Chapter 1

Introduction

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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:

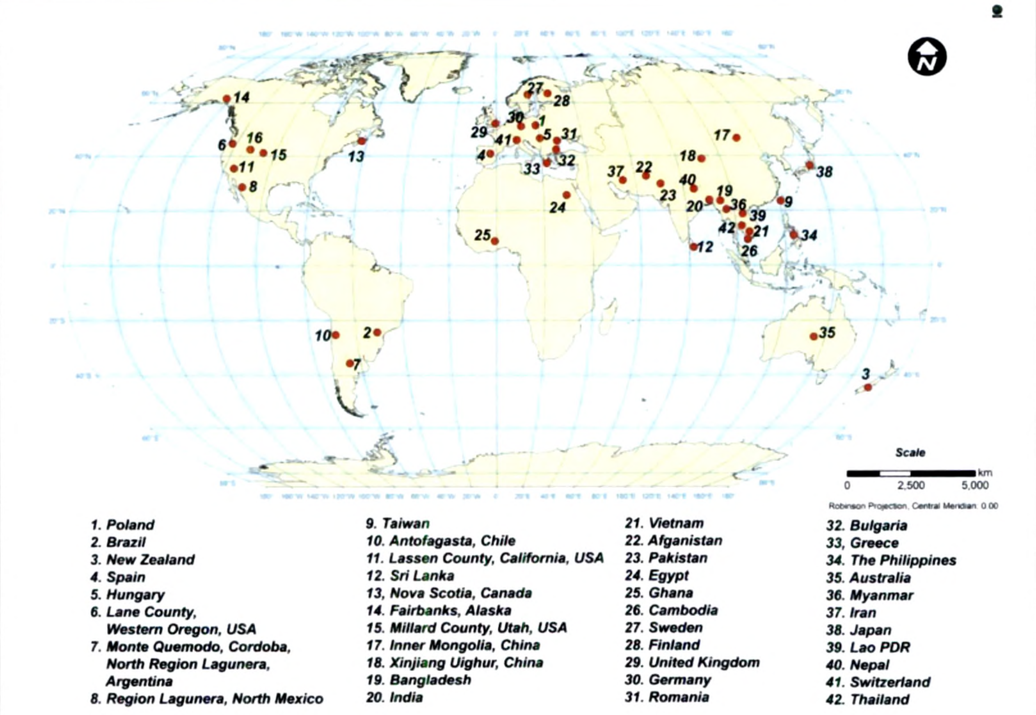

Fig. 1.1: Arsenic Contamination Scenario around the World (after Mukherjee et al. 2006)

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

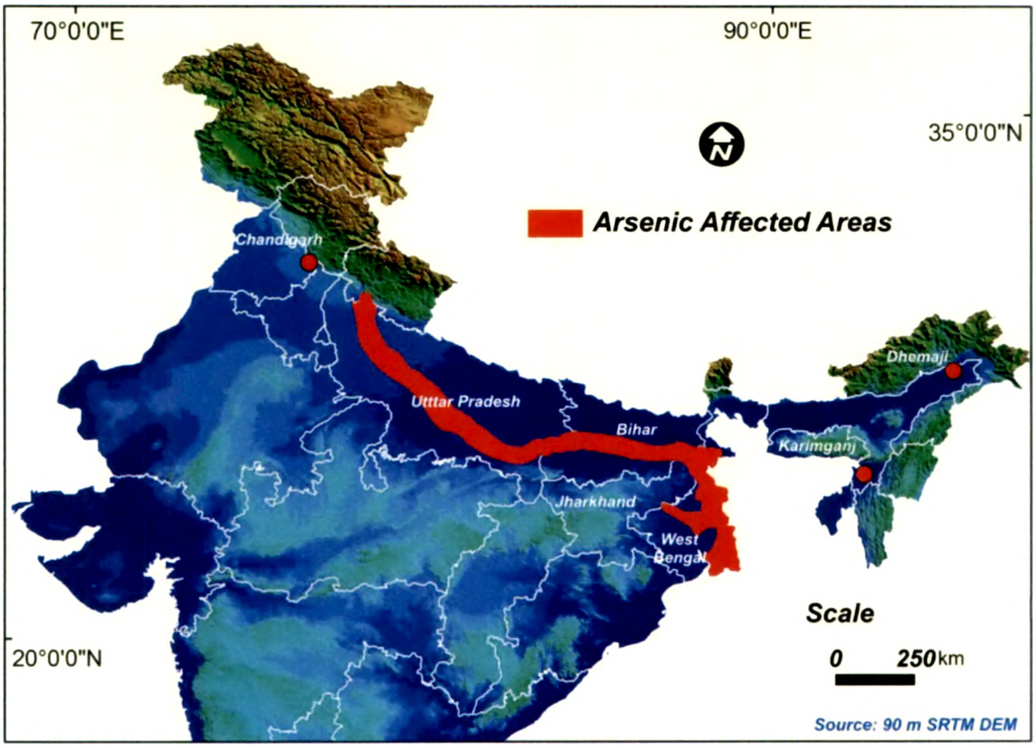

Fig. 1.2: Arsenic affected areas in India (Modified after Report work done by SOES, 2004)

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.*

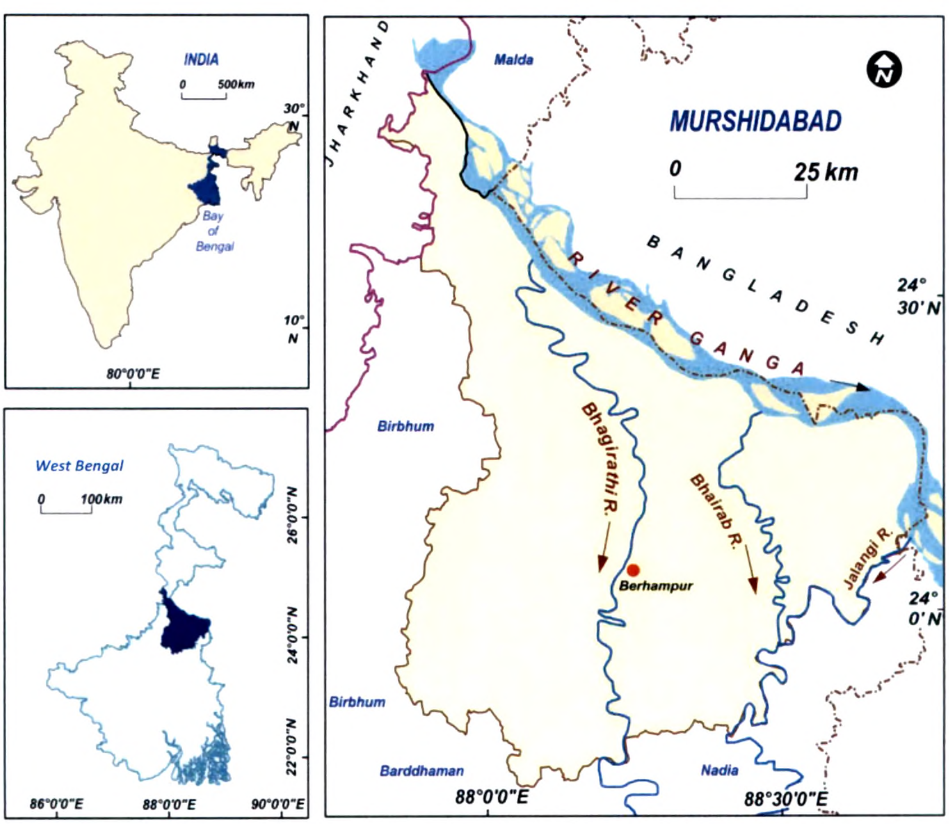

Fig. 1.3: Location Map of Murshidabad District

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)

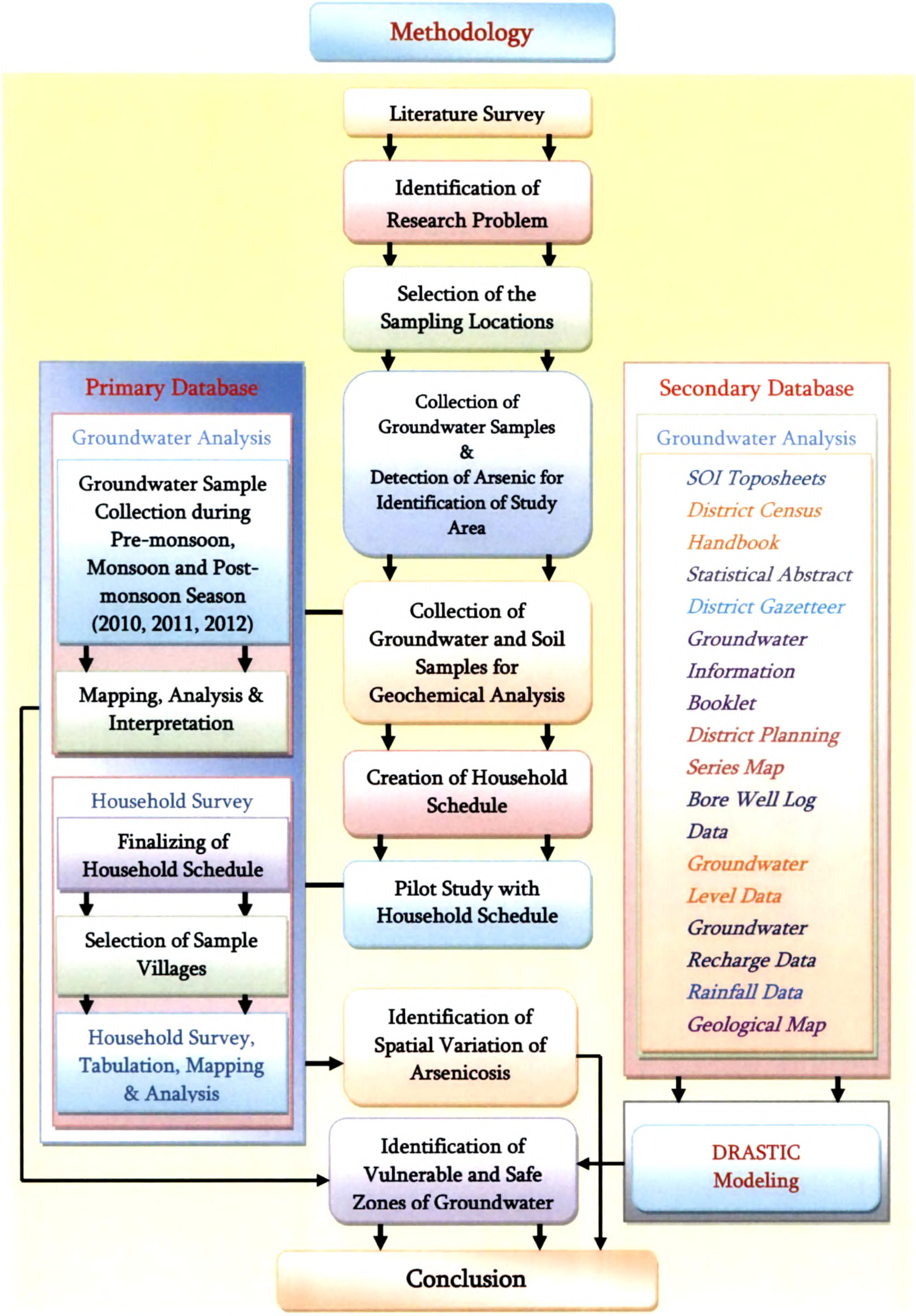

Fig. 1.4: Flow Diagram of Methodology

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.

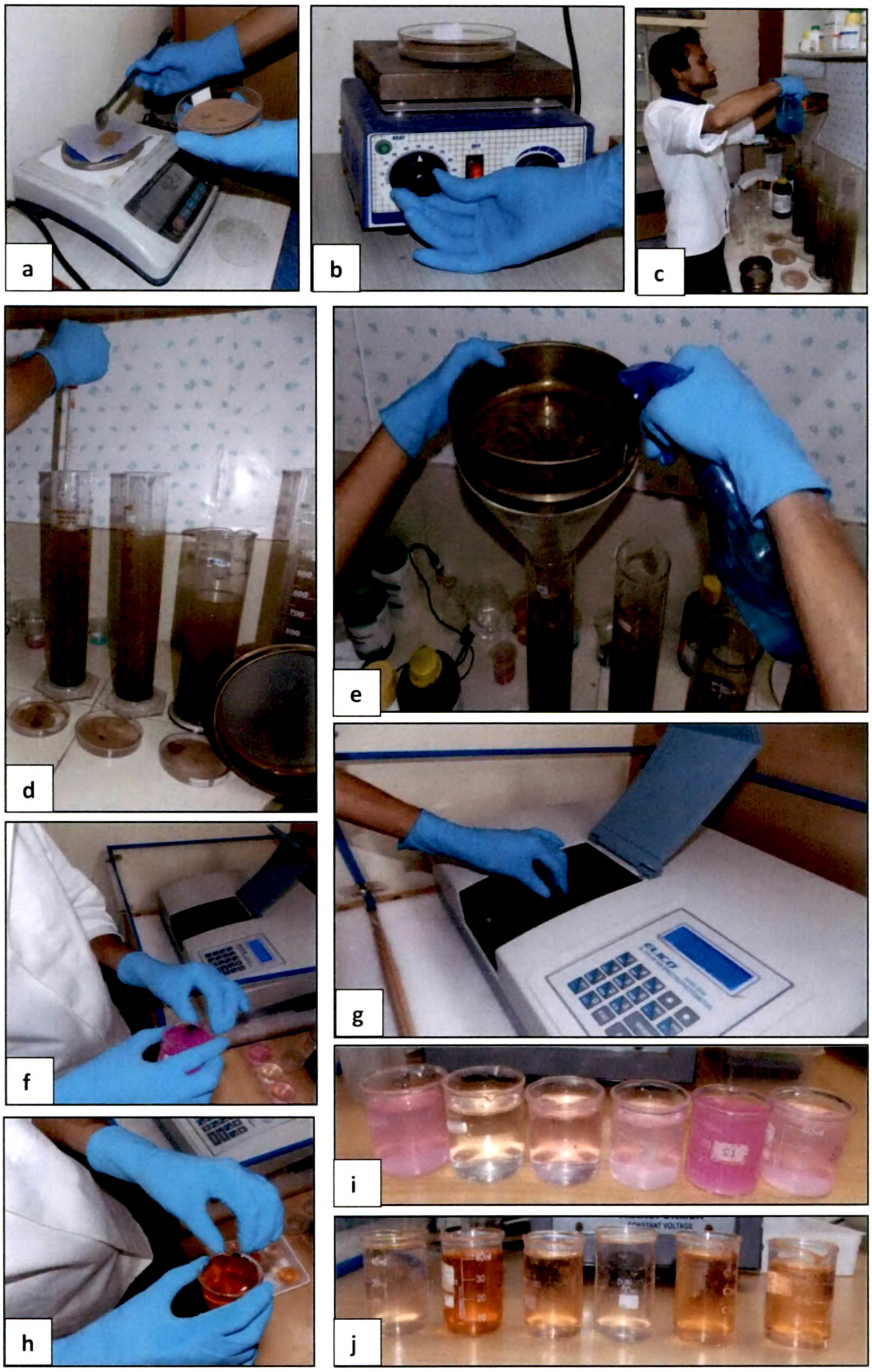

Fig. 1.5a -1.5e Wet Sieving Process
Fig. 1.5f -1.5j Spectrophotometric Determination of Nitrite (Pink Solution) and Iron (Orange Solution)

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.