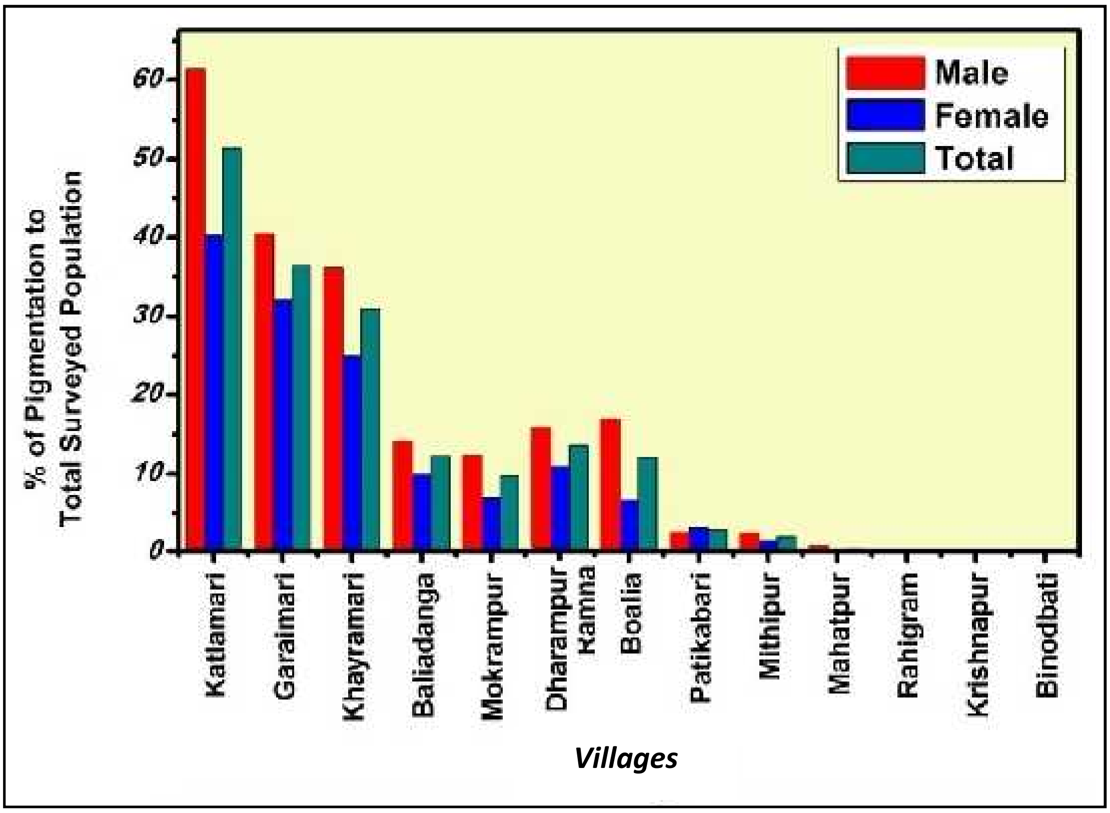


Fig. 4.27: Village wise % of Pigmentation

In *Katlamari* village of *Raninagar-2* block, 51.43% of the persons had pigmentation. The villages of *Garaimari* (*Domkal* block) and *Khayramari (Jalangi)* the percentage of affected persons were 36.50 and 30.98 respectively (Fig.4.27). In rest of the villages, the percentage varied between 0.04 in *Mahatpur* village of *Bhagawangola-1* block to 12.2 in *Baliandanga* village of *Berhampur* block. In all the villages, the males were more affected than the females. Highest percentage was noticed in *Katlamari* village (61.48) *(Raninagar-2)* and least in *Mahatpur* village of *Bhagawangola-1* block (0.78). Amongst the females it ranged between 40.26% (*Katlamari* village) to 1.22% in *Raghunathganj-2* block 100% males were affected in *Mahatpur* village and in *Garaimari* village 57.99% while highest percentages of affected females were found in the village of *Patikabari* village of *Nawda* block (53.85%) and lowest in *Boalia* village of *Bhagawangola-2* block (25.53%) (Fig. 4.27) (Fig. 4.34).

Table 4.22: Percentage of Pigmentation in the Surveyed Villages

Sr. No	Block Name	Village Name	Arsenic concentration	(%) of Total Pigmentation to Surveyed Population			(%) of Total Pigmentation to Affected Population	
				Male	Female	Total	Male	Female
1	Raninagar-2	Katlamari	0.03	61.48	40.26	51.43	62.95	37.05
2	Domkal	Garaimari	0.37	40.50	32.13	36.50	57.99	42.01
3	Jalangi	Khayramari	0.12	36.21	24.90	30.98	62.87	37.13
4	Berhampur	Balia Danga	0.02	14.08	9.91	12.25	64.52	35.48
5	Beldanga-1	Mokrampur	0.16	12.30	6.90	9.71	65.96	34.04
6	Hariharpara	Dharampur Ramna	0.05	15.86	11.00	13.58	62.07	37.93
7	Bhagawangola-2	Boalia	0.04	16.83	6.63	12.08	74.47	25.53
8	Nawda	Patikabari	0.03	2.51	3.14	2.81	46.15	53.85
9	Raghunathganj-2	Mithipur	0.02	2.39	1.44	1.96	66.67	33.33
10	Bhagawangola-1	Mahatpur	0.08	0.78	0.00	0.40	100.00	0.00
11	Burwan	Rahigram	0.03	0.00	0.00	0.00	0.00	0.00
12	Lalgola	Krishnapur	0.03	0.00	0.00	0.00	0.00	0.00
13	Sagardighi	Binodbati	0.02	0.00	0.00	0.00	0.00	0.00

Source: Calculated from the Primary Data Collected from Field

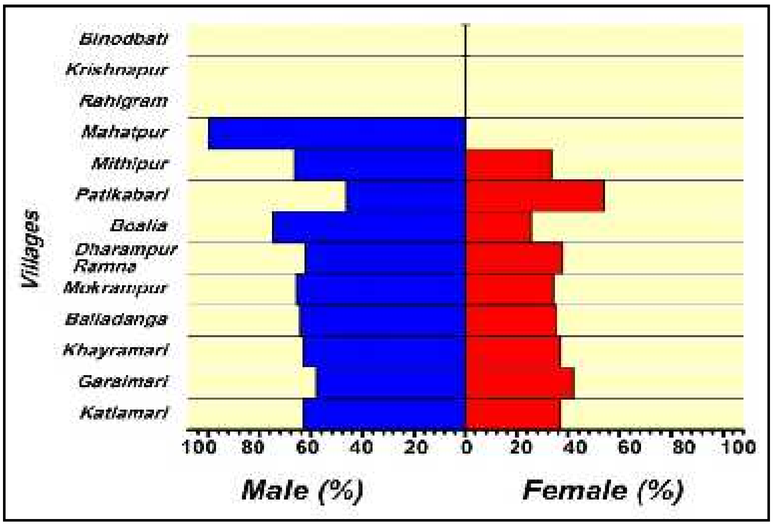


Fig. 4.28: Gender wise % of Persons Having Pigmentation

4.5.4 Keratosis and Carcinoma:

Katlamari village of *Raninagar-2*, *Garaimari* village of *Domkal* block and *Khayramari* village of *Jalangi* block had higher co-morbidity of *keratosis*, *carcinoma* and severe

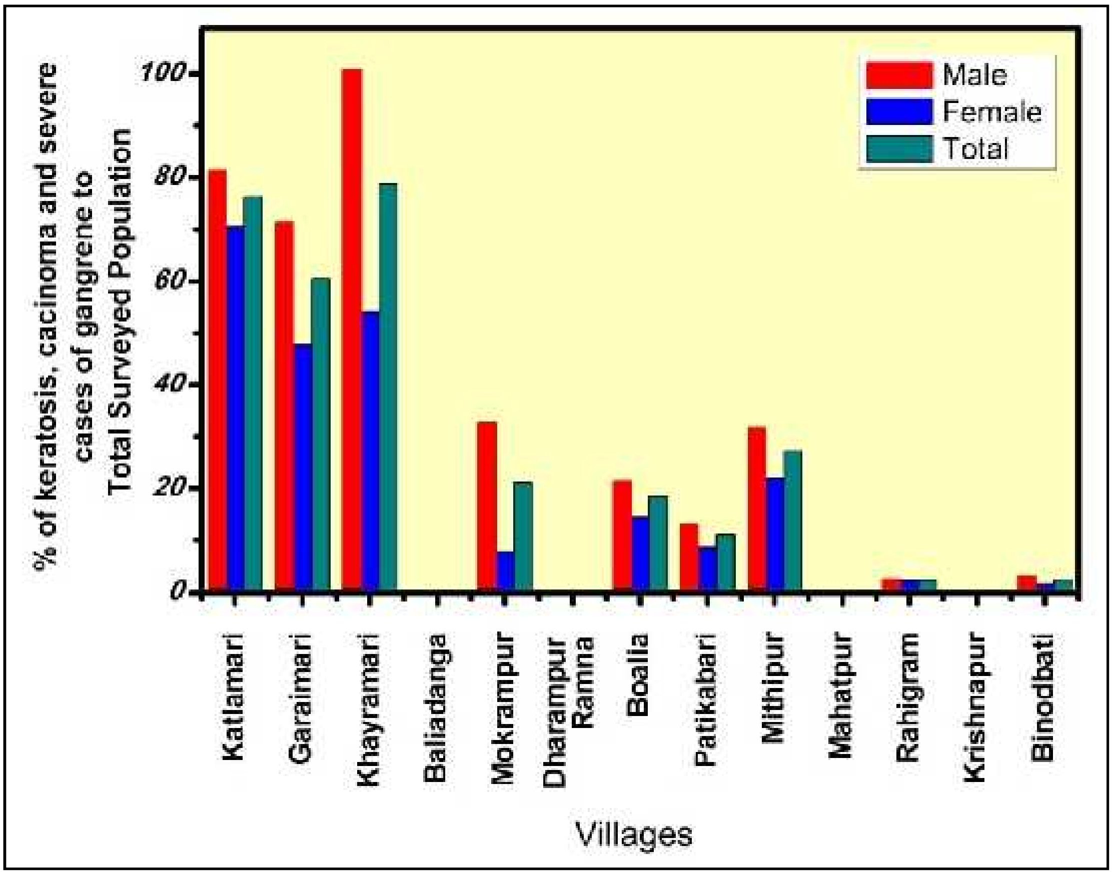


Fig. 4.29: Village wise Percentage of Keratosis, Carcinoma and Gangrene

cases of *gangrene* (78.69%, 76.24% and 60.48% respectively). Other than these villages, *Dharampur Ramna* village of *Hariharpara* block and *Boalia* village of *Bhagawangola-2* block had 27.17% and 21.08% of affected persons (Fig.4.29) .

Like other villages, males were more affected than the females. In the village of *Katlamari (Raninagar-2)* had highest percentage of male affected persons (100.78%). In other villages like *Garaimari* village of *Domkal* and *Khyaramari* village of *Jalangi* 81.40% and 71.38% of males were affected. In *Garaimari* village of *Domkal* block, *Khayramari* village of *Jalangi* block and *Katlamari* village of *Raninagar-2* block 70.59%, 54.11% and 47.79% respectively of females were affected (Fig. 4.36a & 36b).

In *Boalia* village of *Bhagawangola-2* block and *Mithipur* village of *Raghunathganj-2* block, the males share was 82.93% and 72.73% respectively. In the villages of *Patikabari* village of *Nawda* block and *Garaimari* village of *Domkal* the percentage of affected females were 45.45% and 44.19% respectively (Fig.4.36a, 4.36b, 4.36c and 4.36d).

Table 4.23: Percentage of Keratosis, Carcinoma and Severe Gangrene Symptoms

Sr. No.	Block Name	Village Name	(%) of Keratosis and Carcinoma and to surveyed Population			(%) of Keratosis and Carcinoma and to Effected Population	
			Male	Female	Total	Male	Female
1	Raninagar-2	Katlamari	100.78	54.11	78.69	67.45	32.55
2	Domkal	Garaimari	81.40	70.59	76.24	55.81	44.19
3	Jalangi	Khayramari	71.38	47.79	60.48	63.50	36.50
4	Berhampur	Balia Danga	21.48	14.41	18.38	65.59	34.41
5	Beldanga-1	Mokrampur	13.10	8.62	10.95	62.26	37.74
6	Hariharpara	Dharampur Ramna	31.72	22.00	27.17	62.07	37.93
7	Bhagawangola-2	Boalia	32.69	7.73	21.08	82.93	17.07
8	Nawda	Patikabari	2.51	2.24	2.38	54.55	45.45
9	Raghunathganj-2	Mithipur	3.19	1.44	2.40	72.73	27.27
10	Bhagawangola-1	Mahatpur	0.00	0.00	0.00	0.00	0.00
11	Burwan	Rahigram	0.00	0.00	0.00	0.00	0.00
12	Lalgola	Krishnapur	0.00	0.00	0.00	0.00	0.00
13	Sagardighi	Binodbati	0.00	0.00	0.00	0.00	0.00

Source: Calculated from the Primary Data Collected from Field Source:

The incidence of *keratosis* was low in the blocks of *Hariharpara* (13.35%), *Berhampur* (10.08%) and *Beldanga-1* blocks (7.02%) with male dominancy. In *Raninagar-2*, *Domkal* and *Jalangi* blocks, affected persons were 43.85%, 39.09% and 31.73% respectively. *Raghunatguanj-2* and *Nawda* blocks ranged between 0.2% to 2%. No person was showing the signs of *Keratosis* in the villages of *Mahatpur*

(*Bhagawangola-1*), *Binodbati* (*Sagardighi*), *Krishnapur* *(Lalgola)* and *Rahigram* *(Burwan).*

In *Garaimari* village of *Domkal* block*, Katlamari* village of *Raninagar-2* block and *Khayramari* village of *Jalangi* block 36.07%, 34.84% and 28.76% of people showed signs of *carcinoma* in different parts of the body. Once again there was dominance of males (Table 4.23) (Fig.4.30). Severe case of gangrene with was observed in the villages of *Garamari* and *Boalia* (Fig. 4.37, Fig. 4.38a and 4.38b).

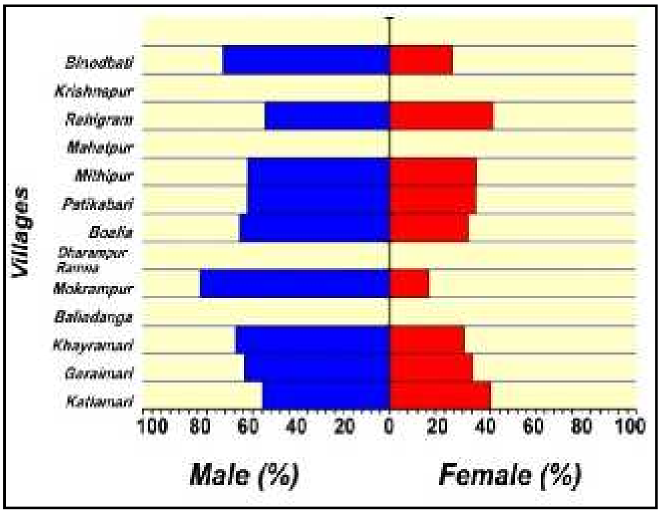


Fig. 4.30: Gender wise % of Persons Having Keratosis and Carcinoma

4.6 Income wise Distribution of Affected and Non-affected Person:

Income is considered to be one of the parameter of social well being,where the level of income indicates the person's ability to obtain amenities. The mean monthly

family income was calculated for both affected and non affected persons. It was observed from the result that, the income of non-affected persons varied between ₹ 821/- *(Sagardighi)* to ₹ 7370/- *(Beldanga-1)* (Fig.4.24). On the other hand, the income of the affected persons ranged from ₹ 2566 *(Raghunathganj-2)* to ₹ 8719 *(Bhagawangola-2)*. The mean per capita monthly income of the affected persons was higher than the affected person in the blocks of *Hariharpara*, *Bhagawangola-2*, *Nawda* and *Bhagawangola-1*. In the above said blocks the income of the non-affected persons was ₹ 2521/-, ₹ 3584/-, ₹ 4593/- and ₹ 5095/- while it was ₹ 8228/-, ₹ 8719/-, ₹ 5328/- and ₹ 5125/- among the affected persons. In the blocks of *Beldanga-1*, *Jalangi* and *Domkal*, the difference between the non affected and affected persons was much more distinct.

In *Beldanaga-1*, the mean per capita income of the non affected persons was ₹ 7370/- while it was ₹ 6119/- among the affected persons. Similar pattern can be observed in the blocks of *Jalangi* and *Domkal* where the income of the non affected and affected persons was ₹ 4274/- and ₹ 3972/- respectively and ₹ 3972/- and ₹ 2832/- respectively. In the block of *Raghunathganj -2*, similar pattern was observed (₹ 3042/- among non affected person and ₹ 2566/- among affected person). The blocks of *Raninagar-2* and *Berhampur* did not show any

Table 4.24: Per Capita Monthly Income of Affected and Non-affected Persons.

Villages	Non-affected income	Affected Income
Katlamari	4419.12	4259.95
Garaimari	3946.36	2832.69
Khayramari	4247.21	3972.65
Baliadanaga	4515.79	4175.92
Mokrampur	7370.21	6119.19
Dharampur		
Ramna	2521.21	8228.61
Boalia	3594.41	8719.58
Patrikabari	4593.74	5328.21
Mithipur	3042.49	2566.67
Mahatpur	5095.03	5125.00
Rahigram	2894.50	0.00
Krishnapur	5183.22	0.00
Binodbati	821.61	0.00

Source: Calculated from the Primary Data Collected from Field

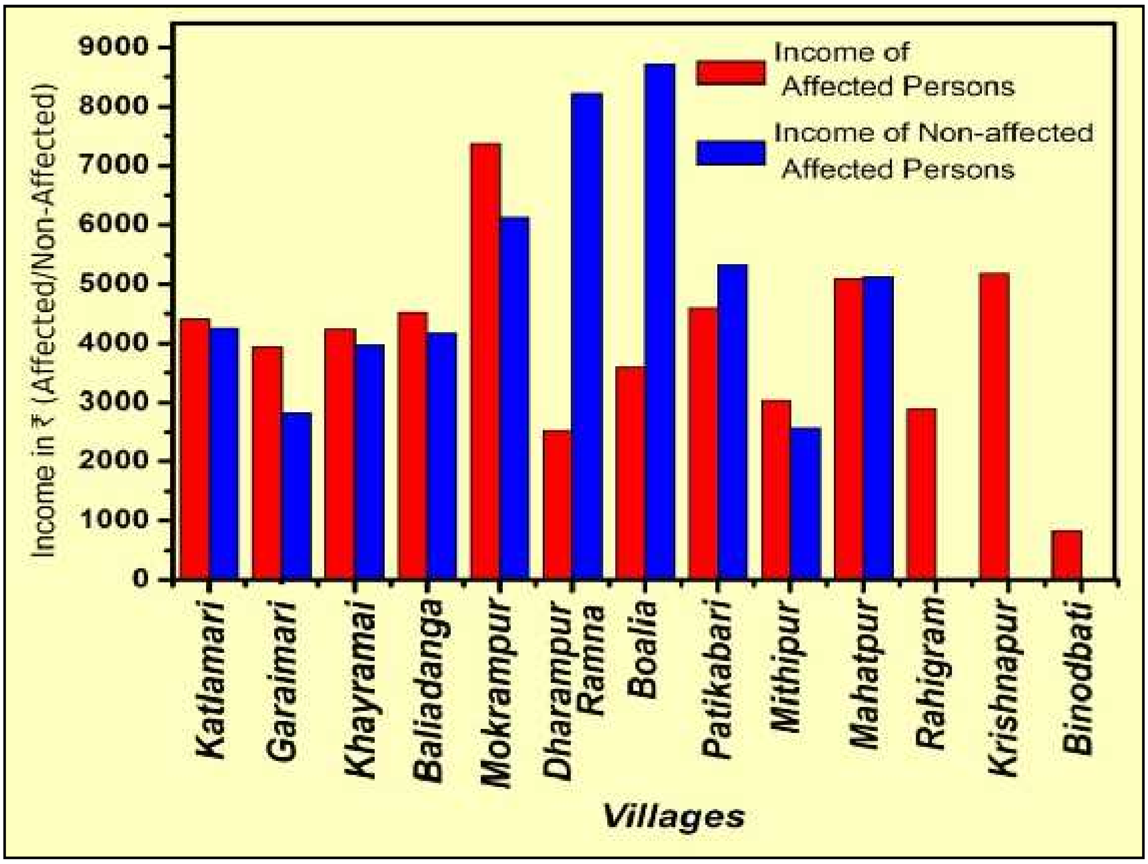


Fig. 4.31: Village wise Per-capita Monthly Income of Affected and Non-Affected Persons

significant variation in income level of the two categories of persons. In rest of the blocks like *Burwan, Lalgola* and *Sagardighi* no person was affected with the *arsenicosis*. Hence, the income of the non affected person was ₹ 2894/-, ₹ 5183/- and ₹ 821/- respectively).

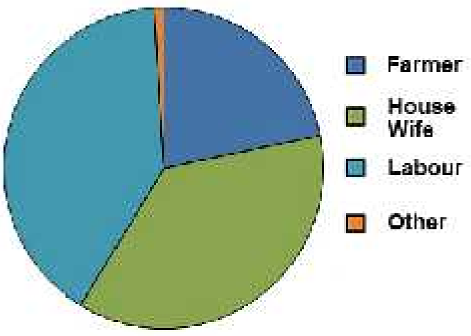
4.7 Occupational Pattern of the Affected Persons:

Farming, labour, service and business were the dominant occupations of the district. The percentage of labour in all the blocks was considerably high. It varied from 15% in *Bhagawangola-2* and *Hariharpara* blocks to 49.36% in *Beldanga-1*, 40.33% in *Raninagar-2* and 46.15% in *Nawda*. Farming was another prime occupation. *Raghunathganj* had highest percentage (44.44%) of farmers who were affected followed by *Bhagawangola-2* (42.50%), *Hariharpara* (40%), *Jalangi* (37.42%), *Berhampur* (34.64%), *Raninagar-1* (21.69%), *Domkal* (20.10%) and *Beldanga-1* (13.92%). Among the affected persons, house wives came next. In *Nawda*, 53.84% of the house wives had *arsenicosis* followed by *Domkal* (41.27%), *Hariharpara* (38.33%), *Jalangi* (38%), *Raninagar-2* (36.94%). *Raghunathganj-2* (33.33%), *Bhagawangola-2* (30%), *Berhampur* (26.79%) and *Beldanga-1* (24.05%) (Fig.4.32).

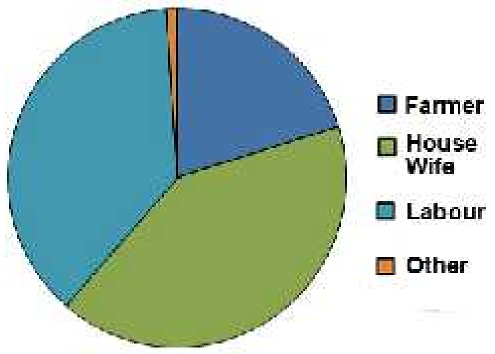
Table 4.25: Occupational Pattern of the Surveyed Villages in Percentage

Villages	Occupations					
	Farmer	Service	House Wife	Business	Labour	Others
Katlamari	21.7	0.00	36.94	0.00	40.33	1.01
Garaimari	20.10	0.00	41.26	0.00	37.57	1.05
Mokrampur	13.92	3.80	24.05	8.87	49.37	N.A.
Boalia	42.50	12.50	30.00	N.A.	15.00	N.A.
Khayramari	37.42	0.00	38.01	0.00	24.56	0.00
Balia Danga	34.64	0.00	26.80	0.00	38.56	N.A.
Dharampur Ramna	40.00	5.00	38.33	1.67	15.00	N.A.
Patikabari	0.00	0.00	53.85	0.00	46.15	N.A.
Mithipur	44.44	N.A.	33.33	N.A.	22.22	N.A.
Mahatpur	100.00	0.00	0.00	0.00	0.00	0.00

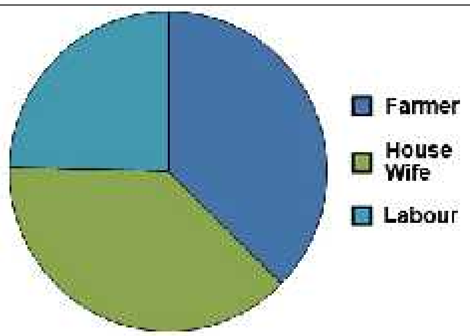
Source: Calculated from the Primary Data Collected from Field


Farmer
House Wife
Labour
Other

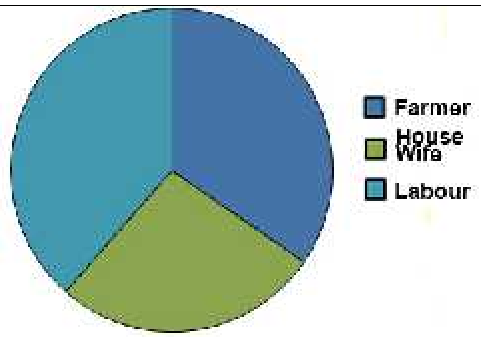
A


Farmer
House Wife
Labour
Other

B


Farmer
House Wife
Labour

C


Farmer
House Wife
Labour

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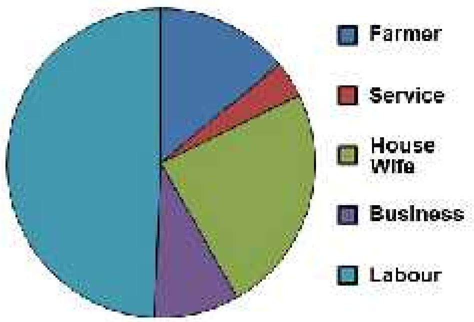
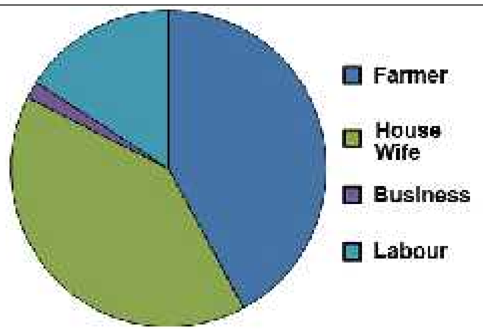
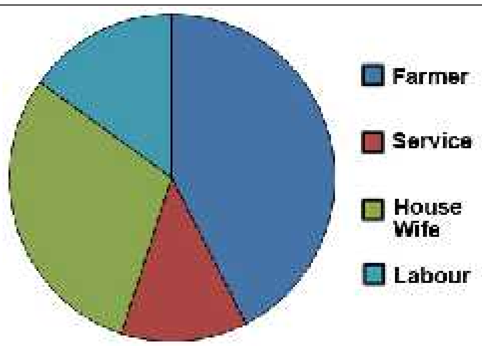

Farmer
Service
House Wife
Business
Labour

E


Farmer
House Wife
Business
Labour

F


Farmer
Service
House Wife
Labour

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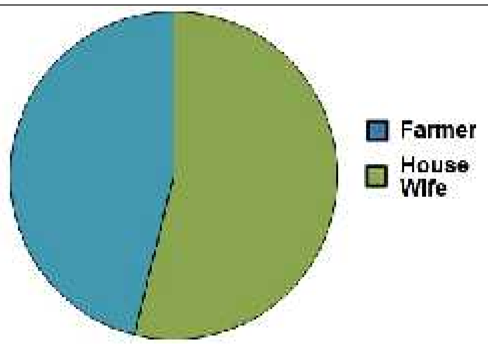
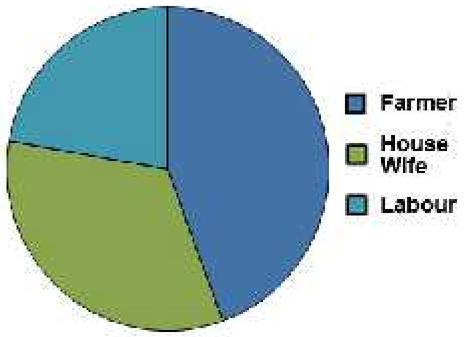

Farmer
House Wife

H



Sr	Blocks	Villages
A	Raninagar-2	Katlamari
B	Domkal	Garaimari
C	Jalangi	Khayramari
D	Behrampur	Balia Danga
E	Beldanga-1	Mokrampur
F	Hariharpara	Dharma Ramna
G	Bhagawangola-1	Boalia
H	Nawda	Patikabari
I	Raghunathganj-2	Mithipur

Fig. 4.32: Village wise Percentage of Different Types of Occupations Among the Persons Having Symptoms of Arsenicosis

The percentage of people engaged in service was relatively lower. The affected persons whose occupation was business, was found in the block of *Beldanga-1* (8.86%). 12.50% of affected persons engaged in service were found in the block of *Bhagawangola-2*. No affected person was found in *Burwan*, *Lalgola* and *Sagardighi* blocks.

4.8 Discussion:

The general symptoms were dominatingly found in labours and farmers. In most of the cases the issues of *limb pain*, *hyperpathia*, and *abnormal sweating* was reported in the males largely because they are engaged in heavy jobs. In this respect the symptoms of *cough* and *nausea/vomiting* were reported from large percentage of people. This symptom is generally associated with the living and working condition of the person while in the later case, quality of water plays a major role. During the analysis of the water quality it was observed that the level of *TDS* and *hardness* was considerably high in the whole of the district. During the survey large number of people also complained about the colour and smell of water. The higher *TDS* and *hardness* can disturb the internal process of body and leads to the *nausea* and *vomiting* (**Kanchan**[2] et. al 2009).

Thickening of skin and *skin lesions* was observed in large population. Roughness of palm and feet is one of the initial symptoms of *arsenicosis* but a direct relationship cannot be established in all the cases. Skin lesions to a large extent is related to the quality of water consumed. The consumption of contaminated water for a longer period of time is one of the major cause of different types of skin ailments (**Kanchan**[1] et. al 2009).

A positive relationship existed between the prevalence rate and *arsenic* concentration in groundwater. As the concentration of *arsenic* in groundwater increases the prevalence rate also increases thus a positive correlation existed between the two (+0.63). The only exception in this case was *Berhampur* where *arsenic* concentration in groundwater was considerably lower (0.02 mg/l) but the prevalence rate was 30.24%.

Fig. 4.33: Household Survey

Black and white pigmentation or *melanosis* on different parts of the body was largely found in the affected population. Among the surveyed villages, the *Katlamari* had highest percentage of people suffering with *melanosis*. Among the male population *melanosis* was commonly observed on chest and back. The effect of *arsenicosis* starts with *melanosis* (**Saha** et. al 1999, **Cheng** et al. 2013). In *Rahigram* village of *Burwan* block, *Krishnapur* village of *Lalgola* block and *Sagardighi* village of *Binodbati* blocks did not showed any cases of *melanosis* in either genders.

Keratosis is another major symptom and is considered to be the next stage of *arsenicosis* (Squibbs et. al 1983, Ravenscroft 2009). *Keratosis*, *carcinoma* and severe cases of *gangrene* are associated with longer period of consumption of *arsenic* affected

Fig. 4.34: Cases of Pigmentation on Chest

Fig. 4.35: Arsenic Removal Plants (ARPs)

water with higher concentration. In the present study, *keratosis* was observed among

Fig. 4.36: Cases of Keratosis on Hand and Feet

the people largely in the age groups of 30-49 years.

In most of the case the households used drinking water from shallow hand pumps (30-100 m). However, deeper hand pumps were also noticed (> 500 m). Numerous Arsenic Removal Plants (ARP's) (Fig. 4.35) were present but a few of them were not functioning properly. These ARP's were mostly associated with the *activated* *alumina* (Chen et al. 2007), which need periodic backwashing to remove the layer from there surface.

It was also found that in different part of the villages the hand pumps were coloured as red and blue indicating unsafe and safe drinking water sign. Present study showed that, there is considerable change in the concentration of *arsenic* in groundwater in different seasons. Thus, it is necessity of periodic testing of the groundwater mot only for *arsenic* but different geochemical parameters. The safe marked hand pumps would be periodically checked to ensure the safe drinking water condition.

Fig.4.37: Cases of Keratosis and Gangrene on Feet

Fig. 4.38: Cases of Gangrene on Hand and Feet

Resume: In this chapter, an effect of arsenic on human health was analysed. It was observed that, eastern portion of the district had higher prevalence rate than the western portion. This region also showed higher concentration of arsenic in groundwater. Age and gender wise distribution of prevalence rate depicted the fact that the age group between 30-50 years had higher percentage of affected persons with male dominance. Labours and farmers were largely affected by the arsenic contamination. It was also found that, the per-capita monthly income of the affected persons were less than the non-affected persons. The following chapter focused upon the groundwater modeling for the identification of the vulnerability zones of groundwater of Murshidabad District.

Chapter – 5

Groundwater Vulnerability Modelling

Chapter – 5

Groundwater Vulnerability Modelling

5.1 Introduction:

Groundwater quality is a significant parameter of environment as it directly and indirectly affects human health. Hence, it is essential to ensure better quality of groundwater and identify the potential zones both in terms of quantity and quality. Thus, there is a need to investigate the issue in a systematic way and identify the vulnerability zones. The term 'Vulnerability of Groundwater by Contamination' was first used by **Margat** in 1968. According to the National Research Council (1993) the groundwater vulnerability due to contamination is the tendency of contaminants to reach to the particular position of the groundwater after introducing in the uppermost aquifer. The first step towards the identification of vulnerability zone is to identify the parameters that are to be used in the decision making. After the identification of the risk zones, it is possible to take necessary measures to minimize the current condition and plan for the future. The chosen parameters are based on their significance as well as availability. To identify the vulnerability of groundwater different types of parameters were applied in different models such as GODS, AVI, IVI (**Gogu** and **Dassargues** 2000). Moreover DRASTIC model is widely used in identifying the groundwater vulnerability zones (**Aller** et al. 1987, **Doerfliger** and **Zwahlen** 1997, **Samake** et al. 2010). In this model, seven critical parameters of groundwater viz. *depth to the water* (D), *recharge* (R), *aquifer media* (A), *soil media* (S), *topography* (T), *impact of vadose zone* (I) and *hydraulic conductivity* (C) were used. According to **Aller** et al.

(1987) the system comprises of designation of mapable units of groundwater and overlying of the relative ranking system. To find out the DRASTIC index of each parameter, relative ranking system and particular weight of each parameter was used. Finally to depict the composite DRASTIC index which helps in identifying the potential zones of contamination, all the seven vulnerability index maps were merged with each other. On the basis of their significance, relative weights were given to each of the factors. The most important factor was assigned with weight of 5 while the least important factor was designated with weight of 1. In this system, depth to the water (D) and impact of vadose zone (I) were given highest priority and were given the higher weights while the relative importance of the topography was assigned lowest weight of 1. After assigning weights of the factors, Aller et al. (1987) also specified the range of each of the factors with their respective weights. These weights (Table 5.1) and rates (Table 5.2) were used in the following formula (1) to find out the composite DRASTIC index of the groundwater-

$$D_R D_W + R_R R_W + A_R A_W + S_R S_W + T_R T_W + I_R I_W + C_R C_W = \text{Pollution Potential (DRASTIC)} \quad (1)$$

Where-

R = Rate,	*D* = Depth to groundwater	*T* = Topography,
W = Weight,	*R* = Recharge,	*I* = Impact of vadose zone,
	A = Aquifer media,	*C* = Hydraulic Conductivity
	S = Soil media,	

Table: 5.1 Assigned Weights of Each Factors	
Factors	**Weights**
Depth	5
Net Recharge	4
Aquifer media	3
Soil	2
Topography	1
Impact of Vadose Zone	5
Hydraulic Conductivity	3
Source: Aller et al. (1987)	

Table: 5.2 DRASTIC Rating System for Different Factors

Depth (D) (Feet)		Net Recharge (R) (Inches)		Aquifer Media (A)	
Range	Rates	Range	Rates	Range	Typical Rating
0-5	10	0-2	1	Massive Shale	2
5-15	9	2-4	3	Metamorphic/ Igneous	3
15-30	7	4-7	6	Weathered Metamorphic/ Igneous	4
30-50	5	7-10	8	Thin Bedded Sandstone, Limestone, Shale sequence	6
50-75	3	10+	9	Massive sandstone	6
75-100	2			Massive limestone	6
				Fine to medium sand	5
100+	1			Sand and gravel	8
				Coarse Sand	8
				Basalt	9
				Karst Limestone	10

Table:5.2 DRASTIC Rating System for Different Factors (continued)

Soil (S)		Topography (T) (% slope)		Hydraulic Conductivity (GPD/FT^2) (C)	
Range	Rates	Range	Rates	Range	Typical Rates
Thin or absent	10	0-2	10	1-100	1
Gravel	10	2-6	9	100-300	2
Sand	9	6-12	5	300-700	4
Peat	8	12-18	3	700-1000	6
Shrinking/ aggreted clay	7	18+	1	1000-2000	8
Sandy loam	6	Impact of Vadose Zone (I)		2000+	10
Loam	5	Range	Typical Rates		
Silty loam	4	Silt/Clay	1		
Clay loam	3	Shale	3		
Muck	2	Limestone	6		
Nonshrinking/ nonaggreted clay	1	Sandstone	6		
		Bedded Limestone, Sandstone, Shale	6		
		Sand and Gravel with significant Silt and Clay	6		
		Metamorphic/Igneous	4		
		Sand and Gravel	8		
		Basalt	9		
		Karst Limestone	10		

Source: Aller et al. (1987), Rahman (2008)

5.2 Workflow of DRASTIC Modelling:

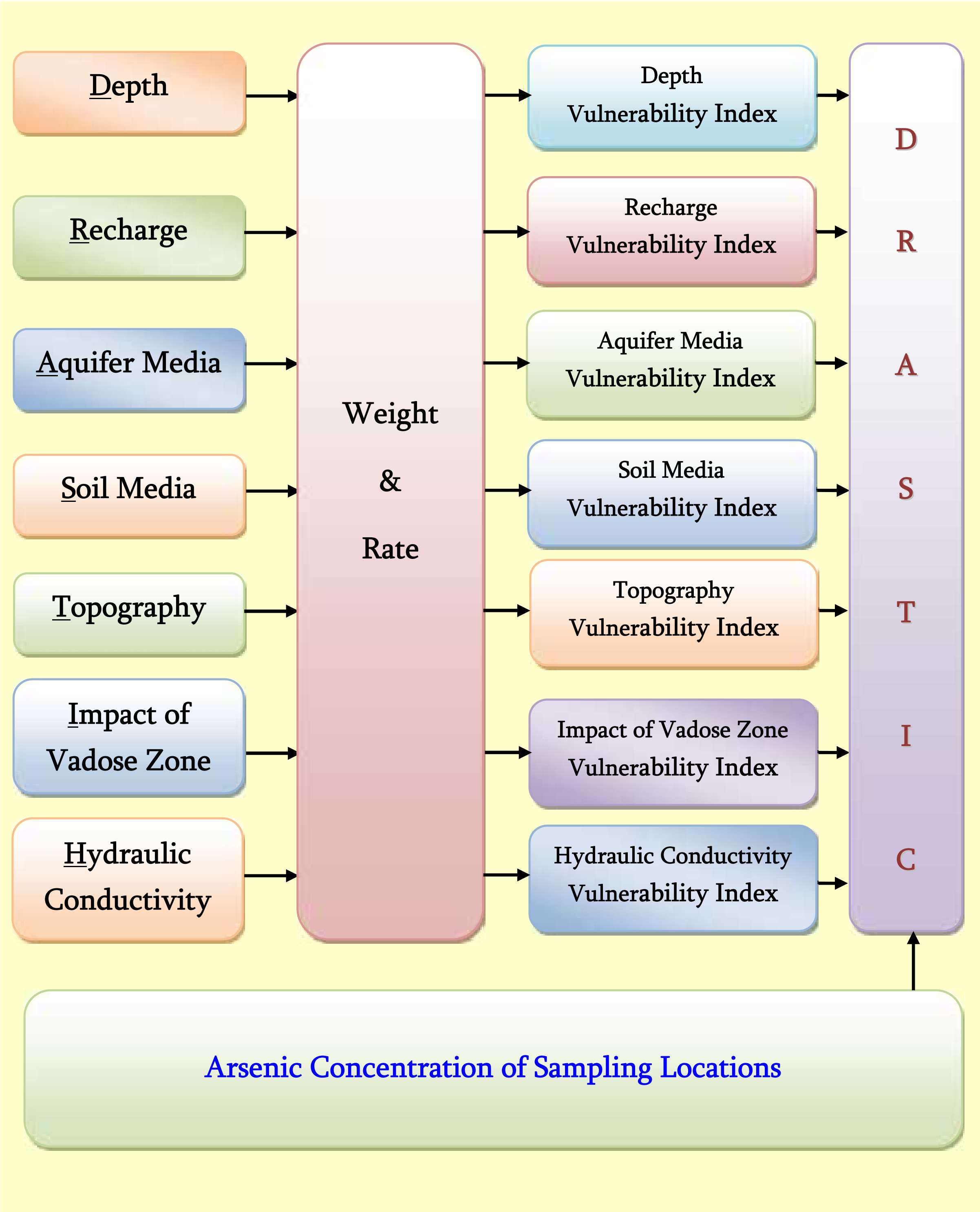


Fig. 5.1 Drastic Modelling Workflow

5.3 Database and Methodology:

The following data was used to generate the DRASTIC model-

1. *Depth to the water* was collected from the data base of Groundwater Authority Board of India website (http://gis2.nic.in/cgwb/Gemsdata.aspx).
2. *Recharge* data was acquired from the Groundwater year Book-2011-12 (http://www.cgwb.gov.in/documents/Ground%20Water%20Year%20Book%20-%202011-12.pdf), District Information Booklet of Murshidabad (http://www.indiawaterportal.org/sites/indiawaterportal.org/files/murshidabad.pdf), Resource Map of Murshidabad District (District Resource Map, Murshidabad, West Bangal, 2008) District Planning Series Map (District Planning Series Map, Murshidabad, West Bengal, 2002) .
3. *Aquifer media* data was generated from the bore well log data collected from the Public Health Engineering Departments, Murshidabad and non government agencies.
4. *Soil media* data was collected from the map prepared by National Bureau of Soil Survey and Land Use Planning, Kolkata.
5. *Topography* layer was generated from the 30 m SRTM data (http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp).
6. *Impact of Vadose Zone* layer was prepared from the subsurface lithological data generated from the bore well logs collected from Public Health Engineering Departments, Murshidabad and non government agencies.
7. *Hydraulic Conductivity* layer was generated from the transitivity data collected from the Murshidabad District Information Booklet (http://www.indiawaterportal.org/sites/indiawaterportal.org/files/murshidabad.pdf).

On the geo-referenced map of *Murshidabad* district the entire data was loaded in the GIS platform. On the basis of reassigned weights and ratings the vulnerability index for each parameter was calculated.

The calculated indices were tabulated as attributes in the GIS platform. Each of the layers were prepared and converted into raster format to prepare parameter wise vulnerability maps. All the raster layers were then combined with each other to find out the composite vulnerability index. The composite vulnerability index was further converted into vector layer to calculate the area of different vulnerability zones. To find out the percentage of surveyed hand pumps located in the particular vulnerability zones, the sample locations of hand pumps were overlaid on the composite vulnerability map.

5.4 Results:

5.4.1 Depth (D):

Depth to the groundwater is the most important parameter that indicates the distance between the surface of the earth and the water table. It also specifies the time taken by the contaminants before mixing with groundwater. As the distance between the surface and groundwater level increases the travel time of the contaminant increases and vice versa. The average depth to the groundwater in three seasons of 2012 was taken into considerations. In the entire region, the depth to the groundwater varied between 2.51 mbgl to 20.21 mbgl. Shallower depth (< 5 m) was observed in the eastern part of the *Murshidabad* district (Fig. 5.2) (Table 5.3) while in the western segment the depth of the groundwater was relatively higher (5-15 m). The obtained data was interpolated in the GIS environment and was classified in to three categories (< 5 m, 5-15 m and > 15 m). The lower value indicated shallower depth and therefore higher vulnerability, while higher value indicated lower vulnerability. The eastern segment of the study area depicted the depth vulnerability index of 50 while the entire western segment had a vulnerability index of 35 with two small patches of vulnerability index of 45 in the western portion.

Table: 5.3 Depth to Water Index

Vulnerability Indices *(D)*	Area Covered (%)
50	58.27
45	2.08
35	39.65

In terms of area, 58.27% of the area was related to high vulnerability, 2.08% fall under the category of medium vulnerability and 39.65% area depicted low vulnerability zone.

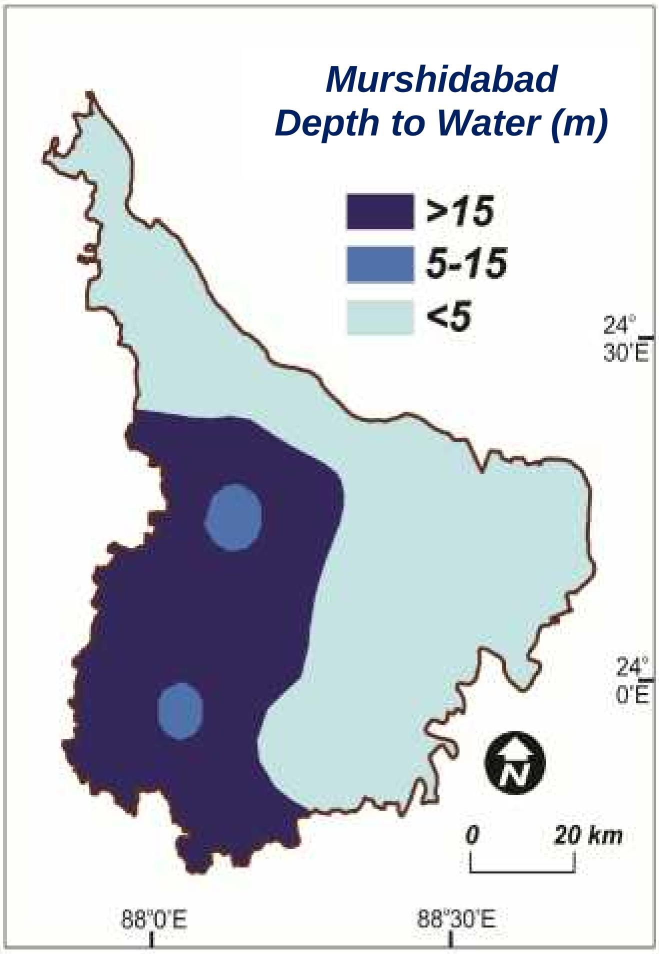


Fig 5.2 Depth to the Water Layer

5.4.2 Net Recharge (R):

Net recharge is total quantity of water, from precipitation, surface water and all other artificial sources that penetrates to the groundwater (**Todd** and **Mays** 2005). With the increasing amount of precipitation, increased availability of surface water (like rivers), the rate of recharge increases. The relative weight of recharge (4) indicates its significance in terms of vulnerability as it is next in importance to the parameter of depth. As the rate of recharge increases, the ability of contaminants to move to a greater distance also increases. Thus, there is a positive relationship between the rate of recharge and possibility of higher rate of movement of contaminants.

The entire region is associated with the higher precipitation as it lies in the hot and humid type of climatic zone (**Mondal** 2012). The average rainfall in *Murshidabad* district is approximately 1600 mm. The other major source of recharge in the study area is the presence of River *Ganga*, its tributaries and distributaries.

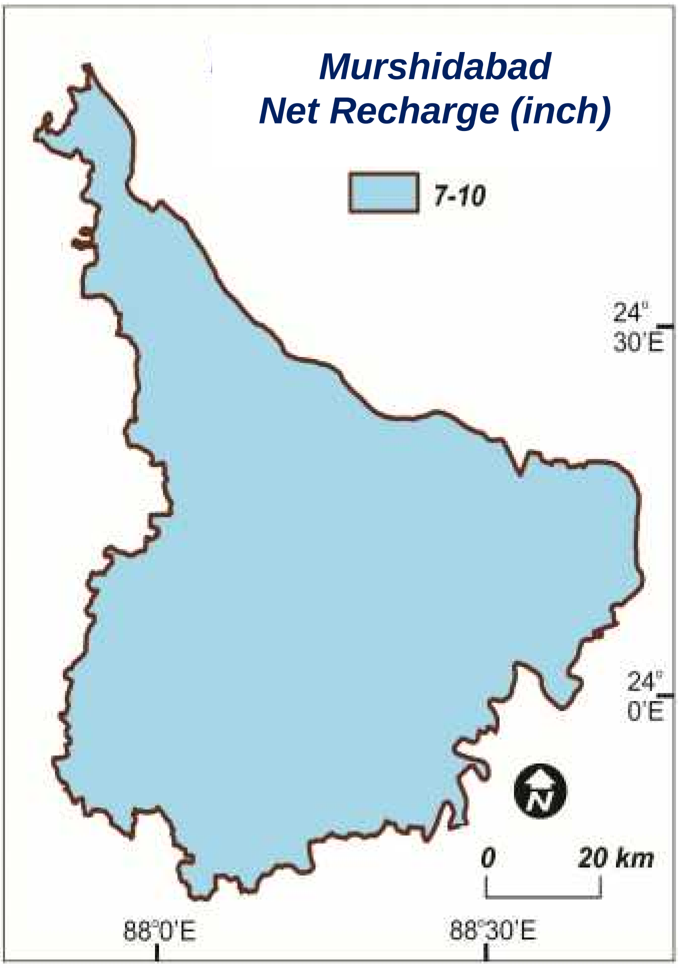


Fig 5.3 Groundwater Net Recharge Layer

Thus, it can be inferred that the entire region is having considerably higher rate of recharge (7-10 inches). Due to availability of only single data for the entire region the recharge of the entire region was considered as constant. After calculating the respective rate and weight it was found that the recharge index was quiet high (32) (Fig. 5.3). The higher value itself is the indicator of higher rate of recharge and the possibility of higher rate of movement of contaminants.

5.4.3 Aquifer Media (A):

To obtain subsurface lithological model, lithologs were placed to their individual positions in terms of longitudes and latitudes. The lithologs were first located and subsequently integrated in the software, which gave the characteristics of the aquifer media. The result showed that, the entire region is associated with the fine/medium sand and coarse sand type of media. Finer the texture of the particles, penetration of the water takes longer time. On the other hand, the rate of penetration of water is much higher in coarser textures. So it

Table: 5.4 Aquifer media Index

Vulnerability Indices *(A)*	Area Covered (%)
15	56.89
24	43.11

can be inferred that, aquifer media associated with finer texture is lesser vulnerable than

the aquifer media associated with coarser texture (Fig. 5.4 and Fig. 5.4). The characteristics of the aquifer media is calculated with the respective rating and weight. It was found that, the eastern part of the district has aquifer media vulnerability index of 24 while in the western side, the aquifer texture is finer and has an index of 15. Thus, higher rating indicates coarser texture and higher vulnerability while lower rating indicates finer texture and lower vulnerability index. In terms of area, 43.11% of the area was related to high vulnerability of aquifer and 56.89% of the area was depicted as low vulnerability zone (Table 5.4) (Fig. 5.5 and Fig. 5.6).

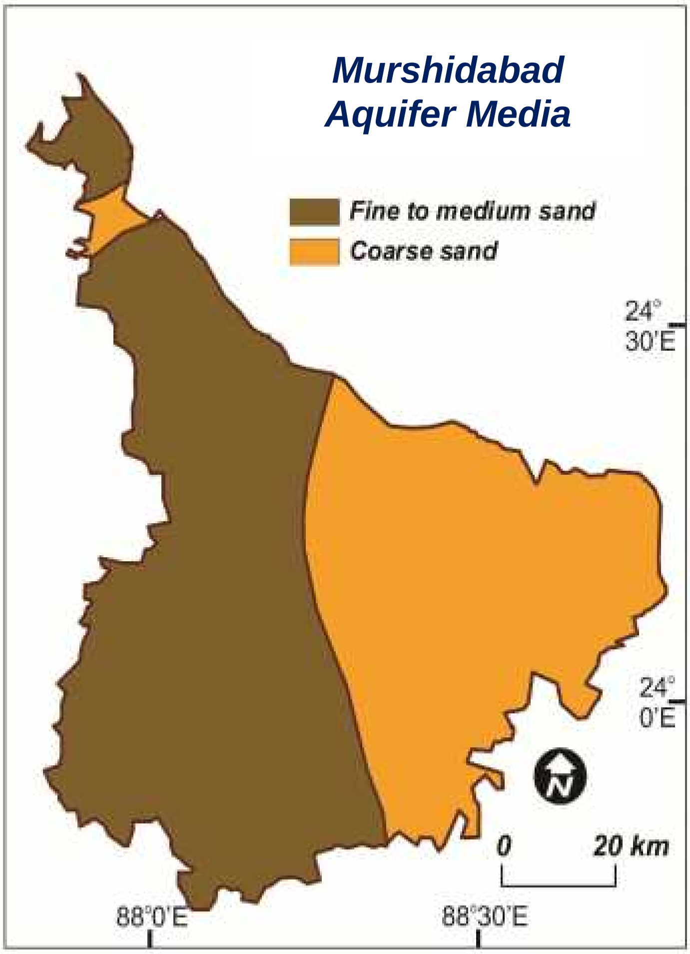


Fig 5.4 Aquifer Media Layer

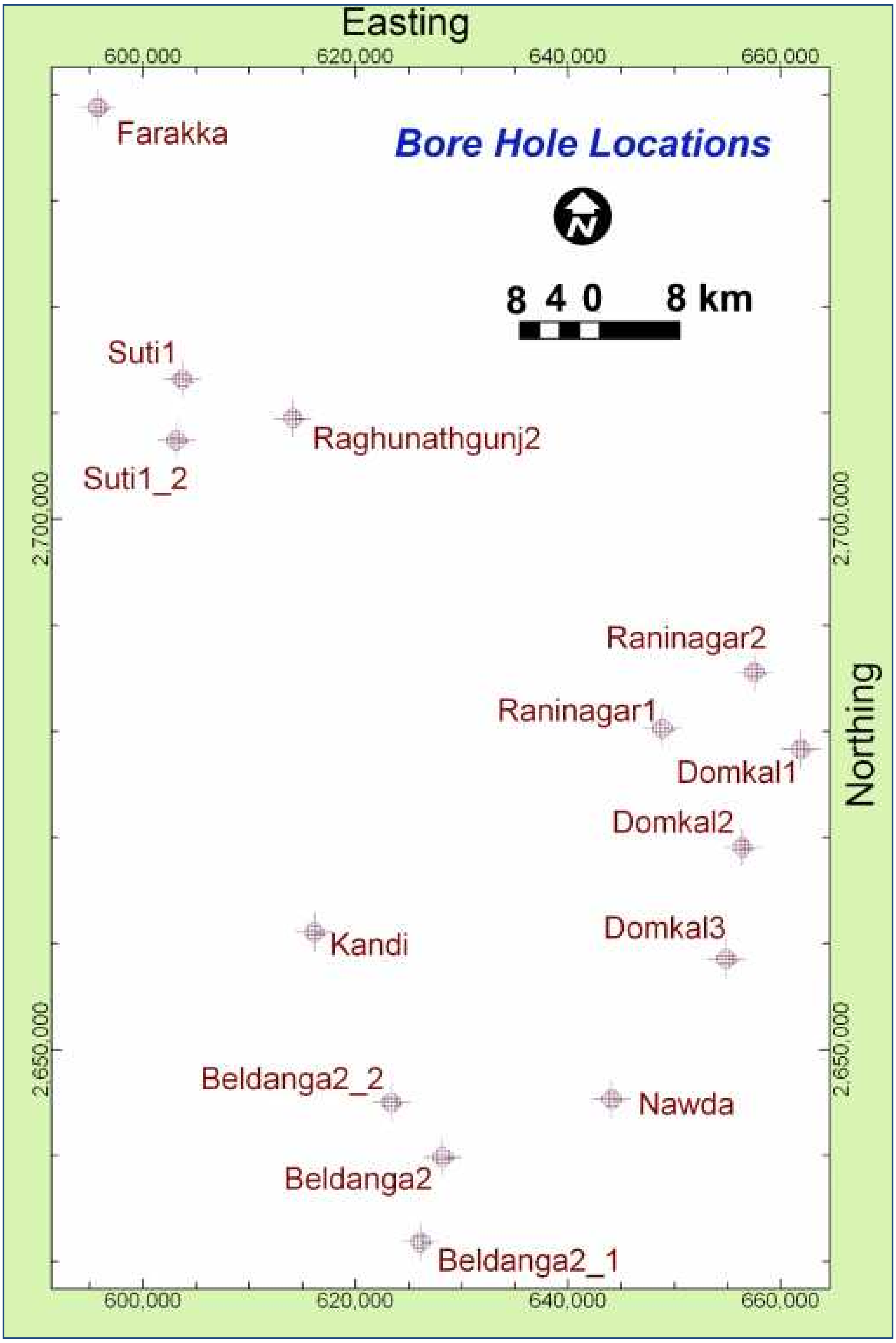
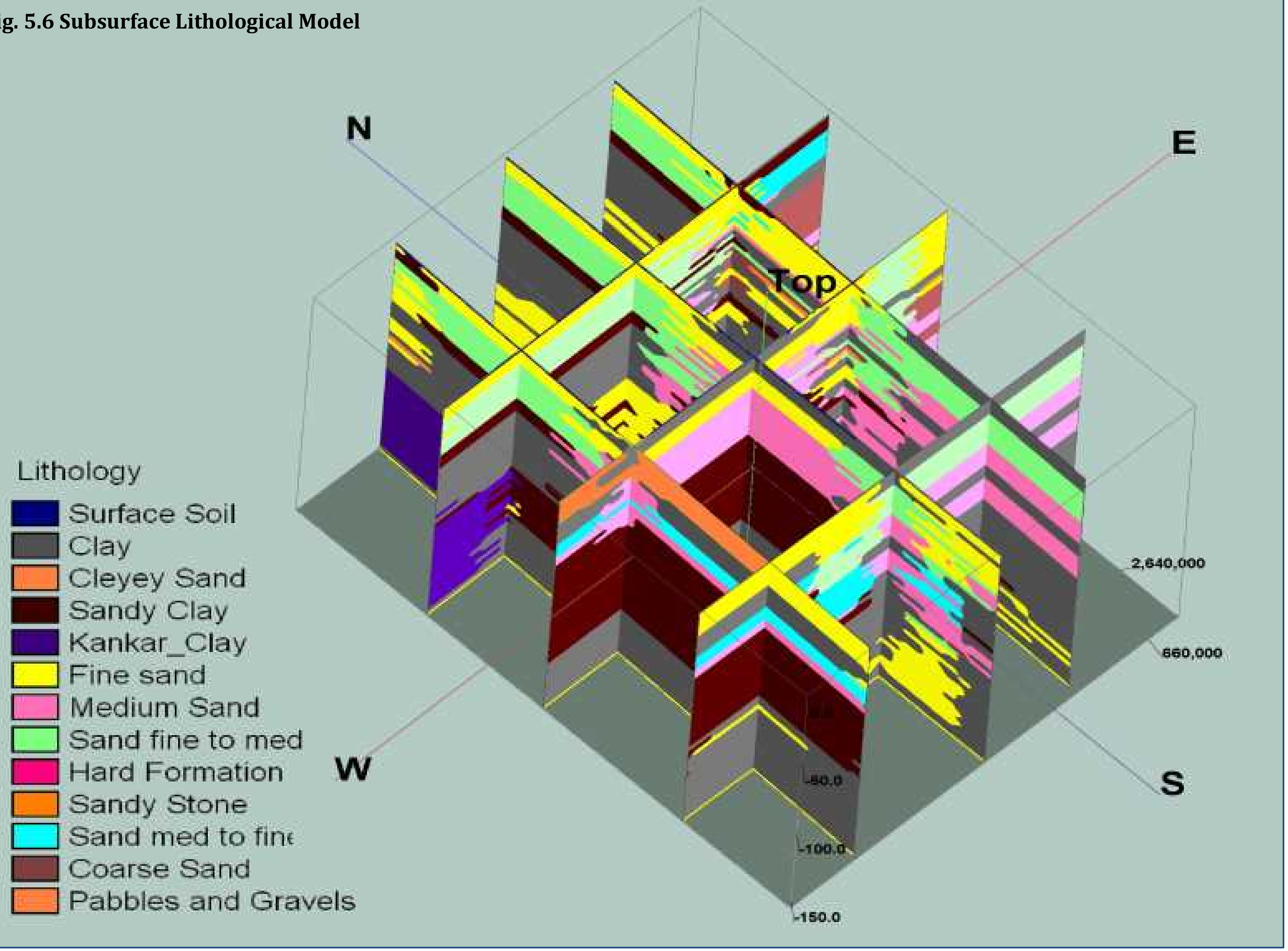


Fig. 5.5 Locations of the Bore Wells

Fig. 5.6 Subsurface Lithological Model



5.4.4 Soil (S):

Soil media is the next parameter that plays a crucial role in determining the contamination of groundwater. Soil is considered to be the first layer through which the surface water penetrates.

Table: 5.5 Soil Vulnerability Index

Vulnerability Indices *(S)*	Area Covered (%)
10	80.87
12	19.13

Permeability of water through the soil depends upon the texture of the soil. As the texture of the soil becomes finer, the distance between the soil particle decreases and void space between them reduces. This leads lesser water to infiltrate through the void space. On the other hand, as the texture becomes coarser, the rate of infiltration increases.

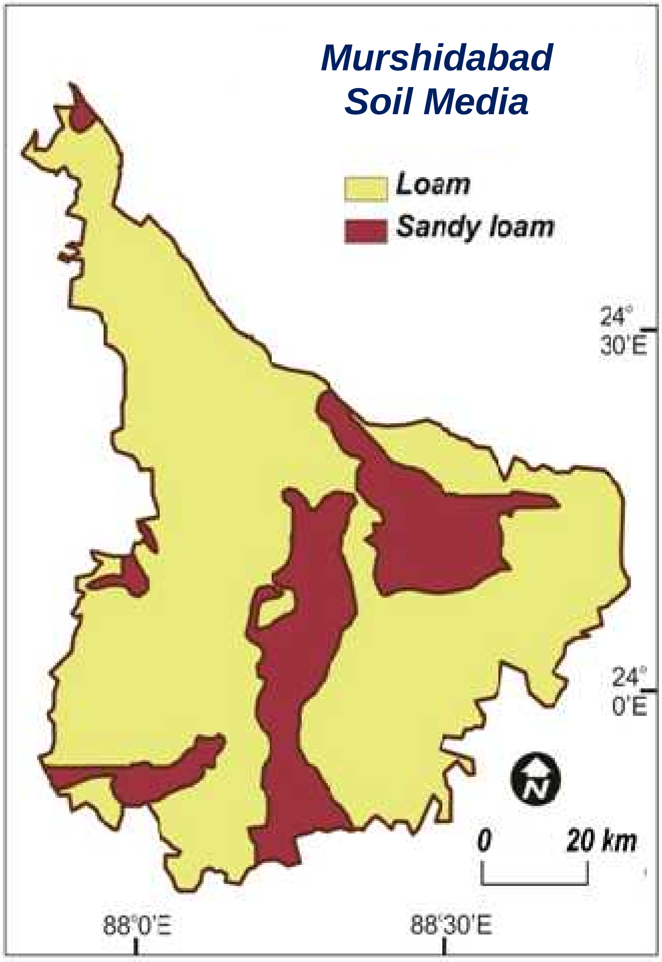


Fig. 5.7 Soil Media Layer (After NBBS &LUP Regional Centre, Kolkata).

The entire district is associated with loamy and coarse sandy type soil. According to the assigned rate and weight, the calculated value of the soil vulnerability index showed higher value (12) (Table 5.5) with 19.13% area in the central and north-eastern segment while the value was considerably lower (10) in the rest of the region and covered 80.87% of the total area (Fig. 5.7).

5.4.5 Topography (T):

The parameter is important and is taken in to considerations although the relative weight of topography is least (1). The slope of the land determines the water to retain at a specific position for particular time. As the slope of the land increases, water tends to move at greater speed with less infiltration rate. On the other hand, as the slope of the land decreases the corresponding potential of water to move from one place to another place also decreases. This leads to greater chance of surface run off to remain in a particular position for longer time and gets more time for infiltration. Thus, there is an inverse relationship between the slope of the land and the infiltration rate of surface run off.

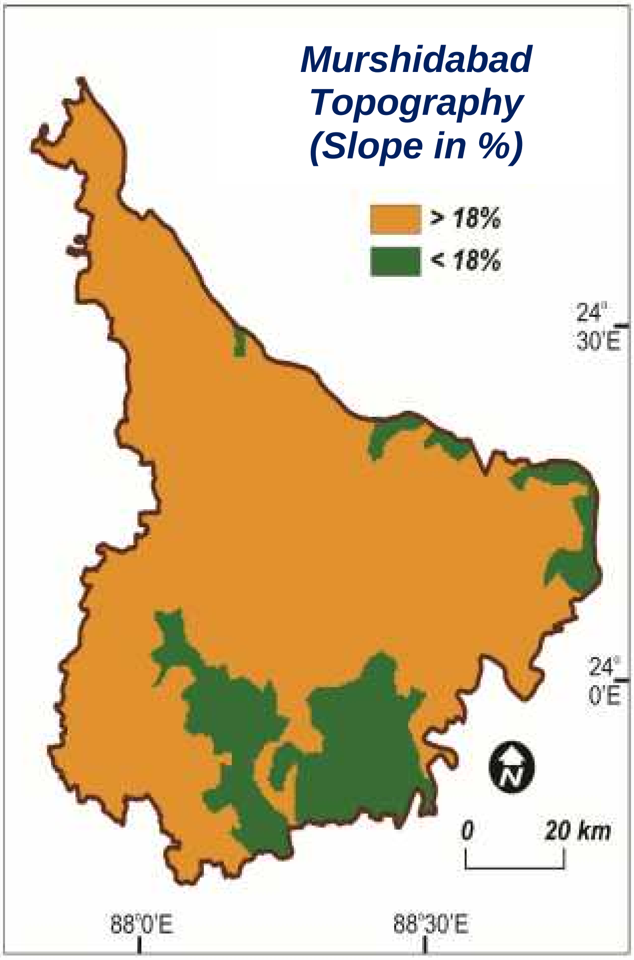


Fig. 5.8 Topography Layer

The entire region is associated with flat topography or plain area. The western part of the district is the extension of *sub -vindhyan* region having the slope of > 18%. On the other hand, the eastern part of the region is associated with flat topography with numerous marshy lands. To depict the elevation of the region 1:50,000 toposheet map and the 30 m SRTM data was combined with each other. It was found that the western part of the district has relatively higher elevation while the rest of the part has a flat topography (Fig. 5.8).

As the elevation of the region increases the relative weight also increases and vice versa. The entire region has a slope of > 18% and corresponding vulnerability index of 1, while the southern portion and some parts of north has a slope of < 18% with corresponding index of 1 (Table 5.6). 83.70% of the area had lower vulnerability index of topography (1) while 16.29% had high vulnerability index (3).

Table: 5.6 Topography Vulnerability Index

Vulnerability Indices *(T)*	Area Covered (%)
1	83.70
3	16.29

5.4.6 Impact of Vadose Zone (I):

Vadose zone is the portion of the subsurface where the inter-granular space is unsaturated with water. The characteristics of the vadose zone is quite complex as it is associated with the surface as well

as subsurface characteristics. The geo-chemical condition and transport of the contaminants through the vadose zone plays an important role and that is the reason of giving high (5) relative weight. The characteristics of impact of vadose zone is similar to the soil media. The vadose zone having coarser materials allow

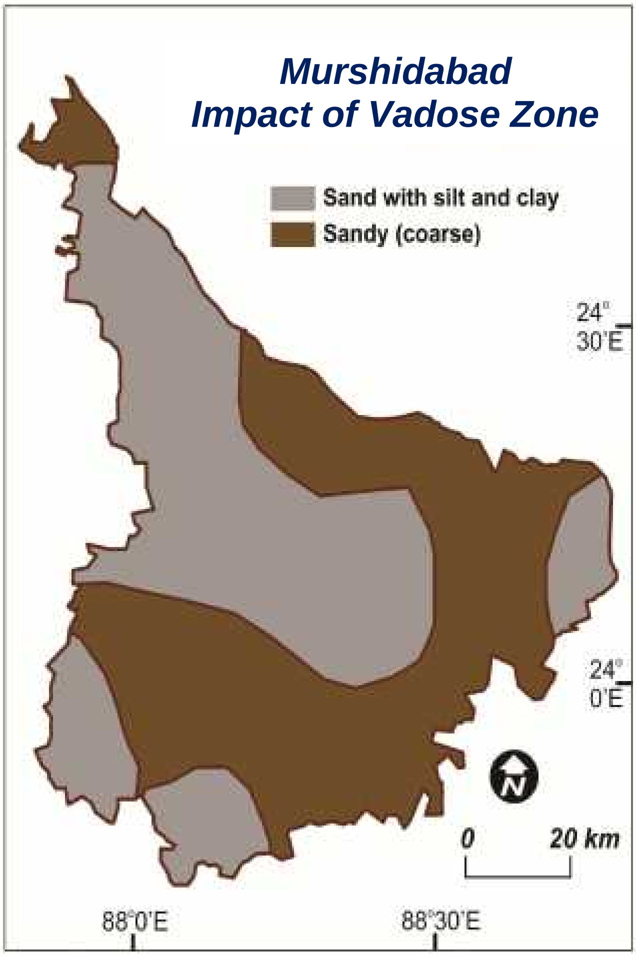


Fig. 5.9 Impact of Vadose Zone Layer

higher rate of infiltration and higher rate of movement of contaminants while lesser movement of water as well as contaminants is associated with finer material. The water table, topography and subsurface lithological data were put in a single frame and the zone between the surface and water table is considered as the vadose zone.

The condition of the vadose zone was analysed through the subsurface lithological model. The eastern part of the vadose zone largely composed of sandy coarser type of texture while western side is associated with sand with significant layers of silt and clay. As the texture of the material increases, the vulnerability index also increases and vice versa.

Table: 5.7 Impact of Vadose Zone Vulnerability Index

Vulnerability Indices *(I)*	Area Covered (%)
30	50.02
40	49.97

In this case, the eastern side of the district has higher index value (40) covering 49.97% of the area (Table 5.7) of the entire district. The western part has relatively lesser value (30) covering 50.02% area (Fig. 5.9).

5.4.7 Hydraulic Conductivity (C):

Hydraulic conductivity is the capacity of the aquifer to transmit water from one place to another place. This parameter is given higher weight of 3, which indicates its relative significance. This parameter is associated with the rate of water flow and the movement of contaminants. There is a direct relationship between hydraulic conductivity and movement of

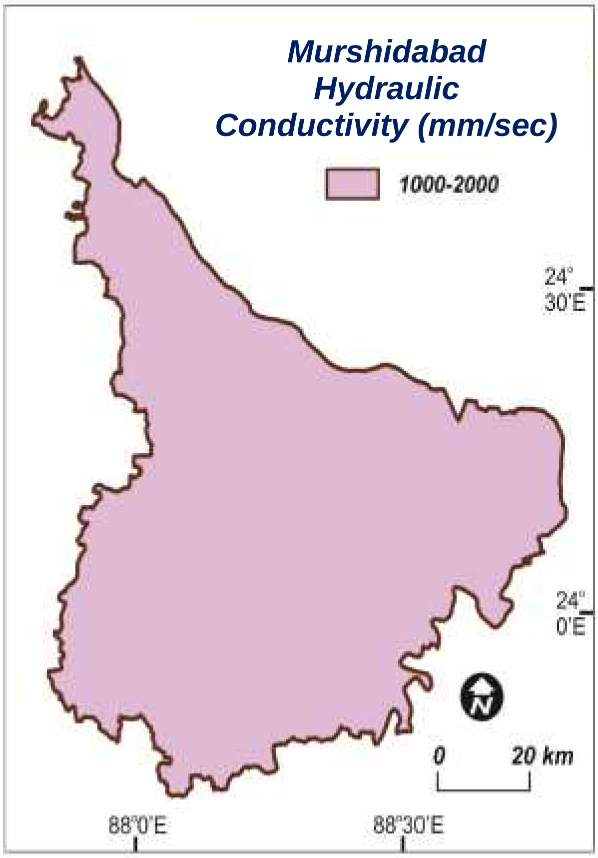


Fig. 5.10 Hydraulic Conductivity Layer

contaminants.

The vulnerability index of hydraulic conductivity was prepared by using transitivity data. The relative weight and rate was used to calculate the corresponding vulnerability index of the particular parameter. The results obtained from the analysis showed that the entire *Murshidabad* district has 24 vulnerability index of hydraulic conductivity (Fig. 5.10).

5.4.8 Composite Vulnerability Index: (DRASTIC)

All the seven layers (depth, recharge, aquifer media, soil media, topography, impact of vadose zone, hydraulic conductivity) were merged and the final composite vulnerability index was attained. The results show that, the vulnerability index is associated with five classes (< 151, 151-160, 160-170, 171-180 and > 180). A continuous patch was observed which stretched from the north central portion to the eastern segment with highest composite vulnerability index of > 180. In the southern part of the district a similar kind of vulnerability zone of highest index was observed in smaller patches. The next class of the vulnerability index ranged between 171 to 180. This **'Zone of Vulnerability'** stretched in the southern as well as in the eastern portion of the district. Some smaller patches of vulnerable zone 2 were observed in the northern peripheral zones in a discontinuous manner and also observed in patch in western part of the district. The third vulnerability zone covered the entire district in the form of discontinuous patches which ranged from 161 to 170 (Table 5.8). Small patches were noticed in the eastern most, central and southwestern part while major patches were observed in the western and north western part. Fourth zone of vulnerability was found in the western, central and south western part of Murshidabad district with a

Table: 5.8 Composite Vulnerability Index

Vulnerability Indices	Vulnerability Category	Area Covered (%)
< 150	Highest	14.13
151-160	High	30.91
161-170	Moderate	25.31
171-180	Low	10.24
> 180	Least	19.41

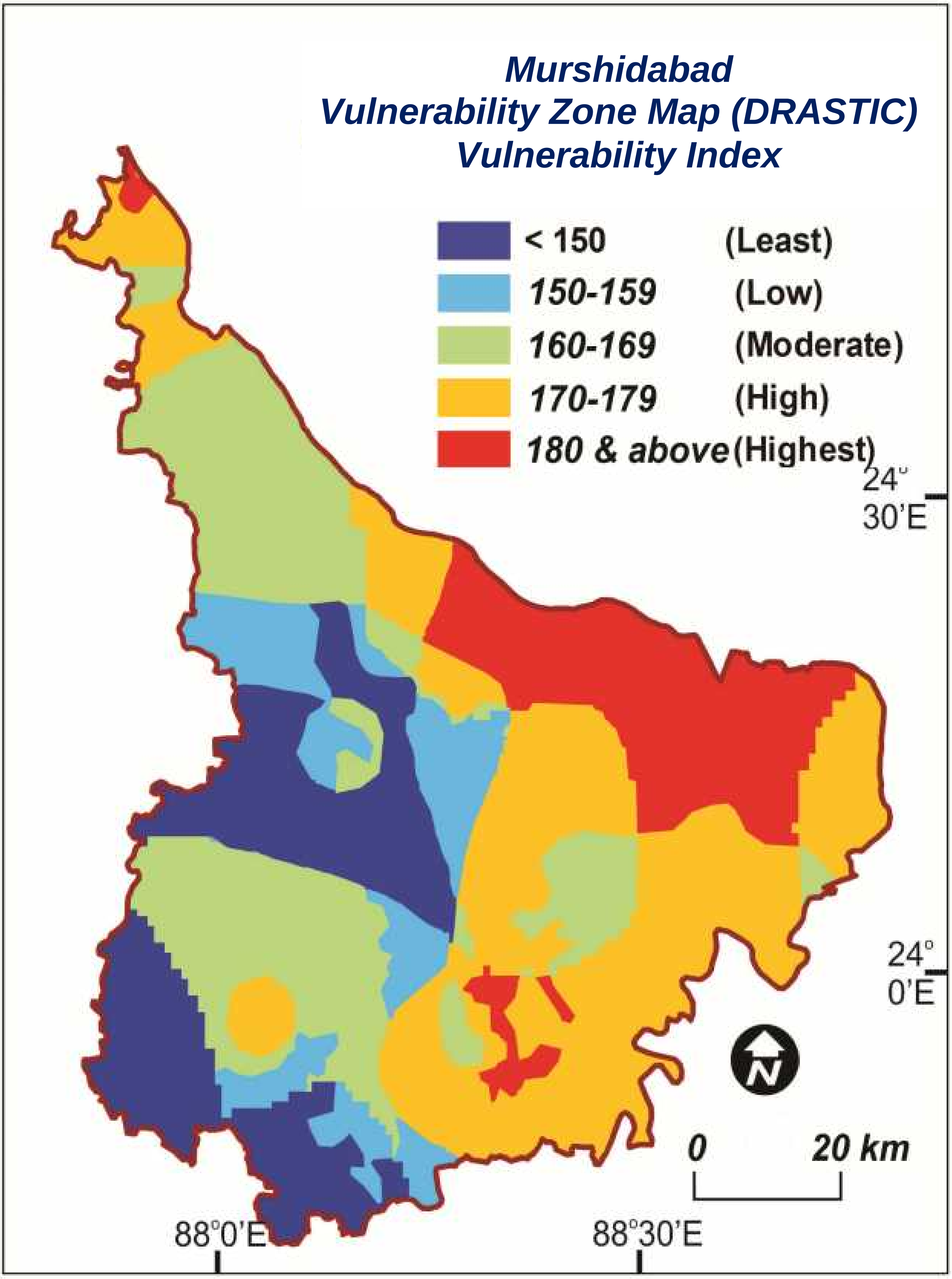


Fig. 5.11 Composite Vulnerability Zone Map

range of 151 to 160 in smaller patches (Fig.5.11). The fifth class of vulnerability was observed in the central and north western part of the study area (< 150).

A portion of the least vulnerability was also found in the western and south western part of the district. In terms of area, 14.13% of the total area was very highly vulnerable. 30.91% of area was under the second category. The third and fourth classes depicted relative percentage of area of 25.31% and 10.24%. The last class illustrated least vulnerable area with 19.41% area.

5.5 Single Map Removal Variation Index:

Composite vulnerability map represents the input of all seven hydrological factors. To understand the contribution of each of the factor, in terms of composite DRASTIC model, sensitivity of each factor is to be examined. Removal of one or more layer from the composite DRASTIC model is one of the ways to analyse the input of different layers. **Napolitano** and **Fabbri** (1996) proposed the following expression for calculation of variation analysis-

$$V_{arix} = \frac{V_i - V_{xi}}{V_i} \times 100 \qquad (2)$$

Where

V_{arix} = Variation Index,

V_i = Vulnerability Index using eq. (1) on the sub-area,

V_{xi} =Vulnerability Index of the sub-area excluding one map layer.

The results obtained from the variation index (eq.2) indicated that among the seven layers of hydrological factors, *Depth* is the major factor with 24.69% impact on the DRASTIC model after its removal. The next factor, i.e. *vadose zone* is related to 22.24% variation index. Thus, it can be analysed from the variation index that, removal of these two parameters *(depth* and *impact of vadose zone)* contributed 46.93% variation to the composite DRASTIC model.

Other than these two factors, the remaining factors like recharge, conductivity, aquifer media and soil layer removal was associated with the variation indices of 18.27%, 14.59%, 13.66% and 5.3% respectively. Among these seven layers, topography had the least variation index of 1.25% (Table 5.9).

Table. 5.9 Layer Removal Result

Layers Used	Layers Removed	Variation Index	Cumulative Variation Index
DRASTI	*C*	14.59	14.59
DRASTC	*I*	**22.24**	36.84
DRASIC	*T*	1.25	38.08
DRATIC	*S*	5.3	43.38
DRSTIC	*A*	13.66	57.04
DASTIC	*R*	18.27	75.31
RASTIC	*D*	**24.69**	100

5.6 Overlay of Sampling Locations on DRASTIC Model:

To establish the relationship between the groundwater vulnerability and location of the sampling wells, both the layers (DRASTIC and sampling locations of the wells) were overlaid. It was found that 12.82% of the total sampling wells were located in the vulnerable zone with highest index (> 180). 39.74% of the total sampling locations were found in the next category

Table: 5.10 Category wise % of Wells

Vulnerability Indices	Vulnerability Category	% of wells located
> 180	Highest	12.82
171-180	High	39.74
161-170	Moderate	26.28
151-160	Low	10.27
< 150	Least	10.89

of vulnerability index (171-180). Third vulnerability zone was associated with 26.28% of the wells. In the last two categories (151-160 and < 151) the percentages of wells were 10.27% and 10.89% respectively (Table 5.10) (Fig. 5.12).

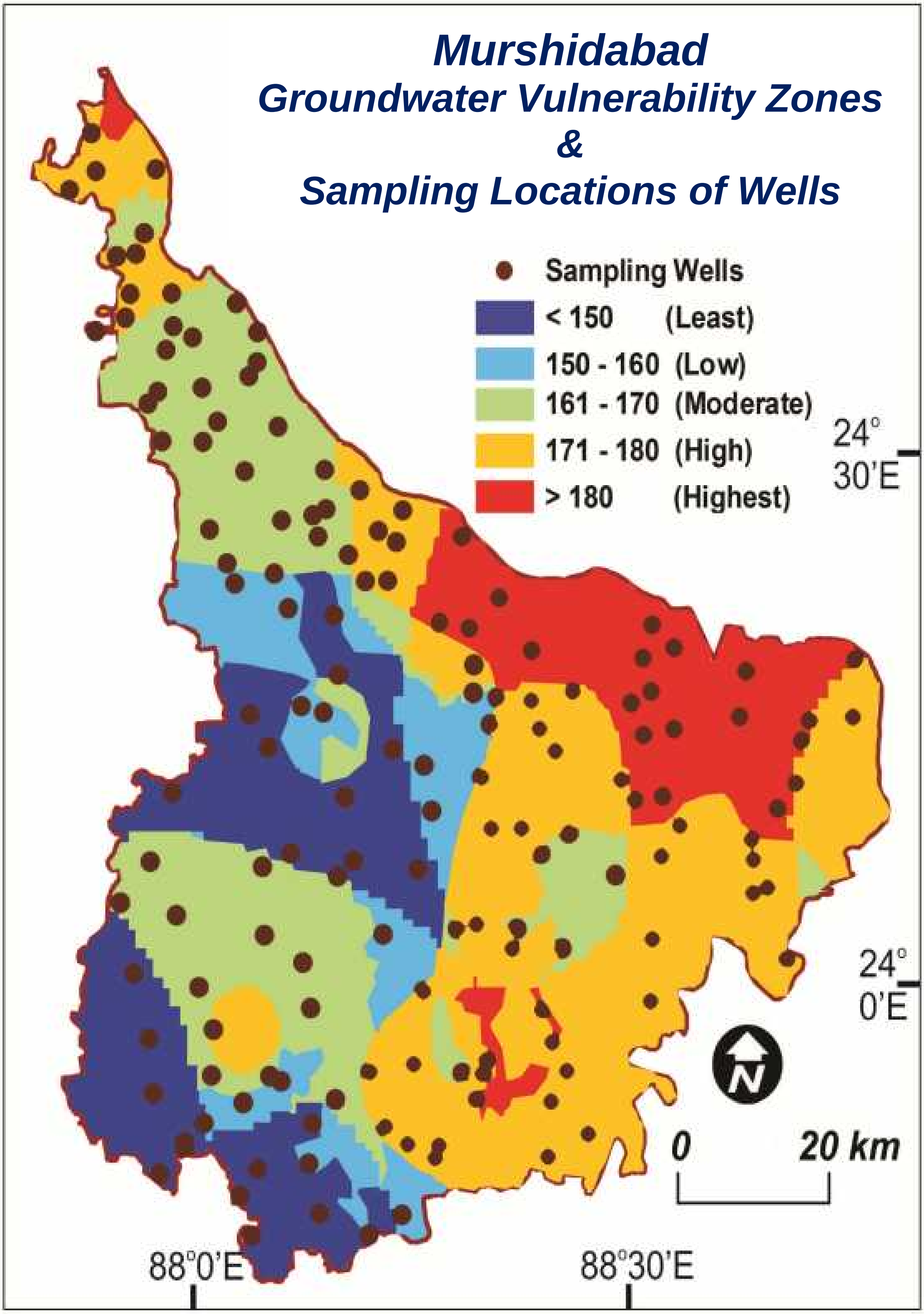


Fig. 5.12 Overlay of Vulnerability Map and Sampling Locations

5.7 Overlay of Arsenic Concentration on DRASTIC model:

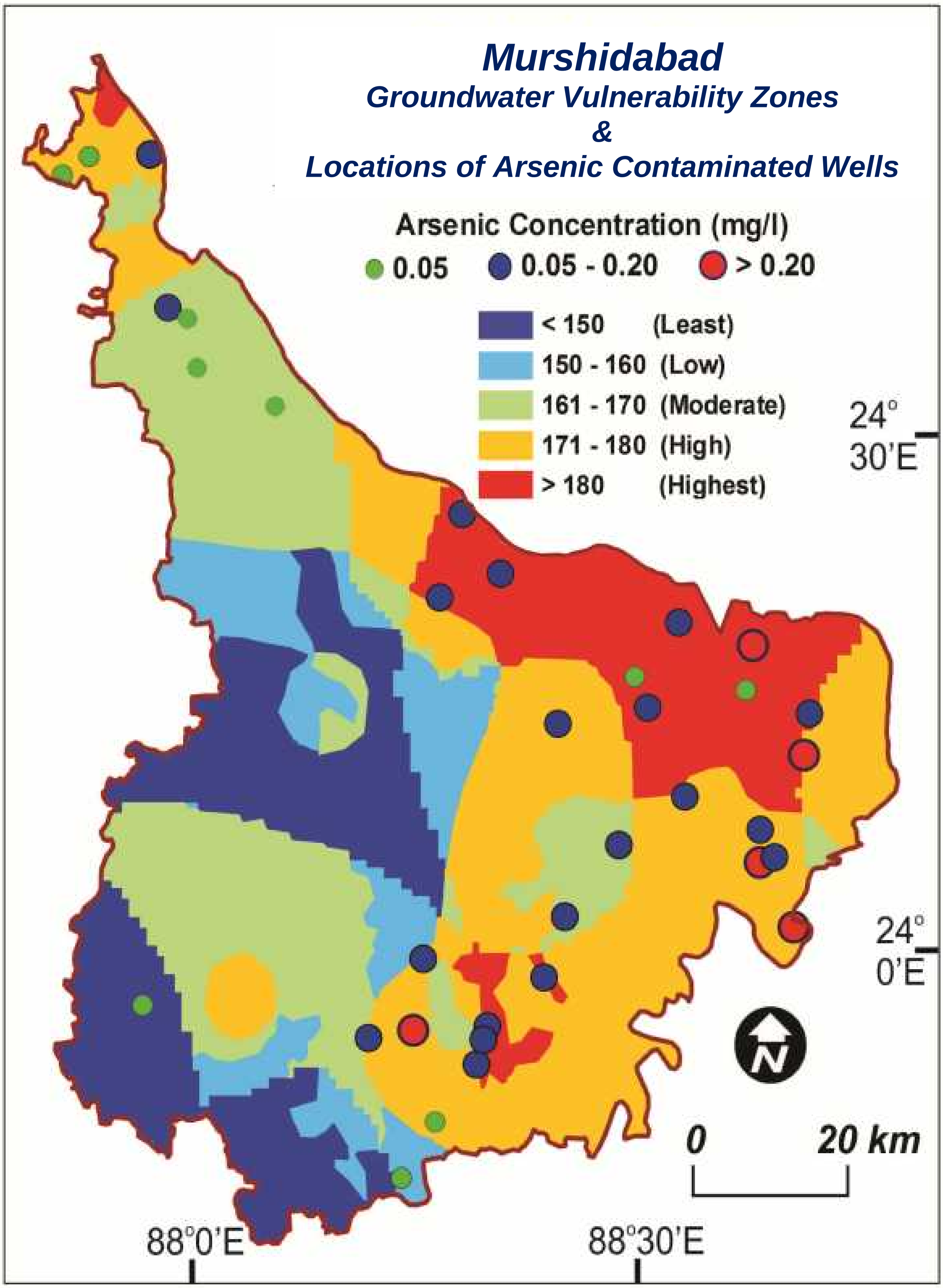


Fig. 5.13 Overlay of Vulnerability Map and Sampling Locations with Average Arsenic Concentration > 0.05 mg/l

The sampling locations of the wells were plotted over the composite DRASTIC model. The average arsenic concentration was taken into considerations.

The wells which showed concentration above 0.05 mg/l throughout the time were taken into consideration. 22.43% wells (out of total surveyed wells) had average arsenic concentration above 0.05 mg/l. 31.43% of the affected wells were located in the highest vulnerability index regions. The subsequent class of vulnerability (171-180) recorded 48.58% sampling locations (Table 5.11) (Fig. 5.13). Together, the two categories covered 83.99% of the total affected wells with arsenic concentration > 0.05 mg/l. Rest of the three classes recorded 14.29%, 2.85% and 2.85% respectively.

Table: 5.11 Category wise % of Arsenic Affected Wells

Vulnerability Indices	Vulnerability Category	% of wells located
> 180	Highest	31.43
171-180	High	48.58
161-170	Moderate	14.29
151-160	Low	2.85
< 150	Least	2.85

5.8 Discussion:

In order to understand vulnerability of groundwater in the *Murshidabad* district, it is necessary to understand the contribution of parameters used in the analysis.

The condition of the aquifer plays an important role in terms of depth (Bhattacharya 1997). The aquifers associated with confining layers of clay (confined aquifer) can slower down the process of permeability of the water, which may lead to delay in travelling of contaminants to reach and mix with groundwater. On the other hand, the aquifers that do not have significant confining or intervening layers (unconfined aquifer) can easily transfer the contaminants within a short time (Fritch 2000). Thus, the confined aquifer has a natural advantage over the unconfined aquifer. Thick unconfined aquifer is found in the eastern part of the study area while in the western portion the aquifer condition is semi-confined. As no confining layer is present, the unconfined aquifer allows large amount of infiltration of water while the western part of the district has several discontinuous confining layers. Depth to the water is an important factor as the water moves from surface to subsurface and is subjected to higher or lower rate of movement due to absence or presence of the confining layers (Rahman 2008). As compared to the western part the eastern segment is more prone to vulnerability. Vulnerability index of the depth factor is ranged between 35-50. The index 50 indicated a very high vulnerability as it is associated with very shallow depth of groundwater. The vulnerability map also depicted similar condition with higher values located in the eastern side and lower values being confined in the western part of the district. The Map Removal Variation Sensitivity Analysis (MRVSA) depicted that due to removal of the layer of Depth from the model, the variation index was 24.69%, indicating the fact that due to removal of this layer there was 24.69% variation in the entire model. Thus, the Depth factor in the present model plays a significant role.

The rate of recharge is also an important parameter, as it determines the movement of the contaminants through the aquifers (Samake 2010). In this respect, the characteristics of the aquifer plays a significant role as it controls the rate of recharge. In the entire study area, the recharge is very high (vulnerability index of 32) and is mainly recharged by the rainfall during the monsoon season and also from the numerous tributaries and sub tributaries of the river *Ganga*. The rate of recharge is found to be constant in the entire region. Thus, in continuation with the previous parameters of depth the addition of recharge data indicates higher vulnerability in the eastern part rather than in the western part of the district. The single map removal variation sensitivity had 18.27% variation. Thus, the particular factor contributed 18.27% in the entire vulnerability model. The layer of depth and recharge collectively contributed a significant percentage of 42.94% in the entire vulnerability model.

Aquifer media is the parameter which to a great extent controls the overall groundwater processes (Chandrashekhar 1999). The eastern segment of the study area depicted vulnerability index of 24 which indicates the presence of medium to coarser sand while the western part has vulnerability index of 15 indicating the presence of relatively finer sand particles. As the particles get finer, the permeability of water to the aquifer lowers and vice versa (Anwar 2003). Thus, the western portion which is composed of relatively finer sand has lesser vulnerability than the western segment. The central and north eastern part showed two patches of moderate vulnerability while the western part depicted least vulnerability. The variation index of aquifer media was 13.66% that indicated a relatively lower percentage of contribution than the former two factors.

The influence of topography is not very much reflected in the result as the entire region is plain, but some smaller patches of low lying area (< 18% slope) were observed in the southern part of the district. The variation index of topography depicted the least percentage (1.25%) and it can be said that the removal of this layer from the model would create least variation.

Composite vulnerability index was classified into five categories viz. highest, high, moderate, low and least. In terms of total area, the highest vulnerable zone has an area of 752.20 sq. km which is 14.13% to the total area, the second zone of vulnerability depicted 1646.45 sq. area (30.93%). The following three categories had relatively lower area of 1367.68 sq. km, 1272.47 sq. km and 285.20 sq. km (25.69%, 23.90% and 5.36% area to the total area respectively). A considerable amount of area in the district is under the condition of high vulnerability, largely located in the eastern side of River *Bhagirathi*. On the other hand, the western part of the river had vulnerability index much lower than the former. A few smaller patches of less vulnerability can be observed in the peripheral region of the district.

The generated model reveals that the two major parameters which are responsible for the present groundwater condition are the depth to the water and impact of vadose zone.

The groundwater vulnerability zone map and results obtained from the analysis of geochemical parameters were overlaid on each other and the percentage of sample hand pumps located in the vulnerable regions were depicted. From the results of the chapter-3 it was found that different geochemical parameters had a probable surface subsurface relationship. Thus, it is essential to classify the surveyed wells according to the categories of vulnerability. Among 156 sampling wells 52.56% of the wells were found in the first two categories of vulnerability zones. Most of these wells were located in the eastern side of the river *Bhagirathi*. Rests 47.44% of the well were found in the remaining three categories.

The *arsenic* concentration in wells were averaged for three years and from three different seasons. 22.43% of the wells had *arsenic* concentration above permissible limit of 0.05 mg/l throughout the time period (2010-2012). The wells associated with higher *arsenic* concentration (> 0.05 mg/l) were largely concentrated in first three categories of the vulnerability. 93.30% to the total sampling wells were located in ***'Dual-risk Zones'***. On one hand, they are located in the highest vulnerability zone as suggested by the DRASTIC model and on the other; they also lie in the region of higher arsenic concentration in groundwater.

It is important to note that the blocks of *Bhagawangola-1, Bhagawangola-2, Raninagar-1, Raninagar-2,* parts of *Domkal* and *Jalangi* were highly vulnerable while, the blocks of *Raghunathgunaj-1, Sagardighi, Nabagram, Khargram,* parts of *Kandi* and *Behramapur* depicted moderate to low vulnerability condition.

Resume: The present chapter groundwater vulnerability model was created by using different groundwater hydrological factors. The result obtained from the model depicted different vulnerability zones. The highest risk zone was found in the east and north-eastern portion. The overlaying of the arsenic affected wells on the vulnerability map depicted the wells that are in located in the 'Dual Risk Zone'. The following final chapter summurises the finding of all the chapters and future aspect of the present study.

Chapter – 6

Conclusion

Chapter – 6

Conclusion

6. Inferences and Future Aspect:

In the present study, groundwater condition of *Murshidabad* District of *West Bengal* is evaluated and probable relationship with human health is analyzed. The following inferences have been inferred from the present study-

1. The analyzed groundwater parameters have definite relationship with pre-monsoon, monsoon and post-monsoon seasons. The concentration of *arsenic* during monsoon season decreases while in pre-monsoon and post-monsoon season the concentrations were analogous. The parameters like *pH*, *TDS* and *EC* have considerable temporal variations, while minute variation is observed in *nitrite* concentration. The levels of *total hardness as* $CaCO_3$, *sulfate* and *chloride* have shown variations with the rainfall.

2. Temporal variation of different parameters, revealed significant variability with seasons. *Iron* is the only exception to this.

3. River *Ganga* and *Bhagirathi* along with their tributaries and distributaries are playing a significant role in controlling the concentration of *TDS* and *EC*.

4. During pre-monsoon season, the concentration of *TDS*, *EC* and *sulfate* were considerably higher while during monsoon season *total hardness as* $CaCO_3$ is

much higher. During post-monsoon season the concentration of *nitrite* had higher level.

5. Higher factor scores were largely concentrated in the eastern part of the district and showed the elevated contribution of different groundwater parameters while in the western segment, the factor scores decreased.

6. The four clusters depicted higher concentration of *arsenic* in different seasons in the eastern portion of the district.

7. Thick unconfined aquifer located in the eastern part of river *Bhagirathi* had higher level of concentration of groundwater parameters while western portion of the river related to thick semi-confined aquifer had relatively lesser concentration. It indicated the probable relationship with the aquifer condition and ground water geochemistry.

8. The eastern portion of the district (blocks of *Domkal, Raninagar-1, Raninagar-2, Jalangi* and *Beldanaga-1)* had higher threat to contamination of groundwater, while the western segment (blocks of *Kandi, Khargram, Burwan* and *Nabagram*) is less vulnerable.

9. The correlation between the prevalence rate and the arsenic concentration in groundwater depicted a positive relationship.

10. The people of the *Murshidabad* district demonstrated symptoms ranged from non-specific general symptoms like limb pain, nausea/vomiting to the symptoms of *Arsenicosis* like *Melanosis, Keratosis, Carcinoma* and *Severe cases of Gangrene.*

11. *Katlamari* village of *Raninagar-2* block, *Garaimari* village of *Domkal* and *Khayramari* village of *Jalangi* block had the higher prevalence rate.

12. Through DRASTIC model, five vulnerability zones of *Murshidabad* district are depicted. The north eastern portion depicted highest vulnerability index while western segment had least vulnerability index.

13. Amongst seven of the groundwater hydrological factors, depth to the water and impact of vadose zone played most important role.

14. 12.82% of the hand pumps are located in the zone with highest vulnerability. These sampling locations are mostly located in the eastern side of *Murshidabad* district comprising of the blocks of *Bhagawangola-1*, *Bhagawangola-2, Raninagar1*, *Raninagar-2* and parts of *Jalangi.*

15. 31.43% of the hand pumps having *arsenic* concentration more than 0.05 mg/l throughout the years are located in the zone with highest vulnerability.

The present study can be extended by-

1. Analysis of time series data with more geochemical parameters for longer time span can give more information about the subsurface hydrology.

2. Long and continuous subsurface core can give the concentration of different parameters at different depths. High resolution deeper core data can depict the relation between the accumulation zones of the particular parameter and the type of sub-surface lithological unit which can represent the probable relationship exists between them.

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Household Schedule

Identification and Spatial Analysis of Groundwater Vulnerability Zones of Murshidabad District (West Bengal)
Department of Geography, Faculty of Science
The Maharaja Sayajirao University of Baroda, Vadodara, Gujarat
Household Schedule

Name of District: Block: Village: Language:

Religion:

1. Number of Person in family:

Sl. No	Relation to the head	Age	Sex	Marital Status	Education	Occupation	Income	Height	Weight
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									

2. Persons suffering from any of the following symptoms:

Effected Pr.	Age	Sex	Symptoms	1. Distal Parestesias	2.Thickening/ Roughness of skin
				3. Limb pain	4.Skin lesions (a.Black/b.White)
				5. Hyperpathia	6.Stomachpain/nausea/vomiting/diarrhea
				7. Calf Complaint	8.Tremor Abnormal Sweating
				9. Conjunctivitis	10. Any other, specify.

3. Physical Verification:

Palm condition –spotted /diffused b) Trunk: c) Whole Body d) Eye

4. Any person in the family suffering from Arsenicosis (Severity of Disease)

S.No	Age	Sex	Keratosis		Carcinoma	Pigmentation	Blindness	Gangrene	Any other
			Hyper	Dorsal	Skin				

5. Any casualty/Death in the family due to effect of arsenic contamination in groundwater:

Relation to head	Age	Sex	Cause of death	Relation to head	Age	Sex	Cause of death

6. Source of Drinking Water: Within the premises: Depth: If no, Source:

7. For how many years you are using this source:

   a)below 1year b)1-5 years c)above 5 years

8. Is there any purification system: Yes/No Distance:

9. Utilization: Working /Non-working

10. What type of treatments do you avail of ? Home remedy/ Pvt Doc./PHC/ Any other:

11. Other observations:

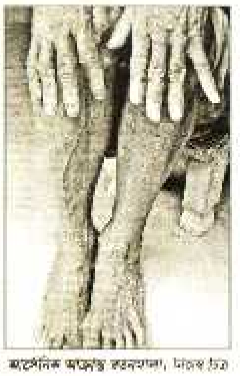
Paper Cuttings

Anandabazar Patrika-Kolkata, Tuesday 1st September 2009

বিড়ি বেঁধে কোনও ক্রমে টিকে আছেন রতনমালা

রানা সেনগুপ্ত ● মাদরা (বর্ধমান)

আর্সেনিকে পরিবারে মৃত ৭, আক্রান্ত ২



আর্সেনিক আক্রান্ত রতনমালা, নিজস্ব চিত্র

আর্সেনিক প্রকল্প নিয়ে কেন্দ্রের স্তুতি মুখ্যমন্ত্রীর

নিজস্ব সংবাদদাতা, হরিণঘাটা: নয়াচর প্রকল্পে চূড়ান্ত ছাড়পত্র পাওয়ার পরে এ বার আর্সেনিক মুক্ত জল প্রকল্পের শিলান্যাস করতে এসে কেন্দ্রের ইউপিএ সরকারের প্রশংসা করলেন রাজ্যের মুখ্যমন্ত্রী বুদ্ধদেব ভট্টাচার্য।

বুধবার নদিয়ার হরিণঘাটা থানার বড়জাগুলি মোড়ের সভায় মুখ্যমন্ত্রী বলেন, "আমরা রাজ্যের আর্সেনিক মুক্ত জল প্রকল্পের জন্য কেন্দ্রীয় সরকারের কাছে টাকা চেয়েছিলাম। দিল্লি সেই টাকা দিয়েছে। সেই টাকায় কাজ হচ্ছে।" মঞ্চে উপস্থিত কেন্দ্রীয় গ্রামোন্নয়ন মন্ত্রকের সচিব শান্তাশীলা নায়ারকে দেখিয়ে তিনি বলেন, "মন্ত্রকের সচিব আমাদের আশ্বাস দিয়েছেন, আর্সেনিক মুক্ত জল প্রকল্পের জন্য যত টাকা চাইব তা দেবেন। এর জন্য কেন্দ্রীয় সরকারকে ধন্যবাদ।" কেন্দ্রীয় গ্রামোন্নয়ন মন্ত্রকের সচিবও বুদ্ধবাবুর পাল্টা প্রশংসা করে বলেন, "আর্সেনিক মুক্ত জল প্রকল্পের কাজ রাজ্যে ভালই হচ্ছে। মুখ্যমন্ত্রীর উদ্যোগ সত্যিই প্রশংসনীয়।"

মুখ্যমন্ত্রী কল্যাণীর ন্যাশনাল ইনস্টিটিউট অফ সায়েন্স-এর প্রসঙ্গ তুলে বলেন, "ইতিমধ্যেই ৩০০ কোটি টাকা ওই প্রকল্পে বরাদ্দ করেছে।" তিনি আরও বলেন, "রাজ্যের প্রায় ৬০ শতাংশ আর্সেনিক কবলিত গ্রামে পরিস্রুত পানীয় জল পাঠাতে পেরেছি। আরও ৪০ শতাংশ গ্রামে তা পাঠাতে হবে। প্রায় ৩০০০ গ্রামে পরিস্রুত পানীয় জল পাঠানোর জন্য প্রায় আড়াই হাজার কোটি টাকা দরকার। কেন্দ্র সেই টাকা দেবে বলেও প্রতিশ্রুতি দিয়েছে।"

ওই প্রকল্প থেকে প্রায় দশ লক্ষ মানুষ উপকৃত হবেন বলে জানিয়েছেন জনস্বাস্থ্য কারিগরি মন্ত্রী গৌতম দেব। তিনি বলেন, "আমরা আগামী দু' বছরের মধ্যে পরিস্রুত পানীয় জল পৌঁছে দেব।" এই জল প্রকল্পের জন্য প্রায় ২২৫ কোটি টাকা বরাদ্দ হয়েছে। হুগলি নদীর পাড়ে চর কাঁচরাপাড়া ও বলাগড়চরে জল তোলার ব্যবস্থা করা হবে। কল্যাণী ও পলাশাছায় সেই জল শোধন করে তা সরবরাহ করা হবে। দু'বছরের মধ্যে কাজ শেষ হবে বলে জানিয়েছেন গৌতমবাবু।

Anandabazar Patrika- Thrusday, 26th February, 2009

আর্সেনিকের করাল গ্রাস

Anandabazar Patrika- Kolkata, Thursday, 15th May, 2009